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Errata

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HP References in this Manual

This manual may contain references to HP or Hewlett-Packard. Please note that Hewlett-Packard's former test and measurement, semiconductor products and chemical analysis businesses are now part of Agilent Technologies. We have made no changes to this manual copy. The HP XXXX referred to in this document is now the Agilent XXXX. For example, model number HP8648A is now model number Agilent 8648A.

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Agilent Technologies



User's Guide

HP 5528A
Laser Measurement System

HEWLETT PACKARD

User's Guide

5528A
LASER MEASUREMENT SYSTEM

Including:

5518A	Laser Head
5508A	Measurement Display
05508-60021	Remote Control Unit
10751A/B	Air Sensor
10757A/B/C	Material Temperature Sensors
10753A	Tripod
10759A	Footspacing Kit
10766A	Linear Interferometer
10767A	Linear Retroreflector
10770A	Angular Interferometer
10771A	Angular Reflector
10772A	Turning Mirror
10773A	Flatness Mirror
10774A	Short Range Straightness Optics
10775A	Long Range Straightness Optics
10776A	Straightness Accessory Kit
10777A	Optical Square
10784A	Base
10785A	Height Adjuster and Post
55280A	Linear Measurement Kit
55281A	Angular Optics
55282A	Flatness Accessory Kit
55283A	Straightness Measurement Kit

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MANUAL PART NUMBER: 05528-90022

PRINTED: MARCH 1992

ELECTRICAL SAFETY CONSIDERATIONS

GENERAL

The product and related documentation must be reviewed for familiarization with safety markings and instructions before operation.

This product is a Safety Class I instrument (provided with a protective earth terminal).

BEFORE APPLYING POWER

Verify that the product is set to match the available line voltage and the correct fuse is installed. Refer to Section II, Installation.

SAFETY EARTH GROUND

An uninterruptible safety earth ground must be provided from the main power source to the product input wiring terminals, power cord, or supplied power cord set.

SAFETY SYMBOLS



Instruction manual symbol: the product will be marked with this symbol when it is necessary for the user to refer to the instruction manual.



Indicates hazardous voltages.



Indicates earth (ground) terminal.

WARNING The **WARNING** sign denotes a hazard. It calls attention to a procedure, practice, or the like, which, if not correctly performed or adhered to, could result in personal injury. Do not proceed beyond a **WARNING** sign until the indicated conditions are fully understood and met.

CAUTION The **CAUTION** sign denotes a hazard. It calls attention to an operating procedure, practice, or the like, which, if not correctly performed or adhered to, could result in damage to or destruction of part or all of the product. Do not proceed beyond a **CAUTION** sign until the indicated conditions are fully understood and met.

WARNING

Any interruption of the protective (grounding) conductor (inside or outside the instrument) or disconnecting the protective earth terminal will cause a potential shock hazard that could result in personal injury. Grounding one conductor of a two conductor outlet is not sufficient protection.

Whenever it is likely that the protection has been impaired, the instrument must be made inoperative and be secured against any unintended operation.

If this instrument is to be energized via an autotransformer (for voltage reduction), make sure the common terminal is connected to the neutral (earthed pole) of the power source.

Servicing instructions are for use by service-trained personnel only. To avoid dangerous electric shock, do not perform any servicing unless qualified to do so.

Adjustments described in the manual are performed with power supplied to the instrument while protective covers are removed. Energy available at many points may, if contacted, result in personal injury.

Capacitors inside the instrument may still be charged even if the instrument has been disconnected from its source of supply.

For continued protection against the fire hazard, replace the line fuse(s) only with 250V fuse(s) of the same current rating and type (for example, normal blow, time delay, etc.). Do not use repaired fuses or short circuited fuseholders.

From 1.8 kilovolts to 12 kilovolts dc is present on the anode of the laser tube in the 5518A. Exercise extreme caution when working inside the instrument. The high voltage could cause serious personal injury if contacted. Any adjustments performed should be by service trained personnel only.

LASER HEAD SAFETY CONSIDERATIONS

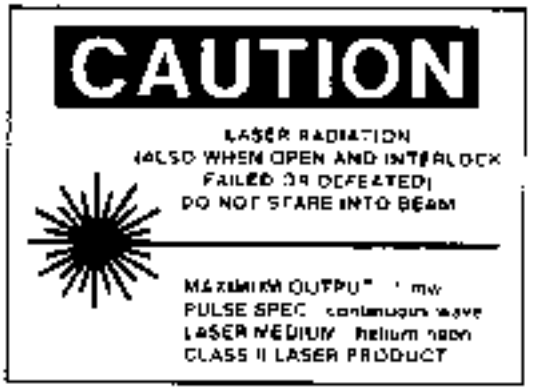
CAUTION

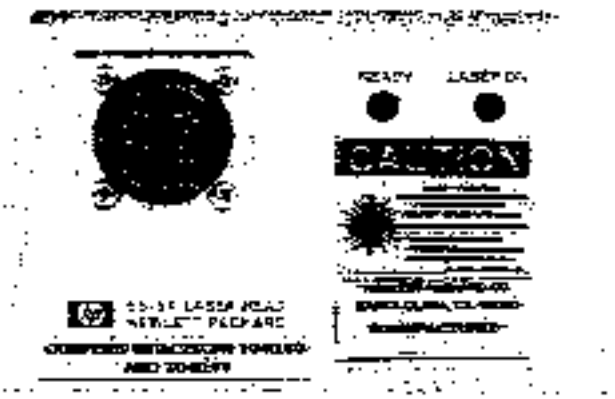
LASER RADIATION IS EMITTED FROM THE APERTURE ON THE 5518A LASER HEAD AS ILLUSTRATED ON THE FOLLOWING PAGE. DO NOT STARE INTO BEAM. THIS PRODUCT IS A CLASS II LASER PRODUCT CONFORMING TO FEDERAL BUREAU OF RADIOLOGICAL HEALTH REGULATIONS 21 CFR 1040.10 AND 1040.11 AND TO INTERNATIONAL LASER SAFETY REGULATIONS. THE MAXIMUM RADIANT POWER OUTPUT IS 1 MILLIWATT. THE PULSE SPECIFICATION IS CONTINUOUS WAVE. THE LASER MEDIUM IS HELIUM-NEON, AND THE WAVELENGTH IS 632.991 NANOMETRES.

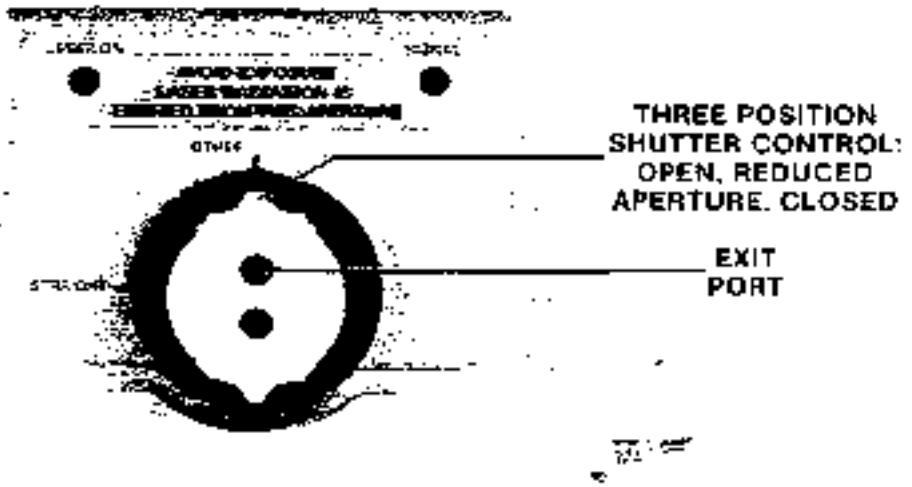
LASER RADIATION IS ACCESSIBLE WHEN THE 5518A COVER IS REMOVED AND THE TEST-NORM SWITCH, A151, IS IN THE TEST POSITION.

USE OF CONTROLS OR ADJUSTMENTS OR PERFORMANCE OF PROCEDURES OTHER THAN THOSE SPECIFIED HEREIN MAY RESULT IN HAZARDOUS RADIATION EXPOSURE.

LASER HEAD SAFETY LABELS







(U.S.A. ONLY)

FEDERAL COMMUNICATIONS COMMISSION RADIO FREQUENCY INTERFERENCE STATEMENT

Warning. This equipment generates, uses, and can radiate radio frequency energy and if not installed and used in accordance with the instructions manual, may cause interference to radio communications. It has been tested and found to comply with the limits for Class A computing device pursuant to Subpart J of Part 15 of FCC Rules, which are designed to provide reasonable protection against such interference when operated in a commercial environment. Operation of this equipment in a residential area is likely to cause interference in which case the user at his own expense will be required to take whatever measures may be required to correct the interference.

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1 Introduction

SECTION 1
INTRODUCTION

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HARDWARE — GENERAL DESCRIPTIONS
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INTRODUCTION TO HP'S 5528A LASER MEASUREMENT SYSTEM

The HP 5528A Laser Measurement System was designed specifically to make a variety of very accurate measurements in a machine tool environment.

This User's Guide is intended to help you learn to use the capabilities of the Laser Measurement System as quickly as possible. Although our examples concentrate on machine tools, you should be able to apply the information presented to your specific measurement task.

HOW TO USE THIS MANUAL

This User's Guide is divided into three major parts —

I GETTING ACQUAINTED — aimed primarily at the first-time user of this product. (white tabs)

II OPERATING PROCEDURES — instructions for making actual measurements. This is information you'll probably want to refer to again and again. (yellow tabs)

III REFFRENCE MATERIAL — more "how-to" information that expands on some of the information in the "Operating Procedures", also some general information about the Laser Measurement System. (light amber tabs)

IV APPENDICES — miscellaneous information you'll need to refer to from time to time, but which is not necessarily related to specific operating procedures or product descriptions. (brown tabs)

In each of these major parts, we've tried to focus information toward a particular need of yours. If you are a first-time user, you should concentrate on the "GETTING ACQUAINTED" information; this part describes first-time operating procedures and gives you background information to help you understand what you and the system are doing.

Once you have become acquainted with the Laser Measurement System, you should be ready to make specific measurements. That's when we expect you to start using the "OPERATING PROCEDURES" information. This part of this User's Guide focuses on how to make measurements, and provides specific procedures to be followed in order to be consistently successful in making measurements.

Supporting the specific operating procedures is a body of general "Reference Material". You will have to become familiar with this information, which will be useful to you in many of the measurements you make with the Laser Measurement System.

The Appendices contain information that is useful or interesting to know, but is not vitally important to your ability to make a measurement with the Laser Measurement System.

HOW SAFE IS THE LASER?

The Laser source used in this measurement system is a low-power (less than 1 mW) Helium-Neon laser. It will not cut metal, burn paper, or cook your food. Special safety equipment in the form of tinted glasses, shielding, etc., is not required.

However, this device is a state-of-the art scientific instrument, and should be treated with care and respect. We are required to provide in this User's Guide certain WARNINGs and CAUTIONs, which you should read before you turn on the laser.

The most important thing to remember is that neither you nor any other person should stare directly at the laser light beam, or at any reflection of it from a polished surface.

For additional WARNINGs and CAUTIONs, see the front of this User's Guide.

WHAT SAFETY PRECAUTIONS SHOULD I TAKE?

In addition to protecting your eyes by avoiding staring at the laser light or bright reflections of it —

1. Remember that the Laser Measurement System is operated from power-line voltages. Take care to be sure that all its cables are always in good condition (no short circuits, damaged insulation, etc.), and that they are routed where they will not be damaged by equipment or people. Also be careful in routing the cables that they will not cause people to trip and/or cause an unwary person to pull one or both of the units off its support.

2. Although the Laser Measurement System's electronics hardware and its Optics are fairly rugged, they can be damaged by abuse (dropping, excessive vibration, excessive temperature or humidity, etc.). Try to use and store the Laser Measurement System's components only in places where they are not subject to abuse. Detailed storage information is given in the system's service manual.

WHERE SHOULD I KEEP THE 5528A WHEN I'M NOT USING IT?

The Laser Measurement System's electronic hardware and Optics should be kept where they are not subject to physical abuse, excessive dirt, temperature, moisture, or vibration. Convenient storage kits are provided for the Optics. Hardware and cables should be kept in boxes, but may be kept on open shelves in relatively clean areas.

WHAT SHOULD I DO IF MY 5528A SEEMS NOT TO BE WORKING?

In general, that depends on what you think the problem is.

Initially, for "Error" messages displayed by the Measurement Display unit, turn to Section 17 for a listing of some actions you can take.

If the problem seems to be "really bad" or "obvious", and is not intermittent, you should probably contact the person responsible for servicing (i.e., repairing) your Laser Measurement System. Service information (including troubleshooting and repair information) for the Laser Measurement System is contained in an Operating and Service Manual that is separate from this User's Guide.

If the problem seems to be "minor", hard to make happen, and is intermittent, you should probably check your setup and procedure. Are the Optics clean? Cleaning instructions are given in Section 20.

Are the Laser Measurement System's connections firm and secure? Are the connector contacts clean? (To check connections, turn off power, then disconnect cables. Do not turn power back on until you have reconnected all cables.)

Is your setup correctly aligned? Repeat the appropriate alignment procedure(s) given in this User's Guide for your setup.

WHAT MEASUREMENTS CAN THE 5528A MAKE?

The Laser Measurement System is a portable, lightweight, measuring system that can make the following measurements —

- Distance
- Velocity
- Angular displacement
- Flatness
- Straightness
- Squareness
- Parallelism

WHAT EQUIPMENT IS REQUIRED TO MAKE THESE MEASUREMENTS?

For all of these measurements you will need the HP Model 5508A Measurement Display unit and the HP Model 5518A Laser Head. You will most likely also need an HP Model 10753A Tripod. In addition, you will need several Optic accessories that manipulate the laser beam as required by the desired measurement.

A listing of the hardware required for each measurement is provided in *Table 1-1*. You are referred to *Table 1-2* and other material in this User's Guide for more detailed descriptions of each piece of hardware listed.

Table 1-1. 5528A Hardware versus Measurement

HP PART NUMBER (NOTE)	LINEAR DISPLACEMENT (Distance)/VELOCITY	ANGULAR	FLATNESS	SHORT-RANGE STRAIGHTNESS	LONG-RANGE STRAIGHTNESS	SQUARENESS	
5508A	1	1	1	1	1	1	
5518A	1	1	1	1	1	1	
10753A	1	1	1	1	1	1	
10759A			1				
10766A	1						
10767A	2						
10770A		1	1				
10771A		1	1				
10772A				1	1	1	
10773A			1				
10774A				1		1	
10775A					1	1	
10776A				1	1	1	
10777A						1	
10784A	2	2					
10785A	2	2					
10786A	1	1	1				
10787A				1	1	1	
*** OPTIONAL ACCESSORIES ***							
10751A/B	1						
10757A/B/C	1,2,3						

NOTE. See *Table 1-2* for descriptions.

Table 1-2. Hardware List (Descriptions)

HP PART NUMBER	DESCRIPTION	FOR MORE INFO, SEE SECTION —
5508A	Measurement Display	2,5,16,17,A
5518A	Laser Head	2,4,5,16,A
10751A	Air Sensor (5-metre/16-foot cable)	2,5,6,7,16,17,A
10751B	Air Sensor (15-metre/50-foot cable)	2,5,6,7,16,17,A
10757A	Material Probe (5-metre/16-foot cable)	2,5,6,16,17,A
10757B	Material Probe (15-metre/50-foot cable)	2,5,6,16,17,A
10757C	Material probe (25-metre/82-foot cable)	2,5,6,16,17,A
10753A	Tripod	4
10758A	Metrology Software	6,7,8,9,10,11, 12,13,14,16
10759A	Footspacing Kit	9
10766A	Linear Interferometer	2,6,7,A
10767A	Linear Retroreflector	2,6,7,A
10770A	Angular Interferometer	2,8,9,A
10771A	Angular Reflector	2,8,9,A
10773A	Flatness Mirror	9
10774A	Straightness Interferometer and Reflector (Short Range)	10,11,12 13,14,A
10775A	Straightness Interferometer and Reflector (Long Range)	10,11,12, 13,14,A
10776A	Straightness Accessory Kit	10,11,12,13,14
10777A	Optical Square	12,13
10784A	Base	2,6,7,8
10785A	Height Adjuster/Post	2,6,7,8,10,12
10786A	Linear/Angular Case	
10787A	Straightness/Squareness Case	

HARDWARE — GENERAL DESCRIPTIONS

For more-detailed description, see Section 2, Section 16, Appendix A and Appendix C.

5508A Measurement Display

The 5508A Measurement Display unit provides the operator interface for the Laser Measurement System. It also provides operating power for the Laser Head and accepts measurement information from the 5518A Laser Head in wavelength units and converts this information into a number in millimeters or inches.

5518A Laser Head

The 5518A Laser Head houses the laser tube which produces the laser beam used in making measurements. It also contains the measurement receiver into which the beam is returned by the measurement Optics.

Optics

Optic accessories are required to allow the Laser Measurement System to make measurements.

The basic sets of Optics available for making specific measurements are —

- Distance Measurement Optics,
- Angular Measurement Optics, and
- Straightness Measurement Optics.

Distance Optics

The Distance Measurement Optics include —

- 10766A Interferometer, and
- 10767A Retroreflector

One of the interferometers and two retroreflectors are necessary for making measurements. Measurements performed by these Optics include Distance and Velocity.

Angular Optics

The Angular Optics include —

- 10770A Angular Interferometer and
- 10771A Angular Retroreflector.

Measurements performed by these Optics include angular rotation (pitch and yaw) and Flatness (for surface plate calibration).

Straightness Optics

There are two sets of Straightness Optics available to be chosen based on the range traveled by the machine.

- The 10774A Short Range Straightness Interferometer is designed for measurements over the range of 100 mm to 3000 mm (4 to 120 inches).
- The 10775A Long Range Straightness Interferometer is designed for measurements over the range of 1000 mm to 30000 mm (40 to 1200 inches).

Measurements performed by the Straightness Optics include horizontal Straightness, vertical Straightness, and Squareness and Parallelism between two axes.

Mounting Hardware

When checking machine tools, the primary application of the Laser Measurement System, it is important to look at how the machine behaves while performing its function, be it cutting, grinding, or whatever. To do this, the calibration process must simulate as closely as possible the actual working conditions. To achieve this using the laser, one Optic must be positioned where the part mounts and the other Optic where the tool mounts. The 10784A Base, the 10785A Height Adjuster and Post, and the 10776A Straightness Accessory Kit have been designed to make the job of mounting the Optics easier.

SECTION 2
FIRST LOOK

CONTENTS

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5508A MEASUREMENT DISPLAY
5518A LASER HEAD
10751 AIR SENSOR AND 10757 MATERIAL TEMPERATURE SENSOR
OPERATION
- PHYSICAL SETUP
- INTERCONNECTION AND TURN-ON
- ASSEMBLY OF OPTICS
- INSTALLATION AND ALIGNMENT OF OPTICS
- MAKING THE MEASUREMENT
- MAKING AN ANGULAR MEASUREMENT

SAFETY PRECAUTIONS

WARNING

BEFORE THE INSTRUMENT IS SWITCHED ON, ALL PROTECTIVE EARTH TERMINALS, EXTENSION CORDS, AUTO-TRANSFORMER AND DEVICES CONNECTED TO IT SHOULD BE CONNECTED TO A PROTECTIVE EARTH GROUNDED SOCKET.

ANY INTERRUPTION OF THE PROTECTIVE (GROUNDING) CONDUCTOR (INSIDE OR OUTSIDE THE INSTRUMENT) OR DISCONNECTING THE PROTECTIVE EARTH TERMINAL WILL CAUSE A POTENTIAL SHOCK HAZARD THAT COULD RESULT IN PERSONAL INJURY. (GROUNDING ONE CONDUCTOR OF A TWO-CONDUCTOR OUTLET IS NOT SUFFICIENT PROTECTION.)

WHENEVER IT IS LIKELY THAT THE PROTECTION HAS BEEN IMPAIRED, THE INSTRUMENT MUST BE MADE INOPERATIVE AND BE SECURED AGAINST ANY UNINTENDED OPERATION.

IF THIS INSTRUMENT IS TO BE ENERGIZED VIA AN AUTOTRANSFORMER (FOR VOLTAGE REDUCTION) MAKE SURE THE COMMON TERMINAL IS CONNECTED TO THE EARTH TERMINAL OF THE POWER SOURCE.

ONLY FUSES WITH THE REQUIRED RATING AND OF THE SPECIFIED TYPE SHOULD BE USED. DO NOT USE A REPAIRED FUSE OR A SHORT-CIRCUITED FUSEHOLDER; DOING SO COULD CAUSE A SHOCK OR FIRE HAZARD.

WARNING

LASER RADIATION IS EMITTED FROM THE APERTURE ON THE 5518A LASER HEAD. DO NOT STARE INTO THE BEAM.

THIS PRODUCT IS A CLASS II LASER PRODUCT CONFORMING TO FEDERAL BUREAU OF RADIOLOGICAL HEALTH REGULATIONS 21 CFR 1040.10 AND 1040.11, AND TO INTERNATIONAL LASER SAFETY REGULATIONS. THE MAXIMUM OUTPUT IS 1 MILLIWATT, THE PULSE SPECIFICATION IS CONTINUOUS WAVE, THE LASER MEDIUM IS HELIUM NEON, THE WAVELENGTH IS 632.991 NM.

CAUTION

Before switching on the instrument, it must be set to the voltage of the power source, or damage to the instrument may result. Refer to the Section 5 of this User's Guide for the procedure for checking and changing the power line voltage selection.

PURPOSE

This manual section is intended to —

1. Introduce you to the function and use of each part of the Laser Measurement System, and —
2. Allow you to make some actual measurements and learn how to use this "User's Guide".

5508A MEASUREMENT DISPLAY

The 5508A Measurement Display

- Provides the power to operate the 5518A Laser Head, —
- Converts measurement information received from the Laser Head into a number that represents a unit of length (or seconds of arc of an angle), —
- Provides the control and display interface for the Laser Measurement System's operator —
- Provides the electrical interface for optional devices (HP Personal Calculator and/or Plotter) that may be connected to enhance the system's capabilities.

The Measurement Display's front panel is shown in *Figure 2-1*.

You can think of the Measurement Display's front-panel keys as being organized into three groups —

INDICATORS: Display measurement values, beam strength, and laser status.

MEASUREMENT MODE KEYS: Allow four different measurements to be made (only one measurement at a time, however).

ENTRY KEYS: Allow manual setting of Set-up keys or inputting of measurement data.

SET-UP KEYS: Allow manipulation of measurement values by providing velocity-of-light (V.O.L.) compensation, thermal expansion compensation, preset calibration numbers, different resolutions, smoothed data, and different sign conventions.

A concise description of each of the Measurement Display unit's front-panel indicators and keys follows. See Section 16 for a more complete explanation of all indicators and connectors

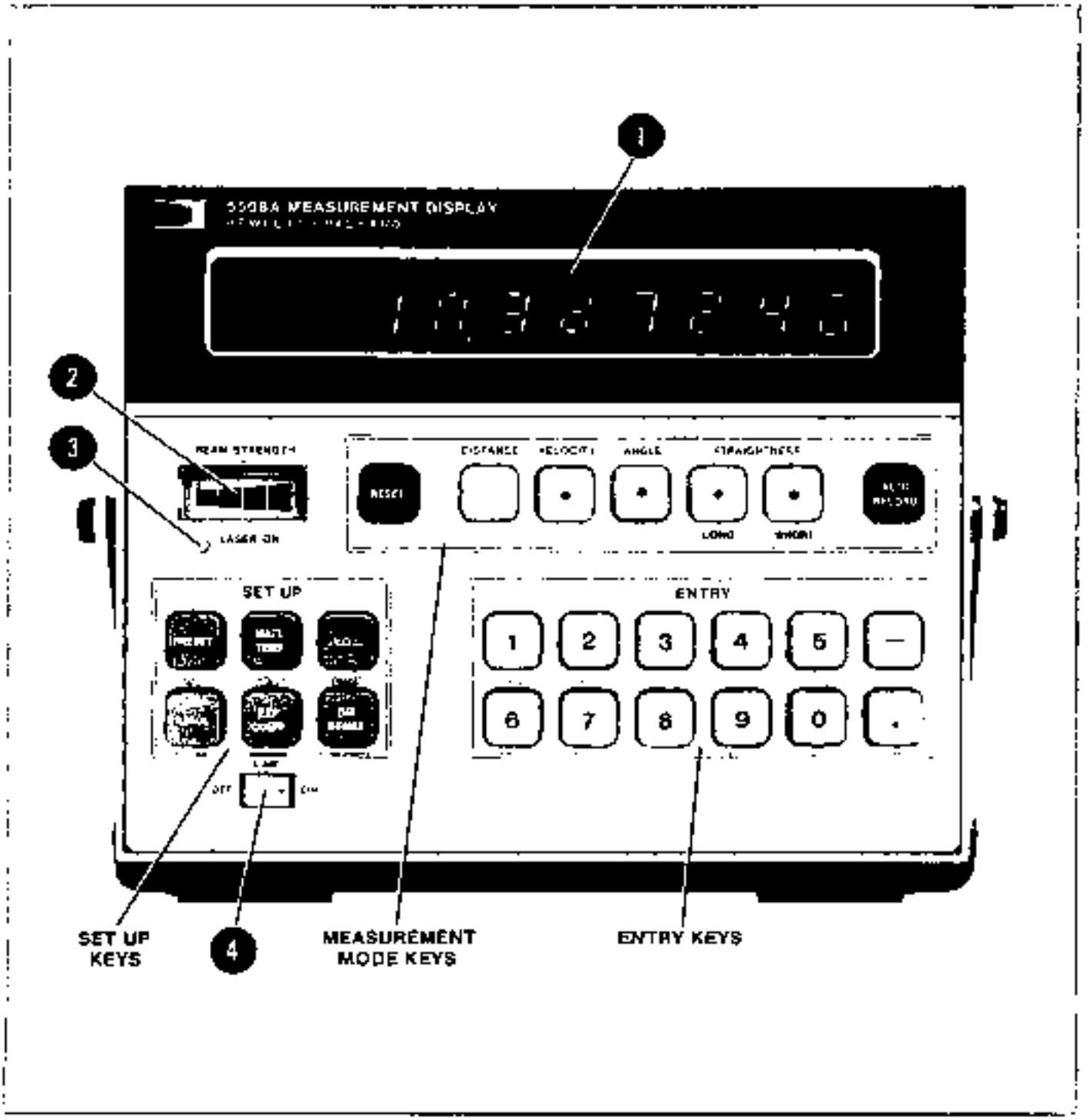


Figure 2-1. Measurement Display Unit — Front Panel

Front Panel — Indicators, Line Switch

ALPHA-NUMERIC DISPLAY (item "1" in *Figure 2-1*): LED indicators used to display numeric data readouts or alpha-character status information.

BEAM STRENGTH Meter (item "2" in *Figure 2-1*): Indicates the relative strength of the laser beam measurement signal. The meter reading can be used to aid in optimizing the optical alignment of the laser and measurement optics. Beam strength indications within the green area of the meter are required for proper operation.

LASER ON Indicator (item "3" in *Figure 2-1*): Indicates that power is being provided to the Laser Head, and that the Laser tube is activated and emitting a laser beam.

LINE Switch (item "4" in *Figure 2-1*): When set to ON, power is applied to the Measurement Display unit, the Laser Head, and any sensors that are connected to the Measurement Display unit. The LASER ON indicators illuminate and the laser tube is powered. Also upon application of power, the system starts into a warm-up period during which a self-test diagnostic routine is executed.

Front Panel — Measurement Mode Keys



RESET Key: Erases all measurement data taken up to the time it was pressed. Releases Laser Measurement System from HP-IB control (if it was operating under HP-IB control). Clears error message, if one is being displayed. Returns Laser Measurement System to most-recently-chosen measurement mode.

NOTE

The RESET key clears **only** the measurement data. A value entered via an ENTRY key will not be changed by RESET.



DISTANCE Key: Programs the Laser Measurement System for a Distance Measurement. Distance Measurements are described in Section 6 of this User's Guide.



VELOCITY Key: Programs the Laser Measurement System for a Velocity Measurement. Velocity Measurements are described in Section 7 of this User's Guide.



ANGLE Key: Programs the Laser Measurement System for an Angular Measurement. Angular Measurements are described in Section 8 of this User's Guide.



STRAIGHTNESS Keys: Either of these keys programs the Laser Measurement System for a Straightness measurement. Straightness measurements are described in Section 10 and Section 11 of this User's Guide. The LONG STRAIGHTNESS key is used for a measurement in the range from 1000 mm to 30,000 mm (39.37 inches to 1200 inches). The SHORT STRAIGHTNESS key is used for a measurement in the range 100 mm to 3000 mm (3.94 inches to 120 inches).



AUTO RECORD Key: This key provides a way for you to record data on an external device, automatically, at a rate you choose

Front Panel — Set Up Keys

NOTE

To enter a value for any of the SET UP keys (listed below) —

a Use the ENTRY keys to specify a numeric value, then —

b Press the SET UP key to which you want to assign that value

c You can use any SET UP key at any time, without loss of measurement data.



PRESET Key: Selects a function depending on the current measurement mode. Offset values can be preset in the distance and velocity modes. Multiplication factors can be preset in the angular and straightness modes. The default values are "0" for distance and velocity, and "1" for angular and straightness.



MATL TEMP Key: Causes material temperature values to be displayed, can be used to enter a material temperature value to be entered manually, if no Material Temperature Sensor is connected.



V.O.L. Key: The V.O.L. key can be used to display the velocity-of-light compensation number, and the air characteristics. It can also be used to enter a velocity-of-light compensation number, if an air sensor is not attached.



RESOL Key: Selects or displays the number of significant decimal places displayed on the Measurement Display unit during measurements. This key also sets the smoothing function on or off



EXP COEFF Key: Used to enter or display the expansion coefficient of the material being measured



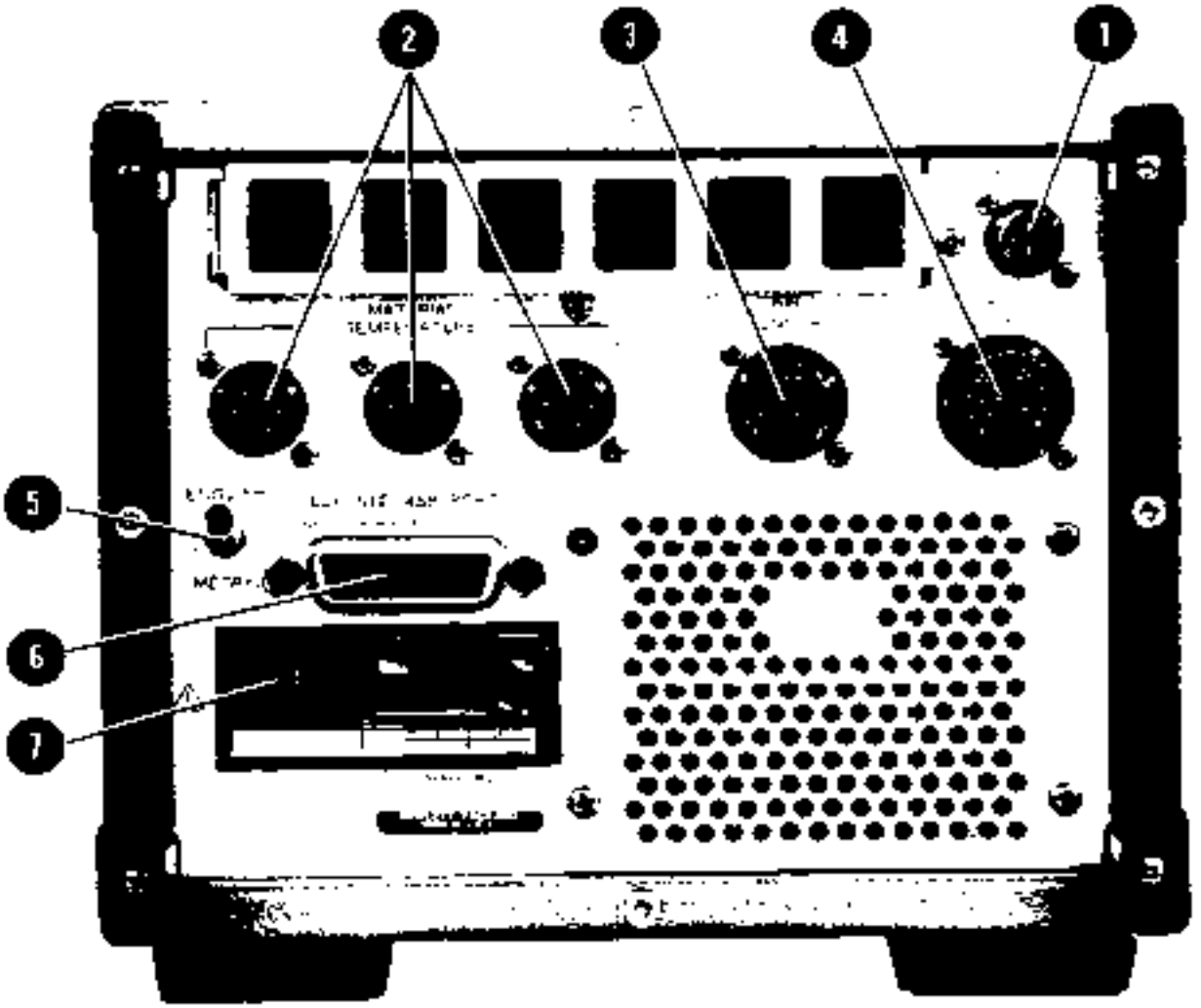
DIR SENSE Key: Reverses the sense of the measurement. For example, if the optics are moving apart and the display indicates an increasing positive displacement, pressing the DIR SENSE key will result in the same movement causing an increasing negative displacement.

Front Panel — Entry Keys

The ENTRY keys allow you to assign values to certain parameters as described above. No measurement information is lost when entering numbers into the Measurement Display.

Rear Panel

The Measurement Display unit's rear panel is shown in *Figure 2-2*. It is important to note the position of the ENGLISH/METRIC switch. This switch changes the displayed measurement on the front panel from millimetres to inches or vice versa.



1. RMT CONT Connector: Connecting point for the 05508-60021 Remote Control Unit.

2. MATERIAL TEMPERATURE Connectors: Connecting points for the Material Temperature Sensor(s).

3. AIR SENSOR Connector: Connecting point for the Air Sensor.

4. LASER SOURCE Connector: Connecting point for the cable between the Measurement Display and the Laser Head.

5. ENGLISH-METRIC Switch: Determines the units of measurements, either English (inches, degrees F) or Metric (millimetres, degrees C).

6. IEEE STD 488 PORT Connector: Connecting point for HP-IB cable(s), if used. HP-IB is a Hewlett-Packard implementation of the IEEE 488 Standard Interface. It is used to connect other equipment to the Measurement Display unit.

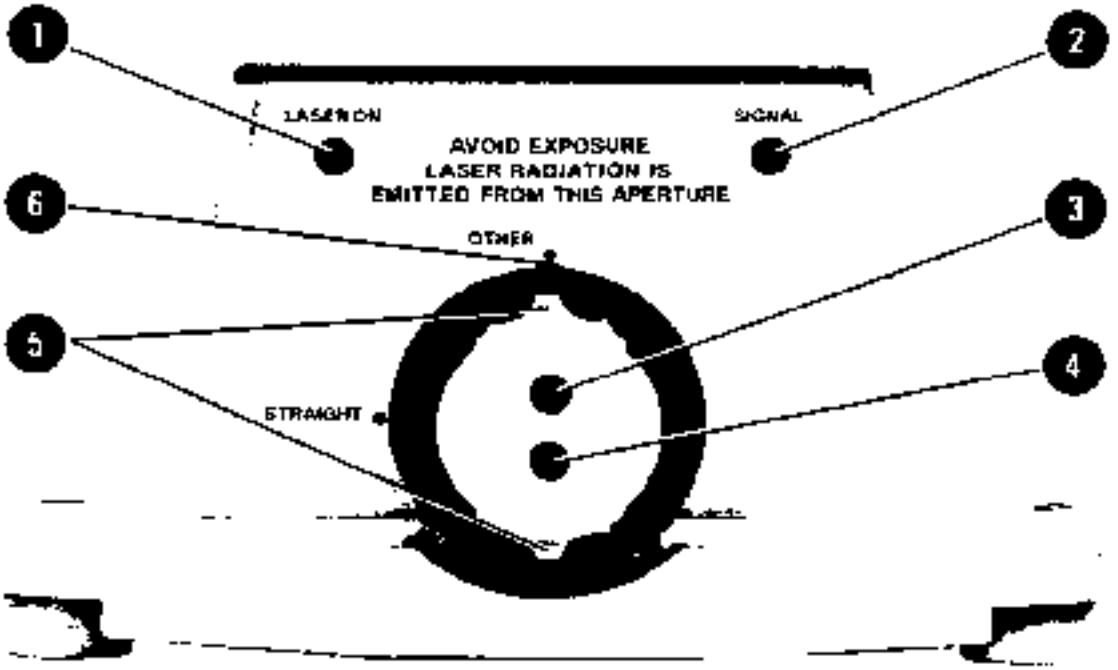
7. POWER LINE Module: Connecting point for line power cord. Also contains the line fuse, and a line voltage selector.

Figure 2-2. Measurement Display Unit — Rear Panel

5518A LASER HEAD

The 5518A Laser Head contains the laser tube which produces the beam used in making measurements. The Laser Head also contains the receiver into which the beam is returned from the measurement optics

Look at the Laser Head and, referring to *Figure 2-3* and *Figure 2-4*, familiarize yourself with the front and rear panels. This information is also shown in Section 16 for your reference.



1. LASER ON Indicator: Indicates when Laser Head is receiving power from Measurement Display unit.

2. SIGNAL Indicator: Indicates that Laser return beam is strong enough for a measurement.

3. LASER EXIT PORT: Source of Laser beam for all measurements. Also, destination of Laser return beam for Straightness measurements.

WARNING

LASER RADIATION IS EMITTED FROM THIS PORT. DO NOT STARE INTO THE BEAM.

4. LASER RETURN PORT: Destination of Laser return beam for Distance, Velocity, and Angular measurements.

5. APERTURE CONTROLS. These are located behind both ports in the turret. The Exit Port's aperture control has three positions — large opening, small opening, and closed. The Return Port's shutter has two positions — open and closed (which displays a target used for alignment).

6. TURRET RING: A two-position selector that switches elements in the Exit and Return beam paths, depending on whether a "STRAIGHTNESS" measurement is being made.

Figure 2-3. Laser Head — Front



1. The "LASER ON" indicator serves the same function as the front-panel "LASER ON" indicator.

2. The "READY" light shows you when the laser is ready to make measurements. At power-up, the laser tube begins a tuning cycle to stabilize its reference frequency. Halfway through the stabilization cycle, "READY" will start flashing; when the cycle has completed, "READY" will be lighted steadily.

3. The "MEASUREMENT DISPLAY" connector is the connecting point for the cable from the Measurement Display unit.

Figure 2-4 Laser Head — Rear

10751 AIR SENSOR AND 10757 MATERIAL TEMPERATURE SENSOR

To appreciate why these sensors are used, you should have some understanding of how the characteristics of the air and your material can affect your measurements. See Section 6 ("DISTANCE MEASUREMENTS") for more-detailed information about these sensors.

Why Measure Air Temperature, Pressure, or Humidity?

The wavelength of the light produced by the laser is used as the scale for **distance** and **velocity** measurements. (The other measurements are "differential" measurements — see Appendix A for details.)

The wavelength (in air) of any light depends on the velocity of light through air. This, in turn, depends on the temperature, pressure, and (to a lesser extent) relative humidity. For example, air that is less dense (as in the case of low pressure, high-temperature air) results in a higher velocity of light and a longer light wavelength.

The Measurement Display unit multiplies the number of wavelengths it counts (from the Laser Head) by a calibration factor that includes the calculated velocity-of-light compensation, thereby correcting for any difference between the "current" velocity of light (in air) and the velocity of light in a vacuum.

Why Measure Material Temperature?

The most significant source of error in machine tool distance measurements is the effect of temperature on the machine tool. By compensating for material temperature, you adjust the actual measurement value to what the measurement value would be at the standard material temperature of 20°C (68°F)*. This will allow you to compare measurements made at different temperatures.

How are Air and Material Characteristics Input to the Measurement Display Unit?

These characteristics can be entered manually or automatically. Attaching the sensors will enable automatic input of the data; otherwise, you must determine the correct calibration numbers and enter them manually. Instructions for inputting air and material compensation factors are provided in Section 6 ("DISTANCE MEASUREMENTS", of this User's Guide.

*This was established in Paris in 1931 by the International Committee on Weights and Measures (ICPM). See ANSI B89.6.2-1973, "Temperature & Humidity Environment for Dimensional Metrology", page 8.

OPERATION

The best way to become familiar with the Laser Measurement System is to sit down and "play" with it. In the next few pages, you will be led through the process of getting acquainted with the Measurement Display, Laser Head, Sensors, and Optics, by setting up for and making a distance measurement.

LET'S START!

Physical Set Up

1. Place the Laser Head on a table.

   In actual practice, you would attach the Laser Head to the Tripod, using instructions given in Section 4.

   For simplicity's sake, we want you to establish a special measurement axis, rather than try to actually measure a machine.

2. Remove *Figure 2-5* ("Template for Initial Set-up") from this User's Guide and fit it under the Laser Head in the appropriately-marked place. This will serve as a guide for moving the optics in the exercises that follow.

3. Attach a straightedge to the location indicated in *Figure 2-5*. This will serve as the measurement path.

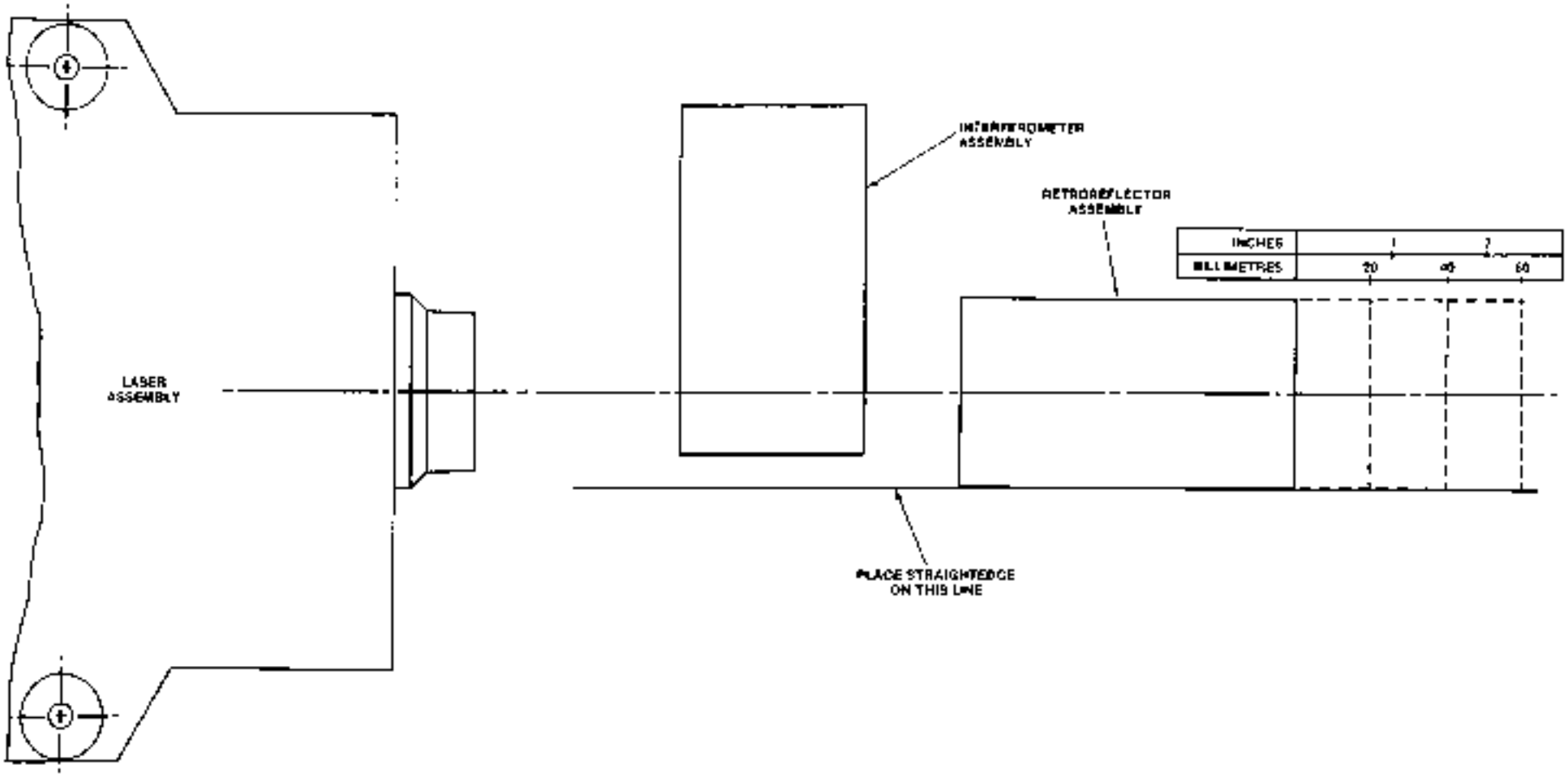


Figure 7-5. Template for Initial Set-Up

Interconnection and Turn-on

NOTE

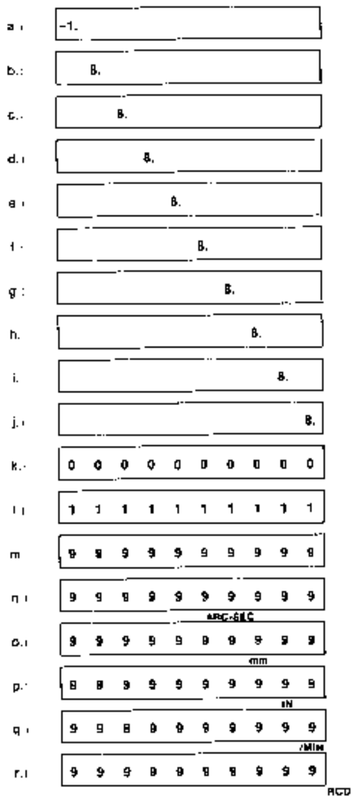
Detailed instructions for step "1" through step "3" below are presented in Section 5 of this User's Guide. Do not perform any of these steps until you have read the related information in Section 5.

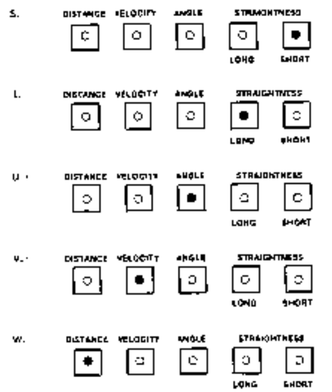
1. Connect the Laser Head and sensors (if you have them) to the Measurement Display.
2. Check the Measurement Display's line voltage selection.
3. Connect the Measurement Display to the power line.
4. Turn on the system. (The LINE switch is at the lower left-hand corner of the Measurement Display's front panel, and turns on power for both that unit and the Laser Head.)

   When power is turned on, the Measurement Display goes through a warm-up routine. Its displays during this time change in the pattern shown in *Figure 2-6*; if your Measurement Display doesn't go through these changes, something may be wrong. Try the test again, then refer to the system's Service Manual or a qualified service person for help.

5508A Power-Up

The self-test sequence is as follows:





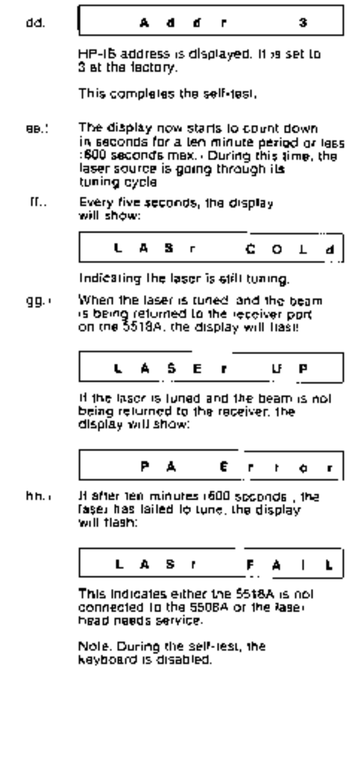


Figure 2-6. Warm-Up Routine

Assembly of Optics

1. Attach one Retroreflector to the Interferometer, as shown in *Figure 2-7*, using the two small knurled screws included with the Retroreflector.
2. Make sure that the "head" of one arrow on the Interferometer's label points toward the Retroreflector, as shown in *Figure 2-7*.
3. See "ASSEMBLY OF OPTICS" information in Section 6 for more details.

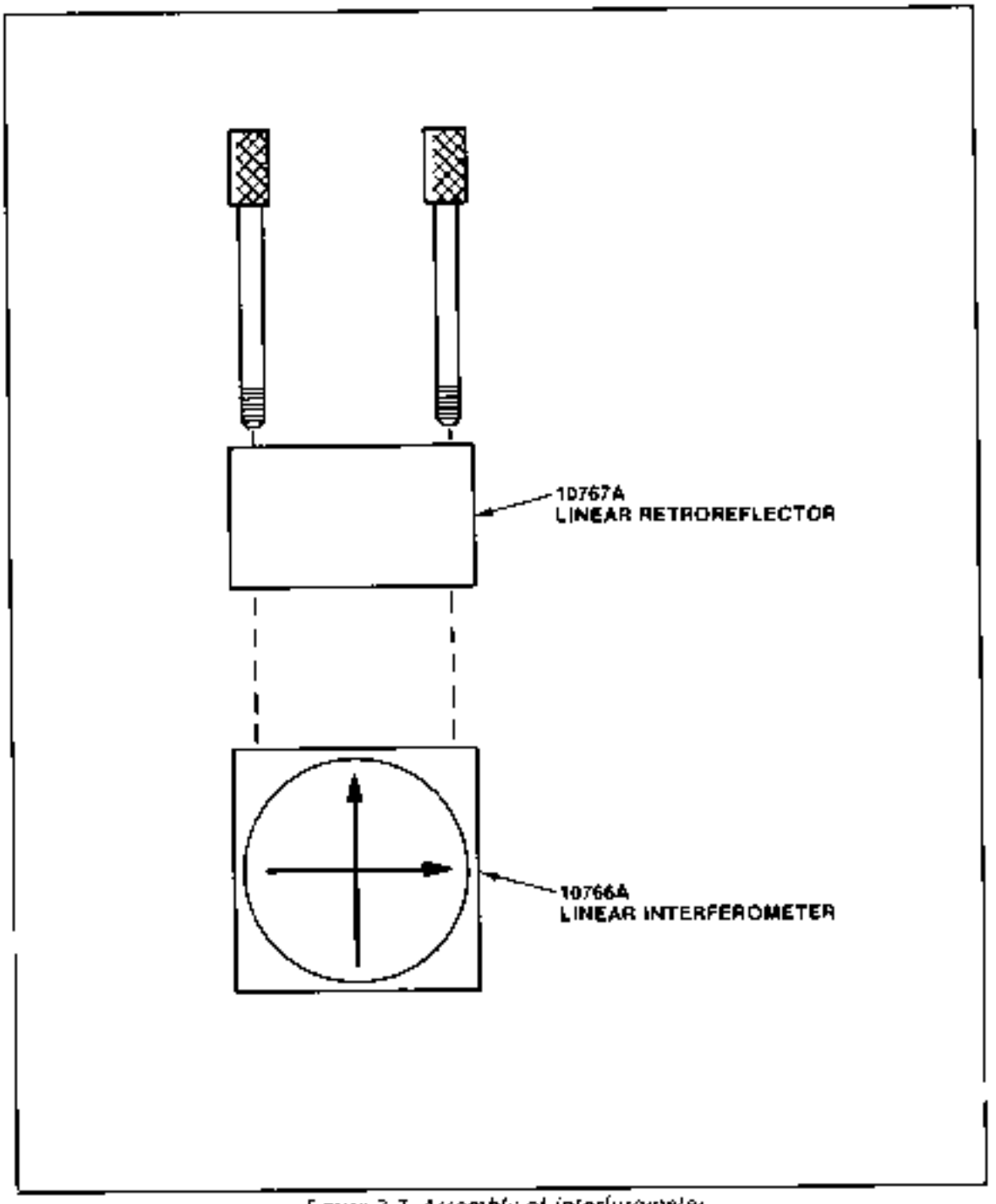


Figure 2-7. Assembly of Interferometer

Installation and Alignment of Optics

Mounting

Three (3) HP 10785A Post and Height Adjusters, and two (2) HP 10784A Bases, are included as part of the Laser Measurement System's Linear Measurement Kit. With these fixtures, you can attach your Optics to most machine surfaces and tool spindles and orient your Optics as required.

Each Optic requires at least one Post and Height Adjuster. Attach the Height Adjuster to the side of the Interferometer as shown in *Figure 2-8*, and then slide the Height Adjuster over a Post supported by a Base.

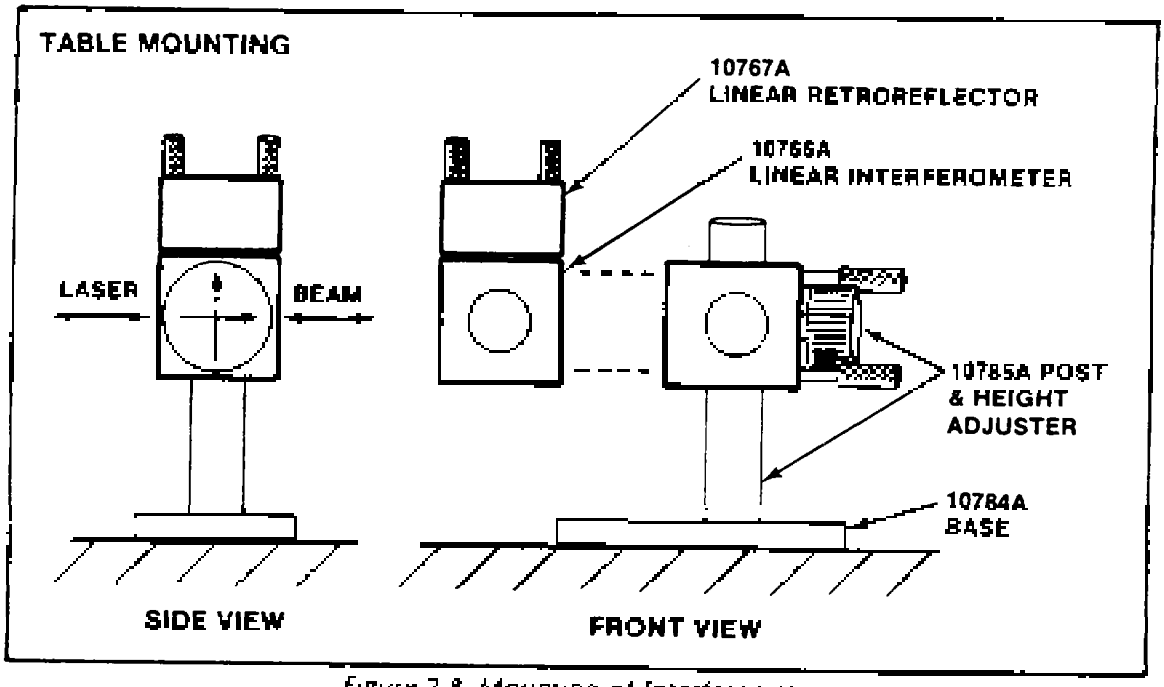


Figure 2-8. Mounting of Interferometer

Do the same for the Retroreflector, as shown in *Figure 2-9*.

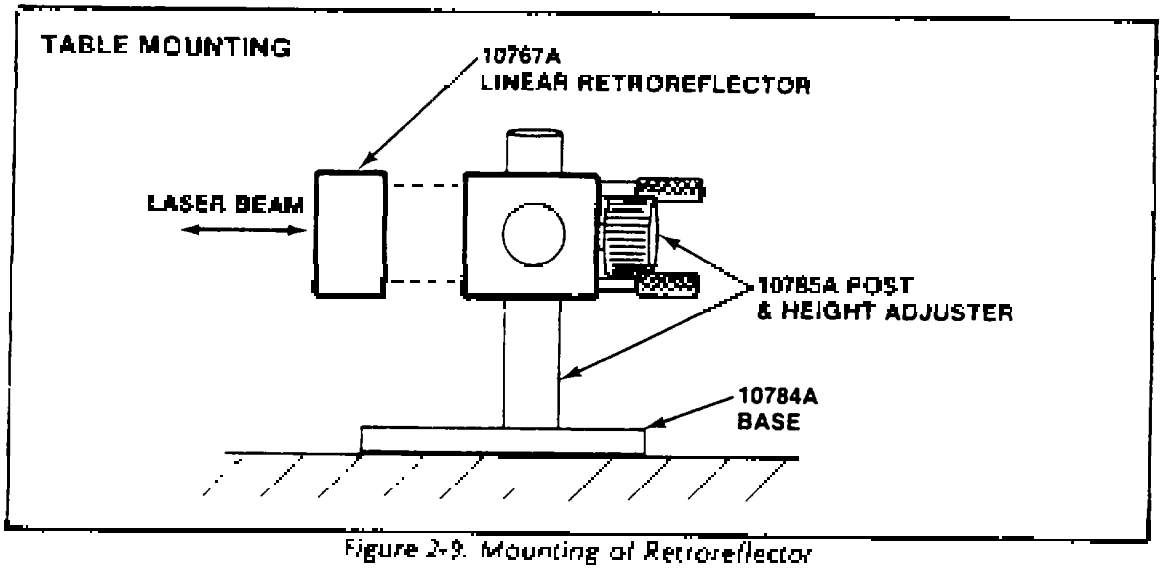


Figure 2-9. Mounting of Retroreflector

Positioning of Optics

1. Position the Optics in the locations indicated on *Figure 2-5*. (You should have already positioned this figure as a template under the Laser Head.) *Figure 2-10* shows how this should look.

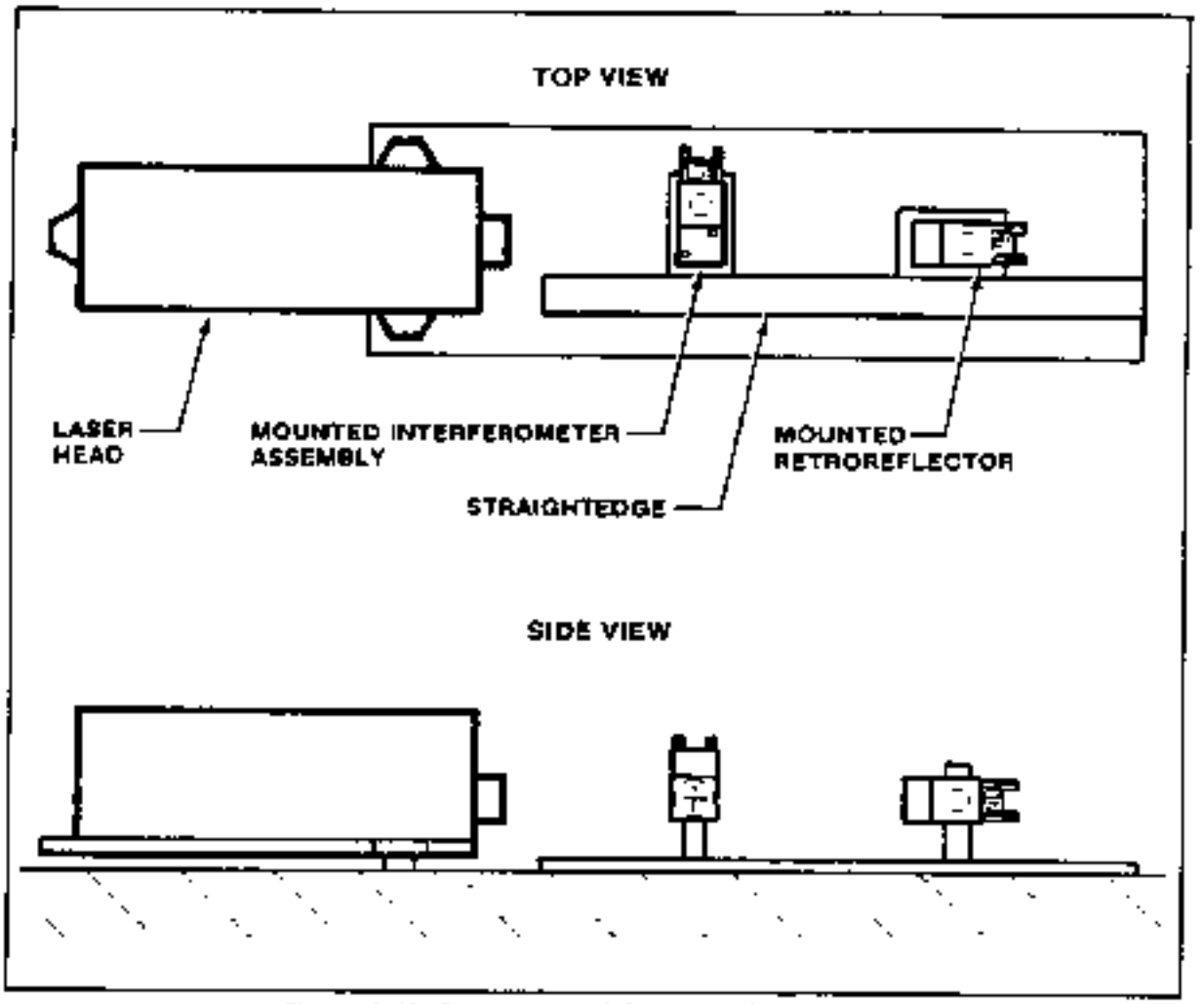


Figure 2-10. Positioning of Optics and Laser Head

2. Refer to *Figure 2-11*, and attach the target to the Interferometer such that —

   - the hole in the Interferometer's target is above the target's crosshair, and —
   - the target is positioned "squarely" on the Interferometer, covering the opening facing the Laser Head. (Use your fingers to line up the edges of the target with the bottom and side edges of the Interferometer.)

3. Attach the target to the Retroreflector (see *Figure 2-11*) such that —

   - the target's crosshair is above its hole, and —
   - the target is positioned squarely on the Retroreflector. (Use your fingers to line up the edges of the target with the edges of the Retroreflector.)

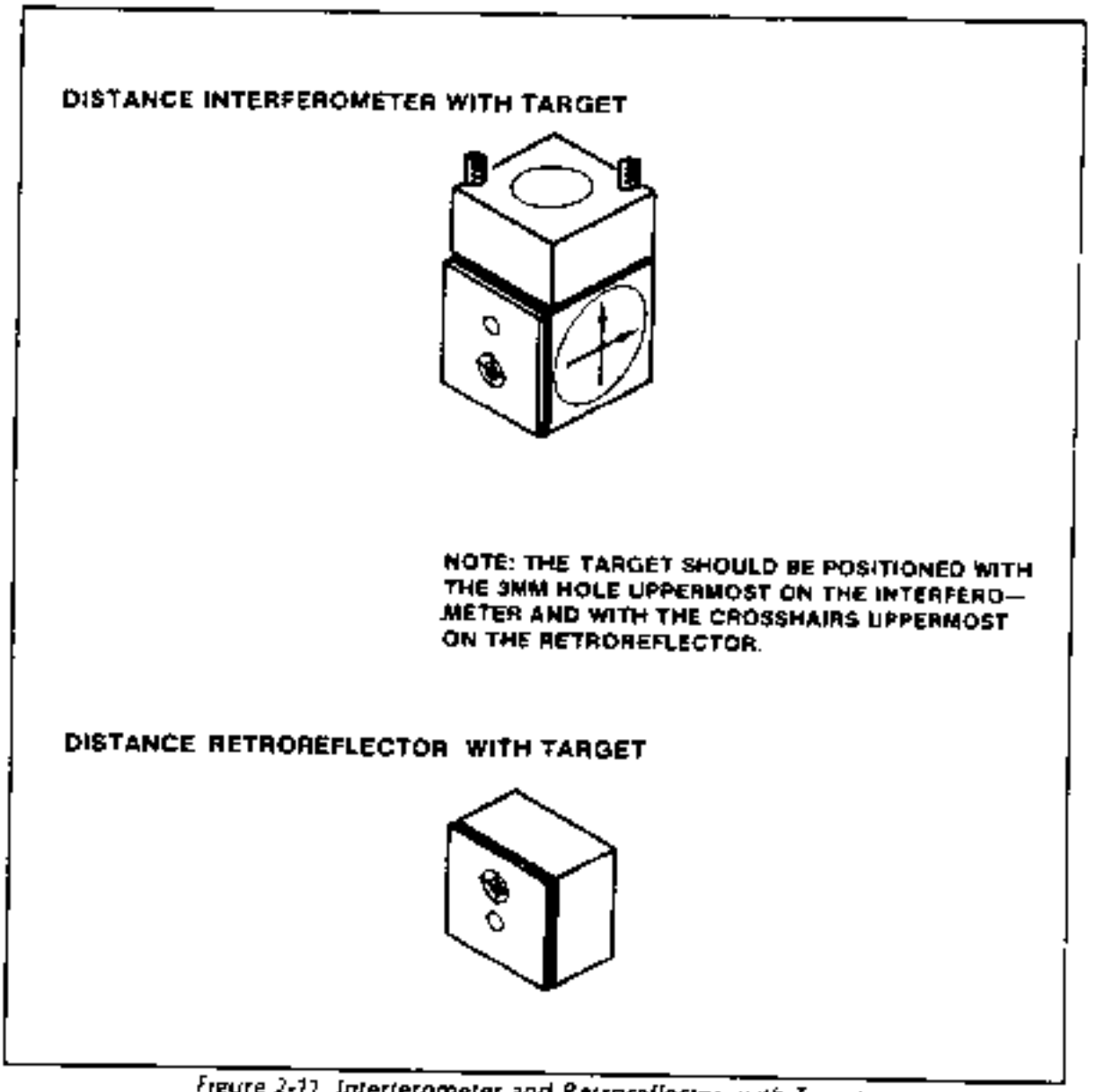


Figure 2-11 Interferometer and Retroreflector, with Targets

4. On the front of the Laser Head, set the exit (top) port's aperture control to select the small aperture.

5. Move the Interferometer up or down (after loosening the Height Adjuster's large knob), or move the Base back and forth, until the Laser Beam passes through the hole in the Interferometer's target.

6. Move the Retroreflector in the same way until the Laser Beam is centered on the crosshair on the Retroreflector's target.

7. Remove the targets from both Optics. You should see two dots on the front of the Laser Head.

8. On the front of the Laser Head, turn the return (bottom) port's aperture control until a target appears in the center of the opening.

9 Put a piece of paper between the Interferometer and the Retroreflector so you block the beam.

Looking at the front of the Laser Head, you should see one dot disappear as you do this. This will be the Retroreflector's return beam. The dot that remains is the Interferometer's return beam.

10 Adjust the Interferometer's position, vertically and horizontally, until its return beam is centered on the return port's target.

11. Adjust the Retroreflector's position, vertically and horizontally, until its return beam is also centered on the return port's target.

You should now see only one dot on the return port's target, since both return beams should overlap completely.

12. Turn both the return port's and the exit port's aperture controls to fully open both ports.

Look at the BEAM STRENGTH meter on the Measurement Display or the Remote Control unit.

You should see the meter's needle move into the "green" area.

13. Move the Retroreflector slightly to one side.

Note how the BEAM STRENGTH indication changes as you do this.

You should note a decrease in beam strength whenever you see the beam being clipped by the Laser Head's return port. (i.e., Any part of the beam that does not enter the return port is lost, as far as contributing to the measurement.)

14. Move the Retroreflector over the full length of the pattern shown on the template that was provided as *Figure 2-5*.

NOTE

Be sure to keep the Retroreflector's base flush against the straightedge as you do this.

Watch the BEAM STRENGTH meter while you do this. Make sure its needle stays in the green area.

If the BEAM STRENGTH needle doesn't stay in the green area, move the straightedge at that point so that the BEAM STRENGTH needle moves back into the green area. Beam strength must be kept in the green area along the full distance of Retroreflector movement (60 mm (2.4 inches)).

You have just **aligned** the Optic's path to the laser beam. In actual practice, you will **align** the laser beam (by adjusting the Laser Head) to match the Optic's path. In any measurement you make with the Laser Measurement System, you will have to **align** the Laser Head to the Optic's or the machine's travel path to return as much signal as possible to the Laser Head's return port.

For Distance and Velocity measurements, alignment is also important for reducing something called "cosine error". (See "WHAT AFFECTS ACCURACY?" in Section 6.)

Actual alignment techniques are described in Section 15. Each measurement section in this User's Guide will either refer you to a technique in Section 15 or it will describe a unique way to align the Laser Head to the Optic's travel path.

Making the Measurement

1. Position the Retroreflector's Base in the rectangle marked on the template of *Figure 2-5*.

2. Set up the display as follows —

DISTANCE



a. Press DISTANCE to set up the Measurement Display unit for Distance mode.

b. Set the rear-panel ENGLISH/METRIC switch to METRIC, so the display will read in "mm".



c. Press RESET.

3. Move the Retroreflector 20 mm (0.80 inch) along the straightedge, to the "20 mm" mark on the template (provided as *Figure 2-5*).

   Note the reading on the display.

4. Specify five-digit display resolution by pressing —



Note how much more frequently the last digit changes.

Keep the same resolution, but turn off "smoothing", by pressing —



Notice how the last four digits now change. By entering a negative number, you told the Measurement Display unit not to "smooth" (average) your measurement data.

Specify six-digit display resolution by pressing —



The display should now show "Or Error", meaning that an "over-range error" has occurred.

Press — 

again

The display will now show "5", which is the maximum allowable resolution value for the metric mode.

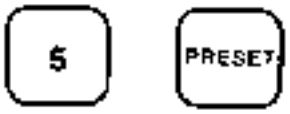
NOTE

If you try to enter a numeric value for any SET UP key that is outside the range allowed for that key, you will first get an "Or Error" or "Ur Error" message, indicating the direction of your error. Pressing the same SET UP key again will cause the limit value for that direction to be displayed. If you are willing to accept the limit value, just press the same SET UP key again.

Specify four-digit display resolution by pressing —

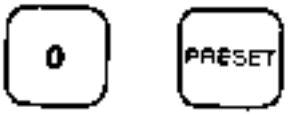


5. Establish a 5 mm PRESET value by pressing —



The Measurement Display will now show a number 5 mm larger, since PRESET adds in this measurement mode. (Preset adds in Distance or Velocity mode, multiplies in Angular or Straightness mode.)

Remove the "preset" value by pressing —



6. Press — 

The sign of the value shown on the display will change.

Press — 

again.

The sign of the displayed value will change back to what it was originally.

7 Display the velocity-of-light compensation number by pressing —

V O L

The display will show the velocity-of-light compensation value provided by the Air Sensor, if connected. If the Air Sensor is not connected, the default value of "728.8" will be displayed

If the Air Sensor is connected, press the "V.O.L." key again.

V O L

The display now shows the air temperature read by the sensor. When the ENGLISH/METRIC switch is in the ENGLISH position, the temperature is displayed in degrees Fahrenheit. When the switch is in the METRIC position, the temperature is displayed in degrees Celsius. (See *Figure 2-12*.)

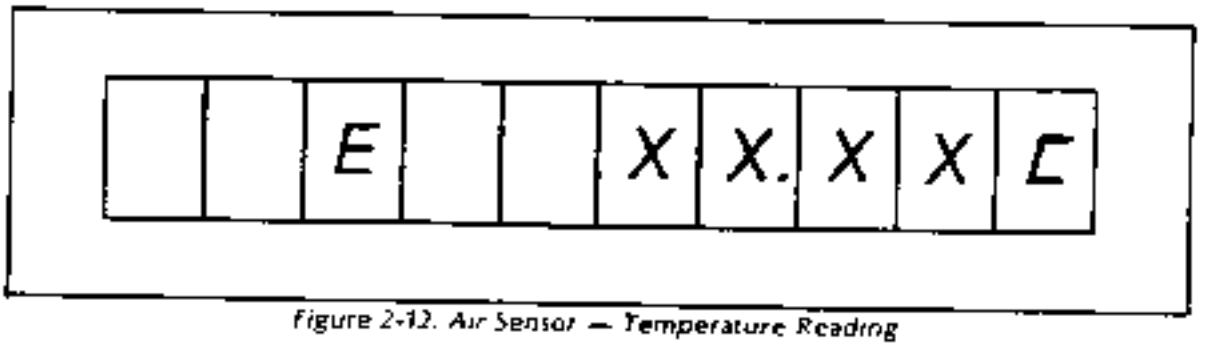


Figure 2-12. Air Sensor — Temperature Reading

If the Air Sensor is connected, press the "V.O.L." key again

V O L

The atmospheric pressure is displayed in either inches or millimetres of mercury depending on the setting of the ENGLISH/METRIC switch. (See *Figure 2-13*.)

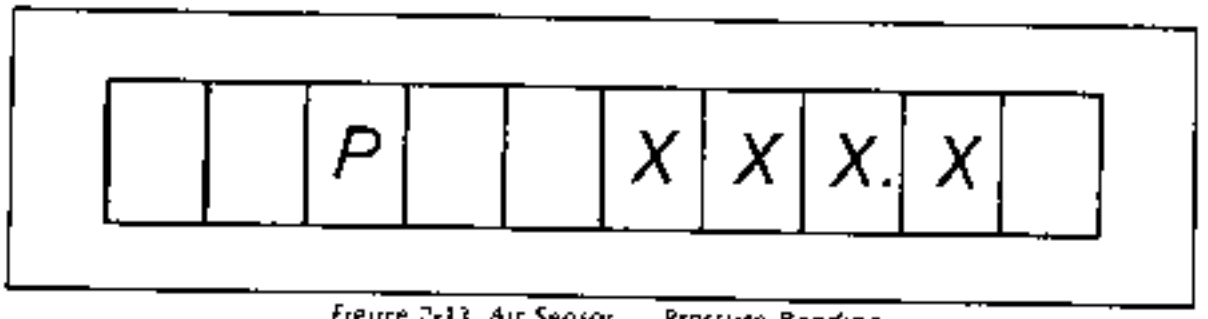


Figure 2-13. Air Sensor — Pressure Reading

If the Air Sensor is connected, press the "V.O.L." key again

V O L

The position of the humidity switch on the sensor is now displayed. Change the position of the humidity switch on the sensor, the reading will change after about two seconds. (See *Figure 2-14*.)

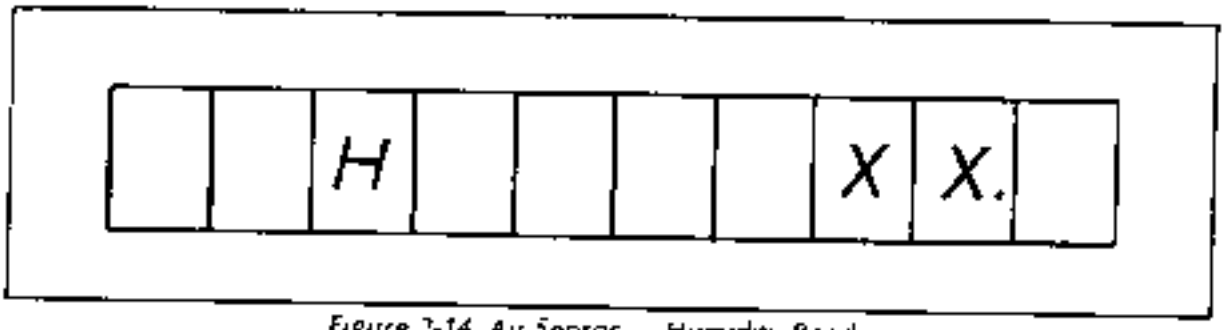


Figure 2-14 Air Sensor — Humidity Reading



Press the "V.O.L." key (again), the display is now back in the measurement mode and the display returns to the old value.

8 Display the Material Temperature value by pressing —



The display will show the average of the Material Temperature values provided by the Material Temperature sensor(s), if connected. (See *Figure 2-15*.)

If no Material Temperature sensor is connected, the displayed value will be 20°C (68°F).

If a Material Temperature Sensor is connected, pressing the MATL TEMP key again will display the reading from material temperature sensor "1" or "2" or "3". The "1" tells you this is "sensor 1". The "1" would be replaced by a "2" or a "3" if a sensor was plugged into "MATERIAL TEMPERATURE" connector "2" or "3" respectively. If more than one material temperature sensor is plugged into the Measurement Display unit, repeated pressing of the MATL TEMP key will successively display the readings from each of the sensors, in turn ("1", "2", "3", etc.).

Press MATL TEMP as often as necessary to cycle through all its displays for your situation.

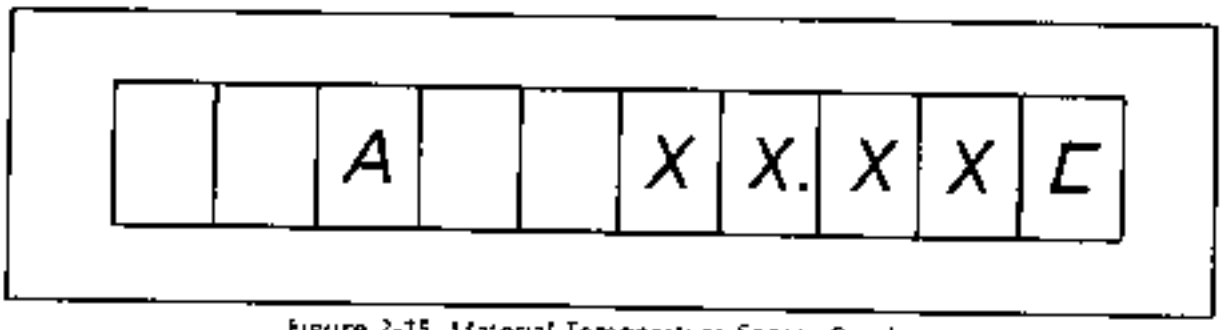


Figure 2-15 *Material Temperature Sensor Reading*

9 Turn off line power, at the Measurement Display unit's front-panel switch.

10 Disconnect the Air Sensor and any Material Temperature Sensor connected to the Measurement Display unit.

11 Turn line power back "on"

After the system has warmed up, the message "LASEr UP" will be displayed

12. Press — 

13 Move the Optics another 20 mm (0.80 inch).

Write down the exact reading.

14. Display the V O L compensation value by pressing — 

The display should show the default value of "728.8"

15 Change the V O L compensation value by about 100, by pressing —



Write down the new reading

The difference between this reading and the value you wrote for step "13" shows the importance of having and using the correct V.O.L compensation number.

16 Display the Material Temperature value by pressing — 

The display should show the default value (20°C or 68°F).

17. Display the expansion coefficient value by pressing — 

The display should show "0.0".

Enter a new expansion value by pressing —



18. Change the Material Temperature value to 25°C by pressing —



Note the new reading. This shows the importance of having the correct Material Temperature and Expansion Coefficient values when you are making a distance measurement.

19. Change the units of measurement by switching the rear-panel ENGLISH/METRIC switch to its ENGLISH position.

CAUTION

This switch has a lock to keep it from accidentally being moved. To avoid damaging the switch, pull its handle "out" while you are moving it from one position to the other. Releasing the handle allows it to lock in its new position.

Note that the values have changed from metric to English units, when you press the following keys —



Resolution will now be five places, instead of four.



Material Temperature will now be 75.97°F.



The expansion coefficient will now be 55.6 times 10^{-6} inch/degree F.

Making an Angular Measurement

1. Replace the Linear Retroreflector with the Angular Reflector, by unscrewing the two long screws on the Height Adjuster.

   Position the Angular Reflector so its label is on top and its Retroreflectors face the Laser Head.

   Be sure you do not move the Height Adjuster or the Base while you are making this change of Optics.

2. Replace the Linear Interferometer with the Angular Interferometer by unscrewing the two long screws on the Height Adjuster.

   Position the Angular Interferometer so the side with two openings faces the Angular Reflector, and the side with one opening faces the Laser Head.

   Be sure you do not move the Height Adjuster or the Base while you are making this change of Optics.

3. Make sure you have adequate beam strength indicated by any reading in the green area. If you didn't move either of your bases when you changed Optics, this should not be a problem.

   The first three steps of this procedure have demonstrated how easy it is to change Optics from those required for one measurement to those required for another.

4. Press — ANGLE



5. Press —



   You are now ready to make an Angular measurement.

6. Tilt the rear of the Angular Reflector's base up slightly, and watch the display. The values shown will be in "arcseconds". (One arcsecond equals 1/3600 of a degree.)

7. Press the PRESET and RESOLution keys as you did for the Distance measurement, and note the differences —



The PRESET value is now used as a multiplier for the actual measured value.



Maximum RESOLution is one place.

3 Measurement Procedures

SECTION 3
MEASUREMENT PROCEDURES SUMMARY

If you started reading at the front of this User's Guide, you have by now connected all your equipment and made a measurement or two, using a table-top template. You should now be ready to try making measurements on a machine or structure.

The remaining portions of this User's Guide are the sections you'll be using every time you make a measurement.

OPERATING PROCEDURES

Table 3-1 shows the sequence of steps required to make any measurement, and where to turn in this User's Guide to find the instructions for that step.

Table 3-1 Operating Procedures — Summary

STEP	USER'S GUIDE SECTION NAME	SEC. NO.
1. Attach Laser Head to Tripod and position it	PHYSICAL SET-UP OF THE LASER HEAD AND TRIPOD	4
2. Interconnect System and turn it on	INTERCONNECTIONS, TURN-ON	5
3. Assemble Optics (Distance only)	"NOTE" Instructions for steps "3" through "7" are found in the User's Guide Section that describes the kind of measurement you want to make (i.e., Distance, Angle, Straightness, etc.)	6
4. Install and Align Optics		1 through 14
5. Adjust settings on Measurement Display unit and position sensors		
6. Make your measurement		
7. Identify what affects accuracy for your measurement		

REFERENCE MATERIAL

For quick reference, or for procedures common to more than one measurement type, turn to Section 15 through Section 21. The information in these sections is listed in *Table 3-2*.

Table 3-2 Guide to Reference Material

Topic/Section Title	Section Number
Alignment Techniques	15
Controls, Connectors, Indicators	16
Errors and Error Messages	17
HP-IB Information	18
V.O.L Compensation Factor	19
Operator Maintenance	20
Straightness and Squareness Considerations	21

MISCELLANEOUS NOTES

Some things to keep in mind when you make measurements are —

1. Keep the Laser Head level (or square) relative to the Optics. By levelling the Later Head as described in Section 4, and by installing and aligning the Optics as described in each measurement section, you will meet this requirement.

2. The Optics and Mounts for each measurement type use **metric** hardware, primarily 3-mm screws. All necessary hardware is included with the Optics.

4. Physical Set-up of Laser & Tripod

SECTION 4
PHYSICAL SET-UP OF THE LASER HEAD AND TRIPOD

CONTENTS

INTRODUCTION
INSTALLING THE LASER HEAD ON THE TRIPOD
LASER HEAD AND TRIPOD POSITIONING CONTROLS
CROSS-SLIDE "FIT" ADJUSTMENTS
POSITIONING THE TRIPOD AND LASER HEAD
LEVELLING THE LASER HEAD

INTRODUCTION

The hardware, other than Optics, you need to make any measurement with the Laser Measurement System and a Tripod is identified in *Figure* 4-1. This hardware is used for all measurements made with the Laser Measurement System and a Tripod.

If you don't use the Tripod discussed in this section, you will have to provide some alternate type of rigid support for the Laser Head. The Laser Head has three mounting "feet" with internal M8x1.25 threads to secure it. Three M8x1.25 screws have been provided.

The Tripod's controls allow easy adjusting of the Laser Head's position to help you align for each measurement, while providing rigidity and an installation position away from the measurement surface.

For hardware used for a specific measurement, see the section of this User's Guide that describes the measurement.

INSTALLING THE LASER HEAD ON THE TRIPOD

The numbers of the steps below are used as references in *Figure* 4-2.

1. Screw the Cross Slide Assembly onto the Transit Adaptor.

2. Insert the Cross Slide/Transit Adaptor Assembly into the Tripod Collar.

   a. Be sure the set screw is in place within the Transit Adaptor and is not protruding.

   b. Position the Cross Slide/Transit Adaptor Assembly so the captive set screw will line up with the access hole in the Tripod's collar.

   c. Use the 3/16-inch allen wrench supplied with the Tripod to tighten the captive set screw in the Transit Adaptor. This keeps the Transit Adaptor from moving in relation to the Tripod's collar.

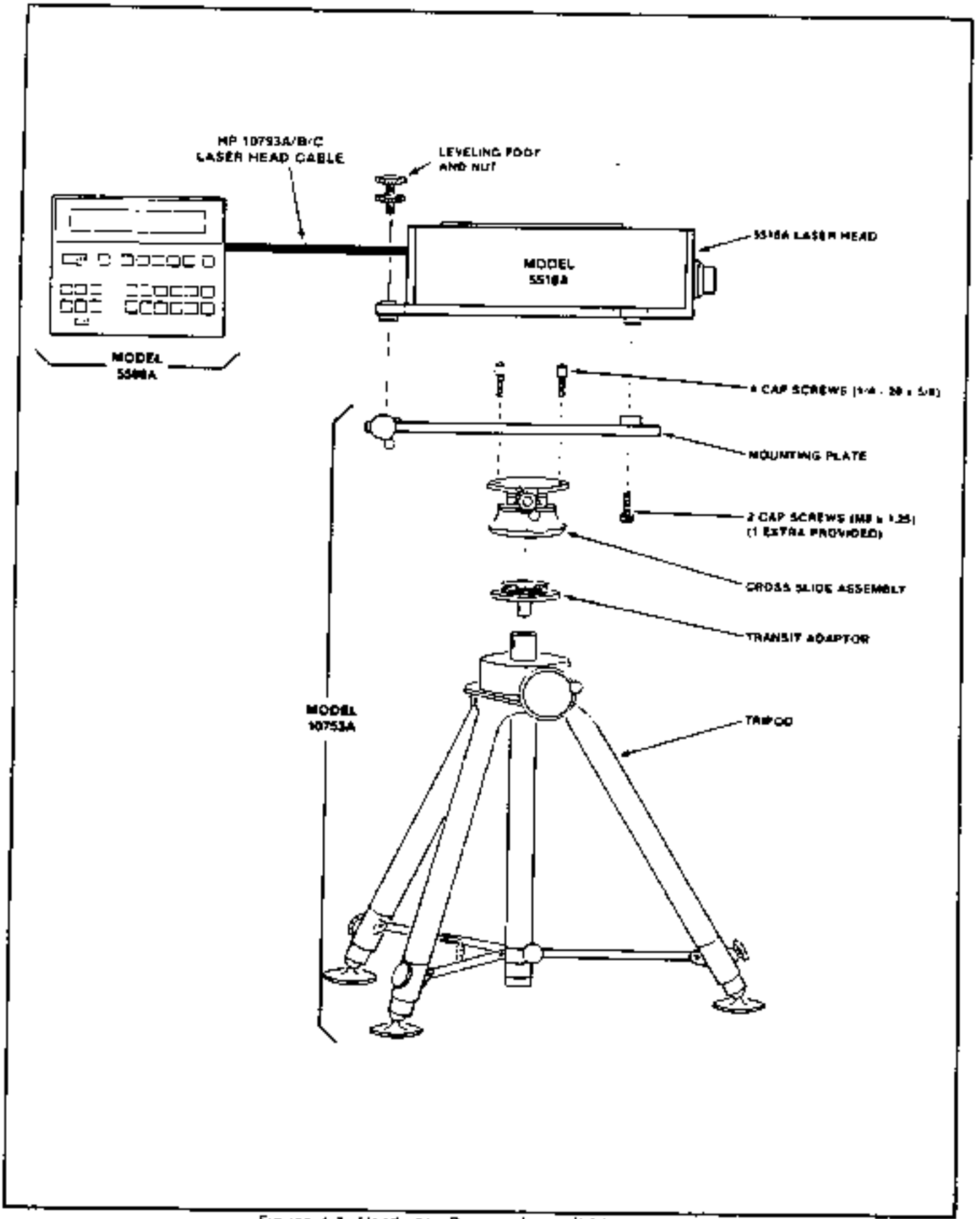


Figure 4-1 *Hardware Required for all Measurements*

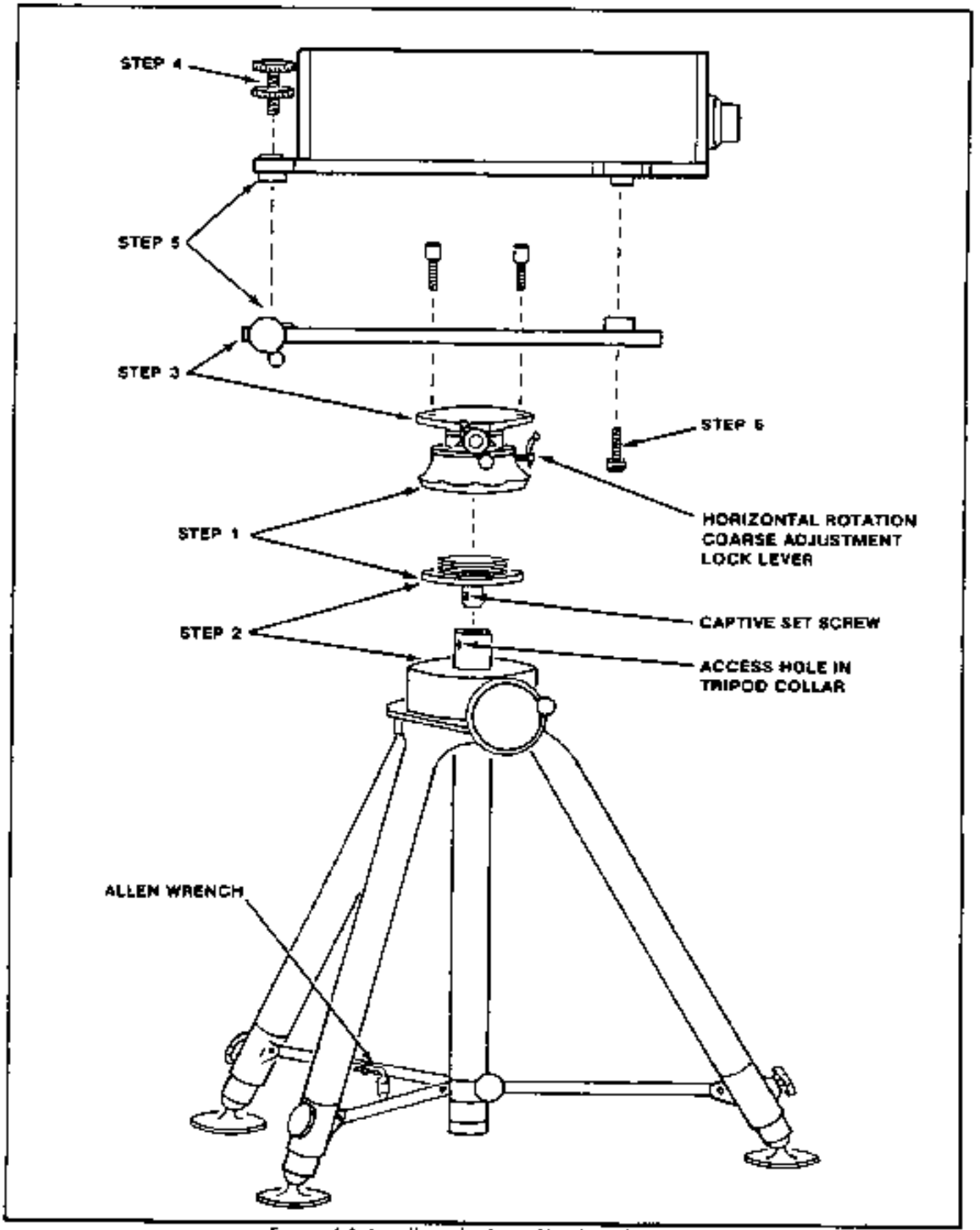


Figure 4-2. Installing the Laser Head on the Tripod

d Lock the Cross Slide's Horizontal Rotation Coarse Adjustment Lock lever (see *Figure 4-2*). This locks the Cross Slide's internal rotations, in preparation for the final tightening of the Cross slide Assembly onto the Transit Adaptor.

e Gently tighten the Cross Slide Assembly onto the Transit Adaptor by turning the Cross Slide Assembly clockwise in relation to the Tripod. This connection should be just tight enough that it won't accidentally loosen while the Laser Measurement System is in use.

3 Attach the Mounting Plate to the Cross Slide Assembly, using the four (4) cap screws provided.

Use the Allen wrench supplied with the Tripod to tighten the cap screws.

4 Screw the Levelling Foot, with its Lock Nut, downward into the Laser Head's rear mounting foot.

5. Place the Laser Head on the Mounting Plate so that its two front feet are in the corresponding Mounting Plate holes, and the Levelling Foot you installed in step "4" drops into the Mounting Plate's miniature Cross-Slide Assembly.

6. Secure the Laser Head to the Mounting Plate, using two of the M8x1.25 screws provided with the Laser Head, screwed upward through the Mounting Plate holes into the Laser Head's front feet.

LASER HEAD AND TRIPOD POSITIONING CONTROLS

Every measurement you make using the Tripod requires translational and turning movements of the Laser Head. You will use these adjustments often, so you should become familiar with them now. The various Tripod adjustments and locks are shown in *Figure 4-3*. Laser Head motions resulting from operating these controls are shown in *Figure 4-4*, separated into vertical and horizontal components.

For **vertical translation** (linear up/down movement) of the Laser Head —

1. Unlock the Vertical Motion Lock, on the "shoulder" of the Tripod Assembly, opposite the large Vertical Translation Handwheel.

2 Turn the Vertical Translation Handwheel to raise or lower the Laser Head to the height you want.

3. Lock the Vertical Motion Lock.

For **vertical rotation** (tilting) of the Laser Head —

1 Unlock the Levelling Foot in the Laser Head's rear mounting foot.

2. Turn (screw) the Levelling Foot in the mounting foot to raise or lower the rear of the Laser Head, as desired.

3. Lock the Levelling Foot at the desired setting, using its Lock Nut.

For **horizontal translation** (linear side-to-side movement) of the Laser Head —

Turn the Horizontal Translation Crank, on the side of the Cross Slide Assembly.

For horizontal rotation (turning) of the Laser Head —

For **coarse adjustment** —

1. Unlock the Horizontal Rotation Coarse Adjustment Lock Lever on the Tripod.
2. Turn the Laser Head so it is pointing in the general direction you want.
3. Lock the Horizontal Rotation Coarse Adjustment Lock Lever on the Tripod.

For fine adjustment —

Turn the Horizontal Rotation Fine Adjust knob on the miniature Cross Slide Assembly at the rear of the Mounting Plate. There is no lock for this assembly.

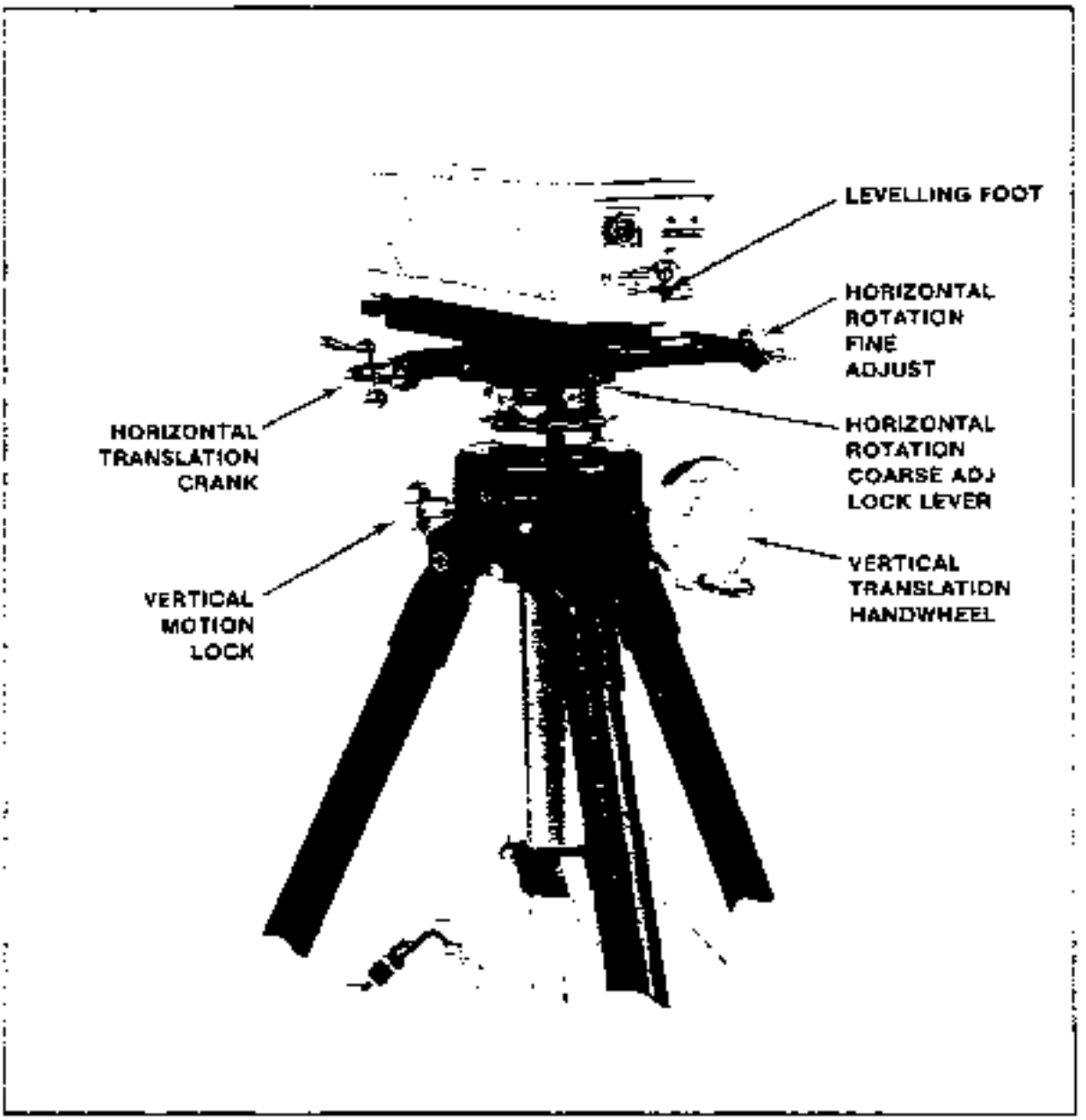


Figure 4-3. Laser Head and Tripod Positioning Controls

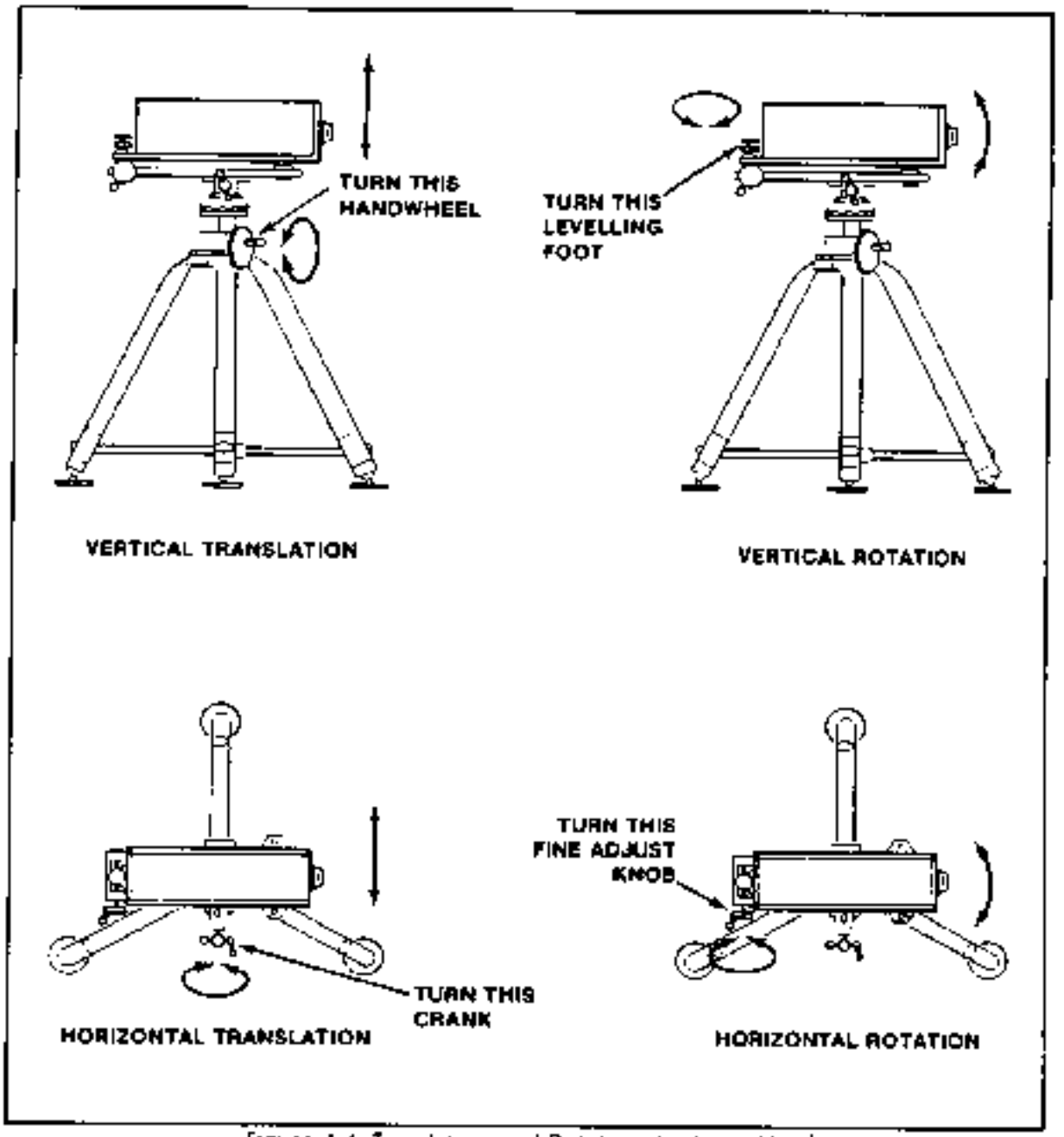


Figure 4-4. Translating and Rotating the Laser Head

CROSS SLIDE "FIT" ADJUSTMENTS

If the Cross Slide's side-to-side movement is too tight or too loose, adjust the three slotted screws on the side of the Cross Slide.

First, tighten the screws, then back off 1/8-turn and tighten the nuts. The screws push a gib against the ways to remove any undesired motion.

If the Cross Slide's rotational movement is too tight or too loose after the rotational lock is released, use a 1/8-inch Allen wrench to adjust the two set screws on the silver part of the Cross Slide Assembly.

POSITIONING THE TRIPOD AND LASER HEAD

Your choice of where to position the Laser Head depends on why you are making your measurements, and where you can mount your Optics.

- If you are calibrating a machine tool, you will probably want to make your measurements as close as possible to the area where the tool meets the workpiece.
- If you are checking the accuracy of a machine's distance measuring system, you will probably want to make your measurements as close as possible to that system, since any offset between your measurement axis and the distance measuring system's axis may introduce error. See "ABBE' ERROR" information in Appendix B.

You can make all Laser System measurements for three different axes from only two set-ups of the Laser Head. These set-ups are pictured in *Figure 4-5*.

Table 4-1 shows which measurements can be made with the Laser Head set up in the two positions shown in Figure 4-5. These measurements are easily made from these two setups since —

1. All the Optics have been designed around a common centerline, allowing complete interchangeability, for all measurements along an axis.

   For Distance and Angular measurements, you can use all of the same mounting hardware with no adjustments between measurements.

2. Measurements on the "Z" axis can be made from either the "X" or "Y" axis by turning the Distance and Angular Interferometers on their sides, or by using a Turning Mirror for Straightness measurements. (See the individual measurement sections in this User's Guide for more information about how to do this.)

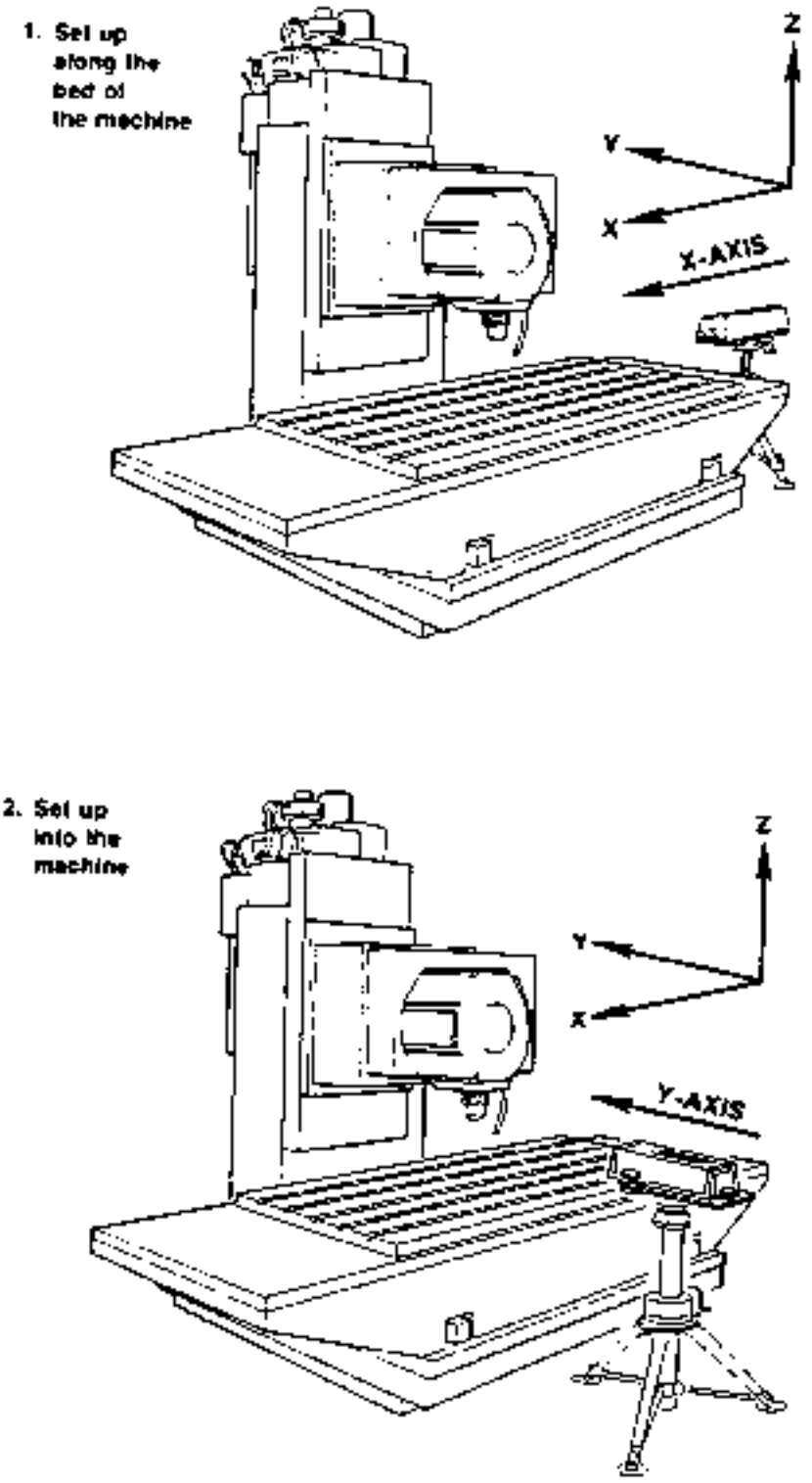


Figure 4-5 Positioning Tripod and Laser

Table 4-1 Measurement versus Setup Axis

To make this measurement	Make your setup along
Distance	
X-axis	X-axis or Y-axis
Y-axis	X-axis or Y-axis
Z-axis	X-axis or Y-axis
Angular	
Pitch	
X-axis	X-axis only
Y-axis	Y-axis only
Z-axis	X-axis only
Yaw	
X-axis	X-axis or Y-axis
Y-axis	X-axis or Y-axis
Z-axis	Y-axis only
Straightness	
Vertical	
X-axis	X-axis only
Y-axis	Y-axis only
Z-axis	X-axis or Y-axis
Horizontal	
X-axis	X-axis only
Y-axis	Y-axis only
Z-axis	X-axis or Y-axis
Squareness	
X-vs-Y	X-axis or Y-axis
X-vs-Z	X-axis only
Y-vs-Z	Y-axis only

LEVELLING THE LASER HEAD

Positioning one leg of the Tripod in line with the Laser beam will usually make it easier to level the baseplate.

Adjust leg lengths until the baseplate is level, as indicated by the bubble level at the rear of the Tripod's Mounting Plate. Do this by loosening the large silver knobs on each leg. Be sure you securely tighten these knobs when you have finished the levelling operation.

SECTION 5
INTERCONNECTIONS
TURN-ON

CONTENTS

INTRODUCTION
SAFETY INFORMATION
CONNECTING THE LASER HEAD TO THE MEASUREMENT DISPLAY
CONNECTING SENSORS TO THE MEASUREMENT DISPLAY
CONNECTING THE REMOTE CONTROL BOX TO THE MEASUREMENT DISPLAY
CONNECTING AN HP PERSONAL COMPUTER AND/OR AN HP PLOTTER TO THE MEASUREMENT DISPLAY
CHECKING THE LINE-VOLTAGE SELECTION
CONNECTING THE SYSTEM TO THE POWER LINE
TURN-ON

INTRODUCTION

This User's Guide section presents the information you should have to make the power and signal connections required by the Laser Measurement System.

Some of the information in this Section is similar to that presented in Section I, Section II, or Section III of the 5528A's Service Manual.

If you are servicing the Laser Measurement System, or performing an incoming inspection on it, we recommend that you refer to the 5528A's Service Manual for all the information you need, including connection information.

SAFETY INFORMATION

WARNING

BEFORE THE INSTRUMENT IS SWITCHED ON, ALL PROTECTIVE EARTH TERMINALS, EXTENSION CORDS, AUTO-TRANSFORMER AND DEVICES CONNECTED TO IT SHOULD BE CONNECTED TO A PROTECTIVE EARTH GROUNDED SOCKET. ANY INTERRUPTION OF THE PROTECTIVE (GROUNDING) CONDUCTOR (INSIDE OR OUTSIDE THE INSTRUMENT) OR DISCONNECTING THE PROTECTIVE EARTH TERMINAL WILL CAUSE A POTENTIAL SHOCK HAZARD THAT COULD RESULT IN PERSONAL INJURY. (GROUNDING ONE CONDUCTOR OF A TWO-CONDUCTOR OUTLET IS NOT SUFFICIENT PROTECTION.)

WHENEVER IT IS LIKELY THAT THE PROTECTION HAS BEEN IMPAIRED, THE INSTRUMENT MUST BE MADE INOPERATIVE AND BE SECURED AGAINST ANY UNINTENDED OPERATION.

IF THIS INSTRUMENT IS TO BE ENERGIZED VIA AN AUTOTRANSFORMER (FOR VOLTAGE REDUCTION) MAKE SURE THE COMMON TERMINAL IS CONNECTED TO THE EARTH TERMINAL OF THE POWER SOURCE.

WARNING (Continued)

ONLY FUSES WITH THE REQUIRED RATING AND OF THE SPECIFIED TYPE SHOULD BE USED. DO NOT USE A REPAIRED FUSE OR A SHORT-CIRCUITED FUSEHOLDER: DOING SO COULD CAUSE A SHOCK OR FIRE HAZARD.

WARNING

LASER RADIATION IS EMITTED FROM THE APERTURE ON THE 5518A LASER HEAD. DO NOT STARE INTO THE BEAM. THIS PRODUCT IS A CLASS II LASER PRODUCT CONFORMING TO FEDERAL BUREAU OF RADIOLOGICAL HEALTH REGULATIONS 21 CFR 1040.10 AND 1040.11, AND TO INTERNATIONAL LASER SAFETY REGULATIONS. THE MAXIMUM OUTPUT IS 1 MILLIWATT, THE PULSE SPECIFICATION IS CONTINUOUS WAVE, THE LASER MEDIUM IS HELIUM NEON, THE WAVELENGTH IS 632.991 NM.

CONNECTING THE LASER HEAD TO THE MEASUREMENT DISPLAY

After you have mounted the Laser Head on the Tripod (as described in Section IV), or some other support, and have placed the Measurement Display unit in the general vicinity where it will be during measurements (within 5 metres (16 feet) of the Laser Head), you can connect these two units using the HP 10793A/B/C Laser Head Cable included with the Measurement Display.

The cable's connectors are identical. You can connect either one of them to the mating connector on the rear of the Laser Head, and the other one to the mating connector on the rear of the Measurement Display unit (see *Figure 5-1*).

The connectors on this cable, and their mating connectors on the Measurement Display unit and the Laser Head, are "keyed" so they will go together in only one way. The connectors normally are quite easy to connect, and should not be forced. You'll see that the plastic "boot" on each cable connector has a mark molded into it that will be "up" when the connections are correctly made.

The cable's connectors include a locking ring to lock the cable to the mating connector on the unit. When you have connected the cable to its mating connector, turn the locking ring about 1/3 turn clockwise to lock the two connectors together; this will keep the cable from accidentally coming loose. You will feel the locking action as you turn the locking ring.

CAUTION

To prevent possible damage to the Measurement Display unit, be sure you turn the line power off before connecting or disconnecting any cable at its rear panel.

CAUTION

Be sure to unlock cable connectors before you try to separate a cable from its mating connector. Failure to do so can cause you to strain the cable, damaging it internally; it can also cause you to damage the connectors.

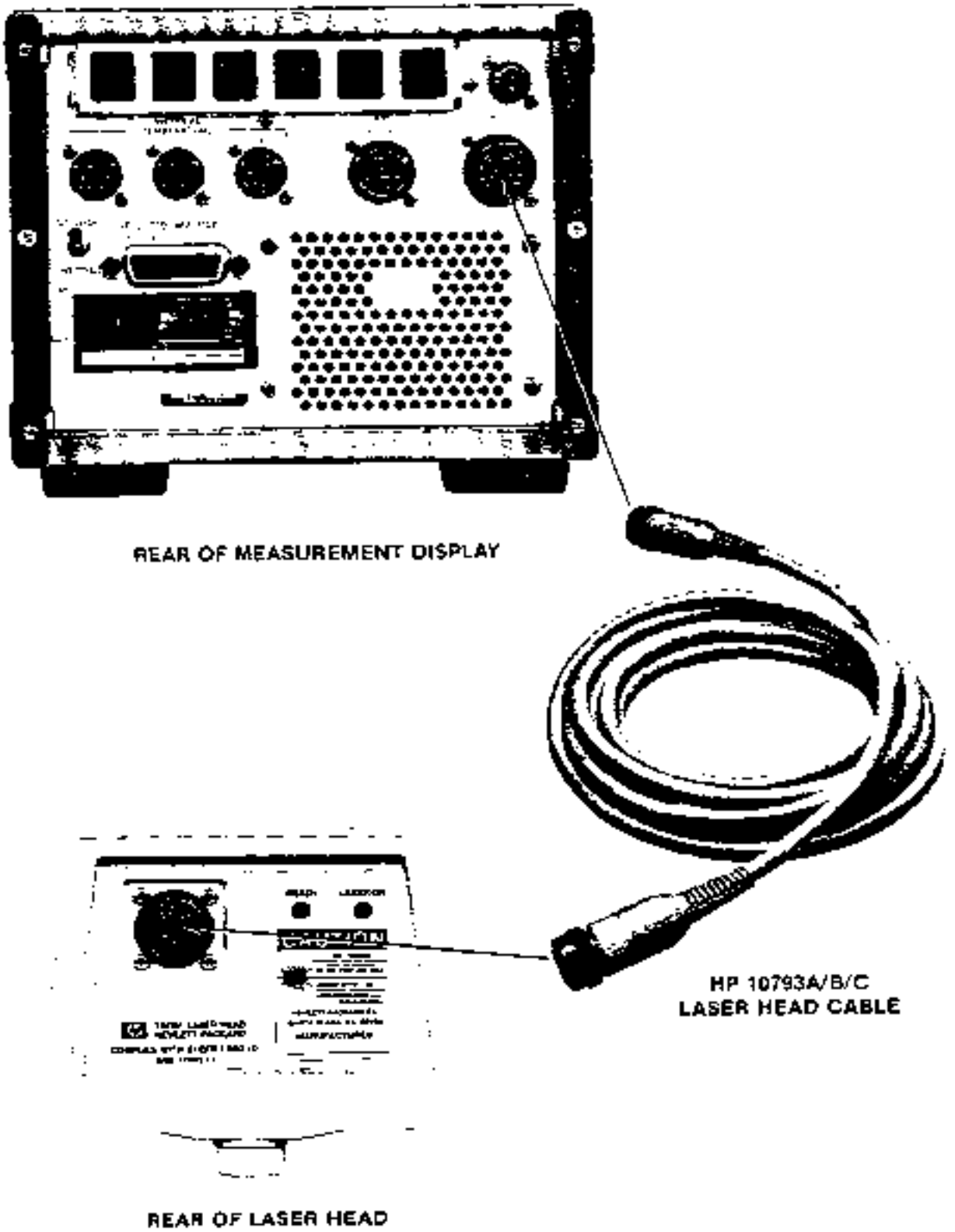


Figure 5-1. Connecting the Laser Head to the Measurement Display

CONNECTING SENSORS TO THE MEASUREMENT DISPLAY

NOTE

The sensors are used only for distance and velocity measurements, and their use is described in Section 6 of this User's Guide ("DISTANCE MEASUREMENTS").

If you have a 10751 Air Sensor and/or any 10757 Material Sensor(s), attach their cables to the appropriate connectors on the Measurement Display's rear panel, as shown in *Figure 5-2*.

Attach the Air Sensor's cable to the connector labelled "AIR SENSOR".

You can attach the Material Sensor(s), in any order, to the "MATERIAL TEMPERATURE" connector(s), marked "1", "2", and "3". The plastic "boot" on each cable connector has a mark molded into it that will be "up" when the connections are correctly made.

The cable's connector includes a locking ring to lock the cable to the mating connector on the unit. When you have connected the cable to its mating connector, turn the locking ring about 1/3 turn clockwise to lock the two connectors together. This will keep the cable from accidentally coming loose. You will feel the locking action as you turn the locking ring.

CAUTION

To prevent possible damage to the Measurement Display unit, be sure you turn the line power off before connecting or disconnecting any cable at its rear panel.

CAUTION

Be sure to unlock cable connectors before you try to separate a cable from its mating connector. Failure to do so can cause you to strain the cable, damaging it internally; it can also cause you to damage the connectors.

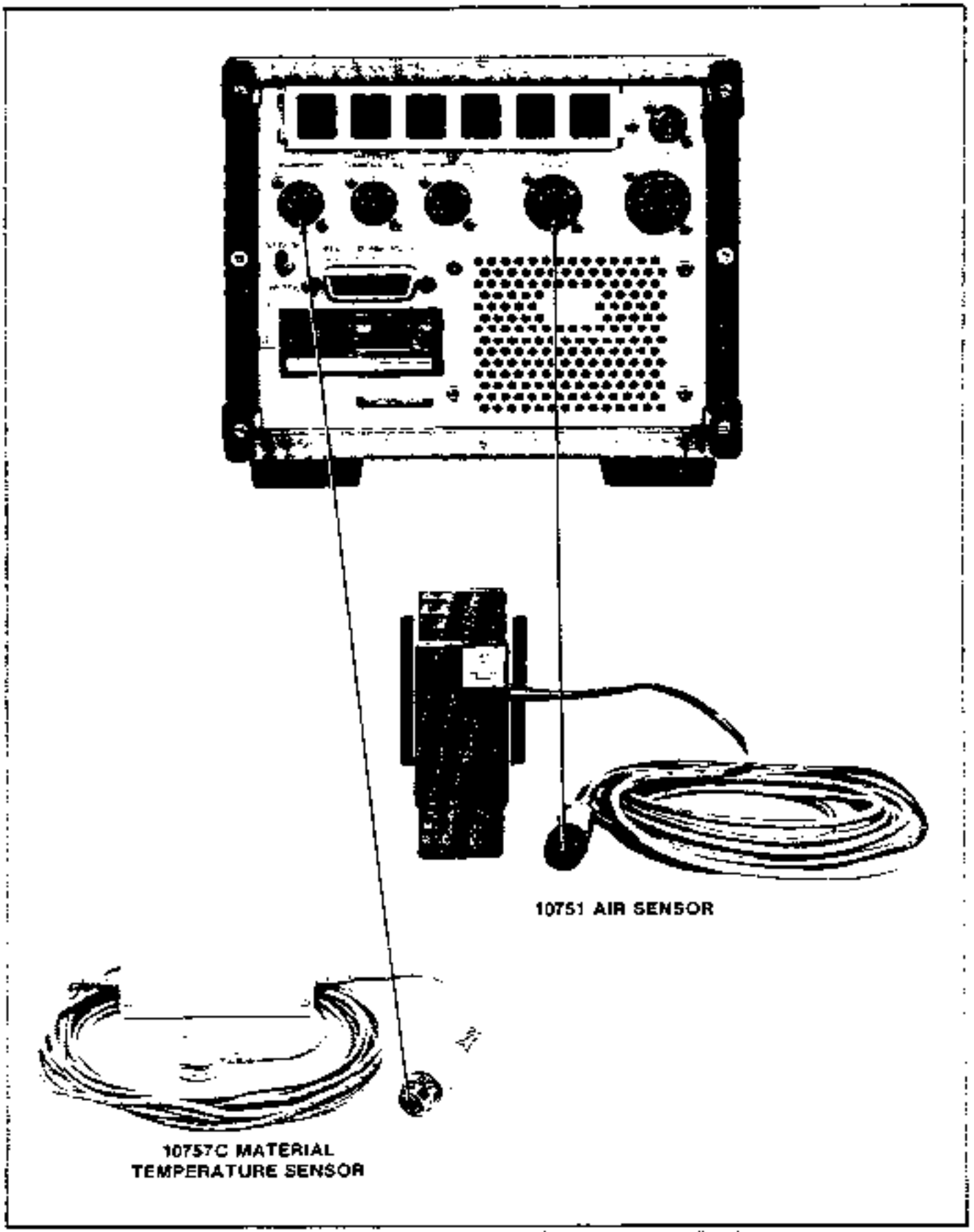


Figure 5-2. Connecting Sensors to the Measurement Display

CONNECTING THE REMOTE CONTROL BOX TO THE MEASUREMENT DISPLAY

Connect the cable from the 05508-60021 Remote Control box to the Measurement Display unit's corresponding rear-panel connector. *(Refer to Figure 5-3.)* The plastic "boot" on this cable's connector has a mark molded into it that will be "up" when the connection is correctly made.

The cable's connector includes a locking ring to lock the cable to the mating connector on the unit. When you have connected the cable to its mating connector, turn the locking ring about 1/3 turn clockwise to lock the two connectors together; this will keep the cable from accidentally coming loose. You will feel the locking action as you turn the locking ring.

CAUTION

To prevent possible damage to the Measurement Display unit, be sure you turn the line power off before connecting or disconnecting any cable at its rear panel.

CAUTION

Be sure to unlock cable connectors before you try to separate a cable from its mating connector. Failure to do so can cause you to strain the cable, damaging it internally; it can also cause you to damage the connectors.

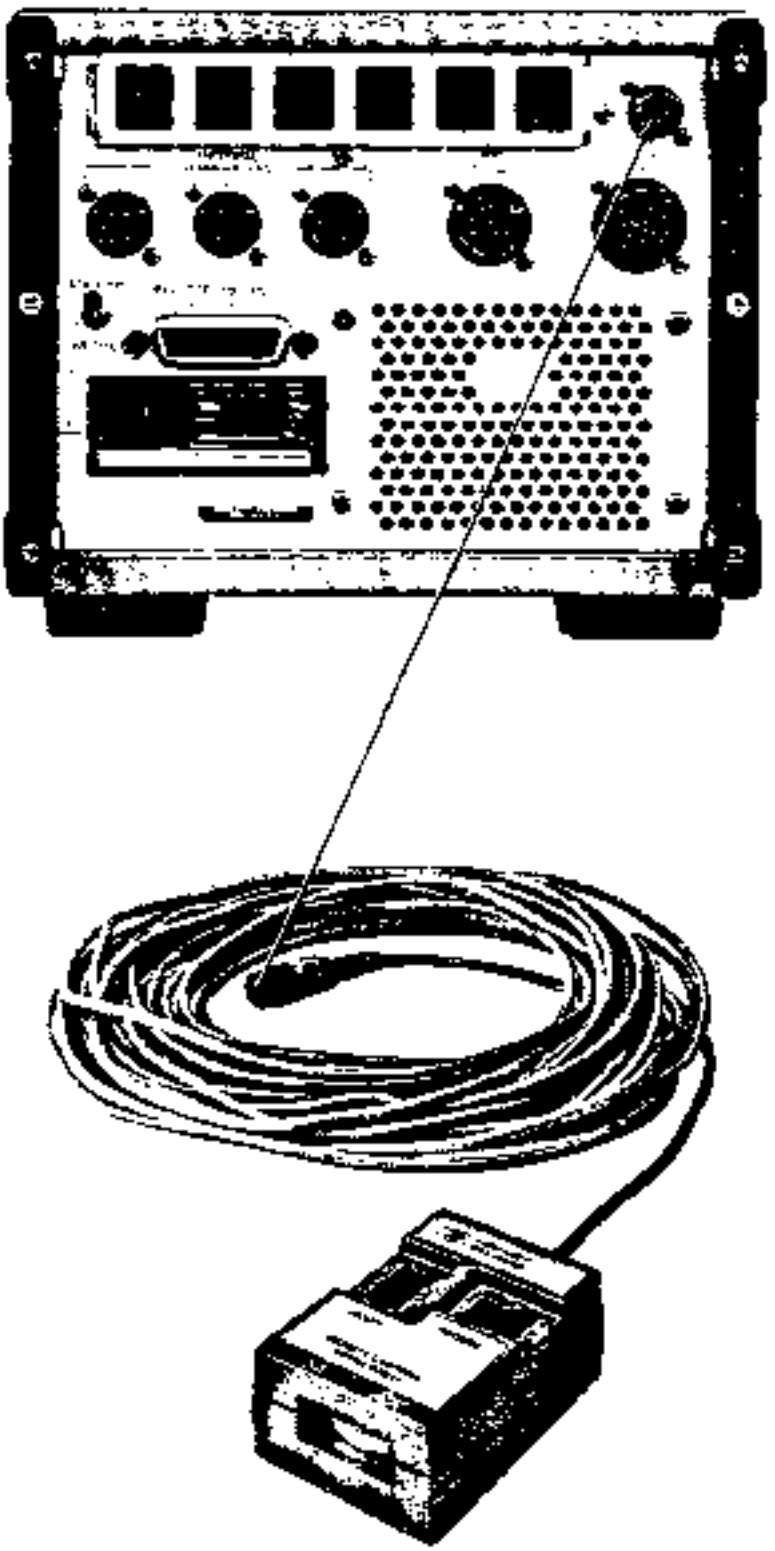


Figure 5-3. Connecting the Remote Control Box to the Measurement Display

CONNECTING AN HP PERSONAL COMPUTER AND/OR AN HP PLOTTER TO THE MEASUREMENT DISPLAY

The HP-IB (Hewlett-Packard Interface Bus) connector allows the Laser Measurement System's capabilities to be increased by the addition of other equipment.

In this case, the other equipment you might connect here would be —

- an HP Personal Computer,
- a compatible Digital Plotter.

An HP Personal Computer is part of the HP Dimensional Metrology Analysis System (which includes the software required to make the Computer work with the Laser Measurement System). The Dimensional Metrology Analysis System is documented in a manual of its own.

A Digital Plotter requires that the HP Personal Computer be connected to the Laser Measurement System. The Plotter will not work with a Laser Measurement System that does not have an HP Personal Computer connected to it.

1. Make sure that the HP Personal Computer and the Plotter are correctly set up to operate from the line voltage available at your site, then connect each of them to the power line.

2. Connect the HP-IB connectors of all units in the system together, using one or two HP-IB cables. *Figure 5-4* shows where the HP-IB connector is located on the Measurement Display unit's rear panel.

   If you cannot find the HP-IB connector on your HP Personal Computer or Plotter, and have not been able to find the required location information in their respective Operating Manuals, contact your local Hewlett-Packard Sales and Service Office for assistance.

The HP-IB cable connectors includes locking screws to lock them together. When you have connected each cable to its mating connector, beginning with the connector on the Measurement Display unit's rear panel, tighten the locking screws; this will keep the cables from accidentally coming loose.

NOTE

On HP-IB cables — black screws have metric threads, silver screws have English threads. The connection at the Measurement Display requires metric threads. Do not try to mate black and silver locking screws.

CAUTION

To prevent possible damage to the Measurement Display unit, be sure you turn the line power off before connecting or disconnecting any cable at its rear panel.

CAUTION

Be sure to unlock cable connectors before you try to seperate a cable from its mating connector. Failure to do so can cause you to strain the cable, damaging it internally; it can also cause you to damage the connectors.

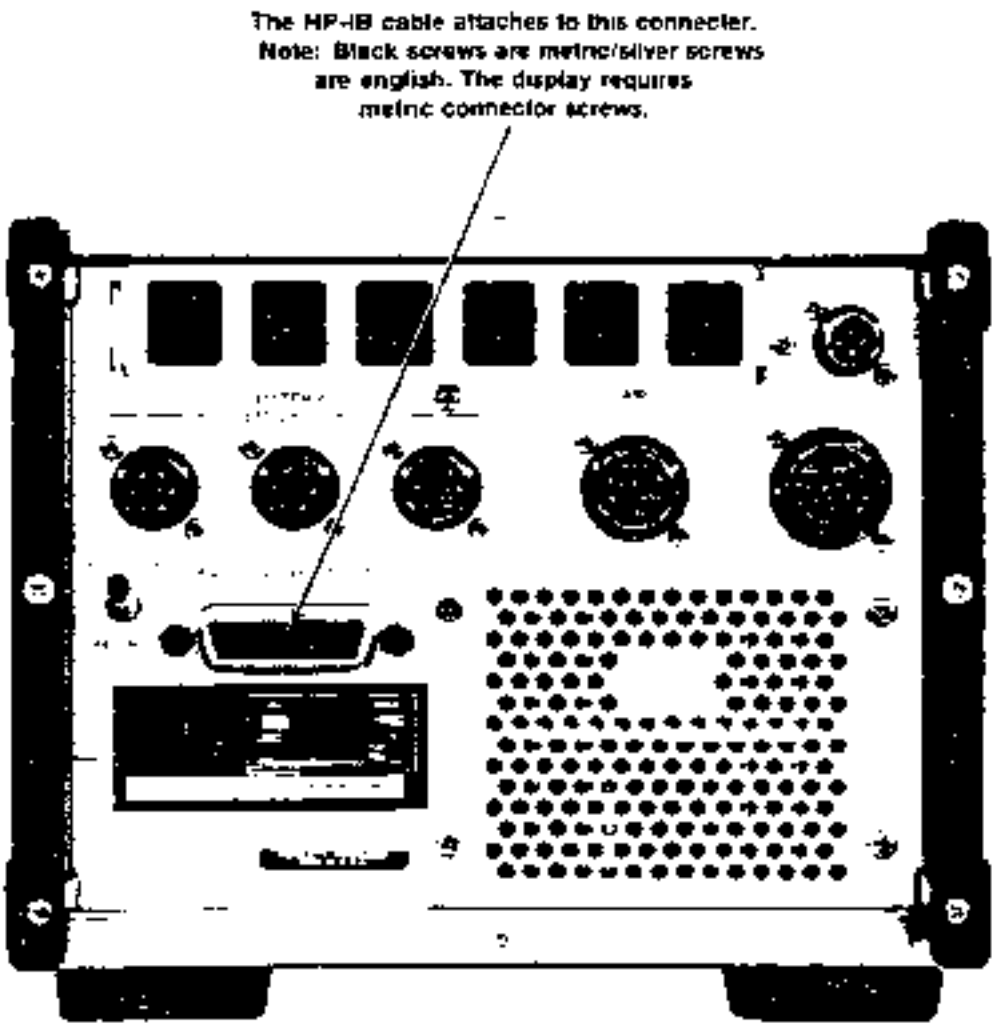


Figure 5-4. HP-IB Connections

CHECKING THE LINE-VOLTAGE SELECTION

To prevent damage to your Laser Measurement System, it must be correctly set up to operate from the power line voltage available at your site.

To check the line voltage setting, look through the window in the Line Power Module on the Measurement Display unit's rear-panel; the numbers you read on the printed circuit board there indicate the (nominal) line voltage your unit is set up to use (see *Figure* 5-5).

If it is necessary to change the setting of the line voltage selector in your unit, follow the instructions presented in *Figure* 5-5. Be sure the line fuse is changed to the required value.

If any other equipment (such as an HP Personal Computer) is connected to your Laser Measurement System, be sure it is also correctly set up to operate from the line voltage available at your site.

CONNECTING THE SYSTEM TO THE POWER LINE

CAUTION

To prevent serious damage to your unit, do not connect it to the power line if the line-voltage number you read through the line power module's window is different from the power line voltage at your site. Instructions for changing the line voltage selection (and fuse) are presented earlier in this user's guide section.

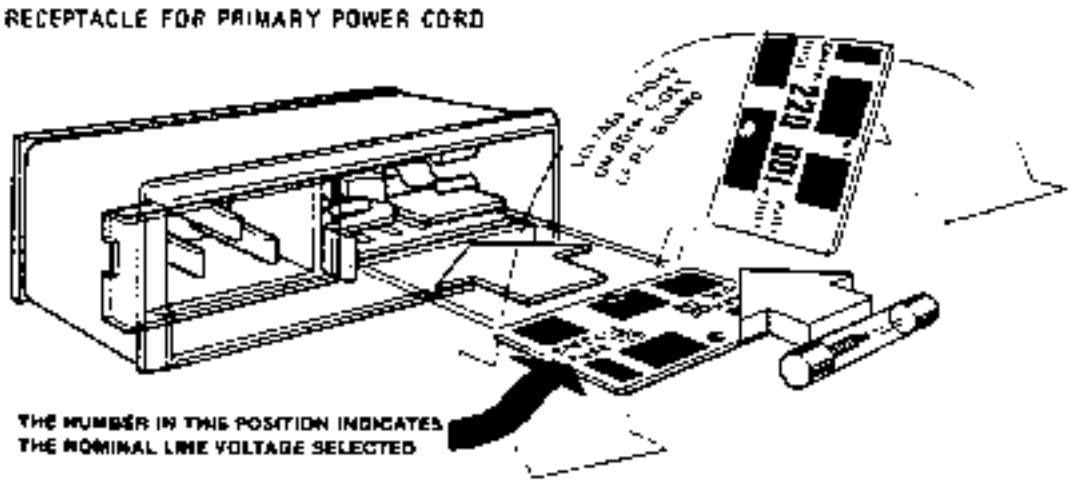
If your laser measurement system includes any optional line-powered equipment (such as an HP Personal Computer), be sure this equipment is also correctly set up to operate from the line voltage available at your site.

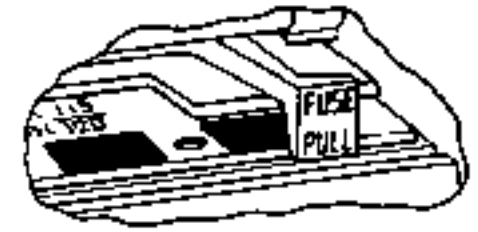
Assuming that you have followed the instructions presented so far in this User's Guide section, and that your Measurement Display unit is correctly set for the line voltage at your site and is connected to the Laser Head (and any optional equipment), you are now ready to connect the system to the power line. The line power connection for the Laser Measurement System is made via the Measurement Display unit's rear panel.

One end of the line power cord supplied with your unit is a three-conductor female connector that mates with the male-connector portion of the Measurement Display unit's rear-panel Line Power Module. Note that a safety-interlocking door is provided on the Line Power Module; in order to connect the line power cord, this door must be moved so it covers the fuse and line-voltage selector area. (Conversely, the fuse cannot be removed or the line-voltage selection changed with the line power cord connected, since the cord prevents the cover from moving away from this area.)

NOTE

The Laser Measurement System is provided with a line power cord whose plug is appropriate for the shipment destination. If the plug on your line cord does not match the the line power receptacle at your site, refer to the Laser Measurement System's Service Manual for the HP Part Numbers of available line power cords.





SELECTION OF OPERATING VOLTAGE

1. Open cover door and rotate fuse-pull to left.
2. Select operating voltage by orienting PC board to position desired voltage on top-left side. Push board firmly into module slot.
3. Rotate fuse-pull back into normal position and reinsert fuse in holders, using caution to select correct fuse value.

When the line voltage number you read is —	The lowest line voltage you can use your system on is —	The highest line voltage you can use your system on is —	The rating of the line fuse that must be installed is —
100V	90V	105V	2A
115V-120V	106V	126V	2A
220V	198V	231V	1A
230V-240V	216V	252V	1A

Figure 5-5. Line Voltage Selection

TURN-ON

WARNING

LASER RADIATION IS EMITTED FROM THE APERTURE ON THE 5518A LASER HEAD. DO NOT STARE INTO THE BEAM.

THIS PRODUCT IS A CLASS II LASER PRODUCT CONFORMING TO FEDERAL BUREAU OF RADIOLOGICAL HEALTH REGULATIONS 21 CFR 1040.10 AND 1040.11, AND TO INTERNATIONAL LASER SAFETY REGULATIONS. THE MAXIMUM OUTPUT IS 1 MILLIWATT. THE PULSE SPECIFICATION IS CONTINUOUS WAVE. THE LASER MEDIUM IS HELIUM NEON, THE WAVELENGTH IS 632.991 NM.

Press the "ON" side of the Measurement Display unit's front-panel LINE switch to turn on the Laser Measurement System (Measurement Display unit and Laser Head). (Other units, such as an HP Personal Computer and Plotter, that may be connected to the Laser Measurement System must be turned on via their own power or line switches.)

At turn-on, the Measurement Display unit immediately performs a series of self-tests, and then waits for the Laser Head to indicate that it has warmed up to its operating temperature. While waiting for the Laser Head, the message "LASr COLD" will be flashed about once every five (5) seconds. For a complete indication of the warm-up operation, refer to *Figure 5-6*.

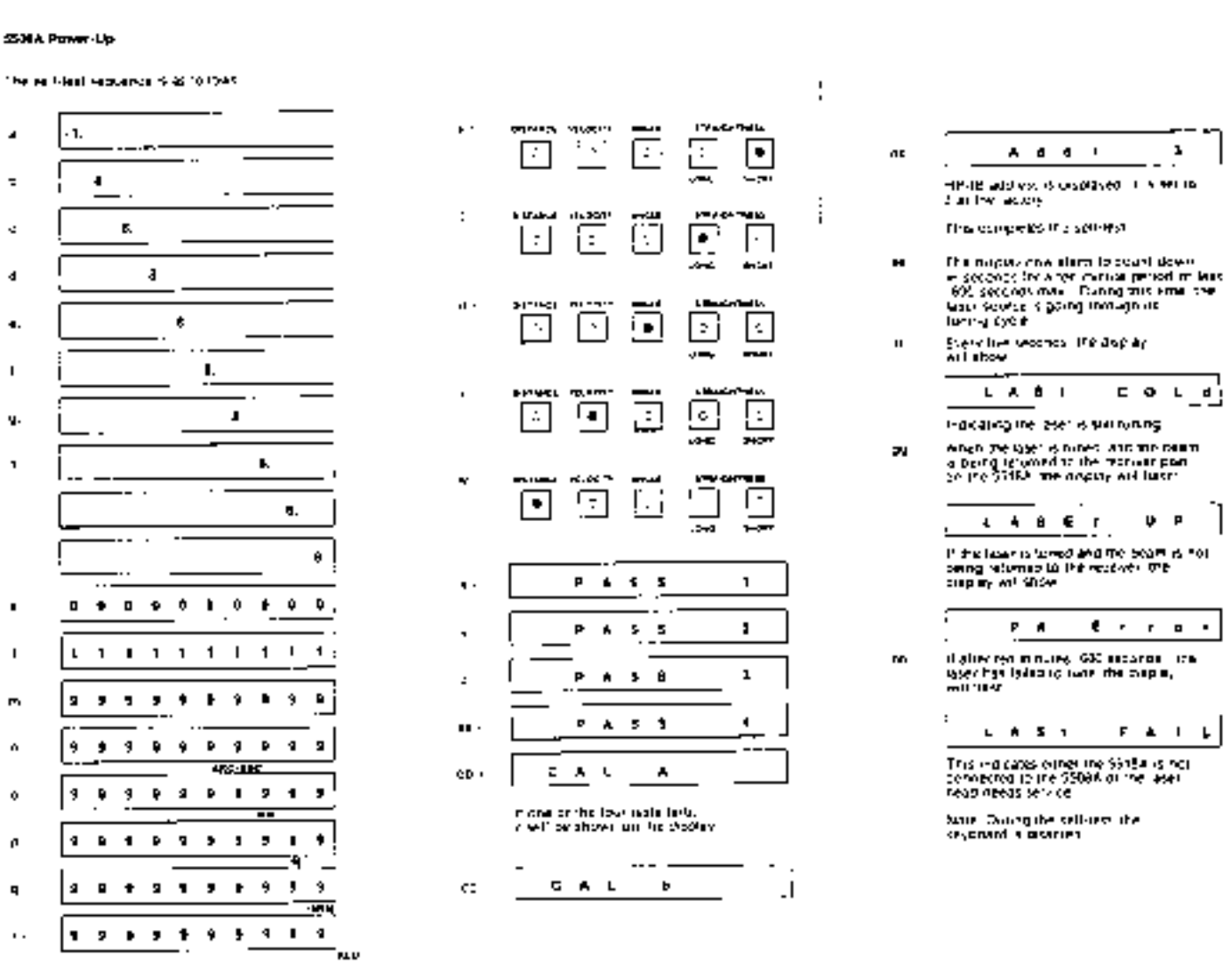


Figure 3-6. Power-Up Routine

SECTION 6
DISTANCE MEASUREMENTS

CONTENTS

INTRODUCTION
OPERATING SPECIFICATIONS
HARDWARE REQUIRED
OPTIONAL HARDWARE
RELATED MEASUREMENTS
REFERENCE MATERIAL
ASSEMBLY OF OPTICS
INSTALLATION AND ALIGNMENT OF OPTICS
MEASUREMENT DISPLAY SETTINGS, SENSOR USE
MAKING A MEASUREMENT
WHAT AFFECTS ACCURACY?

INTRODUCTION

This User's Guide section provides instructions for measuring a distance along the Laser beam. Keep in mind that the Distance measurement is made by measuring the **change** in position of one of the Optics while the other Optic is held stationary. See Appendix A for a description of the principles on which this measurement is based.

OPERATING SPECIFICATIONS

Accuracy: Distance measurements are accurate within the following tolerances depending on the velocity of light compensation method and operating temperature. Values shown apply at a known material temperature with a known coefficient of thermal expansion.

Resolution: Metric Units Mode: 0.01 micron (0.00001 mm)
English Units Mode: 1 microinch

Maximum Velocity

16000 mm/minute (720 inches/minute)

Measurement Range/Axial Separation: (Typical, with proper alignment, 15–25°C)

Maximum Separation and Range	Optics Configuration	
	Moving Retroreflector (Interferometer Within 5 Metres of Laser Head)	Moving Interferometer
Axial Separation (Head to Retroreflector)	50 metres (165 feet)	15 metres (50 feet)
Measurement Range (Distance of Travel)	40 metres (130 feet)	15 metres (50 feet)

Operating Temperature Range[2]	Velocity of Light (VOL) Compensation Method	
	Manual (VOL Exactly Known in Beam Path)	Automatic[3] (Using 10751A/B Air Sensor)
19.5–20.5°C	±0.1 ppm	±1.5 ppm
15–25°C	±0.1 ppm	±1.7 ppm
0–40°C	±0.1 ppm	±3.0 ppm

[1]If automatic material temperature sensing is used, the system error will be increased by Te (ppm). Te (ppm) = coefficient of expansion in ppm/°C × average sensor error in °C. (See 10752A/B Maximum Sensor Error Specification.)

[2]Temperature of all system components are stabilized anywhere within the temperature range shown.

[3]10751A/B mounted in recommended orientation. 12 month calibration interval used. Humidity switch set to position closest to actual humidity. If humidity switch set to 50%, tolerances are ±1.75 ppm at 20°C, ±2.00 ppm at 15–25°C, and ±3.70 ppm at 0–20°C. If 10751A/B mounted incorrectly, add ±2 ppm.

HARDWARE REQUIRED

In addition to the hardware required for any measurement using the Laser Measurement System (see *Figure 4-1*), any Distance measurement requires the hardware shown in *Figure 6-1*.

OPTIONAL HARDWARE

Optional hardware, shown in *Figure 6-2*, can be connected to your Laser Measurement System to allow measurements to be made faster, more accurately, or with less effort on your part.

RELATED MEASUREMENTS

Velocity Measurements ..... Section 7

REFERENCE MATERIAL

Physical Setup of the Laser Head and Tripod ..... Section 4
Interconnections, Turn-on ..... Section 5
Alignment Techniques ..... Section 15

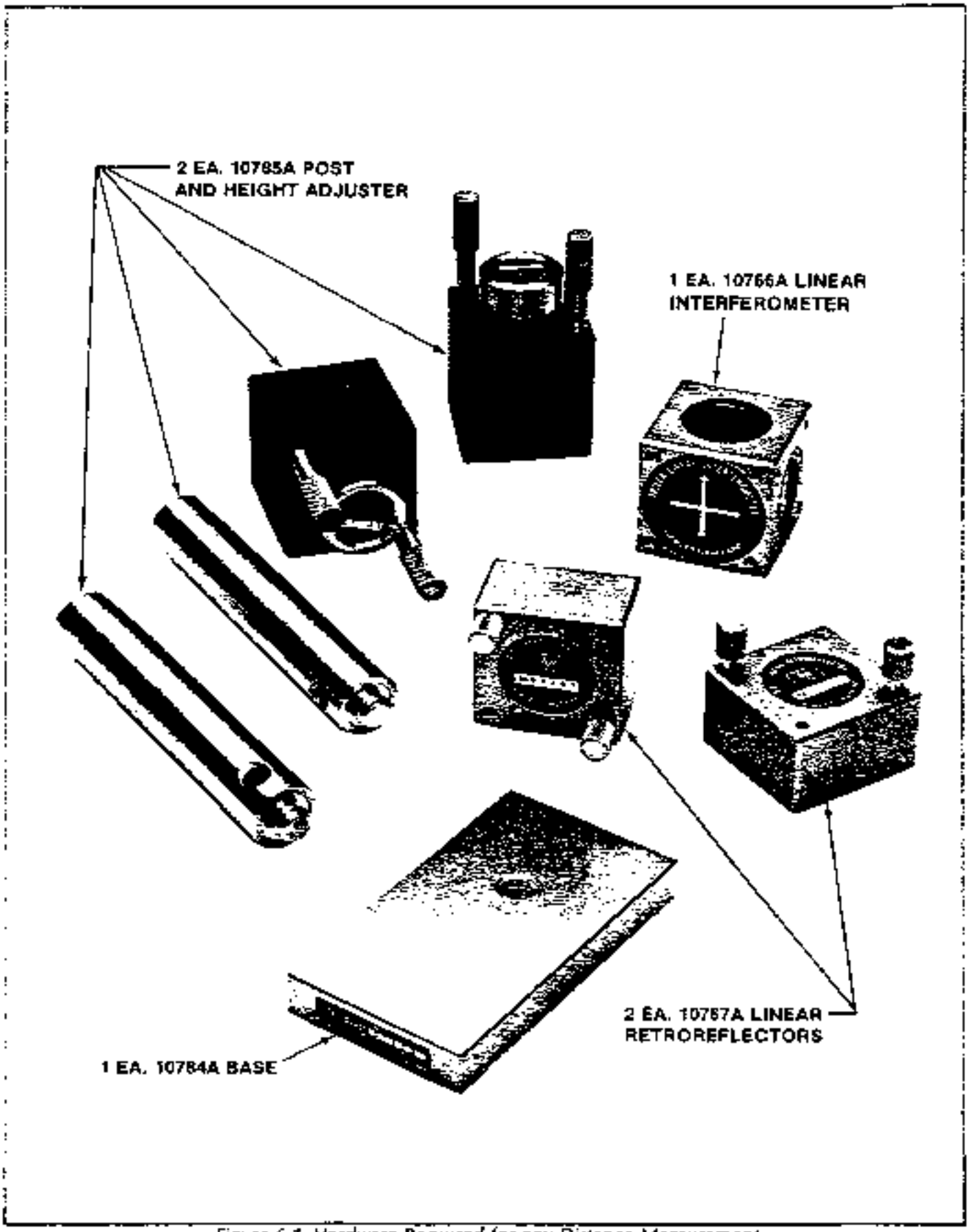


Figure 6-1. Hardware Required for any Distance Measurement

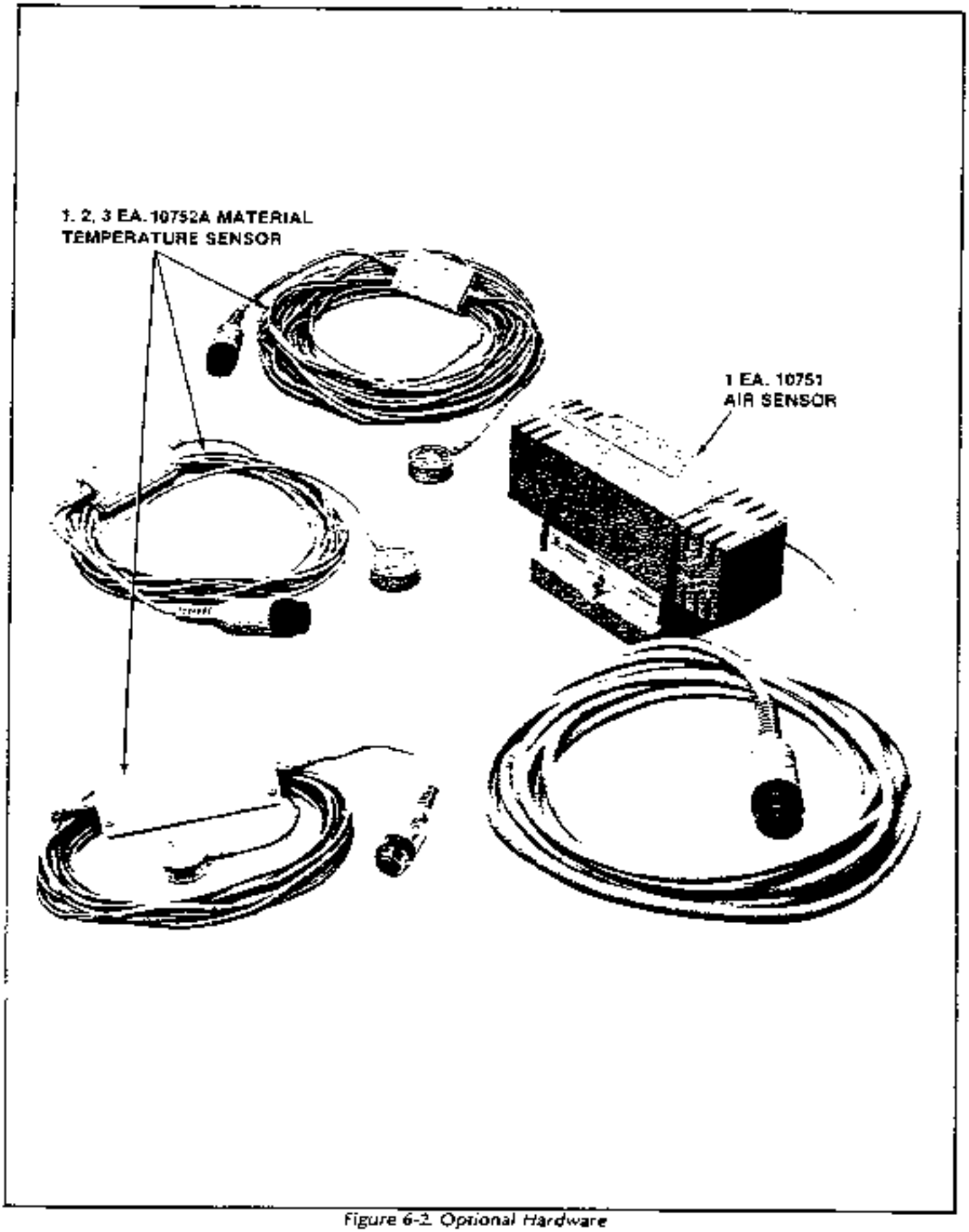


Figure 6-2. Optional Hardware

ASSEMBLY OF OPTICS

Interferometer Assembly

A Distance measurement is made using two Retroreflectors and one Interferometer.

The Interferometer is placed in the path between the Laser Head and the two Retroreflectors, as shown in *Figure 6-3(a)*. In actual practice, one of the Retroreflectors will be physically attached to the Interferometer and the other one will be allowed to move with respect to the Interferometer.

When planning your setup, it is important to note that the "tail" end of one of the arrows on the Interferometer's label must be toward the Laser Head, and the "head" of each of the arrows must point toward a Retroreflector, whether attached or moving.

When the measurement you want to make is along the Laser beam, your Interferometer Assembly will look like *Figure 6-3(b)*.

When the measurement you want to make is along an axis at right angles to the Laser beam, your Interferometer Assembly will look like *Figure 6-3(c)*. Note that each of the views in *Figure 6-3* is a side view.

Attach one Retroreflector to the Interferometer as shown in *Figure 6-3(b)*, using the two small knurled screws included with the Retroreflector. In actual practice, you set up for a measurement perpendicular to the Laser beam the same as shown in *Figure 6-3(b)*, except you rotate the Interferometer until the arrows point in the directions you need. [See *Figure 6-9* for set-ups for Distance measurements perpendicular to the Laser beam.]

For the rest of this section, we will refer to this assembly of Interferometer and Retroreflector as the "Interferometer".

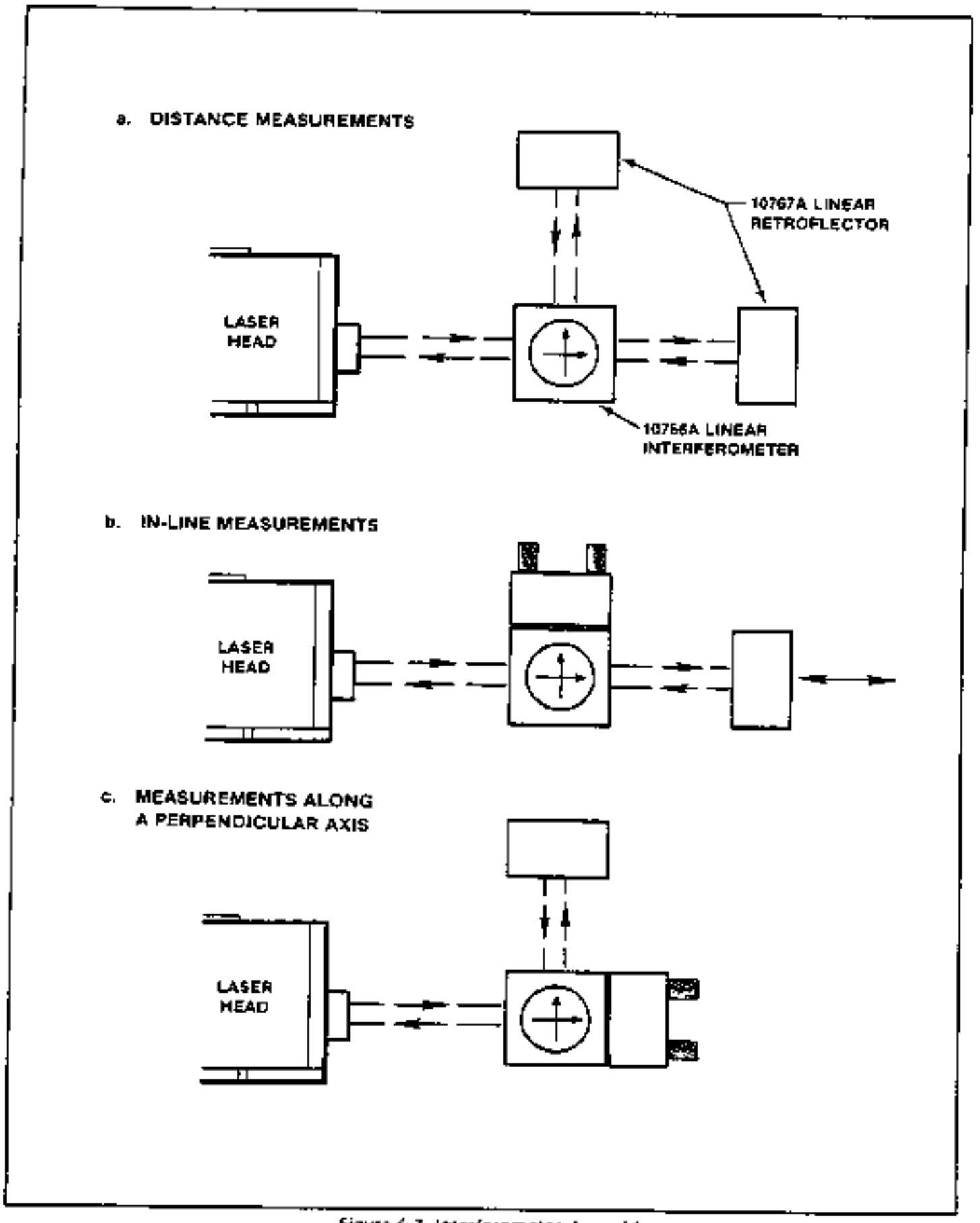


Figure 6-3. Interferometer Assembly

INSTALLATION AND ALIGNMENT OF OPTICS

Important Considerations

1. The Interferometer Assembly must be located between the Laser Head and the Retroreflector in the Laser beam.

2. The beam from the Laser Head must enter the Interferometer at the "tail" of one of the arrows on its label.

3. Vibrations and loose connections must be minimized by proper mounting. Avoid long extensions. Make sure that all supports are completely stationary. A spindle, for example, must be secured by a brake so it won't rotate. (If a brake isn't available try using a hose clamp or a wedge.

4. The Laser beam must be returned to the bottom port on the Laser Head's turret.

5. The Optics must be aligned to the Laser beam well enough to keep the cosine error at an acceptable level. (See "What Affects Accuracy?" and the "Error Budget Worksheet".)

6. The Optics must be aligned to the Laser beam well enough to keep the Beam Strength indicator in the green region along the entire Optics' path.

7. If the Angular Optics have previously been installed, you can install the Distance Optics by simply changing the Optics, without changing the mounting hardware.

8. The Laser Head turret ring should be set to "OTHER".

Description

1. You will initially position the Optics around the Laser beam while they are at the near end of travel using the procedures below.

2. Next, you will adjust the Laser Head to track the Optic's progression along the travel path, while maintaining the beam's near-end-of-travel position. (See "GUNSIGHT" alignment method in Section 15 of this User's Guide.)

3. Finally, you will check your alignment to insure the "Important Considerations" #5 and #6 have been fulfilled.

NOTE

Use of the Gunsight Alignment method is described in the following procedure. Once you become familiar enough with alignment principles, you may want to start with "Autoreflection" (described in Section 15; or to align by the same philosophy as the "Gunsight" method, but without targets. (This is called the "Overlapping Dots" method and is also described in Section 15).

Procedure

1. Move the moveable part of your machine as close to the Laser Head as possible.

   Note that the "moveable" part of the machine may depend on the axis you are measuring. That is, the "X"-axis moveable part may not necessarily also be the "Y"-axis or "Z"-axis moveable part.

   This will keep the machine from hitting the Laser Head during a measurement and will help establish the "near end of travel".

2. Visually align the Laser Head as well as you can parallel to the direction of travel and position it at an appropriate height. Some things to consider are —

   - Position for an axis appropriate for what you want to do (review Section 4's material on this).

   - If you think you will be making a Straightness or Squareness measurement later, establish a measurement axis at a height above the table that will allow easy interchanging of the Optics. To do this, mount a Retroreflector on a Height Adjuster that is flush with the top of the post supported by the base; then position the Laser Head so the return beam from the Retroreflector enters the Laser Head's lower port.

   - Use "Autoreflection" to help you do this once you become proficient at Laser System measurements. If you use "Autoreflection" you won't have to do any further alignment, you'll only need to check for beam strength and cosine error once you have installed the Optics.

3. Decide where you will position the Optics so that:

   - The Interferometer is between the Reflector and the Laser Head.

   - One Optic is where the tool mounts and the other is where the workpiece mounts.

   - The Optics are at the "near end of travel". (This means that any subsequent motion of the machine will separate the Optics further rather than bring them closer together.) (See *Figure 6-4.*)

   - If you want to measure perpendicular axes from the same Laser Head position, position the Interferometer on a part of the machine that remains stationary and can serve as a beginning point to measure these axes. (See *Figure 6-9.*)

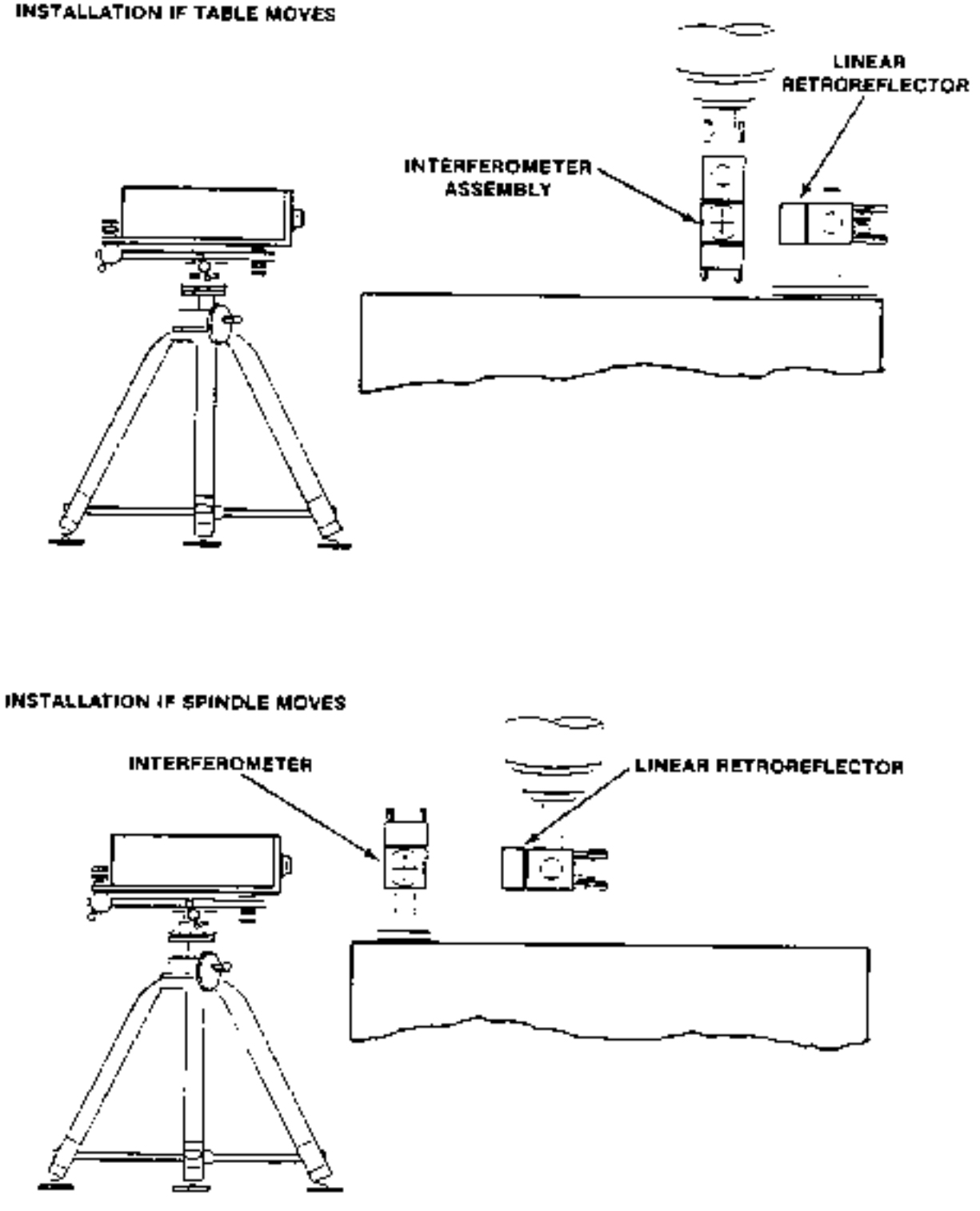


Figure 6-4 Positioning the Optics

4. Attach the Interferometer and the Retroreflector to a Height Adjuster and Post to accomodate the positions you chose in step "3". (See *Figure 6-5* and *Figure 6-6.*)

   a. For the Optic you mount on the table, support the post with a base. If you think you will be making a Straightness or Squareness measurement later, position the Height Adjuster flush with the top of the Post, to allow easy interchanging of the Optics.

   b. For the Optic you mount in a spindle, either attach the Height Adjuster to a Post as you would for table mounting, or screw the Post into the Height Adjuster after removing the large knurled knob. This latter arrangement will make it easier to change to Straightness Optics.

   c. For longer distances it is important to reduce beam scattering by making sure the Laser beam does not strike the corners of the glass inside the Retroreflector. Do this by turning the Retroreflector so none of the corners are vertical. You can see the corners as the three lines that are closest to the Retroreflector's front surface. The other three lines are reflections. This will help maximize beam strength.

5. Select the small opening for the Laser Head's exit port, and rotate the target into place over the Laser Head's bottom (return) port.

6. Move the Interferometer in the laser beam while watching the front of the Laser Head. Position the Interferometer or the Laser Head so the return beam is centered on the Laser Head return port's target.

7. Secure the entire assembly to the machine in such a way that the Interferometer is as square as possible relative to the incoming beam. (Pitch limitations are ±2 degrees, yaw and roll limitations are ±5 degrees.) The pitch requirement will be taken care of automatically by using the HP 10785A Post and Height Adjuster.

8. Position the Retroreflector as closely as possible to the Interferometer. Look at the front of the Laser Head and adjust the Retroreflector until its return beam also hits the bottom port's target. Block the laser beam path between the Interferometer and Retroreflector to distinguish between the two returning beams. (The dot that remains on the front of the Laser Head is the Interferometer's return beam. It may be helpful to start by lining up the edges of the Retroreflector with those of the Interferometer.)

9. Secure the Reflector assembly to the machine.

10. Attach the targets to the Interferometer and Retroreflector, so that —

    - the hole in the Interferometer's target is centered around the beam, and —
    - the crosshairs on the Retroreflector's target are also centered on the beam. (See *Figure 6-7.*)

11. You are now ready to align the Laser to the machine's travel.

    Turn to Section 15 of this User's Guide and follow the instructions there for "GUNSIGHT" alignment.

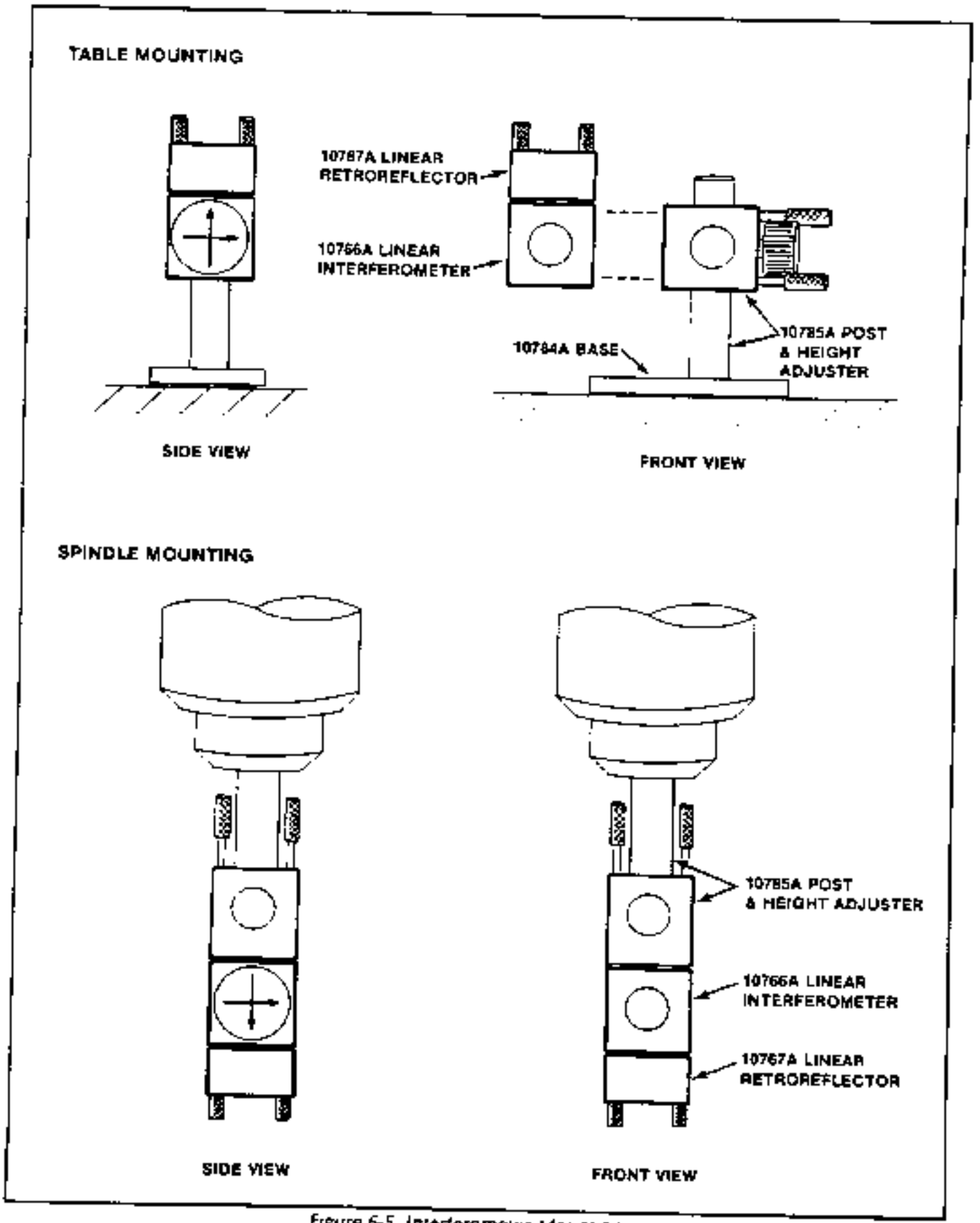


Figure 6-5. Interferometer Mounting

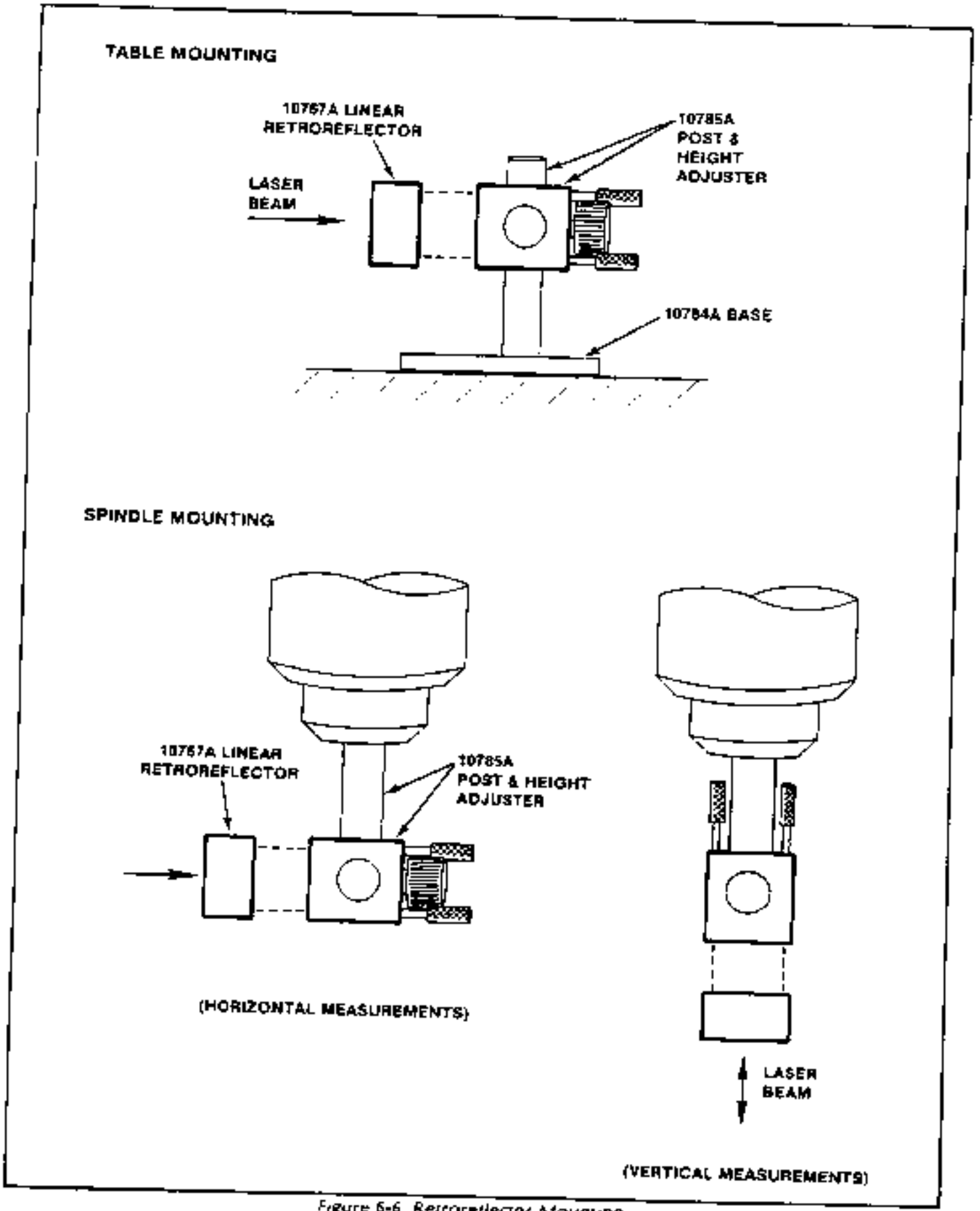
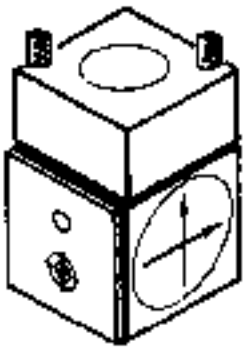


Figure 6-6 Retroreflector Mounting

DISTANCE INTERFEROMETER WITH TARGET



NOTE: THE TARGET SHOULD BE POSITIONED WITH THE 3MM HOLE UPPERMOST ON THE INTERFERO— METER AND WITH THE CROSSHAIRS UPPERMOST ON THE RETROREFLECTOR.

DISTANCE RETROREFLECTOR WITH TARGET



Figure 6-7. Interferometer and Retroreflector, with targets

Checking Alignment for Beam Strength

1. You are now ready to make sure you have sufficient beam strength over the full length of travel.
2. Open both Laser Head ports to their largest openings.
3. Move the Optics over their full travel length while watching the BEAM STRENGTH meter.

   Any reading in the meter's green area indicates sufficient beam strength.
4. If the meter's reading goes into the red area at any time, return the Optics to their "near-end-of-travel" position and reposition them so their return dots overlap on the Laser Head's crosshair target (after you rotate the target into position at the return port and rotate the small aperture into position at the exit port). Then repeat both alignment checks.

Checking Alignment for Cosine Error

NOTE

1. The following technique is the only way to tell how large your cosine error is. This information is important in helping you determine the final accuracy of your Laser Measurement System. (See "WHAT AFFECTS ACCURACY" and the "ERROR BUDGET WORKSHEET", near the end of this User's Guide Section.)

2. You should always use this technique to check how well your system is aligned, whether you have used the Gunsight, Autoreflection, or Overlapping Dots alignment method.

1. Remove the Optics' targets, if you used them. Make sure that the exit port's small aperture is selected, and the return port's target is in place.

2. Observe two dots on the Laser Head's return port target. The dots may be overlapped completely (thus appearing as a single dot).

3. Move the machine you are measuring over its full length of travel.

4. Observe how much motion occurs between the two dots. Note that it's the **change** in spacing between the dots, not the original spacing between them, that's important. One dot should not move, depending on which Optic is stationary. If there is any motion, cosine error is present. (See Figure 6-8.)

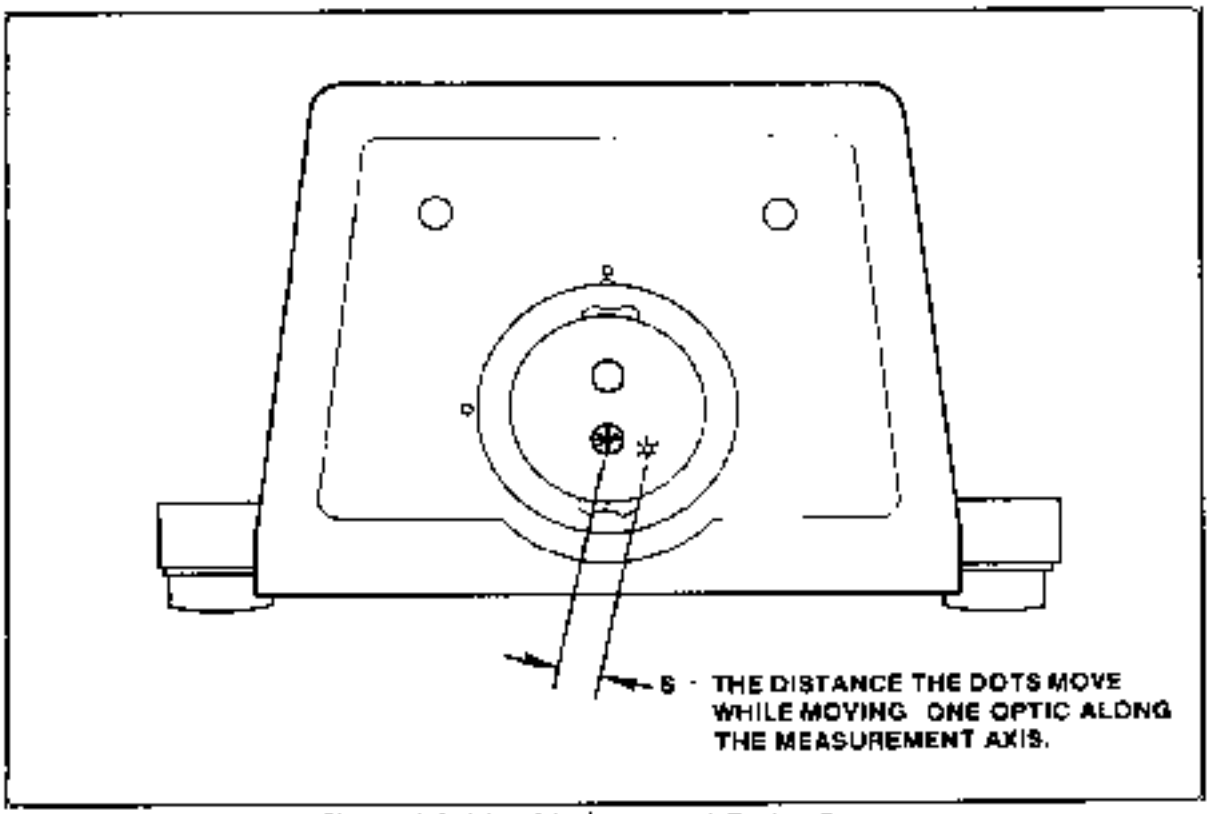


Figure 6-8. Visual Indication of Cosine Error

5. Calculate the amount of cosine error as follows —

   a. Judge the amount of motion between the dots.

      The smallest motion you are likely to perceive is about 0.25 mm (0.010 inch). Let this distance be "S" in the formula below.

   b. Determine the length of machine (Optic) travel. Let this be "D" in the formula below.

   c. Your cosine error ("E") will then be —

      $E = \frac{S^2}{8D^2}$, in parts-per-million, or —

      E × D , in absolute terms,

      For example, assume that —

      The movement of the dots on the Laser Head's turret is 0.5 mm (0.020 inch), and —

      The amount of machine (Optic) travel that produced this movement is 500 mm (20 inches).

      The amount of cosine error would be —

      0.13 ppm, or 0.00006 mm (0.000003 inch)

6. Use the "Error Budget Worksheet" (See "WHAT AFFECTS ACCURACY?") to find out if the cosine error in your setup is within the limits you need for your measurement. If the cosine error is larger than you can tolerate, use the "OVERLAPPING DOTS" alignment method (described in Section 15 of this User's Guide) to reduce any motion between the dots.

   In some cases where the travel path length is very short, there may still be cosine error, even though there seems to be no motion between the dots. For example, if —

   S = 0.2 mm (0.008 inch), and —

   D = 125 mm (4.92 inches), then —

   E = 0.3ppm, and the

   absolute error = 0.3 ppm × 125 mm = 0.00004 mm (0.000002 inch).

   In these cases, you should use the "Maximum Measurement Reading" method to reduce cosine error.

Measurements Along A Perpendicular Axis

When a measurement axis is perpendicular to the Laser beam, mount the Interferometer in line with the Laser, and at the end of the axis you will be measuring (see *Figure 6-9* for illustrations of set-ups for Distance measurements perpendicular to the Laser beam). Be sure to rotate the Interferometer so the arrows on its side line up with the Laser beam and the measurement axis.

To align the Laser Measurement System along an axis perpendicular to the Laser beam, attach the Interferometer target to the opening facing the Laser Head (see *Figure 6-7*) and follow the Instructions presented in the preceding few pages.

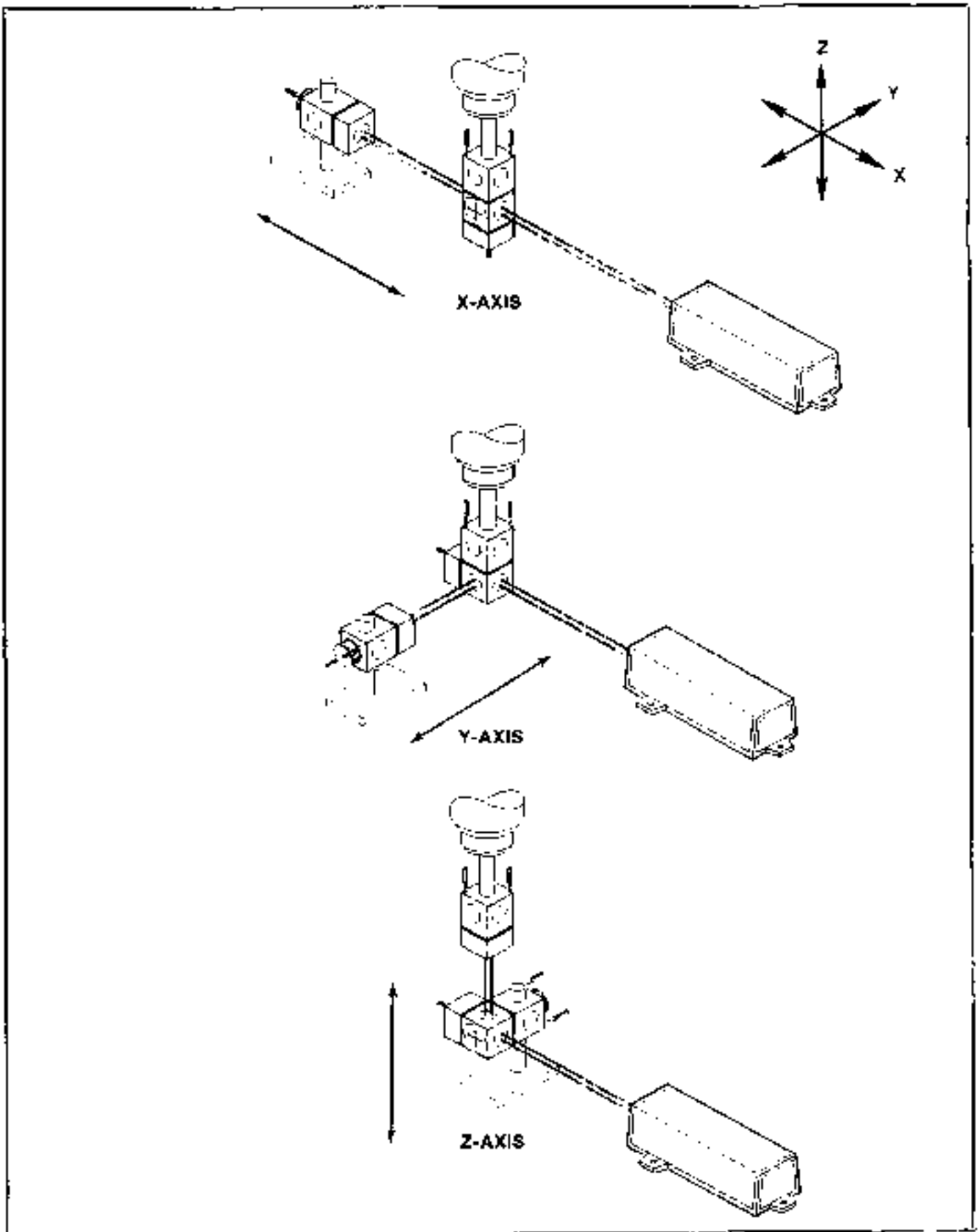


Figure 6-9 Three Axes Positioning of Optics

LINEAR MEASUREMENTS USING THE ANGULAR OPTICS

The Angular optics (10770A Angular Interferometer and 10771A Angular Reflector) can be configured to make linear measurements. When the 10767A Linear Reflector is attached to the Angular Interferometer, as shown in Figure 6-9a, the Angular Interferometer will operate as a linear interferometer. This interferometer can be configured, as the 10766A Linear Interferometer can, to turn the laser beam perpendicular to the laser head axis (see Figure 6-9b).

The alignment procedures and measurement setup for this set of optics is the same as that for the linear (Distance Measurement) optics. After the linear measurement has been made with this configuration of the angular optics, the angular measurement can be made by simply removing the 10767A Linear Retroreflector.

Some caution should be given when this configuration is used for linear measurements when the ambient temperature is changing. This configuration allows the reference path and measurement through the glass to be different. This can cause a measurement error if the temperature of the Angular Interferometer changes during a measurement. For example, if the interferometer changes temperature by 3°C (5°F) over the duration of the measurement, there will be an error of 2.5 microns (89 microinches).

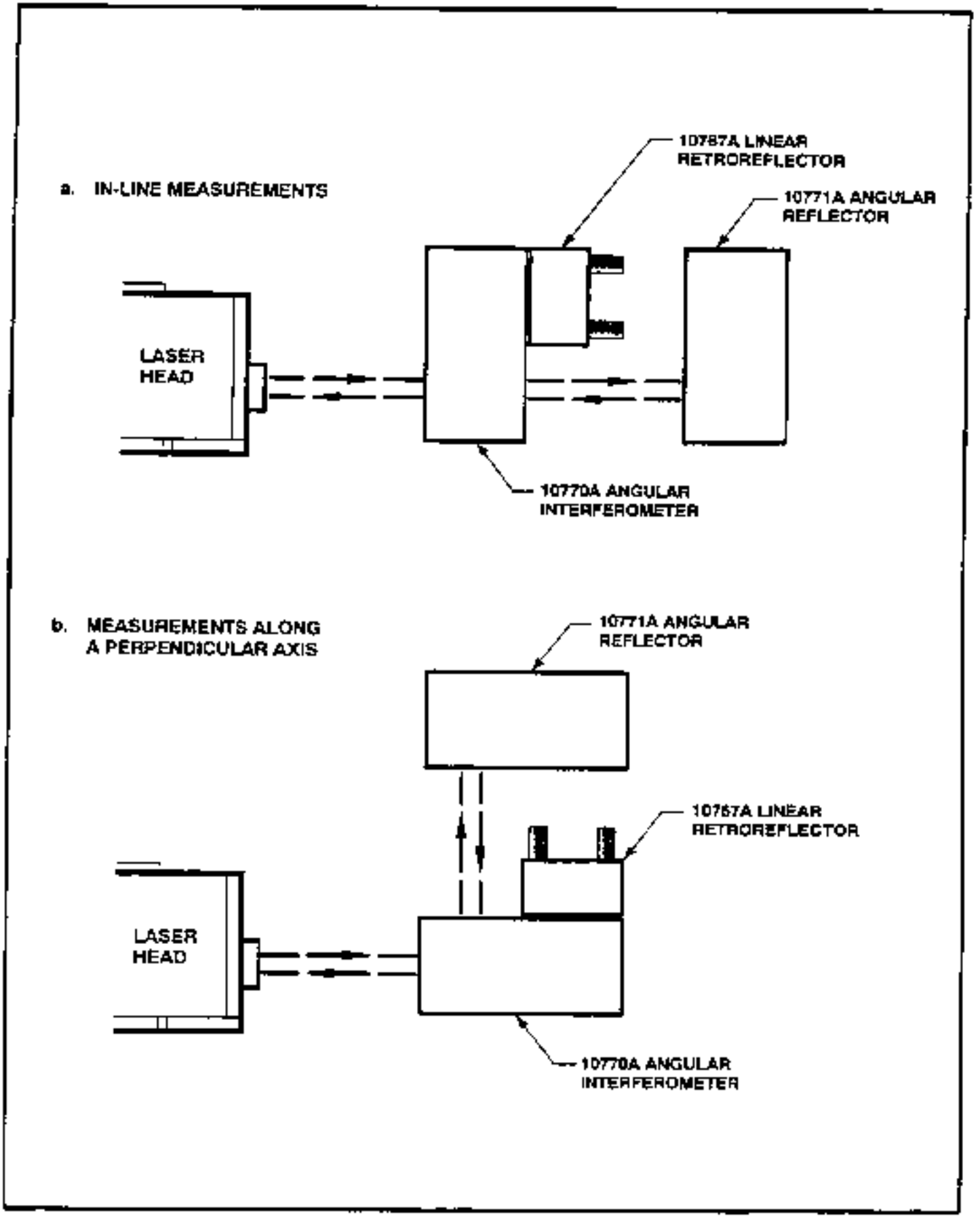


Figure 6-9a Angular Optics Configuration for Linear Measurements

Other Mounting Requirements

Although we have tried to provide you with a maximum of mounting flexibility, there may be situations when you need more capability. For more information, you should turn to Appendix C for dimensions of the Optics, and the Mounting Hardware.

Figure 6-10 shows how you can use two Height Adjusters and their Posts to make a right-angle mount.

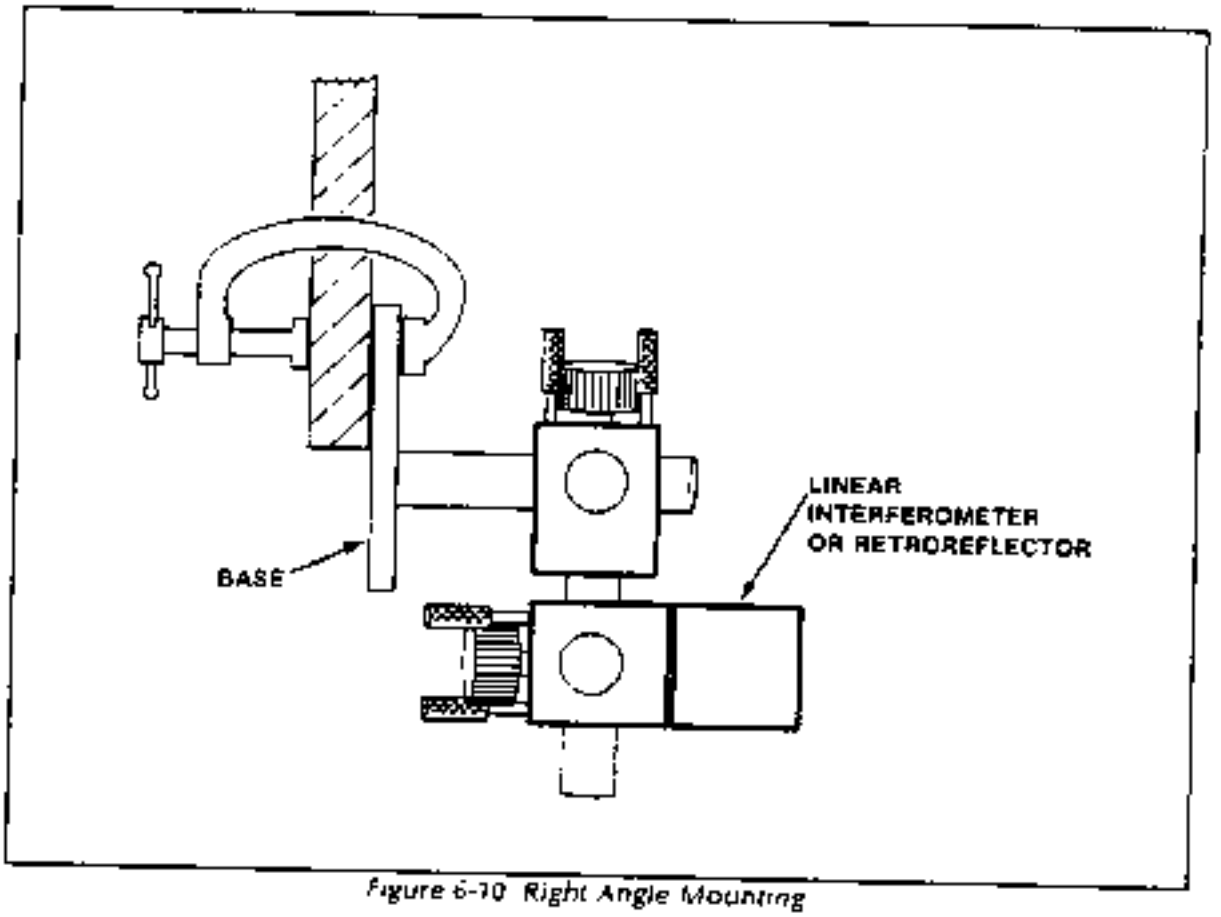


Figure 6-10. Right Angle Mounting

MEASUREMENT DISPLAY SETTINGS, SENSOR USE

Selecting "Measurement Units"

The Measurement Display can give you your measurement results in either "English" (inches, degrees Farenheit, etc.) or "Metric" (mm, degrees Celsius, etc.) units. You make the selection by setting the toggle switch on the Measurement Display unit's rear panel. (See Section 16, "CONTROLS, CONNECTORS, INDICATORS".)

The toggle switch is the "locking" type. To change the setting of the rear-panel "English/Metric" toggle switch —

1. Gently pull the switch handle "out", along its current position.
2. Move the switch to the position for the units you want to use.

3. Release the switch handle. this will allow it to lock at the new setting.

When you are entering data via the Measurement Display unit's keyboard. remember to enter values appropriate for the measurement units you have selected: also, you can't mix "English" and "Metric" units (inches and degrees Celsius, for example).

If you change the setting of the rear-panel ENGLISH/METRIC switch, all previously-entered values will automatically be converted to equivalent values in the newly-selected system.

To provide your Laser Measurement System with information it needs to know about the environmental and material conditions at the time of measurement. use the appropriate procedure below, depending on whether or not you have one or more sensors connected to the Measurement Display unit.

Using Sensors

Sensor Attachment

The Air Sensor and Material Sensor(s) should already be attached. See Section 5 for instructions.

CAUTION

To prevent possible damage to the Measurement Display unit, be sure you turn the line power off before connecting or disconnecting any cable at its rear panel.

NOTE

Be sure to "lock" the connections, so they won't accidentally come undone.

Sensor Placement

In order to accurately correct for the effects of environmental and machine temperature on the laser reading, you must locate the sensors where they can accurately monitor the conditions influencing the laser. The 10751 Air Sensor (which monitors the atmospheric conditions) should always be mounted as closely as possible to the actual MEASUREMENT PATH so it can monitor the conditions the laser beam is experiencing. When monitoring material temperature to account for material expansion, the 10757 Material Temperature Sensor should be placed on the part of the machine closest to its displacement measurement system.

As an example for sensor placement, let's consider making a measurement on a mill, shown in *Figure 6-11*. In this case, it is easy to determine where the sensors should be. The 10751 Air Sensor should be placed next to the beam in the measurement path. The 10757 Material Temperature Sensor should be placed as close as possible to the machine's displacement measurement system. For this machine, it is the table top.

NOTE

The Air Sensor should be mounted with its arrow pointing **up**, to maximize accuracy, as shown in *Figure 6-12*. It should also be located in an area with good air flow.

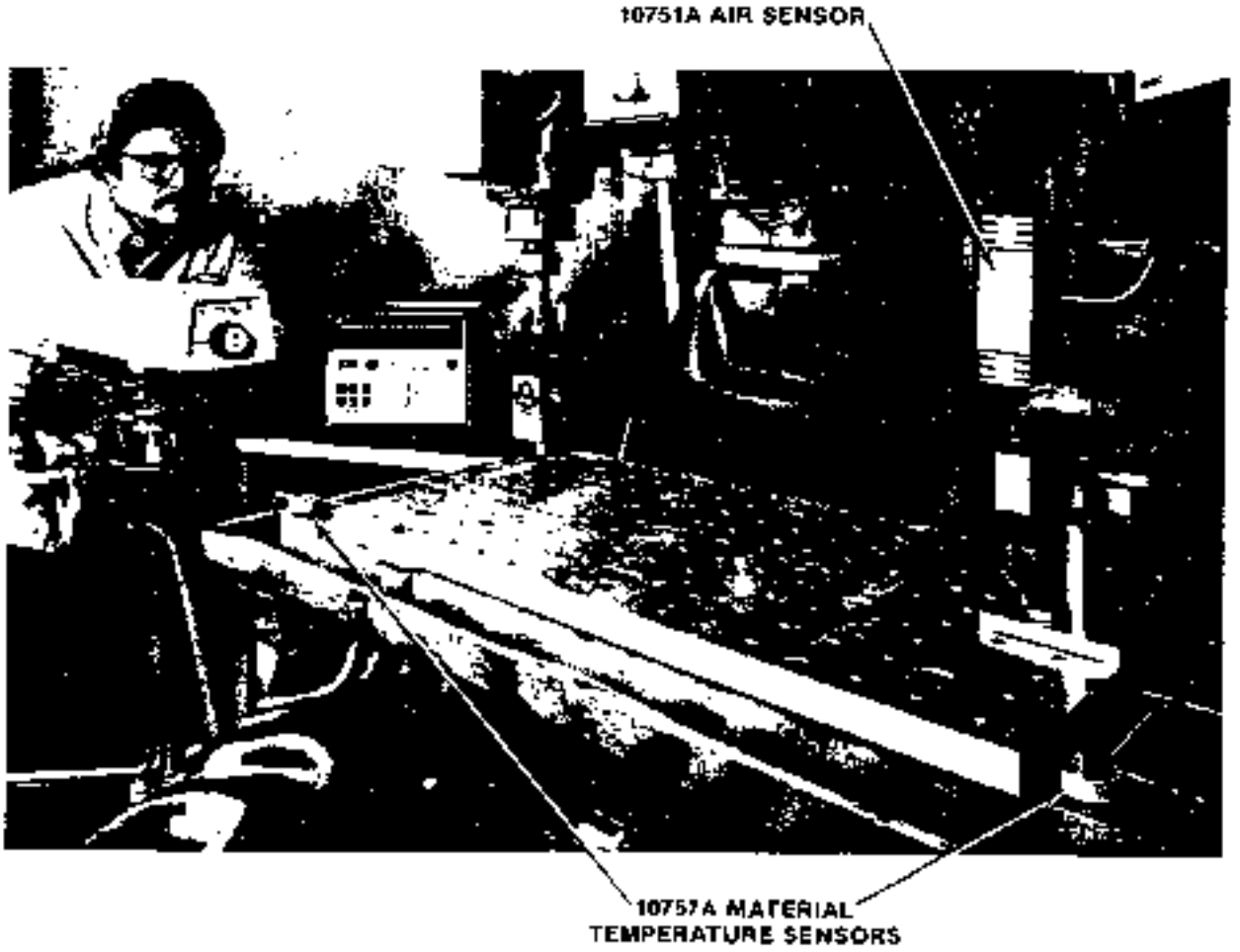


Figure 6-11. Sensor Placement

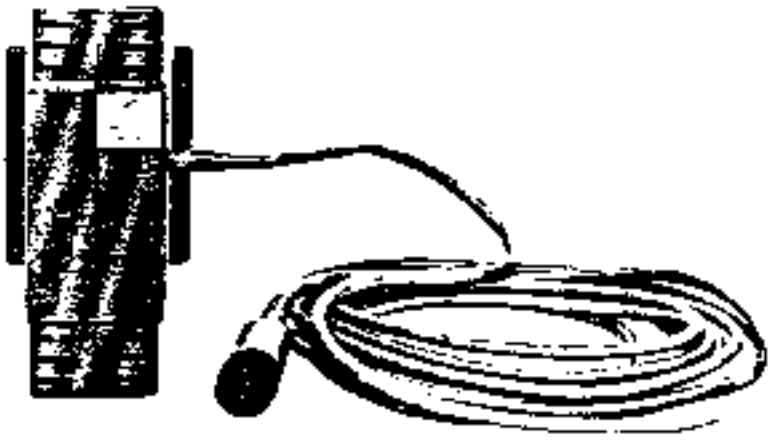


Figure 6-12. Air Sensor Orientation

Adjusting for Humidity

The 10751A Air Sensor has a "Humidity" switch on one side (opposite its connecting cable). You must set the switch handle to the position corresponding to the relative humidity in the area you are measuring. The choices are "25%", "50%", and "75%".

Measurement Display Settings (with sensors)

Measurement Mode Keys

DISTANCE



Push the DISTANCE key.

Set-up Keys

NOTES

1. To enter a value for any key —

   a. Use the ENTRY keys to specify the numeric value, then —

   b Press the key to assign the value to that key.

2. To check the current status of any of these keys, just press the key. Then press the key again, to return to the mode you selected earlier.

3. More information about each key is available in Section 16 of this User's Guide.



a. Material Temperature and V.O.L are now automatically calculated and updated, so you do not have to enter any information with these keys





b Enter a preset number (constant) if you want one used. The value you enter will be added to the measured results and the total will be displayed. If you do not enter a number "0" is automatically used here.



c Determine which direction you want to be "positive" and use this button to make sure it happens.



d Enter the EXPansion COEFFicient for the material whose temperature you are measuring. Enter the value in parts-per-million-per-degree (ppm/degree). For steel, the expansion coefficient is 11.7 ppm-per-degree C. You should enter —

11.7

then press 

NOTE

Be sure the Measurement Display unit's rear-panel ENGLISH/METRIC switch is set to the system you will be using, and that you enter your value in the appropriate units.



e. Determine the resolution you need from the accuracy you want. Enter the number of places you want, and then press this key. Resolution extends to five places (0.00001) for millimetres, and to six places (0.000001) for inches.

This key also allows you to "smooth" your data by entering a positive number. A negative resolution number will remove any smoothing. Smoothing reduces the effects of vibration.

Measurement Display Settings (without Sensors)

Measurement Mode Keys

DISTANCE



Push the DISTANCE key.

Setup Keys

NOTES

1. Making a measurement without using the automatic sensors is practical only when the measurement environment is not changing, since it is difficult to continually update your compensation data manually while the measurement is running.

2. To enter a value for any key —

   a. Use the ENTRY keys to specify the numeric value, then —

   b. Press the key to assign the value to that key.

3. To check the current status of any of these keys, just press the key. Then press the key again, to return to the mode you selected earlier.

4. More information about each key is available in Section 16 of this User's Guide



a. You must calculate the V.O.L. compensation number using Section 19 of this User's Guide.

You will need to determine the air pressure and the air temperature to determine the Compensation values shown in Section 19

NOTE

The default value for V.O.L. is 728.8. This corresponds to an air temperature of 20°C (68 F), an air pressure equivalent to 760 mm (29.921 inches) of Mercury, and relative humidity of 50%.

Enter the calculated compensation factor by pressing —





b. Measure the average material temperature by some means and enter it by pressing —



NOTE

The default value for MATL TEMP is 20° C or 68° F.



c. Enter a preset number (constant) if you want one used. The value you enter will be added to the measured results and the total will be displayed. If you do not enter a number, "0" is automatically used here.



d. Determine which direction you want to be "positive" and use this button to make sure it happens.



e. Enter the EXPansion COEFFicient for the material whose temperature you are measuring. Enter the value in parts-per-million-per-degree (ppm/degree). For steel, the expansion coefficient is 11.7 ppm-per-degree C. You should enter —

11.7

then press 

NOTE

Be sure the Measurement Display unit's rear-panel ENGLISH/METRIC switch is set to the system you will be using, and that you enter your value in the appropriate units.



f. Determine the resolution you need from the accuracy you want. Enter the number of places you want, and then press this key. Resolution extends to five places (0.00001; for millimetres, and to six places (0.000001; for inches.

This key also allows you to "smooth" your data by entering a positive number. A negative resolution number will remove any smoothing. Smoothing reduces the effects of vibration.

MAKING A MEASUREMENT

System Checks

1. Make sure both Laser Head ports are switched to their large apertures.

2. The Laser Head turret must be set to "OTHER"

3. The Laser Head's "READY" indicator must be lighted steadily (i.e., not blinking).

4. Make sure the Laser Measurement System is properly interfaced with other instruments, as needed to record your data.

   a. If you record your data manually, no interfacing is necessary.

   b. If you want to record your data automatically, but you aren't using the HP Dimensional Metrology Analysis System or another HP-IB controller, you must have an HP-IB compatible printer connected to the Measurement Display unit, via the rear panel HP-IB ("IEEE STD 488 PORT") connector. You must also make sure the Measurement Display is set-up to output to a printer via HP-IB. See Section 18 and follow the instructions for "Data Transfer without an HP-IB Controller".

   c. For formatted automatic records, you should have the HP Dimensional Metrology Analysis System or an HP-IB controller with your own programs to make it work with the Laser Measurement System. The HP Analysis System comes with an HP Personal Computer and programs to make it work with the Laser Measurement System. The operating manual for the Analysis System will explain how to use it. In either case, you must first make sure the Measurement Display is set-up to accept a controller via HP-IB. See Section 18 and follow the instructions for "Data Transfer with an HP-IB Controller".

Procedure

1. Push the RESET key on the Measurement Display or on the Remote Control unit connected to the Measurement Display. (Remember to do this only when the Optics are as close together as possible to prevent "deadpath error".)

2. Move one of the Optics a predetermined distance.

3. Press the RECORD button on the Remote Control Unit. One measurement is made each time you press this button.

If an HP Personal Computer or an HP-IB Printer is not connected to the Measurement Display unit, pressing RECORD will cause the message "Lr Error" to be displayed.

WHAT AFFECTS ACCURACY?

The Laser Measurement System's Distance measuring accuracy depends on the System's ability to adjust for environmental changes and on your ability to set up and operate the system properly. In the next few pages we will describe some potential measurement errors, examine how they affect Distance measurements, and what can be done about them to maximize measurement accuracy.

The Laser Measurement System has an inherent accuracy limit of 0.1 part-per-million. All of the following measurement errors add to this value.

Distance Measurement Error Sources

Sources of error in a Distance measurement are —

1. Measurement of air temperature, pressure, and humidity to determine the velocity of light (V.O.L. Compensation)
2. Material temperature measurement
3. Mis-alignment between machine travel and Laser Measurement axis (Cosine Error)
4. Uncompensated measurement path lengths (Deadpath Error)

The accumulation of all the errors listed above determines the overall accuracy of the Laser Measurement System in your application.

An "Error Budget Worksheet" has been included at the end of this section to help you keep track of each potential error and its magnitude for each measurement you make.

Velocity-Of-Light Compensation

Description

The wavelength of the light produced by the Laser is used as the reference for Distance measurements. The wavelength of any light, however, depends on the velocity of light through air. This, in turn, depends on the temperature, pressure, and (to a lesser extent) humidity.

Thus the absolute accuracy of the Laser Measurement System is directly determined by how accurately the ambient conditions are known. Specifically, a Distance measurement can vary one part per million for any one of the following —

- An **air temperature** change of 1 degree Celsius (2 degrees Farenheit), or —
- An **air pressure** change of 2.5 mm (0.1 inch) of mercury, or —
- A change in **humidity** of 80 percent.

Minimizing Effects

The Measurement Display unit multiplies the number of wavelengths it counts (from the Laser Head) by a compensation factor for the velocity-of-light, thereby correcting for any difference between the "current" velocity of light (in air) and the velocity of light in a vacuum.

This calibration factor can be determined and entered either manually or automatically. Attaching the 10751 Air Sensor will automatically provide the calibration data; otherwise, you must calculate the correct calibration numbers and enter them manually. (Remember that manual entry won't provide automatic correction for changing conditions.)

For manual entry of the compensation factor, you must —

- Determine the correct compensation factor from Section 19, "V.O.L. Compensation Factor".

- Enter the factor into the Display with the ENTRY keys.
- Press the V.O.L. key.

Both automatic and manual compensation for V.O.L. have been described earlier in this User's Guide section, under the heading "MEASUREMENT DISPLAY SETTINGS, SENSOR USE"

Material Temperature Measurement

Description

Most materials change size as a result of a change in temperature. If a part is measured at two different temperatures, two different measurement values will result (unless, of course, the length of the measurement device changes at the same rate as what is being measured). This difference can easily be as great as one part in 10^4, and be one of the most significant sources of error in a Distance measurement.

Measurement errors result from not identifying material expansion or contraction due to temperature changes. Ideally, any Distance measurement made with the Laser Measurement System would be done in a temperature-controlled room held at the standard temperature of exactly 20 degrees C (68 degrees F). Then all parts would be at their "true" size, as defined by the International Committee on Weights and Measures.

Since a temperature-controlled room is not always available, some way of comparing measurements made at different temperatures is needed. The important thing that you need to know is the temperature of the material at the time you measure it. This information, and the material's coefficient of expansion (which, for most materials, can be found in reference handbooks) allow you to determine the amount of change due to temperature change from one measurement to another.

Minimizing Effects

The Laser Measurement System can automatically minimize the effect of material temperature on your measurement. It does this by adjusting its actual measurement to what the measurement value would be at the standard material temperature of 20°C (68 F), given the material's current temperature and its coefficient of expansion. To cause this adjustment to be made, you must —

1. Look up the coefficient of expansion of the material of the machine's displacement measurement system.
2. Enter this value via the Measurement Display unit's front-panel keyboard, using the ENTRY keys followed by the EXP COEFF key.
3. Determine the temperature of the machine's displacement measurement system, either automatically with the HP 10757 Material Sensors or by some other means.
4. Provide the Measurement Display with the material temperature. If determined with an HP 10757 Material Sensor, this will be done automatically. If determined by some other means, this must be done via HP-IB or by entering the value via the front keyboard.

Enabling the Measurement Display to do the above is also discussed in the section titled "MEASUREMENT DISPLAY SETTINGS, SENSOR USE".

Misalignment Between Machine Travel Axis and Laser Measurement Axis (Cosine Error)

Description

If the Laser beam's path doesn't duplicate the machine's travel path you won't be measuring the actual path, but a path offset by some angle. The resulting error is called "Cosine Error" and depends on the true path length and the cosine of the offset angle. (See *Figure 6-13*).

Minimizing Effects

Cosine error is reduced by making the Laser beam parallel to the Optics' travel path. Parallelism is indicated by the absence of motion between the return dots from the Interferometer Assembly and the Retroreflector at the Laser Head's bottom port, as the Optics are moved along the measurement axis.

The "OVERLAPPING DOTS" alignment method, described in Section 15 of this User's Guide, describes how to minimize the motion between the return dots and, therefore, minimize the cosine error.

In special short-distance, high-accuracy, measurement situations, lack of motion between the return dots is not a strong enough assurance of minimal cosine error. In these cases, you should use the "Maximum Measurement Reading" technique, described in Section 15, to reduce cosine error to a negligible level.

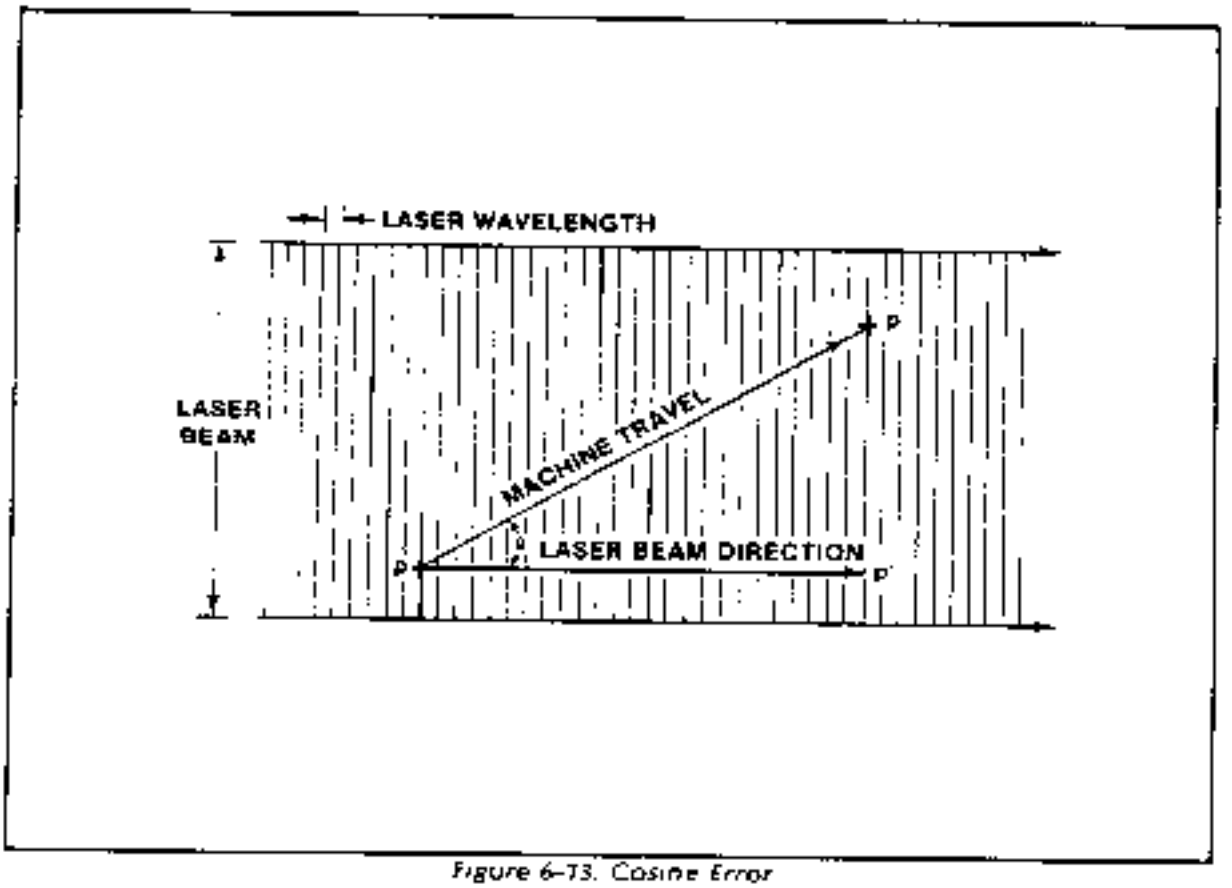


Figure 6-13. Cosine Error

Uncompensated Measurement Path Length (Deadpath Error)

Description

This is a complication of the "Velocity-of-Light" error.

Compensation for velocity-of-light error is applied only in proportion to the distance measured. The error, however, exists over the whole path between the Optics, including those parts not measured. Any time the Laser Measurement System is reset with some distance existing between the Optics, the length of the "open" distance will be uncompensated, and will result in an error. The name for this kind of error is "Deadpath Error".

Minimizing Effects

To minimize the amount of this error, the only time you should reset the Laser Measurement System is when the Optics are as close together as possible.

The only way this error can be eliminated is to reset the Laser Measurement System when the Optics (not their bases) are actually touching. For most applications, resetting when the Optics are within five centimeters (2 inches) will be enough to nullify the error.

Using The "Error Budget Worksheet"

The objective of this worksheet is to maximize the Laser Measurement System accuracy level by "budgeting" among potential sources of error.

Use this worksheet for each axis you measure. Follow this procedure using *figure 6-14* as an example. The numbers in parentheses in the procedure below are those used in *Figure 6-14*.

1. Identify the axis ("X").

2. Identify the length of travel (508 mm, 20 inches).

3. Determine the accuracy you need. You will generally need an accuracy at least three times better than the accuracy specifications of what you are measuring (0.00424 mm, or 0.000167 inch).

4. Identify the accuracy of your compensation for velocity-of-light (V.O.L.) changes.

   If you use the 10751 Air Sensor, use the accuracy value given in the worksheet for your temperature range. (These accuracy values are also given in the Laser Measurement System's Service Manual.

   If you don't use the Air Sensor, you should still be able to determine the accuracy value by estimating how accurately you can measure the ambient air's properties, and then relating this to the effect on Distance measurement accuracy. (See "V.O.L. ERROR DESCRIPTIONS" above.)

   a. Enter the accuracy in parts-per-million (ppm) in column "A".

      For our example, let's assume that you are using the HP 10751A Air Sensor, and that you are operating in the 15-25°C (59-77°F) range. The accuracy then is 1.5 ppm.

b. Multiply the number you just entered (1.5 × 10 −6) by the length of travel (508 mm, or 20 inches) and enter the product in column "B" (0.00080 mm, or 0.00031 inch).

5. Identify the accuracy of your material temperature compensation.

a. Identify the type of material you are measuring.

b. Determine this material's coefficient of thermal expansion. Some typical values are presented below. For our example, we'll use "steel."

steel = 11.7 ppm per degree Celsius
aluminum = 23.6 ppm per degree Celsius
copper = 16.5 ppm per degree Celsius

c. Identify the accuracy of your temperature sensor. The 10757 Material Sensor has a specified accuracy of ±0.10°C, as shown on the "Error Budget Worksheet". (These values are also given in the Laser Measurement System's Service Manual.) Multiply this accuracy by the expansion coefficient and enter the product in column "A" (1.2 ppm).

NOTE

To attain the specified accuracy of ±0.10°C, the output characteristics of the 10757 Material Sensor must be matched to particular 5508A Measurement Display. Please refer to the calibration matching procedure in Section 4-45 in the Laser Measurement System's Service Manual.

d. Multiply the accuracy value you just calculated (1.2 ppm) by the length of travel (508 mm, or 20 inches) and enter in column "B" (0.00061 mm, or 0.000024 inch).

6. Since you should always be starting your measurements when the Optics are close together, assume that the error due to deadpath will always be negligible.

7. Multiply 0.1 ppm (the accuracy limitation of the Laser Measurement System itself) by the length of travel (500 mm, or 20 inches) and enter the product in column "B" (0.00005 mm, or 0.000002 inch).

8. Identify the magnitude of the cosine error in your setup —

a. Identify how much **motion** there is between the two return dots if the Optics are moved over the entire measurement axis. (The Laser Head's exit port should have the small opening for this, and the return port should have the target in place.)

The smallest movement you are likely to detect will be about 0.25 mm (0.010 inch). This value will be "S" in the formula below. For our example, we'll let "S" = "0.25 mm" (0.010 inch).

b. Enter the length of Optic travel as "D" in the formula below.

c. The cosine error in your setup is —

$$E = \frac{S^2}{8D^2}$$ in parts-per-million, or E × D, in absolute terms

where —

"S" is the movement between return dots.

"D" is the length of travel, and

"E" is the cosine error, in parts-per-million

Enter the value for "E" in line "8" column "A". (If S = 0.25 mm and "D" = 508 mm (20 inches), then "E" = 0.03ppm

d. Multiply the cosine error (in ppm) by the length of travel, and enter in line "8", column "B". 0.03 ppm * 508 mm = 0.00001 mm or 0.0000005 inch.

9. Add line "4" through line "8" to determine the total maximum error magnitude (0.00147 mm, 0.000058 inch).

Enter this number in line "9", column "B" and column "C"

10. Subtract line "9" from line "3" (0.00277 mm, 0.000109 inch).

As long as this number is positive, your Laser Measurement System will provide enough accuracy for your application.

ERROR BUDGET WORKSHEET

	A Accuracy (ppm)	B Accuracy (Absolute) "A" × length of travel:	C TOTAL
REQUIRED ACCURACY			
1. Measurement Axis. X			
2. Length of travel: 508mm			
3. Required Laser System accuracy:	xxxxxx	xxxxxxxx	0.00424mm
MAXIMUM ERROR MAGNITUDES			
4. Velocity of Light Compensation	1.5	0.00080	
Column "A" values for HP 10751 Air Sensor: 1.3 ppm for 19.5 to 20.5°C; 1.5 ppm for 15 to 25°C; 2.8 ppm for 0 to 40°C			
5. Material Temp Compensation	1.2	0.00061	
Column "A" values for HP 10757 Material Sensor: ±0.10°C when cal match adjusted; ±0.35°C when unadjusted			
Type of material: Steel; K = Material Expansion coeff.: 11.7ppm/°C			
6. Deadpath (assume none)	(0)	(0)	
7. Laser System Limitations (0.1 ppm)	0.1	0.00005	
8. Cosine Error (S²/8D², ppm	0.03	0.00001	
9. Total Errors ("4" through "9"	xxxxxx	0.00147	0.00147mm
10. Difference between Required accuracy and Total Errors (Line 3 — Line 9)	xxxxxx	xxxxxxxx	0.00277mm

Figure 6-14. Error Budget Worksheet — Example

ERROR BUDGET WORKSHEET

	A Accuracy (ppm	B Accuracy (Absolute) ("A" x length of travel)	C TOTAL
REQUIRED ACCURACY			
1. Measurement Axis: _____			
2. Length of travel: _____			
3. Required Laser System accuracy:	xxxxxx	xxxxxxx	_____
MAXIMUM ERROR MAGNITUDES			
4. Velocity of Light Compensation	_____	_____	
Column "A" values for HP 10751 Air Sensor: 1.3 ppm for 19.5 to 20.5°C; 1.5 ppm for 15 to 25°C; 2.8 ppm for 0 to 40°C			
5. Material Temp Compensation	_____	_____	
Column "A" values for HP 10757 Material Sensor: ±0.10°C when cal match adjusted; ±0.35°C when unadjusted			
Type of material: _____ K = Material Expansion coeff: _____			
6. Deadpath (assume none.	|0|	0	
7. Laser System Limitations (0.1 ppm)	_____	_____	
8. Cosine Error ($S^2/8D^2$) ppm	_____	_____	
9. Total Errors ("4" through "9")	xxxxxx	_____	_____
10. Difference between Required accuracy and Total Errors (Line 3 — Line 9)	xxxxxx	xxxxxxx	_____

7 Velocity Measurements

SECTION 7
VELOCITY MEASUREMENTS

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INTRODUCTION

This User's Guide section provides instructions for measuring a velocity along the Laser beam.

Keep in mind that a Velocity measurement is made by measuring the **change in** position of one of the Optics while the other Optic is held stationary. See Appendix A for a description of the principles on which this measurement is based.

To make a Velocity measurement, begin as if you were making a Distance measurement. Most instructions for the Velocity measurement are identical to those for a Distance measurement. Values for set-up keys will be different, and, of course, you'll have to push the VELOCITY key instead of the DISTANCE key.

OPERATING SPECIFICATIONS

Accuracy: ±0.1% of displayed value

Resolution: Metric units: 0.1 mm/min
English units: 0.01 inch/min

Range (Travel of Optics): Same as for a Distance Measurement, see Section 6

Maximum Velocity: ±18000 mm/min
(± 720 inches/min, 60 feet/min)

HARDWARE REQUIRED

In addition to the hardware required for any measurement using the Laser Measurement System (see *Figure 4-1*), any Velocity measurement requires the same hardware as a Distance measurement, as shown in *Figure 6-1*.

OPTIONAL HARDWARE

Optional hardware, shown in *Figure 6-2*, can be connected to your Laser Measurement System to allow measurements to be made faster, more accurately, or with less effort on your part.

REFERENCE MATERIAL

Physical Setup of the Laser Head and Tripod ..... Section 4

Interconnections, Turn-on ..... Section 5

Distance Measurements ..... Section 6

Alignment Techniques ..... Section 15

ASSEMBLY, INSTALLATION, AND ALIGNMENT, OF OPTICS

For each of these procedures, use the instructions given under the same heading in Section 6 of this User's Guide, "DISTANCE MEASUREMENTS".

MEASUREMENT DISPLAY SETTINGS, SENSOR USE

Selecting "Measurement Units"

The Measurement Display can give you your measurement results in either "English" (inches, degrees Farenheit, etc.) or "Metric" (mm, degrees Celsius, etc.) units. You make the selection by setting the toggle switch on the Measurement Display unit's rear panel. (See Section 16, "Controls, Connectors, and Indicators".)

The toggle switch is the "locking" type. To change the setting of the rear-panel "English/Metric" toggle switch —

1. Gently pull the switch handle "out", along its current position.
2. Move the switch lever to the position for the units you want to use.
3. Release the switch handle; this will allow it to lock at the new setting.

When you are entering data via the Measurement Display unit's keyboard, remember to enter values appropriate for the measurement units you have selected; also, you can't mix "English" and "Metric" units (inches and degrees Celsius, for example).

To provide your Laser Measurement System with information it needs to know about the environmental conditions at the time of measurement, use the appropriate procedure below, depending on whether or not you have one or more sensors connected to the Measurement Display unit.

Using Sensors

Sensor Attachment

The Air Sensor should already be attached. See Section 5 for instructions.

CAUTION

To prevent possible damage to the Measurement Display unit, be sure you turn the line power off before conencting or disconnecting any cable at its rear panel.

NOTE

Be sure to "lock" the connections, so they won't accidentally come undone.

Sensor Placement

In order to accurately correct for the effects of environmental and machine temperature on the laser reading, you must locate the sensors where they can accurately monitor the conditions influencing the laser. The 10751 Air Sensor (which monitors the atmospheric conditions) should always be mounted as closely as possible to the actual MEASUREMENT PATH, so it can monitor the conditions the laser beam is experiencing.

As an example for sensor placement, let's consider making a measurement on a mill, shown in *Figure 6-11*. In this case, it is easy to determine where the sensor should be. The 10751 Air Sensor should be placed next to the beam in the measurement path.

NOTE

The Air Sensor should be mounted with its arrow pointing up, to maximize accuracy, as shown in *Figure 6-12*. It should should also be located in an area with good air flow.

Adjusting For Humidity

The 10751 Air Sensor has a "Humidity" switch on one side (opposite its connecting cable). You must set the switch handle to the position corresponding to the relative humidity in the area you are measuring. The choices are "25%", "50%", and "75%".

Measurement Display Settings (with sensors)

Measurement Mode Keys



Push the VELOCITY key.

Set-up Keys

NOTES

1. To enter a value for any key —
   a. Use the ENTRY keys to specify the numeric value, then —
   b. Press the key to assign the value to that key.

2. To check the current status of any of these keys, just press the key. Then press the key again, to return to the mode you selected earlier.

3. More information about each key is available in Section 16 of this User's Guide.



a. V.O.L. is now automatically calculated and updated, so you do not have to enter any information with this key.



b. Enter a preset number (constant), if you want one used. The value you enter will be added to the measured results, and the total will be displayed. If you do not enter a number, "0" is automatically used here.



c. Determine which direction you want to be "positive" and use this button to make sure it happens.



d. Determine the resolution you need from the accuracy you want. Enter the number of places you want, and then press the keys. Resolution extends to one place (0.1) for millimetres, and to two places (0.01) for inches.

This key also allows you to "smooth" your data by entering a positive number. A negative resolution number will remove any smoothing. Smoothing reduces the effects of vibration.

Measurement Display Settings (without sensors)

Measurement Mode Keys



Push the VELOCITY key

Set-up Keys

NOTES

1. Making a measurement without using the automatic sensors is practical only when the measurement environment is not changing, since it is difficult to continually update your compensation data manually while the measurement is running.

NOTES (Continued)

2. To enter a value for any key —

   a Use the ENTRY keys to specify the numeric value, then —

   b Press the key to assign the value to that key.

3. To check the current status of any of these keys, just press the key. Then press the key again, to return to the mode you selected earlier.

4. More information about each key is available in Section 16 of this User's Guide.



a You must calculate the V.O.L. compensation number using Section 19 of this User's Guide.

You will need to determine the air pressure and the air temperature to determine the Compensation values shown in Section 19.

NOTE

The default value for V.O.L. is 728.8. (This corresponds to an air temperature of 20 C (68 F), an air pressure equivalent to 760 mm (29.921 inches) of Mercury, and relative humidity of 50%.

Enter the calculated compensation factor by pressing —





b. Enter a preset number (constant), if you want one used. The value you enter will be added to the measured results, and the total will be displayed. If you do not enter a number, "0" is automatically used here.



c Determine which direction you want to be "positive" and use this button to make sure it happens.



d Determine the resolution you need from the accuracy you want. Enter the number of places you want, and then press the keys. Resolution extends to one place (0.1) for millimetres, and to two places (0.01) for inches. This key also allows you to "smooth" your data by entering a positive number. A negative resolution number will remove any smoothing. Smoothing reduces the effects of vibration.

MAKING A MEASUREMENT

System Checks

1 Make sure both Laser Head ports are switched to their large apertures.

2 The Laser Head turret must be set to "Other".

3. The Laser Head's "READY" indicator must be lighted steadily (i.e., not blinking).

4. Make sure you are properly interfaced with other instruments as needed to record your data.

   a. If you record your data manually, no interfacing is necessary.

   b. If you want to record your data automatically, but you aren't using the HP Dimensional Metrology Analysis System or another HP-IB controller, you must have an HP-IB compatible printer connected to the Measurement Display unit, via the rear panel HP-IB connector. You must also make sure the Measurement Display is set up to output to a printer via HP-IB. See Section 18 and follow the instructions for "Data Transfer without an HP-IB Controller".

   c. For formatted automatic records, you should have the HP Dimensional Metrology Analysis System or an HP-IB controller with your own programs to make it work with the Laser Measurement System. The HP Analysis System comes with an HP Personal Computer and programs to make it work with the Laser Measurement System. The operating manual for the Analysis System will explain how to use it. In either case, you must first make sure the Measurement Display is set up to accept a controller via HP-IB. See Section 18 and follow the instructions for "Data Transfer with an HP-IB Controller".

Procedure

1. Press the RESET key on the Measurement Display unit, or the Remote Control unit's RESET key. (Remember to do this only when the Optics are as close together as possible to prevent "deadpath error".)

2. Set up the Measurement Display to make measurements at specific time intervals (i.e., "on the fly"). (If you are interfacing to a controller, you should probably do this through its programs.)

   a. Enter the time interval you want between measurements (0.05 to 12 seconds).

   b. Push the AUTO RECORD key. This will start the automatic taking of data. (See Section 16 for more information about using this key.)

3. Move one optic along the full measurement path. A measurement is made automatically every so many seconds until you press the AUTORECORD key again.

4. Press the AUTORECORD key when the end of travel is reached. This will turn off the AUTO RECORD, and stop the recording of measurements.

   If an HP Personal Computer or an HP-IB Printer is not connected to the Measurement Display unit, pressing RECORD or AUTORECORD will cause the message "Lr Error" to be displayed.

WHAT AFFECTS ACCURACY?

The Laser Measurement System's Velocity measuring accuracy depends on the System's ability to adjust for environmental changes and on your ability to set up and operate the system properly. In the next few pages we will describe some potential measurement errors, examine how they affect Velocity measurements, and what can be done about them to maximize measurement accuracy.

Velocity Measurement Error Sources

Sources of error in a Velocity measurement are —

1. Measurement of air temperature, pressure, and humidity to determine the velocity of light (V.O.L. Compensation).
2. Mis-alignment between machine travel and Laser Measurement axis.
3. Uncompensated measurement path lengths (Deadpath Error).

The accumulation of all the errors listed above determines the overall accuracy of the Laser Measurement System in your application.

Velocity-Of-Light Compensation

Description

The wavelength of the light produced by the Laser is used as the reference for a Velocity measurement. The wavelength of any light, however, depends on the velocity of light through air. This, in turn, depends on the temperature, pressure, and (to a lesser extent) humidity.

Thus the absolute accuracy of the Laser Measurement System is directly determined by how accurately the ambient conditions are known. Specifically, a Velocity measurement can vary one part per million for any **one** of the following —

- An **air temperature** change of 1 degree Celsius (2 degrees Farenheit), or —
- An **air pressure** change of 2.5 mm (0.1 inch) of mercury, or —
- A change in **humidity** of 80 percent.

Minimizing Effects

The Measurement Display unit multiplies the number of wavelengths it counts (from the Laser Head) by a compensation factor for the velocity-of-light, thereby correcting for any difference between the "current" velocity of light (in air) and the velocity of light in a vacuum.

This calibration factor can be determined and entered either manually or automatically. Attaching the 10751 Air Sensor will automatically provide the calibration data, otherwise, you must calculate the correct calibration numbers and enter them manually. (Remember that manual entry won't provide automatic correction for changing conditions.)

For manual entry of the compensation factor —

- Determine the correct compensation factor from Section 19, "V.O.L. Compensation Factor".
- Enter the number into the Display, using the ENTRY keys.
- Press the V.O.L. key.

Both automatic and manual compensation for V.O.L. have been previously described in this section, under the heading "MEASUREMENT DISPLAY SETTINGS, SENSOR USE".

Misalignment Between Machine Travel Axis and Laser Measurement Axis

Description

If the Laser beam's path doesn't duplicate the machine's travel path, you won't be measuring the actual Velocity, but a Velocity that is slightly less (See "COSINE ERROR" material in Section 6, and *Figure* 6-13 ;

Minimizing Effects

The error is reduced by making the Laser beam parallel to the Optics' travel path. Parallelism is indicated by the absence of motion between the return dots from the Interferometer Assembly and the Retroreflector at the Laser Head's bottom port, as the Optics are moved along the measurement axis

The "OVERLAPPING DOTS" alignment method, described in Section 15 of this User's Guide, describes how to minimize the motion between the return dots and, therefore, minimize the cosine error

Uncompensated Measurement Path Length (Deadpath Error)

Description

This is a complication of the "Velocity-of-Light" error.

Compensation for velocity-of-light error is applied only in proportion to the distance measured. The error, however, exists over the whole path between the Optics, including those parts not measured. Any time the Laser Measurement System is reset with some distance existing between the optics, the length of the "open" distance will be uncompensated, and will result in an error. The name for this kind of error is "Deadpath Error".

Minimizing Effects

To minimize the amount of this error, the only time you should reset the Laser Measurement System is when the Optics are as close together as possible.

The only way this error can be eliminated is to reset the Laser Measurement System when the optics (not their bases) are actually touching. For most applications, resetting when the optics are within five centimetres (2 inches) will be enough to nullify the error.

SECTION 8
ANGULAR MEASUREMENTS

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INTRODUCTION

An "Angular" measurement is the measurement of the relative angular movement between the Reflector and the Interferometer as one of them is moved. See Appendix A for a description of the principles on which this measurement is based.

OPERATING SPECIFICATIONS

ACCURACY: Angle measurements are accurate within ±0.2% of displayed value ±0.05 arc-sec per metre of traveled distance of the moving optic. This assumes that all angles greater than ±3600 arc-sec have been corrected, the Reflector is aligned within 10 arc-min using autoreflection techniques, roll alignment by the operator is within 1 degree relative to the measurement plane, and the temperature of all optical components is stabilized in the range 15–25°C.

RESOLUTION: 0.1 arc-sec

RANGE: ±36000 arc-sec

AXIAL SEPARATION: (Typical, with proper alignment, 15–25°C, distance between the Laser Head and the Reflector) 15 metres (50 feet).

HARDWARE REQUIRED

In addition to the hardware required for any measurement using the Laser Measurement System (see *Figure 4-1*), any Angular measurement requires the hardware shown in *Figure 8-1*.

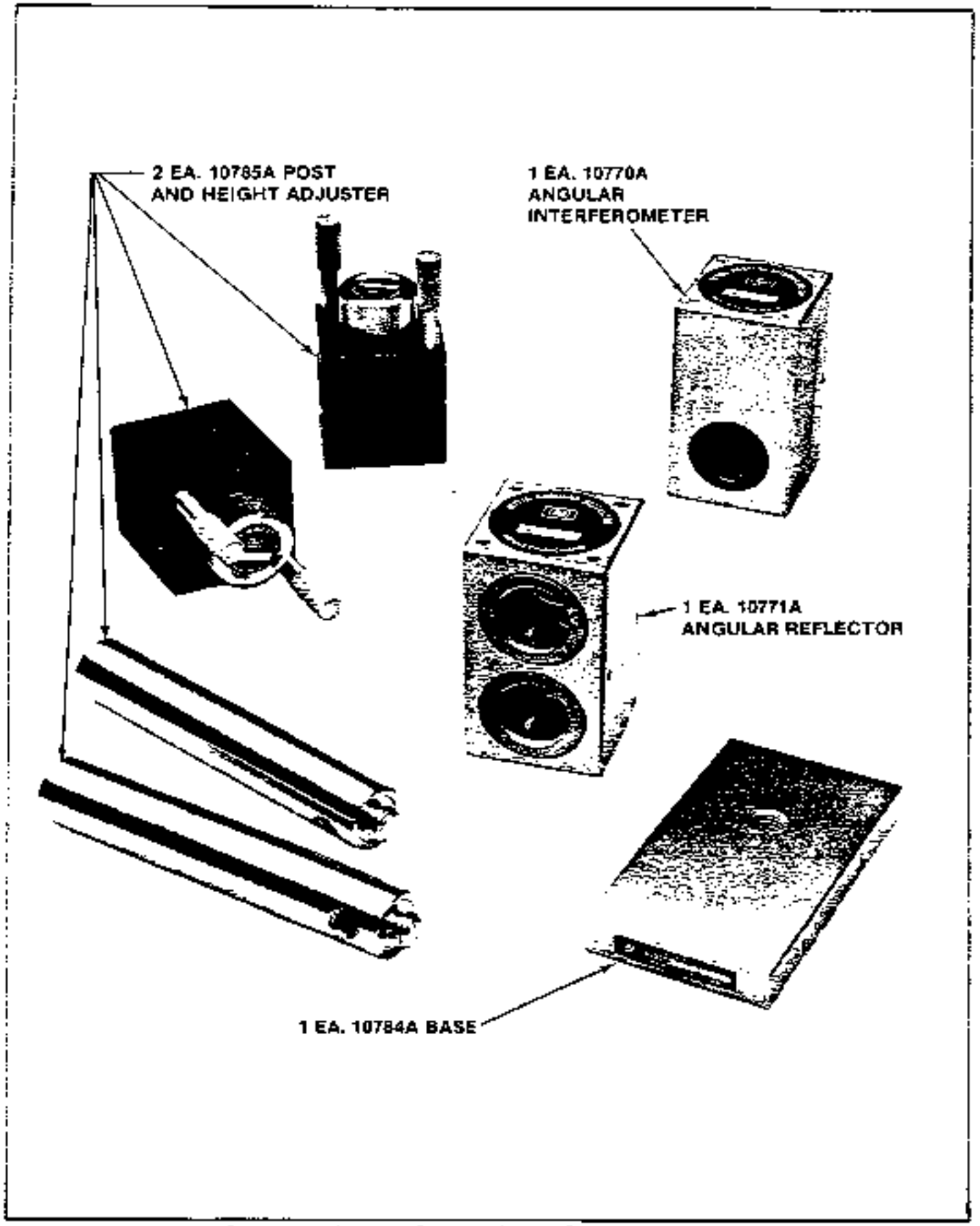


Figure 8-1. Hardware Required for any Distance Measurement

RELATED MEASUREMENTS

Flatness ..... Section 9

REFERENCE MATERIAL

Physical Setup of the Laser Head and Tripod ..... Section 4

Interconnections, Turn-on ..... Section 5

Alignment Techniques ..... Section 15

INSTALLATION AND ALIGNMENT OF OPTICS

Important Considerations

1. The Angular Interferometer must be located between the Laser Head and the Angular Reflector in the Laser beam.

2. The beam from the Laser Head must enter the Angular Interferometer —

   - through the single opening on one side, for an **in-line** measurement, or —
   - through the opening in the bottom, for a measurement along an axis perpendicular to the Laser beam.

   The side of the Angular Interferometer with two openings should always be facing the Angular Reflector. (See *Figure 8-8* and *Figure 8-9*.)

3. Vibrations and loose connections must be minimized by proper mounting. Avoid long extensions. Make sure that all supports are completely stationary. A spindle, for example, must be secured by a brake so it won't rotate. (If a brake isn't available try using a hose clamp or a wedge.)

4. The Laser beam must be returned to the bottom port on the Laser Head's turret.

5. The Optics must be aligned to the Laser beam well enough to keep the Beam Strength indicator in the green region along the entire optics' path.

6. If the Distance Optics have previously been installed, you can install the Angular Optics by simply changing the Optics, without changing the mounting hardware.

7. The Laser Head's turret ring should be set to "OTHER".

Description

1. You will initially position the Optics around the Laser beam while they are at the near end of travel using the procedures that follow.

2. Next, you will adjust the Laser Head to track the Optic's progression along the travel path, while maintaining the beam's near-end-of-travel position. (See "GUNSIGHT" alignment method in Section 15 of this User's Guide.)

3. Finally, you will check your alignment to insure the "Important Considerations" number "5" has been fulfilled.

NOTE

Use of the Gunsight Alignment method is described in the following procedure. Once you become familiar enough with alignment principles, you may want to start with "Autoreflection" (described in Section 15; or to align by the same philosophy as the "Gunsight" method, but without targets. (Your entire interferometer opening would be the interferometer target and the Laser Head's return port target would become the Reflector's target.)

Procedure

1 Move the moveable part of your machine as close to the Laser Head as possible.

Note that the "moveable" part of the machine may depend on the axis you are measuring. That is, the "X"-axis moveable part may not necessarily also be the "Y"-axis or "Z"-axis moveable part.

This will keep the machine from hitting the Laser Head during a measurement and will help establish the "near-end-of-travel".

2. Visually align the Laser Head as well as you can parallel to the direction of travel and position it at an appropriate height. Some things to consider are —

- Position for an axis appropriate for what you want to do (review Section 4's material on this).
- If you think you will be making a Straightness or Squareness measurement later, establish a measurement axis at a height above the table that will allow easy interchangeability of the Optics. To do this, mount a Retroreflector on a Height Adjuster that is flush with the top of the post supported by the base; then position the Laser Head so the return beam from the Retroreflector enters the Laser Head's lower port.
- Use "Autoreflection" to help you do this once you become proficient at Laser System measurements. If you use "Autoreflection" you won't have to do any further alignment, you'll only need to check for beam strength.

3 Decide where you will position the Optics so that:

- The Interferometer is between the Reflector and the Laser Head.
- One Optic is where the tool mounts and the other is where the workpiece mounts.
- The Optics are at the "near end of travel". (This means that any subsequent motion of the machine will separate the optics further rather than bring them closer together.) (See *Figure 8-2.*)
- If you want to measure perpendicular axes from the same Laser Head position, position the Interferometer on a part of the machine that remains stationary and can serve as a beginning point to measure these axes. (See *Figure 8-9* and *Figure 8-10.*)

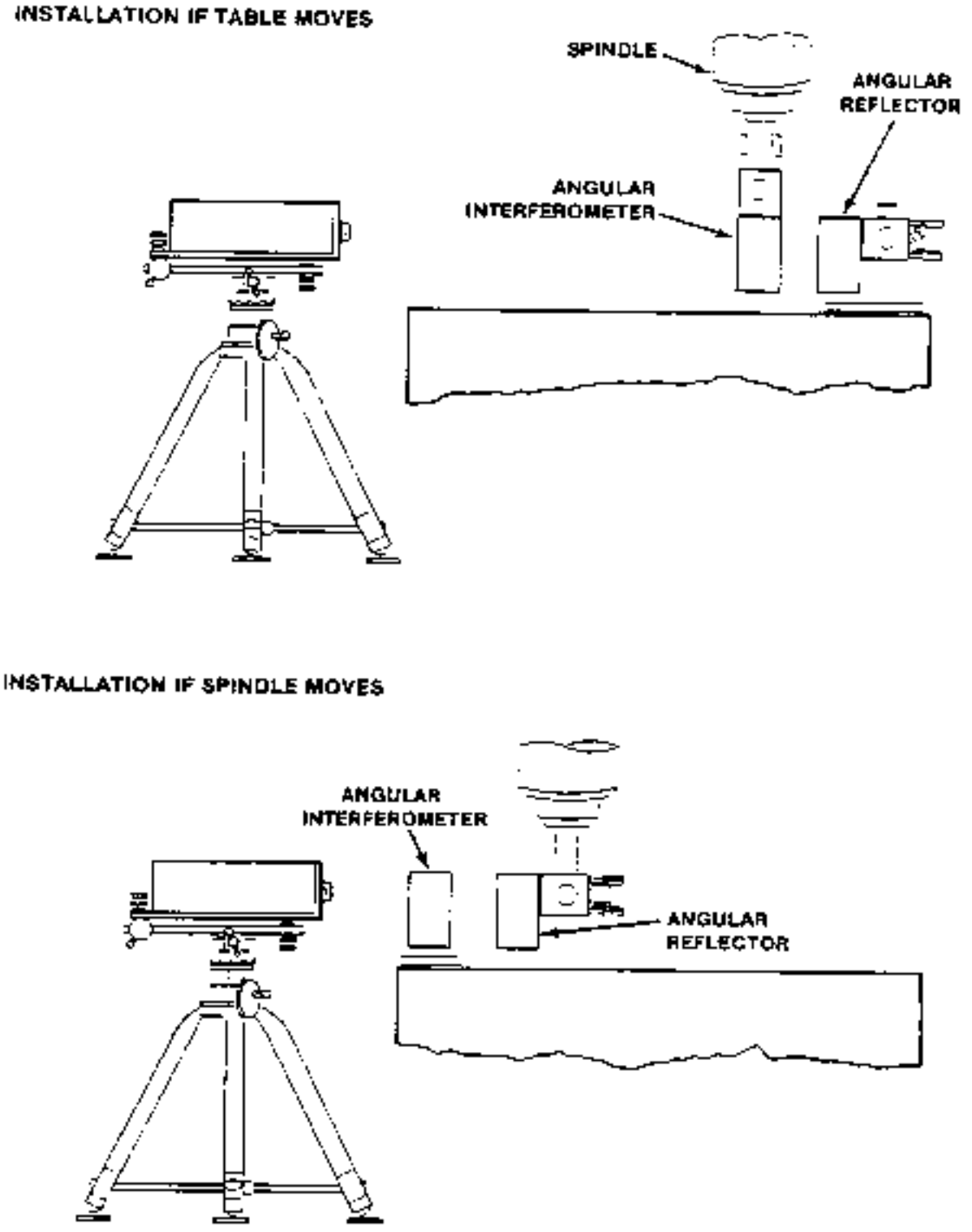


Figure 8-2. Positioning the Optics

4. Attach the Angular Interferometer and the Angular Reflector to a Height Adjuster and Post to accomodate the positions you chose in step "3". (See *Figure 8-3, Figure 8-4, Figure 8-5,* and *Figure 8-6.*)

   a For the Optic you mount on the table, support the post with a base. If you think you will be making a Straightness or Squareness measurement later, position the Height Adjuster flush with the top of the Post, to allow easy interchanging of the Optics.

   b For the Optic you mount in a spindle, either attach the Height Adjuster to a Post as you would for table mounting, or screw the Post into the Height Adjuster after removing the large knurled knob. This latter arrangement may make it easier to change to Straightness Optics.

   c. Orient the Optics horizontally or vertically to match the type of measurement you would like to make (pitch or yaw).

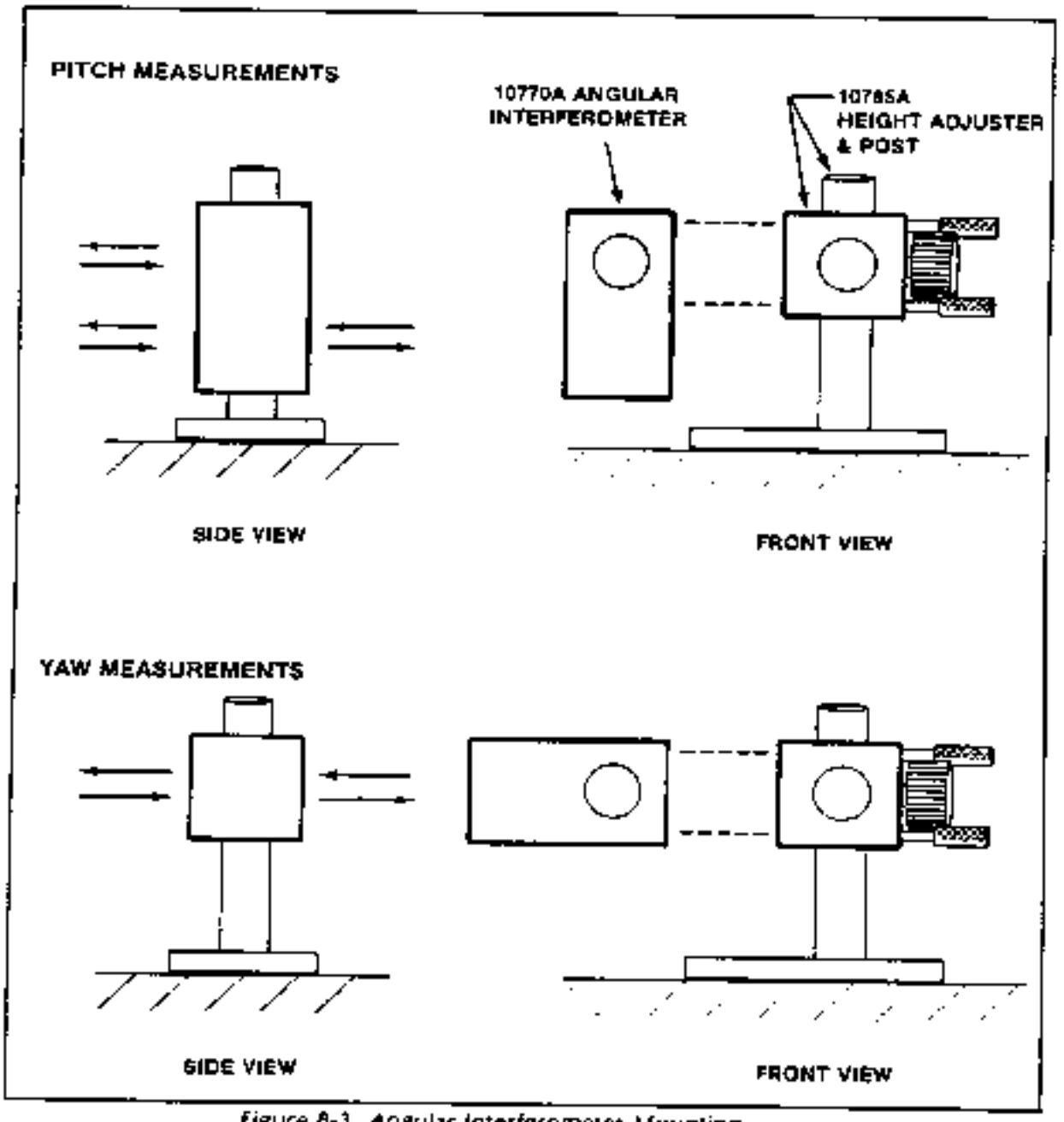


Figure 8-3. Angular Interferometer Mounting

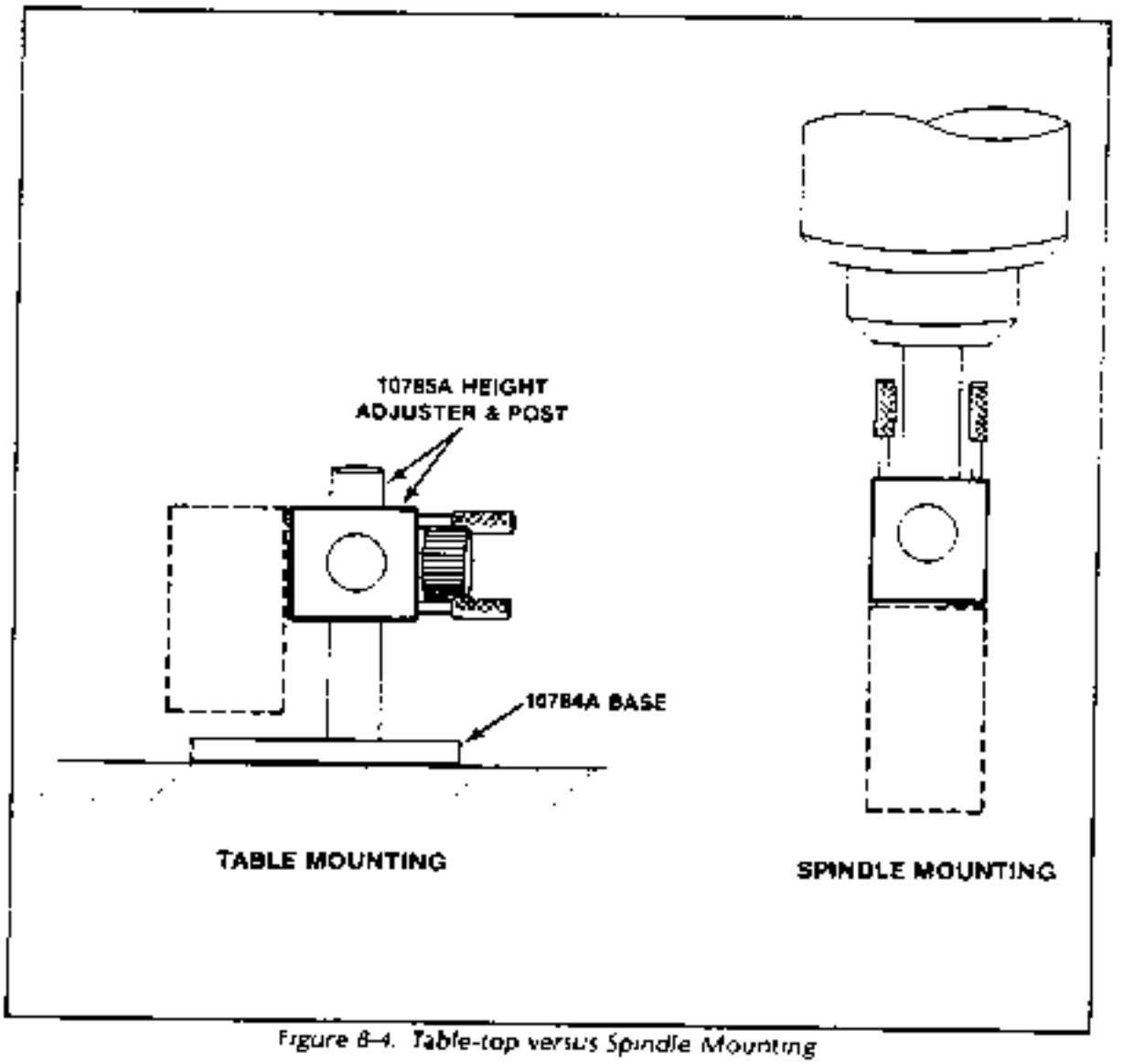


Figure 8-4. Table-top versus Spindle Mounting

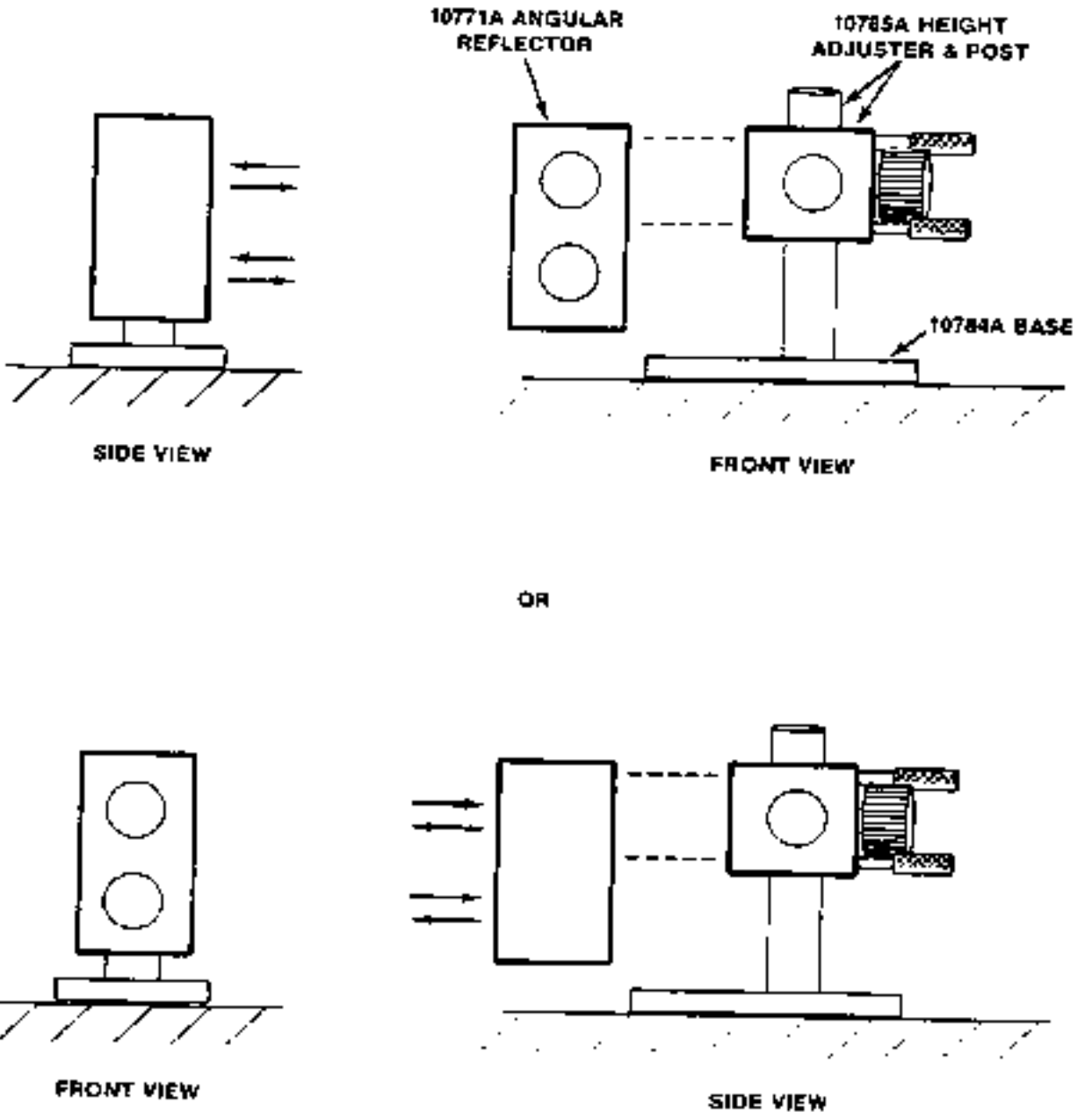


Figure 8-5. Angular Reflector Mounting — for Pitch Measurement

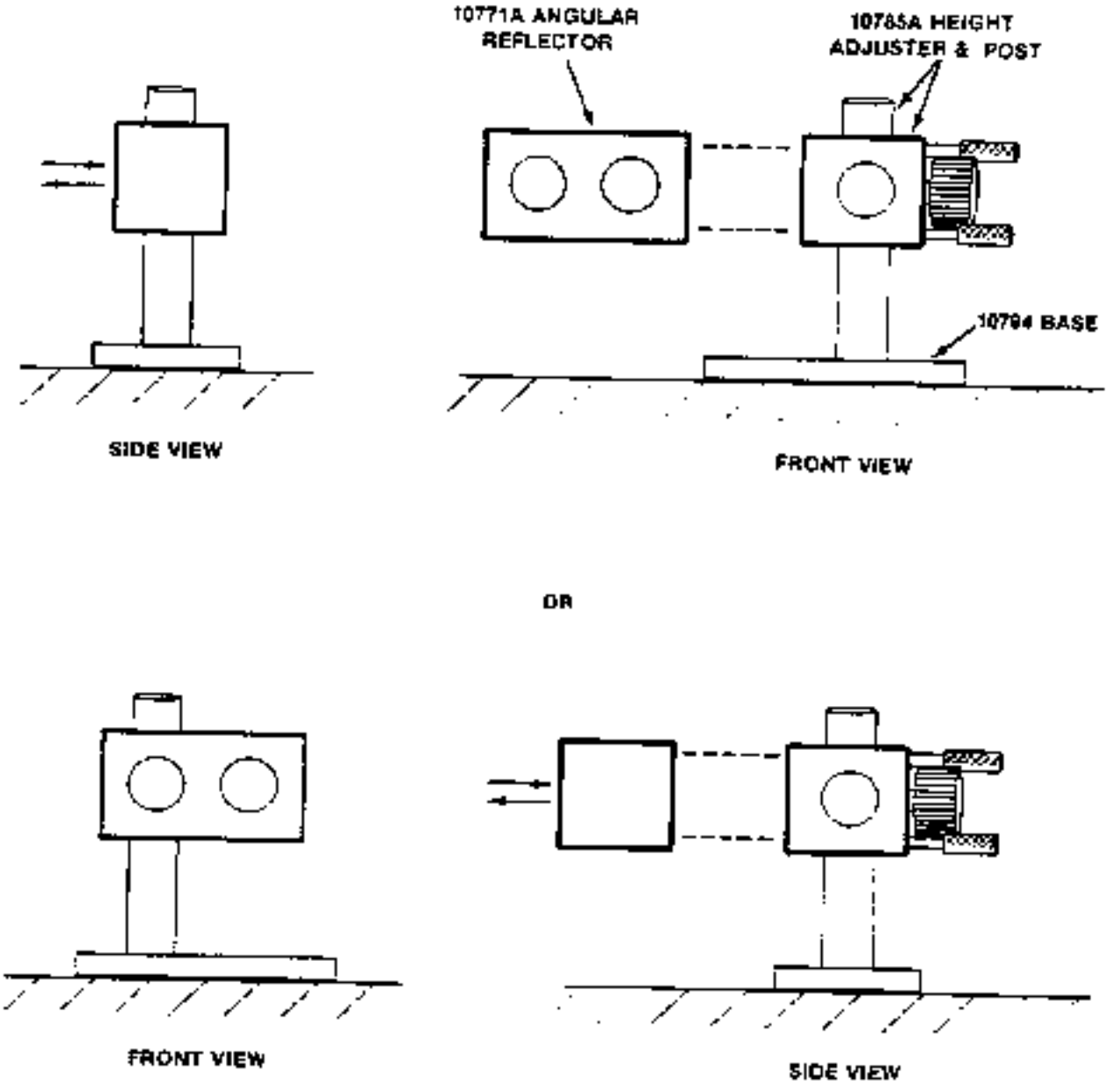


Figure 8-6. Angular Reflector Mounting — for Yaw Measurements

5. Select the small opening for the Laser Head's exit port, and rotate the target into place over the Laser Head's bottom (return) port.

6. Attach the target to the Angular Interferometer (see *Figure 8-7*). This target is included with the Optics.

   The target should be attached to the Angular Interferometer opening that is directed toward the Laser Head, and in such a way that the small (3 mm) hole is above the crosshair.

   Make sure the target is positioned as squarely as possible relative to the edges of the Optic. Use your fingers to match edges.

7. Move the Angular Interferometer (or translate the Laser Head) so the Laser Beam goes through the target's hole.

8. Secure the entire assembly to the machine in such a way that the Interferometer is as square as possible relative to the incoming beam. (The Interferometer housing's pitch, yaw, and roll limitations are ±2 degrees relative to the incoming beam. The HP 10785A Post and Height Adjuster will take care of two of the three requirements, depending on your measurement set-up.)

9. Remove the target from the Interferometer.

10. Position the Reflector as closely as possible to the Interferometer. Look at the front of the Laser Head and adjust the Reflector until the return beams hit the Laser Head bottom port's target. This establishes the "near end of travel". It may help to start by visually lining up the Reflector's edges with the edges of the Interferometer.

11. Secure the Reflector assembly to the machine so it is square relative to the incoming beam and so that it is *not* out-of-square in the "roll" direction by more than ±1 degree. The HP 10785A Post and Height Adjuster should automatically take care of this.

12. Reattach the targets to the Interferometer and Reflector, except now attach them so —

    - the hole in the Interferometer's target is centered around the beam, and —
    - the crossbairs on the Reflector's target are also centered on the beam. (You can position the target over either Retroreflector. See *Figure 8-8*.)

    This time you don't have to line up the edges of the targets with the edges of the Optics (in fact, you may not be able to do so and still meet the conditions above).

13. You are now ready to align the Laser to the machine's travel.

    Turn to Section 15 of this User's Guide and follow the instructions there for "GUNSIGHT" alignment.

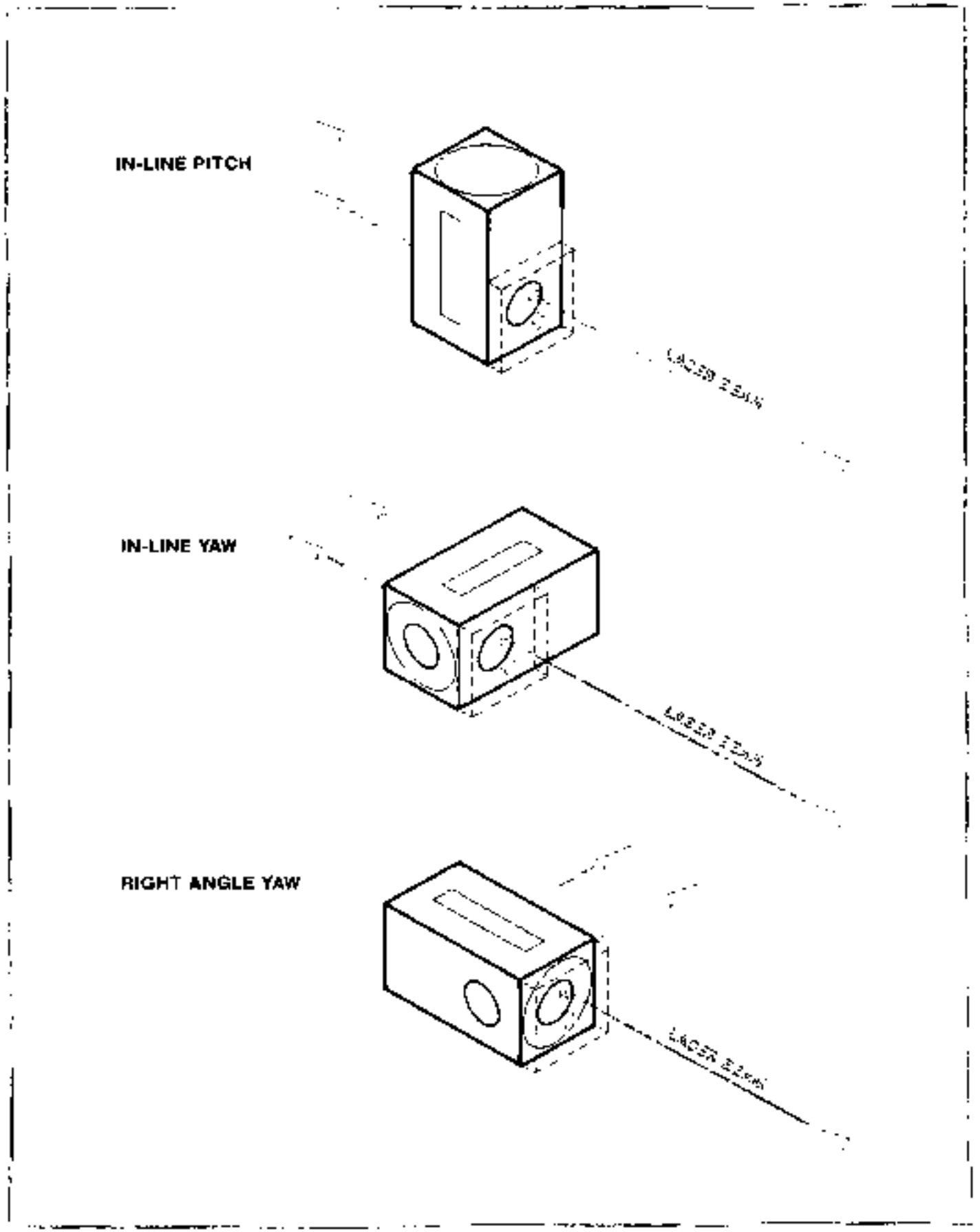


Figure 8-7. Attaching Alignment Target to Angular Interferometer

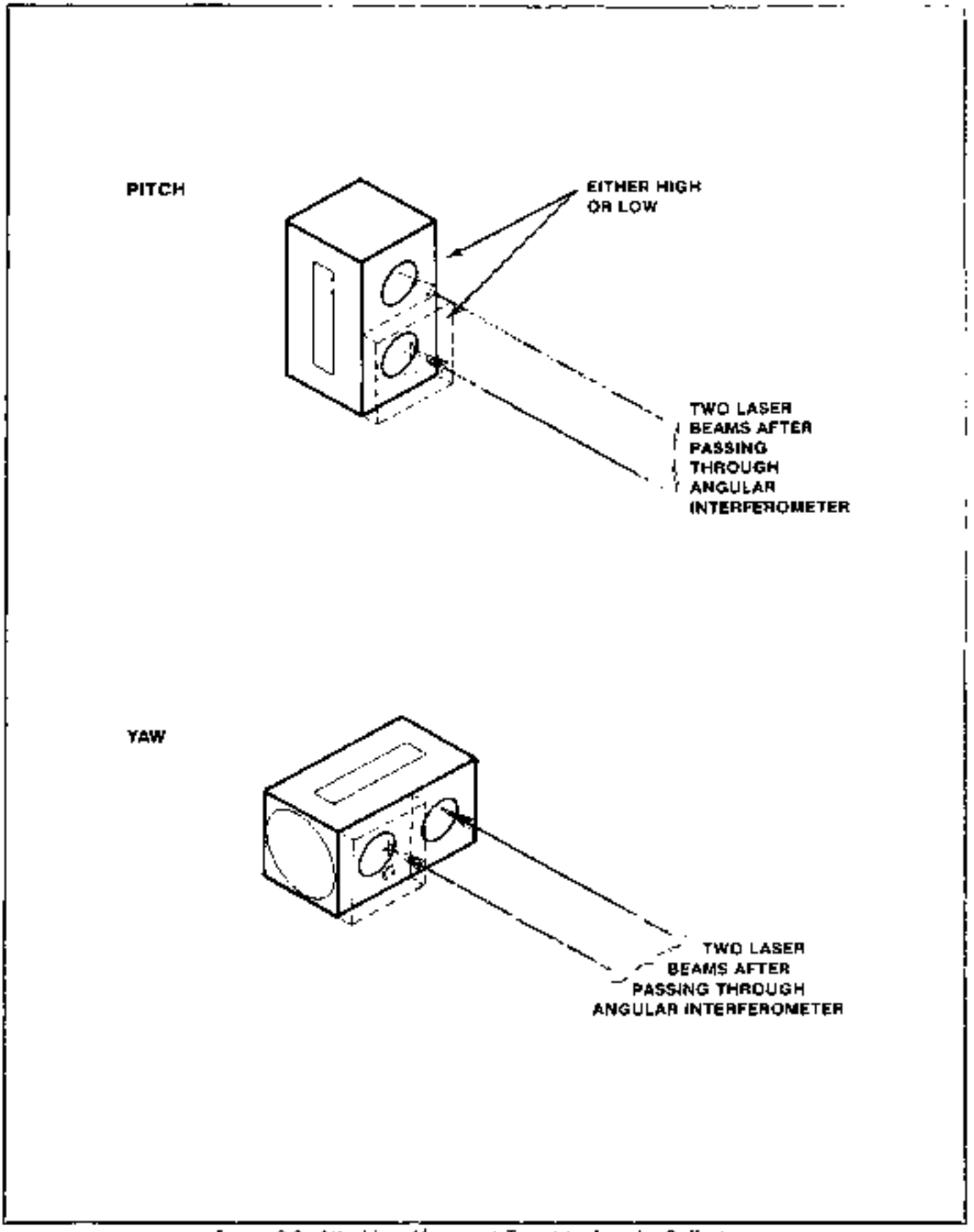


Figure 8-8. Attaching Alignment Target to Angular Reflector

Checking Alignment for Beam Strength

1 Select the large opening for the Laser Head's exit and return ports.

Remove the targets from the Optics.

2. Move the Optics over their full travel length while watching the BEAM STRENGTH meter

The Laser beam is strong enough for making a measurement as long as the BEAM STRENGTH needle stays in the green area of the meter

If the BEAM STRENGTH meter's needle moves into the red area —

a. Move the Optics to the near end of travel

b. Select the small aperture for the Laser Head's exit port, and the target for the return port.

c Adjust the Optics to overlap their return dots on the Laser Head's return port target

d. Switch back to the large exit port aperture and the fully open return port

e Check again for BEAM STRENGTH.

If alignment is still not good enough to make BEAM STRENGTH read in its green area, repeat the entire Alignment procedure

Measurements Along A Perpendicular Axis

When a measurement axis is perpendicular to the Laser beam, mount the Angular Interferometer in line with the Laser, and at the end of the axis you will be measuring (see *Figure 8-9* and *Figure 8-10* for illustrations of set-ups for measurements perpendicular to the Laser beam). Be sure to rotate the Angular Interferometer so the bottom opening lines up with the Laser beam and the side with two openings faces the moving Retroreflector.

To align the Laser Measurement System along an axis perpendicular to the Laser beam, attach the Interferometer target to the bottom opening on the Interferometer (see *Figure 8-7*), and follow all the instructions presented in the last few pages.

Other Mounting Requirements

Although we have tried to provide you with a maximum of mounting flexibility, there may be situations when you need more capability. For more information, you should turn to Appendix C for dimensions of the Optics, and the mounting hardware.

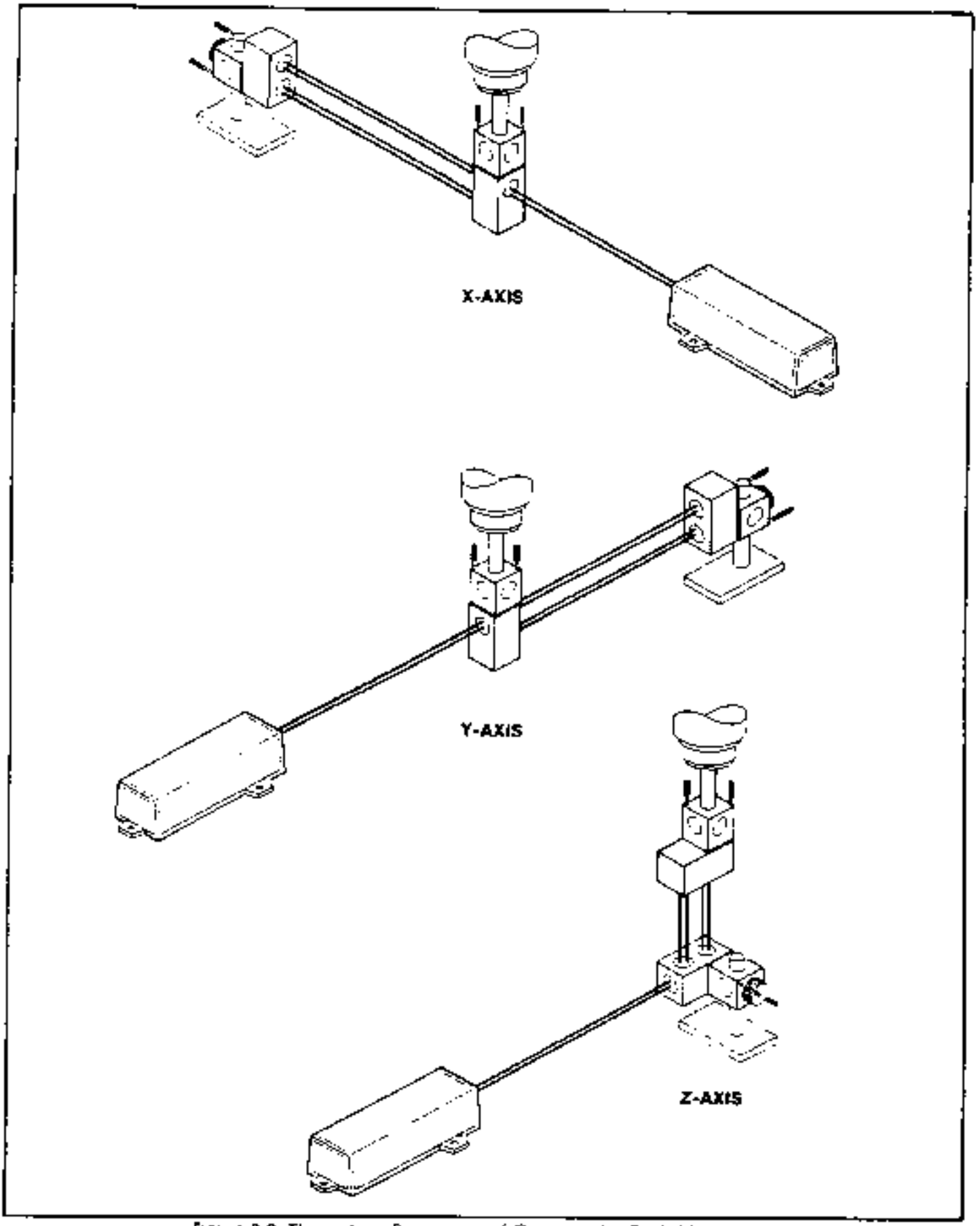


Figure 8-9. Three Axes Positioning of Optics — for Pitch Measurements

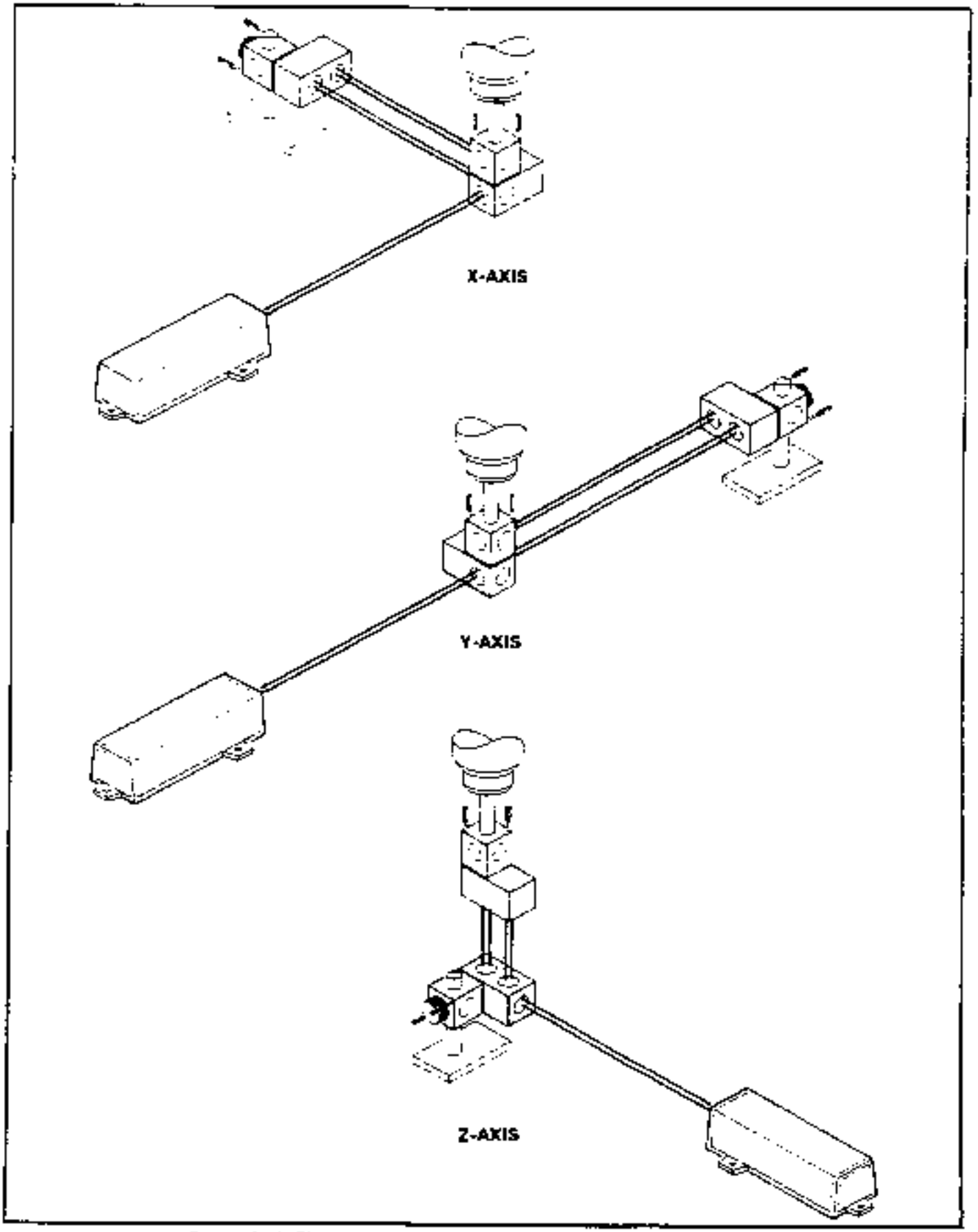


Figure 8-10. Three Axes Positioning of Optics — for Yaw Measurements

MEASUREMENT DISPLAY SETTINGS

Measurement Units

Your Angular measurements are displayed in units of "arc-seconds" (" ARC-SEC"), regardless of the setting of the Measurement Display's rear-panel "English/Metric" switch.

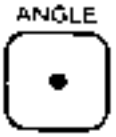
"Arcseconds" is a short way of saying "seconds of arc". One arcsecond equals 1/3600 of one degree.

Another way to visualize an arcsecond is that it is equivalent to 0.000005 mm (or inches) for every mm (or inch) from your measurement axis. (This is the same as 0.5 mm in 100 metres, or about 1/4-inch in about 4000 feet.)

NOTE

Measurement Display settings are the same with or without sensors

Measurement Mode Keys



Push the ANGLE key.

Set-up Keys

NOTE

1. To enter a number for any key —

   a. Use the ENTRY keys to specify the numeric value then —
   b. Press the selected SET UP to assign the value to that key.

2. To check the current status of any of these keys, just press the key. Then press the key again to return to your previous mode.

3. More information about each key is available in Section 16 of this User's Guide.



Your measurement data can be multiplied by a value from "0" to "2" before it is displayed. This key allows you to specify what the multiplier value will be. One use of this capability is to allow you to extend Angular measurement accuracy, described in the "WHAT AFFECTS ACCURACY?" section, below. If you do not specify some other value, "1.0" will automatically be used as the multiplier here.



Determine which tilt direction you want to be "positive" and use this button to make sure it happens.

RESOL There are only two choices for this key in this measurement mode. Resolution can be extended only to 0.1 arcsecond. Therefore, push —

1 RESOL for "tenths" resolution, or —

push —

0 RESOL for "units" resolution

This key also allows you to "smooth" your data by entering a positive number. A negative resolution number will remove any smoothing. Smoothing reduces the effects of vibration.

MAKING A MEASUREMENT

System Checks

1. Make sure both Laser Head ports are switched to their large apertures.
2. The Laser Head turret must be set to "OTHER".
3. The Laser Head's READY indicator must be lighted steadily (i.e., not blinking).
4. Make sure you are properly interfaced with other instruments as needed to record your data.
   a. If you record your data manually, no interfacing is necessary.
   b. If you want to record your data automatically, but you aren't using the HP Dimensional Metrology Analysis System or another HP-IB controller, you must have an HP-IB compatible printer connected to the Measurement Display unit, via the rear panel HP-IB connector. You must also make sure the Measurement Display is set-up to output to a printer via HP-IB. See Section 18 and follow the instructions for "Data Transfer without an HP-IB Controller".
   c. For formatted automatic records, you should have the HP Dimensional Metrology Analysis System or an HP-IB controller with your own programs to make it work with the Laser Measurement System. The HP Analysis System comes with an HP Personal Computer and programs to make it work with the Laser Measurement System. The operating manual for the Analysis System will explain how to use it. In either case, you must first make sure the Measurement Display is set-up to accept a controller via HP-IB. See Section 18 and follow the instructions for "Data Transfer with an HP-IB Controller".

Procedures

Two different measurement methods are available. You can have your system make measurements —

- only at points you specify, or —
- automatically, at the time interval you specify, without regard to the location of the Optics.

Measurements At Specific Physical Locations

To have your Laser Measurement System make measurements only at specific physical locations —

1. Push the RESET key. (You can also RESET from the Remote Control Unit.)
2. Move one of the optics a predetermined distance.
3. Press the RECORD button on the Remote Control Unit connected to the Measurement Display. One measurement is made each time you press this button.

Measurements At Specified Time Intervals

To have your Laser Measurement System make measurements at specific time intervals (i.e., "on-the-fly"): —

1. Push the RESET key. (You can also RESET from the Remote Control Unit.)
2. Enter the time interval you want between measurements (0.05 to 72 seconds).
3. Press the AUTO RECORD key. This will start the automatic taking of data. (See Section 16 for more information about using this key.)
4. Move one optic along the full measurement path. A measurement is made automatically every so many seconds until you press the AUTO RECORD key again.
5. Press the AUTO RECORD key when the end of travel is reached. This will turn off the AUTO RECORD mode, and end the recording of measurements.

If an HP Personal Computer or an HP-IB Printer is not connected to the Measurement Display unit, pressing RECORD or AUTO RECORD will cause the message "Lr Error" to be displayed.

WHAT AFFECTS ACCURACY?

Angular accuracy is dependent upon the accuracy of the initial alignment between the angular reflector and interferometer in pitch and roll.

Laser System Error Sources

The one potential Laser System error source for Angular measurements is the distance between the Retroreflectors. If this distance changes during a measurement, the measurement results will be incorrect. The only time the distance between the Retroreflectors will change is if the temperature of the Angular Reflector's housing changes during a measurement; thus you should keep this temperature as constant as you can.

Minimizing Errors, and Required Laser System Accuracy

As was described above, your Angular measurement's reliability depends on the stability of the temperature of the Angular Reflector's housing. To minimize these changes, you should —

- Avoid excessive handling of the Angular Reflector —
- Avoid moving the Angular Reflector over heated (or cooled) surfaces —
- Avoid having heated (or cooled) air moving past the Angular Reflector

The Laser Measurement System's accuracy specification for Angular measurements is given at the beginning of this section

9 Flatness Measurements

SECTION 9
FLATNESS MEASUREMENTS

CONTENTS

INTRODUCTION
OPERATING SPECIFICATIONS
HARDWARE REQUIRED
RELATED MEASUREMENTS
REFERENCE MATERIAL
INSTALLATION AND ALIGNMENT OF OPTICS
MEASUREMENT DISPLAY SETTINGS
MAKING A MEASUREMENT
WHAT AFFECTS ACCURACY?

INTRODUCTION

Flatness deviation can be calculated from angle information from the Angular Optics and from the length dimensions of the Footspacing Pads used. The HP Dimensional Metrology Analysis System programs calculate and plot flatness data for this application.

These measurements are best suited for surface plates, since we use the same method used with autocollimators (sometimes referred to as the "Moody" method).

In this User's Guide section (Section 9), we describe how to set up for and make a Flatness measurement using the Angular Optics. See Appendix A for a description of the principles on which this measurement is based.

OPERATING SPECIFICATIONS

The following specifications assume that the optional Dimensional Metrology Analysis System is used in conjunction with the HP 5528A to gather, analyze and plot flatness calibration results and that the temperature of all optical components is stabilized in the range 15-25°C. Values do not include effects of surface cleanliness or operator positioning repeatability.

Accuracy: ±0.2% of displayed value.

Resolution (per step):

Table 9-1. Accuracy Term

FOOTSPACING DIMENSION	ACCURACY TERM
2 inches	0.03 micron (1.0 microinch)
4 inches	0.05 micron (2.0 microinch)
6 inches	0.08 micron (3.0 microinch)

Reference Plane Accuracy: The uncertainty of a surface plate flatness measurement is bounded by two parallel planes spearated by the value below.

Metric Units Mode: 0.03 M^2 microns
English Units Mode: 0.12 F^2 microinches
where:
M = length of the surface diagonal in metres
F = length of the surface diagonal in feet

Lateral Offset and Flatness Range. The combination of lateral offset and maximum flatness deviation must not displace the Reflector more than ±1.0 mm (0.04 inch) from the beam path in any direction.

Axial Separation. Same as for an Angular measurement; see Section 8.

HARDWARE REQUIRED

In addition to the hardware required for any measurement using the Laser Measurement System (see *Figure* 4-1), any Flatness measurement requires the hardware shown in *Figure* 9-1, plus —

- an HP Dimensional Metrology Analysis System (which includes an HP Personal Computer and programs), and —
- a Straightedge that is at least as long as the diagonal of the surface plate you're measuring, and thick enough to contact the sides of the Footspacers (and not their small ground pads).

REFERENCE MATERIAL

Physical Setup of the Laser Head and Tripod ..... Section 4
Interconnections, Turn-on ..... Section 5
Angular Measurements ..... Section 8
Alignment Techniques ..... Section 15

INSTALLATION AND ALIGNMENT OF OPTICS

Important Considerations

1. The Angular Interferometer must be located between the Laser Head and the Angular Reflector in the Laser beam.
2. The beam from the Laser Head must enter the Angular Interferometer through the single opening on one side.

   The side of the Angular Interferometer with two openings should always be facing the Angular Reflector.
3. The Laser beam must be returned to the bottom port on the Laser Head's turret.

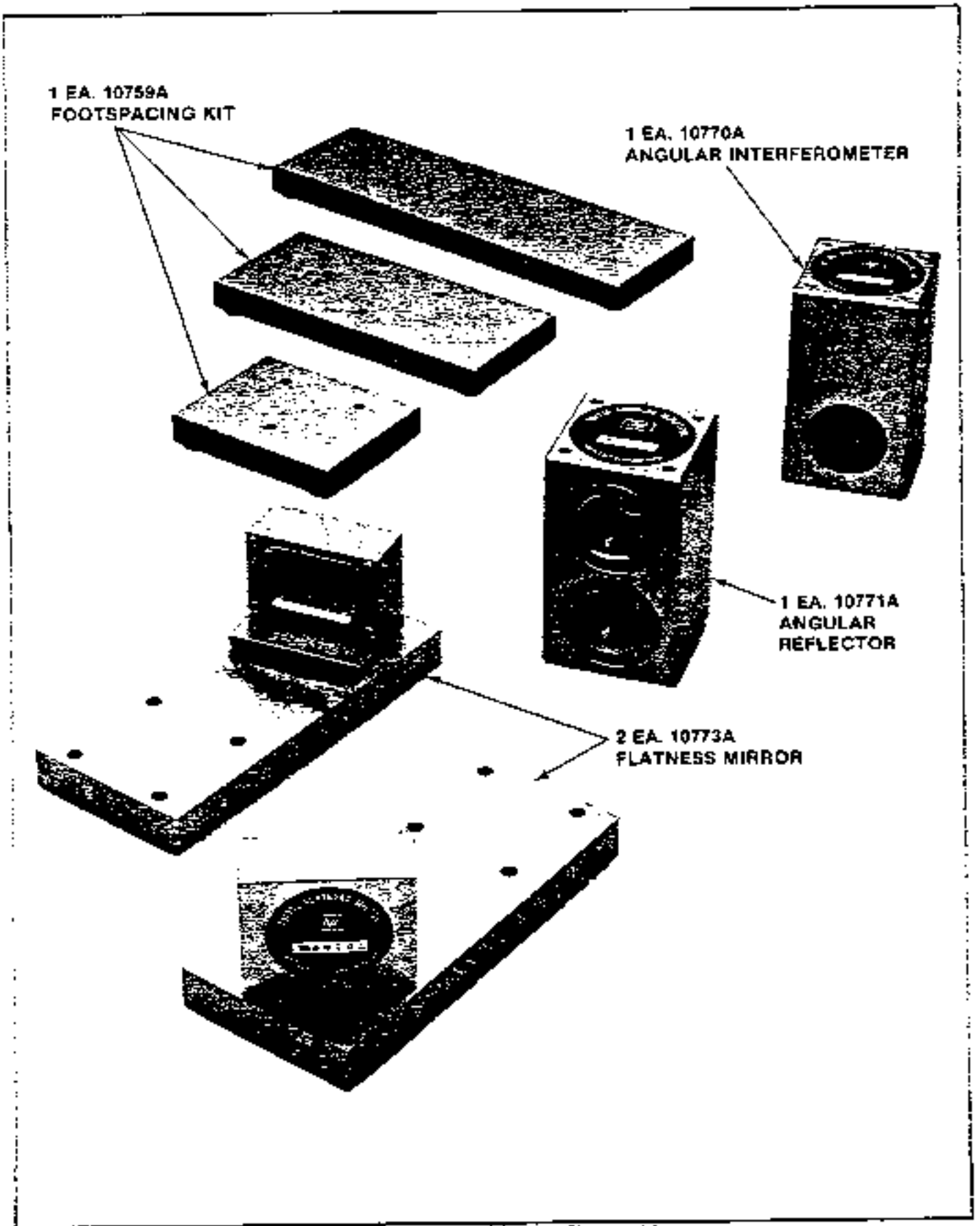


Figure 9-1. Hardware Required for any Flatness Measurement

4. The Optics must be aligned to the Laser beam well enough to keep the Beam Strength indicator in the green region along each measurement path.

5. The Laser Head's turret ring should be set to "OTHER".

Description

1. To measure "flatness" of a surface you will have to draw a "grid" on it and make measurements along each edge and diagonal of this grid.

2. For each line you measure —

   a. You will initially position the Optics around the Laser beam while they are at the near end of travel using the procedures that follow.

   b. Next, you will adjust the Laser Head to track the Optic's progression along the travel path, while maintaining the beam's near-end-of-travel position. (See "GUNSIGHT" alignment method in Section 15 of this User's Guide.)

   c. Finally, you will check your alignment to insure that "Important Considerations" number "4" has been met.

NOTE

Use of the Gunsight Alignment method is described in the following procedure. Once you become familiar enough with alignment principles, you may want to use the following procedures, but without targets. (Your entire interferometer opening would be the interferometer target and the Laser Head's return port target would become the Reflector's target.)

3. The following procedures will only instruct you to set-up and align along one specific measurement "line" on the surface plate. You must adapt these instructions to other measurement paths to finish measuring the entire grid.

Procedure

1. Mount the Angular Interferometer on the Flatness Mirror, using the four Cap-Head M3 × .5 screws included.

   Make sure the single opening is facing toward the mirror, and the side with two openings is facing away from the mirror. (See *Figure* 9-2.)

2. Mount the Angular Reflector on a Footspacer, using the three Cap-Head M3 × .5 screws included, as shown in *Figure* 9-3. (Refer to step "3" below to help you decide which Footspacer to use.)

NOTE

These Optics are **always** oriented vertically, relative to their Footspacers and the Flatness Mirrors.

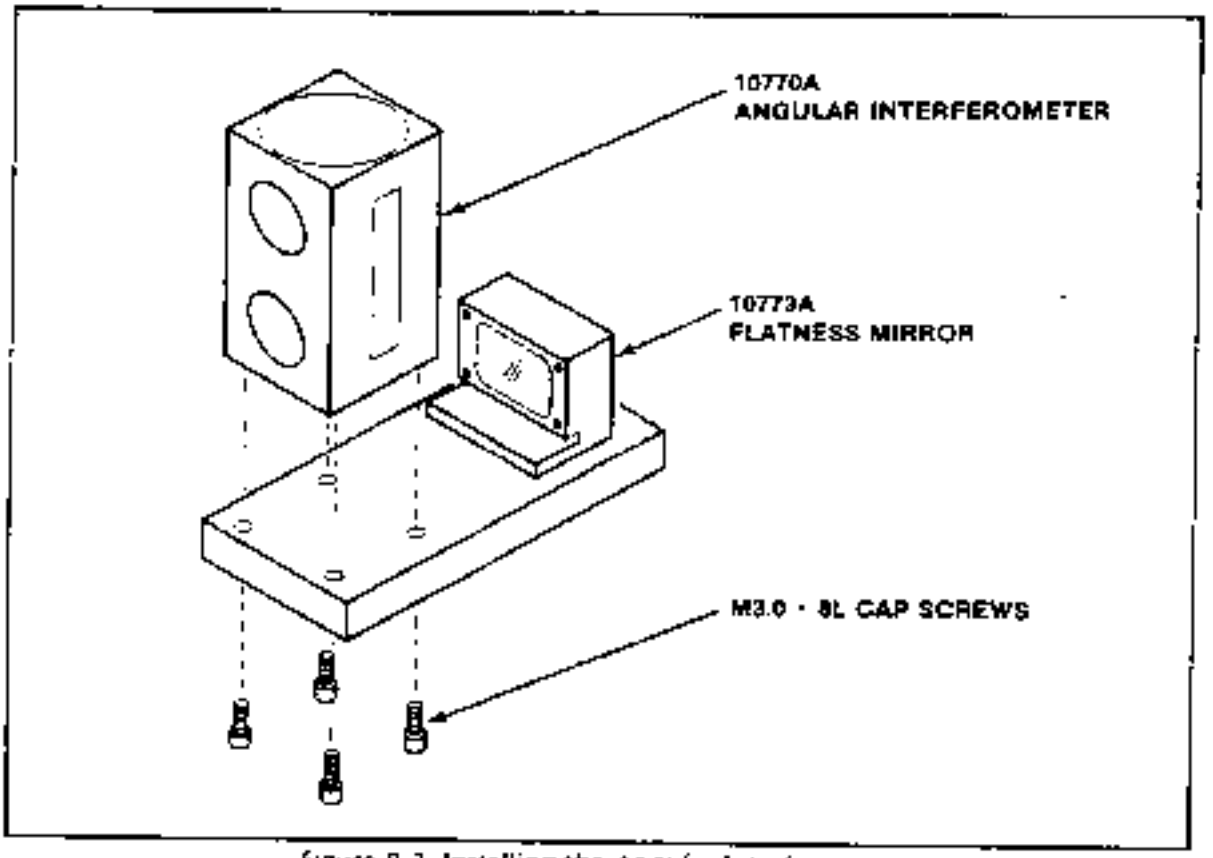


Figure 9-2. Installing the Angular Interferometer

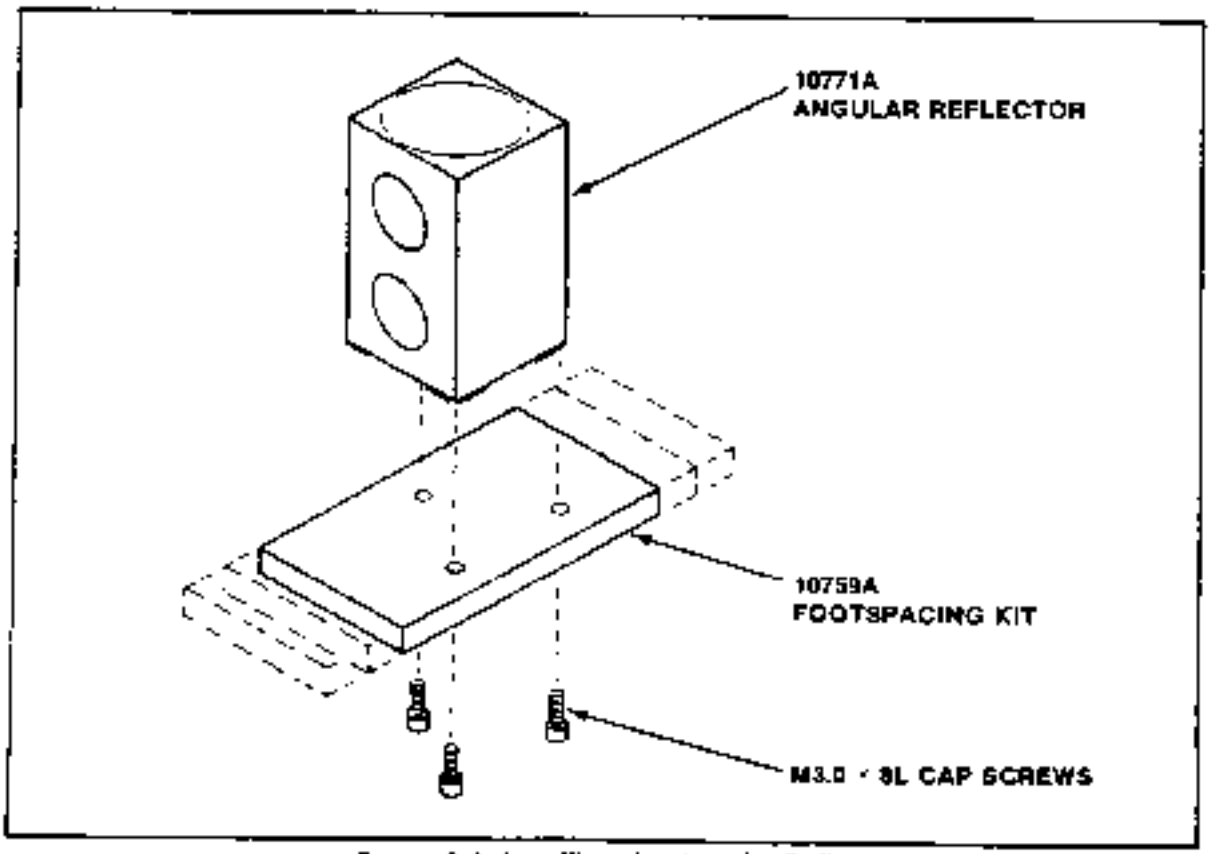


Figure 9-3. Installing the Angular Reflector

3. Draw a "map" of the Surface Plate.

   The map should be drawn on a sheet of paper with highlights located on the surface plate itself with lead pencil. Take care not to put markings directly on the grid lines, since the equipment must be free to slide on the granite surface along these lines. The grid system must contain the eight basic lines, as shown in *Figure 9-4*.

   The length of each line in this grid should be an even-integer ("2", "4", etc.) multiple of the length of the Footspacer to which the Angular Reflector is attached. For a very large Surface Plate, you will probably want to use a larger Footspacer, since measurements points will be determined by end-to-end positioning of the Footspacers. There should also be a 7.5 cm (3-inch) margin between the outside of the grid and the edge of the Surface Plate on three of the sides, and a 10 cm (4-inch) margin on the side that will be in line with the Laser Head.

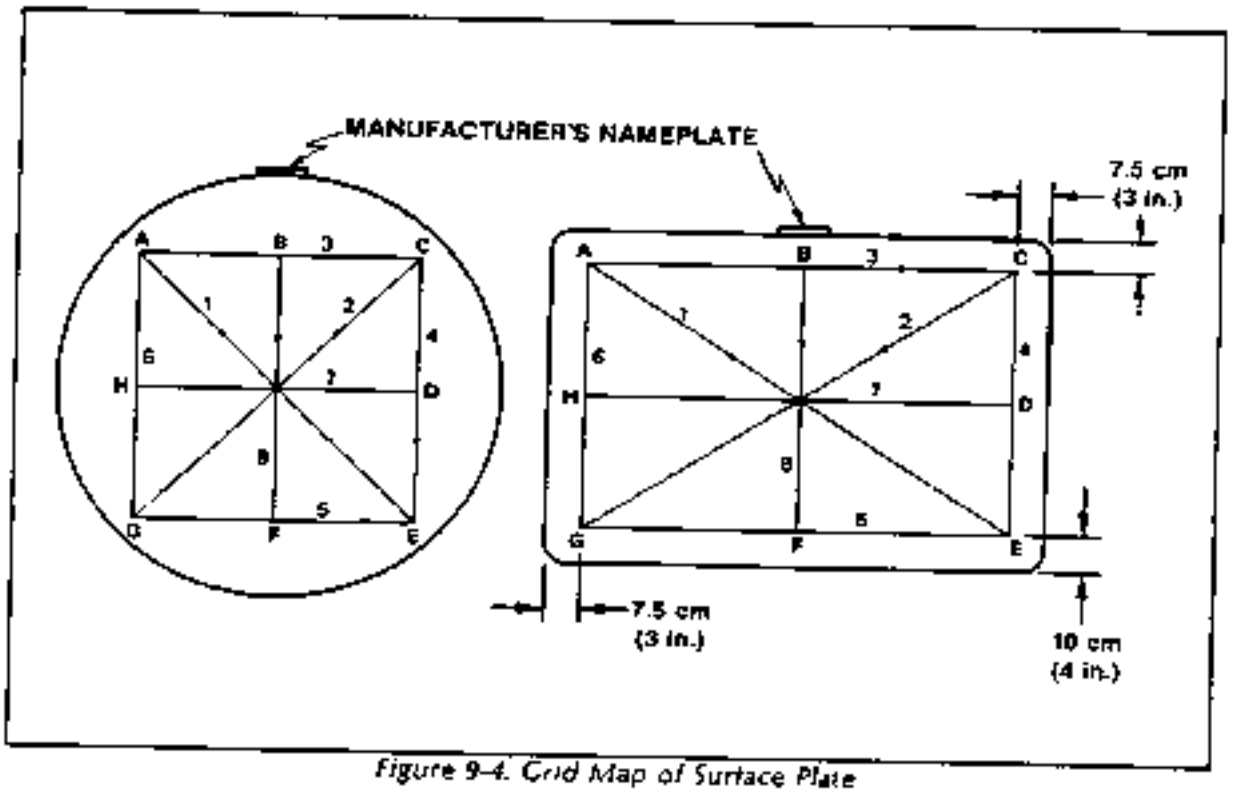


Figure 9-4. Grid Map of Surface Plate

4. Align the Laser Head, using the "Autoreflection" method, parallel to the surface plate and to perimeter line "GE", 7.5 cm (3 inches) outside the grid. (This is 2.5 cm (1 inch) in from the edge of the Surface Plate, as shown in *Figure 9-5*.)

   a. Place one of the Flatness Mirrors so the long edge of its base is flush with the edge of the Surface Plate and parallel to line "GE".

   b. Turn the Flatness Mirror until the mirror is perpendicular to the edge of the surface plate, and faces the Laser Head.

   c. Visually align the Laser Head so its beam hits the mirror.

   d. Turn to Section 15 in this User's Guide, and follow the instructions for "Autoreflection", starting at step "4".

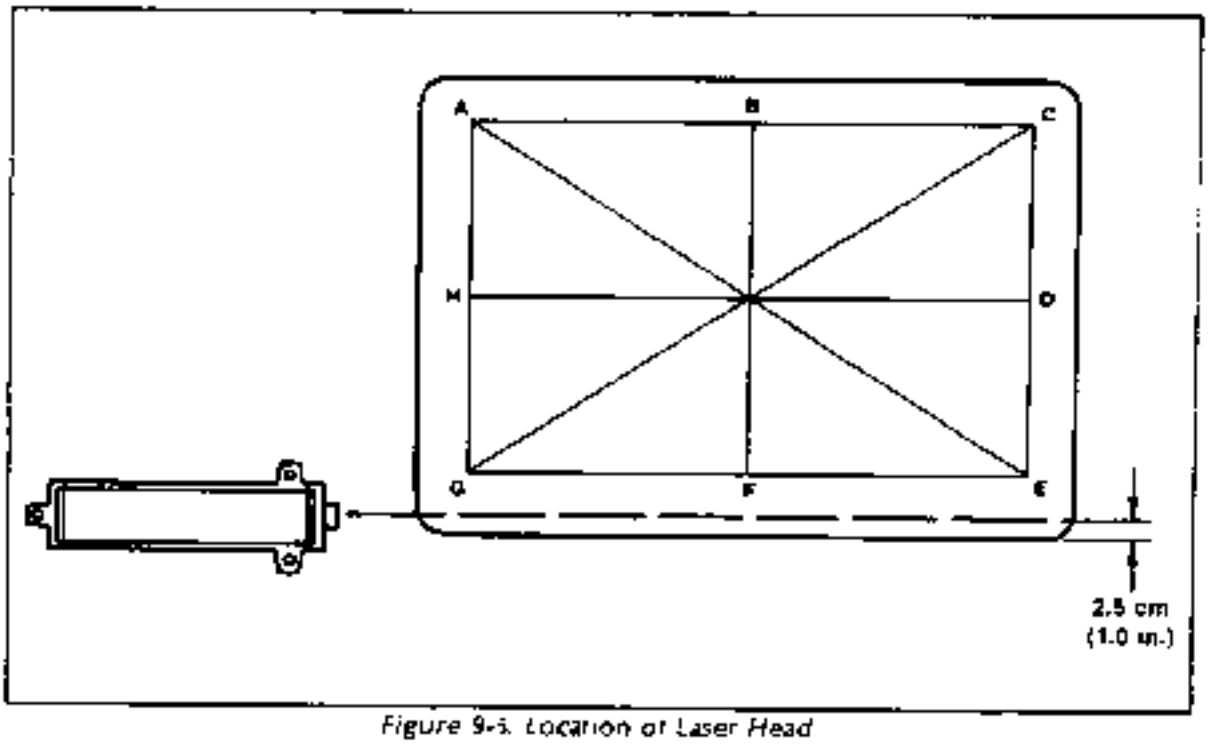


Figure 9-5. Location of Laser Head

5 Place the Flatness Mirror **without** the Angular Interferometer in corner "C" in the Laser beam's path, so its base is parallel to edge "CE" and flush with the corner of the Surface Plate. (See *Figure* 9-6.)

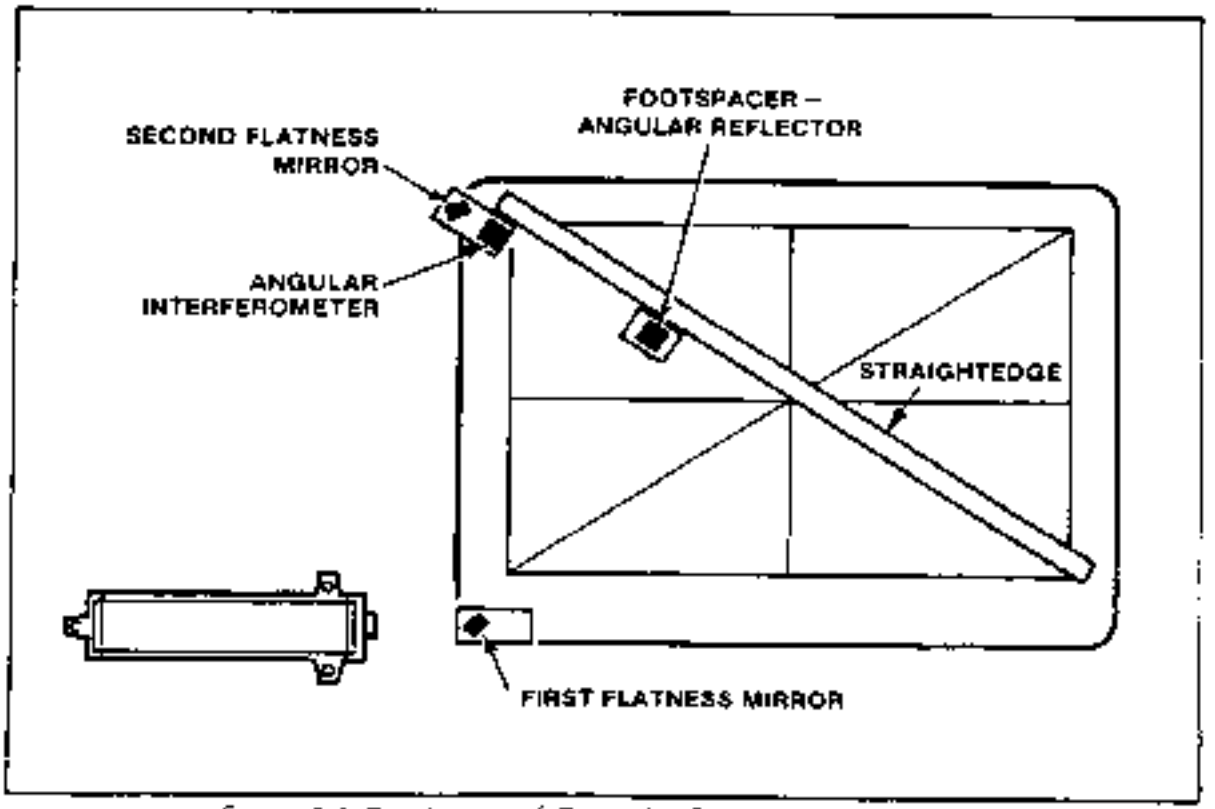


Figure 9-6 Positioning of Optics for First Measurement Line

6. At corner "A", position the Flatness Mirror with the Angular Interferometer so that the Angular Interferometer's two openings are pointed along the diagonal "AE". (See *Figure 9-6.*)

   Make sure the edge of the Flatness Mirror's base is at the edge of the grid, and does not protrude into it.

   Turn the Flatness Mirror so its "HP" label is facing the Flatness Mirror in corner "G". This will help you align the Optics later.

7. Secure a Straightedge along the diagonal, so that —

   - it is flush with the long side of the Flatness Mirror in corner "A", and —
   - it is directed along the path you want to measure.

   Mark increments on the Straightedge corresponding to the length of the Footspacer you have chosen to use.

8. Position the Angular Reflector with its Footspacer along the Straightedge in such a way that the two Retroflectors face toward the Angular Interferometer. Locate the Angular Reflector so it is touching the base of corner "A"'s Flatness Mirror and is flush with the Straightedge.

9. Move the small aperture into place on the Laser Head's exit port. Move the target into place over the Laser Head's return port.

10. Adjust the Laser Head so its beam hits the Flatness Mirror in corner "G". (See *Figure 9-6.*) It may be helpful to turn the mirror 180 degrees, and aim for a spot just above the "HP" logo.

11. Turn the Flatness Mirror in corner "G" until the Laser beam is in the vertical plane passing through corner "A"'s Flatness Mirror. (The beam itself doesn't have to hit the corner "A" Flatness Mirror, it just has to be vertically in line with it.) Again, turn corner "A"'s mirror 180 degrees, and aim for a spot just above the "HP" logo.

    You may need to hold a piece of paper in the beam's path to see where the beam is.

12. Tilt the Laser Head vertically up or down until the Laser beam is centered just above the "HP" logo of corner "A"'s Flatness Mirror. Do this by adjusting the knob at the rear of the Laser Head (see *Figure 4-4* for Laser Head/Tripod adjustments).

    If this tilting causes the Laser beam to move off of corner "G"'s Flatness Mirror, translate the Laser Head vertically until the beam is again centered on the mirror. (See *Figure 4-4* for an illustration of translation.)

13. If, after step "12", the Laser beam in corner "A" is at the correct height, but not centered above the Flatness Mirror's "HP" label, turn corner "G"'s Flatness Mirror slightly. You should now have alignment between the mirrors.

14. Attach the alignment target to the Angular Interferometer. (See *Figure 8-7.*)

    The target should be attached to the Interferometer opening that is directed toward the Flatness Mirror, and in such a way that the small (3 mm) hole is above the crosshair.

    Make sure the target is positioned as squarely as possible relative to the edges of the Optic. Use your fingers to match edges.

15. Turn corner "A"'s Flatness Mirror around, so the Laser beam is in line vertically with the small hole in the Angular Interferometer's target.

16. If the Laser beam is too high or too low to go through the target hole, **translate** the Laser Head vertically. The beam should now pass through the hole.

17. Remove the target from the Interferometer.

18. Make sure the Angular Reflector's Foorspacer is square relative to the Straightedge and to the Interferometer's Flatness Mirror. Look at the Laser Head and turn corner "A"s Flatness Mirror until the return beams are in line with the target at the Laser Head's bottom port. Then turn the Laser Head up or down to get the beams to overlap on the target. This establishes the "near end of travel".

19. Attach the targets to the Interferometer and the Reflector, so that —

    - the hole in the Interferometer's target is centered on the beam, and —
    - the crosshairs on the Reflector's target are centered on the beam. (See *Figure 8-8*.

    This time you don't have to line up the edges of the targets with the edges of the Optics. (In fact, you may not be able to do so and still meet the conditions above.)

20. You are now ready to align the Laser to the Optic's travel path.

    Turn to Section 15 of this User's Guide and follow the instructions there for "Gunsight" alignment, keeping in mind the following —

    > Too much turning of the Laser Head may cause the laser beam to move off either of the Flatness Mirrors. If this happens, start over at step "10" from your new Laser Head position.

21. You have now aligned your Laser Measurement System along one pathway of your grid. Repeat this process along each leg or diagonal of your measurement grid, when it is time to measure it.

Checking Alignment for Beam Strength

1. Select the largest opening for the Laser Head's exit and return ports.

   Remove the targets from the Optics.

2. Move the Optics over their full travel length while watching the BEAM STRENGTH meter.

   The Laser beam is strong enough for making a measurement as long as the BEAM STRENGTH needle stays in the green area of the meter.

   If the BEAM STRENGTH meter's needle moves into the red area —

   a. Move the Optics to the near end of travel.

   b. Select the small aperture for the Laser Head's exit port, and the target for the return port.

   c. Translate the Laser Head vertically or turn corner "A"'s Flatness Mirror to cause the return beams to overlap on the Laser Head's return port target.

d. Switch back to the large exit port aperture and the fully open return port.

e. Check again for BEAM STRENGTH.

If alignment is still not good enough to make BEAM STRENGTH read in its green area, repeat the entire Alignment procedure.

MEASUREMENT DISPLAY SETTINGS

Measurement Units

The displayed units for your Flatness measurements will be identical to those for an Angular measurement. Review "MEASUREMENT UNITS" information in Section 8 of this User's Guide.

Measurement Mode Keys



Push the ANGLE key.

Set-Up Keys

NOTES

1. To enter a value for any key —

   a. Use the ENTRY keys to specify the numeric value, then —
   b. Press the key to assign the value to that key.

2. To check the current status of any of these keys, just press the key. Then press the key again, to return to the mode you selected earlier.

3. More information about each key is available in Section 16 of this User's Guide.



Set this key to be "1.0" by pressing —







Resolution should be extended to 0.1 arcsecond for this measurement. To do this, press —







This is an important set-up key because the Calculator program must know which tilt is "positive" and which is "negative".

Once the Optics are aligned, tilt the Reflector and its Footspacer so its back foot is higher than its front foot. The Measurement Display unit's reading should be positive; if it isn't, press the DIR SENSE key.

MAKING A MEASUREMENT

System Checks

1. Make sure both Laser Head ports are switched to their large apertures.
2. The Laser Head turret must be set to "Other".
3. The Laser Head's READY indicator must be lighted steadily (i.e., not blinking).
4. Make sure your laser Measurement System is properly connected to the HP Dimensional Metrology Analysis System.

   Make sure the Measurement Display is set up to accept a controller via HP-IB. Follow the instructions for "Data Transfer with an HP-IB Controller", in Section 18 of this User's Guide.

Procedure

NOTE

The HP Dimensional Metrology Analysis System expects the lines to be patterned exactly like those in *Figure 9-4*, the arrows indicating the direction of travel of the Angular Reflector. However, the order of the lines does not matter. See *Figure 9-7* for a suggested routine of the measurement, but ignore the direction arrows for each line.

1. For each line —
   a. Tell The Metrology program the location of the Angular Reflector and Angular Interferometer according to the direction of travel shown in *Figure 9-4*.
   b. Position the Footspacer at the appropriate end of the line being measured
   c. Press **RESET** on the Measurement Display unit or on the Remote Control unit
   d. Move the Footspacer a distance equal to its footspacing. (These increments should be marked on the Straightedge.)
   e. Press the Remote Control Unit's RECORD button. One measurement is made each time you press this button.
   f. Continue moving the Footspacer in increments equal to its footspacing, pressing the RECORD button after each move.
2. Refer to *Figures 9-4* and *9-7* for appropriate Optics positions for the remaining lines being measured, keeping in mind that *Figure 9-7* is for reference only.

   Refer to *Figure 9-7* to see where you can position the Optics to measure each line of your grid.

   Keep in mind that *Figure 9-7* is not the only way to make these measurements. You can set up in any arrangement that is easiest for your particular application.

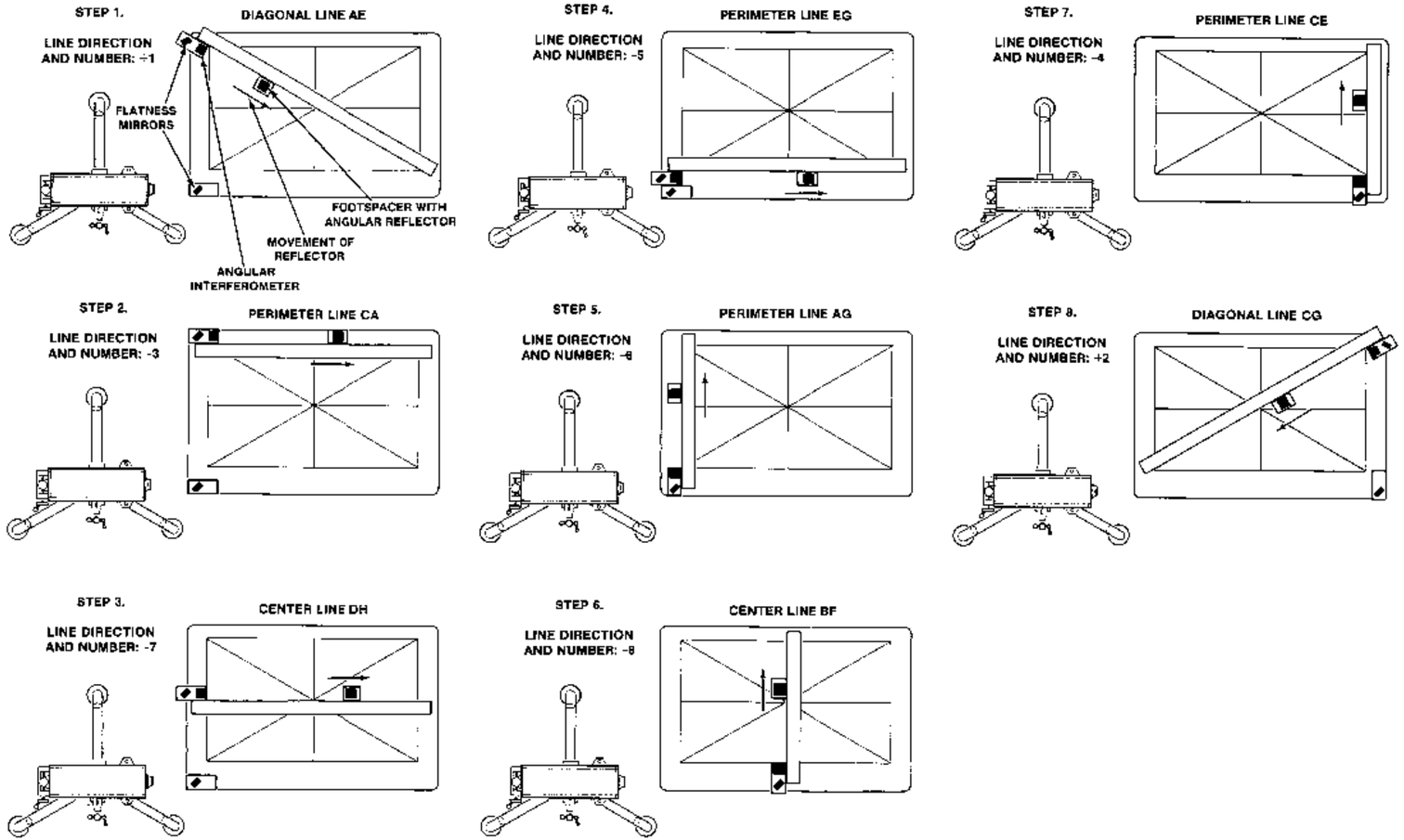


Figure 9-7. Suggested Routine For Positioning Optics

WHAT AFFECTS ACCURACY?

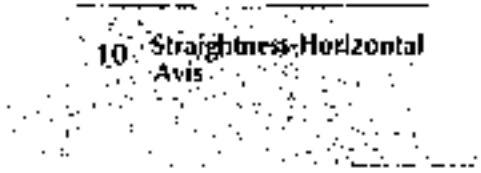
Refer to Section 6, ANGULAR MEASUREMENTS, for a description of potential errors and how to reduce or cancel errors. When using the Angular Optics

A tumble up or down of dirt on the measuring surface can cause error in your flatness measurement. Be sure to clean the measurement surface thoroughly.

If you move a Surface Plate or calibrator, be sure you allow it temperature to stabilize before you measure its flatness.

Figure 9-7
SUGGESTED ROUTINE FOR POSITIONING OPTICS

>> Page 9-11


10 Straightness-Horizontal
Axis

SECTION 10
STRAIGHTNESS MEASUREMENTS (ALONG A HORIZONTAL AXIS)

CONTENTS

INTRODUCTION
OPERATING SPECIFICATIONS
HARDWARE REQUIRED
RELATED MEASUREMENTS
REFERENCE MATERIAL
INSTALLATION AND ALIGNMENT OF OPTICS
MEASUREMENT DISPLAY SETTINGS
MAKING A MEASUREMENT
WHAT AFFECTS ACCURACY?

INTRODUCTION

A "Straightness" measurement is the measurement of perpendicular motion along a travel path. This perpendicular motion can either be horizontally or vertically oriented. See Appendix A for a description of the principles on which this measurement is based.

OPERATING SPECIFICATIONS

The following specifications assume that the optional Dimensional Metrology Analysis System is used in conjunction with the HP 5528A to provide averaging and calculation capabilities for Straightness, Parallelism and Squareness measurements and that the Optical Square is aligned within 5 arc-min using autoreflection techniques.

Accuracy: Overall accuracy is the sum of the two components below.[1]

Overall Accuracy = Optical Reference Accuracy + Measurement Accuracy

Optical Reference Accuracy[2]

Short Range Optics[3]
Metric Units Mode: 0.15 M^2 microns TIR
English Units Mode: 0.5 F^2 microinches TIR
Long Range Optics:
Metric Units Mode: 0.015 M^2 microns TIR
English Units Mode: 0.05 F^2 microinches TIR
where:
TIR = Total Indicated Reading
M = distance of travel of the moving optic in metres
F = distance of travel of the moving optic in feet

Measurement Accuracy:

Short Range Optics:

Temperature Range	Displayed Value	
	0-10 microns (0-400 microinches)	10-1500 microns (400-60000 microinches)
15-25° C	±3.5%	±1% ±0.25 microns (10 microinches)
0-40° C	±6%	±1% ±0.5 microns (20 microinches)

Long Range Optics:

Temperature Range	Displayed Value	
	0-100 microns (0-4000 microinches)	100-1500 microns (4000-60000 microinches)
15-25° C	±5%	±2.5% ±2.5 microns (100 microinches)
0-40° C	±7.5%	±2.5% ±5 microns (200 microinches)

[1]This is analogous to the traditional straightedge and indicator method of measuring straightness, where Optical Reference Accuracy corresponds to the straightedge accuracy, and Measurement Accuracy corresponds to the indicator accuracy.

[2]Optical reference error can be eliminated by using straightedge (mirror) reversal techniques.

RESOLUTION:

Short-Range:
Metric Units Mode: 0.01 micron (0.00001 mm)
English Units Mode: 1 microinch

Long-Range:
Metric Units Mode: 0.1 micron (0.0001 mm)
English Units Mode: 10 microinches

STRAIGHTNESS DEVIATION RANGE:

±1.5 mm (0.060 inch)

AXIAL SEPARATION RANGE (Typical, with proper alignment, 15-25°C):

Distance of travel between the Interferometer and Reflector. Interferometer located within 5 metres (16.5 feet) of Laser Head.

Short-Range: 0.1-3 metres (4-120 inches)

Long-Range Optics: 1-30 metres (3-100 feet)

HARDWARE REQUIRED

In addition to the hardware required for any measurement using the Laser Measurement System (see *Figure 4-1*), any Straightness measurement along a Horizontal axis requires the hardware shown in *Figure 10-1*.

RELATED MEASUREMENTS

Straightness Measurements (Using the Straightness Retroreflector ..... Section 11

Squareness Measurements (In a Horizontal Plane) ..... Section 12

Squareness Measurements (In a Vertical Plane) ..... Section 13

Parallelism Measurements ..... Section 14

REFERENCE MATERIAL

Physical Setup of the Laser Head and Tripod ..... Section 4

Interconnections, Turn-on ..... Section 5

Alignment Techniques ..... Section 15

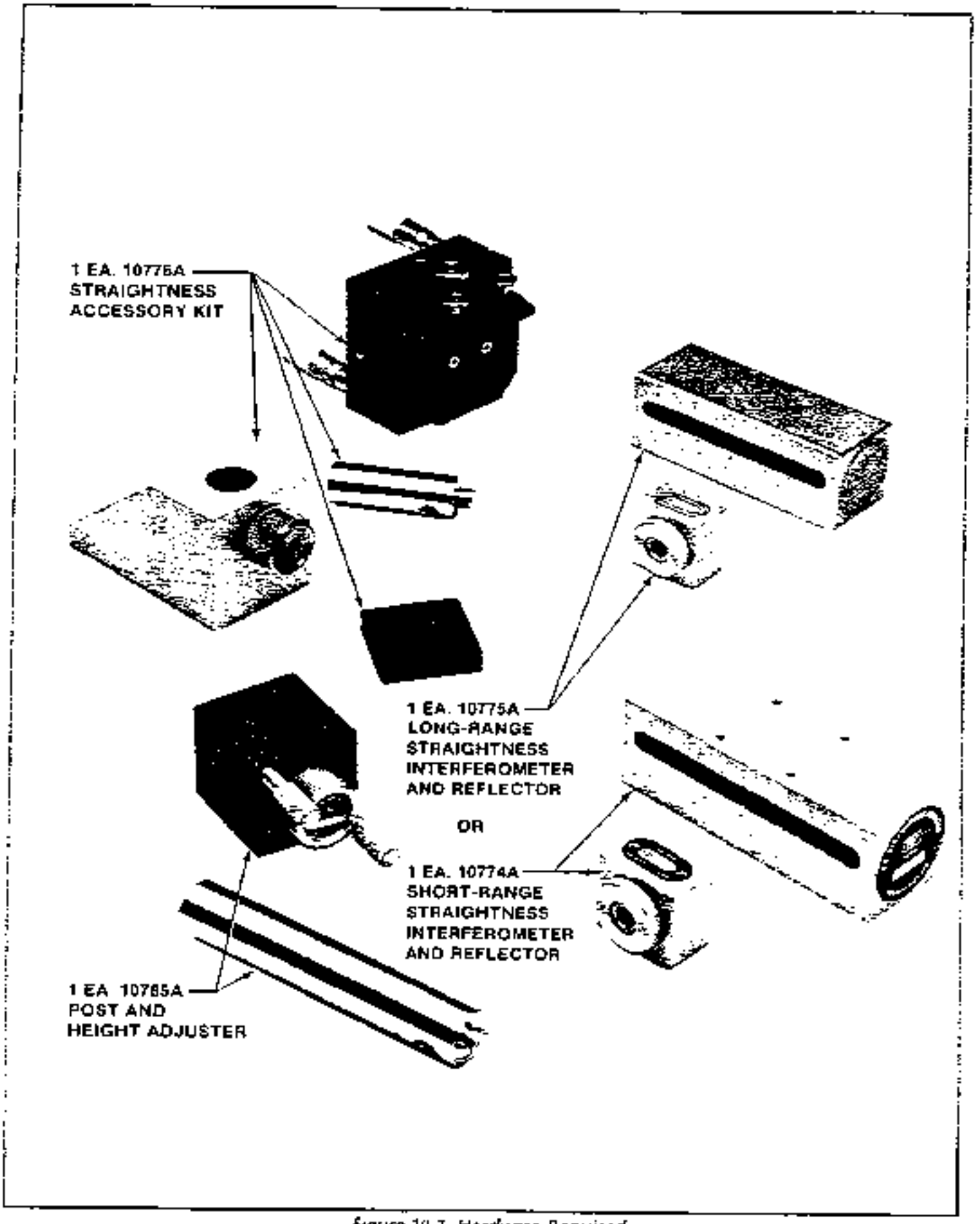


Figure 10-1. Hardware Required

INSTALLATION AND ALIGNMENT OF OPTICS

Important Considerations

1. The Straightness Interferometer must be located between the Laser Head and the Straightness Reflector in the Laser beam.

2. The Interferometer must be mounted where the tool mounts.

   The Reflector must be mounted where the workpiece mounts.

   (On some machines it isn't possible to satisfy both "1" and "2". In these cases, you will need a Straightness **Retro**reflector. (See Section 11.)

3. Vibrations and loose connections must be minimized by proper mounting. Avoid long extensions. Make sure that all supports are completely stationary. A spindle, for example, must be secured by a brake so it won't rotate. (If a brake isn't available, try using a hose clamp or a wedge.)

4. The Laser beam must be returned to the top port on the Laser Head's turret, **not** to the bottom ("return") port.

5. The Optics must be aligned to the Laser beam well enough to keep the Beam Strength indicator in the green region along the entire optics' path.

6. The Optics must be aligned to the Laser beam well enough to eliminate "slope" if the HP Dimensional Metrology Analysis System isn't used.

7. If either Distance or Angular Optics have previously been installed, the Straightness Optics can be installed by making only minor changes to the mounting hardware.

8. The Laser Head's turret ring should be set to "OTHER" during installation, to take advantage of the strongest possible beam, which this setting provides.

Description

1. You will position the Laser Head along the axis you want to measure.

2. You will position the Interferometer in the laser beam.

3. You will position the Reflector in the laser beam and close to the Interferometer.

4. You will align the Laser Head to track the Optic's progression along the travel path. You will do this by —

   - Reviewing the "GUNSIGHT" alignment method in Section 15 of this User's Guide.
   - Keeping the beam within the hole on the Interferometer target, to maintain the beam's near-end-of travel position, and —
   - Keeping a two-dot pattern in line with the junction of the Straightness Reflector's mirrors, and symmetrical about its slotted opening, to match the Optic's travel.

5. Finally, you will check your alignment to insure that "Important Considerations" number "5" and number "6" have been met.

NOTE

Use of the Gunsight Alignment method is described in the following procedure. Once you become familiar enough with alignment principles, you may want to start with "Autoreflection" (described in Section 15).

Procedure

1. Move the machine's table (if it moves) **as close as possible** to the Laser Head.

   Move the machine's spindle (if it moves) **as far as possible** away from the Laser Head

   Note that the "moveable" part of the machine may depend on the axis you are measuring. That is, the "X"-axis moveable part may not necessarily also be the "Y"-axis or "Z"-axis moveable part

   This will keep the machine from hitting the Laser Head during a measurement and will help establish the "near-end-of-travel".

2. Visually align the Laser Head as well as you can parallel to the direction of travel and position it at an appropriate height. Some things to consider are —

   - Position for an axis appropriate for what you want to accomplish (review Section 4's material on this)

   - If you think you will be making a Distance or Angular measurement later, establish a measurement axis at a height above the table that will allow easy interchanging of the Optics. To do this, mount the Straightness Reflector as shown in *Figure 10-4*, and keep the Reflector as low as possible on its Base, without covering up the hole in the Reflector Mount's Post. Then position the Laser Head so its beam strikes the center of the slot.

   - Use "Autoreflection" to help you do this once you become proficient at Laser System measurements. If you use "Autoreflection" you won't have to do any further alignment, you'll only need to check for beam strength (and remove slope, if you don't use the HP Dimensional Metrology Analysis System).

3. Decide where you will position the Optics so that:

   - The Interferometer is between the Reflector and the Laser Head. (Also see "OTHER MOUNTING REQUIREMENTS", below.)

   - **The Interferometer is where the tool mounts.**

   - **The Reflector is where the workpiece mounts.**

   - The Optics are at the "near end of travel". (This means that any subsequent motion of the machine will separate the optics further rather than bring them closer together.) (See *Figure 10-2.*)

     For Short range measurements this should be about 100 mm (4 inches).

     For Long range measurements this should be about 900 mm (3 feet).

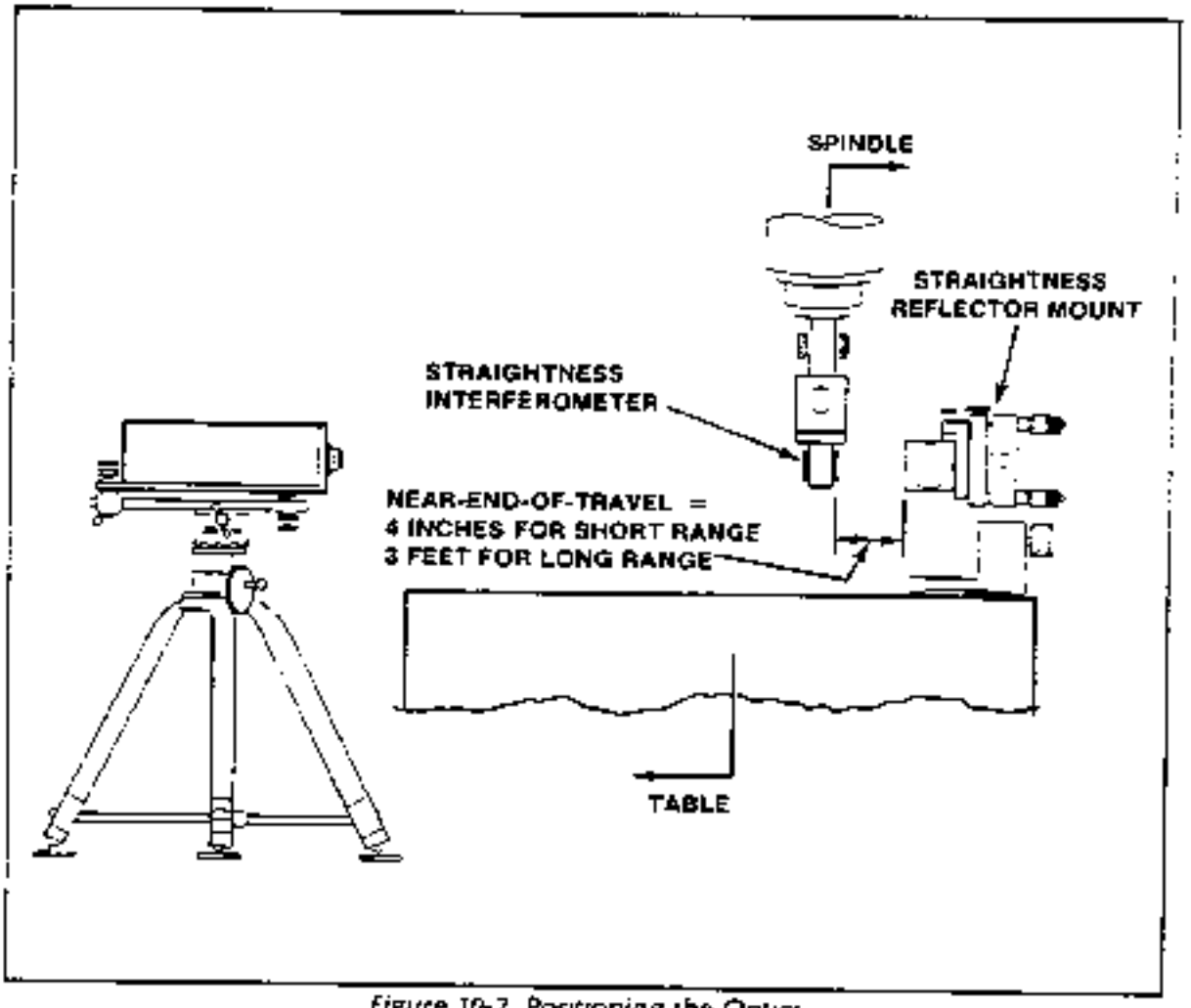


Figure 10-2. Positioning the Optics

4. Attach the Straightness Interferometer and the Straightness Reflector to their mounting hardware to accomodate the positions you chose in step "3". (See *Figure 10-3* and *Figure 10-4*).

   a. Mount the Interferometer in the spindle, by either —

      - attaching the Height Adjuster to a Post as you would for table mounting, or —
      - screwing its base directly into the post, or —
      - screwing the Post into the Height Adjuster after removing the large knurled knob. This latter arrangement may make it easier to change to Distance and Angular Optics

   b. Orient the Straightness Reflector horizontally or vertically to match the type of measurement you would like to make (horizontal or vertical straightness).

5. Select the small opening for the Laser Head's exit port, and set the turret ring to "OTHER". (When aligning your setup, it is good practice to work with the strongest possible beam, which this setting provides.)

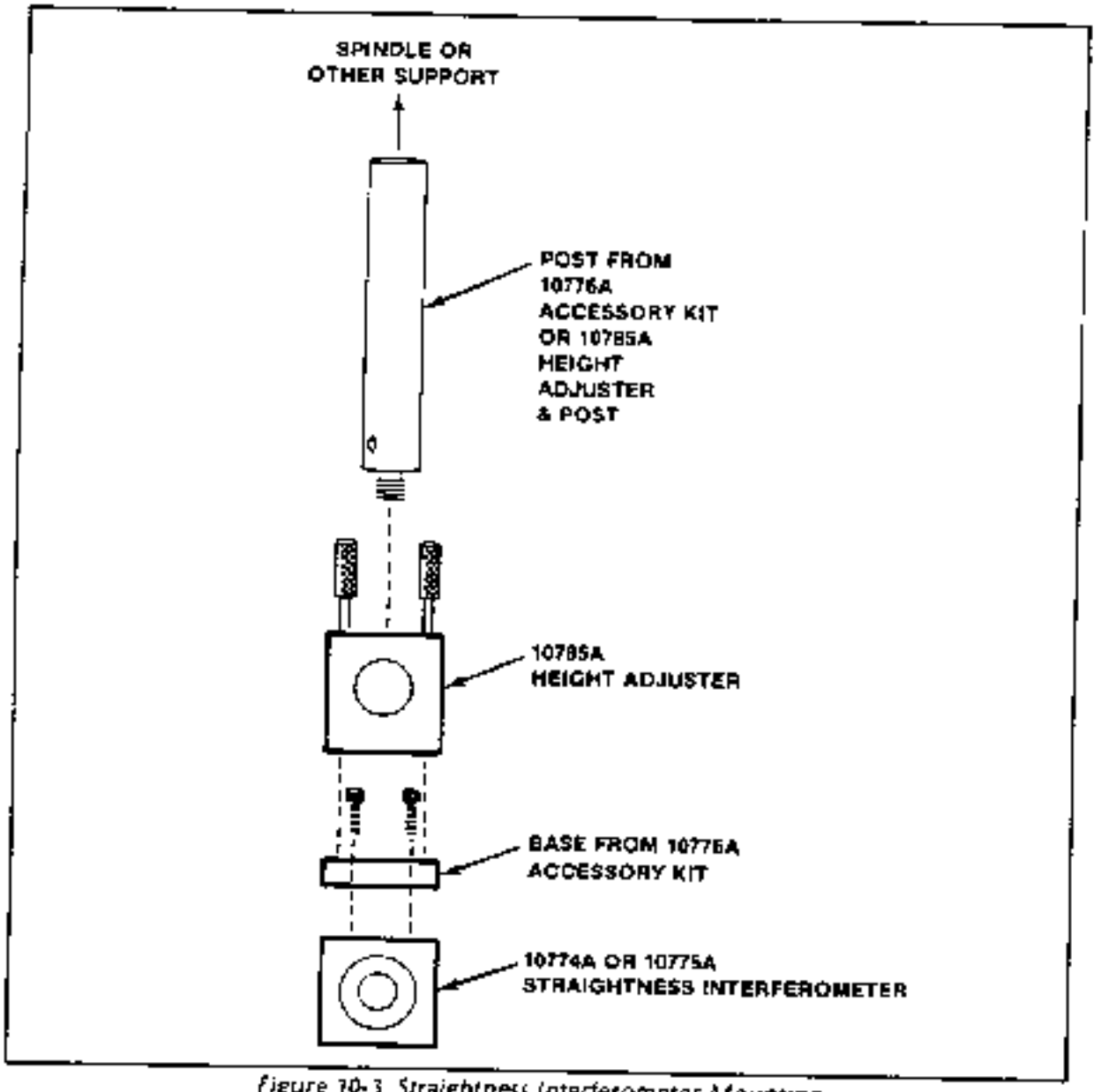


Figure 10-3 Straightness Interferometer Mounting

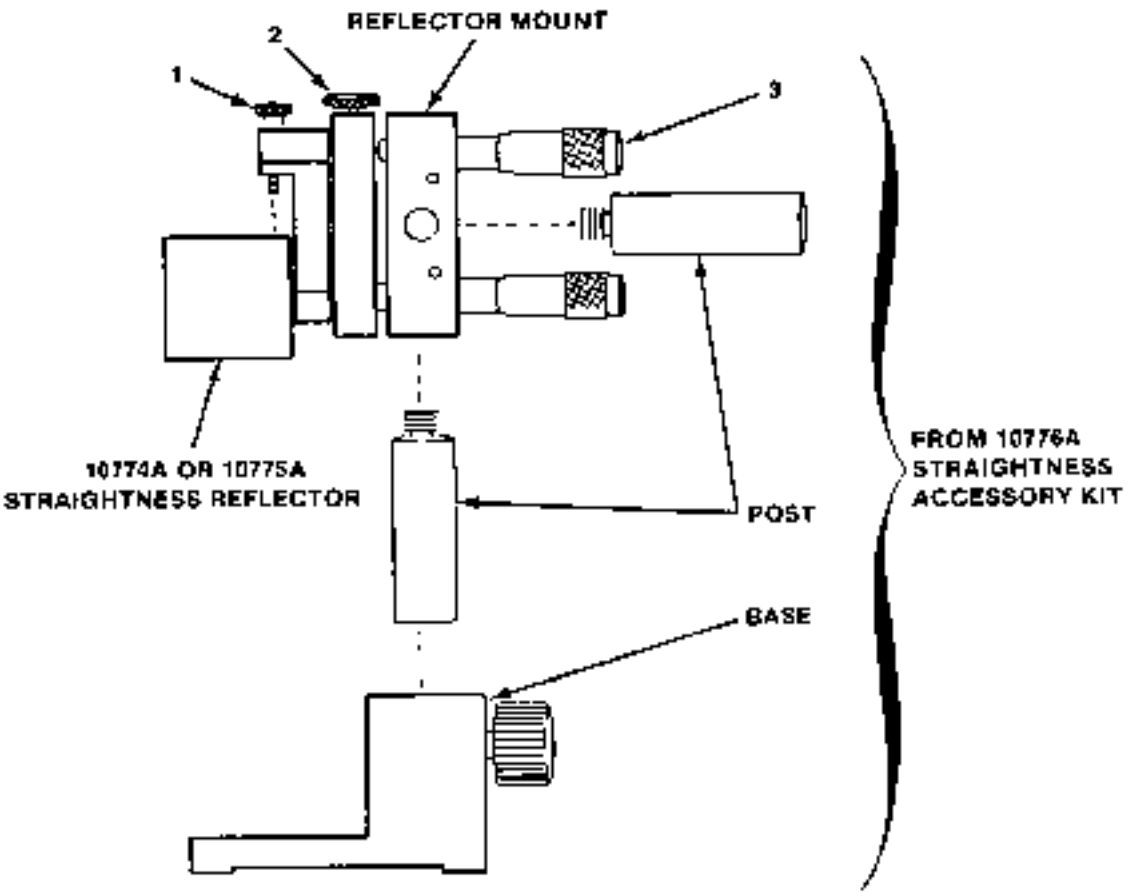
6. Attach the target to the Straightness Interferometer. This target is included with the Optics.

   The target should be attached to the Straightness Interferometer opening that is directed toward the Laser Head.

   Make sure the target is positioned as closely as possible relative to the edges of the Optic. Use your fingers to match edges.

7. Adjust the Straightness Interferometer (or translate the Laser Head) so the Laser Beam goes through the target's hole.

   Secure the Interferometer to the machine in such a way that the Interferometer is as square as possible relative to the incoming beam. The Interferometer housing's pitch limitations are ±2 degrees; its yaw and roll limitations are ±5 degrees. The pitch requirement will be taken care of automatically by using the mounting hardware listed above.



Assemble the Straightness Reflector and its mounting hardware, using the procedure below.

a. Attach the Straightness Reflector to the adjustable mount, using the screws identified by "1".

   Make sure the slot is closest to the screws identified by "1". (This will allow 180-degree rotation of the mirror without moving the mounting hardware.)

b. Screw the Accessory Kit's Post into any side or the rear of the Adjustable Mount, as required for positioning.

c. Slide the Post into the Base and secure with the large knurled knob.

   Adjustment "2" allows 360-degree rotation of the reflector.

   Adjustment "3" rotates the reflector over very small angles to help in final alignment.

Figure 10-4. Straightness Reflector Mounting

8. Remove the target from the Interferometer.

9. Select the large aperture for the Laser Head's exit port.

10. Rotate the Interferometer's bezel until the bezel's scribe line is oriented 90 degrees to the slotted opening in the Straightness Reflector. (See *Figure 10-5.*) Two beams should now come out of the Interferometer, in a plane perpendicular to the slotted opening in the Reflector.

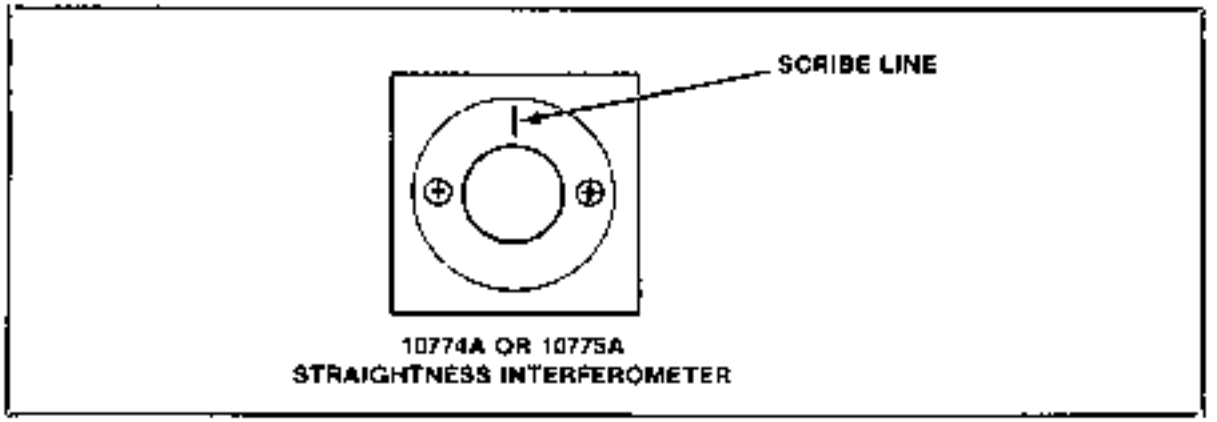


Figure 10-5. Interferometer Bezel — Scribe Line

11. Position the Reflector within **100** mm (4 inches) for Short Range measurements or **900** mm (36 inches) for Long Range measurements of the Interferometer.

    Position the Reflector so that the two dots resulting from step "10" are oriented along the junction of the Straightness Reflector's mirrors and are symmetrical about the mirrors' slotted opening. (See *Figure 10-6.*)

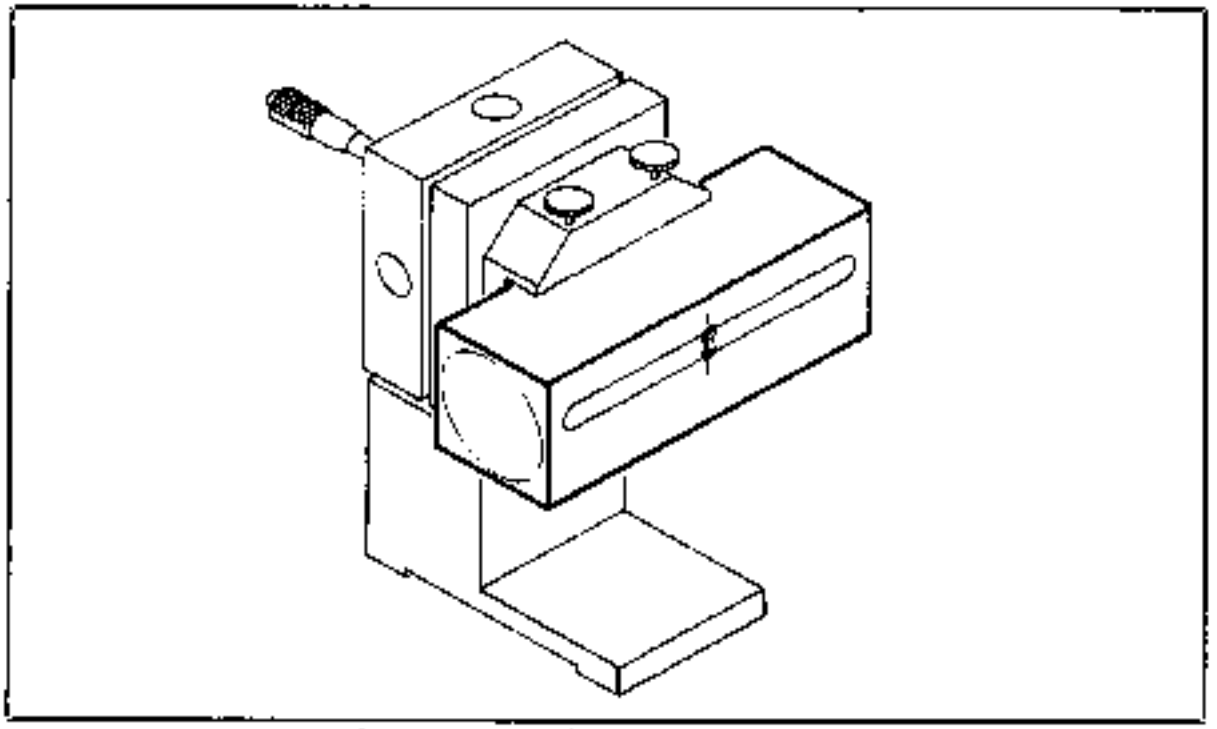


Figure 10-6. Initial Positioning of Reflector

12. Select the small aperture for the Laser Head's exit port and repeat step "11".

13. Secure the Reflector assembly so it is square relative to the incoming laser beam within ±5 degrees.

14. Reattach the target to the Interferometer so the hole in the Interferometer's target is centered around the beam.

15. You are now ready to align the Laser to the machine's travel.

    Review the "GUNSIGHT" method of alignment in Section 15 of this User's Guide.

    Your goal is to adjust the Laser Head to track the Optic's progression along the travel path, while maintaining the beam's near-end-of-travel position. You will do this by —

    - keeping the beam in the small hole on the Interferometer target, to maintain the beam's near-end-of travel position, and —

    - keeping a two-dot pattern in line with the junction of the Reflector's mirrors, and symmetrical about its slotted opening, to match the Optic's travel.

    This will be a little different than aligning for Distance and Angular measurements, since with these alignments you were only watching one dot relative to a target crosshair.

16. Move the Optics to the far end of travel.

17. **Rotate** the Laser Head, vertically and horizontally, to keep the two dots lined up on the junction of the Reflector's mirrors, and symmetrical about its slotted opening. (See *Figure 10-7.*)

    Since the dots will move apart as the Optics move, you may have to hold a card on each side of the Reflector's slot to follow their movement.

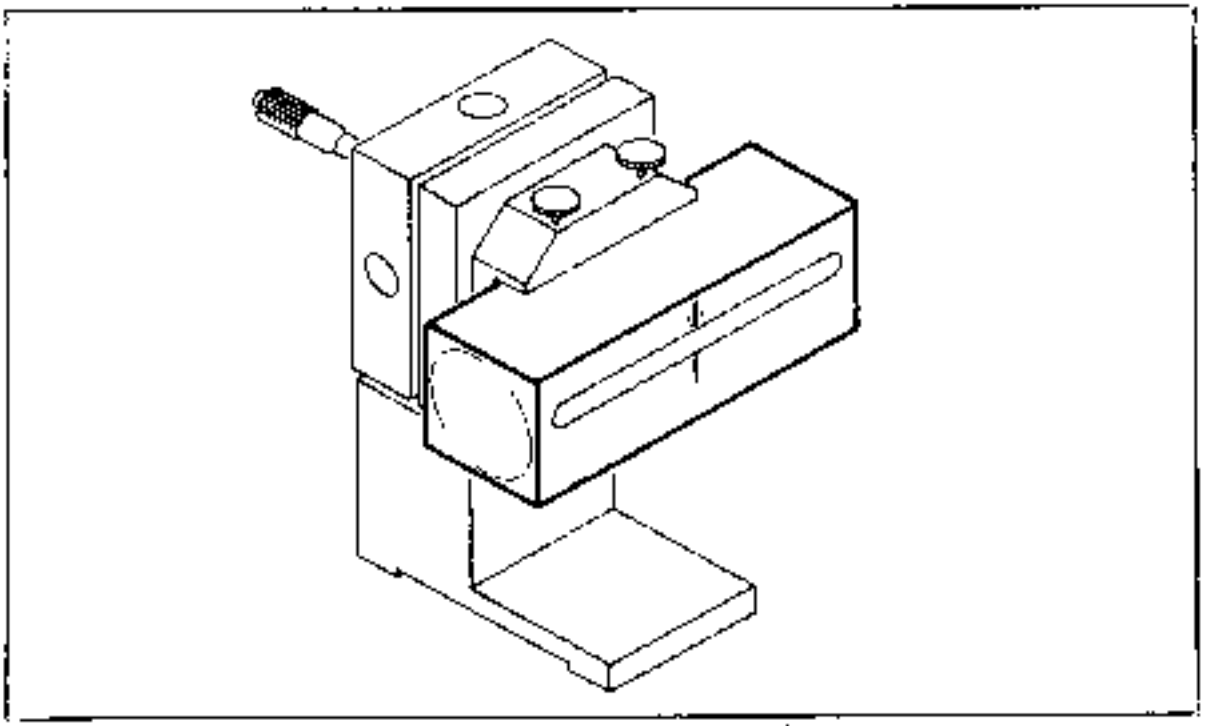


Figure 10-7 Two Dots on the Reflector

18. **Translate** the Laser Head, horizontally and vertically, to keep the beam from being clipped by the small hole in the Interferometer target.

    Any translation of the Laser Head will cause the two dots to move from their position on the Reflector, so you will have to again rotate and translate the Laser Head (i.e., repeat step "17" and step "18") several times before you are finished.

    You are finished with this procedure when the beam goes through the Interferometer target and the two dots are symmetrical about the Reflector's slotted opening and in line with the junction of its mirrors. (See *Figure 10-7.*)

Final Adjustments (After Aligning)

1. Remove the Interferometer Target.

2. Turn the Laser Head's turret ring to "OTHER", if not already so.

3. Watch the front of the Laser Head as you turn the Interferometer's bezel to bring the scribed line parallel to the Straightness Reflector's slot.

    You should see two dots cross close to the Laser Head's exit port. If you can't see these dots —

    a. Cut a hole in the middle of a piece of paper.

    b. Hold this paper between the Interferometer and the Reflector, but closer to the Interferometer. You should see either one dot or two closely spaced dots on the piece of paper.

    c. Adjust the Reflector Mount's micrometers until the dot(s) disappear into the Interferometer.

    d. Remove the paper and look at the Laser Head. You should now see two dots on the front of the Laser Head.

    Turn the bezel until the dots overlap.

4. Adjust the Reflector Mount's micrometers until the overlapping dots are centered on the exit port, and "halo" the small aperture.

5. Set the Laser Head's turret ring to "STRAIGHT".

6. Select the Laser Head exit port's large aperture.

7. Turn the bezel slightly until the Laser Head's "SIGNAL" light comes on and the BEAM STRENGTH meter indication is in the green area.

    NOTE

    Only a slight adjustment of the bezel is necessary to do this.

8. Further adjust the Reflector Mount's micrometers until the BEAM STRENGTH meter indication is at a maximum.

Checking Alignment for Beam Strength

Move the machine over its full travel range, making sure that BEAM STRENGTH is adequate (in the green area) at all positions.

If beam strength decreases at any point, —

a. Check for clipping of the beam by the Optics. Reposition the Optics, if necessary, and then re-check.

b. If you see part of the return beam on the edge of the Exit (top) port, rotate the Laser Head until the return beam disappears.

If this didn't correct the "reduced beam strength" problem, refer to the "MANUAL REMOVAL OF SLOPE" information below.

NOTE

If the BEAM STRENGTH indication never reaches the right-hand half of the meter's range, at any point along the Optics' full travel distance, your Optics may need cleaning. Thoroughly clean all optical surfaces, as described in Section 20 of this User's Guide.

Checking for Mis-alignment Between the Reflector's Reference Bisector and the Optics Travel Path ("Slope")

1. Press the Measurement Display unit's "LONG" or "SHORT" STRAIGHTNESS key corresponding to the length of your measurement.

2. Press the RESET key.

3. Again, move the machine over its full travel range, this time checking the Measurement Display unit to see if there is a steady change in the number displayed, rather than either a random scattering of numbers or a constant number.

   A steady change of numbers indicates misalignment between the machine's travel axis and the Laser beam. This error is called "slope", and you must remove it — either manually or automatically (using a Calculator). See "WHAT AFFECTS ACCURACY?" information, below.

Manual Removal of Slope

Description

1. At the far end of travel (i.e., Optics are as far apart as possible), you will tilt the Straightness Reflector to change the displayed measurement value to a newly-calculated value "V_N".

   Tilting the Reflector in this way moves its reference bisector toward the Optic's travel path (see *Figure 10-8*).

2. At the near end of travel (i.e., Optics are close together), you will translate the Straightness Interferometer (or the Reflector) so the displayed value is "zero" at this point. (See *Figure 10-8*.)

   Moving the Interferometer in this way lines up the Reflector's reference bisector with the center of the Straightness Interferometer.

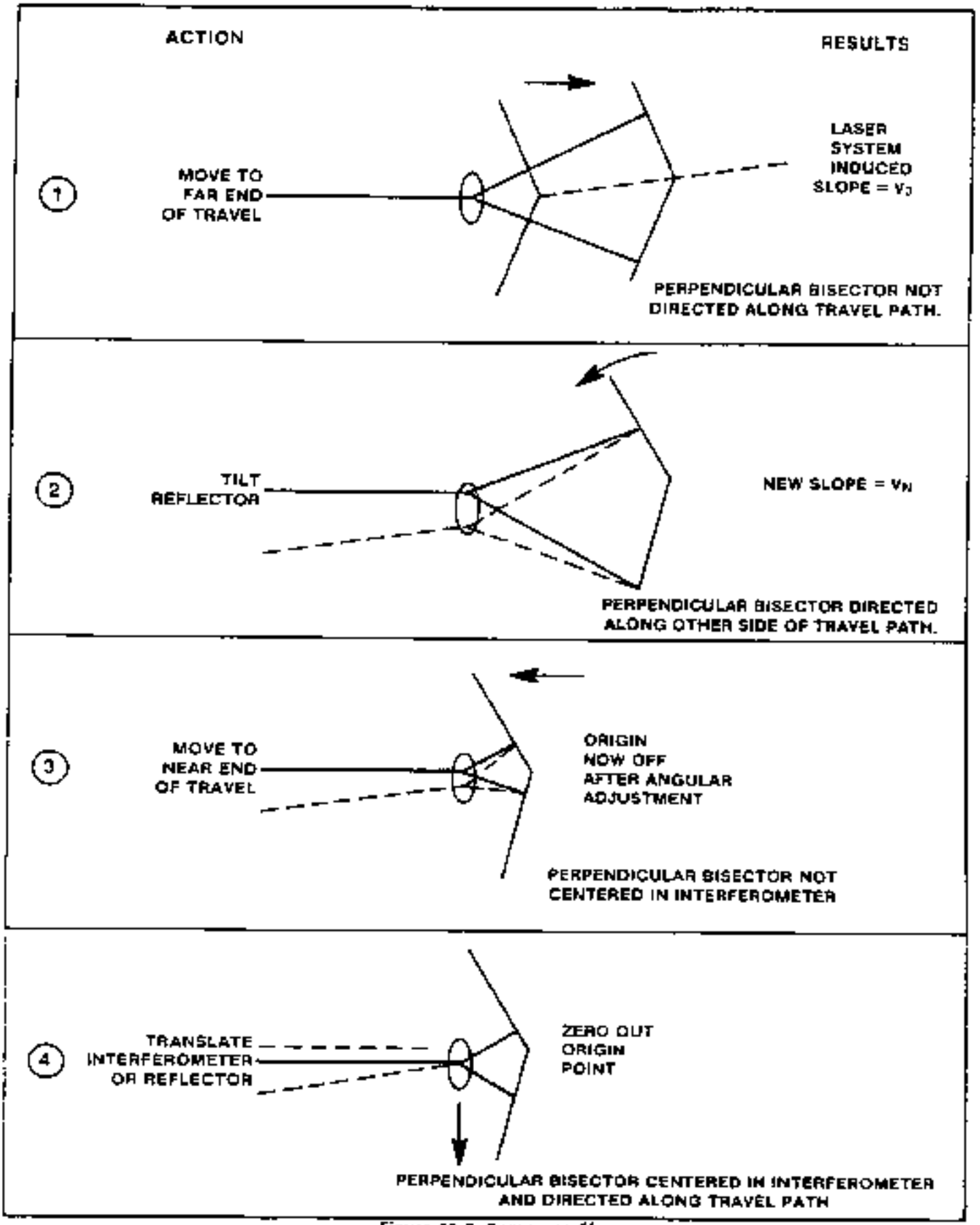


Figure 10-8 Removing Slope

3. No adjustment will be made to the Laser Head unless the adjustments described in step "1" and step "2" above cause the BEAM STRENGTH indicator to move into the "red" region. If this happens, you should rotate the Laser head until there is enough beam strength, while translating the Laser Head to keep the beam centered in the Interferometer.

   In making any adjustment to the Laser head, keep in mind that the Straightness Optics appear as a plane mirror relative to the Laser Head. That is why you should rotate the Laser Head to increase beam strength.

Procedure

1. Reset the Measurement Display with the Optics at the near end of travel.

2. Move the machine (and Optics) to the far end of travel and note the slope measurement on the Measurement Display.

3. Adjust the micrometer that controls motion in the plane of the Straightness Reflector's slot to cause the displayed number to change to the value calculated below —

$$V_N = \frac{-D_{NE}}{D_{FE}} \times V_O$$

where —

V_N = the New Value

D_{NE} = Distance between Optics at Near End position

D_{FE} = Distance traveled by moving Optic to Far End position

V_O = the Old Value ("slope")

For example, suppose the near-end spacing of the Optics ("NE") is 100 mm (4 inches), and the distance traveled by the moving Optic to the far-end spacing ("FE") is 600 mm (24 inches). Additionally, suppose that the measured slope at the far end is 0.0500 mm (0.00197 inch).
You should adjust the Reflector's tilt until the displayed value changes to —

$$-\frac{100\text{ mm}}{600\text{ mm}} \times 0.05\text{ mm} = -0.0083\text{ mm } (-0.00032\text{ inch})$$

If you start losing too much beam strength, and —

   a. If you see any part of the return beam striking the front of the Laser Head (around the exit port), rotate the Laser Head until the return beam disappears into the port.

   b. If you see any part of the Laser beam striking any part of the Interferometer (other than the glass), translate the Laser Head until the beam strikes only the glass.

      Remember that rotating or translating the Laser Head will not change the numbers in the display.

4. Reset the Measurement Display, and return the machine to the near end of travel.

5. At the near end of travel, move the Interferometer or the Reflector in a direction parallel with the slotted opening in the Reflector until the Measurement Display reads zero.

   If beam strength again gets too low, turn the Laser Head to regain adequate beam strength, and translate the Laser Head to prevent clipping of the beam by the Interferometer.

6. Repeat step "1" through step "5" as often as necessary to make measurements at both ends of travel come out to be "zero".

Measurements Along A Perpendicular Axis

Perpendicular straightness measurements made on other horizontal axes should be made from a second Laser Head set-up in line with the new axis.

Straightness measurements on vertical perpendicular axes are described in the next section.

Figure 10-9 and *Figure 10-10* show positioning of Straightness Optics on three different axes. Two Laser Head set-ups are needed.

Other Mounting Requirements

Although we have tried to provide you with a maximum of mounting flexibility, there may be situations when you need more capability. For more information, you should turn to Appendix C for dimensions of the Optics and the mounting hardware.

It may sometimes be impossible for you to position the Interferometer between the Laser Head and the Straightness Reflector while at the same time mounting the Interferometer where the tool mounts and the Reflector where the workpiece mounts. In these cases, you should use the Straightness Retroreflector (provided in the Straightness Accessory Kit) to make your measurement. (See Section 11.)

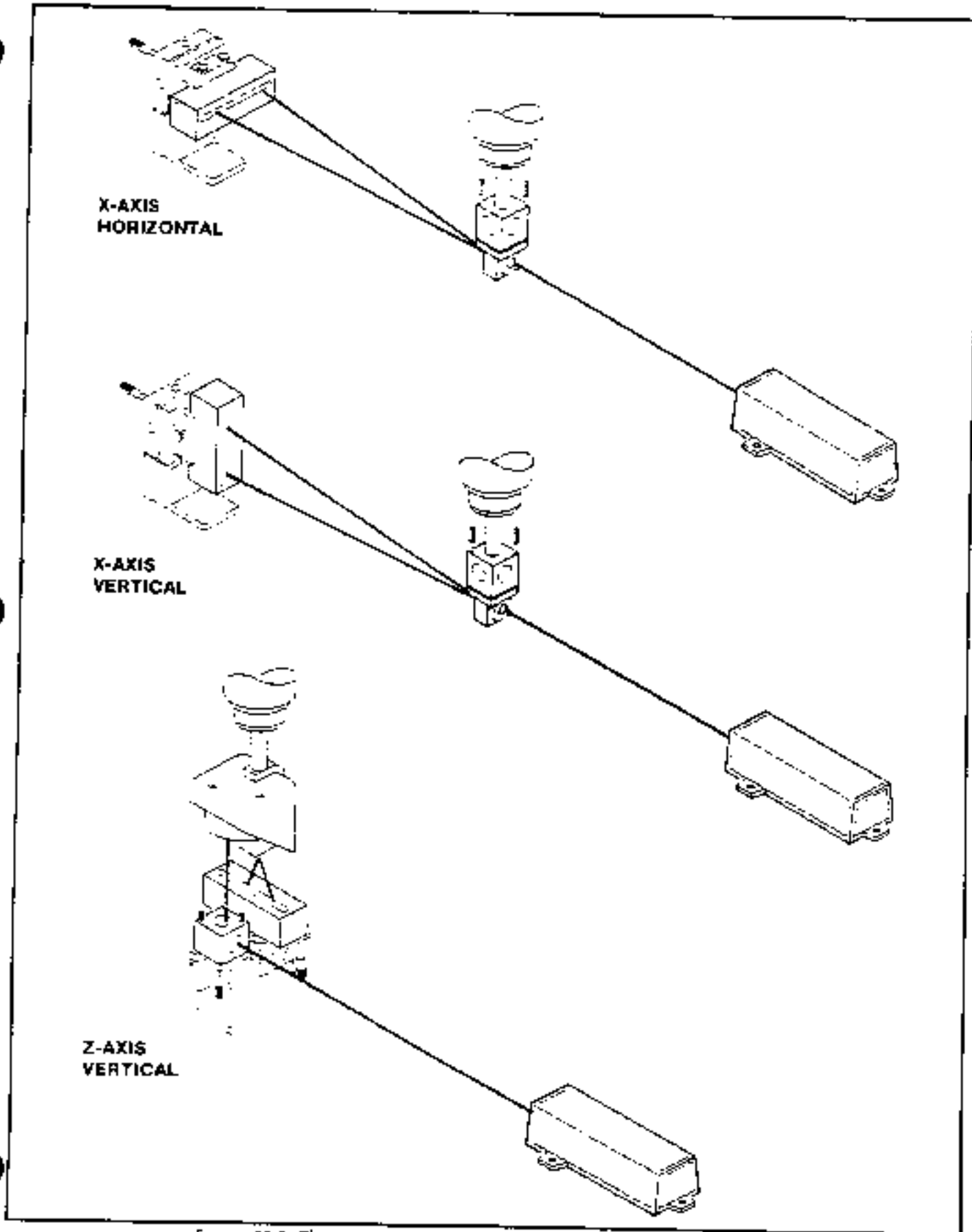


Figure 10-9. Three-axes Positioning of Optics — First Laser Head Setup

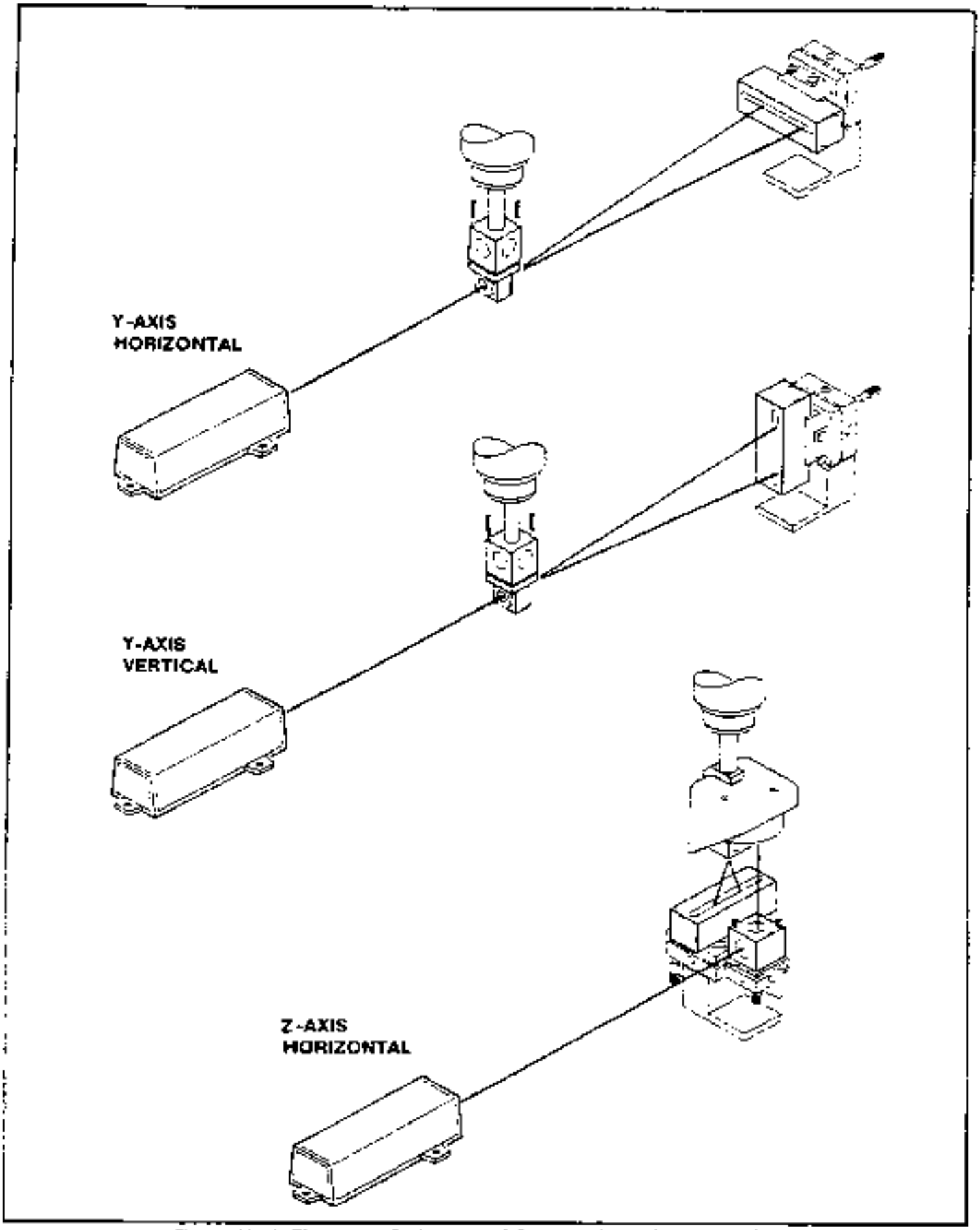


Figure 10-10. Three-axes Positioning of Optics — Second Laser Head Setup

MEASUREMENT DISPLAY SETTINGS

NOTE

Measurement Display settings are the same with or without sensors.

Measurement Mode Keys



Press the key corresponding to the length of the measurement —

Use LONG for 1 metre to 30 metres (3 feet to 100 feet)

Use SHORT for 100 mm to 3 metres (4 in. to 10 feet)

Set-Up Keys

NOTES

1. To enter a value for any keys —
   a. Use the ENTRY keys to specify the numeric value.
   b. Press the key to assign the value to that key.
2. To check the current status of any of these keys, just press the key. Then press the key again, to return to the mode you selected earlier
3. More information about each key is available in Section 16 of this User's Guide.



Determine which direction of motion you want to be "positive" or "negative", by pressing slightly on the Straightness Interferometer and pressing this button if the direction you pushed caused the "wrong" sign for the reading. Remember that opposite perpendicular motions for the Interferometer and the Reflector result in readings with the same sign.



Determine the resolution you need from the accuracy you want. Enter the number of places you want, and then press this key.

For Short Straightness measurements, resolution extends to five places (0.00001) for millimetres, and to six places (0.000001) for inches. For Long Straightness measurements, resolution extends to four places (0.0001) for millimetres, and to five places (0.00001) for inches.

This key also allows you to "smooth" your data by entering a positive number. A negative resolution number will remove any smoothing. Smoothing reduces the effects of vibration.



In this measurement mode, this key multiplies the measured value by a preset (stored) value. The multiplier value is "1", unless you have entered some other value (other than "0").

You must enter a calibration factor for the particular Straightness Reflector you are using. You will find the calibration number you need on the label without the serial number on the side of the Straightness Interferometer. Enter this number ("x.xx"), using the ENTRY keys to specify the numeric value, and then pressing PRESET.

NOTE

If you are using a Straightness Reflector from the HP 5526A System, enter the **reciprocal** of the calibration number you find on the Reflector (i.e., "1/cal nbr").

MAKING A MEASUREMENT

System Checks

1. Make sure the Laser Head's Exit port is switched to its large aperture.
2. The Laser Head turret must be set to "STRAIGHT".
3. The Laser Head's READY indicator must be lighted steadily (i.e., not blinking).
4. Make sure you are properly interfaced with other instruments as needed to record your data.
   a. If you record your data manually, no interfacing is necessary.
   b. If you want to record your data automatically, but you aren't using the HP Dimensional Metrology Analysis System or another HP-IB controller, you must have an HP-IB compatible printer connected to the Measurement Display unit, via the rear panel HP-IB connector. You must also make sure the Measurement Display is set-up to output to a printer via HP-IB. See Section 18 and follow the instructions for "Data Transfer without an HP-IB Controller".
   c. For formatted automatic records, you should have the HP Dimensional Metrology Analysis System or an HP-IB controller with your own programs to make it work with the Laser Measurement System. The HP Analysis System comes with an HP Personal Computer and programs to make it work with the Laser Measurement System. The operating manual for the Analysis System will explain how to use it. In either case, you must first make sure the Measurement Display is set-up to accept a controller via HP-IB. See Section 18 and follow the instructions for "Data Transfer with an HP-IB Controller".

Procedures

Two different measurement methods are available. You can have your system make measurements —

- only at points you specify, or —
- automatically, at the time interval you specify, without regard to the location of the Optics.

Measurements at Specific Physical Locations

To have your Laser Measurement System make measurements only at specific physical locations —

1. Push the RESET key. (You can also RESET from the Remote Control Unit.)
2. Move one of the optics a predetermined distance.
3. Press the RECORD button on the Remote Control Unit connected to the Measurement Display. One measurement is made each time you press this button.

Measurements at Specified Time Intervals

To have your Laser Measurement System make measurements at specific time intervals (i.e., "on-the-fly". —

1. Push the RESET key. (You can also RESET from the Remote Control Unit.)
2. Enter the time interval you want between measurements (0.05 to 12 seconds).
3. Press the AUTO RECORD key. This will start the automatic taking of data. (See Section 16 for more information about using this key.)
4. Move one optic along the full measurement path. A measurement is made automatically every so many seconds until you press the AUTO RECORD key again.
5. Press the AUTO RECORD key when the end of travel is reached. This will turn off the AUTO RECORD mode, and end the recording of measurements.

NOTES

- Make sure the frequency at which you want to take measurements isn't greater than the rate at which the Measurement Display unit can update measurements for the resolution you have requested. (The update rate decreases as resolution increases.) If you exceed the update rate for a given resolution, "Sr Error" will be displayed.

  Update rates are given in the Laser Measurement System's Service Manual.

- If an HP Personal Computer or an HP-IB Printer is not connected to the Measurement Display unit, pressing RECORD or AUTO RECORD will cause the message "Lr Error" to be displayed.

WHAT AFFECTS ACCURACY?

Potential Straightness measurement errors are unlike those for either Distance or Angular measurements.

Laser System Error Sources

Error sources within the Laser Measurement System are —

a. Straightness Reflector mirrors.

b. Mis-alignment between the machine's travel axis and the Laser Measurement axis ("slope").

c. Environment (e.g., machine and atmosphere).

Straightness Reflector Mirrors

Description

The limiting accuracy of a Straightness measurement is directly related to the accuracy of the mirror calibration factor and to the difference in flatness of the two plane mirrors that serve as the Straightness Reflector. V.O.L. error is negligible compared to the overall measurement accuracy.

For example, suppose one of the mirrors is flat, but the other is convex by a small amount ("C"), as shown in Figure 10-11. Even if the Straightness Interferometer were to travel a straight path with respect to the Mirror's axis, the optical path length of f_1 would be shortened by an amount equal to "C" with respect to the optical path of f_2, and this would be interpreted by the Interferometer as "out-of-straightness" in the Interferometer's travel.

Straightness accuracy limitations resulting from the Reflector's mirrors are given under "OPTICAL STRAIGHTEDGE ACCURACY", in the "OPERATING SPECIFICATIONS" at the beginning of this User's Guide Section.

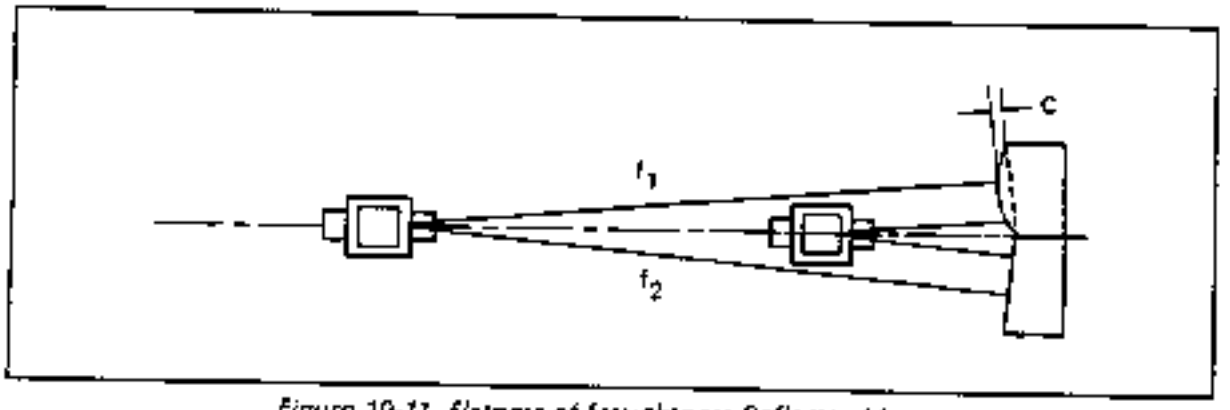


Figure 10-11. Flatness of Straightness Reflector Mirrors

Minimizing Effects

The accuracy of the HP Straightness Measurement is given at the beginning of this section. Accuracy consists of an Optical Straightedge component and a Linearity component. This accuracy can be improved to the Linearity limits alone given in the matrix under "OPERATING SPECIFICATIONS", by rotating the Straightness Reflector through 180 degrees, and making a second pass.

The Straightness Reflector and its Mount are designed to rotate around the junction of the Reflector's mirrors to make this procedure easier. (The slotted opening in the Reflector must be as close as possible to the screws identified by "1" in *Figure 10-4.*)

Misalignment Between Machine Travel and the Laser Measurement Axis (Slope)

Description

This does not cause a cosine error, as it did in Distance measurements. Instead, misalignment causes a slope to be measured, since the Straightness Reflector is not directing its reference bisector along a path parallel to the axis of travel. (See *Figure 10-12.*)

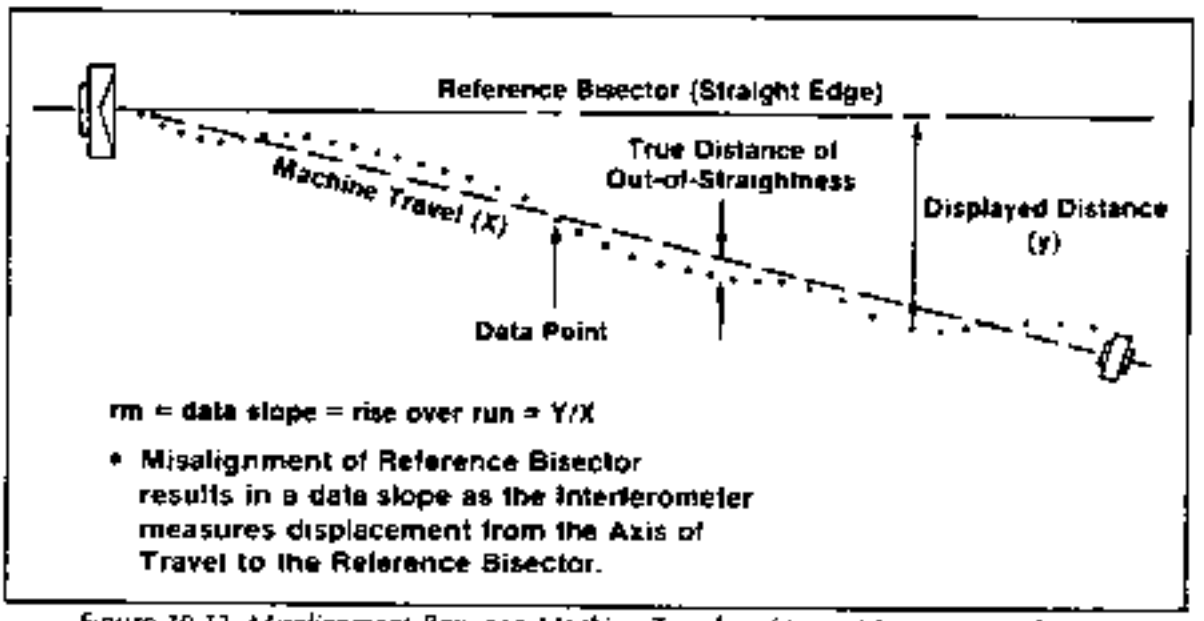


Figure 10-12. Misalignment Between Machine Travel and Laser Measurement System

Minimizing Effects

The three ways to remove slope from the Straightness data are —

1. Automatic Calculator reduction and plot of data.
2. Manual mathematic reduction and plot of data.
3. Manually aligning the slope out with a zero-end-point fit.

Manual alignment may be necessary if the slope becomes great enough to reset the Measurement Display before the end of travel is reached, or if a subsequent squareness measurement is to be made.

If you have the HP Dimensional Metrology Analysis System (DMAS), you will want to use method "1" above, and automatically remove slope. If you don't have the DMAS, you will have to use method 2 or method 3.

Method 2 is done by calculating either a zero-end-point or a least-squares best line fit through the data points, and subtracting the slope at each command position. See Section 21 for instructions.

Method 3 is described in detail in the "INSTALLATION AND ALIGNMENT OF OPTICS" part of this User's Guide Section.

Environmental Errors

Description

As with any accurate measurement, and in particular with all Laser System measurements, the environment plays a very important role.

Environmental errors come from —

1. Thermal expansion of the machine or part.
2. Machine vibration.
3. Air turbulence.

A Straightness measurement is especially susceptible to environmental effects. It is impossible to quantitatively determine how these environmental characteristics will affect the measurement, although it is sometimes possible to identify when they are having an effect.

Excessive vibration and/or air turbulence can be identified by —

1. Random drifting of the measurement results when the Optics are at rest.
2. Drifting increasing as the distance between the Optics increases

The effects of vibration can be further identified if the drifting of the measurement stops when the machine is turned off, or by exceeding the slew rate during the measurement (disrupting the measurement).

Minimizing Effects

1. Thermal expansion of the machine or Optics.

   These effects can be minimized by letting the machine and Optics reach thermal equilibrium before making a measurement.

2. Machine Vibrations

   a. Adequate fixturing is the main way to reduce the effects of vibration.

      Make sure the Straightness Reflector's Base is securely fastened to the table, and that the Post is securely fastened to the base on one end and the Reflector on the other.

      Avoid long extensions

   b. Vibrational effects can also be reduced by —

      - Averaging successive runs or averaging successive averages.
      - More accurate manual slope removal.
      - Reduced feed rates.
      - Pads under the reflector's base as a last resort in high-vibration, low-accuracy work.

3 Air Turbulence

Air turbulence is caused by temperature differences in the air. To remove these differences, you should remove their sources (e.g., open doors, lamps, exhaust fans, motors, etc...). Alternatively, you should mix the air thoroughly along the measurement path, using a large fan. If you can reduce the sources of temperature differences **and** mix the measurement path air, you'll be even better off.

11 Straightness-with Retroreflector

SECTION 11
STRAIGHTNESS MEASUREMENTS USING THE STRAIGHTNESS RETROREFLECTOR

CONTENTS

INTRODUCTION
OPERATING SPECIFICATIONS
HARDWARE REQUIRED
RELATED MEASUREMENTS
REFERENCE MATERIAL
INSTALLATION AND ALIGNMENT OF OPTICS
MEASUREMENT DISPLAY SETTINGS
MAKING A MEASUREMENT
WHAT AFFECTS ACCURACY?

INTRODUCTION

Any Straightness measurement along a Vertical axis, and Straightness measurements along a Horizontal axis that are in line with a horizontal spindle, require use of a Straightness **Retro**retreflector to reverse the direction of the laser beam.

The Straightness **Retroreflector** is a large **Retroreflector** mounted in a housing that also supports the Straightness Interferometer. **The Retroreflector** is placed in the laser beam to reverse the beam and allow the Interferometer to be mounted in the machine's spindle, even though you can't install an Optic behind the spindle.

NOTE

If you are interested in a vertical Squareness measurement, do **not** make a Straightness measurement as described in this User's Guide Section. Instead, use the instructions given in Section 13. This Section (Section 11) is intended for someone who wants to make Straightness measurements only.

OPERATING SPECIFICATIONS

The following specifications assume that the optional Dimensional Metrology Analysis System is used in conjunction with the HP 5528A to provide averaging and calculation capabilities for Straightness, Parallelism and Squareness measurements and that the Optical Square is aligned within 5 arc-min using autoreflection techniques

Accuracy: Overall accuracy is the sum of the two components below.*

Overall Accuracy = Optical Reference Accuracy + Measurement Accuracy

Optical Reference Accuracy [2]

Short Range Optics:
Metric Units Mode: 0.75 M^2 microns TIR
English Units Mode: 0.5 F^2 microinches TIR
Long Range Optics:
Metric Units Mode: 0.015 M^2 microns TIR
English Units Mode: 0.05 F^2 microinches TIR
where:
TIR = Total Indicated Reading
M = distance of travel of the moving optic in metres
F = distance of travel of the moving optic in feet

Measurement Accuracy:

Short Range Optics

Temperature Range	Displayed Value	
	0-10 microns 0-400 microinches	10-1500 microns 400-60000 microinches
15-25° C	±3.5%	±1% ±0.25 microns ±10 microinches
0-40° C	±6%	±1% ±0.5 microns ±20 microinches

Long Range Optics:

Temperature Range	Displayed Value	
	0-100 microns (0-4000 microinches)	100-1500 microns (4000-60000 microinches)
15-25° C	±5%	±2.5% ±2.5 microns 100 microinches
0-40° C	±7.5%	±2.5% ±5 microns 200 microinches

*This is analogous to the traditional straightedge and indicator method of measuring straightness, where Optical Reference Accuracy corresponds to the straightedge accuracy, and Measurement Accuracy corresponds to the indicator accuracy.

[2]Optical reference error can be eliminated by using straightedge mirror reversal techniques

RESOLUTION:

Short-Range:
Metric Units Mode: 0.01 micron (0.00001 mm)
English Units Mode: 1 microinch

Long-Range:
Metric Units Mode: 0.1 micron (0.0001 mm)
English Units Mode: 10 microinches

STRAIGHTNESS DEVIATION RANGE:

±1.5 mm (0.060 inch)

AXIAL SEPARATION RANGE (Typical, with proper alignment, 15–25°C).

Distance of travel between the Interferometer and Reflector. Interferometer located within 5 metres (16.5 feet) of Laser Head.

Short-Range: 0.1–3 metres (4–120 inches)

Long-Range Optics: 1–30 metres (3–100 feet)

HARDWARE REQUIRED

In addition to the hardware required for any measurement using the Laser Measurement System (see *Figure 4-1*), any Straightness measurement along a Vertical axis requires the hardware shown in *Figure 11-1*.

NOTE

There are both a Straightness Reflector and a Straightness **Retro**reflector. In this User's Guide Section, we will try to always type "**Retro**reflector" like this, with the "Retro" in bold type, to emphasize when that is the one that is to be used.

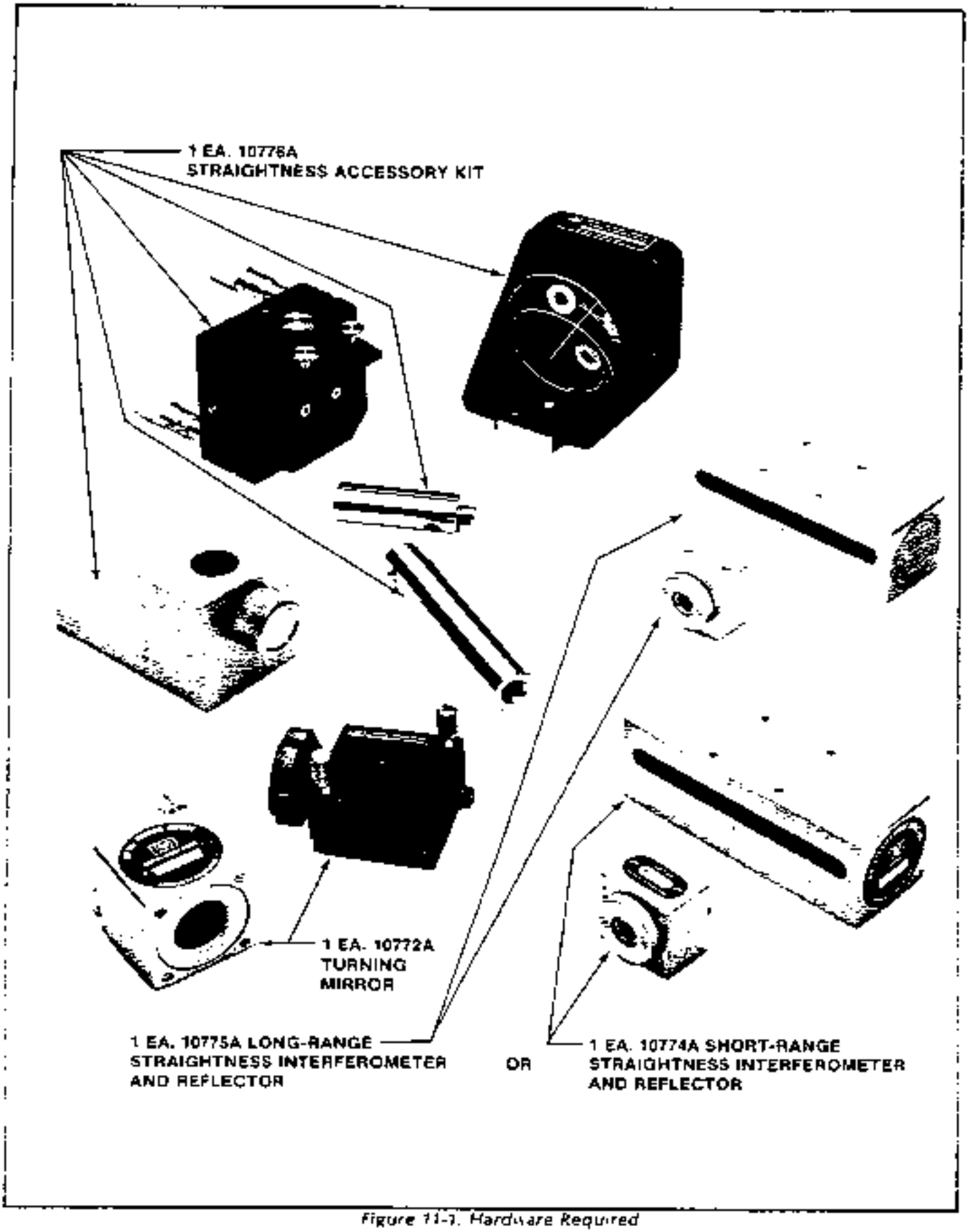


Figure 11-1. Hardware Required

RELATED MEASUREMENTS

Straightness Measurements (Along a Horizontal Axis) ... Section 10

Squareness Measurements (In a Horizontal Plane) ... Section 12

Squareness Measurements (In a Vertical Plane) ... Section 13

Parallelism Measurements ... Section 14

REFERENCE MATERIAL

Physical Setup of the Laser Head and Tripod ... Section 4

Interconnections, Turn-on ... Section 5

Alignment Techniques ... Section 15

INSTALLATION AND ALIGNMENT OF OPTICS

Important Considerations

1. The Straightness Interferometer must be located between the Laser Head and the Straightness Reflector in the Laser beam.

   The sequence of Optics along the laser beam is —

   - Laser Head
   - Turning Mirror (required for Vertical-axis measurements only)
   - Straightness Retroreflector
   - Interferometer
   - Reflector

2. The Retroreflector/Interferometer must be mounted where the tool mounts. The Reflector must be mounted where the workpiece mounts.

3. Vibrations and loose connections must be minimized by proper mounting. Avoid long extensions. Make sure that all supports are completely stationary. A spindle, for example, must be secured by a brake so it won't rotate. (If a brake isn't available try using a hose clamp or a wedge.

4. The Laser beam must be returned to the top port on the Laser Head's turret, **not** to the bottom (return) port.

5. The Optics must be aligned to the Laser beam well enough to keep the Beam Strength indicator in the green region along the entire optics' path.

6. The Optics must be aligned to the Laser beam well enough to eliminate "slope" if the HP Dimensional Metrology Analysis System isn't used

7. The Laser Head's turret ring should be set to "OTHER" during installation, to take advantage of the strongest possible beam, which this setting provides.

Description

1. You will initially position the Optics in their relative positions as described in "IMPORTANT CONSIDERATIONS", above, and at the near end of travel.

2. You will position the Laser Head so the beam strikes the Optics.

NOTE

Two separate procedures will be provided for step "1" and step "2" above. One procedure is for Vertical axes, the other is for Horizontal axes.

3. You will align the Laser Head to track the Optic's progression along the travel path, while maintaining the beam's near-end-of-travel position. You will do this by —

   - Reviewing the "GUNSIGHT" alignment method in Section 15 of this User's Guide.
   - Keeping the beam within the Alignment ring on the Straightness Retroreflector, to maintain the beam's near-end-of travel position, and —
   - Keeping a two-dot pattern in line with the junction of the Straightness Reflector's mirrors, and symmetrical about its slotted opening, to match the Optic's travel.

4. Finally, you will check your alignment to insure that "Important Considerations" number "5" and number "6" have been met.

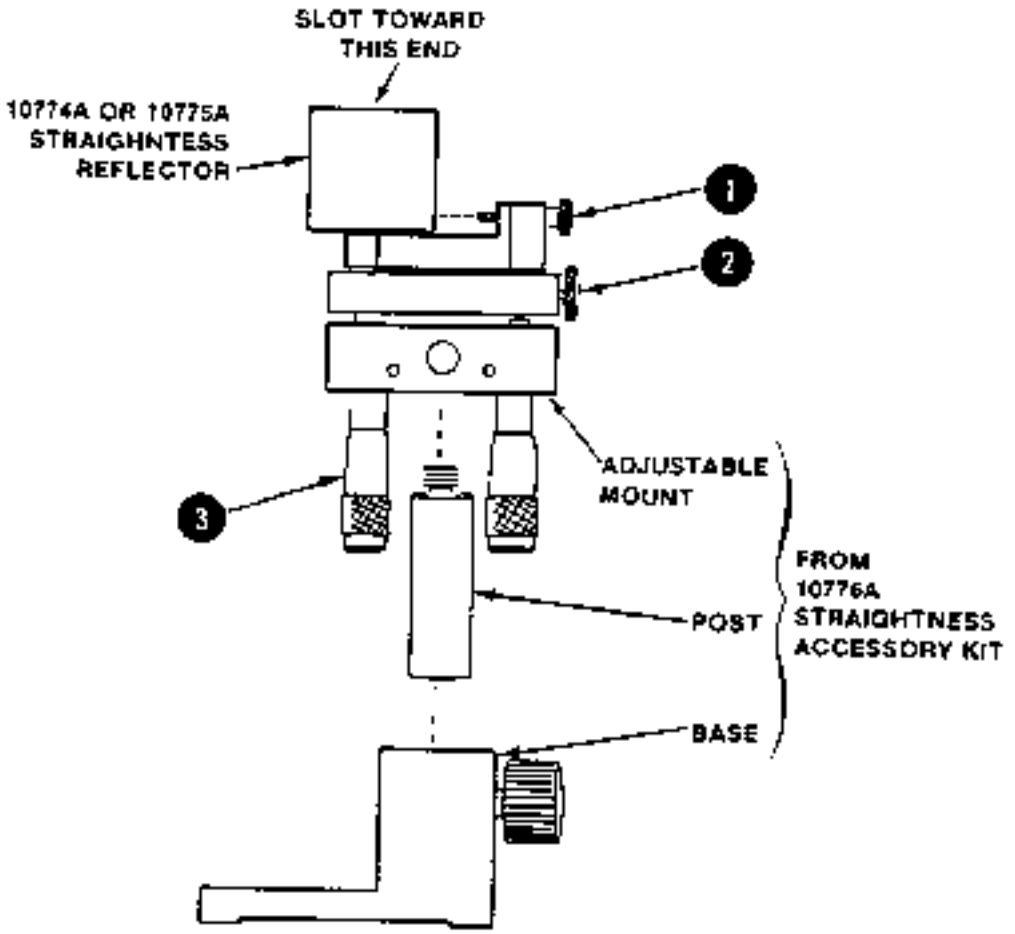
Installing Optics For A Vertical-Axis Measurement

1. Assemble the Straightness Reflector and its mount as you would for a measurement along a horizontal axis, except attach the post to the rear of the Adjustable Mount (see Figure 11-2). Be sure the Straightness Reflector's slot is oriented away from the mounting screws, and toward where the Turning Mirror will be mounted. (This is opposite of the way the Reflector was mounted for Straightness measurements along a Horizontal axis, described in Section 10.)

   The Straightness Reflector's mirrors should now be oriented "up".

NOTE

If you think you will be making a Distance or Angular measurement later, establish a measurement axis at a height above the table that will allow easy interchanging of the Optics. To do this, adjust the height of the Reflector/Turning Mirror assembly to be as low as possible on its Base.



Assemble the Straightness Reflector and its mounting hardware, using the procedure below.

a Attach the Straightness Reflector to the adjustable mount, using the screws identified by "1".

Make sure the slot is as far as possible from the screws identified by "1". This will allow for correct spacing between the Turning Mirror and the Reflector.

b Screw the Accessory Kit's Post into the rear of the Adjustable Mount.

c Slide the Post into the Base and secure with the large knurled knob.

Adjustment "2" allows 360-degree rotation of the reflector.

Adjustment "3" rotates the reflector over very small angles to help in final alignment.

Figure 11-2 Straightness Reflector Mounting

2. Attach the Turning Mirror's base to the side of the Reflector's Mount that is recessed, as shown in *Figure 11-3*.

3. Position the Reflector and its mounting hardware on the part of the machine that normally holds the workpiece, in line with the vertical axis to be measured. (See *Figure 11-4*.)

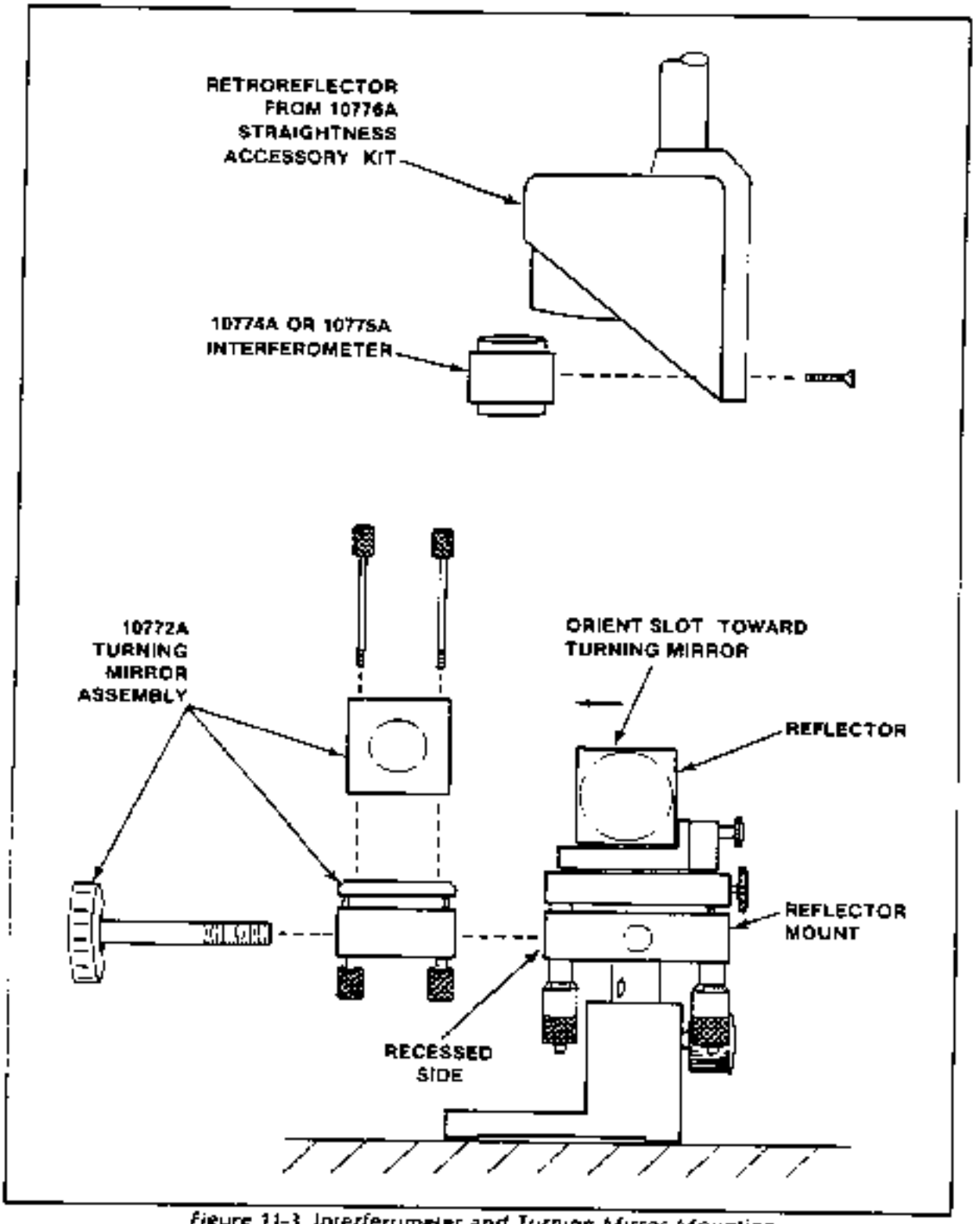


Figure 11-3. Interferometer and Turning Mirror Mounting

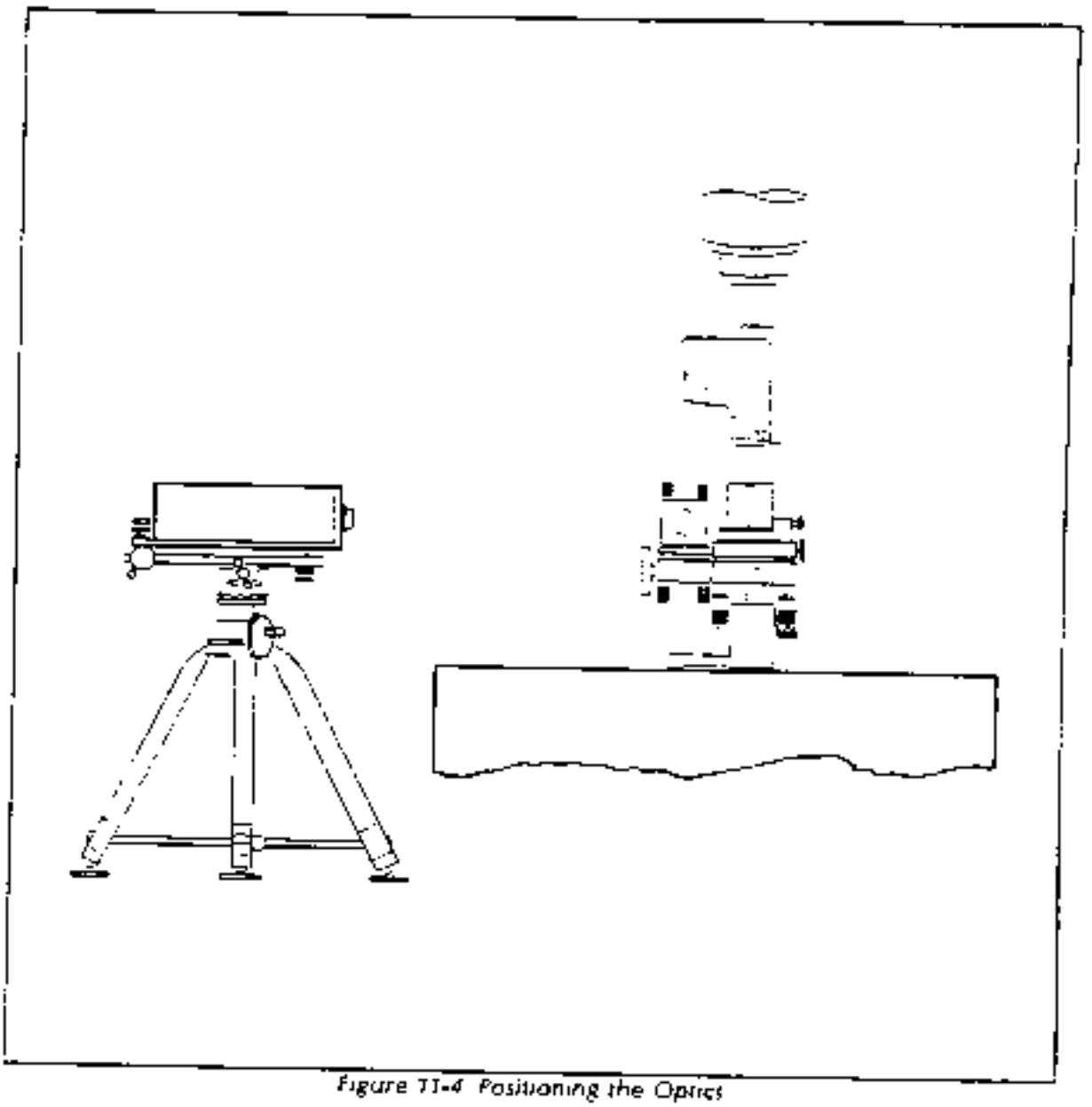


Figure 11-4 Positioning the Optics

4 Decide whether you are making a Vertical or a Horizontal Straightness measurement on this axis, and turn the Reflector so its slot is in the plane you want to measure, and the Turning Mirror is on the appropriate side of the Reflector (see *Figure 11-5*).

If you are making a Straightness measurement in the plane perpendicular to the Laser beam (Horizontal Straightness), orient the Straightness Reflector perpendicular to the Laser beam with the Turning Mirror's base toward the Laser Head.

If you are making a Straightness measurement in the plane parallel to the Laser beam (Vertical Straightness), orient the Straightness Reflector parallel to the Laser beam and with the Turning Mirror's base off to one side.

As *Figure 11-5* shows, the Straightness Reflector's slot should be as close as possible to the Turning Mirror.

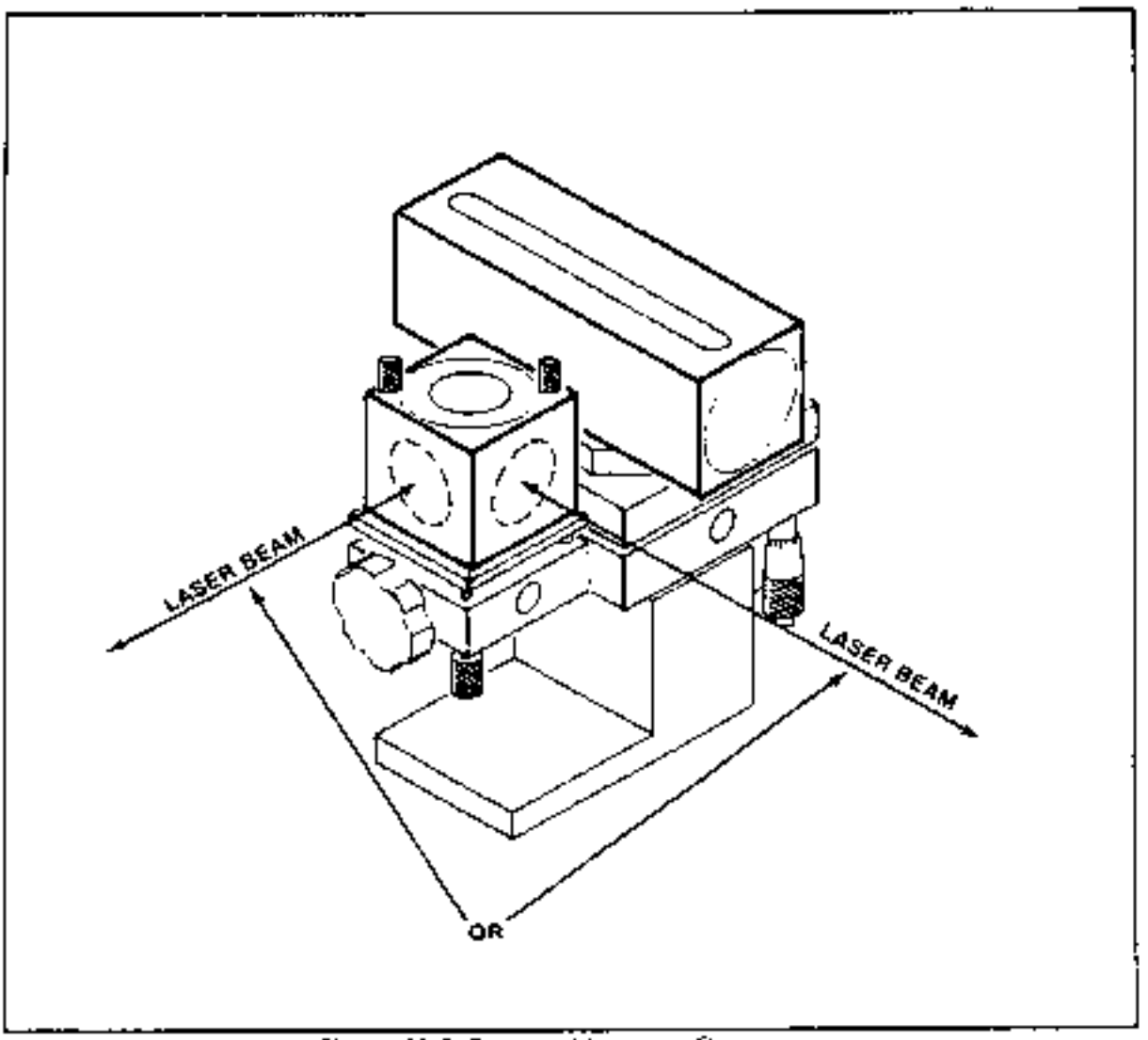


Figure 11-5 Turning Mirror — Orientation

5 Mount the Turning Mirror on its base, using its captive screws, such that it will deflect the Laser beam upward.

6. Mount the Vertical Straightness Kit's Straightness **Retro**reflector where the tool normally mounts, as shown in *Figure 11-3*.

   Screw the Interferometer into the large **Retro**reflector, using the two 3 mm flathead screws provided.

7 Orient the **Retro**reflector so it overlaps the Straightness Reflector and the Turning Mirror, but with the Interferometer over the Straightness Reflector.

   Fasten the **Retro**reflector to the machine in such a way that the Interferometer is as square as possible to the Reflector and to the incoming beam. The Interferometer housing's pitch limitations are ±2 degrees; its yaw and roll limitations are ±5 degrees. The pitch and yaw requirements will be taken care of automatically by using the Straightness **Retro**reflector and an HP Post.

8. Position the Reflector and Turning Mirror relative to the **Retro**reflector and Interferometer, as follows —

   a. Bring the Interferometer/**Retro**reflector assembly close enough to the Straightness Reflector to line up the Interferometer with the junction of the Reflector's mirrors.

      Also position the Interferometer in the other axis so its opening is positioned in the center of the Reflector's slot. (Look straight down into the Reflector and make sure the Interferometer's opening is in the middle.)

      This is a very important step. If the Optics are not physically lined up at this point, aligning along the vertical travel axis will be impossible.

      Be sure this establishes the "near end of travel", i.e., that any later movement of the machine can only increase the distance between the Optics.

   b. Make sure the Reflector is square relative to the machine and to the Interferometer (within ±5 degrees), and then secure the Reflector/Turning Mirror assembly to the machine.

   c. Make sure the Turning Mirror is square relative to the Reflector, and is not tilted to either side.

9. Switch to the large aperture on the Laser Head's exit port, and set the turret ring to "OTHER". (When aligning your set up it is good practice to work with the strongest possible beam, which this setting provides.).

10. Visually align the Laser Head as well as you can parallel to the machine's table, and position it to have the beam strike the center of the Turning Mirror's opening.

    (Use the Interferometer's target or a piece of paper to help you to this.)

11. Adjust the Turning Mirror's position with the small screws at its base until the Laser beam goes through the small alignment ring on the **Retro**reflector, and passes through the Interferometer without being clipped. (See *Figure 11-6.*)

    To do this —

    a. Get the beam to go through the alignment ring

    b. Look at the side of the Interferometer facing the **Retro**reflector, and adjust until you see no red reflection.

12. Orient the Interferometer bezel's scribed line 90 degrees to the Reflector's slotted opening. Two dots should appear on the Reflector's front surface unless the Optics are quite close together. (See *Figure 11-7.*) If so, insert a piece of paper across the front of the Straightness Reflector to see the dots.

13. Move your machine (or slide the Turning Mirror/Reflector assembly) back and forth (or side-to-side) until the Laser beam hits the junction of the Reflector's mirrors and is centered in the slotted opening. You will need to separate the Optics to about 75 mm (3 inches) for Short Range, or about 600 mm (2 feet) for Long Range, in order to do this.

    If the Interferometer clips the beam after this adjustment, readjust the tilt of the Turning Mirror, using its small screws, and then try again to move the entire assembly so the two beams line up on the junction of the mirrors.

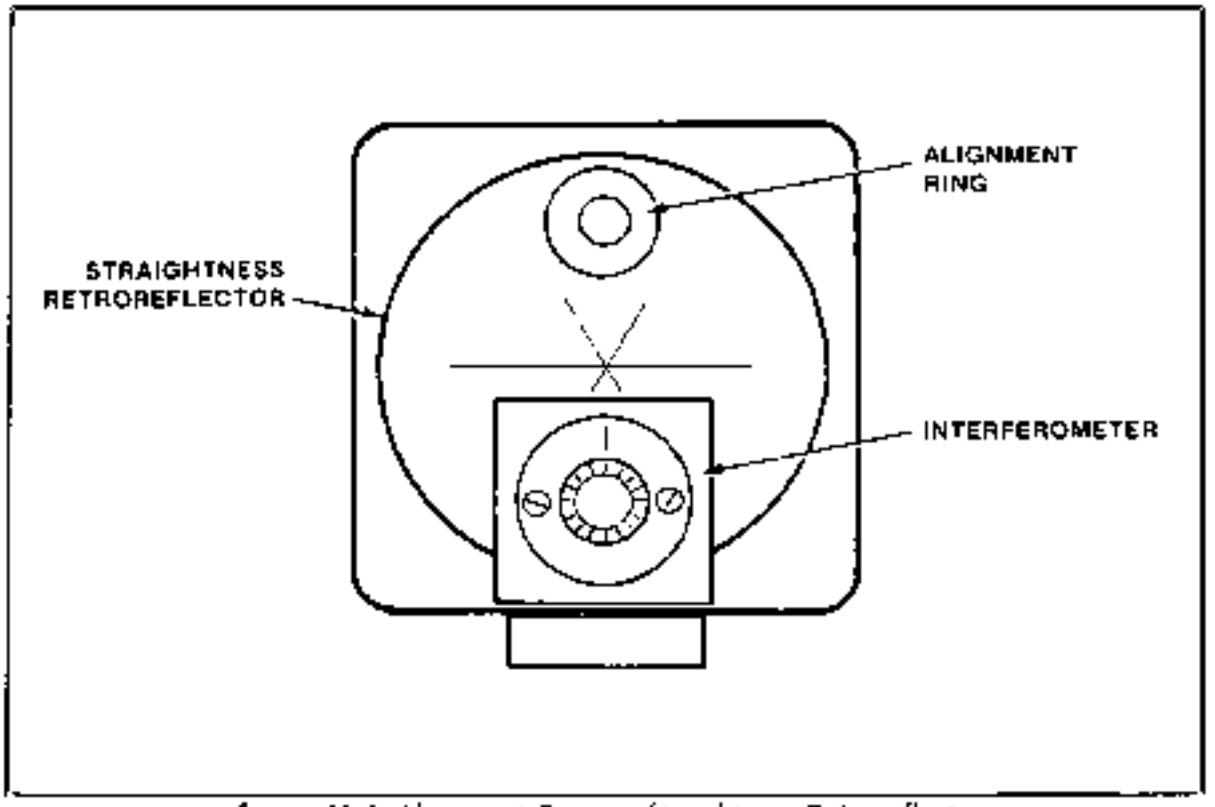


Figure 11-6. Alignment Ring on Straightness Retroreflector

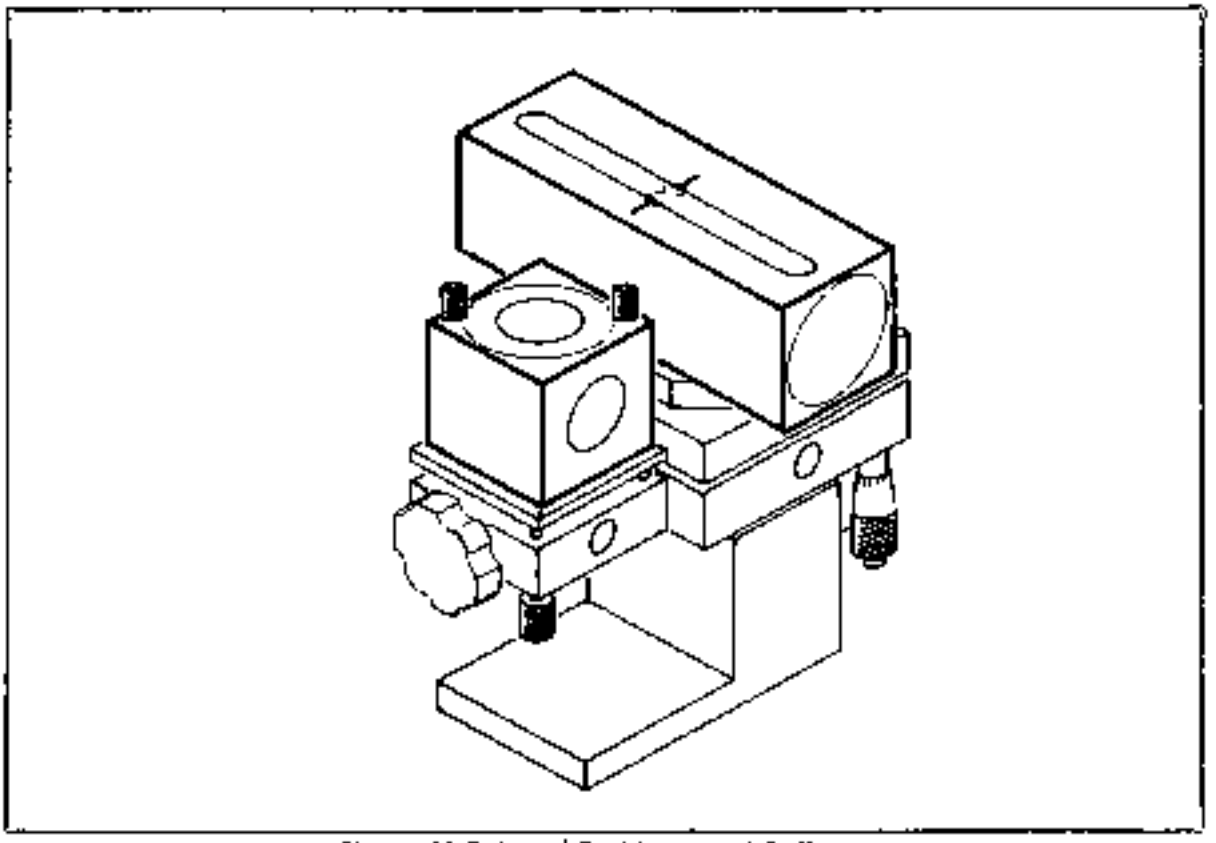


Figure 11-7. Initial Positioning of Reflector

14. Switch the exit port to the small aperture and redo step "13".

15. Secure the Turning Mirror/Reflector Assembly to the machine, if you had to loosen it to do step "13" and step "14".

16. Go to the "Alignment Procedure (for Horizontal or Vertical Axis)".

Installing Optics For A Horizontal-Axis Measurement

1. Assemble the Straightness Reflector and its mount as you would for a measurement along a Horizontal axis (see *Figure 10-4*).

NOTE

If you will be making a Distance or Angular measurement later, establish a measurement axis at a height above the table that will allow easy interchanging of the Optics.

To do this, mount the Straightness Reflector as low as possible on its Base, without covering up the hole in the Reflector Mount's post.

2. Position the Reflector and its mounting hardware on the part of the machine that normally holds the workpiece, in line with and facing the spindle.

3. Decide whether you are making a Vertical or a Horizontal Straightness measurement on this axis, and turn the Reflector so its slot is in the plane you want to measure.

4. Mount the Vertical Straightness Kit's Straightness Retroreflector where the tool normally mounts, except orient it horizontally instead of vertically. (See *Figure 11-8*.)

   Screw the Interferometer into the large Retroreflector, using the two 3 mm flathead screws provided.

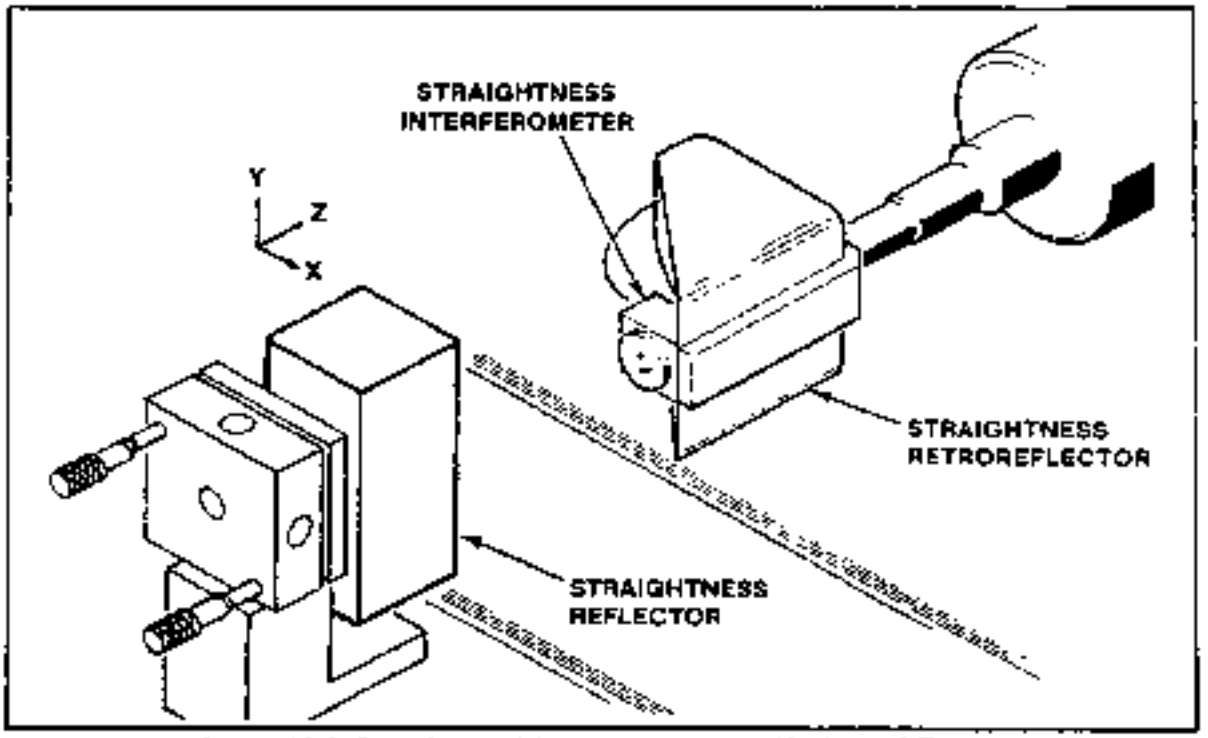


Figure 11-8. Straightness Measurements on a Horizontal Z-Axis

5. Orient the **Retro**reflector so the Interferometer lines up with the center of the Reflector's slotted opening and the top half of the **Retro**reflector is exposed to the laser beam that will come from the other side of the Straightness Reflector.

   Fasten the **Retro**reflector to the machine in such a way that the Interferometer is as square as possible to the Reflector and to the incoming beam. The Interferometer housing's pitch limitations are ±2 degrees; its yaw and roll limitations are ±5 degrees. The pitch and yaw requirements will be taken care of automatically by using the Straightness **Retro**reflector and an HP Post.

6. Position the Reflector relative to the **Retro**reflector and Interferometer.

   Bring the Interferometer/**Retro**reflector assembly close enough to the Straightness Reflector to line up the Interferometer with the junction of the Reflector's mirrors.

   Also position the Interferometer in the other axis so its opening is positioned in the center of the Reflector's slot. (Look straight into the Reflector and make sure the Interferometer's opening is in the middle.)

   This is a very important step. If the Optics are not physically lined up at this point, aligning along the travel axis will be impossible.

   Be sure this establishes the "near end of travel", i.e., that any later movement of the machine can only increase the distance between the Optics.

7. Make sure the Reflector is square relative to the machine and to the Interferometer (within ±5 degrees), and then secure the Reflector to the machine.

8. Switch to the large aperture on the Laser Head's exit port, and set the turret ring to "OTHER". (When aligning your set up it is good practice to work with the strongest possible beam, which this setting provides.).

9. Visually align the Laser Head as well as you can parallel to the machine's table, and position it to have the beam go over the Straightness Reflector and through the **Retro**reflector's Alignment ring. (See *Figure 11-6.*)

10. Orient the Interferometer bezel's scribed line 90 degrees to the Reflector's slotted opening. Two dots should appear on the Reflector's front surface unless the Optics are quite close together. (See *Figure 10-6.*) If so, insert a piece of paper across the front of the Straightness Reflector to see the dots.

11. Further adjust the Reflector's position until the two dots are directly in line with the junction of the Reflector's mirrors and are also symmetrical about its slotted opening.

12. Secure the Reflector assembly to the machine, if you had to move it in step "11".

Alignment Procedure (For Horizontal Or Vertical Axis)

1. Select the exit port's large aperture.

2. You are now ready to align the Laser to the machine's travel

   Review the "GUNSIGHT" method of alignment in Section 15 of this User's Guide.

   Your goal is to adjust the Laser Head to track the Optic's progression along the travel path, while maintaining the beam's near-end-of-travel position. You will do this by —

   - Keeping the beam in the ring on the **Retroreflector**, to maintain the beam's near-end-of travel position, and —

   - Keeping a two-dot pattern in line with the junction of the Reflector's mirrors, and symmetrical about its slotted opening, to match the Optic's travel

   This will be a little different than aligning for Distance and Angular measurements, since with these alignments you were only watching one dot relative to a target crosshair.

3. Move the Optics to the far end of travel.

4. **Rotate** the Laser Head vertically and horizontally to keep the two dots lined up on the junction of the Reflector's mirrors, and symmetrical about its slotted opening. (See *Figure 11-9*.)

   Since the dots will move apart as the Optics move, you may have to hold a card on each side of the Reflector's slot to follow their movement

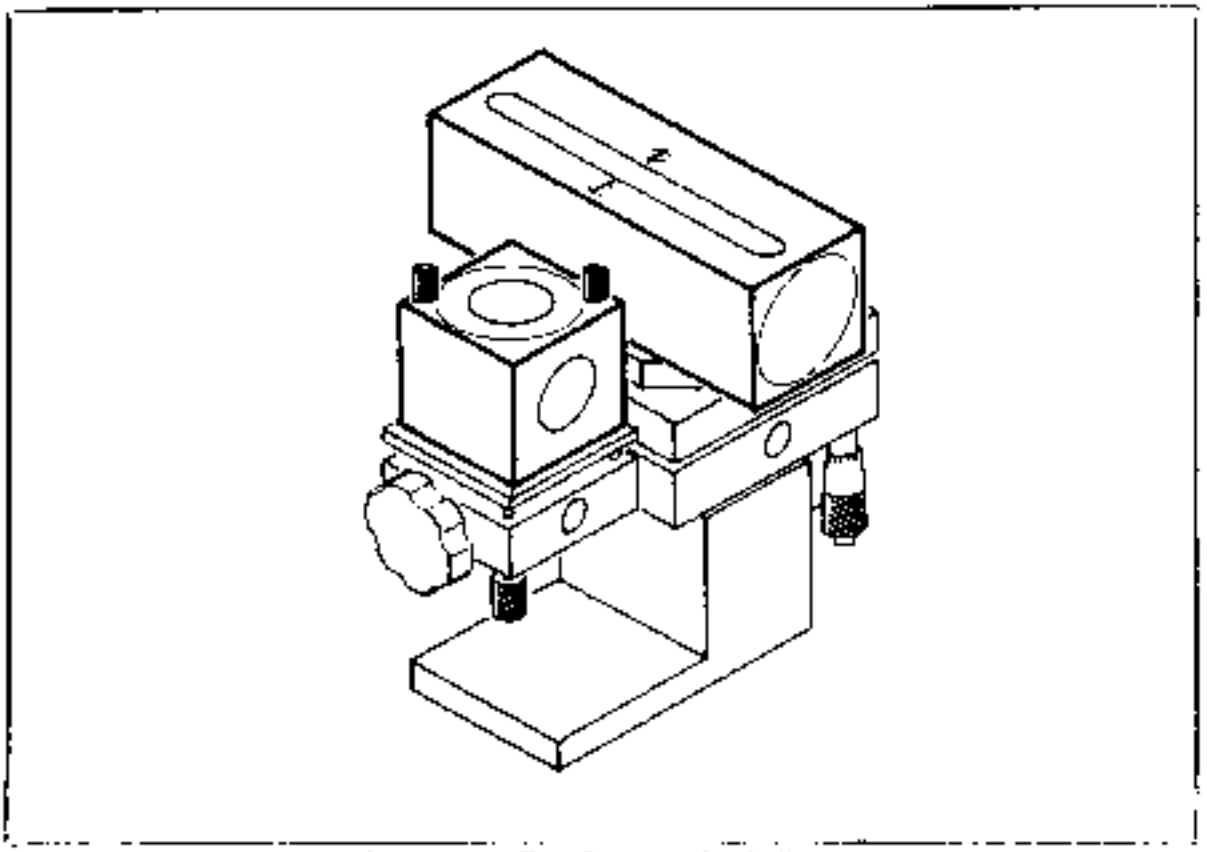


Figure 11-9. Two Dots on the Reflector

5. **Translate** the Laser Head vertically and horizontally to keep the Laser beam from being clipped by the alignment ring on the Straightness **Retro**reflector.

   Check this by making sure you can't see the beam on the Interferometer surface that faces the **Retro**reflector.

   Any translation of the Laser Head will cause the two dots to move from their position on the Reflector, so you will again have to rotate and translate the Laser Head (i.e., repeat step "4" and step "5" several times) before you are done.

   You are finished with this procedure when the beam goes through the Interferometer without being clipped, and the two dots are symmetrical about the Reflector's slotted opening and in line with the junction of its mirrors. (See *Figure* 11-9.)

Final Adjustments (After Aligning)

1. Turn the Laser Head's turret ring to "OTHER", if it is not already there.

2. Select the Exit port's small aperture.

3. Watch the front of the Laser Head as you turn the Interferometer's bezel to bring the scribed line parallel to the Straightness Reflector's slot.

   You should see two dots cross close to the Laser Head's exit port. If you can't see these dots —

   a. Cut a hole in the middle of a piece of paper.

   b. Hold this paper between the Interferometer and the Reflector, but closer to the Interferometer. You should see either one dot or two closely spaced dots on the piece of paper. Be careful not to block the beam going from the Turning Mirror to the **Retro**reflector (vertical axis only).

   c. Adjust the Reflector Mount's micrometers until the dot(s) disappear into the Interferometer.

   d. Remove the paper and look at the Laser Head. You should now see two dots on the front of the Laser Head.

   Turn the bezel until the dots overlap.

4. Adjust the Reflector Mount's micrometers until the overlapping dots are centered on the exit port, and "halo" the small aperture.

5. Set the Laser Head's turret ring to "STRAIGHT".

6. Select the Laser Head exit port's large aperture.

7. Turn the bezel slightly until the Laser Head's "SIGNAL" light comes on and the BEAM STRENGTH meter indication is in the green area.

NOTE

Only a slight adjustment of the bezel is necessary to do this.

8. Further adjust the Reflector Mount's micrometers until the BEAM STRENGTH meter indication is at a maximum.

Checking Alignment for Beam Strength

Move the machine over its full travel range, making sure that BEAM STRENGTH is adequate (in the green area) at all positions.

If beam strength decreases at any point, —

a. Check for clipping of the beam by the Optics. Reposition the Optics, if necessary, and then re-check.

b. If you see part of the return beam on the edge of the Exit (top) port, rotate the Laser Head until the return beam disappears.

If this didn't correct the "reduced beam strength" problem, refer to the "MANUAL REMOVAL OF SLOPE" information below.

NOTE

If the BEAM STRENGTH indication never reaches the right-hand half of the meter's range, at any point along the Optics' full travel distance, your Optics may need cleaning. Thoroughly clean all optical surfaces, as described in Section 20 of this User's Guide.

Checking for Mis-Alignment Between the Reflector's Reference Bisector and the Optics Travel Path ("Slope")

1. Press the Measurement Display unit's "LONG" or "SHORT" STRAIGHTNESS key corresponding to the length of your measurement.

2 Press the RESET key.

3 Again, move the machine over its full travel range, this time checking the Measurement Display unit to see if there is a steady change in the number displayed, rather than either a random scattering of numbers or a constant number.

A steady change of numbers indicates misalignment between the machine's travel axis and the Laser beam. This error is called "slope", and you must remove it — either manually or automatically (using a Calculator). See "WHAT AFFECTS ACCURACY?" information, below.

Manual Removal of Slope

Description

1 At the far end of travel (i.e., Optics are as far apart as possible), you will tilt the Straightness Reflector to change the displayed measurement value to a newly-calculated value "V_N".

Tilting the Reflector in this way moves its reference bisector toward the Optic's travel path (see *Figure 11-10*).

2. At the near end of travel (i.e., Optics are close together), you will translate the Straightness Interferometer (or the Reflector) so the displayed value is "zero" at this point. (See *Figure 11-10.*)

   Moving the Interferometer in this way lines up the Reflector's reference bisector with the center of the Straightness Interferometer.

3. No adjustment will be made to the Laser Head unless the adjustments described in step "1" and step "2" above cause the BEAM STRENGTH indicator to move into the "red" region. If this happens, you should rotate the Laser head until there is enough beam strength, while translating the Laser Head to keep the beam centered on the Interferometer.

   In making any adjustment to the Laser head, keep in mind that the Straightness Optics appear as a plane mirror relative to the Laser Head. That is why you should rotate the Laser Head to increase beam strength.

Procedure

1. Reset the Measurement Display with the Optics at the near end of travel.

2. Move the machine (and Optics) to the far end of travel and note the slope measurement on the Measurement Display.

3. Adjust the micrometer that controls motion in the plane of the Straightness Reflector's slot to cause the displayed number to change to the value calculated below —

$$V_N = \frac{-D_{NE}}{D_{FE}} \times V_O$$

where —

V_N = the New Value

D_{NE} = Distance between Optics at Near End position

D_{FE} = Distance traveled by moving Optic to Far End position

V_O = the Old Value ("slope")

For example, suppose the near-end spacing of the Optics ("NE") is 100 mm (4 inches), and the distance traveled by the moving Optic to the far-end spacing ("FE") is 600 mm (24 inches). Additionally, suppose that the measured slope at the far end is 0.0500 mm (0.00197 inch).

You should adjust the Reflector's tilt until the displayed value changes to —

$$\frac{-100\ mm}{600\ mm} \times 0.05\ mm = -0.0083\ mm\ (-0.00032\ inch)$$

If you start losing too much beam strength, and —

a. If you see any part of the return beam striking the front of the Laser Head (around the exit port), rotate the Laser Head until the return beam disappears into the port.

b. If you see any part of the Laser beam striking any part of the Interferometer (other than the glass), translate the Laser Head until the beam strikes only the glass.

   Remember that rotating or translating the Laser Head will not change the numbers in the display.

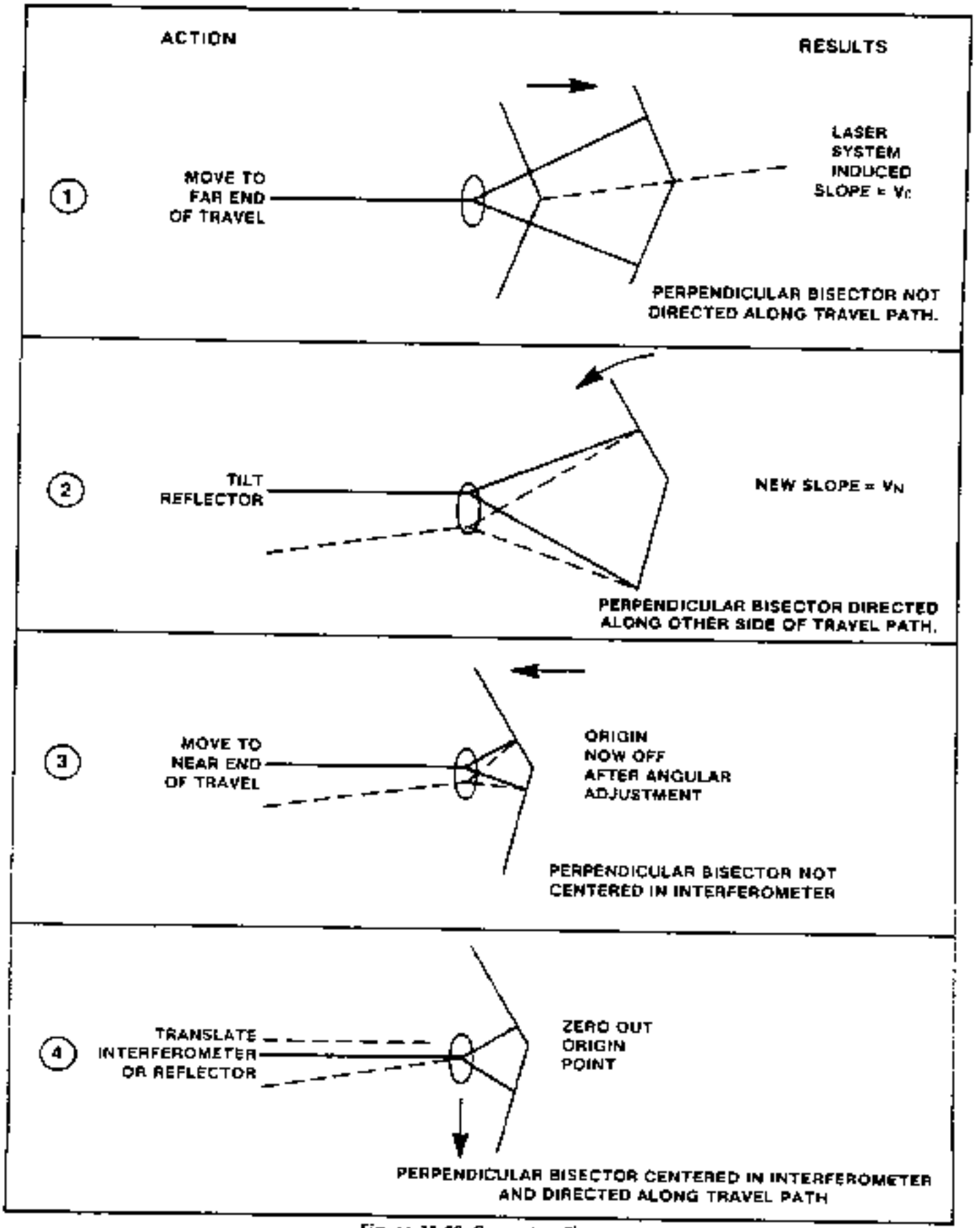


Figure 11-10. Removing Slope

4 Reset the Measurement Display, and return the machine to the near end of travel.

5 At the near end of travel, move the interferometer or the Reflector in a direction **parallel** with the slotted opening in the Reflector until the Measurement Display reads zero.

If beam strength again gets too low, turn the Laser Head to regain adequate beam strength, and translate the Laser Head to prevent clipping of the beam by the Interferometer.

6 Repeat step "4" through step "5" as often as necessary to make measurements at both ends of travel come out to be "zero".

Other Mounting Requirements

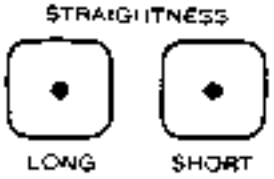
Although we have tried to provide you with a maximum of mounting flexibility, there may be situations when you need more capability. For more information, you should turn to Appendix C for dimensions of the Optics and the mounting hardware.

MEASUREMENT DISPLAY SETTINGS

NOTE

Measurement Display settings are the same with or without sensors.

Measurement Mode Keys



Press the key corresponding to the length of the measurement —

Use LONG for 1 metre to 30 metres (3 feet to 100 feet).

Use SHORT for 100 mm to 3 metre (4 in. to 10 feet).

Set-Up Keys

NOTES

1. To enter a value for any keys —
   a. Use the ENTRY keys to specify the numeric value.
   b. Press the key to assign the value to that key.
2. To check the current status of any of these keys, just press the key. Then press the key again, to return to the mode you selected earlier.
3. More information about each key is available in Section 16 of this User's Guide.

DIR SENSE

Determine which direction of motion you want to be "positive" or "negative", by pressing slightly on the Straightness interferometer and pressing this button if the direction you pushed caused the "wrong" sign for the reading. Remember that opposite perpendicular motions for the Interferometer and the Reflector result in readings with the same sign.

RESOL

Determine the resolution you need from the accuracy you want. Enter the number of places you want, and then press this key.

For a Short Straightness measurement, resolution extends to five places (0.00001) for millimetres, and to six places (0.000001) for inches.

For a Long Straightness measurement, resolution extends to four places (0.0001) for millimetres, and to five places (0.00001) for inches.

This key also allows you to "smooth" your data by entering a positive number. A negative resolution number will remove any smoothing. Smoothing reduces the effects of vibration.

PRESET

In this measurement mode, this key multiplies the measured value by a preset (stored) value. The multiplier value is "1", unless you have entered some other value (other than "0").

You must enter a calibration factor for the particular Straightness Reflector you are using. You will find the calibration number you need on the label without the serial number on the side of the Straightness Interferometer. Enter this number ("x.xx"), using the ENTRY keys to specify the numeric value, and then pressing PRESET.

NOTE

If you are using a Straightness Reflector from the HP 5526A System, enter the **reciprocal** of the calibration number you find on the Reflector (i.e., "1/cal nbr").

MAKING A MEASUREMENT

System Checks

1. Make sure the Laser Head's Exit port is switched to its large aperture.
2. The Laser Head turret must be set to "STRAIGHT".
3. The Laser Head's READY indicator must be lighted steadily (i.e., not blinking).
4. Make sure you are properly interfaced with other instruments as needed to record your data.
   a. If you record your data manually, no interfacing is necessary.
   b. If you want to record your data automatically, but you aren't using the HP Dimensional Metrology Analysis System or another HP-IB controller, you must have an HP-IB compatible printer connected to the Measurement Display unit, via the rear panel HP-IB

connector. You must also make sure the Measurement Display is set-up to output to a printer via HP-IB. See Section 18 and follow the instructions for "Data Transfer without an HP-IB Controller".

c. For formatted automatic records, you should have the HP Dimensional Metrology Analysis System or an HP-IB controller with your own programs to make it work with the Laser Measurement System. The HP Analysis System comes with an HP Personal Computer and programs to make it work with the Laser Measurement System. The operating manual for the Analysis System will explain how to use it. In either case, you must first make sure the Measurement Display is set-up to accept a controller via HP-IB. See Section 18 and follow the instructions for "Data Transfer with an HP-IB Controller".

Procedures

Two different measurement methods are available. You can have your system make measurements —

- only at points you specify, or —
- automatically, at the time interval you specify, without regard to the location of the Optics.

Measurements at Specific Physical Locations

To have your Laser Measurement System make measurements only at specific physical locations —

1. Push the RESET key. (You can also RESET from the Remote Control Unit.)
2. Move one of the optics a predetermined distance.
3. Press the RECORD button on the Remote Control Unit connected to the Measurement Display. One measurement is made each time you press this button.

Measurements at Specified Time Intervals

To have your Laser Measurement System make measurements at specific time intervals (i.e., "on-the-fly") —

1. Push the RESET key. (You can also RESET from the Remote Control Unit.)
2. Enter the time interval you want between measurements (0.05 to 12 seconds).
3. Press the AUTO RECORD key. This will start the automatic taking of data. (See Section 16 for more information about using this key.)
4. Move one optic along the full measurement path. A measurement is made automatically every so many seconds until you press the AUTO RECORD key again.
5. Press the AUTO RECORD key when the end of travel is reached. This will turn off the AUTO RECORD mode, and end the recording of measurements.

NOTES

- Make sure the frequency at which you want to take measurements isn't greater than the rate at which the Measurement Display unit can update measurements for the resolution you have requested. (The update rate decreases as resolution increases). If you exceed the update rate for a given resolution, "Sr Error" will be displayed. Update rates are provided in the Laser Measurement System's Service Manual.

- If an HP Personal Computer or an HP-IB Printer is not connected to the Measurement Display unit, pressing RECORD or AUTO RECORD will cause the message "Lr Error" to be displayed.

WHAT AFFECTS ACCURACY?

Potential Straightness measurement errors are unlike those for either Distance or Angular measurements.

Laser System Error Sources .

Error sources within the Laser Measurement System are —

a. Straightness Reflector mirrors.

b. Mis-alignment between the machine's travel axis and the Laser Measurement axis ("slope").

c. Environment (e.g., machine and atmosphere).

Straightness Reflector Mirrors

Description

The limiting accuracy of a Straightness measurement is directly related to the accuracy of the mirror calibration factor and to the difference in flatness of the two plane mirrors that serve as the Straightness Reflector. V O L error is negligible compared to the overall measurement accuracy.

For example, suppose one of the mirrors is flat, but the other is convex by a small amount ("C"), as shown in *Figure* 10-11. Even if the Straightness Interferometer were to travel a straight path with respect to the Mirror's axis, the optical path length of f_1 would be shortened by an amount equal to "C" with respect to the optical path of f_2, and this would be interpreted by the Interferometer as "out-of-straightness" in the Interferometer's travel.

Straightness accuracy limitations resulting from the Reflector's mirrors are given under "OPTICAL STRAIGHTEDGE ACCURACY", in the "OPERATING SPECIFICATIONS" at the beginning of this User's Guide Section.

Minimizing Effects

You can't improve the accuracy of a vertical Straightness measurement by rotating the Straightness Reflector 180 degrees, as you can with Straightness measurements along a horizontal axis (see Section 10).

In order to get the correct spacing between the Turning Mirror and the Reflector for a Straightness measurement along a vertical axis, you must assemble the Reflector in its mount with the slotted opening away from the screws labelled "1" in *Figure 11-2*. Because of this, the Reflector can't be rotated around the junction of its mirrors to provide a measurement with its mirrors rotated 180 degrees.

Misalignment Between Machine Travel and the Laser Measurement Axis (Slope)

Description

This does **not** cause a cosine error, as it did in Distance measurements. Instead, misalignment causes a slope to be measured, since the straightness reflector is not directing its reference bisector along a path parallel to the axis of travel. (See *Figure 10-12.*)

Minimizing Effects

The three ways to remove slope from the Straightness data are —

1. Automatic Calculator reduction and plot of data.
2. Manual mathematic reduction and plot of data.
3. Manually aligning the slope out with a zero-end-point-fit.

Manual alignment may be necessary if the slope becomes great enough to reset the Measurement Display before the end of travel is reached, or if a subsequent squareness measurement is to be made.

If you have the HP Dimensional Metrology Analysis System (DMAS), you will want to use method "1" above, and automatically remove slope. If you don't have the DMAS, you will have to use method 2 or method 3.

Method 2 is done by calculating either a zero-end-point or a least-squares best line fit through the data points, and subtracting the slope at each command position. Section 21 describes how to do this.

Method 3 is described in detail in the "INSTALLATION AND ALIGNMENT OF OPTICS" part of this User's Guide Section.

Environmental Errors

Description

As with any accurate measurement, and in particular with all Laser System measurements, the environment plays a very important role.

Environmental errors come from —

1. Thermal expansion of the machine or part.
2. Machine vibration.

3 Air turbulence

A Straightness measurement is especially susceptible to environmental effects. It is impossible to quantitatively determine how these environmental characteristics will affect the measurement, although it is sometimes possible to identify when they are having an effect.

Excessive vibration and/or air turbulence can be identified by —

1. Random drifting of the measurement results when the Optics are at rest.

2. Drifting increasing as the distance between the Optics increases.

The effects of vibration can be further identified if the drifting of the measurement stops when the machine is turned off, or by exceeding the slew rate during the measurement (disrupting the measurement).

Minimizing Effects

1. Thermal expansion of the machine or Optics.

   These effects can be minimized by letting the machine and Optics reach thermal equilibrium before making a measurement.

2. Machine Vibrations.

   a. Adequate fixturing is the main way to reduce the effects of vibration.

      Make sure the Straightness Reflector's Base is securely fastened to the table, and that the Post is securely fastened to the base on one end and the Reflector on the other.

      Avoid long extensions.

   b. Vibrational effects can also be reduced by —

      - Averaging successive runs or averaging successive averages.
      - More accurate manual slope removal.
      - Reduced feed rates.
      - Pads under the reflector's base as a last resort in high-vibration, low-accuracy work.

3. Air Turbulence

   Air turbulence is caused by temperature differences in the air. To remove these differences, you should remove their sources (e.g., open doors, lamps, exhaust fans, motors, etc.). Alternatively, you should mix the air thoroughly along the measurement path, using a large fan. If you can reduce the sources of temperature differences **and** mix the measurement path air, you'll be even better off.

12 Squareness-Horizontal Plane

SECTION 12
SQUARENESS MEASUREMENTS (IN A HORIZONTAL PLANE)

CONTENTS

INTRODUCTION
OPERATING SPECIFICATIONS
HARDWARE REQUIRED
REFERENCE MATERIAL
FIRST-AXIS MEASUREMENT
SECOND-AXIS MEASUREMENT
WHAT AFFECTS ACCURACY?

INTRODUCTION

A "Squareness" measurement consists of two Straightness measurements, perpendicular to each other, made with a fixed Straightness Reflector. This is typically done by first making a horizontal Straightness measurement along one axis using an Optical Square, then removing the Optical Square, moving the Laser Head, and making a horizontal Straightness measurement along the second axis. This process is diagrammed in *Figure 12-1*.

This section is organized to provide instructions for each axis you should measure to compute a "Squareness". Separate procedures are provided for the "first-axis" measurement and the "second-axis" measurement.

NOTE

There are both a Straightness Reflector and a Straightness Retroreflector. In this User's Guide Section, we will try to always type "Retroreflector" like this, with the "Retro" in bold type, to emphasize when that is the one that is to be used.

OPERATING SPECIFICATIONS

Accuracy

Short Range Optics:
Metric Units Mode: $\pm(1.0^{1} \pm 0.1M)$ arc-sec $\pm 1\%$ of θ
English Units Mode: $\pm(1.0^{1} \pm 0.03M)$ arc-sec $\pm 1\%$ of θ

Long Range Optics:
Metric Units Mode: $\pm(1.0^{1} \pm 0.01M)$ arc-sec $\pm 2.5\%$ of θ
English Units Mode: $\pm(1.0^{1} \pm 0.003M)$ arc-sec $\pm 2.5\%$ of θ

where:
θ = calculated out-of-squareness angle in arc-sec
M = distance of travel of the moving optic in metres
F = distance of travel of the moving optic in feet

NOTE

"1.0" can be as large as 1.2 arc-sec with maximum allowable misalignment of the optical square as per the alignment procedure.

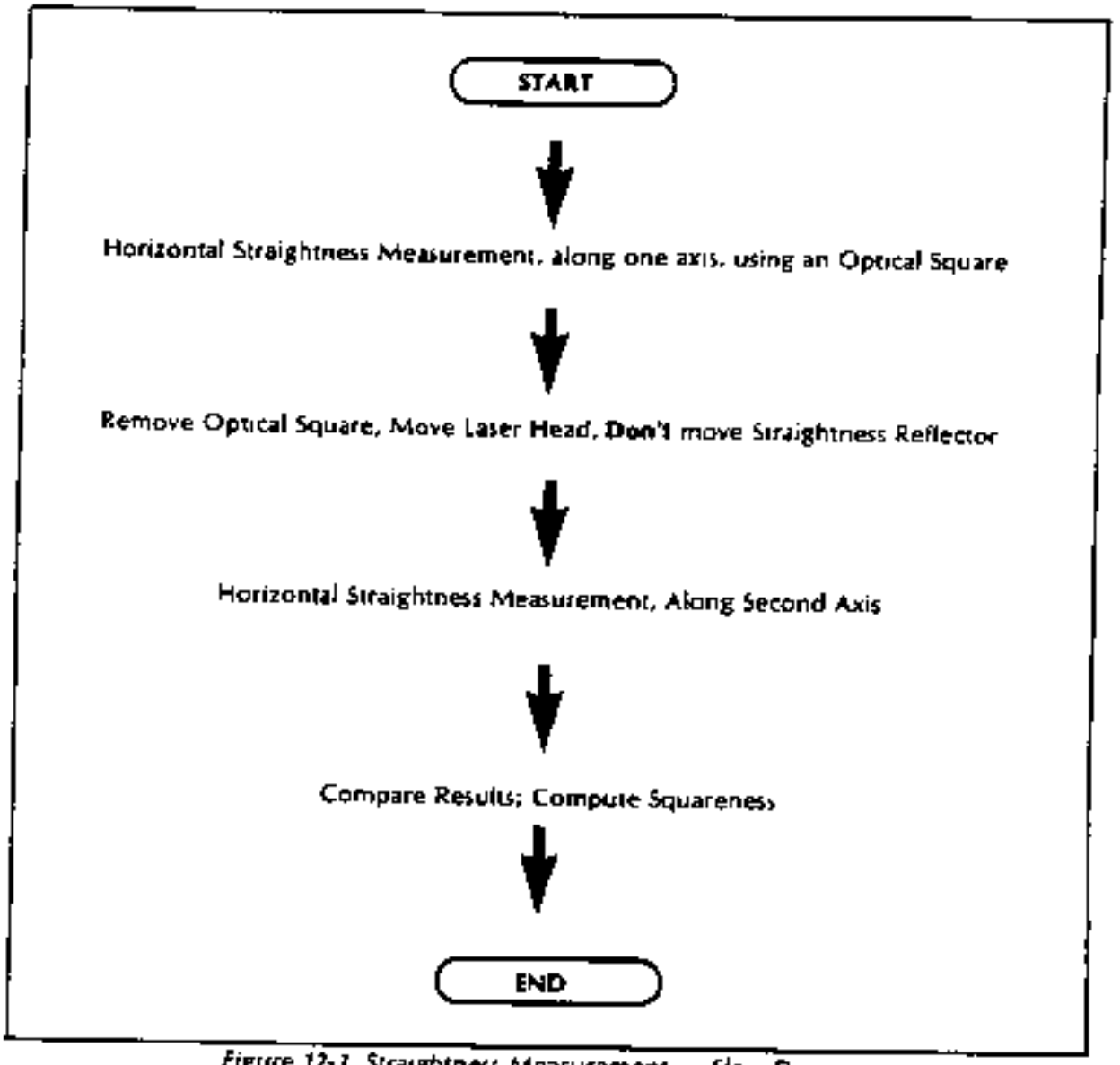


Figure 12-1 Straightness Measurement — Flow Diagram

HARDWARE REQUIRED

In addition to the hardware required for any measurement using the Laser Measurement System (see *Figure 4-1*), any horizontal Squareness measurement requires the hardware shown in *Figure 12-2*. This hardware is the same as that required for a Straightness measurement, plus an Optical Square and its Mount.

If you are measuring a machine with a horizontally oriented spindle you will also need a Straightness Retroreflector.

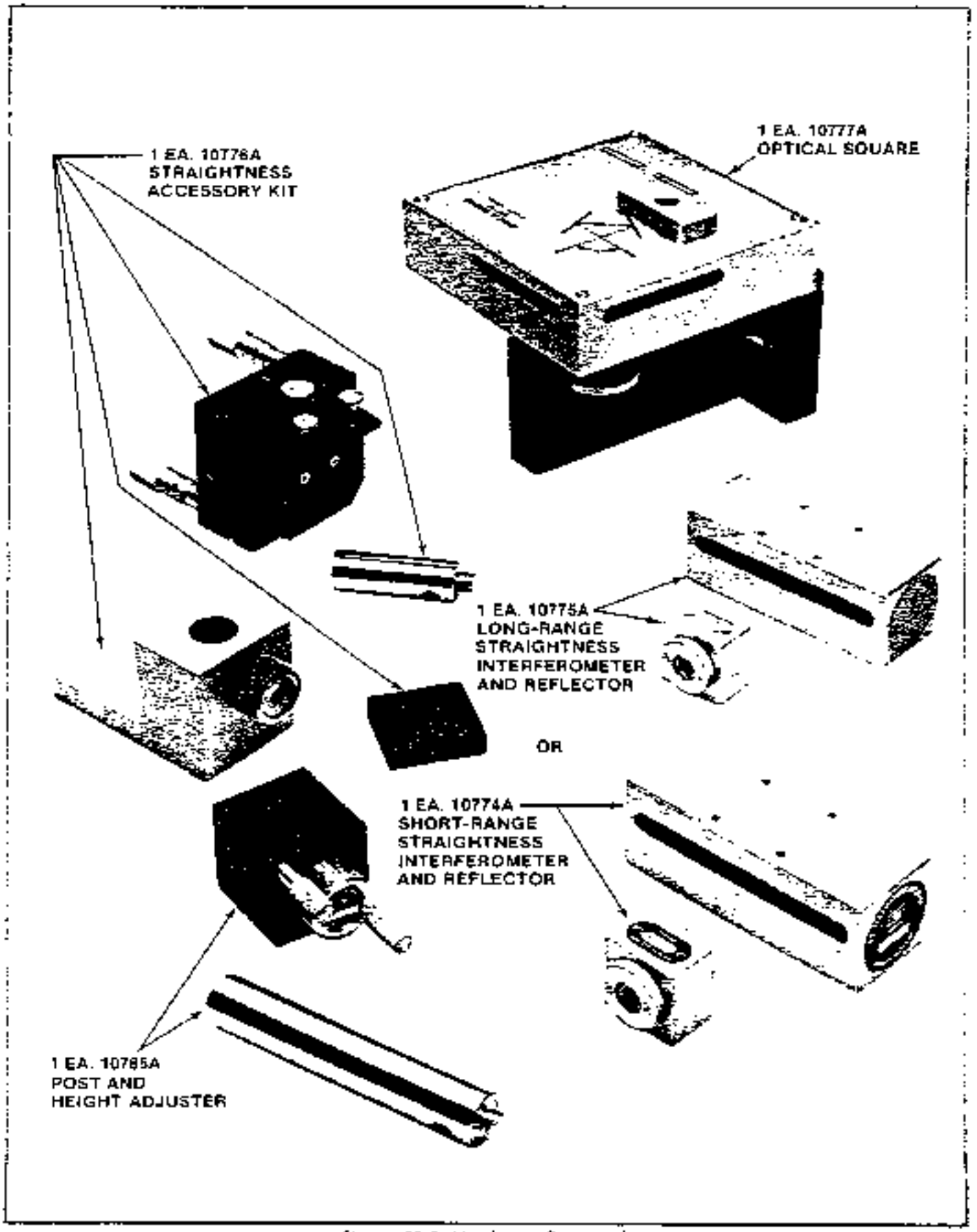


Figure 12-2 Hardware Required

REFERENCE MATERIAL

Physical Setup of the Laser Head and Tripod ..... Section 4
Interconnections, Turn-on ..... Section 5
Straightness Measurements (Horizontal Axis) ..... Section 10
Straightness Measurements (Using the Straightness Retroreflector) ..... Section 11
Alignment Techniques ..... Section 15

FIRST-AXIS MEASUREMENT (Using an Optical Square)

The first-axis measurement is a horizontal Straightness measurement along a horizontal axis using an Optical Square. (See *Figure 12-3.*) This axis should be perpendicular to the Straightness Reflector.

The instructions presented in this User's Guide Section (Section 12) will highlight the additional things you need to know (beyond the information presented in Section 10 and in Section 11) in order to make this Squareness measurement.

Installation and Alignment of Optics

Important Considerations

1. See "Important Considerations" in both Section 10 and Section 11.

2. Try to manually remove as much slope as possible once you are aligned. This will make your second axis alignment much easier.

3. If you can move the Interferometer along one of the axes, it may be possible for you to make both Straightness measurements from one Laser Head position. One Straightness measurement would be made with the Interferometer between the Straightness Reflector and the Optical Square, and the second measurement is made with the Interferometer between the Optical Square and the Laser head. To do this, make your first axis be the axis that the Interferometer can't travel along.

Description

For the measurement of the first axis you will install and align the Optics in three distinct steps. First, you will install the Optical Square, the Interferometer, and the Retroreflector (if required) and align the Laser Head to the path traveled by the Interferometer and the Optical Square. Second, you will install the Straightness Reflector. Third, you will make final adjustments to the tilt of the Reflector to maximize Beam Strength.

1. Installation and Alignment of the Interferometer and the Optical Square.

   The procedures below are similar to those found in Section 10 and Section 11 of this User's Guide, except that the Straightness Reflector is replaced with the Optical Square.

ON MACHINES WITH VERTICAL SPINDLES

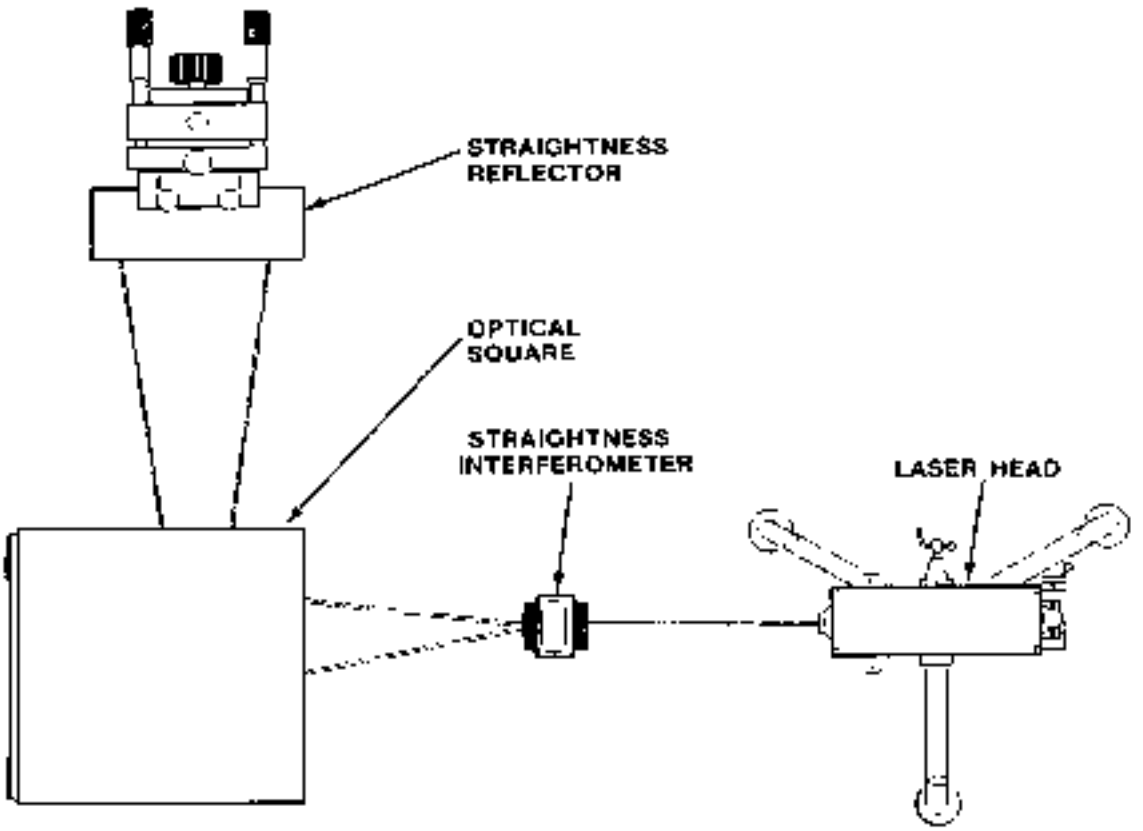


Figure 12-3. First-axis Positioning of Optics

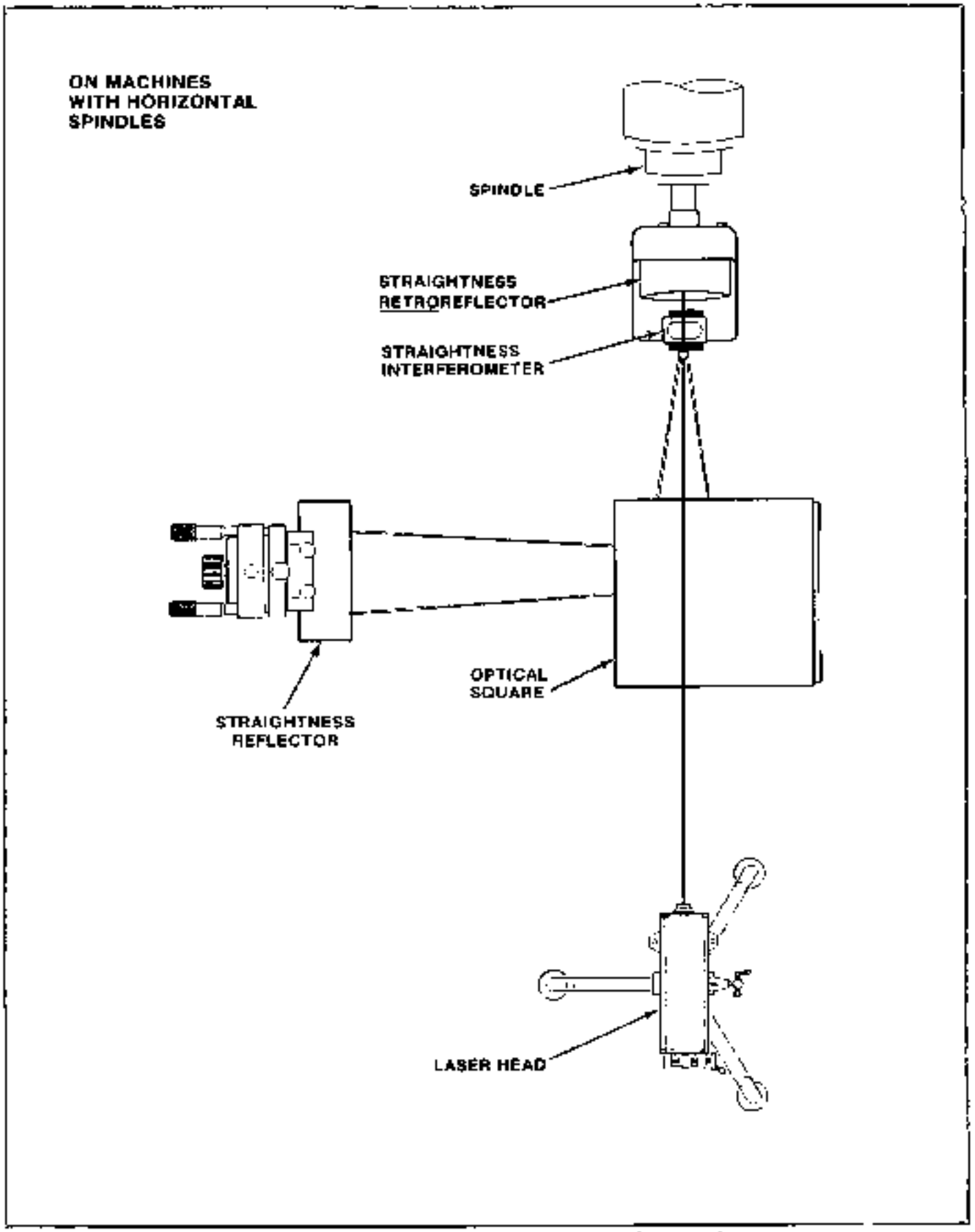


Figure 12-3. First-axis Positioning of Optics (Continued)

NOTE

There are two separate procedures for this step, depending on whether your machine's spindle (toolholder) is oriented vertically or horizontally.

2. Installation of the Straightness Reflector

   After the Optical Square and the Interferometer have been installed and aligned you will use the Laser beam to position the Reflector.

3. Final Adjustments

   You will use a special technique to adjust the Reflector to bring the beams back to the Laser Head and provide sufficient beam strength.

Installation and Alignment of Interferometer and Optical Square

For A Machine With A Vertical Spindle

NOTE

A machine with a vertical spindle should have space behind the spindle to mount either the Straightness Reflector or the Optical Square.

1. Attach the Optical Square to its Mount (See *Figure* 12-4) and orient it on its side so its slots are parallel to the machine's table.

2. Identify the axes you are going to measure to make your Squareness measurement. Identify which axis will be your first measurement axis and which will be your second. Try to maximize travel paths for each axis. (The Optical Square is fairly large and will shorten the axis it is used to measure.)

3. Position the Optical Square at the apex of your square with each of its slots facing one measurement axis.

   This should be out in front or to the side of the machine since your second measurement will be made without the Optical Square and will require a straight line from the Laser Head, through the Interferometer, and into the Reflector.

4. Attach the Straightness Interferometer to its mounting hardware (see *Figure* 10-3), and to the machine's spindle, by —

   - attaching the Height Adjuster to a Post as you would for table mounting, or —
   - screwing its base directly into the post, or —
   - screwing the Post into the Height Adjuster after removing the large knurled knob. This latter arrangement may make it easier to change to Distance and Angular Optics

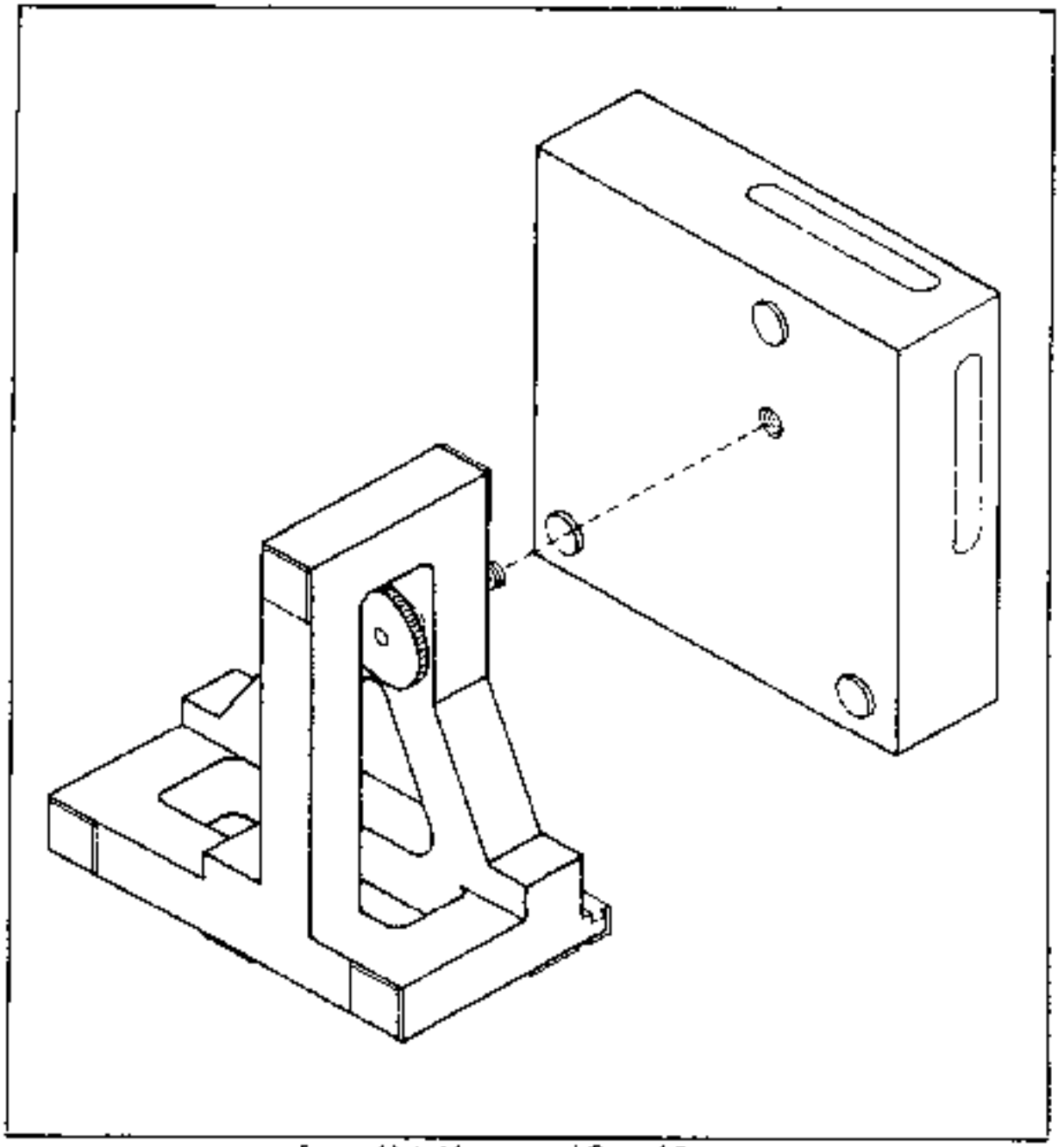


Figure 12-4. Mounting of Optical Square

5 Position the Straightness Interferometer relative to the Optical Square.

- Bring the Interferometer close enough to the Optical Square to line up the Interferometer with the center of the Optical Square's slot. Be sure it is centered in both axes (up-and-down, and side-to-side).
- This is a very important step. If the Optics are not physically lined up at this point, aligning along the travel axis will be impossible.
- Be sure this establishes the "near end of travel", i.e., that any later movement of the machine can only increase the distance between the Optics.

6. Secure the Interferometer to the machine in such a way that the Interferometer is as square as possible relative to the incoming beam. The Interferometer housing's pitch limitations are ± 2 degrees; its yaw and roll limitations are ± 5 degrees. The pitch requirement will be taken care of automatically by using the mounting hardware listed above.

7. Make sure the Optical Square is fairly square relative to the machine and to the Interferometer, and then secure it to the machine.

8. Select the small opening for the Laser Head's exit port, and set the turret ring to "OTHER". (When aligning your setup, it is good practice to work with the strongest possible beam, which this setting provides.)

9. Attach the target to the Straightness Interferometer. This target is included with the Optics.

   The target should be attached to the Straightness Interferometer opening that is directed toward the Laser Head.

   Make sure the target is positioned as closely as possible relative to the edges of the Optic. Use your fingers to match edges.

10. Visually align the Laser Head as well as you can parallel to the direction of travel and position it so its beam enters via the hole in the middle of the Interferometer's target.

    Use "Autoreflection" to help you do this once you become proficient at Laser System measurements.

11. Rotate the Interferometer's bezel until the bezel's scribe line is oriented 90 degrees to the Optical Square's slot. Two beams should now come out of the Interferometer, in a plane perpendicular to the Optical Square's slot.

12. Looking at the Optical Square's slot that faces the Interferometer, move the Optical Square or the Interferometer until the two dots are in line with the scribed line in the center of the Optical Square's slot and symmetrical within the opening (see Figure 12-5).

    Make sure the beam still goes through the Interferometer's target hole.

    If it is too difficult doing this with the small-aperture beam and the Interferometer target, do it first using a full beam and no target.

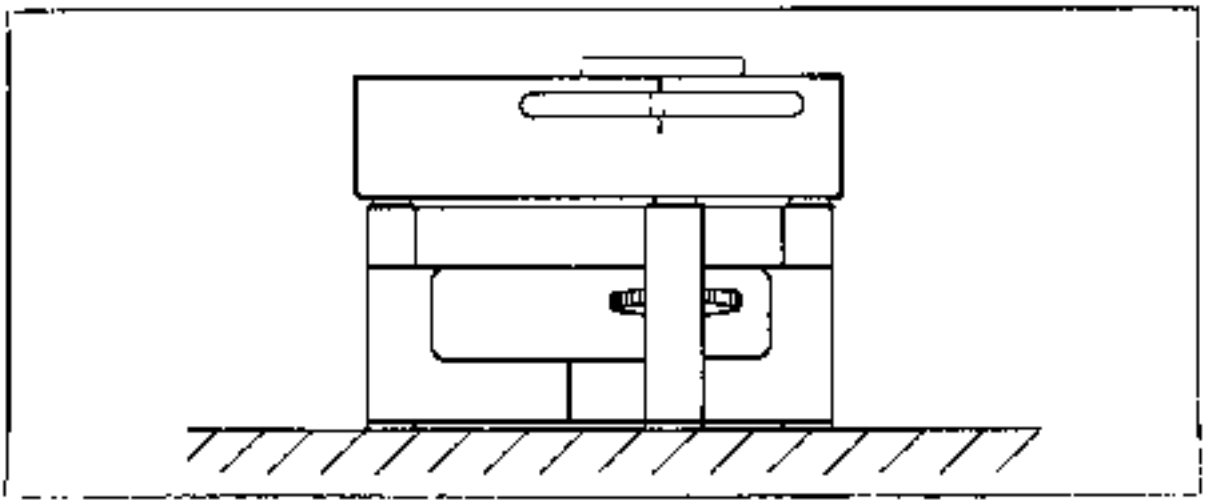


Figure 12-5. Initial positioning of the Optical Square

13. Re-secure the Optical Square assembly to the machine, if you had to move it in step "12".

14. You are now ready to align the Laser to the Interferometer's or Optical Square's travel.

    Review the "GUNSIGHT" method of alignment in Section 15 of this User's Guide.

    Your goal is to adjust the Laser Head to track the Optic's progression along the travel path, while maintaining the beam's near-end-of-travel position. You will do this by —

    - Keeping the beam in the small hole on the Interferometer target, to maintain the beam's near-end-of-travel position, and —
    - Keeping a two-dot pattern in line with the line at the center of the Optical Square's slot, and symmetrical about its opening, to match the Optic's travel.

      This will be a little different than aligning for Distance and Angular measurements, since with these alignments you were only watching one dot relative to a target crosshair.

15. Move the Optics to the far end of travel. Be sure the target is in place on the Interferometer and the small aperture is selected for the Laser Head's exit port.

16. **Rotate** the Laser Head, vertically and horizontally, to keep the two dots lined up on the scribed line at the center of the Optical Square's slot, and symmetrical about its opening (see *Figure 12-6*).

    Since the dots will move apart as the Optics move, you may have to hold a card on each side of the Optical Square's slot to follow their movement.

17. **Translate** the Laser Head, horizontally and vertically, to keep the beam from being clipped by the small hole in the Interferometer target.

    Any translation of the Laser Head will cause the two dots to move from their position on the Optical Square, so you will again have to rotate and translate the Laser Head (i.e., repeat step "16" and step "17") several times before you are finished.

    You are finished with this procedure when the beam goes through the Interferometer target and the two dots are symmetrical about the Optical Square's slot and in line with the scribed line at the center of the slot. (See *Figure 12-6.*)

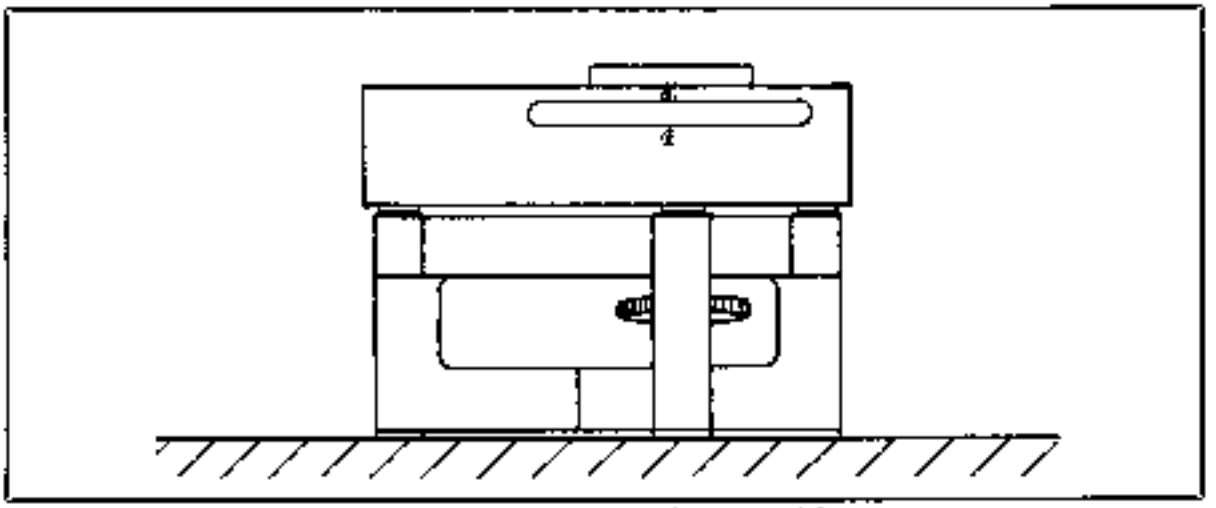


Figure 12-6. Two Dots on the Optical Square

18. Now go to the "PROCEDURE FOR INSTALLING THE STRAIGHTNESS REFLECTOR", below.

For A Machine With A Horizontal Spindle

NOTE

A machine with a horizontal spindle will not have space behind the spindle to mount either the Straightness Reflector or the Optical Square. For these machines, you will have to use a Straightness **Retro**reflector to reverse the Laser Beam

1. Attach the Optical Square to its Mount (See Figure 12-4) and orient it on its side so its slots are parallel to the machine's table

2. Identify the axes you are going to measure to make your Squareness measurement. Identify which axis will be your first measurement axis and which will be your second. Try to maximize travel paths for each axis. (The Optical Square is fairly large and will shorten the axis it is used to measure.)

3. Position the Optical Square at the apex of your square with each of its slots facing one measurement axis.

   This should be out in front or to the side of the machine since your second measurement will be made without the Optical Square and will require a straight line from the Laser Head, through the Interferometer, and into the Reflector.

4. Mount the Vertical Straightness Kit's Straightness **Retro**reflector where the tool normally mounts, except orient it horizontally instead of vertically. (See *Figure* 12-7.)

   Screw the Interferometer into the large **Retro**reflector, using the two 3 mm flathead screws provided.

5. Orient the **Retro**reflector so the Interferometer lines up with the center of the Optical Square's slot opening and the top half of the **Retro**reflector is exposed to the laser beam that will come from the other side of the Optical Square.

   Fasten the **Retro**reflector to the machine in such a way that the Interferometer is as square as possible to the Reflector and to the incoming beam. The Interferometer housing's pitch limitations are ±2 degrees; its yaw and roll limitations are ±5 degrees. The pitch and yaw requirements will be taken care of automatically by using the Straightness **Retro**reflector and an HP Post.

6. Position the Optical Square relative to the **Retro**reflector and Interferometer.

   - Be sure this establishes the "near end of travel", i.e., that any later movement of the machine can only increase the distance between the Optics.
   - Bring the Interferometer/**Retro**reflector assembly close enough to the Optical Square to line up the Interferometer with the center of the Optical Square's slot. Be sure it is centered in both axes (up-and-down and side-to-side).
   - This is a very important step. If the Optics are not physically lined up at this point, aligning along the travel axis will be impossible.

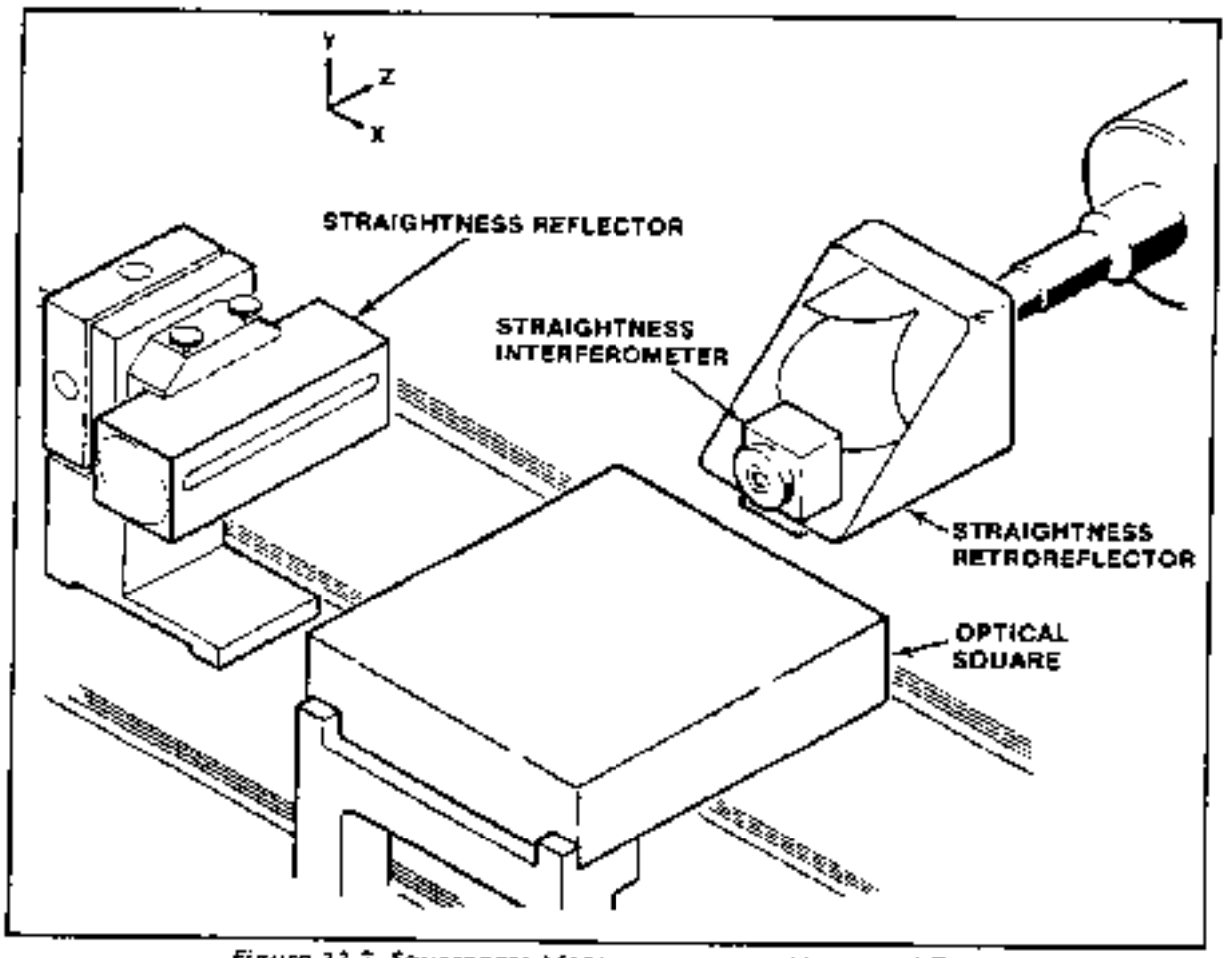


Figure 12-7. Squareness Measurement on a Horizontal Z-axis

7. Make sure the Optical Square is fairly square relative to the machine and to the Interferometer, and then secure it to the machine.

8. Switch to the large aperture on the Laser Head's exit port, and set the turret ring to "OTHER" (When aligning your set up it is good practice to work with the strongest possible beam, which this setting provides.)

9. Visually align the Laser Head as well as you can parallel to the machine's table, and position it to have the beam go over the Optical Square and through the Retroreflector's Alignment ring. (See *Figure 12-8.*)

NOTE

Once you become familiar with alignment principles, you may want to do this using "AUTOREFLECTION" techniques.

10. Orient the Interferometer bezel's scribed line 90 degrees to the Optical Square's slotted opening. Two dots should appear on the Optical Square's front surface unless the Optics are quite close together. If so, insert a piece of paper across the front of the Optical Square to see the dots.

11. Further adjust the Optical Square's position, if necessary, until the two dots are directly in line with the scribed line at the center of the Optical Square's slot and are also symmetrical within its opening. (See *Figure 12-5.*)

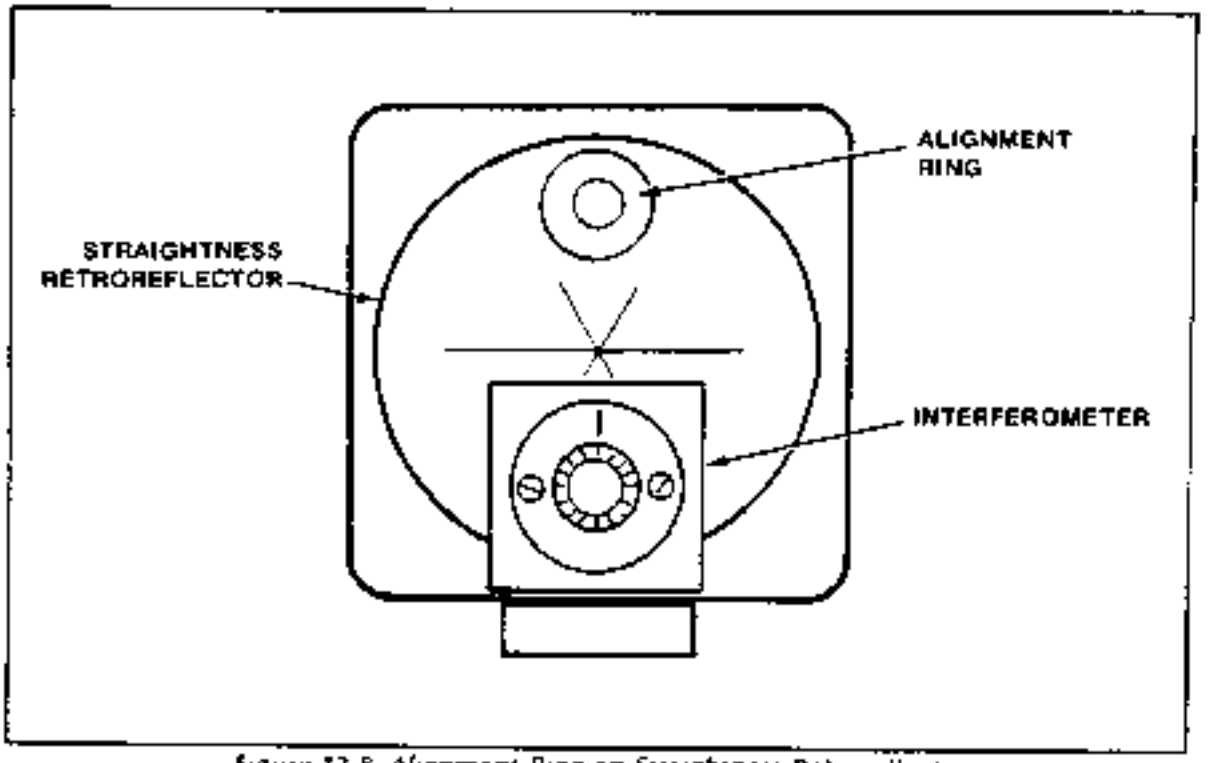


Figure 12-8 Alignment Ring on Straightness Retroreflector

12. Re-Secure the Optical Square assembly to the machine, if you had to move it in step "11"

13 Select the exit port's large aperture.

14 You are now ready to align the Laser to the machine's travel

Review the "GUNSIGHT" method of alignment in Section 15 of this User's Guide

Your goal is to adjust the Laser Head to track the Optic's progression along the travel path, while maintaining the beam's near-end-of-travel position. You will do this by —

- Keeping the beam in the Alignment ring on the Retroreflector, to maintain the beam's near-end-of travel position, and —
- Keeping a two-dot pattern in line with the center of the Optical Square's slot, and symmetrical about it, to match the Optic's travel.

  This will be a little different than aligning for Distance and Angular measurements, since with these alignments you were only watching one dot relative to a target crosshair

15 Move the Interferometer or the Optical Square to the far end of travel.

16. **Rotate** the Laser Head vertically and horizontally to keep the two dots lined up on the scribed line at the center of the Optical Square's slot and symmetrical about this opening. (See *Figure 12-6.*)

Since the dots will move apart as the Optics move, you may have to hold a card on each side of the Optical Square's slot to follow their movement

17. **Translate** the Laser Head vertically and horizontally to keep the Laser beam from being clipped by the alignment ring on the Straightness **Retro**reflector.

    Check this by making sure you can't see the beam on the Interferometer surface that faces the **Retro**reflector.

    Any translation of the Laser Head will cause the two dots to move from their position on the Optical Square, so you will again have to rotate and translate the Laser Head (i.e., repeat step "16" and step "17" several times) before you are done.

    You are finished with this procedure when the beam goes through the Interferometer without being clipped, and the two dots are symmetrical about the Optical Square's slotted opening and in line with the scribed line at the center of the slot. (See *Figure 12-6.*)

Procedure for Installing the Straightness Reflector

1. Select the small aperture for the exit port on the Laser Head. (You can also use the large aperture.)

2. Make sure the Interferometer bezel's scribe line is oriented 90 degrees relative to the slot in the Optical Square.

3. Move the Optics back to the near end of travel, so that they almost touch, and close enough together to get both dots to go through the Optical Square's first slot without being clipped.

4. Position the Straightness Reflector at the end of the second measurement axis and center the two dots on the junction between its mirrors and symmetrical about its slotted opening.

   Be sure to orient the Reflector to make a horizontal straightness measurement.

   If you can not get two dots to strike the surface of the Reflector, remove the Interferometer from the laser beam path and repeat this step with only one dot.

5. Secure the Straightness Reflector to the machine after making sure it is as square as possible to the incoming beam.

Final Adjustments (After Aligning)

1. Turn the Laser Head's turret ring to "OTHER", if it's not already there.

2. Select the Exit port's small aperture.

3. Rotate the bezel until its scribed-line is parallel to the slot in the Optical Square.

4. Look at the side of the Optical Square facing the Reflector. If you don't see two dots, adjust the Reflector Mount's micrometer head that controls vertical motion until both dots appear on the side of the Optical Square.

   a. Turn the Interferometer bezel until the dots line up **parallel** to the slot in the Optical Square.

   b. Adjust the Reflector Mount's horizontal motion micrometer until both dots are symmetrical about the scribed line at the center of the Optical Square's slot. (See *Figure 12-9.*)

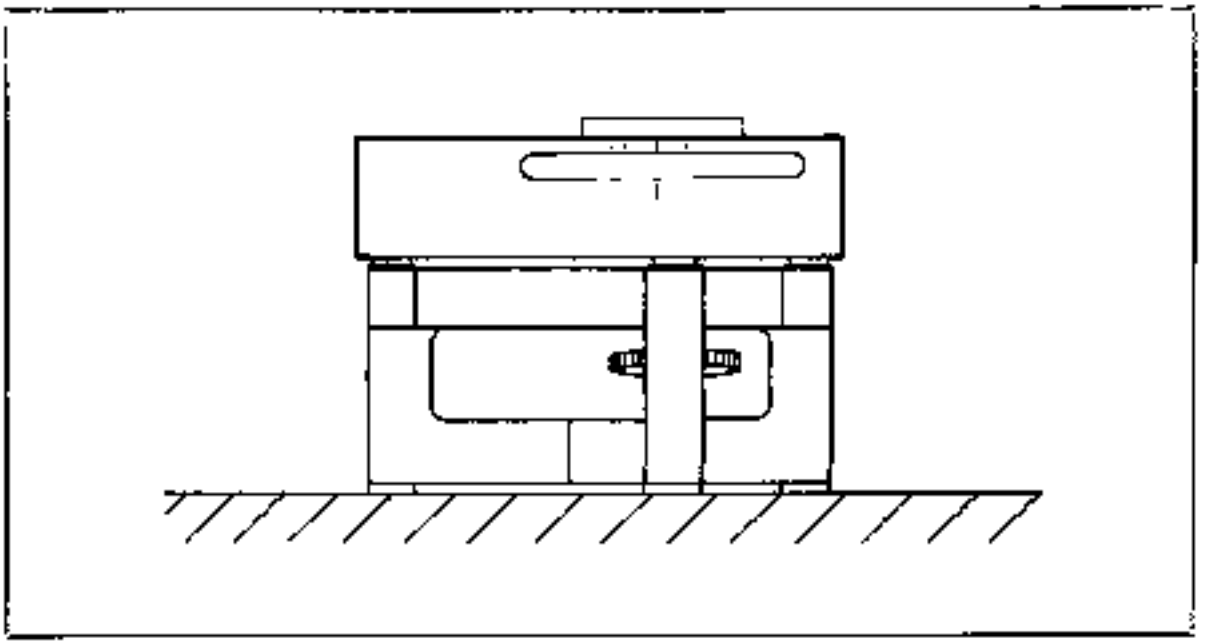


Figure 12-9. Result of Horizontal Motion Adjustment to the Straightness Reflector

c. Adjust the Reflector Mount's vertical motion micrometer until both dots disappear into the Optical Square's slot.

5. Look at the Laser Head. You should see two dots. If you don't see the dots —

   a. Look at the side of the Interferometer facing the Optical Square.

   b. You should see either one or two closely spaced dots on the Interferometer.

   c. Adjust the Reflector Mount's micrometers until the dot(s) disappear into the Interferometer.

   d. Look at the Laser Head. You should now see the dot(s) on the front of the Laser Head.

6. Turn the bezel until the dots overlap.

7. Adjust the Reflector Mount's micrometers until the overlapping dots are centered on the exit port, and "halo" the small aperture.

8. Set the Laser Head's turret ring to "STRAIGHT".

9. Select the Laser Head exit port's large aperture.

10. Turn the bezel slightly until the Laser Head's "SIGNAL" light comes on and the BEAM STRENGTH meter indication is in the green area.

NOTE

Only a slight adjustment of the bezel is necessary to do this.

11. Further adjust the Reflector Mount's micrometers until the Beam Strength meter indication is at a maximum.

Checking Alignment For Beam Strength

Move the machine over its full travel range, making sure that BEAM STRENGTH is adequate (in the green area) at all positions.

If beam strength decreases at any point, —

a. Check for clipping of the beam by the Optics. Reposition the Optics, if necessary, and then re-check.

b. If you see part of the return beam on the edge of the Exit (top) port, rotate the Laser Head until the return beam disappears.

If this didn't correct the "reduced beam strength" problem, refer to the "Manual Removal of Slope" information below.

NOTE

If the BEAM STRENGTH indication never reaches the right-hand half of the meter's range, at any point along the Optics' full travel distance, your Optics may need cleaning. Thoroughly clean all optical surfaces, as described in Section 20 of this User's Guide.

Checking for Mis-alignment Between the Reflector's Reference Bisector Optics Travel Path ("Slope")

Follow the instructions given under this heading in Section 10.

Manual Removal of Slope

Follow the instructions given under this heading in Section 10. Try to remove as much slope as possible; this will help make it easier to get adequate beam strength when you measure the second axis.

Measurement Display Settings

1. Use the instructions given in Section 10 of this User's Guide.

2. When entering values for the SET UP keys, be sure you choose the correct sign convention for DIR SENSE. The sign convention is critical in a squareness measurement. Use the instructions given in Section 21 of this User's Guide, under the heading of "Squareness Sign Conventions".

Making A Measurement

System Checks

1. Use the instructions in Section 10 for "SYSTEM CHECKS", under "MAKING A MEASUREMENT".

2. Make sure you input a calibration factor for the Optical Square to the HP Dimensional Metrology Analysis System's program, if you use that system. You will find the calibration number next to the serial number on the Square's front surface.

Procedure

Since a Squareness measurement requires comparing two Straightness measurements, you must have the measurement data from the first axis available for comparison with the second-axis data. This is easily done with the HP Dimensional Metrology Analysis System. Refer to the Analysis System's Operating Manual and programs for exactly how to record and store the data for this first axis.

If you don't use the HP Dimensional Metrology Analysis System, follow the instructions in Section 10 for "PROCEDURE", under "MAKING A MEASUREMENT". Then refer to Section 21 of this User's Guide to help you calculate Squareness from your data.

What Affects Accuracy?

See the information presented under this heading in Section 10 of this User's Guide.

SECOND-AXIS MEASUREMENT (Horizontal Axis)

This second-axis measurement is merely a horizontal Straightness measurement along a horizontal axis (see Figure 12-10). Thus, you should follow the instructions given in Section 10 of this User's Guide, and add to that (as appropriate) the information below.

Installation and Alignment of Optics

NOTE

Do not move or adjust the Straightness Reflector from its position after the first measurement. The Reflector is the reference point used in determining the slopes of the two axes; these slopes are then compared in order to calculate Squareness.

Procedure

1. Remove the Optical Square and Retroreflector (if you used one).

2. Move the Laser Head to line up with the new measurement axis, so the beam hits the junction of the Reflector's mirrors.

3. Follow the "INSTALLATION AND ALIGNMENT" instructions in Section 10. Remember, **Do not move or adjust the Straightness Reflector.**

Final Adjustments (After Aligning)

Follow the "FINAL ADJUSTMENT" instructions in Section 10, except:

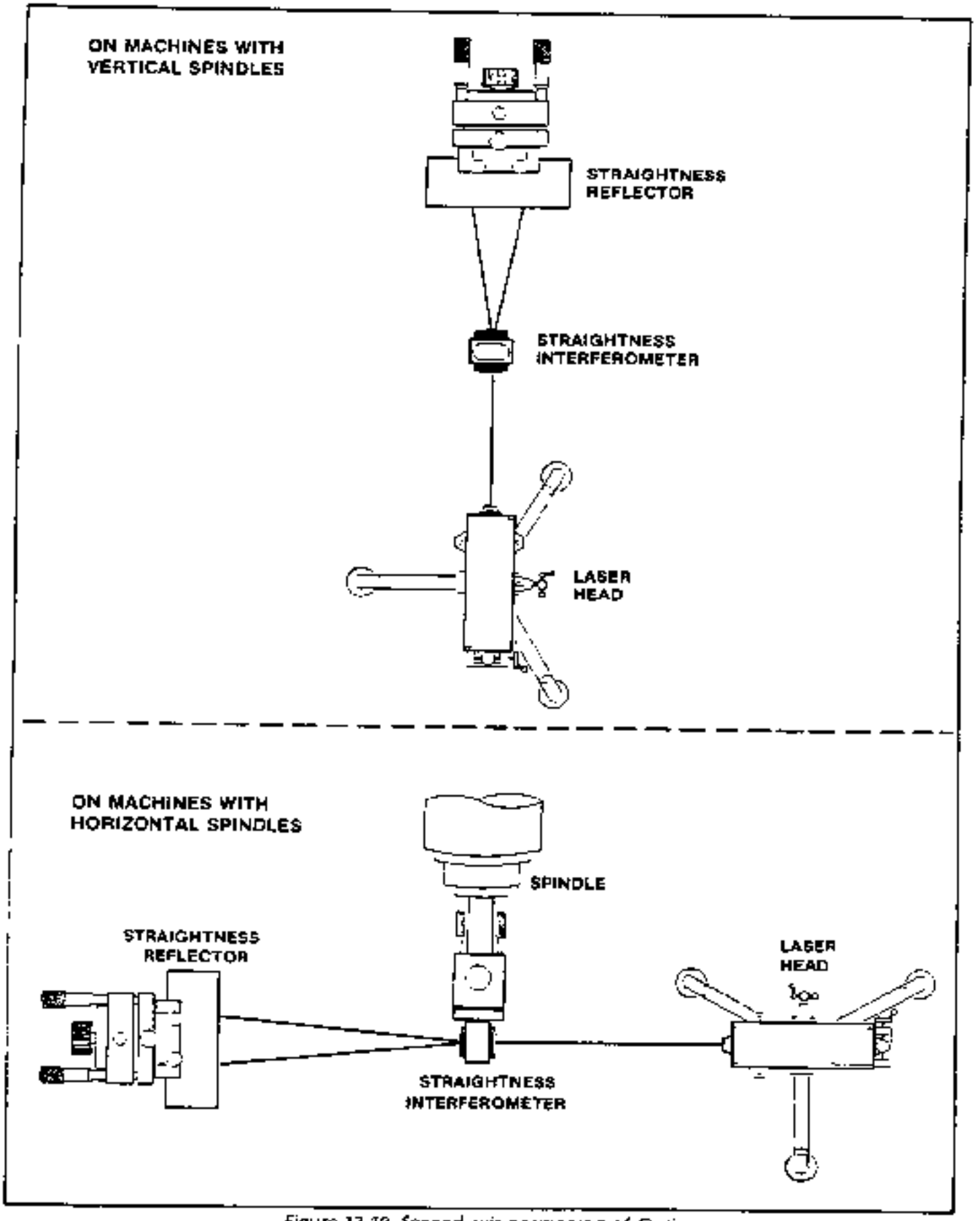


Figure 12-10. Second-axis positioning of Optics

NOTE

Whenever an instruction calls for adjusting the Reflector Mount's micrometers, adjust the Laser Head's vertical and horizontal rotational controls instead

Checking Alignment For Beam Strength

Follow the instructions given in Section 10

Checking for Mis-Alignment Between the Reflector's Reference Bisector Optics Travel Path ("Slope")

You should not check for or try to remove slope in this second axis, since the the slope of this axis will be used to determine squareness.

Measurement Display Settings

1. Use the instructions given in Section 10 of this User's Guide

2 When entering values for the SET UP keys, be sure you choose the correct sign convention for DIR SENSE The sign convention is critical in a Squareness measurement Use the instructions given in Section 21 of this User's Guide, under the heading of "Squareness Sign Conventions".

Making A Measurement

System Checks

1 Use the instructions in Section 10 for "SYSTEM CHECKS", under "MAKING A MEASUREMENT"

2 Make sure you input a calibration factor for the Optical Square to the HP Dimensional Metrology Analysis System's program, if you use that system You will find the calibration number next to the serial number on the Square's front surface.

Procedure

Since a Squareness measurement requires comparing two Straightness measurements, you must have the measurement data from the first axis available for comparison with the second-axis data This is easily done with the HP Dimensional Metrology Analysis System. Refer to the Analysis System's Operating Manual and programs for exactly how to record and store the data for this second axis

If you don't use the HP Dimensional Metrology Analysis System, follow the instructions in Section 10 for "PROCEDURE", under "MAKING A MEASUREMENT". Then refer to Section 21 of this User's Guide to help you calculate Squareness from your data.

What Affects Accuracy?

Since straightness optics are used in the squareness measurement, squareness accuracy is affected by the same factors that influence straightness accuracy. See the information in Section 10 of this User's Guide. In addition, the squareness accuracy is also affected by the accuracy of the optical square's calibration number, flatness of the mirrors in the square, which contributes additional error like that illustrated in Figure 10-11, and misalignment of the input beam out of the optical plane of the square. These errors can be minimized by using the correct calibration number of the square for calculations, proper alignment of the square, and utilization of the procedures given in Section 10 of this User's Guide.

13 Squareness-Vertical Plane

SECTION 13
SQUARENESS MEASUREMENTS (IN A VERTICAL PLANE)

CONTENTS

INTRODUCTION
OPERATING SPECIFICATIONS
HARDWARE REQUIRED
REFERENCE MATERIAL
FIRST-AXIS MEASUREMENT
SECOND-AXIS MEASUREMENT
WHAT AFFECTS ACCURACY?

INTRODUCTION

A "Squareness" measurement consists of two Straightness measurements, perpendicular to each other, made with a fixed Straightness Reflector. This is typically done by making a vertical Straightness measurement along a vertical axis, using an Optical Square, a Turning Mirror and a Straightness **Retro**reflector, then removing these Optics and making a vertical Straightness measurement along a horizontal axis. This process is diagrammed in *Figure 13-1*.

NOTE

There are both a Straightness Reflector and a Straightness Retroreflector. In this User's Guide Section, we will try to always type "**Retro**reflector" like this, with the "Retro" in bold type, to emphasize when that is the one that is to be used.

OPERATING SPECIFICATIONS

Accuracy

Short Range Optics:
Metric Units Mode: $\pm(1.0^{1}\ \pm 0.1M)$ arc-sec $\pm 1\%$ of θ
English Units Mode: $\pm(1.0^{1}\ \pm 0.03M)$ arc-sec $\pm 1\%$ of θ

Long Range Optics:
Metric Units Mode: $\pm(1.0^{1}\ \pm 0.01M)$ arc-sec $\pm 2.5\%$ of θ
English Units Mode: $\pm(1.0^{1}\ \pm 0.003M)$ arc-sec $\pm 2.5\%$ of θ

where:
θ = calculated out-of-squareness angle in arc-sec
M = distance of travel of the moving optic in metres
F = distance of travel of the moving optic in feet

NOTE

"1.0" can be as large as 1.2 arc-sec with maximum allowable misalignment of the optical square as per the alignment procedure

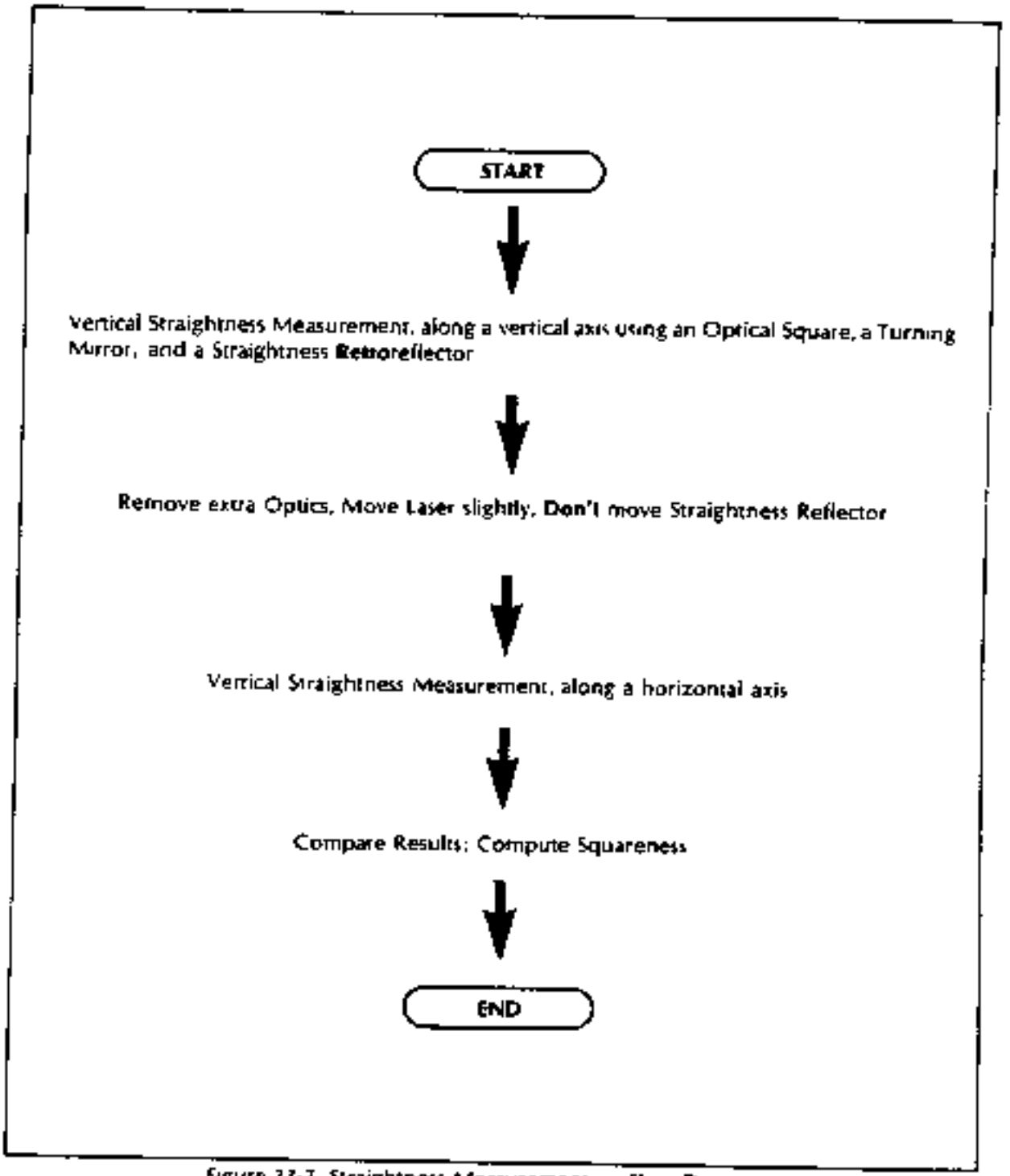


Figure 13-1 Straightness Measurement — Flow Diagram

HARDWARE REQUIRED

In addition to the hardware required for any measurement using the Laser Measurement System (see *Figure 4-1*), any vertical Squareness measurement requires the hardware shown in *Figure 13-2*. This hardware is the same as that required for a Straighrness measurement, plus an Optical Square and its Mount, a Turning Mirror, and a Straightness Retroreflector.

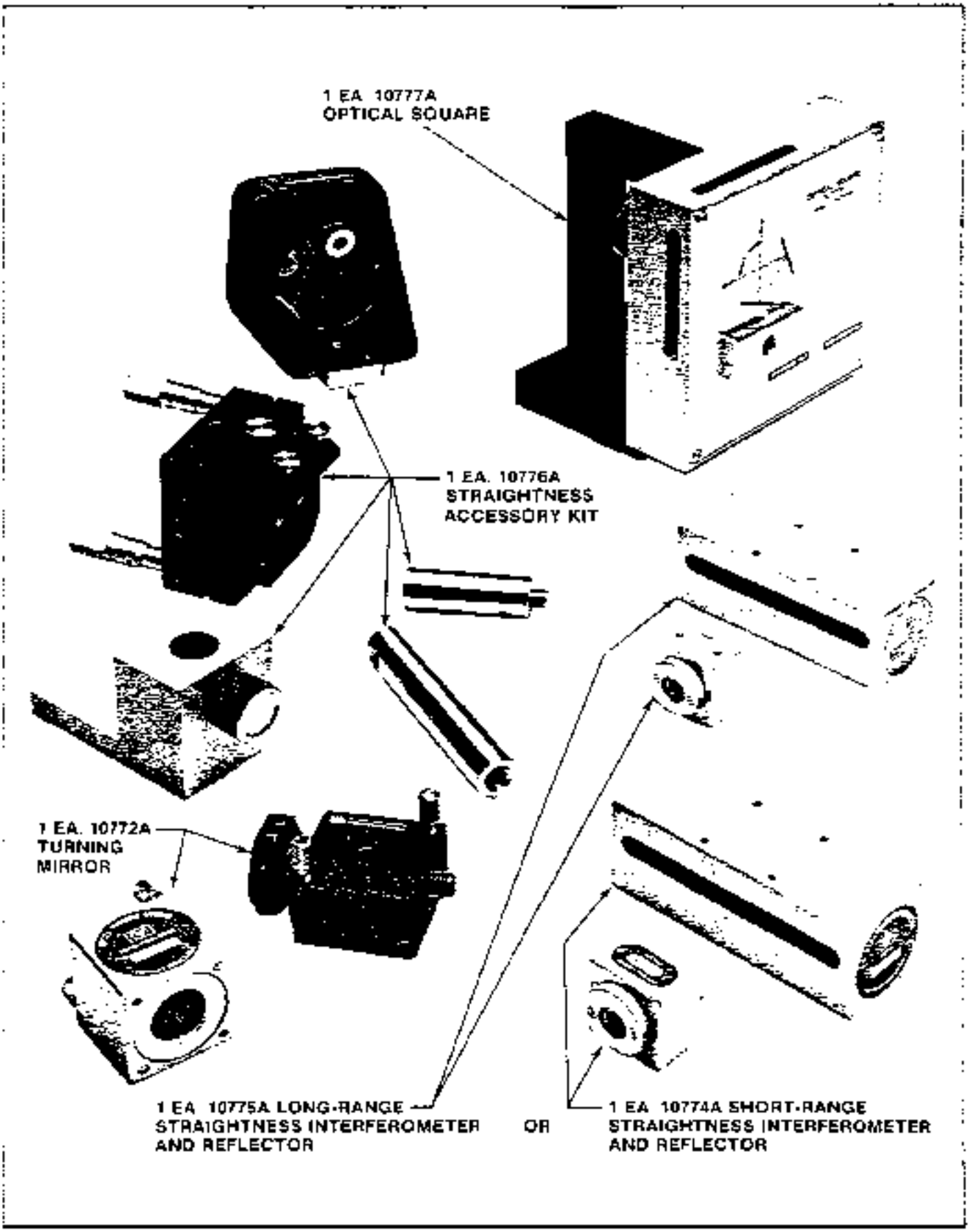


Figure 13-2. Hardware Required

REFERENCE MATERIAL

Physical Setup of the Laser Head and Tripod ..... Section 4

Interconnections, Turn-on ..... Section 5

Straightness Measurements (Horizontal Axis) ..... Section 10

Straightness Measurements (Using the Straightness Retroreflector) ..... Section 11

Alignment Techniques ..... Section 15

FIRST-AXIS MEASUREMENT (Vertical Axis Using an Optical Square)

The first-axis measurement is a vertical Straightness measurement along a vertical axis. It will be similar to the Straightness measurement along a vertical axis described in Section 11, except you will use an Optical Square, and the Straightness Reflector will be oriented along a horizontal axis rather than along the vertical axis. (See *Figure 13-1*.

Except for information about installation and alignment of Optics, the instructions presented in this User's Guide Section will highlight the additional things you must do beyond the instructions given in Section 11. Installation and alignment instructions are given in their entirety below.

Installation and Alignment of Optics

Important Considerations

1. See "IMPORTANT CONSIDERATIONS" in Section 11.
2. The sequence of Optics along the laser beam is —
   - Laser Head
   - Turning Mirror
   - Straightness Retroreflector
   - Interferometer
   - Optical Square
   - Reflector
3. Try to manually remove as much "slope" as possible, once your setup is aligned. This will make your second-axis alignment easier.

DESCRIPTION

For the measurement of the first axis you will install and align the Optics in three distinct steps. First, you will install the Optical Square, the Interferometer, and the Retroreflector, and align the Laser Head to the path traveled by the Interferometer and the Optical Square. Second, you will

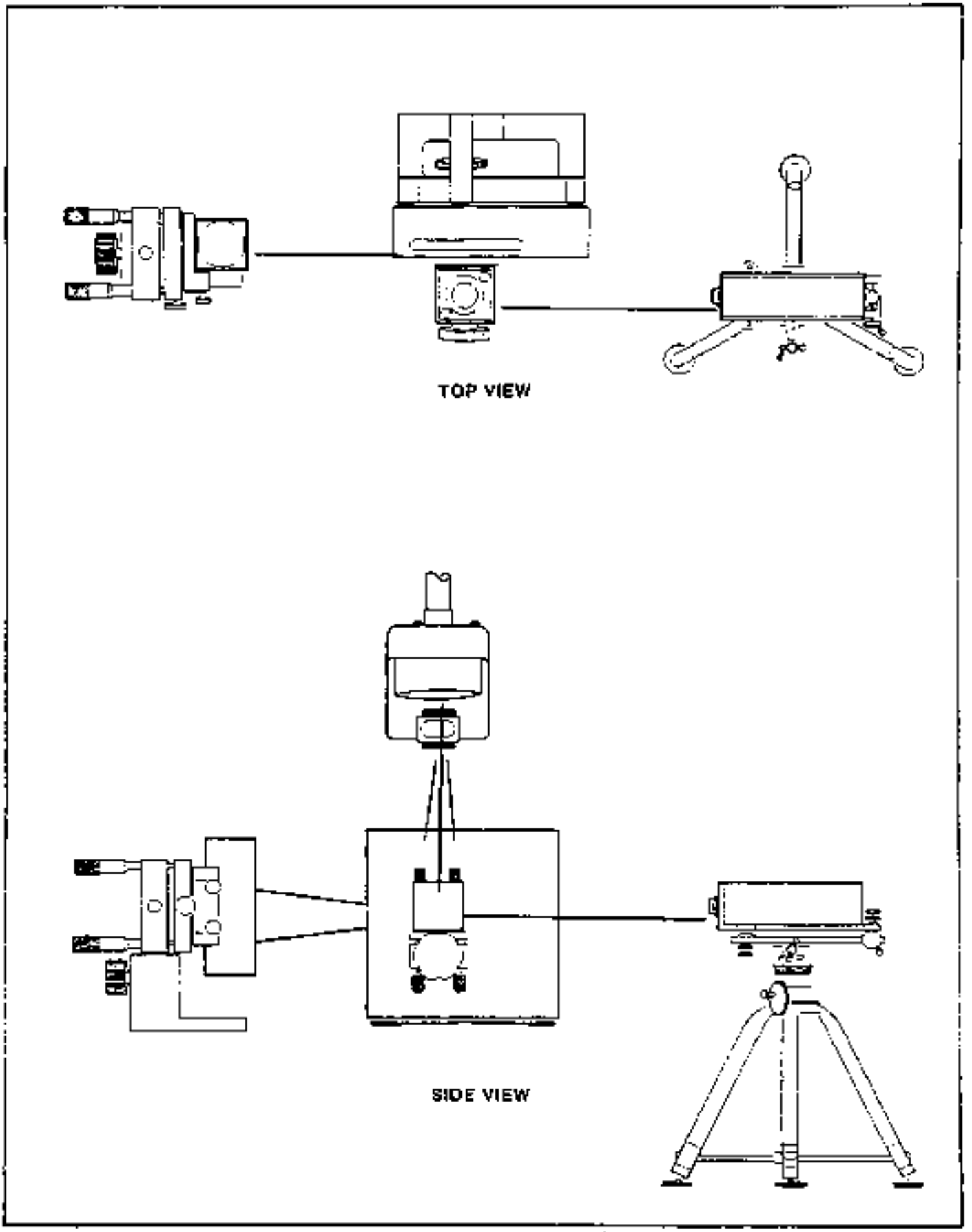


Figure 13-3 First-axis Positioning of Optics

install the Straightness Reflector. Third, you will make final adjustments to the tilt of the Reflector to maximize Beam Strength.

1. Installation and Alignment of the Interferometer/Retroreflector assembly and the Optical Square

   You will use procedures similar to those in Section 11 of this User's Guide to do this. You will set up and align these Optics just as if the Optical Square were the Straightness Reflector.

2. Installation of the Straightness Reflector

   After the Optical Square and the Interferometer have been installed and aligned you will use the Laser beam to position the Reflector.

3. Final Adjustments

   You will use a special technique to adjust the Reflector to bring the beams back to the Laser Head and provide sufficient beam strength.

Procedure For Installation and Alignment of Interferometer and Optical Square

1. Align the Laser Head to the horizontal axis using the most convenient method:
   a. Autoreflection
   b. Gunsight (targets)
   c. Overlapping dots

NOTE

Distance optics must be used with the overlapping dots method.

2. Attach the Optical Square to its mount, as shown in *Figure 13-4*.

3. Attach the Turning Mirror's base to the side of the Optical Square, as shown in *Figure 13-5*.

4. Identify the axes you are going to measure to make your Squareness measurement.

5. Position the Optical Square so that its top slot lines up with your vertical axis and its side slot faces along the second measurement axis.

NOTE

The Optical Square must be square relative to the machine. Use parallel bars in the machine's T-slots or other machine features to align the Optical Square relative to the machine. (The Optical Square must be square relative to the incoming laser beam within minutes of a degree or measurement errors will be induced.)

6. Mount the Turning Mirror on its base, using its captive screws, such that one opening faces where the Laser Head will be located, and the other faces upward.

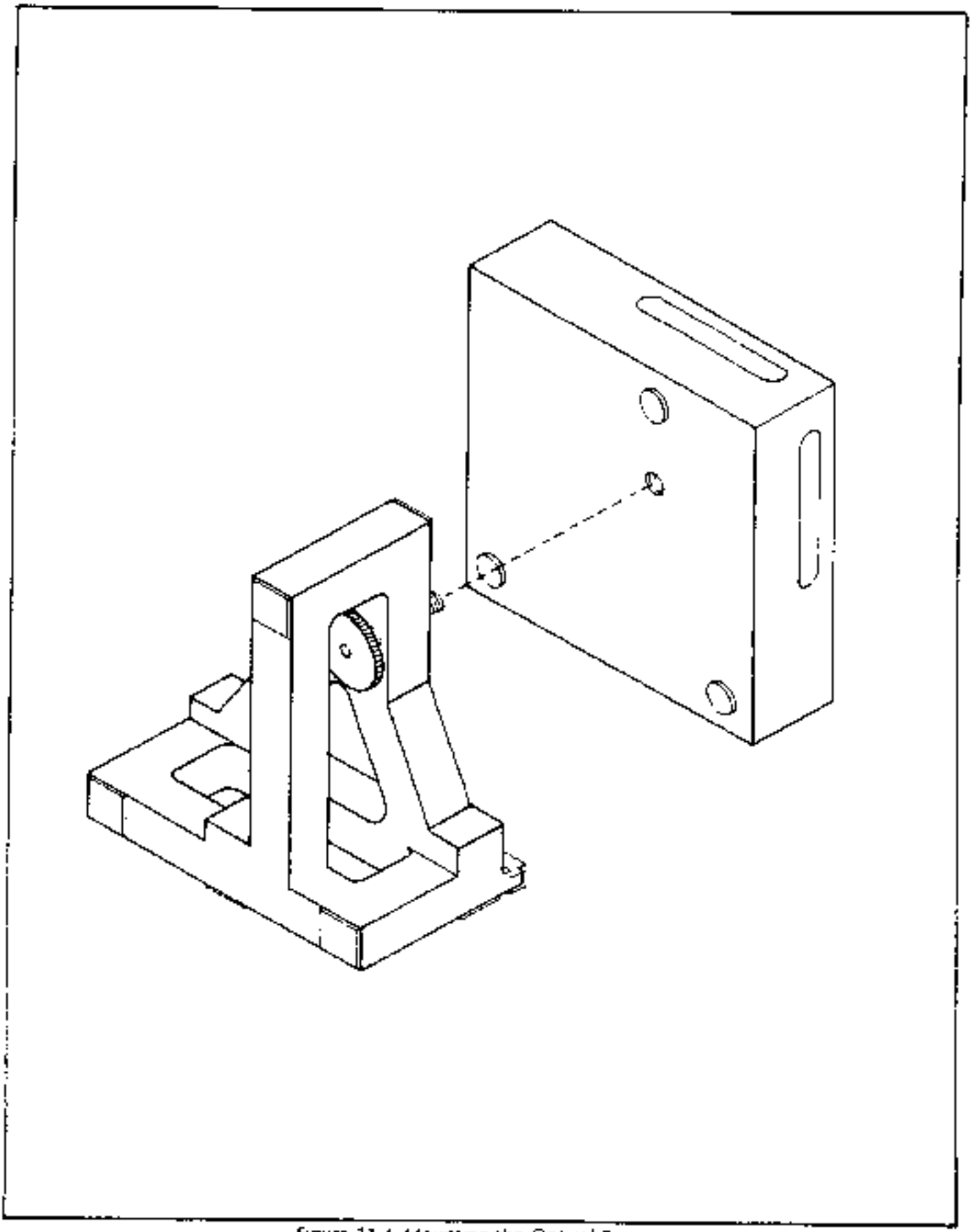


Figure 13-4. Mounting the Optical Square

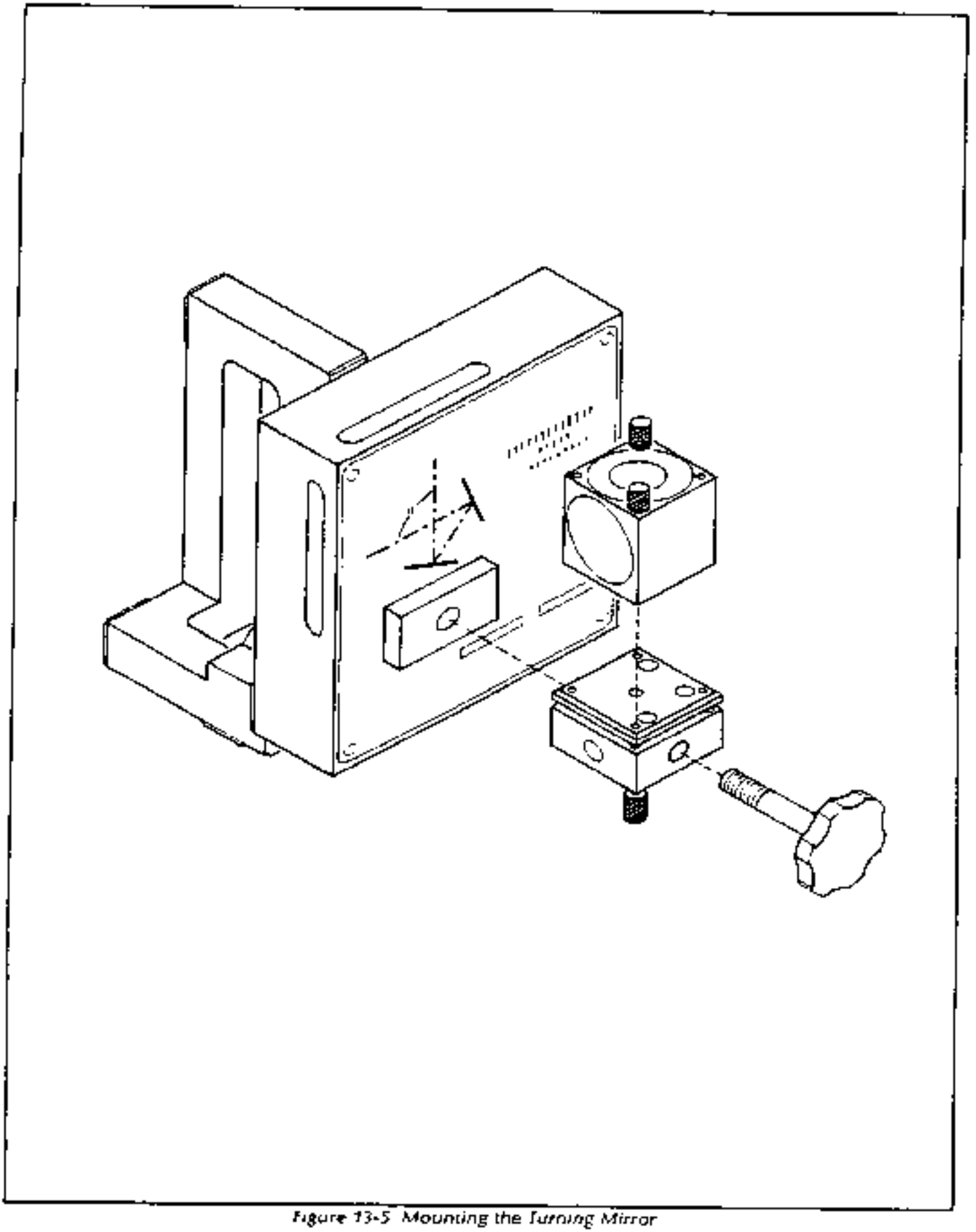


Figure 13-5. Mounting the Turning Mirror

7 Mount the Straightness Accessory Kit's Straightness **Retro**reflector where the tool normally mounts, as shown in Figure 13-6.

8 Screw the Interferometer into the large **Retro**reflector, using the two 3 mm flathead screws provided.

9 Orient the **Retro**reflector so it overlaps the Optical Square and the Turning Mirror, but with the Interferometer over the Optical Square.

10 Fasten the **Retro**reflector assembly to the machine in such a way that the Interferometer is as square as possible to the Optical Square and to the incoming beam. The Interferometer housing's pitch limitations are ±2 degrees; its yaw and roll limitations are ±5 degrees. The pitch and yaw requirements will be taken care of automatically by using the Straightness **Retro**reflector and an HP Post.

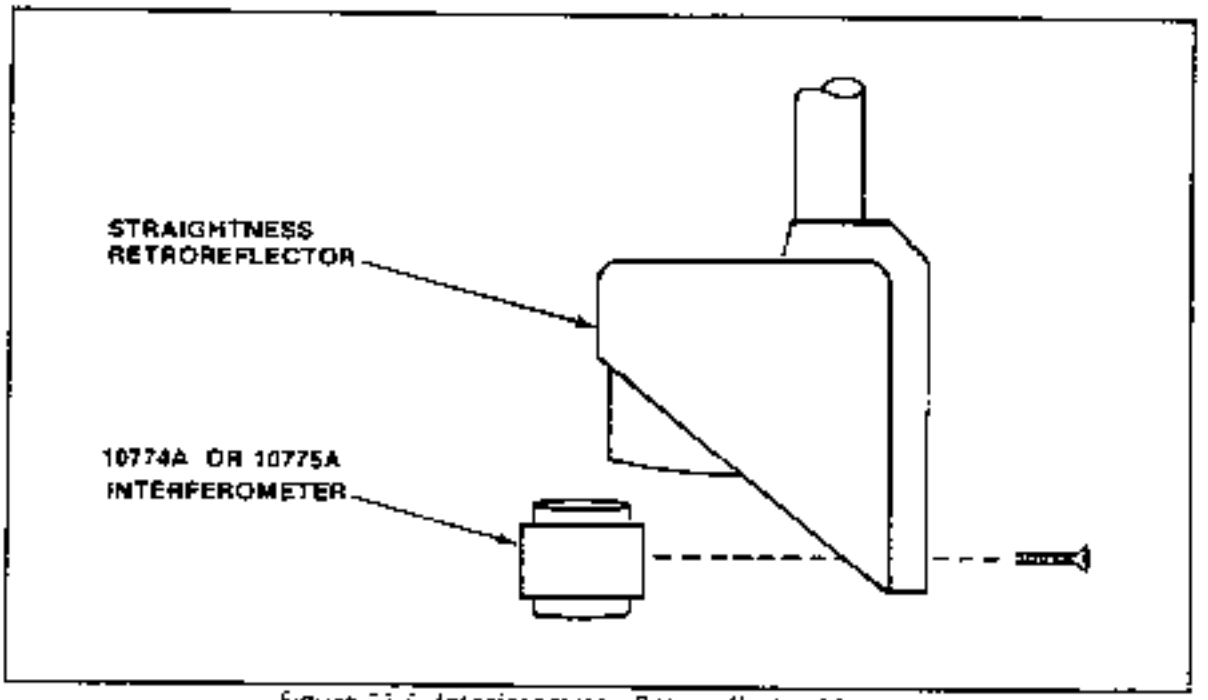


Figure 13-6. Interferometer Retroreflector Mounting

11 Position the Optical Square and Turning Mirror relative to the **Retro**reflector and Interferometer.

a **B**ring the Interferometer-**Retro**reflector assembly close enough to the Optical Square to line up the Interferometer with the center of the Optical Square's slot. (Look into the Optical Square's other slot to help do this.)

This is a very important step. If the Optics are not physically lined up at this point, aligning along the vertical travel axis will be impossible. This also establishes the "near end of travel", i.e., any later movement of the machine can only increase the distance between the Optics.

b Make sure the Turning Mirror is square relative to the Optical Square, and is not tilted to either side.

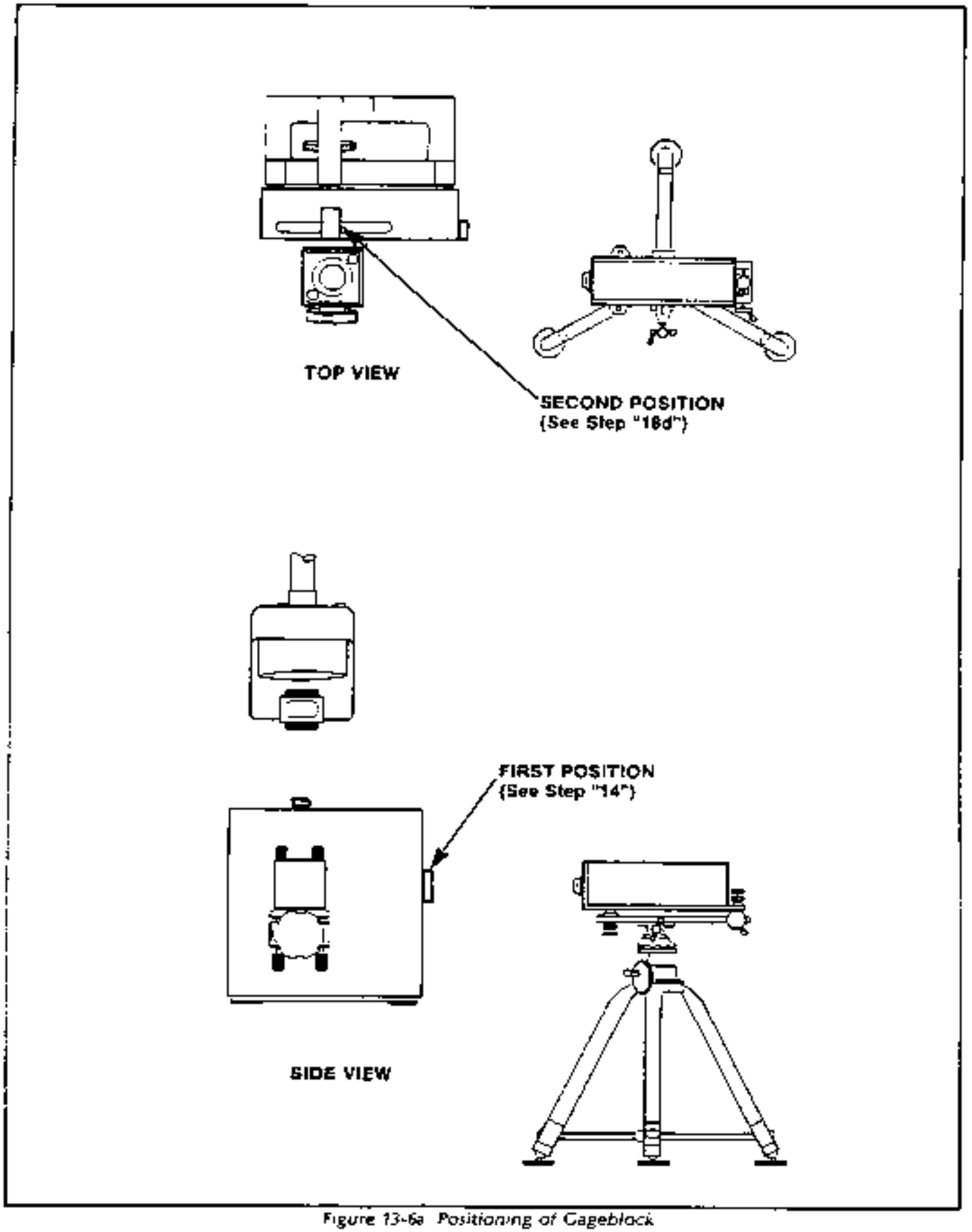


Figure 13-6a *Positioning of Cageblock*

12. Set the Laser Head's turret ring to "STRAIGHTNESS", and select the small aperture for the exit port. You can also do this using the full beam from the large aperture.

13. Translate the Laser Head horizontally so that the beam strikes the threaded port on the side of the Optical Square facing the Laser Head.

14. Place the gageblock over the threaded port so that the beam is reflected back towards the Laser Head (see Figure 13-6a). Use a rubber band to secure the gageblock.

15. Rotate the Optical Square so that the reflected beam strikes the Laser Head and is centered vertically on its exit port.

NOTE

If you cannot position the Optical Square using the reflected beam, mount an indicator in the spindle and move the table along the horizontal axis. Rotate the Optical Square so that its sides are parallel to the direction of travel.

16. Secure the Optical Square in this location.

17. Translate the Laser Head horizontally so that the beam strikes the center of the Turning Mirror's opening.

    Use the Interferometer's target or a piece of paper to help you do this.

18. Adjust the Turning Mirror's angle with the small screws at its base until the Laser beam goes through the small alignment ring on the **Retro**reflector, passes through the Interferometer without being clipped, and then is centered on the Optical Square's top slot. (See Figure 13-7 for a picture of the alignment ring.)

    a. Get the beam to go through the alignment ring.

    b. Look at the side of the Interferometer facing the **Retro**reflector, and adjust the Turning Mirror's angle until you see no red reflection.

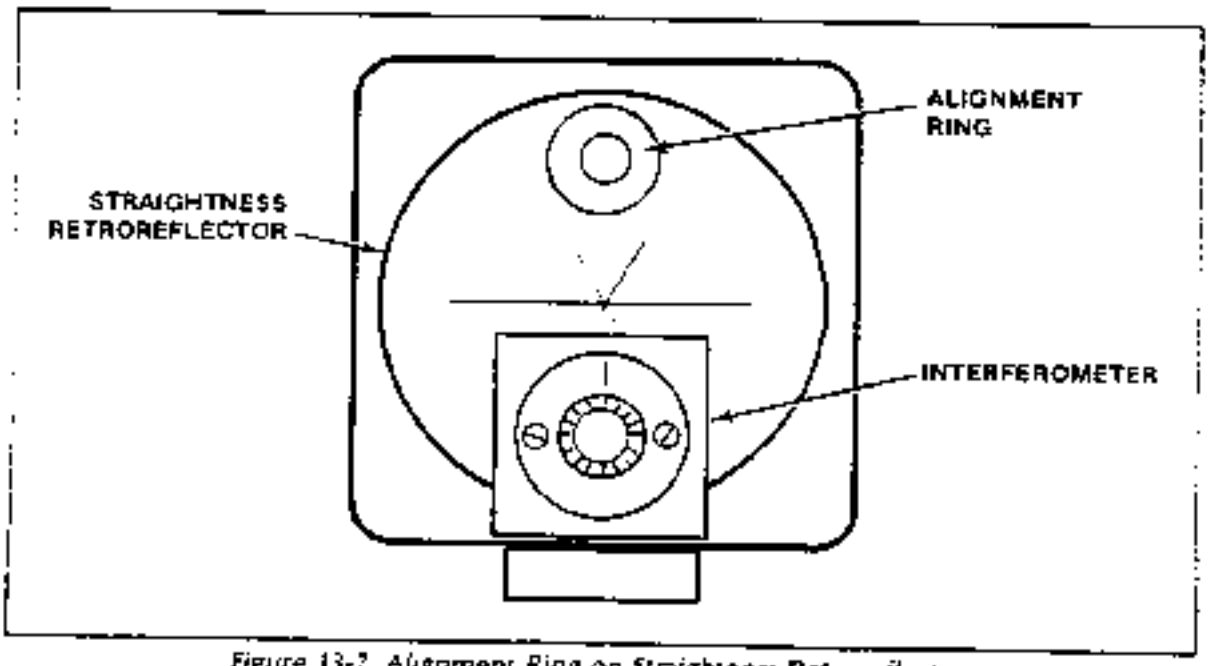


Figure 13-7. Alignment Ring on Straightness **Retro***reflector*

c. Remove the Interferometer from the **Retro**reflector.

d. Place the gageblock over the Optical Square's top slot (see *Figure 13-6a*). The beam should strike the gageblock and be reflected back towards the Laser Head.

e. Adjust the Turning Mirror so that the reflected beam strikes the Laser Head and is centered on its exit port.

NOTE

If you cannot position the Turning Mirror using the reflected beam, continue with steps "f", "g" and "h", and skip step "i". Look at the top of the Optical Square, and adjust the Turning Mirror so that the two dots are in line with the scribed line and symmetrical within the opening (see *Figure 13-8*).

f. Remove the gageblock.

g. Screw the Interferometer into the **Retro**reflector.

h. Rotate the Interferometer bezel until its scribed line is oriented 90 degrees relative to the Optical Square's slot.

i. Look at the top of the Optical Square, and translate the Laser Head until the two dots are in line with the scribed line and symmetrical within the opening. (See *Figure 13-8*.

If the Optics are very close together, you should insert a piece of paper to see the dots.

NOTE

This process will be impossible if the Optics were not positioned well enough in step "11". If you have problems with this step, go back to step "11" and redo it.

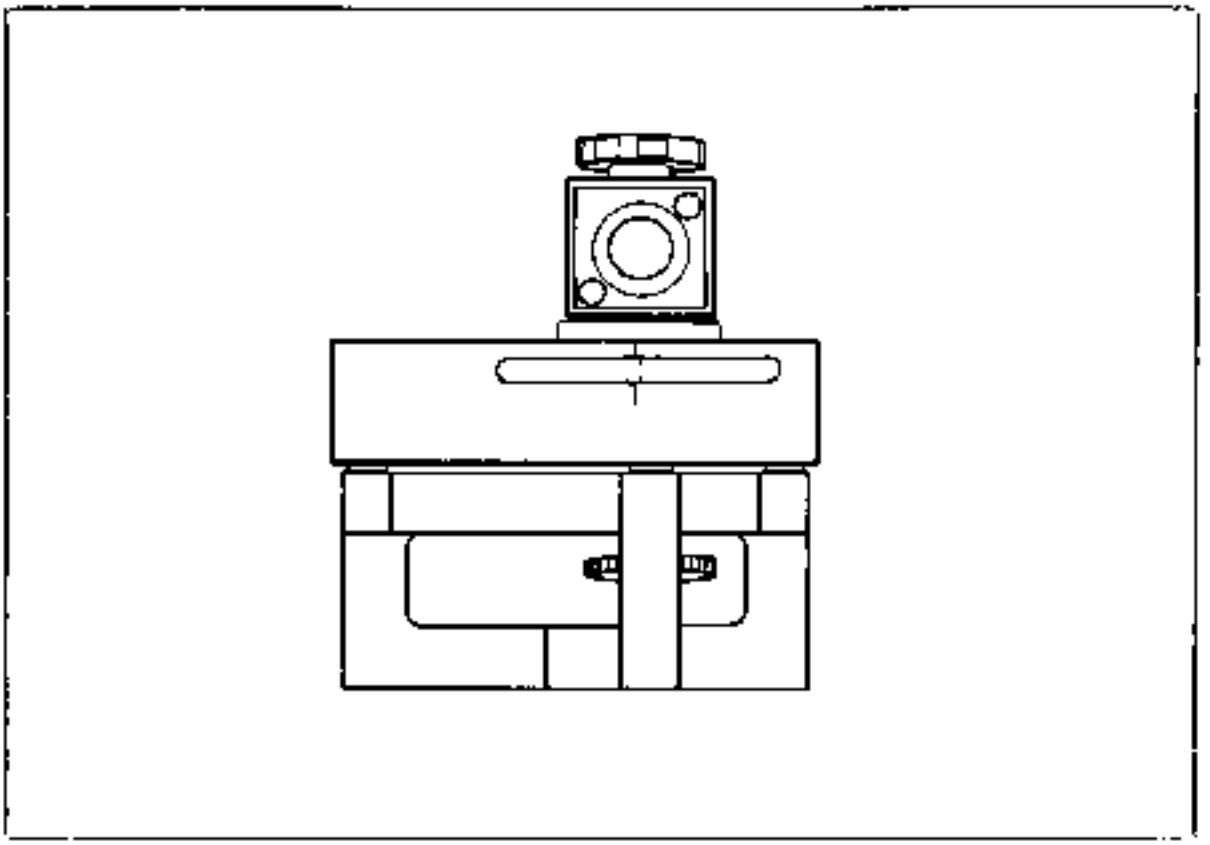


Figure 13-8. Initial Positioning of Optical Square

19. You are now ready to align the Laser to the Interferometer's travel path.

    Review the "GUNSIGHT" method of alignment in Section 15 of this User's Guide.

    Your goal is to adjust the Laser Head to track the Interferometer's travel path, while maintaining the beam's near-end-of-travel position. You will do this by:

    - Keeping the beam in the alignment ring on the **Retroreflector**, to maintain the beam's near-end-of-travel position.. and —
    - Keeping a two-dot pattern in line with the center of the Optical Square's slot as the Optics move over the travel path.

    This will be a little different than aligning for Distance and Angular measurements, since with these alignments you were only watching one dot relative to a target crosshair.

20. Move the Optics to the far end of travel.

21. **Rotate** the Laser Head vertically and horizontally to keep the two dots lined up on the scribed line at the center of the Optical Square's slot, and symmetrical about the slot. (See *Figure 13-9.*)

    Since the dots will move apart as the Optics move, you may have to insert a piece of paper on top of the Optical Square to watch the dots over the full travel distance.

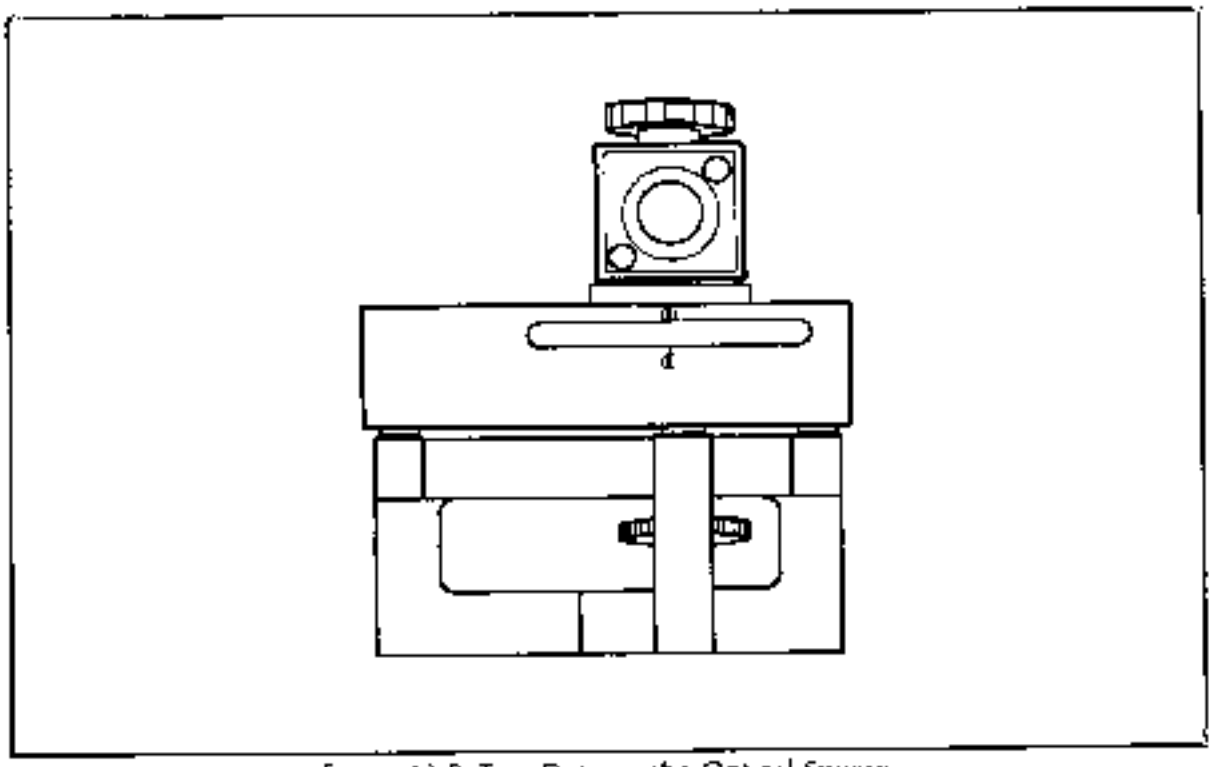


Figure 13-9 Two Dots on the Optical Square

22 **Translate** the Laser Head vertically and horizontally to keep the Laser beam from being clipped by the alignment ring on the Straightness **Retro**reflector.

Check this by making sure you can't see the beam on the Interferometer surface that faces the **Retro**reflector.

Any translation of the Laser Head will cause the two dots to move from their position on the Optical Square, so you will again have to rotate and translate the Laser Head (i.e., repeat step "16" and step "17" several times) before you are done.

You are finished with this procedure when the beam goes through the Interferometer without being clipped, and the two dots are symmetrical about the Optical Square's top slot (see *Figure 13-9*).

Procedure For Installing the Straightness Reflector

1 Select the small aperture for the exit port on the Laser Head. (You can also do this using the full beam from the large aperture.)

2. Make sure the Interferometer bezel's scribed line is oriented 90 degrees relative to the slot in the Optical Square.

3 Move the Optics to the near end of travel. Position the Interferometer as close as you can to the Optical Square.

4. Attach the Reflector to its mounting hardware as shown in *Figure 10-4*.

5. Orient the Reflector to make a vertical measurement along a horizontal axis.

6. Place the Reflector at the end of the horizontal axis you will measure when you make the measurement along the second axis.

   a. Position the Reflector such that the two dots coming from the Optical Square are centered on the junction between the Reflector's mirrors and symmetrical about its slotted opening. (See *Figure 13-10.*)

      If you can not get two dots to strike the surface of the Reflector, remove the Interferometer from the **Retro**reflector and repeat this step with only one dot.

   b. Secure the Reflector to the machine.

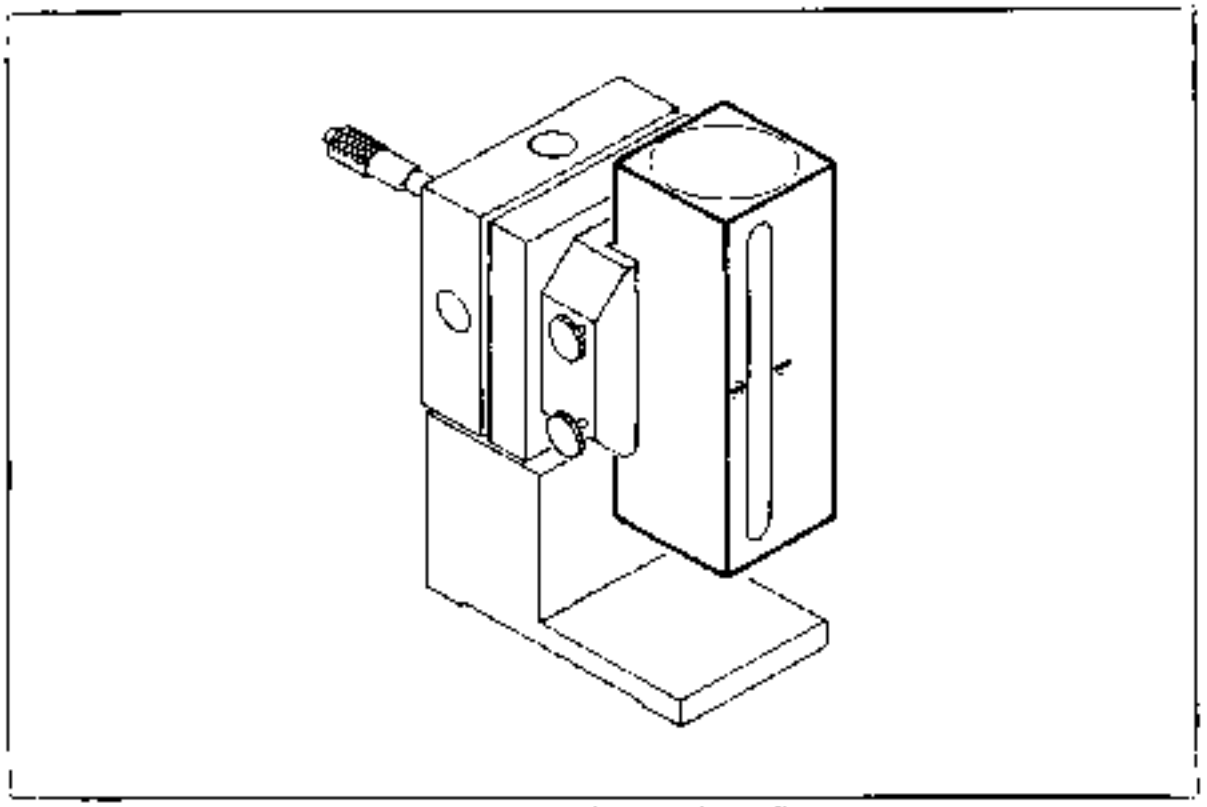


Figure 13-10. Two dots on the Reflector

Final Adjustments (After Aligning)

1. Select the small aperture for the Laser Head's exit port.

2. Rotate the Interferometer bezel until its scribed line is parallel to the slot in the Optical Square.

3. Look at the side of the Optical Square facing the Reflector. If you don't see two dots, adjust the Reflector Mount's micrometer head that controls horizontal motion until both dots appear on the side of the Optical Square.

   a. Turn the Interferometer bezel until the dots line up parallel to the slot in the Optical Square.

   b. Adjust the Reflector Mount's vertical motion micrometer until both dots are symmetrical about the scribed line at the center of the Optical Square's slot. (See *Figure 13-11.*)

c. If one dot is brighter than the other, raise or lower the Reflector Mount until both dots are of equal intensity, and then repeat step "b" above.

d. Adjust the Reflector Mount's horizontal motion micrometer until both dots disappear into the Optical Square's slot.

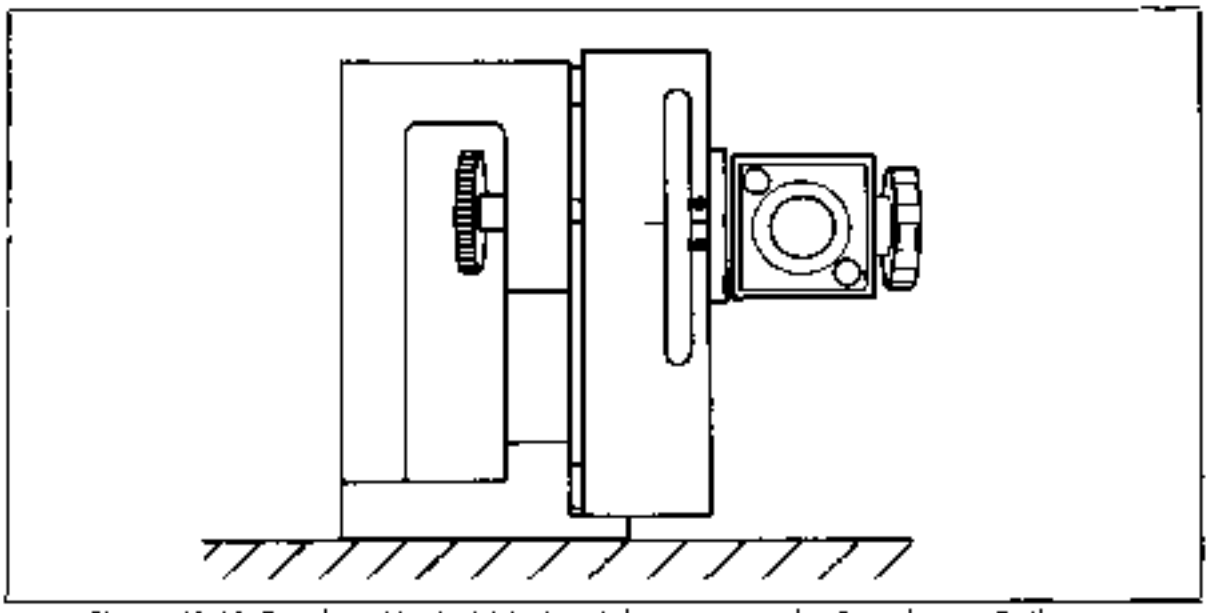


Figure 13-11. Result of Vertical Motion Adjustment to the Straightness Reflector.

5 Look at the Laser Head. You should see two dots. If you don't see the dots —

a. Look at the side of the Interferometer facing the Optical Square.

b. You should see either one or two closely spaced dots on the Interferometer.

c. Adjust the Reflector Mount's micrometers until the dot(s) disappear into the Interferometer.

d. Look at the Laser Head. You should now see the dot(s) on the front of the Laser Head.

6 Turn the Interferometer bezel until the dots overlap.

7. Adjust the Reflector Mount's micrometers until the overlapping dots are centered on the exit port, and "halo" the small aperture.

8. Select the large aperture for the Laser Head's exit port.

9 Turn the Interferometer bezel slightly until the Laser Head's "SIGNAL" light comes on and the BEAM STRENGTH meter indication is in the green area.

NOTE

Only a slight adjustment of the bezel is necessary to do this.

10. Further adjust the Reflector Mount's micrometers until the Beam Strength meter indication is at a maximum.

Checking Alignment For Beam Strength

Move the machine over its full travel range, making sure that BEAM STRENGTH is adequate (in the green area) at all positions.

If beam strength decreases at any point, —

a Check for clipping of the beam by the Optics. Reposition the Optics, if necessary, and then re-check.

b If you see part of the return beam on the edge of the Exit (top) port, rotate the Laser Head until the return beam disappears.

If this didn't correct the "reduced beam strength" problem, refer to the "Manual Removal of Slope" information below.

NOTE

If the BEAM STRENGTH indication never reaches the right-hand half of the meter's range, at any point along the Optics' full travel distance, your Optics may need cleaning. Thoroughly clean all optical surfaces, as described in Section 20 of this User's Guide.

Checking For Mis-Alignment Between the Laser Beam and the Optics Travel Path ("Slope")

Follow the instructions given under this heading in Section 11.

Manual Removal of Slope

Follow the instructions given under this heading in Section 11. Try to remove as much slope as possible; this will help make it easier to get adequate beam strength when you measure the second axis.

Measurement Display Settings

1 Use the instructions given in Section 10 of this User's Guide.

2 When entering values for the SET UP keys, be sure you choose the correct sign convention for DIR SENSE. The sign convention is critical in a Squareness measurement. Use the instructions given in Section 21 of this User's Guide, under the heading of "Squareness Sign Conventions".

Making A Measurement

System Checks

1 Use the instructions in Section 10 for "SYSTEM CHECKS", under "MAKING A MEASUREMENT".

2. Make sure you input a calibration factor for the Optical Square to the HP Dimensional Metrology Analysis System's program, if you use that system. You will find the calibration number next to the serial number on the Square's front surface.

Procedure

Since a Squareness measurement requires comparing two Straightness measurements, you must have the measurement data from the first axis available for comparison with the second-axis data. This is easily done with the HP Dimensional Metrology Analysis System. Refer to the Analysis System's Operating Manual and programs for exactly how to record and store the data for this first axis.

If you don't use the HP Dimensional Metrology Analysis System, follow the instructions in Section 10 for "PROCEDURE", under "MAKING A MEASUREMENT". Then refer to Section 21 of this User's Guide to help you calculate Squareness from your data.

What Affects Accuracy?

1. See the information presented under this heading in Section 10 of this User's Guide.

2. The orientation of the Optical Square relative to the Laser beam is very important. Any angular misalignment (even a few minutes of a degree) will induce errors in your measurement. To prevent this from happening, secure the Optical Square against parallels in T slots or other similar machine features that are square relative to the machine's motions.

SECOND-AXIS MEASUREMENT (Horizontal Axis)

This second-axis measurement is merely a vertical Straightness measurement along a horizontal axis (see *Figure 13-12*). Thus, you should use the instructions given in Section 10 of this User's Guide (or in Section 11, if your machine has a horizontal spindle and you are measuring "Z-Y" Squareness), and add to that (where appropriate) the information below.

Installation and Alignment of Optics

NOTE

Do not move or adjust the Straightness Reflector from its position after the first measurement.

Procedure

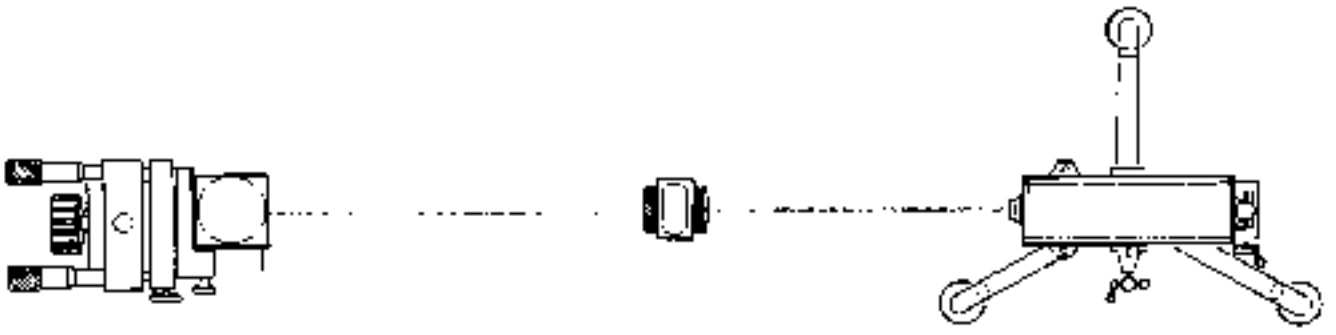
1. Remove the Optical Square, Turning Mirror, Interferometer and Retroreflector.

2. Mount the Interferometer (and the Retroreflector if the spindle is horizontal) where the tool normally mounts.

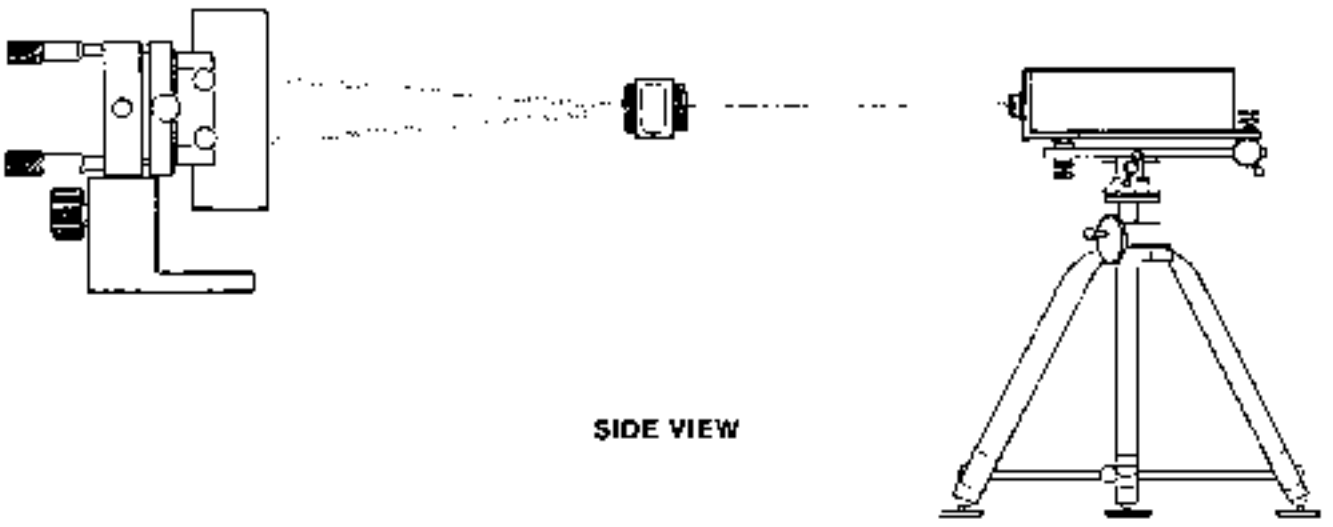
3. Adjust the Laser Head to line up with the new measurement axis. The output beam should hit the junction of the Reflector mirrors, and the reflected beam should hit the Laser Head's exit port.

   a. **Translate** the Laser Head so that the output beam goes through the Interferometer and strikes the junction of the Reflector mirrors.

   b. **Rotate** the Laser Head so that the reflected beam strikes the center of its exit port.



TOP VIEW



SIDE VIEW

Figure 13-12. Second-axis Positioning of the Optics

4. For any Vertical Squareness measurement except "Z-Y" on a machine with a horizontal spindle, follow the "INSTALLATION AND ALIGNMENT" instructions in Section 10.

   For a Vertical "Z-Y" Squareness measurement on a machine with a horizontal spindle, follow the "INSTALLATION AND ALIGNMENT" instructions in Section 11.

   Remember, **don't move or adjust the Reflector**

Final Adjustments (After Aligning)

Follow the "FINAL ADJUSTMENT" instructions in Section 10, or Section 11 except —

NOTE

Whenever an instruction calls for adjusting the Reflector Mount's micrometers, adjust the Laser Head's vertical and horizontal rotational controls instead

Checking Alignment For Beam Strength

Follow the instructions given in Section 10 or Section 11

Checking For Mis-Alignment Between the Laser Beam and The Optics Travel Path ("Slope")

You should not check for or try to remove slope in this second axis, since the slope of this axis will be used to determine squareness.

Measurement Display Settings

1 Use the instructions given in Section 10 or Section 11 of this User's Guide.

2 When entering values for the SET UP keys, be sure you choose the correct sign convention for DIR SENSE. The sign convention is critical in a Squareness measurement. Use the instructions given in Section 21 of this User's Guide, under the heading of "Squareness Sign Conventions".

Making A Measurement

System Checks

1. Use the instructions in Section 10 or Section 11 for "SYSTEM CHECKS", under "MAKING A MEASUREMENT".

2. Make sure you input a calibration factor for the Optical Square to the HP Dimensional Metrology Analysis System's program, if you use that system. You will find the calibration number next to the serial number on the Square's front surface

PROCEDURE

Since a Squareness measurement requires comparing two Straightness measurements, you must have the measurement data from the first axis available for comparison with the second-axis data. This is easily done with the HP Dimensional Metrology Analysis System. Refer to the Analysis System's Operating Manual and programs for exactly how to record and store the data for this second axis.

If you don't use the HP Dimensional Metrology Analysis System, follow the instructions in Section 10 or Section 11 for "PROCEDURE", under "MAKING A MEASUREMENT". Then refer to Section 21 of this User's Guide to help you calculate Squareness from your data.

What Affects Accuracy?

Since Straightness optics are used in the Squareness measurement, Squareness accuracy is affected by the same factors that influence Straightness accuracy. See the information in Section 10 of this User's Guide. In addition, the Squareness accuracy is also affected by the accuracy of the Optical Square's calibration number, flatness of the mirrors in the Square, which contributes additional error like that illustrated in *Figure* 10-11, and misalignment of the input beam out of the optical plane of the Square. These errors can be minimized by using the correct calibration number of the Square for calculations, proper alignment of the Square, and utilization of the procedures given in Section 10 of this User's Guide.

SECTION 14
PARALLELISM MEASUREMENTS

CONTENTS

INTRODUCTION
HARDWARE REQUIRED
REFERENCE MATERIAL
LINEAR PARALLELISM MEASUREMENTS
ROTATIONAL PARALLELISM MEASUREMENTS

INTRODUCTION

There are two types of "Parallelism" measurements — "Linear" and "Rotational". In any Parallelism measurement, you compare the slopes of two Straightness measurement, measured from the same Straightness Reflector position.

A "Linear Parallelism" measurement consists of two Straightness measurements, made along the same measurement axis but with the Interferometer moving in the one measurement and the Reflector moving in the other measurement.

A "Rotational Parallelism" measurement is made on a lathe. It consists of two Straightness measurements, each made with the Reflector held in the lathe's spindle (the workpiece location), but with the spindle rotated 180 degrees for the second measurement.

HARDWARE REQUIRED

In addition to the hardware required for any measurement using the Laser Measurement System (see Figure 4-1), any Parallelism measurement will need all the same hardware as required for a Straightness measurement, plus a Turning Mirror and possibly a Straightness Retroreflector.

REFERENCE MATERIAL

Physical Setup of the Laser Head and Tripod ..... Section 4

Interconnections, Turn-on ..... Section 5

Straightness Measurements (Along a Horizontal Axis) ..... Section 10

Straightness Measurements (Using the Straightness Retroreflector) ..... Section 11

Alignment Techniques ..... Section 15

LINEAR PARALLELISM MEASUREMENTS

With this type of Parallelism measurement, you will make two Straightness Measurements along the same measurement axis. In one measurement the Reflector will move and in the other the Interferometer will move.

First-Axis Measurement

Installation and Alignment of Optics

Install and align your optics for the first measurement by following the instructions given in Section 10 or Section 11 of this User's Guide.

1. Move either the Interferometer or the Retroreflector.

2. Try to manually remove as much slope as possible. This will help make it easier to get adequate beam strength when you make the second measurement.

Measurement Display Settings

Use the instructions given in Section 10 or Section 11 of this User's Guide.

Note the direction of positive readings, by pressing slightly on the Interferometer. This will be important when you measure the second axis.

Making A Measurement

System Checks

Use the instructions for "SYSTEM CHECK" given in Section 10 or Section 11 of this User's Guide.

Procedure

If you use the HP Dimensional Metrology Analysis System, refer to its Operating Manual to record and store the data for this first axis.

If you don't use the HP Dimensional Metrology Analysis System, follow the instructions given in Section 10 or Section 11 of this User's Guide. Then refer to Section 21 of this User's Guide and calculate the slope of your measurement data.

Second Axis Measurement

Installation and Alignment of Optics

Make any changes that are necessary to allow the Optic either the Interferometer or the Reflector that didn't move in the first measurement to move in the second measurement.

Do not adjust the tilt of the Straightness Reflector.

Measurement Display Settings

1. Use the instructions given in Section 10 or Section 11 of this User's Guide.

2. When entering values for the SET UP keys, be sure you choose the correct sign convention for DIR SENSE. The sign convention is critical in a Parallelism measurement.

   Make sure that positive readings appear in the same direction as they did when you measured the first axis. Press slightly on the Interferometer to do this. Study *Figure 14-1* and Figure 14-2 to see the importance of the slopes' sign directions.

Making A Measurement

System Checks

Use the instructions for "SYSTEM CHECK" given in Section 10 or Section 11 of this User's Guide.

Procedure

If you use the HP Dimensional Metrology Analysis System, refer to its Operating Manual to record and store the data for this second axis.

If you don't use the HP Dimensional Metrology Analysis System, follow the instructions given in Section 10 or Section 11 of this User's Guide, then refer to Section 21 and calculate the slope of this second-axis measurement.

Calculating Linear Parallelism

Once you have the slope for each measurement axis (from Section 21), translate the slope values into a Parallelism value. What you must do is —

1. For each axis, determine the angle of misalignment (θ).

   This is done by taking the arctangent of the slope (m) of each Straightness measurement and multiplying by "3600", to convert to "arcseconds".

   θ = (arctangent (m)) x 3600 (arcseconds)

   Be sure your slope value is dimensionless, i.e., metre/metre or inch/inch.

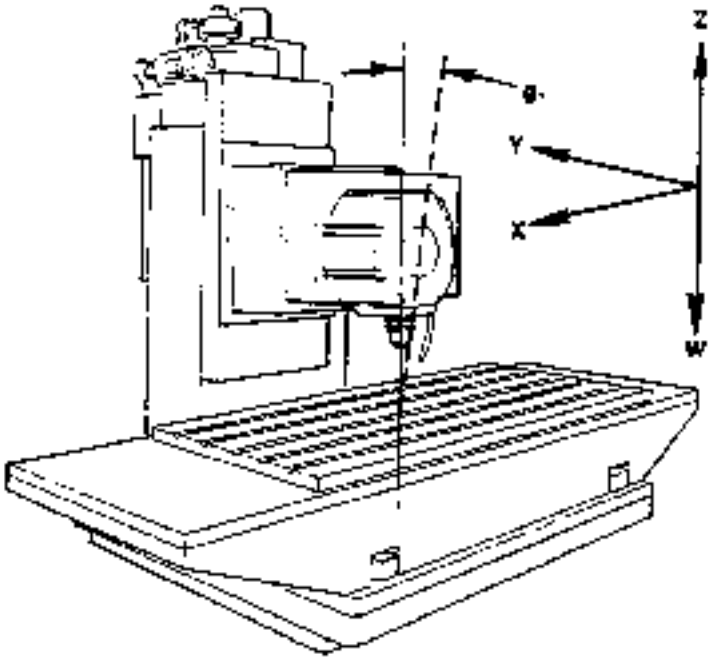
2. Add the angles together.

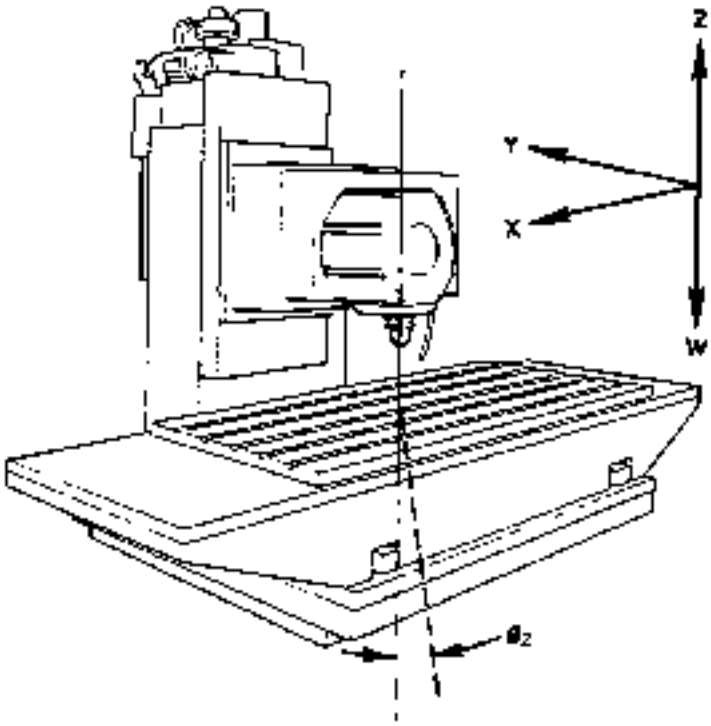
   Linear Parallelism = $\theta_1 + \theta_2$

   In order to do this, both the first- and second-axis measurements must have deflections of the interferometer produce the same sign convention when in the same direction.

   Figure 14-1 shows that the "z" and "w" axes are not parallel by the amount $\theta_1 + \theta_2$.

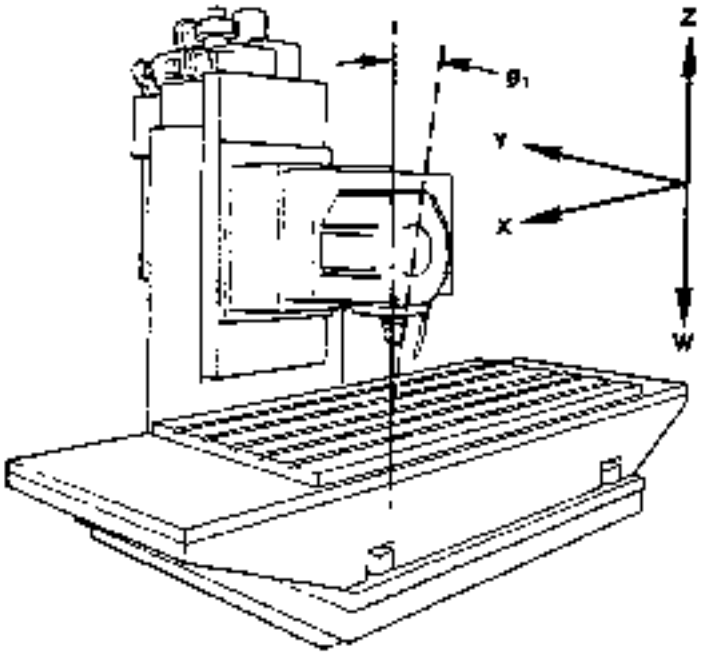
   Figure 14-2 shows that the "z" and "w" axes are parallel if the magnitude of θ_1 equals the magnitude of θ_2. When you add $\theta_1 + \theta_2$, you are actually adding $\theta_1 + (-\theta_2) = \theta_1 - (-\theta_1) = 0$

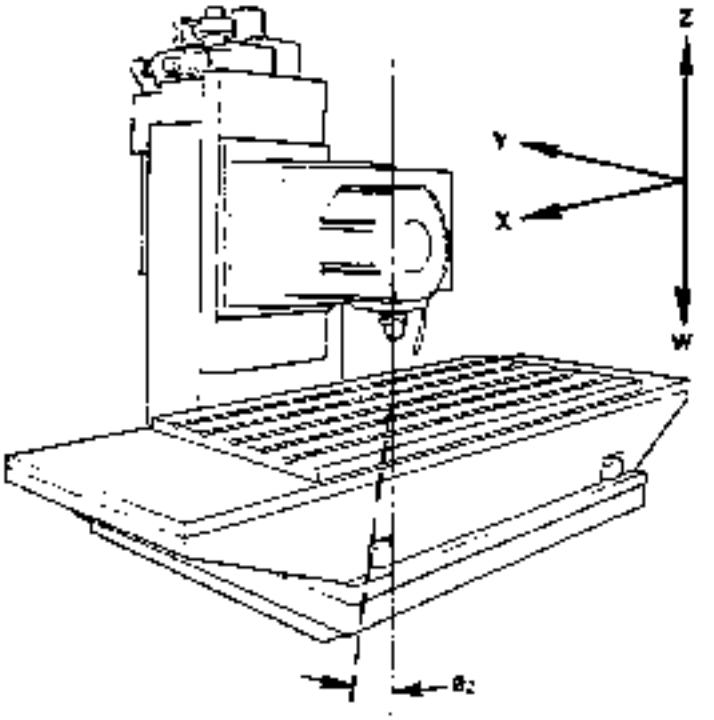




LINEAR PARALLELISM ERROR = $\theta_1 + \theta_2$

Figure 14-1. Linear Parallelism — Divergent Axes





LINEAR PARALLELISM ERROR = $\theta_1 - \theta_2$

Figure 14-2. Linear Parallelism — Parallel Axes

ROTATIONAL PARALLELISM MEASUREMENTS

This type of measurement is used to determine the parallelism between a lathe's spindle axis and its tool's travel path. Two Straightness measurements are made, with the Straightness Reflector held in the lathe's spindle, the spindle (and Reflector) are rotated 180 degrees between the first and second measurement, otherwise the two measurements are the same.

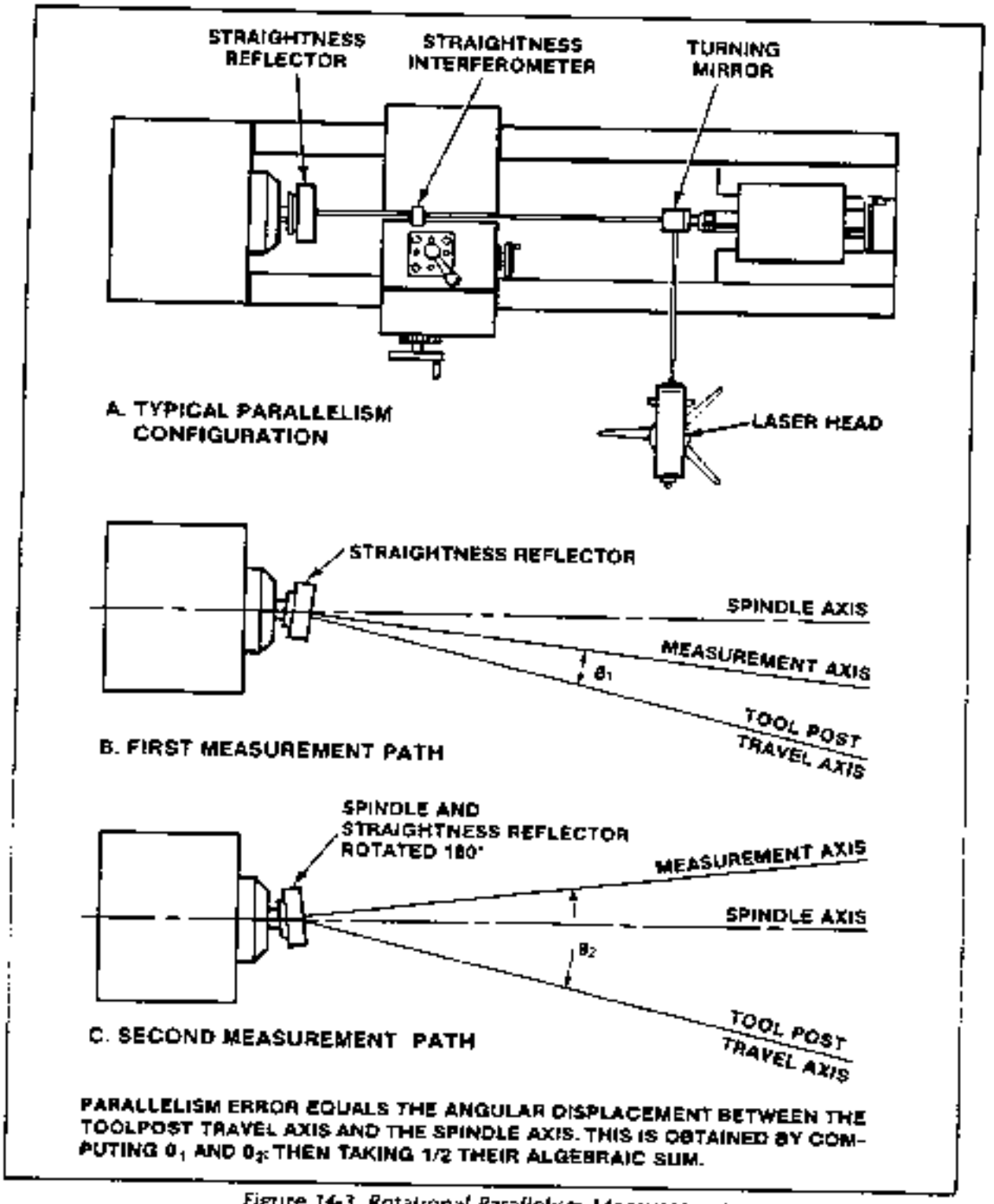


Figure 14-3. Rotational Parallelism Measurements

First-Axis Measurement

Installation and Alignment of Optics

(See Figure 14-3.)

1. Attach the Straightness Reflector to the spindle.

2. Attach the Straightness Interferometer to the tool post.

3. Attach a Turning Mirror to the tailstock, unless it is a hollow tail stock.

   Removal of a heavy tail stock is not recommended, since that would change the static loading of the lathe's bed and cause additional errors.

4. Position the Laser Head and tripod to the side if you use the Turning Mirror, or behind the tail stock if it is hollow.

5. Align the Optics just as you would for any Straightness measurement, except the beam goes through the Turning Mirror first. To do this —

   a. Position the Turning Mirror as squarely as possible.

   b. Get the laser beam to strike the center of the Turning Mirror.

   c. Adjust the Turning Mirror or the Laser Head so the laser beam strikes the junction of the Straightness Reflector's mirrors.

   d. Align the Laser Head to the Interferometer's travel using the principles presented in Section 10.

      Do not make any further adjustments to the Turning Mirror when you are aligning the Laser Head, unless your adjustments to the Laser Head are extreme enough to move the laser beam off the Turning Mirror. If this happens, readjust the Laser Head to strike the center of the Turning Mirror and start over.

6. Once aligned, try to manually remove as much slope as possible; this will help make it easier to get adequate beam strength when you make the second measurement.

Measurement Display settings

Use the instructions given in Section 10 of this User's Guide.

Making A Measurement

System Checks

Use the instructions given in Section 10 of this User's Guide.

Procedure

If you use the HP Dimensional Metrology Analysis System, refer to its Operating Manual to record and store the data for this first axis.

If you don't use the HP Dimensional Metrology Analysis System, follow the instructions given in Section 10 of this User's Guide, then refer to Section 21 of this User's Guide and calculate the slope of your measurement data.

Second-Axis Measurement

To measure the second axis, you only have to rotate the spindle and Straightness Reflector 180 degrees and make a measurement.

The instructions below indicate the extra things you should do for this measurement axis.

Installation and Alignment of Optics

Rotate the spindle 180 degrees. Do not adjust the tilt of the Straightness Reflector.

Measurement Display Settings



You must change the Direction Sense for this second measurement. Press the DIR SENSE key.

Making A Measurement

Use the same instructions you did for the first axis measurement.

Calculating Rotational Parallelism

Once you have the slope for each measurement axis (from Section 21), translate the slope values into a Parallelism value. What you must do is —

1. For each axis, determine the angle of misalignment (θ).

   This is done by taking the arctangent of the slope (m) of each Straightness measurement and multiplying by "3600", to convert to "arcseconds".

   θ = |arctangent (m)| × 3600 (arcseconds)

   Be sure your slope value is dimensionless, i.e., metre/metre or inch/inch.

2. Add the angles together and divide by two.

   Rotational Parallelism Error = $(\theta_1 + \theta_2)/2$

   In order to do this, the first- and second-axis measurements must have deflections of the interferometer produce opposite sign conventions when in the same direction.

SECTION 15
ALIGNMENT TECHNIQUES

CONTENTS

INTRODUCTION
SUMMARY OF ALIGNMENT METHODS
TRANSLATING AND TURNING THE LASER HEAD
GUNSIGHT METHOD
OVERLAPPING DOTS METHOD
AUTOREFLECTION METHOD
MAXIMUM MEASUREMENT READING METHOD

INTRODUCTION

This section provides the information you need to adjust the Laser Head to the travel path followed by the Optics.

You should develop an understanding of the principles involved in each alignment method. This will allow you to adapt any method to your particular application.

SUMMARY OF ALIGNMENT METHODS

Alignment methods are listed in *Table 15-1*, along with advantages and disadvantages of each.

Table 15-1 Summary of Alignment Methods

METHOD	APPLICATION	ADVANTAGES	DISADVANTAGES
A. Gunsight	All Measurements	Simplest—No reflection Possible in all situations No other hardware required	Inaccurate over small travels
B. Overlapping Dots	Distance and Velocity Measurements only	Possible in all situations No other hardware required	More complicated working with reflections
C. Auto-Reflection	All Measurements	Speedy	More complicated working with reflections Need special hardware Not always possible
D. Maximum Measurement Reading	In connection with Methods A, B, and C for Distance and Velocity Measurements	Increases accuracy of methods A, B, and C	

The only alignment methods that can be used for all measurement types are "GUNSIGHT" and "AUTOREFLECTION". The "OVERLAPPING DOTS" and "MAXIMUM MEASUREMENT READING" alignment methods are used for Distance and Velocity measurements only.

TRANSLATING AND TURNING THE LASER HEAD

Each alignment method requires translational and turning movements of the Laser Head. It is easiest to separate these motions into vertical and horizontal components. You will use these adjustments over and over again, so you should become familiar with them now, if you haven't already. This information is presented in Section 4, with *Figure 4-3* and *Figure 4-4*.

GUNSIGHT METHOD

This method can be used for any measurement

Procedure

1. Attach targets to the Optics as instructed in each measurement type's "Installation and Alignment of Optics" section. Both Optics must be at the "near end of travel" and already adjusted around the laser beam.

2. Move the Retroreflector or Reflector (depending on the type of measurement you're making) away from the Laser. Stop movement when the Laser beam is about to move off the Retroreflector's or Reflector's target surface, or when the Optics reach the end of travel.

3. Now make a series of adjustments to the Laser Head until the beam returns to where it originally was on the reflecting Optic or its target. (This process is illustrated in *Figure 15-1.*)

   a. **Rotate** (turn) the Laser Head to move the beam back toward the crosshairs or etched line on your reflecting Optic. (See step "2" in *Figure 15-1.*)

      As soon as you do this, the Laser beam will be partially or fully blocked by the Interferometer's target hole.

   b. **Translate** the Laser Head vertically and horizontally until the beam again goes through the hole in the Interferometer's target. (See step "3" in *Figure 15-1.*)

      If the Laser beam is not now hitting the correct point on the reflecting Optic, perform again the process of turning and translating the Laser Head.

4. Continue this process of moving the Reflecting Optic and then adjusting the Laser Head as many times as necessary until the end of travel is reached. At this point, the Laser will be aligned to the table and to the optics.

Summary

1. Translate the Laser Head or move the optics to initially position the optics around the laser beam according to instructions given in each measurement section.

2. After movement of one optic:

   a. **Rotate** (tilt or turn) the Laser Head any time the Laser's beam doesn't hit the Retroreflector's target.

   b. **Translate** the Laser Head linearly (up/down or left/right) any time the Laser beam doesn't go through the Interferometer's target hole.

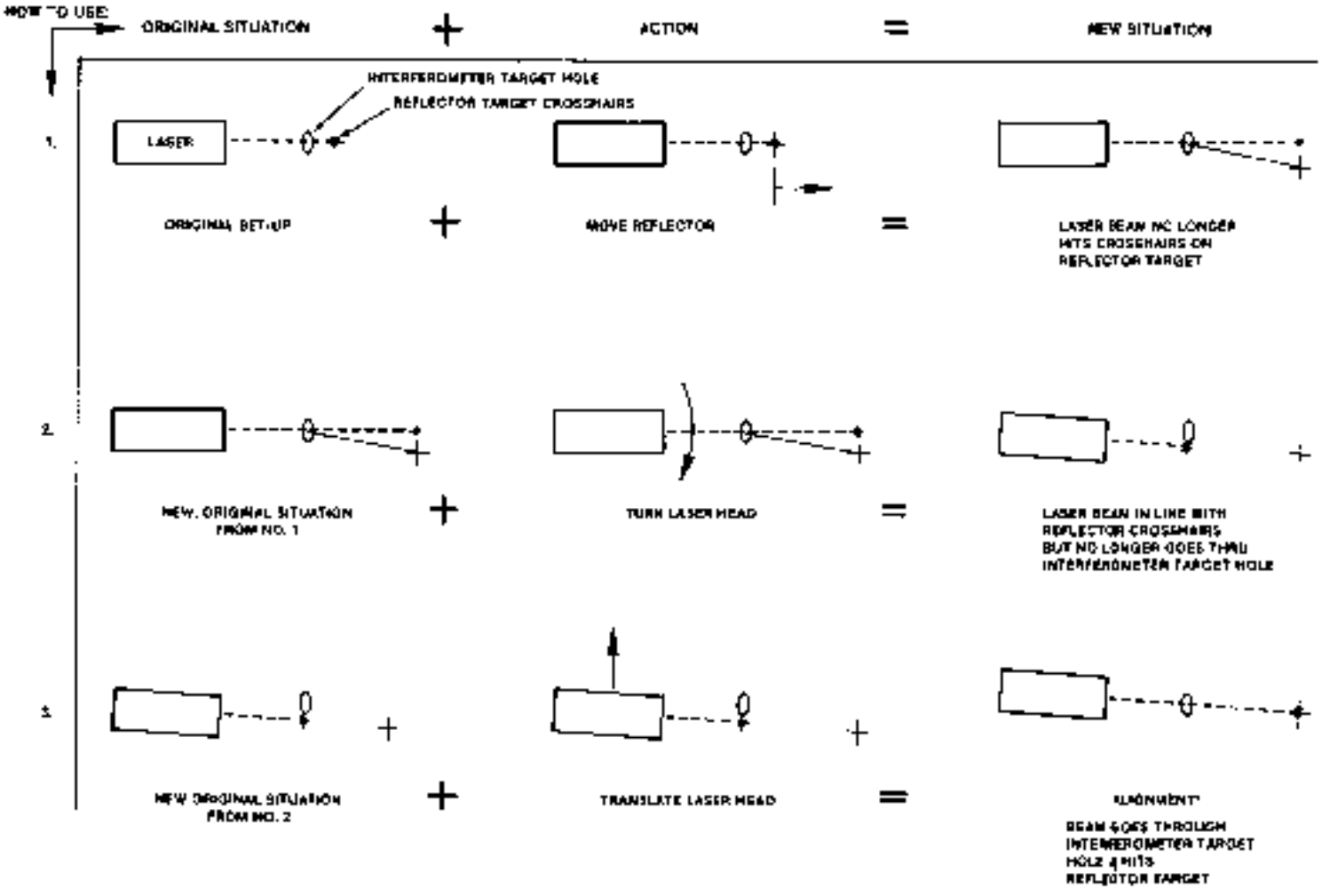


Figure 15-1. Straight Alignment Sequence

OVERLAPPING DOTS METHOD

The alignment method is used only for Distance or Velocity measurements.

Description

The "Overlapping Dots" method is identical to the "Gunsight" method, except that the Interferometer and Retroreflector Targets are removed and the Laser Head return port becomes the target.

Procedure

1. Install the Optics as described in Section 3 of the User's Guide "DISTANCE MEASUREMENTS."

   The return beam from your Distance Optics should completely overlap on the Laser Head's laser return port. The Optics should be at the "near end of travel."

   NOTE

   You should **not** have targets in place.

2. Move the Retroreflector away from the Laser to separate the Optics.

   If the Laser is not aligned to the travel axis, the Retroreflector dot will begin to move from the target port. The dot will move until the beam is cut off by the edge of the Interferometer's window. Stop moving the Retroreflector before the beam is fully blocked, or when the end of travel is reached. Figure 15-2 shows why the return dot moves.

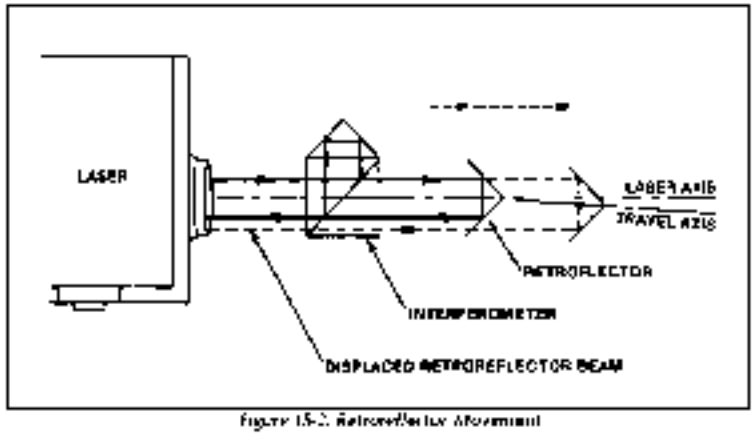


Figure 15-2. Retroreflector Movement

   This step is identical to the "Gunsight" alignment method's step "2", except that you may look at the Laser Head instead of the targets on the optics.

Figure 15-3 illustrates a typical two dot pattern that you may see after the optics move.

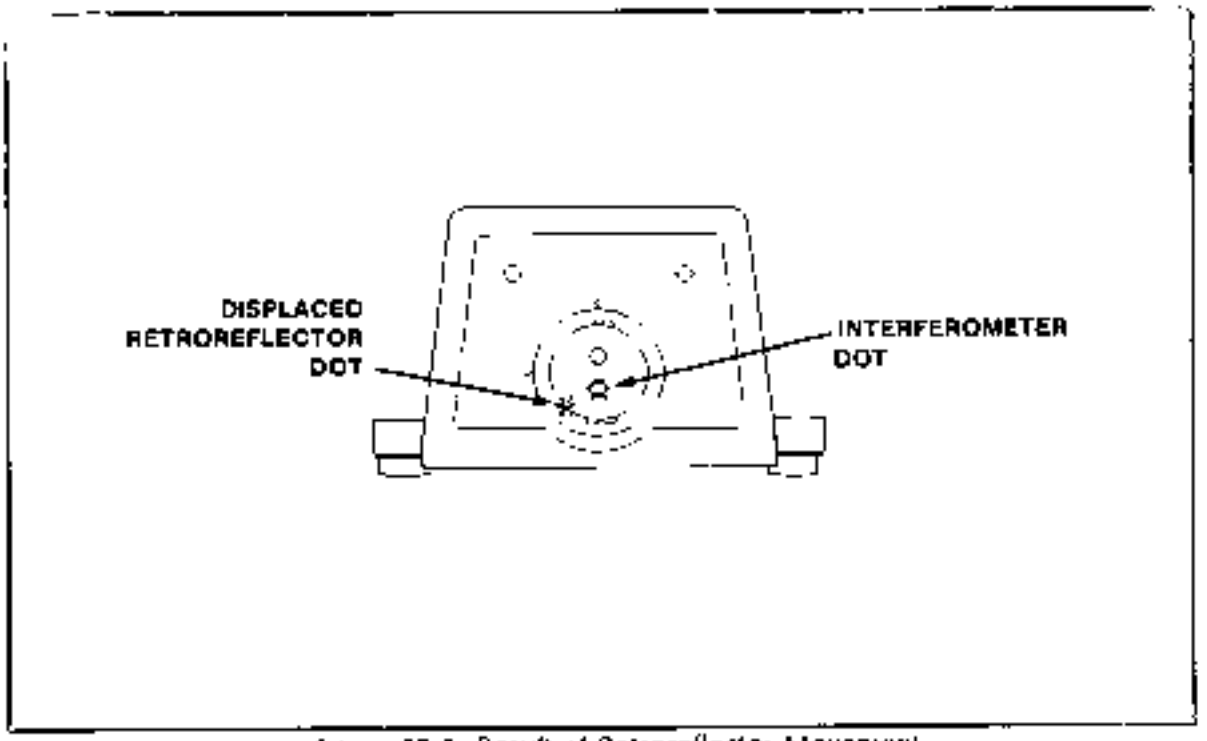


Figure 15-3. Result of Retroreflector Movement

3. Now make a series of adjustments to the Laser Head until the beams returning from both Optics are again centered on the Laser Head's return port target. (Use the procedure given below with *Figure 15-4*.)

Vertical Axis

a. Tilt the Laser Head up or down until both return dots are in line. (See step "1" in *Figure 15-4*.) (You are matching the Retroreflector's position with this adjustment.)

b. Now translate the Laser Head up or down until the Interferometer's return dot is again centered on the Laser Head's return port. (See step "2" in *Figure 15-4*.) (You are maintaining the Interferometer's position with this adjustment.) If the dots are no longer in line at this point, keep repeating steps "a" and "b" until the dots are in line, as shown in step "2" of *Figure 15-4*.

Horizontal Axis

c. Turn the Laser Head left or right until both dots overlap. (See step "3" in *Figure 15-4*.) (You are matching the Reflector's position with this adjustment.)

d. Now translate the Laser left or right until both dots move to the center of the return port. (See step "4" of *Figure 15-4*.) (You are maintaining the Interferometer's position with this adjustment.)

If the dots separate at this time, repeat steps "c" and "d" again. At the end of this procedure, both dots should overlap completely at the Laser Head's return port.

4. After aligning, continue to move the Retroreflector toward the end of travel. Stop and repeat the previous procedures each time the Retroreflector return beam gets close to being clipped by the Interferometer, or at the end of travel.

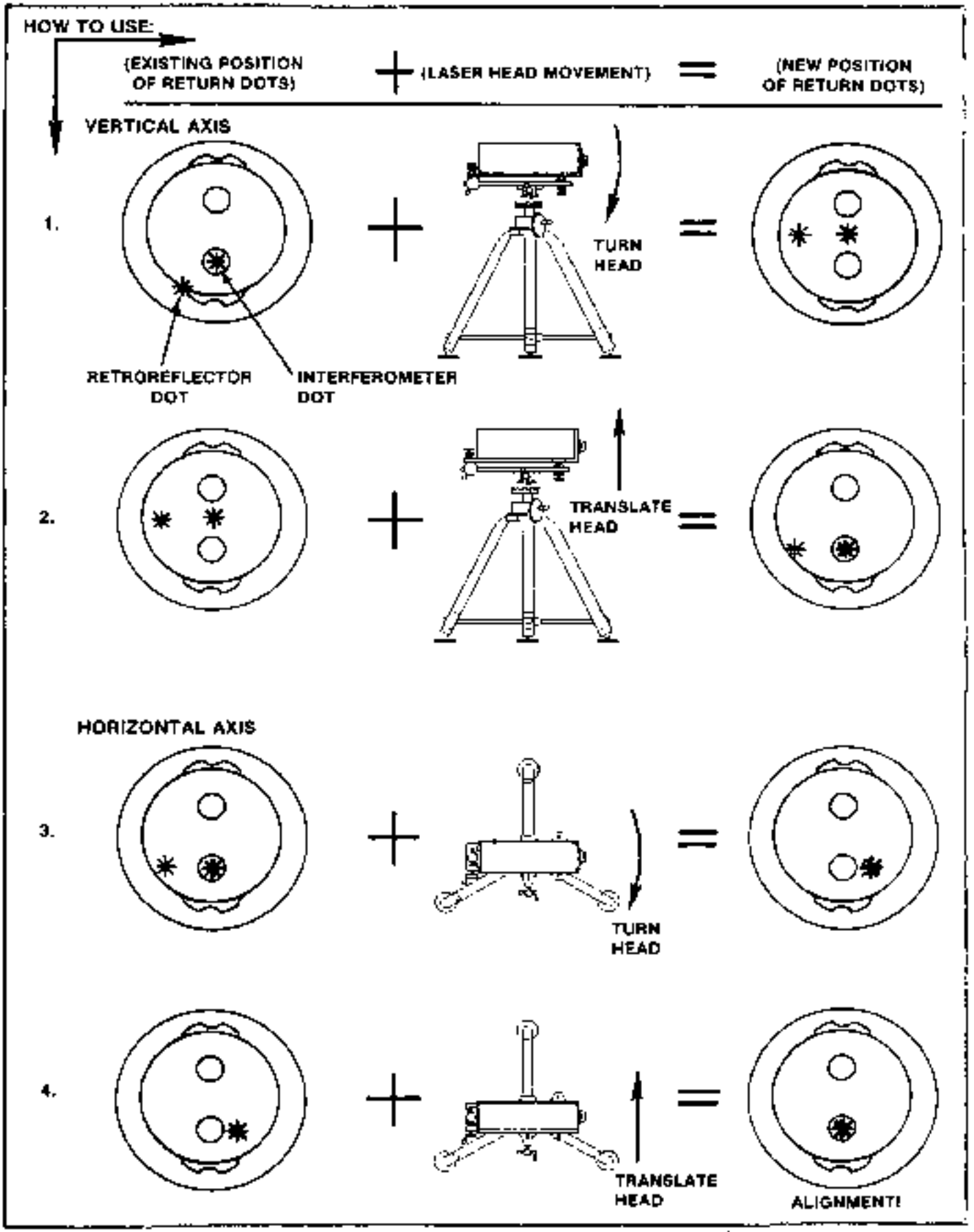


Figure 15-4 Overlapping Dots Alignment Procedure

Summary

1. **Translate the Laser Head** or move the Optics to initially position the Optics around the laser beam according to instructions given in Section 6.

2. After movement of one Optic:

   a. **Rotate** (tilt or turn) the Laser Head any time the Laser's beam doesn't hit the Retroreflector's target. Turn until the dots line up.

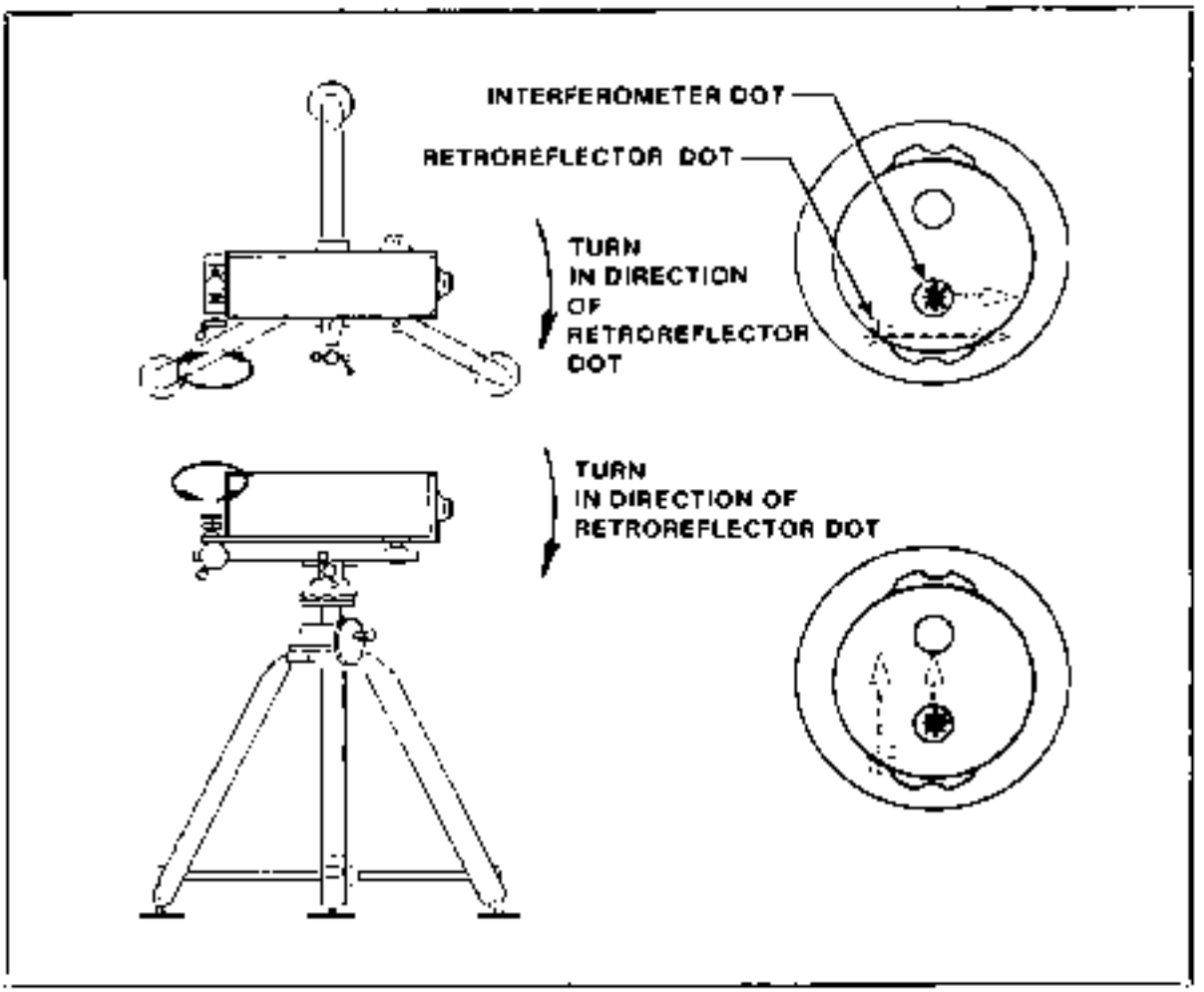


Figure 15-5. When to Turn the Laser

   b. **Translate the Laser Head** (up-down or left-right) any time the Interferometer return dot is not in the return port target (See *Figure 15-6*). (The Interferometer return dot is the one that remains when the path between the Retroreflector and the Interferometer is blocked.)

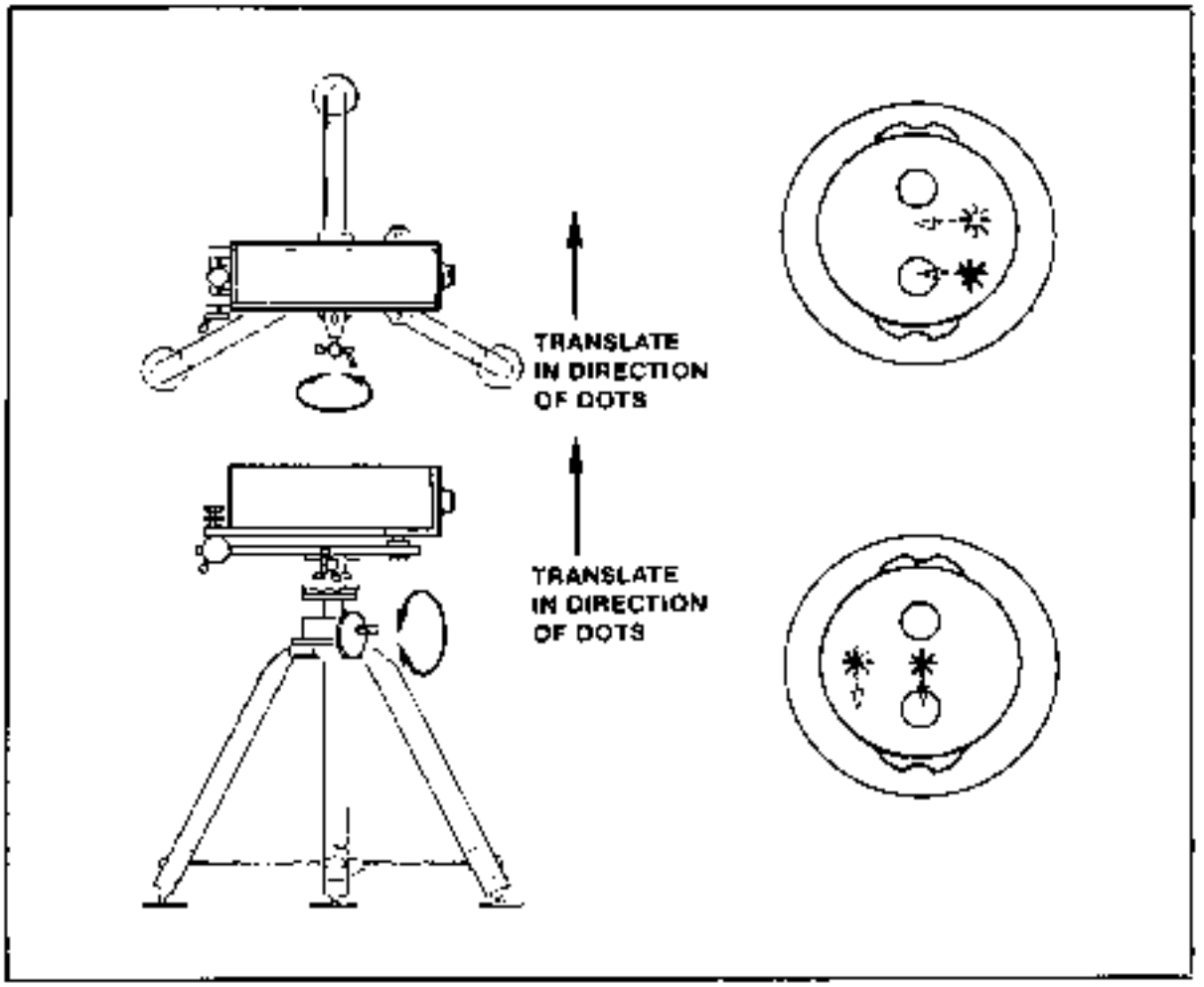


Figure 15-6 When to Translate

AUTOREFLECTION METHOD

This alignment method can be used with any type of measurement.

NOTE

This alignment method does not use any Optic used to make measurements. Instead, you must establish a plane mirrored surface perpendicular to the path that will be travelled by the Optics by using some feature of the machine's geometry (e.g., T-slots).

Procedure

1. Visually align the Laser as well as you can parallel to the direction of machine travel.

2. Provide a flat front-surface mirror, perpendicular to the machine axis to be measured.

   Typical reflectors having required mirror flatness and reference for autoreflection are —

   True squares

   Other precision angle plates or squares with a gage block wrung to the appropriate surface.

   Typical means for making the mirrored surface perpendicular to machine travel are —

   a. Locating the mirror's reference surfaces against fixed reference surfaces on the machine table (see *Figure 15-7*).

   b. Indicating the reference surfaces on the mirror/true square/gauge block/with a dial indicator, and adjusting the angular position of the mirror surface.

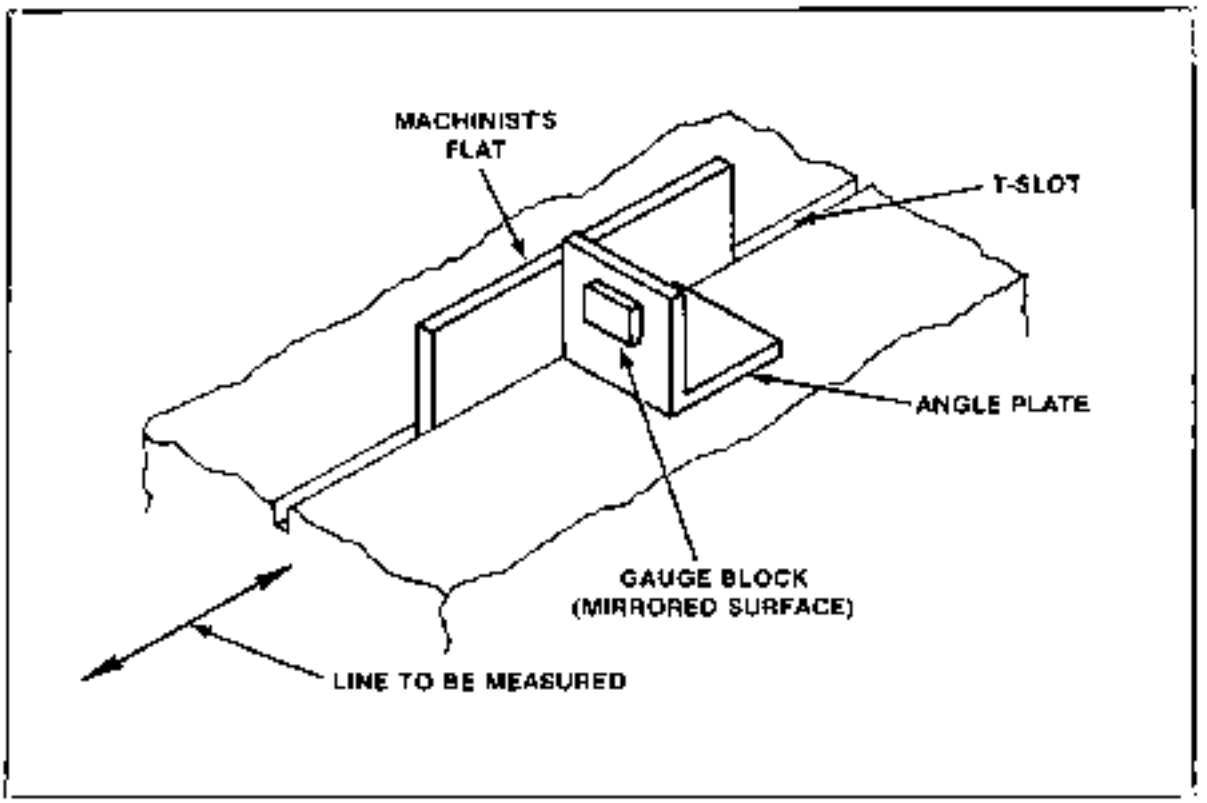


Figure 15-7 Using Reference Surfaces to Align Mirror

3. Place the perpendicular mirrored surface as far from the Laser as possible, along the desired Optics' travel path.

4. Position the Laser vertically and horizontally so a red dot appears on the mirrored surface, at a height appropriate for the optics (see *Figure 15-8*).

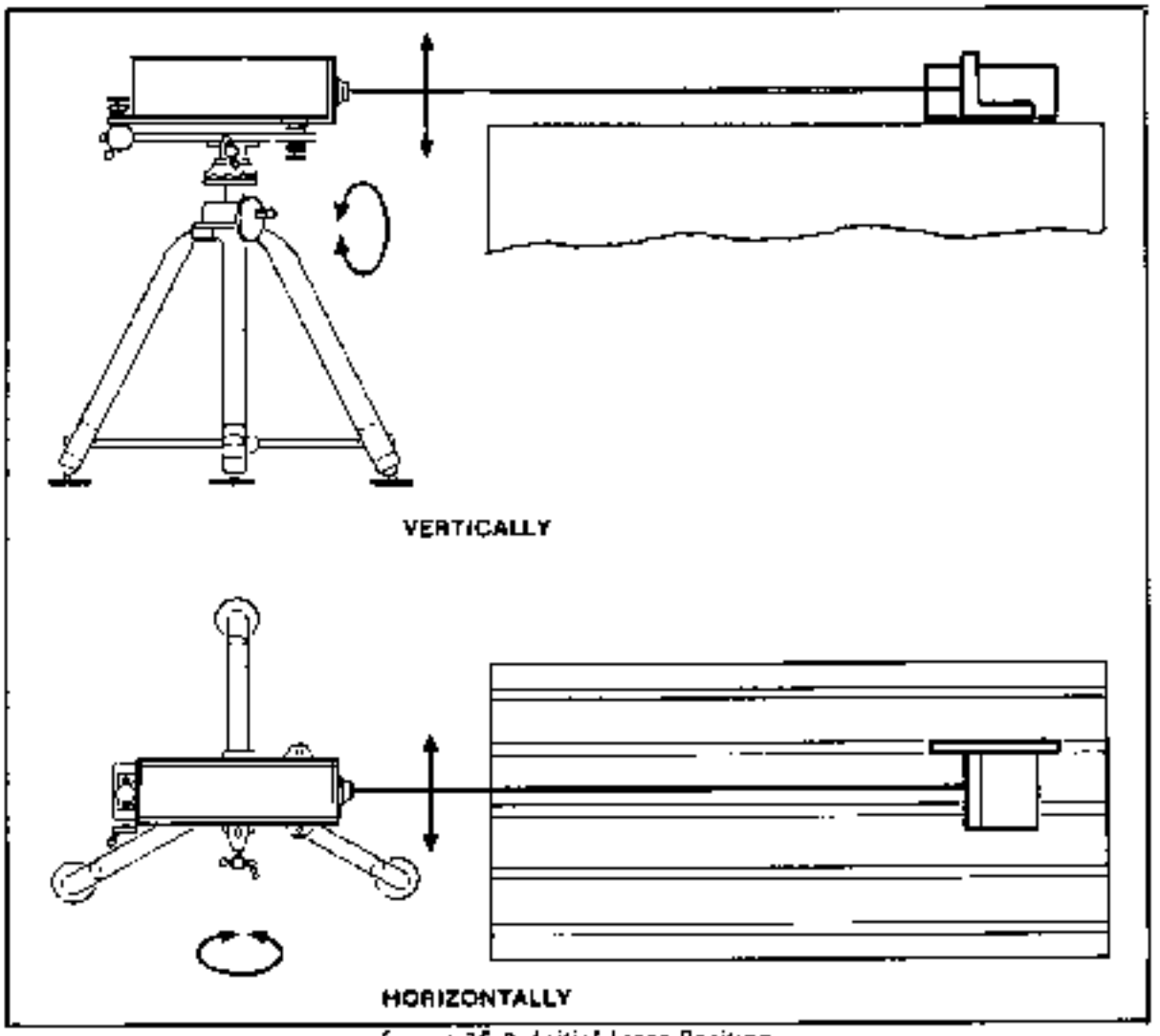


Figure 15-8. Initial Laser Position

5. Look back at the front of the Laser Head for the reflected dot.

   If the dot does not appear somewhere on the Laser Head, hold a sheet of paper (with a hole in it to allow the Laser Head's output beam to pass through it) between the Laser Head and the mirrored surface. Look for the return beam's dot somewhere on the paper.

6. Rotate the Laser Head vertically, then horizontally, until the reflected beam is centered on its upper (exit) port.

   NOTE

   The target for autoreflection is the exit port, instead of the return port, since the return beam is not offset by a Retroreflector.

   If you turn the Laser Head too far, the beam may move off the autoreflecting surface. If this happens, translate the Laser Head until the beam again hits the autoreflecting surface.

   Your Laser Measurement System is now aligned. Unlike the "gunsight" or "overlapping dots" methods, there is no progressive alignment for autoreflection techniques.

7. Remove the autoreflector and install the optics as outlined in each particular measurement section.

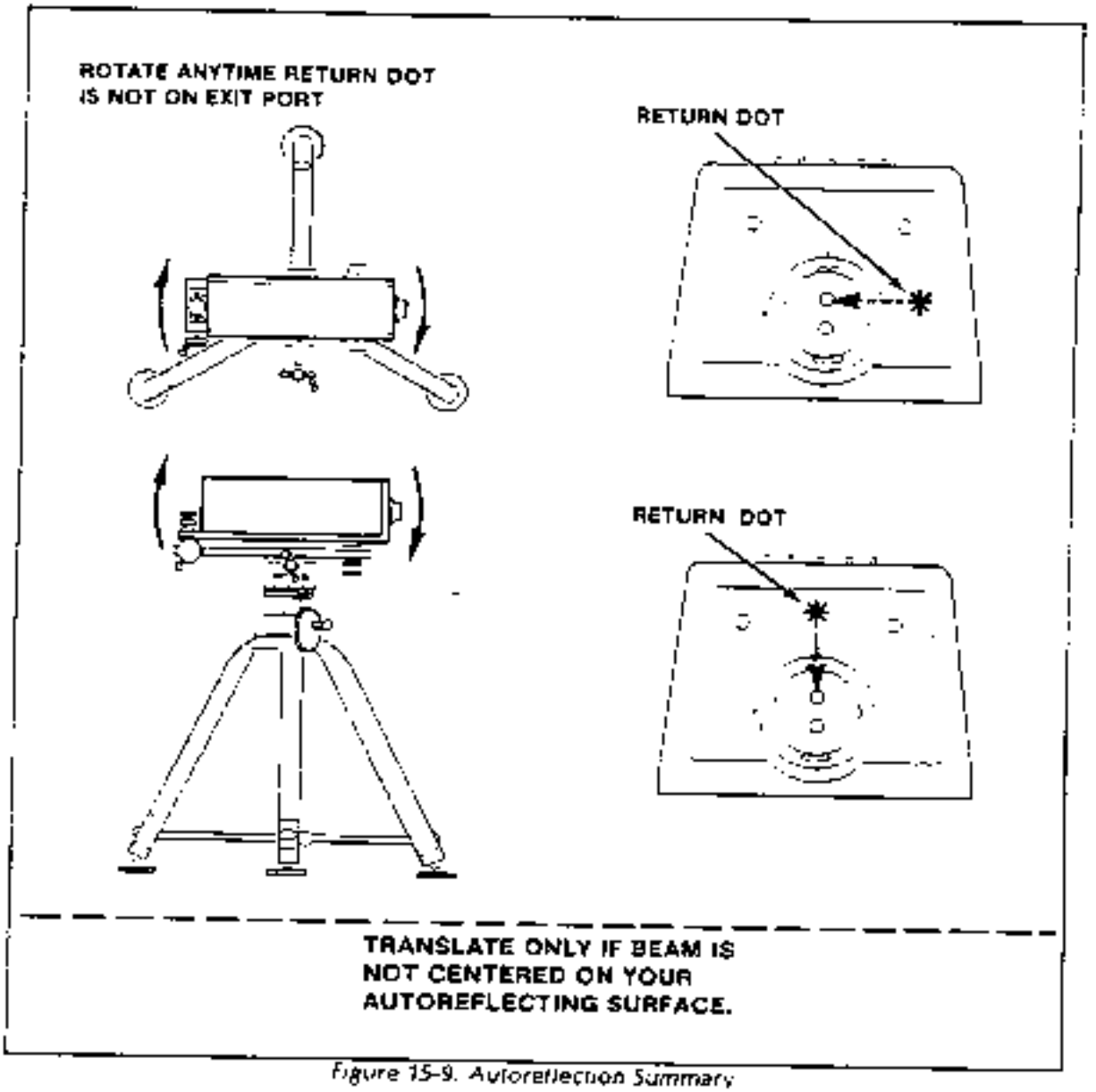


Figure 15-9. Autoreflection Summary

MAXIMUM MEASUREMENT READING METHOD

This alignment method is used only for Distance or Velocity measurements.

You should use this method in critical high accuracy measurements where any cosine error, no matter how small, is unacceptable

Description

The Laser Measurement System will only measure the component of distance or velocity parallel to its laser beam. This component can be represented by the long leg of a right triangle with the hypotenuse of that triangle representing the actual path traveled by the optics. (See *Figure* 6-13) This means that if any cosine error is present, the Laser System's reading will be slightly less than the actual traveled distance or velocity.

In this method you will slightly rotate the Laser Head until the reading on the Measurement Display reaches a maximum, thereby moving the laser beam to the hypotenuse of the triangle described above and eliminating cosine error.

Procedure

1. At the "near end of travel", make sure the return beams from the Optics are completely overlapped

   a. Position the Retroreflector within 5 mm (.2 in.) of the Interferometer.

   b. Tilt and rotate the Laser Head slightly. If there is any change in the Measurement Display's reading the return beams from the Optics are not completely overlapped and centered on the Laser Head's return port

   c. Adjust the Optics until the reading doesn't change.

2. Move to the "far end of travel".

3. Rotate and then tilt the Laser Head slightly while watching the Measurement Display. Stop movement when a maximum value is found in each axis.

16 Controls, Connectors, Indicators

SECTION 16
CONTROLS, CONNECTORS, INDICATORS

CONTENTS

INTRODUCTION
MORE ABOUT THE RESET KEY
MORE ABOUT AUTORECORD
MORE ABOUT THE SET UP KEYS
  GENERAL
  MORE ABOUT THE PRESET KEY
  MORE ABOUT THE MATL TEMP KEY
  MORE ABOUT THE V O L KEY
  MORE ABOUT THE RESOL KEY
  MORE ABOUT THE EXP COEFF KEY

INTRODUCTION

This User's Guide Section describes the Controls, Connectors, and Indicators that are found on the electronic units in the Laser Measurement System.

The basic information is presented in Figures illustrating the front and rear (as appropriate) of each of these units.

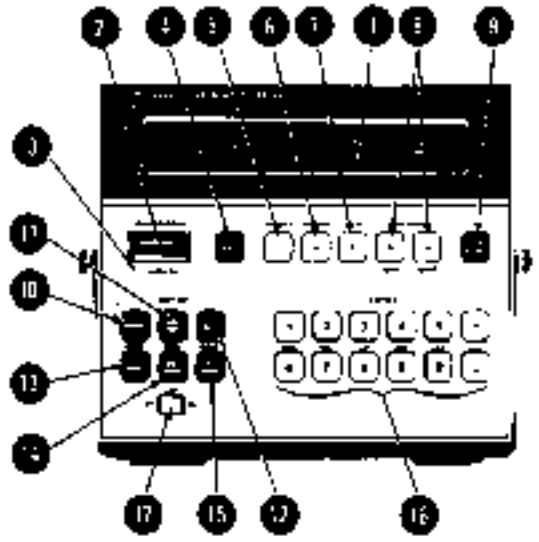
Where the description of any item is too long to fit easily into a figure, you are referred to additional material outside the figure, but still within this Section.

The Measurement Display unit's front-panel controls and indicators are illustrated and briefly described in *Figure 16-1*.

The Measurement Display unit's rear-panel controls and connectors are illustrated and briefly described in *Figure 16-2*.

The Laser Head's indicators are illustrated and briefly described in *Figure 16-3*.

The Remote Control unit's controls and indicator are illustrated and briefly described in *Figure 16-4*.



1 ALPHA-NUMERIC DISPLAY. LED indicators used to display numeric data readouts or alpha-character status information.

2 BEAM STRENGTH Meter. Indicates the relative strength of the laser beam measurement signal. The meter reading can be used to aid in optimizing the optical alignment of the laser and measurement optics. Beam strengths and ations within the green area of the meter are required for proper operation.

3. LASER ON Indicator. Indicates that power is being provided to the Laser Head, and that the laser tube is activated and emitting a laser beam.

   The indicator is connected in parallel with the LASER ON indicator on the Laser Head. All of these indicators should be lighted at the same time.

4 RESET Key. Erases all measurement data taken up to the time it was pressed. Removes Laser Measurement System from HP-IB control (if it was operating under HP-IB control). Clears error message, if one is being displayed. Returns Laser Measurement System to most-recently-chosen measurement mode.

NOTE

The RESET key clears only the measurement data. A value entered via an ENTRY key will not be changed by RESET.

Additional information about the RESET key is presented in text outside this figure.

5. DISTANCE Key. Programs the Laser Measurement System for a Distance Measurement. Distance Measurements are described in Section 6 of the User's Guide.

6. VELOCITY Key: Programs the Laser Measurement System for a Velocity Measurement. Velocity Measurements are described in Section 7 of the User's Guide.

7. ANGLE Key: Programs the Laser Measurement System for an Angular Measurement. Angular Measurements are described in Section 8 of the User's Guide.

8. STRAIGHTNESS Keys. Either of these keys programs the Laser Measurement System for a Straightness measurement. Straightness measurements are described in Section VI and Section 11 of the User's Guide. The LONG STRAIGHTNESS key is used for a measurement in the range from 1000 mm to 30,000 mm (39.37 inches to 1200 inches). The SHORT STRAIGHTNESS key is used for a measurement in the range 100 mm to 3000 mm (3.94 inches to 120 inches).

9. AUTO RECORD Key: This key provides a way for you to record data on an external device. Automatically, at a rate you choose.

   Additional information about the AUTO RECORD key is presented in text outside this figure.

10 PRESET Key. Selects a function depending on the current measurement mode. Offset values can be preset in the distance and velocity modes. Multiplication factors can be preset in the angular and straightness modes. The default values are "0" for Distance and Velocity, and "1" for Angular and Straightness. The PRESET key can be used any time without loss of measurement data. Changing a preset value in any one particular mode does not affect the preset values of the other modes.

    Additional information about the PRESET key is presented in text outside the figure.

11. MATL TEMP Key. The Material Temperature Sensor(s) are used to compensate for thermal expansion or contraction of the material being measured by the Laser Measurement System. The MATL TEMP key can be used any time without loss of measurement data. The MATL TEMP key can be used to:

    a. display the average temperature of all sensors connected. —

    b. display the temperature of each individual sensor connected. —

    c. display the default average temperature value: 20°C or 68°F if all sensors are disconnected. —

    d. enter an average workpiece temperature when all sensors are disconnected.

    Additional information about the MATL TEMP key is presented in text outside the figure.

12. V.O.L. Key: The V.O.L. key can be used to display or select the Velocity-of-Light Compensation number.

    Additional information about the V.O.L. key is presented in text outside the figure.

13. RESOL Key: Selects or displays the number of significant decimal places displayed on the Measurement Display unit during measurements. The key also sets the smoothing function on or off. The RESOL key can be used any time without loss of measurement data.

    Additional information about the RESOL key is presented in text outside the figure.

14. EXP COEFF Key: Used to enter or display the expansion coefficient of the material being measured.

    Additional information about the EXP COEFF key is presented in text outside this figure.

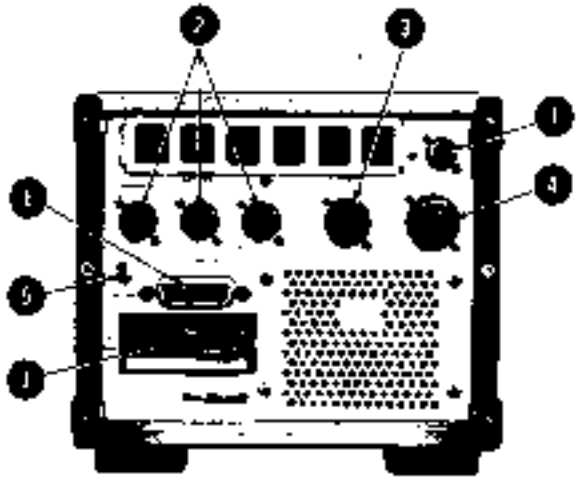
15 DIR SENSE Key. Reverses the sense of the measurement. For example, if the operator is moving a retroreflector and the display indicates an increasing positive displacement, pressing the DIR SENSE key will result in the same movement causing an increasing negative displacement or a decreasing positive displacement.

   The DIR SENSE key may be pressed at any time without losing the current data. Also, this key reflects the current position about the preset value. For example, if the preset value is 5.00000 and the display reads 7.00000, pressing the DIR SENSE key will result in a display of 3.00000.

16 ENTRY Keys. The ENTRY keys allow the user to assign values to certain parameters as described above. Numeric entry information is lost when entering numbers into the Measurement Display.

17. LINE Switch. When set to ON, power is applied to the Measurement Display unit, the Laser Head, and any sensors that are connected to the Measurement Display unit. The LASER ON indicators illuminate and the laser tube is powered. Also upon application of power, the system starts into a warm-up period during which a self-test diagnostic routine is executed.

Figure 4-1. 5528A Measurement Display — Front Panel



1 RMT CONT Connector. Connecting point for the 05926-60001 Remote Control Unit. See section 3 of the User's Guide for connection information.

2 MATERIAL TEMPERATURE Connectors. Connecting points for the Material Temperature Sensors. See Section 3 of the User's Guide for connection information.

3 AIR SENSOR Connector. Connecting point for the Air sensor. See Section 3 of the User's Guide for connection information.

4 LASER SOURCE Connector. Connecting point for the cable between the Measurement Display and the Laser Head. See Section 3 of the User's Guide for connection information.

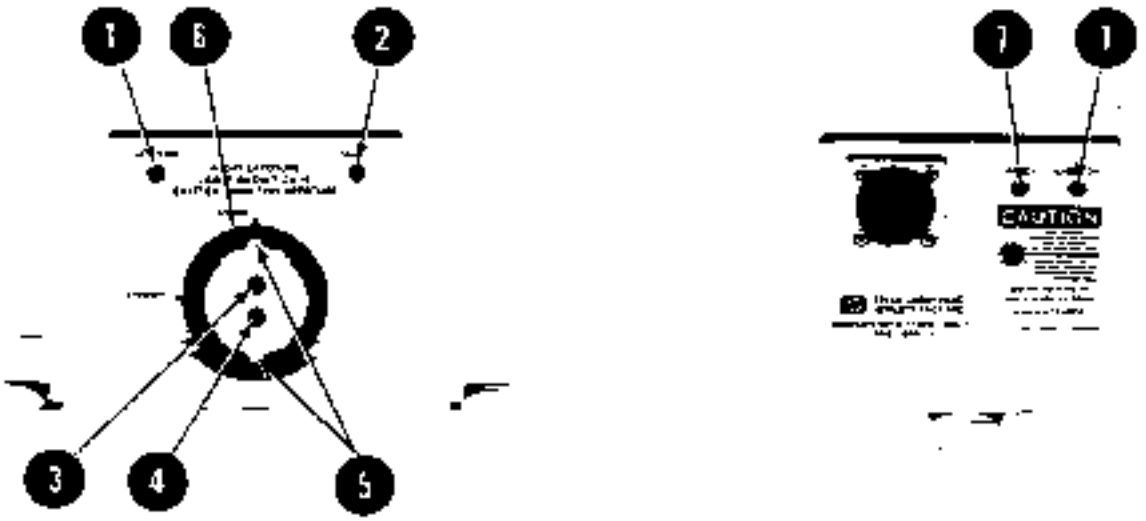
In this connector is left open when turning on the system the Measurement Display unit will display LASER FAIL after 4 min (through a warm-up operation (approximately 3 to 15 minutes).

5 ENGLISH-METRIC Switch. Determines the units of measurements, either English: inches, degrees F, or Metric: millimeters, degrees C.

The switch setting can be changed regardless of the Measurement Display unit function, without loss of measurement data. It converts all temperatures, distances, and related constants in the Measurement Display unit memory to the current measurement mode. No RESET is required.

6 IEEE STD 488 PORT Connector. Connecting point for HP-IB cable. HP-IB is a Hewlett-Packard implementation of the IEEE 488 standard interface. It is used to connect other equipment to the Measurement Display unit. The lettering just above the connector indicates the IEEE STD 488 (HP-IB) capabilities of the Laser measurement System. (Refer to Section 3 of the Laser Measurement System's Service Manual for details. Refer to Section 2 of the Laser Measurement System's Service Manual for pin connections, signal names, and logic conventions). Information required to use the Measurement Display unit with HP-IB is covered in Section 3 of the User's Guide.

7 POWER LINE Module. Connecting point for line power cord. Also contains the line fuse, and a line voltage selector. Details of line voltage selection, line fuse selection, and line cords are contained in Section 5 of the User's Guide.



1. LASER ON Indicator: Indicates when Laser Head is receiving power from Measurement Display unit.

2. SIGNAL Indicator: Indicates that Laser return beam is strong enough for a measurement.

3. LASER EXIT PORT. Source of Laser beam for all measurements. Also, destination of Laser return beam for Straightness measurements.

WARNING

LASER RADIATION IS EMITTED FROM THIS PORT. DO NOT STARE INTO THE BEAM.

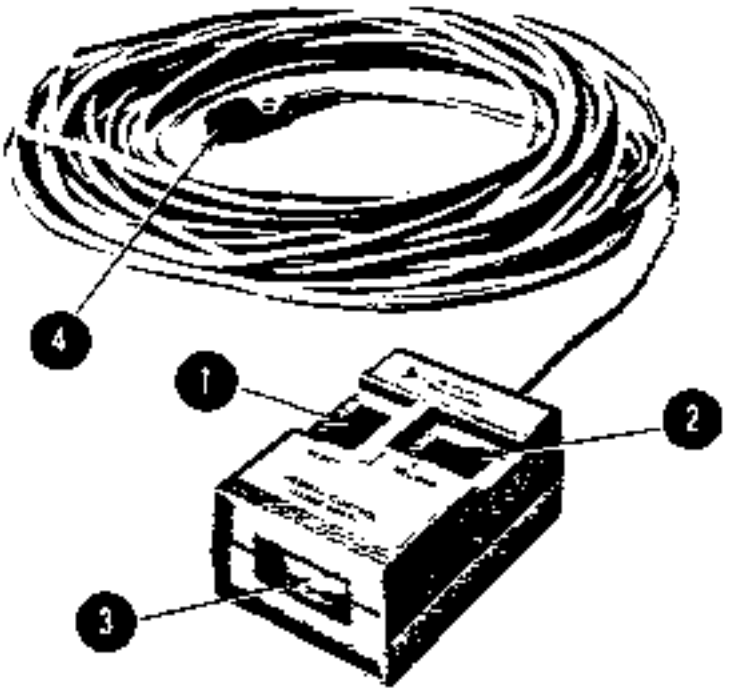
4. LASER RETURN PORT: Destination of Laser return beam for Distance, Velocity, and Angular measurements.

5. APERTURE CONTROLS: These are located behind both ports in the turret. The Exit Port's aperture control has three positions — large opening, small opening, and closed. The Return Port's shutter has two positions — open and closed (which displays a target used for alignment).

6. TURRET RING: A two-position selector that switches elements in the Exit and Return beam paths, depending on whether a "STRAIGHTNESS" measurement is being made.

7. READY Indicator: Provides a general indication of the Laser's operating status. "Off" for about the first half of the warm-up time, blinking during the last half (approximately ½ of the warm-up time), "On" steadily when Laser tube is fully warmed up and ready for use.

Figure 16-3. Laser Head — Front and Rear



1 RESET Key. Same as Measurement Display unit's RESET key. Erases all measurement data taken up to the time it was pressed. Releases Laser Measurement System from HP-IB control if it was operating under HP-IB control. Clears error message, if one is being displayed. Returns Laser Measurement System to most-recently-chosen measurement mode.

NOTE

The RESET key clears **only** the measurement data. A value entered via an ENTRY key will not be changed by RESET.

Additional information about the RESET key is presented in text outside this figure.

2 RECORD Key: Each time you press this key, your current measurement data is recorded on an external recorder connected to the Measurement Display unit via the HP-IB (IEEE STD 488 PORT) connector. This is a "manual-only" function, and operates independently of the Measurement Display unit's "AUTO RECORD" key.

3. Meter: This meter provides beam-strength indication. It duplicates the Measurement Display unit's BEAM STRENGTH meter.

4. Connector: This connector mates with the Measurement Display unit's rear-panel RMT CONT connector.

Figure 16-4. Remote Control Unit 05508-60021, Controls, Connector, and Indicator

MORE ABOUT THE RESET KEY

When you press the RESET key, all measurement data that was taken until then is erased; if the Laser Measurement System was operating under HP-IB control, it will be returned to LOCAL control.

While you continue holding the RESET key in, the display fills with "0"'s

When you release the RESET key, the Laser Measurement System returns to the last measurement mode selected before RESET was pressed

NOTE

The RESET key clears only the measurement data. If user-selected values have been entered via the Measurement Display unit's ENTRY keys, these values will not be changed by RESET

If you press RESET while viewing a temperature sensor value, resolution number, etc., the Measurement Display unit will return to the most-recently-selected measurement mode

The RESET key must be used to clear any "Error" message that was not caused by incorrect use of a SET UP key. If the cause of such an error is not eliminated, pressing RESET will cause the Laser Measurement System to return to its previously selected mode of operation, and the same error message will again be displayed. Except for a sensor-caused error, the message will reappear almost instantly. For a sensor-caused error, the message will take up to three seconds to appear

MORE ABOUT AUTO RECORD

This key provides a way for you to record data on an external device at a rate you choose, via HP-IB. HP-IB (Hewlett-Packard Interface Bus) is Hewlett-Packard Company's implementation of the IEEE Standard 488 Interface Bus.

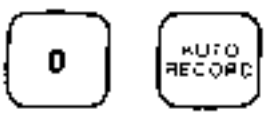
To use the AUTO RECORD function, connect an HP-IB compatible device to the IEEE STD 488 PORT connector on the Measurement Display unit's rear panel. The recording device should be configured as an HP-IB listener, using instructions in its Operating Manual. For more information about HP-IB terminology and capabilities, see the "Data Transfer to External Devices" description, in Section 3 of the Laser Measurement System's Service Manual.

NOTE

To transfer data to a device configured in its HP-IB "Listen Only" mode, the Measurement Display unit must be configured in its "TALK-ONLY" mode. See Section 18 for instructions on selecting the "TALK-ONLY" mode

Selecting the Auto Record Output Rate

You can select any time increment in the nominal range of 0.05 second to 12 seconds in steps of 0.05 second; however, the time increment you choose should not exceed the maximum input rate of the listening device.



Pressing "0 AUTO RECORD" transfers data to the listening device at the rate of the slowest listening device. If a data sample has been completely transferred, then at the end of a Measurement Display unit update cycle, the updated display value will be held and made available for transfer.

NOTE

HP-IB ERRORS can occur when listener rates are not compatible. During auto record, the "Lr Error" listener error will be displayed when an attempt is made to output a data sample while the previous data sample has not yet been completely accepted by the HP-IB listener. This error will not occur if there is no listener connected and the Measurement Display unit is configured to Talk-Only on HP-IB.

To record timed samples, enter the time increment with the ENTRY keys, then press the AUTO RECORD key. The RCD indicator will light, and the current display will be transmitted over the HP-IB bus once per selected time increment. For example, 2 AUTO RECORD will cause an output sample every 2 seconds. To turn off the auto record, press AUTO RECORD.

MORE ABOUT THE SET UP KEYS

General

The six SET UP keys allow you to display and/or enter numeric values associated with various characteristics of the measurement you are making.

The general procedure for displaying the value associated with any of these keys is to simply press the key. Typically, the value will continue to be displayed until the key is pressed again, or until you change the measurement mode. Some keys have several different values associated with them, and will display each value on successive presses of the key.

The general procedure for entering a value for any of these keys is to use the ENTRY keys to set up the numeric value, and then press the SET UP key to which you want that number assigned.

When the value associated with any key is incorrect, either because the number you entered is not allowed, or because a sensor returned an out-of-range value, an "Error" message usually results. A complete list of "Error" messages is given in Section 17 of this User's Guide, and in the Laser Measurement System's Service Manual. Two of these messages — "Or Error" and "Ur Error" — are associated with manual entry of data.

If the number you try to enter for any SET UP key is not allowed for that key in your current measurement mode, the message "Or Error" or "Ur Error" will be displayed.

"Or Error" indicates that the value you tried to enter was too large.

"Ur Error" indicates that the value you tried to enter was either too small, or was negative where a negative value is not allowed.

In response to either an "Or Error" or a "Ur Error" —

1. Press again the SET UP key that you were using.

   This will cause the "Error" message to be replaced with a number that represents the maximum value in the direction of the error.

   If you don't want to accept the "limit" value as the value to be assigned to the particular SET UP key you are using, use the ENTRY keys to specify a new numeric value.

2 Press again the SET UP key that you were using.

The number being displayed at it is within the limits for that key at in that measurement mode) will be assigned to that key.

More About the Preset Key

This key allows you to enter a number that will be used to modify the "raw" measurement results produced by the Laser Measurement System. You can store one "preset" number for each major measurement type (DISTANCE, VELOCITY, ANGLE, STRAIGHTNESS). *Table 16-1* shows how these preset values are applied to the measurement results, and the default value and limits of each.

You can use the PRESET key at any time without loss of measurement data. Changing a preset value in any one particular mode does not affect the preset value for any other mode.

Entering a Preset Number

See "GENERAL" information for SET UP keys, above.

Viewing a Preset Number

To find out what the current preset number for your measurement mode is, all you have to do is press PRESET. This number will remain displayed until you either press PRESET again or until you press the key to call up some other measurement mode.

NOTE

To display the preset value for any mode other than the current one, you will first have to press the key corresponding to that mode.

Table 16-1. Preset Key Functions, Default Values, and Ranges

	DISTANCE	VELOCITY	ANGLE	STRAIGHTNESS
Display shows	Measured Displacement + Preset	Measured Velocity + Preset	Measured Angle * Preset	Measured Displacement * Preset
DEFAULT	0	0	1	1
RANGE	±50.000 mm (±2.000 in)	±20.000 mm/min (±720 in/min)	0* to 2	0* to 2

* Measurement Display unit will accept "zero" as a multiplier for ANGLE or STRAIGHTNESS, without giving an error message. However, your measurements will not be displayed, since any measurement value multiplied by zero will result in a zero value.

More About the MATL TEMP KEY

The Material Temperature Sensors are used to compensate for thermal expansion or contraction of the material being measured by the Laser Measurement System. You can use the MATL TEMP key at any time without losing of measurement data to —

a display the average temperature of all sensors connected. —

b display the temperature of each individual sensor connected. —

c display the default average temperature value (20°C or 68°F) if all sensors are disconnected. —

d enter an average workpiece temperature when all sensors are disconnected.

The range of the 10757A/B/C Material Temperature Sensor is 0 to 40°C (32 to 104°F). When a sensor reaches a temperature outside this range, an appropriate error message is displayed by the Measurement Display unit. See Section 17, "ERROR MESSAGES" for explanation of these messages. The same error messages are used when a temperature signal error occurs due to a hardware failure.

To Display the Material Temperature

To display the material temperature, press the MATL TEMP key.

The first time this key is pressed, an "A" (indicating "average") appears on the left-hand side of the display, and the temperature (fixed to two decimal places) is shown on the right, followed by a "C" or an "F" (centigrade or fahrenheit, depending on the setting of the ENGLISH-METRIC switch).

Each successive press of the MATL TEMP key will display the temperature of the sensors, in the order "1", "2", "3". If the next sensor to be read is not connected, the Measurement Display unit will skip that reading. Thus, if only sensors "1" and "3" are connected, successive presses of MATL TEMP will give the average temperature, the temperature at sensor "1", the temperature at sensor "3", and a return to the measurement mode. If no sensor is connected, successive presses of MATL TEMP will show the average temperature and then return to the measurement mode.

If you select some other function while the temperature of a particular sensor is being displayed, and then press MATL TEMP, the display will go back to showing the temperature of that sensor; successive presses of MATL TEMP will cycle through the sensors and "average", as described above.

For example, assume that all three Material Temperature sensors are connected, and that the temperature of sensor number "2" is being displayed. If you then press the VELOCITY key (to find out how fast the optics are moving), and then press the MATL TEMP key again, the temperature at sensor number "2" will be displayed again. Successive presses will then display the temperature at sensor "3", and then a return to mode.

To Enter A Material Temperature

See "GENERAL" information for SET UP keys, above

NOTES

1. The Measurement Display unit accepts a manually-entered MATL TEMP value **only** when no Material Temperature sensor is connected at its rear panel.

2. The Measurement Display unit assigns any manually-entered MATL TEMP value it accepts as the "average" MATL TEMP value.

3. The allowable range of values for MATL TEMP is —

   0 to 50°C (32 to 122°F)

4. If no Material Temperature sensor is connected to the Measurement Display, and you do not manually enter MATL TEMP value, the "standard" value (20°C, 68°F) is automatically assigned

If you try to enter a material temperature value while a Material Temperature sensor is connected to the Measurement Display unit, the value you enter will be ignored, and the average of the temperatures from all connected Material Temperature sensors will be used. Since the averaging process can take up to 3 seconds, pressing MATL TEMP shortly after you "enter" a temperature in this case may allow the entered temperature to be seen for a short time

The only exception to the above statement is when a sensor error occurs, due either to an "out-of-range" condition or a malfunction. When this type of error occurs, a sensor error message is displayed The next time you press MATL TEMP, an "ERROR" will be displayed, indicating a problem with one of the sensors. Successive pressings of MATL TEMP will cause readings from "good" sensors to be displayed, in the usual sequence. there will be no reading from any "bad" sensor, just as if the sensor was not connected.

More About the V.O.L. key

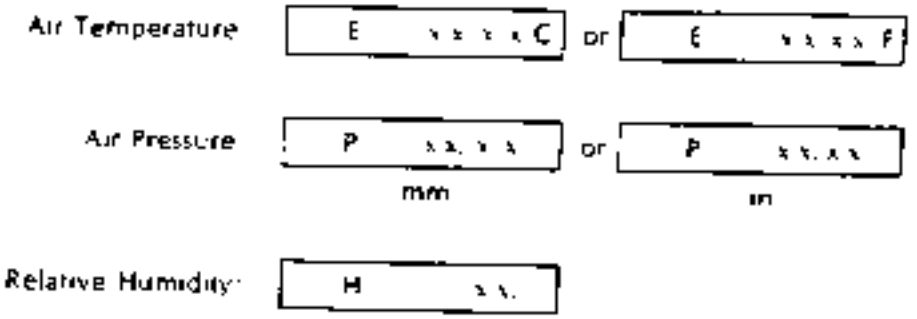
The V.O.L. key is used to display or enter the "Velocity-of-Light" Compensation number. The V.O.L. number is used by the Measurement Display unit to correct for the change in laser wavelength due to atmospheric conditions. The V.O.L. number used by the Measurement Display unit is "0.999abcd", however, only the "abcd" part of this number is displayed on the Measurement Display unit, in the form "abc.d". The Measurement Display unit multiplies measurement data by the V.O.L. Compensation number before the data is displayed. Velocity-of-Light Compensation is necessary for Distance and Velocity measurements only.

The V.O.L. number is derived from measurements provided by the Air Sensor. If the Air Sensor is not used, the V.O.L. number defaults to "728.8". The DEFAULT VALUE, 728.8, corresponds to 20 degrees C (68 degrees F) air temperature, 760 mm (29.921 inches) Hg air pressure, and 50% relative humidity.

To View the Current V.O.L. Compensation Number

To view the current compensation number, just press the V.O.L. key.

Successive presses of V.O.L. will give the air temperature, the air pressure, and finally the air humidity, as shown below:



Since all three values are provided by the Air Sensor, they are either all present or all absent, unless a sensor error or failure has occurred. If the Air Sensor is used, the compensation number is updated approximately every three seconds by the Measurement Display unit.

If you select some other function while an Air Sensor value is being displayed, and then press V.O.L., the display will go back to showing the last displayed Air Sensor value; successive presses of V.O.L. will cycle through the Air Sensor values, as described above.

For example, if the air pressure is being monitored, and you want to momentarily select another function, when the V.O.L. button is pressed again, the first data displayed will be the air pressure. Successive presses of the V.O.L. key will then give air humidity and then a return to the current measurement mode.

To Enter A V.O.L. Compensation Number

See "GENERAL" information for SET UP keys, above.

NOTES

1. The Measurement Display unit accepts a manually-entered V.O.L. value **only** when an Air Sensor is not connected at its rear panel.

2. The allowable range of values for V.O.L. is —

   "0" to "999.9"

   The Measurement Display unit will also allow you to enter the value "1000.0". This is a special case that sets the V.O.L. compensation number to "1.0000000", i.e., there is no compensation.

3. If an Air Sensor is not connected to the Measurement Display, and you do not manually enter a V.O.L. compensation factor, the compensation for "standard" air temperature, pressure, and humidity is assigned; this value is "728.6".

"Standard" air temperature is 20°C (68°F) pressure is 760 mm (29.921" Hg) humidity is 50%.

If you try to enter a V.O.L. compensation number while an Air Sensor is connected to the Measurement Display unit, the value you enter will be ignored, and the value derived from the Air Sensor's inputs will be used.

When an Air Sensor error occurs, the appropriate message immediately appears on the display (unless there is a higher priority error) and the next press of the V.O.L. key will yield "C Error" indicating that an error condition exists with one of the air sensor measurements. Successive presses will display the valid air sensor data, and pass over the invalid sensor data.

NOTE

Connecting or disconnecting the Air Sensor during a measurement may result in a measurement error.

More About the RESOL key

This key allows you to select or display the number of significant decimal places displayed on the Measurement Display unit during a measurement. This key also sets the "smoothing" function "on" or "off".

You can use the RESOL key at any time, without loss of measurement data.

To Display the Resolution Value

To display the current resolution value, just press the RESOL key. Pressing the key again sends the Laser Measurement System back to the current measurement mode.

Resolution limits are different for each measurement mode, and, except as noted below, English unit resolution is one place greater than the metric equivalent. You can see this by viewing the current resolution and switching the ENGLISH/METRIC switch on the Measurement Display unit's rear panel from one position to the other. Except as noted below, changing the ENGLISH/METRIC switch setting does not change the smoothing function.

To Specify a Resolution Value

See "GENERAL" information for SET UP keys, above.

SMOOTHING

Measurement data can be averaged by the Measurement Display unit to reduce the amount of number-changing you see in the display. This is called "smoothing".

To turn smoothing "on", enter the resolution number you want, as a positive number (i.e., just enter the number).

To turn smoothing "off", enter the resolution number you want as a negative number (i.e., preceded by the "-" key in the ENTRY key group).

EXAMPLE (Distance mode with English units selected):



sets the display to four places after the decimal point, with smoothing on.

EXAMPLE (Distance mode with English units selected):



sets the display to five places after the decimal point, with smoothing off.

More About the EXP COEFF key

You can use this key to enter or display the expansion coefficient of the material being measured. The expansion coefficient is expressed as parts-per-million-per-degree of temperature, ("ppm").

You can use the EXP COEFF key at any time, without loss of measurement data.

To View the Expansion Coefficient Value

To view the current expansion coefficient value, just press the EXP COEFF key; the value will be displayed until either the EXP COEFF key is pressed again (thus returning to the current mode) or another key is pressed.

To Enter an Expansion Coefficient Value

To enter an expansion coefficient value —

See "GENERAL" information for SET UP keys, above.

NOTE

The range of values you can enter for this key is "–720" to "+720" (ppm), in either metric or English units. If no value is entered, the value "0.0" is automatically assigned.

SECTION 17
ERRORS AND ERROR MESSAGES

Table 17-1 provides a listing of the Laser Measurement System's error messages, their meanings, and action you can take to try to eliminate the error.

If performing the indicated "Action" does not eliminate the error, refer to the Laser Measurement System's Service Manual.

Table 17-1 Laser Measurement System Error Messages

Message	Meaning	Action
A Error	Error in "average" value of MATL TEMP	This means that you are trying to view the average material temperature, but one or more material temperature sensors are indicating an error. Cycle through the MATERIAL TEMPERATURE key to determine which sensor(s) is bad. This error should be cleared, without loss of measurement information, by removing the bad sensor. Unplug the bad sensor(s) and have it repaired. If the error condition persists, the Measurement Display may need service.
AE Error **AH Error** **AP Error**	Error in "temperature" value from Air Sensor (see V.O.L. information) Error in "humidity" value from Air Sensor (see V.O.L. information) Error in "pressure" value from Air Sensor (see V.O.L. information)	This error should be cleared, without loss of measurement information, by removing the bad sensor. Unplug the Air Sensor and have it repaired. If the problem persists, the Measurement Display may need service.
C Error	Compensation error (due to a sensor error) (see V.O.L. information)	This means that you are trying to view the Velocity-of-Light Compensation value, but an Air Sensor error (i.e. air temperature, pressure, or humidity) prevents the Measurement Display from calculating that value. Cycle through the V.O.L. key to determine which part(s) of the Air Sensor is bad. This error should be cleared, without loss of measurement information, by removing the bad sensor. Unplug the Air Sensor and have it repaired. If the error condition persists, the Measurement Display may need service.

Table 17-1 Laser Measurement System Error Messages

Message	Meaning	Action
FAIL 1 **FAIL 2** **FAIL 3** **FAIL 4**	Failed part of Measurement Display Power-up Self-Test Failed part of Measurement Display Power-up Self-Test Failed part of Measurement Display Power-up Self Test Failed part of Measurement Display Power-up Self Test	Cycle the power switch on the Measurement Display again. If the error condition persists, unplug all cables from the rear of the Measurement Display, one by one, and cycle the power each time. In this way you can determine which, if any of the external sensors of the Laser Head is causing the problem. Have the bad instrument repaired. If this error condition persists with all external cables disconnected, have the Measurement Display repaired. These errors cannot be cleared and a measurement cannot be made unless an action taken above results in their removal from the Display
Hd Error	Laser Head error	Press RESET on the Measurement Display. This may clear the problem (but with a corresponding loss of measurement information). If HD Error is not cleared by the RESET key, cycle the power on the Measurement Display and wait for the Laser Head to warm up again. This error can only be cleared by resetting Display, and results in a loss of measurement data.
LASr FAIL	Flashes instead of "LASr UP" when the Laser Head is not yet ready for operation at the end of the warm-up countdown.	Make sure the Laser Head is connected to the Measurement Display by the correct cable. Verify "LASER ON" LED's are lit on the Laser Head. If not, the Laser Head may not be receiving power from the Measurement Display, or there may be a fault in the Laser Head. If the LASr FAIL persists after cycling the power, the problem is probably in the Laser Head, and cannot be cleared, and a measurement cannot be made.
Lr Error	HP-IB Problem	You have picked an HP-IB sample rate that is too fast for one or more of your HP-IB listeners. Verify that all HP-IB devices are properly configured on the bus. If they are OK, then slow down the sample rate to accommodate the slowest device on the HP-IB. This error can be cleared without loss of measurement information by pressing any key on the keyboard (except the RESET key).
Or Error	Overrange error. Value is larger (or more positive) than allowed.	Press the key again and the Display will show you the maximum allowable value for that key. Enter a value less than the maximum.

Table 17-1. Laser Measurement System Error Messages (Continued)

Message	Meaning	Action
P1 Error **P2 Error** **P3 Error**	Error in value from Material Temperature Sensor Number 1 Error in value from Material Temperature Sensor Number 2 Error in value from Material Temperature Sensor Number 3	The operating temperature of the material temperature sensor specified is out of its range, or there is a fault in the material sensor. Remove the bad sensor and verify that the error condition goes away. If so, have it repaired. If not, the Display may need servicing. These errors can be cleared without loss of measurement information by removing the bad sensor.
PA Error	Path Error – Measurement Path return beam has been interrupted.	Make sure the Beam strength meter on the Measurement Display points to the green region over the entire length of the measurement travel. If not, improve the alignment. The beam must not be broken at any time during the measurement, and the Beam Strength meter must not point into the red region, or, PA Error will appear and measurement data will be lost. This error can only be cleared by resetting the Measurement Display, and results in a loss of measurement data.
Pr Error	Programming error	The Measurement Display has received an HP-IB command that it doesn't recognize, or a misuse of an allowed command. Carefully check your programming instructions and refer to the Service Manual for proper syntax and application. This error can be cleared, without loss of measurement data, by pressing any key on the keyboard (except the RESET key).
SL Error	Signal Loss error. May indicate rate of Optic movement (during velocity measurement) is too high, or there is a problem in the measurement path	Make sure the optics do not exceed the rated maximum velocities shown in this User's Guide, in each Measurement Section. Also make sure the Beam Strength meter on the Measurement Display points to the "green" region over the entire length of the measurement travel. If not, improve the alignment. The Beam Strength meter must not point into the red region at any time during a measurement. This error can only be cleared by resetting the Display, and results in a loss of measurement data.

Table 17-1 Laser Measurement System Error Messages (Continued)

Message	Meaning	Action
Sr Error	Sample Rate too high	You are requesting sampled data over the HP-IB (via AUTO RECORD) faster than the Display can calculate new values to display. Refer to the Service Manual Specifications for measurement mode update rate information. You must not exceed these rates with your AUTO RECORD time interval. This error can be cleared without loss of measurement data by pressing any key on the keyboard (except the RESET key).
55 Error	Failed part of Measurement Display Power-up Self-Test	Cycle the power switch on the Measurement Display. If the error condition persists, unplug all cables from the rear of the Display, one by one, and cycle the power each time. In this way you can determine which, if any, of the external sensors or the laser head are causing the problem. If the error condition persists with all external cables disconnected, have the Measurement Display repaired. This error cannot be cleared and a measurement cannot be made unless an action taken above results in its removal from the Display.
Ur Error	Underrange error. The value is smaller (or more negative) than allowed.	Press the key again and the display will show you the minimum allowable value for that key. Enter a value greater than the minimum

SECTION 18
HP-IB INFORMATION

CONTENTS

INTRODUCTION
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INTRODUCTION

This User's Guide section provides a simplified description of the HP-IB and the Laser Measurement System's HP-IB capabilities. It also provides instructions on how to use a Printer with the Laser Measurement System via the HP-IB, and how to connect an external HP-IB controller.

For information about use of the Laser Measurement System with an external HP-IB controller, see the Laser Measurement System's Service Manual.

DESCRIPTION

The Laser Measurement System can be used with the Hewlett-Packard Interface Bus (HP-IB). HP-IB is Hewlett-Packard's implementation of IEEE Standard 488-1978, "Standard Digital Interface for Programmable Instrumentation". HP-IB capability gives you an easy way to send your measurement data to a recording device; it also enables more-automated applications, since it allows the Measurement Display unit's functions to be completely controlled from an external controller.

An HP-IB compatible device is used in an HP-IB system in one or more of the following ways —

- As a LISTENER, a device must be capable of accepting data from the interface. Examples of Listeners are printers and plotters.

  The Measurement Display unit has limited listener capability.

- As a TALKER, a device must be capable of outputting data to the interface. Examples of Talkers are voltmeters and tape readers.

  The Measurement Display unit has full talker capability.

- As a CONTROLLER, a device must be capable of specifying the Talker and Listener(s) of a data transfer (including itself).

  The Measurement Display unit has no controller capability.

The two major categories of HP-IB systems are those with, and those without, a "controller". Each type of system is described separately below.

A typical example of an HP-IB system without a controller is simply connecting the Laser Measurement System to a suitable Printer. A typical example of a HP-IB system with a controller is one in which the Laser Measurement System is connected to an HP Personal Calculator that has been set up to act as a controller.

A listing of the Measurement Display unit's HP-IB capabilities, in terms of the IEEE 488 Interface Function Codes, is given in *Table 18-1*.

Table 18-1. HP-IB Capabilities

IEEE Function Code	Meaning
C0	No Controller Capability
T5	Basic Talker, Serial Poll, Talk Only Mode, Untalk If My Listen Address
L4	Basic Listener, No Listen Only Mode, Unlisten If My Talk Address
SH1	Source Handshake Capability
AH1	Acceptor Handshake Capability
SR1	Service Request Capability
RL1	Remote-Local Capability Including Local Lockout
PP0	No Parallel Poll Capability
DC1	Device Clear Capability
DT1	Device Trigger Capability
E1	Open-collector Outputs

DATA TRANSFER WITHOUT AN HP-IB CONTROLLER

Introduction

The simplest HP-IB arrangement consists of one "talker" (in this case the Laser Measurement System), one "listener" (typically a Printer), and no "controller". In this configuration, data transfer is limited to direct transfer from the "talker" to the "listener". The Measurement Display unit is used in its HP-IB "TALK-ONLY" mode. The "listener" device must have "LISTEN-ONLY" capability (indicated by IEEE Function Code "L1" or "L3").

Operation of this type of arrangement requires no programming knowledge.

Set-Up

1. Set the Measurement Display unit to TALK-ONLY, —
   a. Set the front-panel LINE switch to OFF.
   b. Disconnect the line cord at the rear of the unit
   c. Using a POZIDRIV screwdriver, loosen the screw at the rear of the top cover

d. Slide the top cover rearward and remove it.

Figure 18-1 shows the location of the TALK-ONLY/ADDRESSABLE switch, on the top of the top printed circuit board, toward the front of the unit.

e. The TALK-ONLY/ADDRESSABLE switch is the second-from-the-left switch in the eight-switch assembly, and is labelled on the printed-circuit board.

Slide this switch to its TALK-ONLY ("1") position.

f. Replace the Measurement Display unit's top cover and tighten the screw that secures it

2. Connect the Measurement Display unit to the Printer, using an HP-IB cable.

The HP Part Number for a typical cable used here begins "10833", and has a letter suffix "A", "B", "C", or "D", that indicates its length, as shown in *Table 18-2*

Table 18-2. HP-IB Cables

HP Part Number	Length Metres	Feet
10833A	1	3.3
10833B	2	6.6
10833C	3	13.2
10833D	0.5	1.6

NOTE: The HP10833x cables will mate with HP10631x cables having the same type of locking screws (metric or English). The HP10833x cables have RFI shielding, the HP10631x cables do not.

a. Connect one end of the HP-IB cable to the Measurement Display unit's rear-panel "IEEE STD 488 PORT" (See *Figure 5-4* or *Figure 16-2* for the location of this connector.)

NOTES

- The HP-IB connectors are keyed (by their "keystone" shape) to fit together only one way. Connectors mate easily, with little force required; do not force connectors together

- HP-IB cable connectors have anchor screws used to secure them to HP-IB jacks. The Measurement Display unit requires the metric version of these screws. Metric-threaded HP-IB screws have a black finish, English-thread HP-IB screws have a silver finish. All HP-IB cables are currently shipped with metric screws

b. Connect the other end of the HP-IB cable to the "listener" device that is to be used with the Laser Measurement System

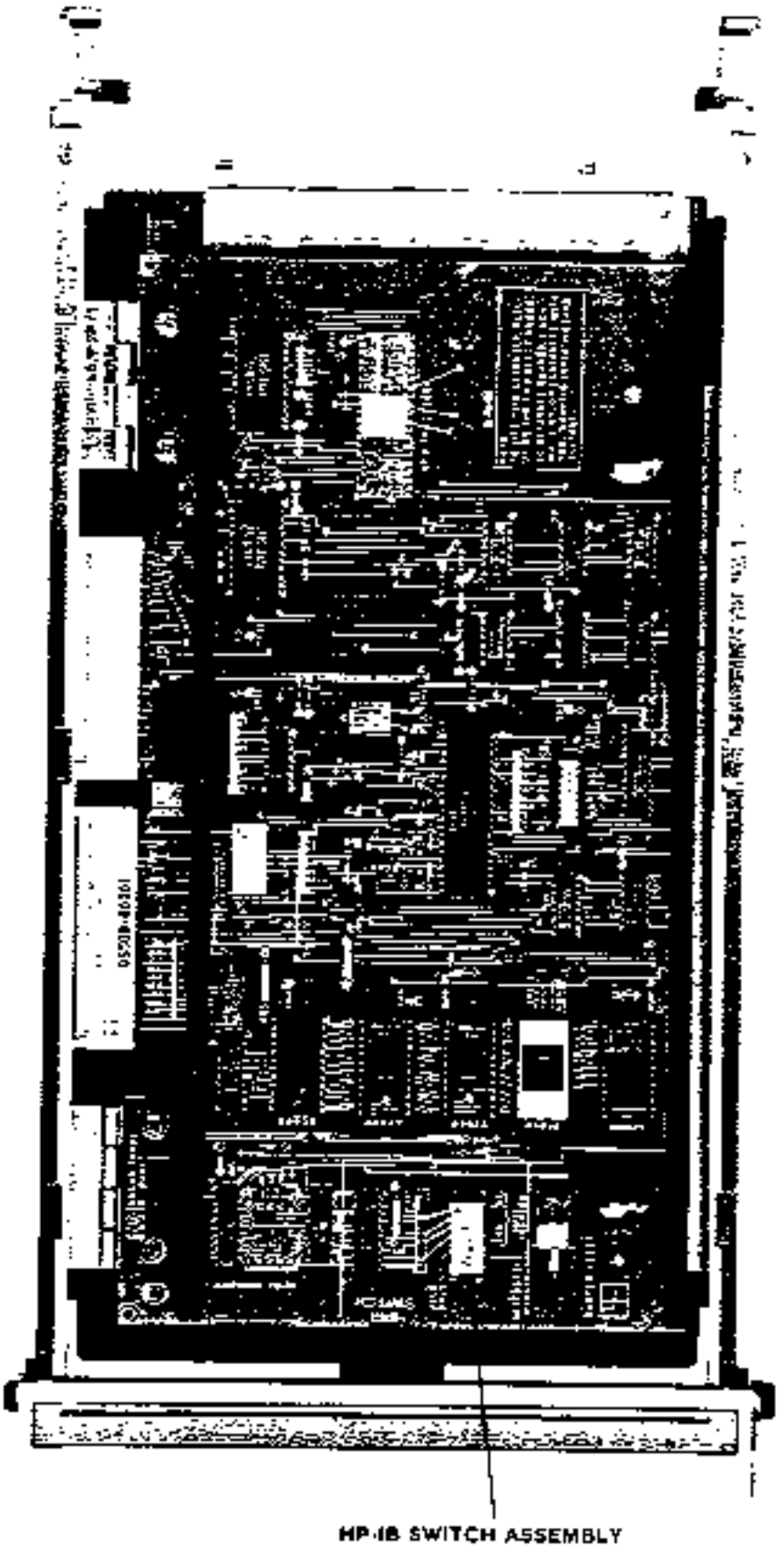


Figure 18-1 Location of TALK-ONLY, ADDRESSABLE and HP-IB ADDRESS Switch

NOTE

If more than one "listener" is to be used, connect each of them, via an HP-IB cable, to any available HP-IB port (connector) that is already part of the system that includes the Laser Measurement System.

The connector at each end of each HP-IB cable has two sides, "male" and "female". The "male" side mates with the HP-IB connector on any HP-IB-compatible instrument, or with any other suitable "female" connector. The "female" side of the connector provides a connecting point for the "male" connector of any other HP-IB cable. This allows cables to be stacked to accomodate up to 15 instruments on the bus. The maximum length of cable that can be used to connect a group of instruments should not be more than 2 metres (6.5 feet) times the number of instruments to be interconnected, or 20 metres (65.6 feet), whichever is less. The HP-IB connector, mating connector part numbers, logic levels, and signal name information are given in the Laser Measurement System's Service Manual.

Operation

Information required to operate a particular device as an HP-IB Listener is contained in its Operating Manual. For example, to use a Printer with the Measurement Display unit, you will usually have to set the Printer to the LISTEN-ONLY mode, this is usually done via a switch located on the Printer's rear panel (Note, however, that the switch may not necessarily be on the rear panel; that's why you should refer to your device's documentation to be sure.)

You can cause the Measurement Display unit to produce an HP-IB data output by using the Measurement Display unit's AUTORECORD key or the Remote Control unit's RECORD key. (See Section 16 of this User's Guide for information about these keys.)

DATA TRANSFER WITH AN HP-IB CONTROLLER

Introduction

All of the Measurement Display unit's measurement functions can be controlled by an external controller, connected via the HP-IB interface. When operated in this way, —

- commands are sent from the controller to the Measurement Display unit, using "BUS COMMANDS" and "INSTRUMENT FUNCTION CODE"s. The details of how this is done are discussed in the Laser Measurement System's Service Manual.
- measurement data can be sent from the Measurement Display unit, to one or more devices that have been instructed to "listen" for it.

When the Measurement Display unit is used with a Controller its "TALK-ONLY/ADDRESSABLE" switch must be set to "ADDRESSABLE", and its "HP-IB ADDRESS" switches set to the address you want to use.

An example of this arrangement is the HP Dimensional Metrology Analysis System with its HP Personal Computer. To install the Analysis System, you must use the procedure below.

Unless you are using the HP Dimensional Metrology Analysis System, operation of this type of arrangement requires some programming knowledge.

Set-Up

1. Set the Measurement Display unit to ADDRESSABLE —

   a Set the front-panel LINE switch to OFF.

   b. Disconnect the line cord at the rear of the unit.

   c. Using a POZIDRIV screwdriver, loosen the screw at the rear of the top cover.

   d Slide the top cover rearward and remove it.

   Figure 18-1 shows the location of the TALK-ONLY/ADDRESSABLE switch, on the top of the top printed circuit board, toward the front of the unit.

   e. The TALK-ONLY/ADDRESSABLE switch is the second-from-the-left switch in the eight-switch assembly, and is labelled on the printed-circuit board

   Slide this switch to its ADDRESSABLE ("0" position.

2. Set the HP-IB ADDRESS switches to the address you want

   The HP-IB ADDRESS switches are part of the eight-switch assembly that contains the TALK-ONLY/ADDRESSABLE switch

   Address switches "A5" through "A1" are set at the factory to address "03" ("A5", "A4", and "A3" are set to "0", "A2" and "A1" are set to "1".

   If you have to select some other address for any reason, you can use any address from "00" to "30"; you cannot use address "31". A complete listing of all combinations for these switches is given in *Table 18-3*.

   You may want to note what HP-IB address you use for your Measurement Display. (This will help you when you are programming your controller to talk to the Laser Measurement System.)

Table 18-3 HP-IB Address Switch Settings

Address	A5	A4	A3	A2	A1
0	0	0	0	0	0
1	0	0	0	0	1
2	0	0	0	1	0
3	0	0	0	1	1
4	0	0	1	0	0
5	0	0	1	0	1
6	0	0	1	1	0
7	0	0	1	1	1
8	0	1	0	0	0
9	0	1	0	0	1
10	0	1	0	1	0
11	0	1	0	1	1
12	0	1	1	0	0
13	0	1	1	0	1
14	0	1	1	1	0
15	0	1	1	1	1
16	1	0	0	0	0
17	1	0	0	0	1
18	1	0	0	1	0
19	1	0	0	1	1
20	1	0	1	0	0
21	1	0	1	0	1
22	1	0	1	1	0
23	1	0	1	1	1
24	1	1	0	0	0
25	1	1	0	0	1
26	1	1	0	1	0
27	1	1	0	1	1
28	1	1	1	0	0
29	1	1	1	0	1
30	1	1	1	1	0
31*	1	1	1	1	1

* HP-IB address "31" is not allowed.

3 Connect the Measurement Display unit to the Controller, using an HP-IB cable.

The HP Part Number for a typical cable used here begins "10833", and has a letter suffix "A", "B", "C", or "D", that indicates its length, as shown in *Table 18-4*.

Table 18-4 HP-IB Cables

HP Part Number	Length Metres	Feet
10833A	1	3.3
10833B	2	6.6
10833C	3	13.2
10833D	0.5	1.6

NOTE: The HP10833x cables will mate with HP10631x cables having the same type of locking screws (metric or English). The HP10833x cables have RFI shielding, the HP10631x cables do not.

a. Connect one end of the **HP-IB cable** to the Measurement Display unit's rear-panel "IEEE STD 488 PORT".

NOTES

- The HP-IB connectors are keyed (by their "keystone" shape) to fit together only one way. Connectors mate easily, with little force required; do not force connectors together.

- HP-IB cable connectors have anchor screws used to secure them to HP-IB jacks. The Measurement Display unit requires the metric version of these screws. Metric-threaded HP-IB screws have a black finish. English-thread HP-IB screws have a silver finish. All HP-IB cables are currently shipped with metric screws.

b. Connect the other end of the HP-IB cable to the device that is to be used as the "controller" in this system.

NOTE

The connector at each end of each HP-IB cable has two sides, "male" and "female". The "male" side mates with the HP-IB connector on any HP-IB-compatible instrument, or with any other suitable "female" connector. The "female" side of the connector provides a connecting point for the "male" connector of any other HP-IB cable. This allows cables to be stacked to accomodate up to 15 instruments on the bus. The maximum length of cable that can be used to connect a group of instruments should not be more than 2 metres (6.5 feet) times the number of instruments to be interconnected, or 20 metres (65.6 feet), whichever is less. The HP-IB connector, mating connector part numbers, logic levels, and signal name information are given in the Laser Measurement System's Service Manual.

c. If any other device (such as a Printer) is to be connected to the system, connect it, via an HP-IB cable, to any available HP-IB port that is already part of the system.

Operation

For information about how to use the HP Dimensional Metrology Analysis System refer to the Analysis System's Operating Manual.

For information about how to program an HP-IB controller to control the Laser Measurement System, refer to —

1. The Laser Measurement System's Service Manual, for —
    - Instrument Function Codes used to control the System,
    - HP-IB Bus Commands recognized by the Laser Measurement System,
    - Status Bytes provided by the Laser Measurement System,
    - Information about the Laser Measurement System's Interrupt capabilities.
2. The documentation for the "controller" device, for —
    - Information about how to create the Bus Commands and Instrument Function Codes required by the Laser Measurement System,
    - Information about how to create (and save) programs (sequences of individual commands) that can be used to control the Laser Measurement System.

19. V.O.L. Compensation Factor

SECTION 19
V.O.L. COMPENSATION FACTOR

CONTENTS

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HOW DO YOU ENTER THE V.O.L. COMPENSATION FACTOR?

INTRODUCTION

You need to know the information presented in this User's Guide section **only** if both of the following are true —

1. You are making a **Distance** or **Velocity** measurement, and —
2. You are **not** using an air sensor with your Laser Measurement System.

If you are **not** making a Distance or Velocity measurement, or if you **are** using an air sensor with your Laser Measurement System, you do **not** need to know the information presented in this User's Guide section.

If you are using an Air Sensor with your Laser Measurement System, the compensation number that is needed will be updated continuously and entered automatically.

WHAT IS THE V.O.L. COMPENSATION FACTOR?

The Laser Measurement System works by counting wavelengths of the laser beam as the various measurement optics are moved. The wavelength, frequency, and velocity of light are related as follows —

$$\text{wavelength (per cycle)} = \frac{\text{velocity}}{\text{frequency}}$$

The velocity of light is constant in a vacuum, but varies in air as a function of the air's temperature, pressure, and humidity. Since the frequency of the laser is held constant, the wavelength of its light will vary as the light's velocity varies, and this variation in wavelength will affect your measurements. A one-part-per-million variation in the velocity of light can result from any **one** of the following —

- a 1–degree C (2–degree F) change in air temperature, —
- a 2.5–mm (0.1–inch) (of mercury) change in air pressure, —
- an 80% change in relative humidity.

The distance shown on the Measurement Display unit at any time is equal to the product of the Laser wavelength (in units of "millimetres" or "inches") times the number of wavelengths counted since RESET was last pressed. In practice, this product operation is done in two steps. First, the

number of wavelengths counted is multiplied by a compensation factor, and this result is then multiplied by the vacuum wavelength of the Laser light (in appropriate units). That is —

$$D = N \times CF \times W_V$$

where —

D = Distance

N = Number of wavelengths of motion

CF = the Compensation Factor. This number has the format "0.999abcd", where "abcd" is the four-digit compensation number you enter for "V.O.L.". The Compensation Factor represents the ratio of the Wavelength of Light in air to the Wavelength of Light in a vacuum (W_A/W_V).

where —

W_A = wavelength in air

W_V = wavelength in vacuum

The vacuum wavelength (W_V) is a constant, and is "hard-wired" into the Measurement Display unit's arithmetic unit. The ratio of air wavelength to vacuum wavelength (W_A/W_V) is a number that is always slightly less than "one", and which depends on ambient conditions.

For example, for air temperature of 25 degrees C (77 degrees F), air pressure of 762.0 mm (30.00 inches) of Mercury (Hg), and relative humidity of 50%, this ratio is equal to 0.9997329. For the operating environment specified for the Laser, no change will ever occur in the first three digits of the ratio; therefore, these three digits are also "hard-wired" inside the Measurement Display unit, and you will have to enter only the last four digits of the value, in the format "abc.d" (in this case, "732.9").

NOTE

This value would be entered manually as "732.9 V.O.L.".

COMPENSATION FACTOR FOR "STANDARD" CONDITIONS

If you check the tables in this User's Guide section, you will see that the compensation values range from about "695" to "832" parts-per-million ("ppm"), for metric, and about "702" to "837" ppm for English, and that there is no "zero" value. This means that you should expect to enter some correction value for "standard" conditions, even if you don't know what they are. The following "standard" conditions are assumed —

Table 19-1. "Standard" Conditions

Description	Metric	English
Air Temperature:	20°C	68°F
Air Pressure (Hg.):	760.0 mm	29.921 in
Relative Humidity:	50%	50%

the tables in this section indicate that the correction value to be applied for these "standard" conditions, for metric or English units, is "728.8", which is the "default" value built into the Measurement Display unit for "V.O.L.". Of course, this value is not likely to be the correct one for your particular conditions; the remainder of this User's Guide section provides details about how to make a more exact determination of the compensation number.

NOTE

If you do not use an Air Sensor, and do not manually enter a V.O.L. value, "728.8" (the value for "standard" conditions) is automatically used.

HOW DO YOU DETERMINE THE V.O.L. COMPENSATION FACTOR?

1. SENSOR CONSIDERATIONS

To determine a V.O.L. compensation value, you must first determine ambient temperature, pressure, and relative humidity.

You should place your sensing devices so that they measure the environment close to the measured path. You should also be sure to allow enough time for the sensors to stabilize. The accuracy with which you determine your compensation number (and, thus, the accuracy of your Distance measurement) will be no better than the accuracy with which you measure your ambient conditions, so your sensors should be accurate. As a guide, an error of one part-per-million will occur in the distance measurement for each error of —

- 1-degree Celsius (2 degrees Farenheit) in air temperature, or —
- 2.5-mm (0.1 inch) of mercury in pressure, or —
- 60% of the relative humidity.

2. "ABSOLUTE" PRESSURE VERSUS "ADJUSTED" PRESSURE

The ambient pressure used in determining your compensation number must be "absolute" pressure, not "adjusted" pressure (which is usually absolute pressure that has been "corrected" to sea level").

"Adjusted pressure", as defined here, is the absolute pressure that you would measure at a given location, if that location was at sea level and the weather conditions were the same. Suppose, for example, that you were in Denver (Colorado, U.S.A.) at a time when the weather report said the pressure was "762 mm" (30.00 inches) of mercury. If this were an "adjusted pressure," and since Denver's altitude is about 1.5 km (5000 feet), the **absolute** air pressure there and then would be closer to 635 mm (25 inches) of mercury.

To measure pressure, you need an absolute pressure indicator, which is equivalent to a barometer that has **not** been corrected to sea level. When such a pressure indicator is not readily available, you can make a reasonable approximation to absolute pressure by reducing the adjusted pressure obtained from the nearest weather station (at the local airport, for instance) by 2.5 mm (0.1 inch) of mercury for each 30 metres (100 feet) of altitude. That is —

$$P_{ABS} = P_{ADJ} - \frac{\text{altitude}}{30} \times 2.5$$

(for metric units)

$$P_{ABS} = P_{ADJ} - \frac{\text{altitude}}{100} \times 0.1$$

(for English units)

Where P_{ABS} is the absolute pressure, and P_{ADJ} is the adjusted pressure.

Note that the altitude of the weather station is not considered here, since the number they report has already been corrected to sea level by the station.

3. USE OF COMPENSATION CHARTS

In most cases, you will find the velocity-of-light compensation number that is to be entered manually somewhere in *Table 19-3* through *Table 19-52*. If you can't find your measurement conditions in any of these tables, you will have to calculate the compensation factor. Instructions for doing this are presented below.

The V.O.L. compensation value tables are divided into a "metric" group (*Table 19-3* through *Table 19-27*), and an "English" group (*Table 19-28* through *Table 19-52*). This is done as a convenience for you, since the V.O.L. compensation number is a ratio (without units) that is the same, regardless of the measurement system you are using.

Table 19-3 and *Table 19-28* are wide-range charts offering coarse compensation numbers for non-precision measurements. *Table 19-4* through *Table 19-27*, and *Table 19-29* through *Table 19-52* are more-detailed charts, progressing from "low" to "high" altitudes, and from "low" to "high" relative humidity.

To find the V.O.L. appropriate compensation factor table, refer first to *Table 19-2* to find the group of tables for your humidity and altitude. Then look at the headings for those tables to find the one for your temperature range. You'll find the compensation number where the row and column for your measurement conditions intersect. If the table you should be using doesn't have the exact value for your measurement, you can calculate the value you need by interpolating between the values given.

Table 19-2. Guide to Compensation Tables

Relative Humidity	Altitude Range (NOTE 1)	Table Number (NOTE 2) Metric	English
50%	Wide	3	28
20%	Low	4–7	29–32
20%	High	8–11	33–36
50%	Low	12–15	37–40
50%	High	16–19	41–44
80%	Low	20–23	45–48
80%	High	24–27	49–52

NOTES

1. "Low" altitude = 720–800 mm Hg, 27–31 in Hg
   "High" altitude = 640–720 mm Hg, 23–27 in Hg
2. For complete table reference designation, add "Table 19–" to number listed below.

4. CALCULATION OF EXACT COMPENSATION FACTOR

If the Laser Measurement System is being operated in an environment that is not included in the tables in this User's Guide section, you can calculate the exact compensation factor by using the following formulas to an accuracy of 0.1 ppm.

CAUTION

The accuracy of your Laser System Measurement is a function of your ability to provide it with the correction compensation factor for your measurement conditions. When determining the compensation factor by calculation rather than by using the compensation factor tables, the result you get depends on the resolution of the equipment on which you make your calculation and on your ability to operate it without error. You will be working with numbers that are very small and numbers that are very large; even the smallest error can have a significant effect on the accuracy of your answer, and any error is extremely difficult to detect or trace. We strongly suggest that you make a "practice" run, using values from any of the compensation value tables, to get a feeling for what is required.

In the formulas below —

T = Air Temperature

P = Air Pressure

H = Relative Humidity

C = Compensation Factor, to be entered manually, via the Measurement Display unit's front-panel keys.

$$C = \frac{10^{-2}}{N+10^{-6}} - 999000$$

where "N" is given in metric and English systems by —

Metric: T in degrees Celsius, P in millimetres of mercury, H in %

$$N = 0.3836391\,P \times \left[\frac{1 + 10^{-6}\,P\,(0.817 - 0.0133T)}{1 + 0.0036610T}\right] - 3.033 \times 10^{-3}\,H\left[e^{0.0676277T}\right]$$

English: T in degrees Farenheit, P in inches of mercury, H in %

$$N = 9.74443P \times \left[\frac{1 + 10^{-6}\,P\,(36.7 - 0.187T)}{0.934915 + 0.0020388T}\right] - 1.089 \times 10^{-2}\,H\left[e^{0.0329147T}\right]$$

EXAMPLE:

Using the "standard" conditions, —

Humidity = 50% = "H"

Pressure (absolute) = 760 mm Hg = "P"

Temperature = 20°C = "T"

we will calculate the compensation factor, using the Metric formula for finding "N", and showing all our work.

$0.0133T = 0.266000000$	(#1)
$0.817 - (\#1) = 0.551000000$	(#2)
$P \times 10^{-6} \times (\#2) = 0.000418760$	(#3)
$1 + (\#3) = 1.000418760$	(#4) (Save)
$0.00366107 = 0.073220000$	(#5)
$1 + (\#5) = 1.073220000$	(#6)
$(\#4) \div (\#6) = 0.932165595$	(#7)
$0.3836391 \times P \times (\#7) = 271.7875292$	(#8) (Save)
$e^{0.0572677} = 3.143409969$	(#9)
$H \times (\#9) = 157.1754985$	(#10)
$3.033 \times 10^{-3} \times (\#10) = 0.476737287$	(#11)
$(\#8) - (\#11) = 271.3108159$	(#12)
$(\#12) \div 10^{6} = 1000271.311$	(#13)
$\frac{10^{12}}{(\#13)} = 999728.7626$	(#14)
$C = (\#14) - 999000 = 728.7626 = 728.8$	(#15)

(for comparison, the answer we were looking for in this example just happens to be "728.8")

HOW DO YOU ENTER THE V.O.L. COMPENSATION VALUE?

Enter the Velocity of Light compensation value by pressing the following Measurement Display keys —



NOTE

The number you enter represents the last four digits ("abcd") of a seven-digit fraction having the form "0.999abcd". This number is the ratio of the velocity of light at your measurement location to the velocity of light in a vacuum. The first three digits in the fraction ("999") are built into the Measurement Display unit's memory, and can't be changed.

Table 19-3 Metric — Wide-Range
(Temp = 2 to 50°C , Press = 525 to 800 mm, 50% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

Table 19-4. Metric — Low Alt, Low Temp, Low Humidity
(Temp = 5 to 13°C , Press = 720 to 800 mm, 20% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
800	698.4	699.1	699.7	700.2	700.8	701.3	701.8	702.4	702.8	703.4	703.9	704.5	704.9	705.5	706.1	706.6	707.1	707.6	708.1
795	693.0	693.5	694.1	694.6	695.1	695.7	696.2	696.7	697.2	697.7	698.2	698.7	699.2	699.7	700.2	700.7	701.2	701.7	702.2
790	687.6	688.1	688.6	689.1	689.6	690.1	690.6	691.1	691.6	692.0	692.5	693.0	693.5	694.0	694.5	695.0	695.5	696.0	696.5
785	682.2	682.7	683.2	683.6	684.1	684.6	685.1	685.6	686.0	686.5	687.0	687.5	688.0	688.5	689.0	689.5	689.9	690.4	690.9
780	676.8	677.2	677.7	678.2	678.6	679.1	679.6	680.0	680.5	681.0	681.5	681.9	682.4	682.9	683.4	683.8	684.3	684.8	685.2
775	671.3	671.8	672.2	672.7	673.2	673.6	674.1	674.5	675.0	675.5	675.9	676.4	676.8	677.3	677.8	678.2	678.7	679.2	679.6
770	665.9	666.3	666.8	667.2	667.7	668.1	668.6	669.0	669.5	669.9	670.4	670.8	671.3	671.8	672.2	672.7	673.1	673.6	674.0
765	660.4	660.9	661.3	661.8	662.2	662.7	663.1	663.6	664.0	664.5	664.9	665.4	665.8	666.3	666.7	667.2	667.6	668.1	668.5
760	655.0	655.4	655.9	656.3	656.8	657.2	657.6	658.1	658.5	659.0	659.4	659.8	660.3	660.7	661.2	661.6	662.1	662.5	663.0
755	649.5	650.0	650.4	650.8	651.3	651.7	652.2	652.6	653.0	653.5	653.9	654.3	654.8	655.2	655.7	656.1	656.5	657.0	657.4
750	644.1	644.5	645.0	645.4	645.8	646.3	646.7	647.1	647.6	648.0	648.4	648.9	649.3	649.7	650.2	650.6	651.0	651.5	651.9
745	638.6	639.1	639.5	639.9	640.4	640.8	641.2	641.7	642.1	642.5	643.0	643.4	643.8	644.2	644.7	645.1	645.5	646.0	646.4
740	633.2	633.6	634.0	634.5	634.9	635.3	635.8	636.2	636.6	637.0	637.5	637.9	638.3	638.8	639.2	639.6	640.0	640.5	640.9
735	627.7	628.1	628.6	629.0	629.4	629.8	630.3	630.7	631.1	631.5	632.0	632.4	632.8	633.2	633.7	634.1	634.5	635.0	635.4
730	622.3	622.7	623.1	623.5	624.0	624.4	624.8	625.2	625.7	626.1	626.5	626.9	627.4	627.8	628.2	628.6	629.0	629.5	629.9
725	616.8	617.2	617.7	618.1	618.5	618.9	619.4	619.8	620.2	620.6	621.0	621.5	621.9	622.3	622.7	623.2	623.6	624.0	624.4
720	611.4	611.8	612.2	612.6	613.1	613.5	613.9	614.3	614.8	615.2	615.6	616.0	616.5	616.9	617.3	617.7	618.2	618.6	619.0
715	605.9	606.3	606.8	607.2	607.6	608.0	608.5	608.9	609.3	609.7	610.2	610.6	611.0	611.4	611.9	612.3	612.7	613.1	613.6
710	600.5	600.9	601.3	601.7	602.2	602.6	603.0	603.4	603.9	604.3	604.7	605.1	605.6	606.0	606.4	606.8	607.3	607.7	608.1
705	595.0	595.4	595.9	596.3	596.7	597.1	597.6	598.0	598.4	598.8	599.3	599.7	600.1	600.5	601.0	601.4	601.8	602.2	602.7
700	589.6	590.0	590.4	590.8	591.3	591.7	592.1	592.5	593.0	593.4	593.8	594.2	594.7	595.1	595.5	595.9	596.4	596.8	597.2
695	584.1	584.5	585.0	585.4	585.8	586.2	586.7	587.1	587.5	587.9	588.4	588.8	589.2	589.6	590.1	590.5	590.9	591.3	591.8
690	578.7	579.1	579.5	580.0	580.4	580.8	581.2	581.7	582.1	582.5	583.0	583.4	583.8	584.2	584.7	585.1	585.5	586.0	586.4
685	573.2	573.6	574.1	574.5	574.9	575.3	575.8	576.2	576.6	577.0	577.5	577.9	578.3	578.8	579.2	579.6	580.0	580.5	580.9
680	567.7	568.2	568.6	569.0	569.4	569.9	570.3	570.7	571.2	571.6	572.0	572.4	572.9	573.3	573.7	574.2	574.6	575.0	575.4
675	562.3	562.7	563.1	563.6	564.0	564.4	564.8	565.3	565.7	566.1	566.5	567.0	567.4	567.8	568.2	568.7	569.1	569.5	570.0
670	556.8	557.2	557.7	558.1	558.5	559.0	559.4	559.8	560.2	560.7	561.1	561.5	562.0	562.4	562.8	563.2	563.7	564.1	564.5
665	551.4	551.8	552.2	552.7	553.1	553.5	554.0	554.4	554.8	555.2	555.7	556.1	556.5	557.0	557.4	557.8	558.2	558.7	559.1
660	545.9	546.3	546.8	547.2	547.6	548.1	548.5	548.9	549.3	549.8	550.2	550.6	551.1	551.5	551.9	552.4	552.8	553.2	553.6
655	540.5	540.9	541.3	541.8	542.2	542.6	543.1	543.5	543.9	544.3	544.8	545.2	545.6	546.1	546.5	546.9	547.3	547.8	548.2
650	535.0	535.4	535.9	536.3	536.7	537.2	537.6	538.0	538.4	538.9	539.3	539.7	540.2	540.6	541.0	541.4	541.9	542.3	542.7
645	529.6	530.0	530.4	530.9	531.3	531.7	532.2	532.6	533.0	533.4	533.9	534.3	534.7	535.2	535.6	536.0	536.4	536.9	537.3
640	524.1	524.5	525.0	525.4	525.8	526.3	526.7	527.1	527.5	528.0	528.4	528.8	529.3	529.7	530.1	530.5	531.0	531.4	531.8
635	518.7	519.1	519.5	520.0	520.4	520.8	521.3	521.7	522.1	522.5	523.0	523.4	523.8	524.3	524.7	525.1	525.5	526.0	526.4
630	513.2	513.6	514.1	514.5	514.9	515.4	515.8	516.2	516.6	517.1	517.5	517.9	518.4	518.8	519.2	519.6	520.1	520.5	520.9
625	507.8	508.2	508.6	509.1	509.5	509.9	510.4	510.8	511.2	511.6	512.1	512.5	512.9	513.4	513.8	514.2	514.6	515.1	515.5
620	502.3	502.7	503.2	503.6	504.0	504.5	504.9	505.3	505.7	506.2	506.6	507.0	507.5	507.9	508.3	508.7	509.2	509.6	510.0
615	496.8	497.2	497.7	498.1	498.5	499.0	499.4	499.8	500.3	500.7	501.1	501.5	502.0	502.4	502.8	503.3	503.7	504.1	504.6
610	491.4	491.8	492.2	492.7	493.1	493.5	494.0	494.4	494.8	495.2	495.7	496.1	496.5	497.0	497.4	497.8	498.2	498.7	499.1
605	485.9	486.3	486.8	487.2	487.6	488.1	488.5	488.9	489.4	489.8	490.2	490.6	491.1	491.5	491.9	492.4	492.8	493.2	493.7
600	480.5	480.9	481.3	481.8	482.2	482.6	483.1	483.5	483.9	484.3	484.8	485.2	485.6	486.1	486.5	486.9	487.3	487.8	488.2
595	475.0	475.4	475.9	476.3	476.7	477.2	477.6	478.0	478.4	478.9	479.3	479.7	480.2	480.6	481.0	481.4	481.9	482.3	482.7
590	469.6	470.0	470.4	470.8	471.3	471.7	472.1	472.6	473.0	473.4	473.8	474.3	474.7	475.1	475.5	476.0	476.4	476.8	477.2
585	464.1	464.5	465.0	465.4	465.8	466.2	466.7	467.1	467.5	468.0	468.4	468.8	469.2	469.7	470.1	470.5	470.9	471.4	471.8
580	458.7	459.1	459.5	460.0	460.4	460.8	461.2	461.7	462.1	462.5	463.0	463.4	463.8	464.2	464.7	465.1	465.5	466.0	466.4
575	453.2	453.6	454.1	454.5	454.9	455.3	455.8	456.2	456.6	457.0	457.5	457.9	458.3	458.8	459.2	459.6	460.0	460.5	460.9
570	447.7	448.2	448.6	449.0	449.4	449.9	450.3	450.7	451.2	451.6	452.0	452.4	452.9	453.3	453.7	454.2	454.6	455.0	455.4
565	442.3	442.7	443.1	443.6	444.0	444.4	444.8	445.3	445.7	446.1	446.5	447.0	447.4	447.8	448.2	448.7	449.1	449.5	450.0
560	436.8	437.2	437.7	438.1	438.5	439.0	439.4	439.8	440.2	440.7	441.1	441.5	442.0	442.4	442.8	443.2	443.7	444.1	444.5
555	431.4	431.8	432.2	432.6	433.1	433.5	433.9	434.4	434.8	435.2	435.6	436.1	436.5	436.9	437.3	437.8	438.2	438.6	439.1
550	425.9	426.3	426.8	427.2	427.6	428.1	428.5	428.9	429.3	429.8	430.2	430.6	431.1	431.5	431.9	432.4	432.8	433.2	433.6
545	420.5	420.9	421.3	421.8	422.2	422.6	423.1	423.5	423.9	424.3	424.8	425.2	425.6	426.1	426.5	426.9	427.3	427.8	428.2
540	415.0	415.4	415.9	416.3	416.7	417.2	417.6	418.0	418.4	418.9	419.3	419.7	420.2	420.6	421.0	421.4	421.9	422.3	422.7
535	409.6	410.0	410.4	410.8	411.3	411.7	412.1	412.6	413.0	413.4	413.8	414.3	414.7	415.1	415.5	416.0	416.4	416.8	417.2
530	404.1	404.5	405.0	405.4	405.8	406.2	406.7	407.1	407.5	408.0	408.4	408.8	409.2	409.7	410.1	410.5	411.0	411.4	411.8
525	398.7	399.1	399.5	400.0	400.4	400.8	401.2	401.7	402.1	402.5	403.0	403.4	403.8	404.2	404.7	405.1	405.5	406.0	406.4
520	393.2	393.6	394.1	394.5	394.9	395.3	395.8	396.2	396.6	397.0	397.5	397.9	398.3	398.8	399.2	399.6	400.0	400.5	400.9
515	387.8	388.2	388.6	389.1	389.5	389.9	390.4	390.8	391.2	391.6	392.1	392.5	392.9	393.4	393.8	394.2	394.6	395.1	395.5
510	382.3	382.7	383.2	383.6	384.0	384.4	384.8	385.3	385.7	386.1	386.5	387.0	387.4	387.8	388.2	388.7	389.1	389.5	390.0
505	376.9	377.3	377.8	378.2	378.6	379.0	379.4	379.9	380.3	380.7	381.1	381.6	382.0	382.4	382.8	383.3	383.7	384.1	384.5
500	371.4	371.8	372.2	372.7	373.1	373.5	374.0	374.4	374.8	375.2	375.7	376.1	376.5	377.0	377.4	377.8	378.2	378.7	379.1
495	365.9	366.3	366.8	367.2	367.6	368.1	368.5	368.9	369.4	369.8	370.2	370.6	371.1	371.5	371.9	372.4	372.8	373.2	373.6
490	360.5	360.9	361.3	361.8	362.2	362.6	363.1	363.5	363.9	364.3	364.8	365.2	365.6	366.1	366.5	366.9	367.3	367.8	368.2
485	355.0	355.4	355.9	356.3	356.7	357.2	357.6	358.0	358.4	358.9	359.3	359.7	360.2	360.6	361.0	361.4	361.9	362.3	362.7
480	349.6	350.0	350.4	350.8	351.3	351.7	352.1	352.6	353.0	353.4	353.9	354.3	354.7	355.2	355.6	356.0	356.4	356.9	357.3
475	344.1	344.5	345.0	345.4	345.8	346.2	346.7	347.1	347.5	348.0	348.4	348.8	349.2	349.7	350.1	350.5	351.0	351.4	351.8
470	338.7	339.1	339.5	340.0	340.4	340.8	341.2	341.7	342.1	342.5	343.0	343.4	343.8	344.2	344.7	345.1	345.5	346.0	346.4
465	333.2	333.6	334.1	334.5	334.9	335.3	335.8	336.2	336.6	337.0	337.5	337.9	338.4	338.8	339.2	339.6	340.0	340.5	340.9
460	327.8	328.2	328.6	329.1	329.5	329.9	330.4	330.8	331.2	331.6	332.1	332.5	332.9	333.4	333.8	334.2	334.6	335.1	335.5
455	322.3	322.7	323.2	323.6	324.0	324.4	324.9	325.3	325.7	326.2	326.6	327.0	327.5	327.9	328.3	328.7	329.2	329.6	330.0
450	316.9	317.3	317.7	318.2	318.6	319.0	319.5	319.9	320.3	320.8	321.2	321.6	322.0	322.5	322.9	323.3	323.8	324.2	324.6
445	311.4	311.8	312.3	312.7	313.1	313.6	314.0	314.4	314.8	315.3	315.7	316.1	316.5	317.0	317.4	317.8	318.3	318.7	319.1
440	305.9	306.4	306.8	307.2	307.7	308.1	308.5	309.0	309.4	309.8	310.3	310.7	311.1	311.6	312.0	312.4	312.9	313.3	313.7
435	300.5	300.9	301.4	301.8	302.2	302.7	303.1	303.5	304.0	304.4	304.8	305.3	305.7	306.1	306.6	307.0	307.4	307.9	308.3
430	295.0	295.4	295.9	296.3	296.7	297.2	297.6	298.0	298.5	298.9	299.3	299.8	300.2	300.6	301.1	301.5	301.9	302.4	302.8
425	289.6	290.0	290.4	290.8	291.3	291.7	292.1	292.6	293.0	293.4	293.9	294.3	294.7	295.2	295.6	296.0	296.5	296.9	297.3
420	284.1	284.5	285.0	285.4	285.8	286.2	286.7	287.1	287.5	288.0	288.4	288.8	289.2	289.7	290.1	290.5	291.0	291.4	291.8
415	278.7	279.1	279.5	280.0	280.4	280.8	281.2	281.7	282.1	282.5	283.0	283.4	283.8	284.2	284.7	285.1	285.5	286.0	286.4
410	273.2	273.6	274.1	274.5	274.9	275.3	275.8	276.2	276.6	277.0	277.5	277.9	278.3	278.8	279.2	279.6	280.0	280.5	280.9
405	267.8	268.2	268.6	269.1	269.5	269.9	270.4	270.8	271.2	271.6	272.1	272.5	272.9	273.4	273.8	274.2	274.6	275.1	275.5
400	262.3	262.7	263.2	263.6	264.0	264.4	264.8	265.3	265.7	266.1	266.5	267.0	267.4	267.8	268.2	268.7	269.1	269.5	270.0
395	256.9	257.3	257.7	258.2	258.6	259.0	259.4	259.9	260.3	260.7	261.1	261.6	262.0	262.4	262.8	263.3	263.7	264.1	264.5
390	251.4	251.8	252.2	252.7	253.1	253.5	254.0	254.4	254.8	255.2	255.7	256.1	256.5	257.0	257.4	257.8	258.2	258.7	259.1
385	245.9	246.3	246.8	247.2	247.6	248.1	248.5	248.9	249.4	249.8	250.2	250.6	251.1	251.5	251.9	252.4	252.8	253.2	253.6
380	240.5	240.9	241.3	241.8	242.2	242.6	243.1	243.5	243.9	244.3	244.8	245.2	245.6	246.1	246.5	246.9	247.3	247.8	248.2
375	235.0	235.4	235.9	236.3	236.7	237.2	237.6	238.0	238.4	238.9	239.3	239.7	240.2	240.6	241.0	241.4	241.9	242.3	242.7
370	229.6	230.0	230.4	230.8	231.3	231.7	232.1	232.6	233.0	233.4	233.9	234.3	234.7	235.2	235.6	236.0	236.4	236.9	237.3
365	224.1	224.5	225.0	225.4	225.8	226.2	226.7	227.1	227.5	228.0	228.4	228.8	229.2	229.7	230.1	230.5	231.0	231.4	231.8
360	218.7	219.1	219.5	220.0	220.4	220.8	221.3	221.7	222.1	222.5	223.0	223.4	223.8	224.3	224.7	225.1	225.5	226.0	226.4
355	213.2	213.6	214.1	214.5	214.9	215.3	215.8	216.2	216.6	217.0	217.5	217.9	218.3	218.8	219.2	219.6	220.1	220.5	220.9
350	207.8	208.2	208.6	209.1	209.5	209.9	210.4	210.8	211.2	211.6	212.1	212.5	212.9	213.4	213.8	214.2	214.6	215.1	215.5
345	202.3	202.7	203.2	203.6	204.0	204.5	204.9	205.3	205.7	206.2	206.6	207.0	207.5	207.9	208.3	208.7	209.2	209.6	210.0
340	196.9	197.3	197.7	198.2	198.6	199.0	199.4	199.9	200.3	200.7	201.1	201.6	202.0	202.4	202.8	203.3	203.7	204.1	204.5
335	191.4	191.8	192.2	192.7	193.1	193.5	194.0	194.4	194.8	195.2	195.7	196.1	196.5	197.0	197.4	197.8	198.2	198.7	199.1
330	185.9	186.3	186.8	187.2	187.6	188.1	188.5	188.9	189.4	189.8	190.2	190.6	191.1	191.5	191.9	192.4	192.8	193.2	193.6
325	180.4	180.9	181.3	181.7	182.2	182.6	183.0	183.5	183.9	184.3	184.8	185.2	185.6	186.1	186.5	186.9	187.3	187.8	188.2
320	175.0	175.4	175.8	176.3	176.7	177.1	177.6	178.0	178.4	178.9	179.3	179.7	180.2	180.6	181.0	181.4	181.9	182.3	182.7
315	169.5	169.9	170.4	170.8	171.2	171.7	172.1	172.5	173.0	173.4	173.8	174.3	174.7	175.1	175.5	176.0	176.4	176.8	177.2
310	164.0	164.4	164.9	165.3	165.8	166.2	166.6	167.1	167.5	167.9	168.4	168.8	169.2	169.7	170.1	170.5	171.0	171.4	171.8
305	158.6	159.0	159.4	159.8	160.3	160.7	161.1	161.6	162.0	162.4	162.8	163.3	163.7	164.1	164.6	165.0	165.4	165.8	166.3
300	153.1	153.5	154.0	154.4	154.8	155.2	155.7	156.1	156.5	157.0	157.4	157.8	158.2	158.7	159.1	159.5	160.0	160.4	160.8
295	147.7	148.1	148.5	149.0	149.4	149.8	150.2	150.7	151.1	151.5	152.0	152.4	152.8	153.2	153.7	154.1	154.5	155.0	155.4
290	142.2	142.6	143.1	143.5	143.9	144.3	144.8	145.2	145.6	146.0	146.5	146.9	147.3	147.8	148.2	148.6	149.0	149.5	149.9
285	136.7	137.1	137.6	138.0	138.4	138.8	139.3	139.7	140.1	140.5	141.0	141.4	141.8	142.3	142.7	143.1	143.5	144.0	144.4
280	131.2	131.6	132.1	132.5	132.9	133.4	133.8	134.2	134.6	135.1	135.5	135.9	136.4	136.8	137.2	137.6	138.1	138.5	138.9
275	125.8	126.2	126.6	127.1	127.5	127.9	128.4	128.8	129.2	129.6	130.1	130.5	130.9	131.4	131.8	132.2	132.7	133.1	133.5
270	120.3	120.7	121.2	121.6	122.0	122.4	122.9	123.3	123.7	124.2	124.6	125.0	125.4	125.9	126.3	126.7	127.2	127.6	128.0
265	114.8	115.2	115.7	116.1	116.5	117.0	117.4	117.8	118.3	118.7	119.1	119.5	120.0	120.4	120.8	121.3	121.7	122.1	122.5
260	109.4	109.8	110.2	110.7	111.1	111.5	112.0	112.4	112.8	113.2	113.7	114.1	114.5	115.0	115.4	115.8	116.2	116.7	117.1
255	103.9	104.3	104.8	105.2	105.6	106.1	106.5	106.9	107.4	107.8	108.2	108.6	109.1	109.5	109.9	110.4	110.8	111.2	111.6
250	98.5	98.9	99.3	99.7	100.2	100.6	101.0	101.5	101.9	102.3	102.8	103.2	103.6	104.1	104.5	104.9	105.4	105.8	106.2
245	93.0	93.4	93.8	94.3	94.7	95.1	95.6	96.0	96.4	96.8	97.3	97.7	98.1	98.6	99.0	99.4	99.8	100.3	100.7
240	87.5	87.9	88.4	88.8	89.2	89.7	90.1	90.5	91.0	91.4	91.8	92.3	92.7	93.1	93.6	94.0	94.4	94.9	95.3
235	82.1	82.5	82.9	83.4	83.8	84.2	84.7	85.1	85.5	85.9	86.4	86.8	87.2	87.7	88.1	88.5	89.0	89.4	89.8
230	76.6	77.0	77.5	77.9	78.3	78.8	79.2	79.6	80.1	80.5	80.9	81.4	81.8	82.2	82.7	83.1	83.5	84.0	84.4
225	71.2	71.6	72.0	72.5	72.9	73.3	73.8	74.2	74.6	75.0	75.5	75.9	76.3	76.8	77.2	77.6	78.1	78.5	78.9
220	65.7	66.1	66.6	67.0	67.4	67.9	68.3	68.7	69.2	69.6	70.0	70.4	70.9	71.3	71.7	72.2	72.6	73.0	73.5
215	60.2	60.7	61.1	61.5	62.0	62.4	62.8	63.3	63.7	64.1	64.6	65.0	65.4	65.9	66.3	66.7	67.2	67.6	68.0
210	54.8	55.2	55.6	56.1	56.5	56.9	57.4	57.8	58.2	58.7	59.1	59.5	60.0	60.4	60.8	61.3	61.7	62.1	62.6
205	49.3	49.7	50.2	50.6	51.0	51.5	51.9	52.3	52.8	53.2	53.6	54.1	54.5	54.9	55.4	55.8	56.2	56.7	57.1
200	43.9	44.3	44.7	45.2	45.6	46.0	46.5	46.9	47.3	47.8	48.2	48.6	49.1	49.5	49.9	50.4	50.8	51.2	51.7

Table 19-5. Metric — Low Alt, Low-Mid Temp, Low Humidity
(Temp = 13.5 to 21.5°C , Press = 720 to 800 mm, 20% Humidity)

TEMPERATURE IN DEGREES CELSIUS

RATIOMETRIC PRESSURE IN MILLIMETERS OF MERCURY	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5
800	707.6	708.1	708.6	709.1	709.7	710.2	710.7	711.2	711.7	712.2	712.7	713.2	713.7	714.2	714.7	715.2	715.7
799	708.5	709.0	709.5	710.0	710.5	711.0	711.5	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
798	709.4	709.9	710.4	710.9	711.4	711.9	712.4	712.9	713.4	713.9	714.4	714.9	715.4	715.9	716.4	716.9	717.4
797	710.3	710.8	711.3	711.8	712.3	712.8	713.3	713.8	714.3	714.8	715.3	715.8	716.3	716.8	717.3	717.8	718.3
796	711.1	711.6	712.1	712.6	713.1	713.6	714.1	714.6	715.1	715.6	716.1	716.6	717.1	717.6	718.1	718.6	719.1
795	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5	717.0	717.5	718.0	718.5	719.0	719.5	720.0
794	712.9	713.4	713.9	714.4	714.9	715.4	715.9	716.4	716.9	717.4	717.9	718.4	718.9	719.4	719.9	720.4	720.9
793	713.8	714.3	714.8	715.3	715.8	716.3	716.8	717.3	717.8	718.3	718.8	719.3	719.8	720.3	720.8	721.3	721.8
792	714.7	715.2	715.7	716.2	716.7	717.2	717.7	718.2	718.7	719.2	719.7	720.2	720.7	721.2	721.7	722.2	722.7
791	715.6	716.1	716.6	717.1	717.6	718.1	718.6	719.1	719.6	720.1	720.6	721.1	721.6	722.1	722.6	723.1	723.6
790	716.5	717.0	717.5	718.0	718.5	719.0	719.5	720.0	720.5	721.0	721.5	722.0	722.5	723.0	723.5	724.0	724.5
789	717.4	717.9	718.4	718.9	719.4	719.9	720.4	720.9	721.4	721.9	722.4	722.9	723.4	723.9	724.4	724.9	725.4
788	718.3	718.8	719.3	719.8	720.3	720.8	721.3	721.8	722.3	722.8	723.3	723.8	724.3	724.8	725.3	725.8	726.3
787	719.2	719.7	720.2	720.7	721.2	721.7	722.2	722.7	723.2	723.7	724.2	724.7	725.2	725.7	726.2	726.7	727.2
786	720.1	720.6	721.1	721.6	722.1	722.6	723.1	723.6	724.1	724.6	725.1	725.6	726.1	726.6	727.1	727.6	728.1
785	721.0	721.5	722.0	722.5	723.0	723.5	724.0	724.5	725.0	725.5	726.0	726.5	727.0	727.5	728.0	728.5	729.0
784	721.9	722.4	722.9	723.4	723.9	724.4	724.9	725.4	725.9	726.4	726.9	727.4	727.9	728.4	728.9	729.4	729.9
783	722.8	723.3	723.8	724.3	724.8	725.3	725.8	726.3	726.8	727.3	727.8	728.3	728.8	729.3	729.8	730.3	730.8
782	723.7	724.2	724.7	725.2	725.7	726.2	726.7	727.2	727.7	728.2	728.7	729.2	729.7	730.2	730.7	731.2	731.7
781	724.6	725.1	725.6	726.1	726.6	727.1	727.6	728.1	728.6	729.1	729.6	730.1	730.6	731.1	731.6	732.1	732.6
780	725.5	726.0	726.5	727.0	727.5	727.9	728.4	728.9	729.4	729.8	730.3	730.8	731.3	731.8	732.3	732.8	733.3
779	726.3	726.7	727.2	727.7	728.2	728.7	729.1	729.6	730.1	730.5	731.0	731.5	732.0	732.4	732.9	733.4	733.8
778	727.2	727.7	728.2	728.6	729.1	729.5	730.0	730.4	730.9	731.4	731.8	732.3	732.8	733.2	733.7	734.2	734.6
777	728.0	728.5	729.0	729.4	729.9	730.3	730.8	731.2	731.8	732.1	732.6	733.0	733.5	734.0	734.4	734.9	735.3
776	728.8	729.3	729.8	730.2	730.7	731.2	731.6	732.1	732.5	733.0	733.4	733.9	734.3	734.8	735.2	735.7	736.1
775	729.7	730.2	730.6	731.1	731.5	732.0	732.4	732.9	733.3	733.8	734.3	734.7	735.2	735.6	736.1	736.5	737.0
774	730.5	731.0	731.5	731.9	732.4	732.8	733.3	733.7	734.2	734.7	735.1	735.6	736.0	736.5	736.9	737.4	737.8
773	731.4	731.8	732.3	732.7	733.2	733.6	734.1	734.6	735.0	735.5	736.0	736.4	736.9	737.3	737.8	738.2	738.7
772	732.2	732.7	733.2	733.6	734.1	734.5	735.0	735.5	735.9	736.4	736.9	737.3	737.8	738.2	738.7	739.1	739.6
771	733.1	733.6	734.0	734.5	735.0	735.4	735.9	736.4	736.8	737.3	737.8	738.2	738.7	739.1	739.6	740.0	740.5
770	734.0	734.4	734.9	735.3	735.8	736.3	736.7	737.2	737.7	738.2	738.6	739.0	739.5	739.9	740.4	740.8	741.3
769	734.8	735.3	735.8	736.2	736.7	737.2	737.6	738.1	738.6	739.0	739.5	739.9	740.4	740.8	741.3	741.7	742.2
768	735.7	736.2	736.6	737.1	737.6	738.0	738.5	739.0	739.4	739.8	740.3	740.7	741.2	741.6	742.1	742.5	743.0
767	736.6	737.0	737.5	738.0	738.4	738.9	739.3	739.7	740.2	740.6	741.1	741.5	742.0	742.4	742.9	743.3	743.8
766	737.4	737.9	738.4	738.8	739.3	739.7	740.2	740.6	741.1	741.5	742.0	742.4	742.9	743.3	743.8	744.2	744.7

Table 19-6. Metric — Low Alt, Mid Temp, Low Humidity
(Temp = 22 to 30°C , Press = 720 to 800 mm, 20% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
800	716.1	716.8	717.4	717.8	718.1	718.6	719.1	719.5	720.0	720.4	720.9	721.4	721.9	722.4	722.8	723.1	723.8
799	716.5	717.0	717.5	718.0	718.4	718.9	719.4	719.9	720.4	720.8	721.3	721.8	722.3	722.7	723.2	723.7	724.1
798	716.9	717.4	717.8	718.3	718.8	719.2	719.8	720.2	720.7	721.2	721.7	722.1	722.6	723.1	723.6	724.0	724.5
797	717.2	717.7	718.2	718.7	719.2	719.6	720.1	720.6	721.1	721.6	722.1	722.6	723.0	723.5	724.0	724.4	724.9
796	717.6	718.1	718.5	719.0	719.6	720.0	720.5	721.0	721.4	721.9	722.4	722.8	723.3	723.8	724.3	724.7	725.2
795	717.9	718.4	718.9	719.4	719.9	720.3	720.9	721.3	721.8	722.3	722.7	723.2	723.7	724.1	724.6	725.1	725.5
794	718.3	718.8	719.3	719.7	720.2	720.7	721.2	721.6	722.1	722.6	723.1	723.6	724.0	724.5	724.9	725.4	725.8
793	718.6	719.1	719.6	720.1	720.6	721.0	721.5	722.0	722.5	722.9	723.4	723.9	724.4	724.8	725.3	725.8	726.2
792	719.0	719.5	720.0	720.4	720.9	721.4	721.9	722.3	722.8	723.3	723.8	724.2	724.7	725.2	725.6	726.1	726.6
791	719.3	719.8	720.3	720.8	721.3	721.7	722.2	722.7	723.2	723.6	724.1	724.6	725.1	725.5	726.0	726.5	726.9
790	719.7	720.2	720.7	721.1	721.6	722.1	722.6	723.0	723.5	724.0	724.4	724.9	725.4	725.9	726.3	726.8	727.3
789	720.1	720.5	721.0	721.5	722.0	722.5	722.9	723.4	723.9	724.3	724.8	725.3	725.8	726.2	726.7	727.2	727.6
788	720.4	720.9	721.4	721.9	722.3	722.8	723.3	723.8	724.2	724.7	725.2	725.6	726.1	726.6	727.0	727.5	727.9
787	720.8	721.3	721.8	722.2	722.7	723.2	723.6	724.1	724.6	725.0	725.5	726.0	726.4	726.9	727.4	727.8	728.3
786	721.1	721.6	722.1	722.6	723.0	723.5	724.0	724.5	724.9	725.4	725.9	726.3	726.8	727.3	727.7	728.2	728.6
785	721.5	722.0	722.4	722.9	723.4	723.9	724.3	724.8	725.3	725.7	726.2	726.7	727.1	727.6	728.1	728.5	729.0
784	721.8	722.3	722.8	723.2	723.7	724.2	724.7	725.2	725.6	726.1	726.6	727.0	727.5	728.0	728.4	728.9	729.3
783	722.2	722.7	723.1	723.6	724.1	724.6	725.0	725.5	726.0	726.4	726.9	727.4	727.8	728.3	728.8	729.2	729.7
782	722.5	723.0	723.5	724.0	724.4	724.9	725.4	725.9	726.3	726.8	727.3	727.7	728.2	728.6	729.1	729.6	730.0
781	722.9	723.4	723.8	724.3	724.8	725.3	725.7	726.2	726.7	727.1	727.6	728.1	728.5	729.0	729.5	729.9	730.4
780	723.2	723.7	724.2	724.7	725.1	725.6	726.1	726.6	727.0	727.5	728.0	728.4	728.9	729.3	729.8	730.3	730.7
779	723.6	724.1	724.6	725.0	725.5	726.0	726.4	726.9	727.4	727.8	728.3	728.8	729.2	729.7	730.2	730.6	731.1
778	724.0	724.4	724.9	725.4	725.8	726.3	726.8	727.3	727.7	728.2	728.7	729.1	729.6	730.1	730.5	731.0	731.5
777	724.3	724.8	725.3	725.7	726.2	726.7	727.1	727.6	728.1	728.5	729.0	729.5	730.0	730.4	730.9	731.3	731.8
776	724.7	725.1	725.6	726.1	726.6	727.0	727.5	728.0	728.4	728.9	729.4	729.8	730.3	730.8	731.2	731.7	732.1
775	725.0	725.5	726.0	726.4	726.9	727.4	727.8	728.3	728.8	729.2	729.7	730.2	730.6	731.1	731.6	732.0	732.5
774	725.4	725.9	726.3	726.8	727.3	727.7	728.2	728.7	729.1	729.6	730.1	730.5	731.0	731.4	731.9	732.3	732.8
773	725.7	726.2	726.7	727.2	727.6	728.1	728.6	729.0	729.5	729.9	730.4	730.9	731.3	731.8	732.2	732.7	733.1
772	726.1	726.6	727.0	727.5	728.0	728.4	728.9	729.4	729.8	730.3	730.7	731.2	731.7	732.1	732.6	733.0	733.5
771	726.4	726.9	727.4	727.9	728.3	728.8	729.3	729.7	730.2	730.6	731.1	731.6	732.0	732.5	733.0	733.4	733.9
770	726.8	727.3	727.7	728.2	728.7	729.1	729.6	730.1	730.5	731.0	731.5	731.9	732.4	732.8	733.3	733.7	734.2
769	727.2	727.6	728.1	728.6	729.0	729.5	730.0	730.4	730.9	731.3	731.8	732.3	732.7	733.2	733.6	734.1	734.6
768	727.5	728.0	728.5	728.9	729.4	729.8	730.3	730.8	731.2	731.7	732.2	732.6	733.1	733.5	734.0	734.4	734.9
767	727.9	728.4	728.8	729.3	729.7	730.2	730.7	731.1	731.6	732.0	732.5	733.0	733.4	733.9	734.3	734.8	735.2
766	728.2	728.7	729.2	729.6	730.1	730.6	731.0	731.5	731.9	732.4	732.9	733.3	733.8	734.2	734.7	735.1	735.6
765	728.6	729.0	729.5	730.0	730.4	730.9	731.4	731.8	732.3	732.7	733.2	733.6	734.1	734.6	735.0	735.5	735.9
764	728.9	729.4	729.9	730.3	730.8	731.3	731.7	732.2	732.6	733.1	733.5	734.0	734.4	734.9	735.4	735.8	736.3
763	729.3	729.8	730.2	730.7	731.1	731.6	732.1	732.5	733.0	733.4	733.9	734.3	734.8	735.2	735.7	736.1	736.6
762	729.6	730.1	730.6	731.0	731.5	732.0	732.4	732.9	733.3	733.8	734.2	734.7	735.1	735.6	736.0	736.5	736.9
761	730.0	730.5	730.9	731.4	731.8	732.3	732.8	733.2	733.7	734.1	734.6	735.0	735.5	735.9	736.4	736.8	737.3
760	730.4	730.8	731.3	731.7	732.2	732.7	733.1	733.6	734.0	734.5	734.9	735.4	735.8	736.3	736.7	737.2	737.6
759	730.7	731.2	731.6	732.1	732.6	733.0	733.5	733.9	734.4	734.8	735.3	735.7	736.2	736.6	737.1	737.5	738.0
758	731.1	731.5	732.0	732.5	732.9	733.4	733.8	734.3	734.7	735.2	735.6	736.1	736.5	737.0	737.4	737.9	738.3
757	731.4	731.9	732.3	732.8	733.3	733.7	734.2	734.6	735.1	735.5	736.0	736.4	736.9	737.3	737.8	738.2	738.7
756	731.8	732.2	732.7	733.2	733.6	734.1	734.5	735.0	735.4	735.9	736.3	736.8	737.2	737.7	738.1	738.6	739.0
755	732.1	732.6	733.1	733.5	734.0	734.4	734.9	735.3	735.8	736.2	736.7	737.1	737.6	738.0	738.5	738.9	739.4
754	732.5	732.9	733.4	733.9	734.3	734.8	735.2	735.7	736.1	736.6	737.0	737.5	737.9	738.4	738.8	739.3	739.7
753	732.8	733.3	733.8	734.2	734.7	735.1	735.6	736.0	736.5	736.9	737.4	737.8	738.3	738.7	739.2	739.6	740.0
752	733.2	733.7	734.1	734.6	735.0	735.5	735.9	736.4	736.8	737.3	737.7	738.2	738.6	739.1	739.5	740.0	740.4
751	733.6	734.0	734.5	734.9	735.4	735.8	736.3	736.7	737.2	737.6	738.1	738.5	739.0	739.4	739.9	740.3	740.7
750	733.9	734.4	734.8	735.3	735.7	736.2	736.6	737.1	737.5	738.0	738.4	738.9	739.3	739.8	740.2	740.6	741.1
749	734.3	734.7	735.2	735.6	736.1	736.5	737.0	737.4	737.9	738.3	738.8	739.2	739.7	740.1	740.6	741.0	741.4
748	734.6	735.1	735.5	736.0	736.4	736.9	737.3	737.8	738.2	738.7	739.1	739.6	740.0	740.5	740.9	741.3	741.8
747	735.0	735.4	735.9	736.3	736.8	737.2	737.7	738.1	738.6	739.0	739.5	739.9	740.4	740.8	741.2	741.7	742.1
746	735.3	735.8	736.2	736.7	737.1	737.6	738.0	738.5	738.9	739.4	739.8	740.3	740.7	741.2	741.6	742.0	742.5
745	735.7	736.1	736.6	737.0	737.5	737.9	738.4	738.8	739.3	739.7	740.2	740.6	741.1	741.5	742.0	742.4	742.8
744	736.0	736.5	736.9	737.4	737.8	738.3	738.7	739.2	739.6	740.1	740.5	741.0	741.4	741.8	742.3	742.7	743.2
743	736.4	736.8	737.3	737.8	738.2	738.6	739.1	739.5	740.0	740.4	740.9	741.3	741.8	742.2	742.6	743.1	743.5
742	736.7	737.2	737.7	738.1	738.6	739.0	739.4	739.9	740.3	740.8	741.2	741.7	742.1	742.5	743.0	743.4	743.9
741	737.1	737.6	738.0	738.5	738.9	739.4	739.8	740.2	740.7	741.1	741.6	742.0	742.5	742.9	743.3	743.8	744.2
740	737.5	738.0	738.4	738.8	739.3	739.7	740.2	740.6	741.0	741.5	741.9	742.4	742.8	743.3	743.7	744.1	744.6
739	737.8	738.3	738.7	739.2	739.6	740.1	740.5	740.9	741.4	741.8	742.3	742.7	743.2	743.6	744.0	744.5	744.9
738	738.2	738.6	739.1	739.5	740.0	740.4	740.9	741.3	741.7	742.2	742.6	743.1	743.5	743.9	744.4	744.8	745.2
737	738.5	739.0	739.4	739.9	740.3	740.8	741.2	741.6	742.1	742.5	743.0	743.4	743.8	744.3	744.7	745.1	745.6
736	738.9	739.3	739.8	740.2	740.7	741.1	741.6	742.0	742.4	742.9	743.3	743.8	744.2	744.6	745.1	745.5	745.9
735	739.2	739.7	740.1	740.6	741.0	741.5	741.9	742.4	742.8	743.2	743.7	744.1	744.5	745.0	745.4	745.8	746.3
734	739.6	740.0	740.5	740.9	741.4	741.8	742.3	742.7	743.1	743.6	744.0	744.5	744.9	745.3	745.8	746.2	746.6
733	739.9	740.4	740.8	741.3	741.7	742.2	742.6	743.1	743.5	743.9	744.4	744.8	745.2	745.7	746.1	746.5	747.0
732	740.3	740.7	741.2	741.6	742.1	742.5	743.0	743.4	743.8	744.3	744.7	745.2	745.6	746.0	746.5	746.9	747.3
731	740.7	741.1	741.5	742.0	742.4	742.9	743.3	743.8	744.2	744.6	745.1	745.5	745.9	746.4	746.8	747.2	747.7
730	741.0	741.5	741.9	742.3	742.8	743.2	743.7	744.1	744.5	745.0	745.4	745.8	746.3	746.7	747.1	747.6	748.0
729	741.4	741.8	742.3	742.7	743.1	743.6	744.0	744.5	744.9	745.3	745.8	746.2	746.6	747.1	747.5	747.9	748.4
728	741.7	742.2	742.6	743.1	743.5	743.9	744.4	744.8	745.2	745.7	746.1	746.5	747.0	747.4	747.8	748.3	748.7
727	742.1	742.5	743.0	743.4	743.9	744.3	744.7	745.2	745.6	746.0	746.5	746.9	747.3	747.8	748.2	748.6	749.0
726	742.4	742.9	743.3	743.8	744.2	744.6	745.1	745.5	745.9	746.4	746.8	747.2	747.7	748.1	748.5	749.0	749.4
725	742.8	743.2	743.7	744.1	744.6	745.0	745.4	745.9	746.3	746.7	747.2	747.6	748.0	748.5	748.9	749.3	749.7
724	743.1	743.6	744.0	744.5	744.9	745.3	745.8	746.2	746.6	747.1	747.5	747.9	748.4	748.8	749.2	749.7	750.1
723	743.5	743.9	744.4	744.8	745.3	745.7	746.1	746.6	747.0	747.4	747.9	748.3	748.7	749.1	749.6	750.0	750.4
722	743.8	744.3	744.7	745.2	745.6	746.0	746.5	746.9	747.3	747.8	748.2	748.6	749.1	749.5	749.9	750.3	750.8
721	744.2	744.6	745.1	745.5	746.0	746.4	746.8	747.3	747.7	748.1	748.6	749.0	749.4	749.8	750.3	750.7	751.1
720	744.6	745.0	745.4	745.9	746.3	746.7	747.2	747.6	748.0	748.5	748.9	749.3	749.8	750.2	750.6	751.0	751.5

Table 19-7. Metric — Low Alt. High-Mid Temp, Low Humidity
(Temp = 30.5 to 38.5°C , Press = 720 to 800 mm, 20% Humidity

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

TEMPERATURE IN DEGREES CELSIUS

	30.5	31.0	31.5	32.0	32.5	33.0	33.5	34.0	34.5	35.0	35.5	36.0	36.5	37.0	37.5	38.0	38.5
800	724.4	724.7	725.2	725.7	726.1	726.6	727.0	727.5	728.0	728.4	728.9	729.4	729.8	730.3	730.7	731.2	731.6
799	724.6	725.1	725.5	726.0	726.5	726.9	727.4	727.9	728.3	728.8	729.3	729.7	730.1	730.6	731.0	731.5	731.9
798	724.7	725.2	725.7	726.1	726.6	727.1	727.5	728.0	728.5	728.9	729.4	729.8	730.3	730.7	731.2	731.6	732.1
797	725.3	725.8	726.3	726.7	727.2	727.6	728.1	728.5	729.0	729.4	729.9	730.3	730.8	731.2	731.7	732.1	732.6
796	725.6	726.1	726.6	727.0	727.5	728.0	728.4	728.9	729.3	729.8	730.2	730.7	731.1	731.6	732.0	732.5	733.0
795	726.0	726.5	726.9	727.4	727.9	728.3	728.8	729.2	729.7	730.1	730.6	731.0	731.5	731.9	732.4	732.9	733.3
794	726.3	726.8	727.2	727.7	728.2	728.6	729.1	729.6	730.0	730.5	730.9	731.4	731.8	732.3	732.7	733.2	733.6
793	726.7	727.1	727.6	728.1	728.5	729.0	729.4	729.9	730.3	730.8	731.2	731.7	732.1	732.6	733.0	733.5	733.9
792	727.0	727.5	728.0	728.4	728.9	729.3	729.8	730.2	730.7	731.1	731.6	732.0	732.5	732.9	733.4	733.8	734.3
791	727.4	727.8	728.3	728.8	729.2	729.7	730.1	730.6	731.0	731.5	731.9	732.4	732.8	733.3	733.7	734.2	734.6
790	727.7	728.2	728.6	729.1	729.6	730.0	730.5	730.9	731.4	731.8	732.3	732.7	733.2	733.6	734.1	734.5	734.9
789	728.1	728.5	729.0	729.4	729.9	730.4	730.8	731.3	731.7	732.2	732.6	733.1	733.5	734.0	734.4	734.8	735.3
788	728.4	728.9	729.3	729.8	730.2	730.7	731.1	731.6	732.0	732.5	732.9	733.4	733.8	734.3	734.7	735.2	735.6
787	728.8	729.2	729.7	730.1	730.6	731.0	731.5	731.9	732.4	732.8	733.3	733.7	734.2	734.6	735.0	735.5	735.9
786	729.1	729.6	730.0	730.5	730.9	731.4	731.8	732.3	732.7	733.2	733.6	734.1	734.5	735.0	735.4	735.8	736.3
785	729.5	729.9	730.4	730.8	731.3	731.7	732.2	732.6	733.1	733.5	734.0	734.4	734.9	735.3	735.8	736.2	736.6
784	729.8	730.2	730.7	731.2	731.6	732.1	732.5	733.0	733.4	733.9	734.3	734.8	735.2	735.6	736.1	736.5	737.0
783	730.1	730.6	731.0	731.5	732.0	732.4	732.9	733.3	733.8	734.2	734.7	735.1	735.6	736.0	736.4	736.9	737.3
782	730.5	731.0	731.4	731.9	732.3	732.8	733.2	733.7	734.1	734.6	735.0	735.4	735.9	736.3	736.8	737.2	737.6
781	730.9	731.3	731.8	732.2	732.7	733.1	733.6	734.0	734.5	734.9	735.3	735.8	736.2	736.7	737.1	737.6	738.0
780	731.2	731.7	732.1	732.6	733.0	733.5	733.9	734.4	734.8	735.2	735.7	736.1	736.6	737.0	737.4	737.9	738.3
779	731.6	732.0	732.5	732.9	733.4	733.8	734.3	734.7	735.1	735.6	736.0	736.4	736.9	737.3	737.8	738.2	738.6
778	731.9	732.4	732.8	733.3	733.7	734.2	734.6	735.0	735.5	735.9	736.3	736.8	737.2	737.7	738.1	738.5	739.0
777	732.3	732.7	733.2	733.6	734.0	734.5	734.9	735.4	735.8	736.2	736.7	737.1	737.6	738.0	738.4	738.9	739.3
776	732.6	733.0	733.5	733.9	734.4	734.8	735.2	735.7	736.1	736.6	737.0	737.5	737.9	738.3	738.8	739.2	739.7
775	732.9	733.3	733.8	734.2	734.7	735.1	735.6	736.0	736.4	736.9	737.3	737.8	738.2	738.7	739.1	739.6	740.0
774	733.3	733.7	734.1	734.6	735.0	735.5	735.9	736.4	736.8	737.3	737.7	738.1	738.6	739.0	739.5	739.9	740.3
773	733.6	734.0	734.5	734.9	735.4	735.8	736.3	736.7	737.2	737.6	738.0	738.5	738.9	739.4	739.8	740.2	740.7
772	734.0	734.4	734.8	735.3	735.7	736.2	736.6	737.1	737.5	737.9	738.4	738.8	739.3	739.7	740.1	740.6	741.0
771	734.3	734.7	735.2	735.6	736.1	736.5	737.0	737.4	737.8	738.3	738.7	739.2	739.6	740.0	740.5	740.9	741.4
770	734.6	735.1	735.5	736.0	736.4	736.9	737.3	737.7	738.2	738.6	739.1	739.5	739.9	740.4	740.8	741.2	741.7
769	735.0	735.4	735.9	736.3	736.8	737.2	737.6	738.1	738.5	739.0	739.4	739.8	740.3	740.7	741.1	741.6	742.0
768	735.3	735.8	736.2	736.7	737.1	737.5	738.0	738.4	738.9	739.3	739.7	740.2	740.6	741.0	741.5	741.9	742.3
767	735.7	736.1	736.6	737.0	737.4	737.9	738.3	738.8	739.2	739.6	740.1	740.5	740.9	741.4	741.8	742.2	742.7
766	736.0	736.4	736.9	737.3	737.8	738.2	738.7	739.1	739.5	740.0	740.4	740.8	741.3	741.7	742.1	742.6	743.0
765	736.3	736.8	737.2	737.7	738.1	738.6	739.0	739.4	739.9	740.3	740.8	741.2	741.6	742.1	742.5	742.9	743.4
764	736.7	737.1	737.6	738.0	738.5	738.9	739.4	739.8	740.2	740.7	741.1	741.5	742.0	742.4	742.8	743.3	743.7
763	737.0	737.5	737.9	738.4	738.8	739.3	739.7	740.1	740.6	741.0	741.4	741.9	742.3	742.7	743.2	743.6	744.0
762	737.4	737.8	738.3	738.7	739.2	739.6	740.0	740.5	740.9	741.3	741.8	742.2	742.6	743.1	743.5	743.9	744.4
761	737.7	738.2	738.6	739.1	739.5	739.9	740.4	740.8	741.2	741.7	742.1	742.5	743.0	743.4	743.8	744.3	744.7
760	738.1	738.5	739.0	739.4	739.8	740.3	740.7	741.2	741.6	742.0	742.5	742.9	743.3	743.7	744.2	744.6	745.0
759	738.4	738.9	739.3	739.7	740.2	740.6	741.1	741.5	741.9	742.4	742.8	743.2	743.7	744.1	744.5	745.0	745.4
758	738.8	739.2	739.6	740.1	740.5	741.0	741.4	741.9	742.3	742.7	743.1	743.6	744.0	744.4	744.9	745.3	745.7
757	739.1	739.6	740.0	740.4	740.9	741.3	741.7	742.2	742.6	743.0	743.4	743.9	744.3	744.8	745.2	745.6	746.0
756	739.5	739.9	740.3	740.8	741.2	741.6	742.1	742.5	742.9	743.4	743.8	744.2	744.7	745.1	745.5	746.0	746.4
755	739.8	740.2	740.7	741.1	741.6	742.0	742.4	742.9	743.3	743.7	744.2	744.6	745.0	745.4	745.9	746.3	746.7
754	740.1	740.6	741.0	741.5	741.9	742.3	742.8	743.2	743.6	744.1	744.5	744.9	745.4	745.8	746.2	746.6	747.0
753	740.5	740.9	741.4	741.8	742.2	742.7	743.1	743.5	744.0	744.4	744.8	745.3	745.7	746.1	746.5	747.0	747.4
752	740.8	741.3	741.7	742.1	742.6	743.0	743.4	743.8	744.3	744.7	745.2	745.6	746.0	746.4	746.9	747.3	747.7
751	741.2	741.6	742.1	742.5	742.9	743.4	743.8	744.2	744.7	745.1	745.5	745.9	746.4	746.8	747.2	747.6	748.1
750	741.5	741.9	742.4	742.8	743.3	743.7	744.1	744.6	745.0	745.4	745.8	746.3	746.7	747.1	747.5	748.0	748.4
749	741.9	742.3	742.7	743.2	743.6	744.0	744.5	744.9	745.3	745.8	746.2	746.6	747.0	747.5	747.9	748.3	748.7
748	742.2	742.7	743.1	743.5	744.0	744.4	744.8	745.2	745.7	746.1	746.5	747.0	747.4	747.8	748.2	748.6	749.1
747	742.6	743.0	743.4	743.9	744.3	744.7	745.2	745.6	746.0	746.4	746.9	747.3	747.7	748.1	748.6	749.0	749.4
746	742.9	743.3	743.8	744.2	744.6	745.1	745.5	745.9	746.4	746.8	747.2	747.6	748.1	748.5	748.9	749.3	749.7
745	743.3	743.7	744.2	744.6	745.0	745.4	745.9	746.3	746.7	747.1	747.5	748.0	748.4	748.8	749.2	749.7	750.1
744	743.6	744.0	744.5	744.9	745.3	745.8	746.2	746.6	747.0	747.5	747.9	748.3	748.7	749.2	749.6	750.0	750.4
743	743.9	744.4	744.8	745.2	745.7	746.1	746.5	747.0	747.4	747.8	748.2	748.6	749.1	749.5	749.9	750.3	750.7
742	744.3	744.7	745.2	745.6	746.0	746.4	746.9	747.3	747.7	748.1	748.5	749.0	749.4	749.8	750.2	750.7	751.1
741	744.6	745.1	745.5	745.9	746.4	746.8	747.2	747.6	748.1	748.5	748.9	749.3	749.7	750.2	750.6	751.0	751.4
740	745.0	745.4	745.8	746.3	746.7	747.1	747.5	748.0	748.4	748.8	749.2	749.7	750.1	750.5	750.9	751.4	751.8
739	745.3	745.8	746.2	746.6	747.0	747.5	747.9	748.3	748.7	749.2	749.6	750.0	750.4	750.9	751.3	751.7	752.1
738	745.7	746.1	746.5	747.0	747.4	747.8	748.2	748.7	749.1	749.5	749.9	750.4	750.8	751.2	751.6	752.0	752.5
737	746.0	746.4	746.9	747.3	747.7	748.2	748.6	749.0	749.4	749.9	750.3	750.7	751.1	751.5	751.9	752.3	752.8
736	746.4	746.8	747.2	747.6	748.1	748.5	748.9	749.3	749.8	750.2	750.6	751.0	751.4	751.9	752.3	752.7	753.1
735	746.7	747.1	747.6	748.0	748.4	748.8	749.3	749.7	750.1	750.5	750.9	751.4	751.8	752.2	752.6	753.0	753.4
734	747.0	747.5	747.9	748.3	748.8	749.2	749.6	750.0	750.4	750.9	751.3	751.7	752.1	752.5	752.9	753.4	753.8
733	747.4	747.8	748.2	748.7	749.1	749.5	749.9	750.4	750.8	751.2	751.6	752.0	752.4	752.8	753.3	753.7	754.1
732	747.7	748.2	748.6	749.0	749.4	749.8	750.3	750.7	751.1	751.5	752.0	752.4	752.8	753.2	753.6	754.0	754.4
731	748.1	748.5	748.9	749.4	749.8	750.2	750.6	751.0	751.5	751.9	752.3	752.7	753.1	753.5	754.0	754.4	754.8
730	748.4	748.9	749.3	749.7	750.1	750.5	751.0	751.4	751.8	752.2	752.6	753.1	753.5	753.9	754.3	754.7	755.1
729	748.8	749.2	749.6	750.0	750.5	750.9	751.3	751.7	752.1	752.5	752.9	753.3	753.8	754.2	754.6	755.0	755.5
728	749.1	749.5	750.0	750.4	750.8	751.2	751.7	752.1	752.5	752.9	753.3	753.7	754.1	754.6	755.0	755.4	755.8
727	749.5	749.9	750.3	750.7	751.2	751.6	752.0	752.4	752.8	753.2	753.6	754.0	754.4	754.9	755.3	755.7	756.1
726	749.8	750.2	750.7	751.1	751.5	751.9	752.3	752.8	753.2	753.6	754.0	754.4	754.8	755.2	755.6	756.0	756.5
725	750.2	750.6	751.0	751.4	751.8	752.3	752.7	753.1	753.5	753.9	754.3	754.7	755.2	755.6	756.0	756.4	756.8
724	750.5	750.9	751.3	751.8	752.2	752.6	753.0	753.4	753.8	754.3	754.7	755.1	755.5	755.9	756.3	756.7	757.1
723	750.9	751.3	751.7	752.1	752.5	752.9	753.4	753.8	754.2	754.6	755.0	755.4	755.8	756.2	756.7	757.1	757.5
722	751.2	751.6	752.0	752.4	752.9	753.3	753.7	754.1	754.5	754.9	755.4	755.8	756.2	756.6	757.0	757.4	757.8
721	751.5	752.0	752.4	752.8	753.2	753.6	754.0	754.5	754.9	755.3	755.7	756.1	756.5	756.9	757.3	757.7	758.1
720	751.9	752.3	752.7	753.1	753.6	754.0	754.4	754.8	755.2	755.6	756.0	756.4	756.9	757.3	757.7	758.1	758.5

Table 19-8. Metric — High Air, Low Temp, Low Humidity
(Temp = 5 to 13°C , Press = 640 to 720 mm, 20% Humidity)

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

TEMPERATURE IN DEGREES CELSIUS

	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
720	728.7	729.2	729.7	730.2	730.7	731.2	731.7	732.2	732.8	733.3	733.8	734.3	734.8	735.3	735.9	736.4	736.9
719	728.1	729.6	730.1	730.6	731.1	731.6	732.1	732.5	733.0	733.5	734.0	734.5	735.0	735.5	736.0	736.5	736.9
718	727.5	728.0	728.5	729.0	729.5	730.0	730.5	731.0	731.5	732.0	732.5	733.0	733.5	734.0	734.5	735.0	735.4
717	726.9	727.4	727.9	728.4	728.9	729.4	729.8	730.3	730.8	731.3	731.8	732.3	732.8	733.3	733.8	734.3	734.8
716	726.3	726.8	727.3	727.8	728.3	728.8	729.3	729.8	730.3	730.8	731.3	731.8	732.3	732.8	733.3	733.8	734.3
715	725.8	726.3	726.8	727.3	727.8	728.3	728.8	729.3	729.8	730.3	730.8	731.3	731.8	732.3	732.8	733.3	733.8
714	725.2	725.7	726.2	726.7	727.2	727.7	728.2	728.7	729.2	729.7	730.2	730.7	731.2	731.7	732.2	732.7	733.2
713	724.6	725.1	725.6	726.1	726.6	727.1	727.6	728.1	728.6	729.1	729.6	730.1	730.6	731.1	731.6	732.1	732.6
712	724.0	724.5	725.0	725.5	726.0	726.5	727.0	727.5	728.0	728.5	729.0	729.5	730.0	730.5	731.0	731.5	732.0
711	723.4	723.9	724.4	724.9	725.4	725.9	726.4	726.9	727.4	727.9	728.4	728.9	729.4	729.9	730.4	730.9	731.4
710	722.8	723.3	723.8	724.3	724.8	725.3	725.8	726.3	726.8	727.3	727.8	728.3	728.8	729.3	729.8	730.3	730.8
709	722.2	722.7	723.2	723.7	724.2	724.7	725.2	725.7	726.2	726.7	727.2	727.7	728.2	728.7	729.2	729.7	730.2
708	721.7	722.2	722.7	723.2	723.7	724.2	724.7	725.2	725.7	726.2	726.7	727.2	727.7	728.2	728.7	729.2	729.7
707	721.1	721.6	722.1	722.6	723.1	723.6	724.1	724.6	725.1	725.6	726.1	726.6	727.1	727.6	728.1	728.6	729.1
706	720.5	721.0	721.5	722.0	722.5	723.0	723.5	724.0	724.5	725.0	725.5	726.0	726.5	727.0	727.5	728.0	728.5
705	719.9	720.4	720.9	721.4	721.9	722.4	722.9	723.4	723.9	724.4	724.9	725.4	725.9	726.4	726.9	727.4	727.9
704	719.3	719.8	720.3	720.8	721.3	721.8	722.3	722.8	723.3	723.8	724.3	724.8	725.3	725.8	726.3	726.8	727.3
703	718.8	719.3	719.8	720.3	720.8	721.3	721.8	722.3	722.8	723.3	723.8	724.3	724.8	725.3	725.8	726.3	726.8
702	718.2	718.7	719.2	719.7	720.2	720.7	721.2	721.7	722.2	722.7	723.2	723.7	724.2	724.7	725.2	725.7	726.2
701	717.6	718.1	718.6	719.1	719.6	720.1	720.6	721.1	721.6	722.1	722.6	723.1	723.6	724.1	724.6	725.1	725.6
700	717.0	717.5	718.0	718.5	719.0	719.5	720.0	720.5	721.0	721.5	722.0	722.5	723.0	723.5	724.0	724.5	725.0
699	716.4	716.9	717.4	717.9	718.4	718.9	719.4	719.9	720.4	720.9	721.4	721.9	722.4	722.9	723.4	723.9	724.4
698	715.8	716.3	716.8	717.3	717.8	718.3	718.8	719.3	719.8	720.3	720.8	721.3	721.8	722.3	722.8	723.3	723.8
697	715.2	715.7	716.2	716.7	717.2	717.7	718.2	718.7	719.2	719.7	720.2	720.7	721.2	721.7	722.2	722.7	723.2
696	714.7	715.2	715.7	716.2	716.7	717.2	717.7	718.2	718.7	719.2	719.7	720.2	720.7	721.2	721.7	722.2	722.7
695	714.1	714.6	715.1	715.6	716.1	716.6	717.1	717.6	718.1	718.6	719.1	719.6	720.1	720.6	721.1	721.6	722.1
694	713.5	714.0	714.5	715.0	715.5	716.0	716.5	717.0	717.5	718.0	718.5	719.0	719.5	720.0	720.5	721.0	721.5
693	712.9	713.4	713.9	714.4	714.9	715.4	715.9	716.4	716.9	717.4	717.9	718.4	718.9	719.4	719.9	720.4	720.9
692	712.3	712.8	713.3	713.8	714.3	714.8	715.3	715.8	716.3	716.8	717.3	717.8	718.3	718.8	719.3	719.8	720.3
691	711.7	712.2	712.7	713.2	713.7	714.2	714.7	715.2	715.7	716.2	716.7	717.2	717.7	718.2	718.7	719.2	719.7
690	711.1	711.6	712.1	712.6	713.1	713.6	714.1	714.6	715.1	715.6	716.1	716.6	717.1	717.6	718.1	718.6	719.1
689	710.6	711.1	711.6	712.1	712.6	713.1	713.6	714.1	714.6	715.1	715.6	716.1	716.6	717.1	717.6	718.1	718.6
688	710.0	710.5	711.0	711.5	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5	717.0	717.5	718.0
687	709.4	709.9	710.4	710.9	711.4	711.9	712.4	712.9	713.4	713.9	714.4	714.9	715.4	715.9	716.4	716.9	717.4
686	708.8	709.3	709.8	710.3	710.8	711.3	711.8	712.3	712.8	713.3	713.8	714.3	714.8	715.3	715.8	716.3	716.8
685	708.2	708.7	709.2	709.7	710.2	710.7	711.2	711.7	712.2	712.7	713.2	713.7	714.2	714.7	715.2	715.7	716.2
684	707.6	708.1	708.6	709.1	709.6	710.1	710.6	711.1	711.6	712.1	712.6	713.1	713.6	714.1	714.6	715.1	715.6
683	707.1	707.6	708.1	708.6	709.1	709.6	710.1	710.6	711.1	711.6	712.1	712.6	713.1	713.6	714.1	714.6	715.1
682	706.5	707.0	707.5	708.0	708.5	709.0	709.5	710.0	710.5	711.0	711.5	712.0	712.5	713.0	713.5	714.0	714.5
681	705.9	706.4	706.9	707.4	707.9	708.4	708.9	709.4	709.9	710.4	710.9	711.4	711.9	712.4	712.9	713.4	713.9
680	705.3	705.8	706.3	706.8	707.3	707.8	708.3	708.8	709.3	709.8	710.3	710.8	711.3	711.8	712.3	712.8	713.3
679	704.7	705.2	705.7	706.2	706.7	707.2	707.7	708.2	708.7	709.2	709.7	710.2	710.7	711.2	711.7	712.2	712.7
678	704.2	704.7	705.2	705.7	706.2	706.7	707.2	707.7	708.2	708.7	709.2	709.7	710.2	710.7	711.2	711.7	712.2
677	703.6	704.1	704.6	705.1	705.6	706.1	706.6	707.1	707.6	708.1	708.6	709.1	709.6	710.1	710.6	711.1	711.6
676	703.0	703.5	704.0	704.5	705.0	705.5	706.0	706.5	707.0	707.5	708.0	708.5	709.0	709.5	710.0	710.5	711.0
675	702.4	702.9	703.4	703.9	704.4	704.9	705.4	705.9	706.4	706.9	707.4	707.9	708.4	708.9	709.4	709.9	710.4
674	701.8	702.3	702.8	703.3	703.8	704.3	704.8	705.3	705.8	706.3	706.8	707.3	707.8	708.3	708.8	709.3	709.8
673	701.2	701.7	702.2	702.7	703.2	703.7	704.2	704.7	705.2	705.7	706.2	706.7	707.2	707.7	708.2	708.7	709.2
672	700.7	701.2	701.7	702.2	702.7	703.2	703.7	704.2	704.7	705.2	705.7	706.2	706.7	707.2	707.7	708.2	708.7
671	700.1	700.6	701.1	701.6	702.1	702.6	703.1	703.6	704.1	704.6	705.1	705.6	706.1	706.6	707.1	707.6	708.1
670	699.5	700.0	700.5	701.0	701.5	702.0	702.5	703.0	703.5	704.0	704.5	705.0	705.5	706.0	706.5	707.0	707.5
669	698.9	699.4	699.9	700.4	700.9	701.4	701.9	702.4	702.9	703.4	703.9	704.4	704.9	705.4	705.9	706.4	706.9
668	698.3	698.8	699.3	699.8	700.3	700.8	701.3	701.8	702.3	702.8	703.3	703.8	704.3	704.8	705.3	705.8	706.3
667	697.8	698.3	698.8	699.3	699.8	700.3	700.8	701.3	701.8	702.3	702.8	703.3	703.8	704.3	704.8	705.3	705.8
666	697.2	697.7	698.2	698.7	699.2	699.7	700.2	700.7	701.2	701.7	702.2	702.7	703.2	703.7	704.2	704.7	705.2
665	696.6	697.1	697.6	698.1	698.6	699.1	699.6	700.1	700.6	701.1	701.6	702.1	702.6	703.1	703.6	704.1	704.6
664	696.0	696.5	697.0	697.5	698.0	698.5	699.0	699.5	700.0	700.5	701.0	701.5	702.0	702.5	703.0	703.5	704.0
663	695.4	695.9	696.4	696.9	697.4	697.9	698.4	698.9	699.4	699.9	700.4	700.9	701.4	701.9	702.4	702.9	703.4
662	694.8	695.3	695.8	696.3	696.8	697.3	697.8	698.3	698.8	699.3	699.8	700.3	700.8	701.3	701.8	702.3	702.8
661	694.3	694.8	695.3	695.8	696.3	696.8	697.3	697.8	698.3	698.8	699.3	699.8	700.3	700.8	701.3	701.8	702.3
660	693.7	694.2	694.7	695.2	695.7	696.2	696.7	697.2	697.7	698.2	698.7	699.2	699.7	700.2	700.7	701.2	701.7
659	693.1	693.6	694.1	694.6	695.1	695.6	696.1	696.6	697.1	697.6	698.1	698.6	699.1	699.6	700.1	700.6	701.1
658	692.5	693.0	693.5	694.0	694.5	695.0	695.5	696.0	696.5	697.0	697.5	698.0	698.5	699.0	699.5	700.0	700.5
657	691.9	692.4	692.9	693.4	693.9	694.4	694.9	695.4	695.9	696.4	696.9	697.4	697.9	698.4	698.9	699.4	699.9
656	691.3	691.8	692.3	692.8	693.3	693.8	694.3	694.8	695.3	695.8	696.3	696.8	697.3	697.8	698.3	698.8	699.3
655	690.8	691.3	691.8	692.3	692.8	693.3	693.8	694.3	694.8	695.3	695.8	696.3	696.8	697.3	697.8	698.3	698.8
654	690.2	690.7	691.2	691.7	692.2	692.7	693.2	693.7	694.2	694.7	695.2	695.7	696.2	696.7	697.2	697.7	698.2
653	689.6	690.1	690.6	691.1	691.6	692.1	692.6	693.1	693.6	694.1	694.6	695.1	695.6	696.1	696.6	697.1	697.6
652	689.0	689.5	690.0	690.5	691.0	691.5	692.0	692.5	693.0	693.5	694.0	694.5	695.0	695.5	696.0	696.5	697.0
651	688.4	688.9	689.4	689.9	690.4	690.9	691.4	691.9	692.4	692.9	693.4	693.9	694.4	694.9	695.4	695.9	696.4
650	687.8	688.3	688.8	689.3	689.8	690.3	690.8	691.3	691.8	692.3	692.8	693.3	693.8	694.3	694.8	695.3	695.8
649	687.3	687.8	688.3	688.8	689.3	689.8	690.3	690.8	691.3	691.8	692.3	692.8	693.3	693.8	694.3	694.8	695.3
648	686.7	687.2	687.7	688.2	688.7	689.2	689.7	690.2	690.7	691.2	691.7	692.2	692.7	693.2	693.7	694.2	694.7
647	686.1	686.6	687.1	687.6	688.1	688.6	689.1	689.6	690.1	690.6	691.1	691.6	692.1	692.6	693.1	693.6	694.1
646	685.5	686.0	686.5	687.0	687.5	688.0	688.5	689.0	689.5	690.0	690.5	691.0	691.5	692.0	692.5	693.0	693.5
645	685.0	685.5	686.0	686.5	687.0	687.5	688.0	688.5	689.0	689.5	690.0	690.5	691.0	691.5	692.0	692.5	693.0
644	684.4	684.9	685.4	685.9	686.4	686.9	687.4	687.9	688.4	688.9	689.4	689.9	690.4	690.9	691.4	691.9	692.4
643	683.8	684.3	684.8	685.3	685.8	686.3	686.8	687.3	687.8	688.3	688.8	689.3	689.8	690.3	690.8	691.3	691.8
642	683.2	683.7	684.2	684.7	685.2	685.7	686.2	686.7	687.2	687.7	688.2	688.7	689.2	689.7	690.2	690.7	691.2
641	682.6	683.1	683.6	684.1	684.6	685.1	685.6	686.1	686.6	687.1	687.6	688.1	688.6	689.1	689.6	690.1	690.6
640	682.1	682.6	683.1	683.6	684.1	684.6	685.1	685.6	686.1	686.6	687.1	687.6	688.1	688.6	689.1	689.6	690.1

Table 19-9. Metric — High Alt. Low-Mid Temp, Low Humidity
(Temp = 13.5 to 21.5°C , Press = 640 to 720 mm, 20% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5
720	736.0	735.5	735.0	734.5	734.0	733.5	733.0	732.5	732.0	731.5	731.0	730.5	730.0	729.5	729.0	728.5	728.0
719	734.8	734.3	733.8	733.3	732.8	732.3	731.8	731.3	730.8	730.3	729.8	729.3	728.8	728.3	727.8	727.3	726.8
718	733.6	733.1	732.6	732.1	731.6	731.1	730.6	730.1	729.6	729.1	728.6	728.1	727.6	727.1	726.6	726.1	725.6
717	732.4	731.9	731.4	730.9	730.4	729.9	729.4	728.9	728.4	727.9	727.4	726.9	726.4	725.9	725.4	724.9	724.4
716	731.2	730.7	730.2	729.7	729.2	728.7	728.2	727.7	727.2	726.7	726.2	725.7	725.2	724.7	724.2	723.7	723.2
715	730.0	729.5	729.0	728.5	728.0	727.5	727.0	726.5	726.0	725.5	725.0	724.5	724.0	723.5	723.0	722.5	722.0
714	728.8	728.3	727.8	727.3	726.8	726.3	725.8	725.3	724.8	724.3	723.8	723.3	722.8	722.3	721.8	721.3	720.8
713	727.6	727.1	726.6	726.1	725.6	725.1	724.6	724.1	723.6	723.1	722.6	722.1	721.6	721.1	720.6	720.1	719.6
712	726.4	725.9	725.4	724.9	724.4	723.9	723.4	722.9	722.4	721.9	721.4	720.9	720.4	719.9	719.4	718.9	718.4
711	725.2	724.7	724.2	723.7	723.2	722.7	722.2	721.7	721.2	720.7	720.2	719.7	719.2	718.7	718.2	717.7	717.2
710	724.0	723.5	723.0	722.5	722.0	721.5	721.0	720.5	720.0	719.5	719.0	718.5	718.0	717.5	717.0	716.5	716.0
709	722.8	722.3	721.8	721.3	720.8	720.3	719.8	719.3	718.8	718.3	717.8	717.3	716.8	716.3	715.8	715.3	714.8
708	721.6	721.1	720.6	720.1	719.6	719.1	718.6	718.1	717.6	717.1	716.6	716.1	715.6	715.1	714.6	714.1	713.6
707	720.4	719.9	719.4	718.9	718.4	717.9	717.4	716.9	716.4	715.9	715.4	714.9	714.4	713.9	713.4	712.9	712.4
706	719.2	718.7	718.2	717.7	717.2	716.7	716.2	715.7	715.2	714.7	714.2	713.7	713.2	712.7	712.2	711.7	711.2
705	718.0	717.5	717.0	716.5	716.0	715.5	715.0	714.5	714.0	713.5	713.0	712.5	712.0	711.5	711.0	710.5	710.0
704	716.8	716.3	715.8	715.3	714.8	714.3	713.8	713.3	712.8	712.3	711.8	711.3	710.8	710.3	709.8	709.3	708.8
703	715.6	715.1	714.6	714.1	713.6	713.1	712.6	712.1	711.6	711.1	710.6	710.1	709.6	709.1	708.6	708.1	707.6
702	714.4	713.9	713.4	712.9	712.4	711.9	711.4	710.9	710.4	709.9	709.4	708.9	708.4	707.9	707.4	706.9	706.4
701	713.2	712.7	712.2	711.7	711.2	710.7	710.2	709.7	709.2	708.7	708.2	707.7	707.2	706.7	706.2	705.7	705.2
700	712.0	711.5	711.0	710.5	710.0	709.5	709.0	708.5	708.0	707.5	707.0	706.5	706.0	705.5	705.0	704.5	704.0
699	710.8	710.3	709.8	709.3	708.8	708.3	707.8	707.3	706.8	706.3	705.8	705.3	704.8	704.3	703.8	703.3	702.8
698	709.6	709.1	708.6	708.1	707.6	707.1	706.6	706.1	705.6	705.1	704.6	704.1	703.6	703.1	702.6	702.1	701.6
697	708.4	707.9	707.4	706.9	706.4	705.9	705.4	704.9	704.4	703.9	703.4	702.9	702.4	701.9	701.4	700.9	700.4
696	707.2	706.7	706.2	705.7	705.2	704.7	704.2	703.7	703.2	702.7	702.2	701.7	701.2	700.7	700.2	699.7	699.2
695	706.0	705.5	705.0	704.5	704.0	703.5	703.0	702.5	702.0	701.5	701.0	700.5	700.0	699.5	699.0	698.5	698.0
694	704.8	704.3	703.8	703.3	702.8	702.3	701.8	701.3	700.8	700.3	699.8	699.3	698.8	698.3	697.8	697.3	696.8
693	703.6	703.1	702.6	702.1	701.6	701.1	700.6	700.1	699.6	699.1	698.6	698.1	697.6	697.1	696.6	696.1	695.6
692	702.4	701.9	701.4	700.9	700.4	699.9	699.4	698.9	698.4	697.9	697.4	696.9	696.4	695.9	695.4	694.9	694.4
691	701.2	700.7	700.2	699.7	699.2	698.7	698.2	697.7	697.2	696.7	696.2	695.7	695.2	694.7	694.2	693.7	693.2
690	700.0	699.5	699.0	698.5	698.0	697.5	697.0	696.5	696.0	695.5	695.0	694.5	694.0	693.5	693.0	692.5	692.0
689	698.8	698.3	697.8	697.3	696.8	696.3	695.8	695.3	694.8	694.3	693.8	693.3	692.8	692.3	691.8	691.3	690.8
688	697.6	697.1	696.6	696.1	695.6	695.1	694.6	694.1	693.6	693.1	692.6	692.1	691.6	691.1	690.6	690.1	689.6
687	696.4	695.9	695.4	694.9	694.4	693.9	693.4	692.9	692.4	691.9	691.4	690.9	690.4	689.9	689.4	688.9	688.4
686	695.2	694.7	694.2	693.7	693.2	692.7	692.2	691.7	691.2	690.7	690.2	689.7	689.2	688.7	688.2	687.7	687.2
685	694.0	693.5	693.0	692.5	692.0	691.5	691.0	690.5	690.0	689.5	689.0	688.5	688.0	687.5	687.0	686.5	686.0
684	692.8	692.3	691.8	691.3	690.8	690.3	689.8	689.3	688.8	688.3	687.8	687.3	686.8	686.3	685.8	685.3	684.8
683	691.6	691.1	690.6	690.1	689.6	689.1	688.6	688.1	687.6	687.1	686.6	686.1	685.6	685.1	684.6	684.1	683.6
682	690.4	689.9	689.4	688.9	688.4	687.9	687.4	686.9	686.4	685.9	685.4	684.9	684.4	683.9	683.4	682.9	682.4
681	689.2	688.7	688.2	687.7	687.2	686.7	686.2	685.7	685.2	684.7	684.2	683.7	683.2	682.7	682.2	681.7	681.2
680	688.0	687.5	687.0	686.5	686.0	685.5	685.0	684.5	684.0	683.5	683.0	682.5	682.0	681.5	681.0	680.5	680.0
679	686.8	686.3	685.8	685.3	684.8	684.3	683.8	683.3	682.8	682.3	681.8	681.3	680.8	680.3	679.8	679.3	678.8
678	685.6	685.1	684.6	684.1	683.6	683.1	682.6	682.1	681.6	681.1	680.6	680.1	679.6	679.1	678.6	678.1	677.6
677	684.4	683.9	683.4	682.9	682.4	681.9	681.4	680.9	680.4	679.9	679.4	678.9	678.4	677.9	677.4	676.9	676.4
676	683.2	682.7	682.2	681.7	681.2	680.7	680.2	679.7	679.2	678.7	678.2	677.7	677.2	676.7	676.2	675.7	675.2
675	682.0	681.5	681.0	680.5	680.0	679.5	679.0	678.5	678.0	677.5	677.0	676.5	676.0	675.5	675.0	674.5	674.0
674	680.8	680.3	679.8	679.3	678.8	678.3	677.8	677.3	676.8	676.3	675.8	675.3	674.8	674.3	673.8	673.3	672.8
673	679.6	679.1	678.6	678.1	677.6	677.1	676.6	676.1	675.6	675.1	674.6	674.1	673.6	673.1	672.6	672.1	671.6
672	678.4	677.9	677.4	676.9	676.4	675.9	675.4	674.9	674.4	673.9	673.4	672.9	672.4	671.9	671.4	670.9	670.4
671	677.2	676.7	676.2	675.7	675.2	674.7	674.2	673.7	673.2	672.7	672.2	671.7	671.2	670.7	670.2	669.7	669.2
670	676.0	675.5	675.0	674.5	674.0	673.5	673.0	672.5	672.0	671.5	671.0	670.5	670.0	669.5	669.0	668.5	668.0
669	674.8	674.3	673.8	673.3	672.8	672.3	671.8	671.3	670.8	670.3	669.8	669.3	668.8	668.3	667.8	667.3	666.8
668	673.6	673.1	672.6	672.1	671.6	671.1	670.6	670.1	669.6	669.1	668.6	668.1	667.6	667.1	666.6	666.1	665.6
667	672.4	671.9	671.4	670.9	670.4	669.9	669.4	668.9	668.4	667.9	667.4	666.9	666.4	665.9	665.4	664.9	664.4
666	671.2	670.7	670.2	669.7	669.2	668.7	668.2	667.7	667.2	666.7	666.2	665.7	665.2	664.7	664.2	663.7	663.2
665	670.0	669.5	669.0	668.5	668.0	667.5	667.0	666.5	666.0	665.5	665.0	664.5	664.0	663.5	663.0	662.5	662.0
664	668.8	668.3	667.8	667.3	666.8	666.3	665.8	665.3	664.8	664.3	663.8	663.3	662.8	662.3	661.8	661.3	660.8
663	667.6	667.1	666.6	666.1	665.6	665.1	664.6	664.1	663.6	663.1	662.6	662.1	661.6	661.1	660.6	660.1	659.6
662	666.4	665.9	665.4	664.9	664.4	663.9	663.4	662.9	662.4	661.9	661.4	660.9	660.4	659.9	659.4	658.9	658.4
661	665.2	664.7	664.2	663.7	663.2	662.7	662.2	661.7	661.2	660.7	660.2	659.7	659.2	658.7	658.2	657.7	657.2
660	664.0	663.5	663.0	662.5	662.0	661.5	661.0	660.5	660.0	659.5	659.0	658.5	658.0	657.5	657.0	656.5	656.0
659	662.8	662.3	661.8	661.3	660.8	660.3	659.8	659.3	658.8	658.3	657.8	657.3	656.8	656.3	655.8	655.3	654.8
658	661.6	661.1	660.6	660.1	659.6	659.1	658.6	658.1	657.6	657.1	656.6	656.1	655.6	655.1	654.6	654.1	653.6
657	660.4	659.9	659.4	658.9	658.4	657.9	657.4	656.9	656.4	655.9	655.4	654.9	654.4	653.9	653.4	652.9	652.4
656	659.2	658.7	658.2	657.7	657.2	656.7	656.2	655.7	655.2	654.7	654.2	653.7	653.2	652.7	652.2	651.7	651.2
655	658.0	657.5	657.0	656.5	656.0	655.5	655.0	654.5	654.0	653.5	653.0	652.5	652.0	651.5	651.0	650.5	650.0
654	656.8	656.3	655.8	655.3	654.8	654.3	653.8	653.3	652.8	652.3	651.8	651.3	650.8	650.3	649.8	649.3	648.8
653	655.6	655.1	654.6	654.1	653.6	653.1	652.6	652.1	651.6	651.1	650.6	650.1	649.6	649.1	648.6	648.1	647.6
652	654.4	653.9	653.4	652.9	652.4	651.9	651.4	650.9	650.4	649.9	649.4	648.9	648.4	647.9	647.4	646.9	646.4
651	653.2	652.7	652.2	651.7	651.2	650.7	650.2	649.7	649.2	648.7	648.2	647.7	647.2	646.7	646.2	645.7	645.2
650	652.0	651.5	651.0	650.5	650.0	649.5	649.0	648.5	648.0	647.5	647.0	646.5	646.0	645.5	645.0	644.5	644.0
649	650.8	650.3	649.8	649.3	648.8	648.3	647.8	647.3	646.8	646.3	645.8	645.3	644.8	644.3	643.8	643.3	642.8
648	649.6	649.1	648.6	648.1	647.6	647.1	646.6	646.1	645.6	645.1	644.6	644.1	643.6	643.1	642.6	642.1	641.6
647	648.4	647.9	647.4	646.9	646.4	645.9	645.4	644.9	644.4	643.9	643.4	642.9	642.4	641.9	641.4	640.9	640.4
646	647.2	646.7	646.2	645.7	645.2	644.7	644.2	643.7	643.2	642.7	642.2	641.7	641.2	640.7	640.2	639.7	639.2
645	646.0	645.5	645.0	644.5	644.0	643.5	643.0	642.5	642.0	641.5	641.0	640.5	640.0	639.5	639.0	638.5	638.0
644	644.8	644.3	643.8	643.3	642.8	642.3	641.8	641.3	640.8	640.3	639.8	639.3	638.8	638.3	637.8	637.3	636.8
643	643.6	643.1	642.6	642.1	641.6	641.1	640.6	640.1	639.6	639.1	638.6	638.1	637.6	637.1	636.6	636.1	635.6
642	642.4	641.9	641.4	640.9	640.4	639.9	639.4	638.9	638.4	637.9	637.4	636.9	636.4	635.9	635.4	634.9	634.4
641	641.2	640.7	640.2	639.7	639.2	638.7	638.2	637.7	637.2	636.7	636.2	635.7	635.2	634.7	634.2	633.7	633.2
640	640.0	639.5	639.0	638.5	638.0	637.5	637.0	636.5	636.0	635.5	635.0	634.5	634.0	633.5	633.0	632.5	632.0

Table 19-10. Metric — High Alt, Mid Temp, Low Humidity
(Temp = 22 to 30°C , Press = 640 to 720 mm, 20% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
720	744.6	745.0	745.4	745.8	746.1	746.7	747.2	747.6	748.0	748.5	748.9	749.4	749.8	750.2	750.6	751.0	751.5
719	744.9	745.4	745.8	746.2	746.7	747.1	747.6	748.0	748.4	748.8	749.3	749.7	750.1	750.6	751.0	751.4	751.8
718	745.3	745.7	746.1	746.6	747.0	747.5	747.9	748.3	748.7	749.2	749.6	750.0	750.5	750.9	751.3	751.7	752.1
717	745.6	746.1	746.5	746.9	747.4	747.8	748.2	748.7	749.1	749.5	750.0	750.4	750.8	751.2	751.7	752.1	752.5
716	746.0	746.4	746.9	747.3	747.7	748.2	748.6	749.0	749.4	749.9	750.3	750.7	751.2	751.6	752.0	752.4	752.9
715	746.3	746.8	747.2	747.6	748.1	748.5	748.9	749.4	749.8	750.2	750.7	751.1	751.5	751.9	752.3	752.8	753.2
714	746.7	747.1	747.6	748.0	748.4	748.9	749.3	749.7	750.1	750.6	751.0	751.4	751.9	752.3	752.7	753.1	753.5
713	747.0	747.5	747.9	748.4	748.8	749.2	749.6	750.1	750.5	750.9	751.4	751.8	752.2	752.6	753.0	753.4	753.9
712	747.4	747.8	748.3	748.7	749.1	749.6	750.0	750.4	750.9	751.3	751.7	752.1	752.6	753.0	753.4	753.8	754.2
711	747.8	748.2	748.6	749.1	749.5	749.9	750.3	750.8	751.2	751.6	752.0	752.5	752.9	753.3	753.7	754.1	754.6
710	748.1	748.5	748.9	749.4	749.8	750.3	750.7	751.1	751.6	752.0	752.4	752.8	753.2	753.7	754.1	754.5	754.9
709	748.5	748.9	749.3	749.8	750.2	750.6	751.0	751.5	751.9	752.3	752.7	753.2	753.6	754.0	754.4	754.8	755.3
708	748.8	749.3	749.7	750.1	750.5	751.0	751.4	751.8	752.3	752.7	753.1	753.6	753.9	754.4	754.8	755.2	755.6
707	749.2	749.6	750.0	750.5	750.9	751.3	751.8	752.2	752.6	753.0	753.4	753.9	754.3	754.7	755.1	755.5	756.0
706	749.5	750.0	750.4	750.8	751.3	751.7	752.1	752.5	753.0	753.4	753.8	754.2	754.6	755.1	755.5	755.9	756.3
705	749.9	750.3	750.7	751.2	751.6	752.0	752.5	752.9	753.3	753.7	754.1	754.6	755.0	755.4	755.8	756.2	756.6
704	750.2	750.7	751.1	751.5	752.0	752.4	752.8	753.2	753.7	754.1	754.5	754.9	755.3	755.7	756.2	756.6	757.0
703	750.6	751.0	751.4	751.9	752.3	752.7	753.2	753.6	754.0	754.4	754.8	755.3	755.7	756.1	756.5	756.9	757.4
702	751.0	751.4	751.9	752.3	752.7	753.1	753.5	753.9	754.4	754.8	755.2	755.6	756.0	756.5	756.9	757.3	757.7
701	751.3	751.7	752.2	752.6	753.0	753.4	753.9	754.3	754.7	755.1	755.5	756.0	756.4	756.8	757.2	757.6	758.0
700	751.7	752.1	752.5	752.9	753.4	753.8	754.2	754.6	755.1	755.5	755.9	756.3	756.7	757.1	757.5	758.0	758.4
699	752.0	752.4	752.9	753.3	753.7	754.1	754.6	755.0	755.4	755.8	756.2	756.7	757.1	757.5	757.9	758.3	758.7
698	752.4	752.8	753.2	753.7	754.1	754.5	754.9	755.3	755.8	756.2	756.6	757.0	757.4	757.8	758.2	758.7	759.1
697	752.7	753.2	753.6	754.0	754.4	754.8	755.3	755.7	756.1	756.5	756.9	757.4	757.8	758.2	758.6	759.0	759.4
696	753.1	753.5	753.9	754.4	754.8	755.2	755.6	756.0	756.5	756.9	757.3	757.7	758.1	758.5	758.9	759.3	759.9
695	753.5	753.9	754.3	754.7	755.1	755.6	756.0	756.4	756.8	757.2	757.6	758.1	758.5	758.9	759.3	759.7	760.1
694	753.8	754.2	754.6	755.1	755.5	755.9	756.3	756.7	757.2	757.6	758.0	758.4	758.8	759.2	759.6	760.0	760.4
693	754.2	754.6	755.0	755.4	755.8	756.2	756.7	757.1	757.5	757.9	758.3	758.7	759.2	759.6	760.0	760.4	760.8
692	754.5	754.9	755.3	755.8	756.2	756.6	757.0	757.4	757.9	758.3	758.7	759.1	759.5	759.9	760.3	760.7	761.1
691	754.9	755.3	755.7	756.1	756.5	757.0	757.4	757.8	758.2	758.6	759.0	759.4	759.8	760.3	760.7	761.1	761.5
690	755.2	755.6	756.1	756.5	756.9	757.3	757.7	758.1	758.6	759.0	759.4	759.8	760.2	760.6	761.0	761.4	761.8
689	755.6	756.0	756.4	756.8	757.2	757.7	758.1	758.5	758.9	759.3	759.7	760.1	760.6	761.0	761.4	761.8	762.2
688	756.0	756.3	756.8	757.2	757.6	758.0	758.4	758.8	759.3	759.7	760.1	760.5	760.9	761.3	761.7	762.1	762.5
687	756.3	756.7	757.1	757.5	758.0	758.4	758.8	759.2	759.6	760.0	760.4	760.8	761.2	761.7	762.1	762.5	762.9
686	756.7	757.1	757.5	757.9	758.3	758.7	759.1	759.5	760.0	760.4	760.8	761.2	761.6	762.0	762.4	762.8	763.2
685	757.0	757.4	757.8	758.2	758.7	759.1	759.5	759.9	760.3	760.7	761.1	761.5	761.9	762.3	762.8	763.2	763.6
684	757.4	757.8	758.2	758.6	759.0	759.4	759.9	760.3	760.7	761.1	761.5	761.9	762.3	762.7	763.1	763.5	763.9
683	757.7	758.1	758.5	759.0	759.4	759.8	760.2	760.6	761.0	761.4	761.8	762.2	762.6	763.0	763.4	763.8	764.2
682	758.1	758.5	758.9	759.3	759.7	760.1	760.6	761.0	761.4	761.8	762.2	762.6	763.0	763.4	763.8	764.2	764.6
681	758.4	758.8	759.2	759.7	760.1	760.5	760.9	761.3	761.7	762.1	762.5	762.9	763.3	763.7	764.1	764.5	764.9
680	758.8	759.2	759.6	760.0	760.4	760.8	761.2	761.7	762.1	762.5	762.9	763.3	763.7	764.1	764.5	764.9	765.3
679	759.1	759.5	760.0	760.4	760.8	761.2	761.6	762.0	762.4	762.8	763.2	763.6	764.0	764.4	764.8	765.2	765.6
678	759.5	759.9	760.3	760.7	761.1	761.5	761.9	762.4	762.8	763.2	763.6	764.0	764.4	764.8	765.2	765.6	766.0
677	759.8	760.2	760.7	761.1	761.5	761.9	762.3	762.7	763.1	763.5	763.9	764.3	764.7	765.1	765.5	765.9	766.3
676	760.2	760.6	761.0	761.4	761.8	762.2	762.7	763.1	763.5	763.9	764.3	764.7	765.1	765.5	765.9	766.3	766.7
675	760.5	761.0	761.4	761.8	762.2	762.6	763.0	763.4	763.8	764.2	764.6	765.0	765.4	765.8	766.2	766.6	767.0
674	760.9	761.3	761.7	762.1	762.5	762.9	763.4	763.8	764.2	764.6	765.0	765.4	765.8	766.2	766.6	767.0	767.4
673	761.3	761.7	762.1	762.5	762.9	763.3	763.7	764.1	764.5	764.9	765.3	765.7	766.1	766.5	766.9	767.3	767.7
672	761.6	762.0	762.4	762.8	763.2	763.7	764.1	764.5	764.9	765.3	765.7	766.1	766.5	766.9	767.3	767.7	768.1
671	762.0	762.4	762.8	763.2	763.6	764.0	764.4	764.8	765.2	765.6	766.0	766.4	766.8	767.2	767.6	768.0	768.4
670	762.3	762.7	763.1	763.6	764.0	764.4	764.8	765.2	765.6	766.0	766.4	766.8	767.2	767.6	768.0	768.4	768.7
669	762.7	763.1	763.5	763.9	764.3	764.7	765.1	765.5	765.9	766.3	766.7	767.1	767.5	767.9	768.3	768.7	769.1
668	763.0	763.4	763.8	764.2	764.7	765.1	765.5	765.9	766.3	766.7	767.1	767.5	767.9	768.3	768.7	769.0	769.4
667	763.4	763.8	764.2	764.6	765.0	765.4	765.8	766.2	766.6	767.0	767.4	767.8	768.2	768.6	769.0	769.4	769.8
666	763.7	764.1	764.5	765.0	765.4	765.8	766.2	766.6	767.0	767.4	767.8	768.2	768.6	769.0	769.4	769.7	770.1
665	764.1	764.5	764.9	765.3	765.7	766.1	766.5	766.9	767.3	767.7	768.1	768.5	768.9	769.3	769.7	770.1	770.5
664	764.4	764.9	765.3	765.7	766.1	766.5	766.9	767.3	767.7	768.1	768.5	768.9	769.3	769.7	770.1	770.5	770.8
663	764.8	765.2	765.6	766.0	766.4	766.8	767.2	767.6	768.0	768.4	768.8	769.2	769.6	770.0	770.4	770.8	771.2
662	765.2	765.6	766.0	766.4	766.8	767.2	767.6	768.0	768.4	768.8	769.2	769.6	770.0	770.3	770.7	771.1	771.5
661	765.5	765.9	766.3	766.7	767.1	767.5	767.9	768.3	768.7	769.1	769.5	769.9	770.3	770.7	771.1	771.5	771.9
660	765.9	766.3	766.7	767.1	767.5	767.9	768.3	768.7	769.1	769.5	769.9	770.3	770.7	771.1	771.5	771.9	772.2
659	766.2	766.6	767.0	767.4	767.8	768.2	768.6	769.0	769.4	769.8	770.2	770.6	771.0	771.4	771.8	772.2	772.5
658	766.6	767.0	767.4	767.8	768.2	768.6	769.0	769.4	769.8	770.2	770.6	770.9	771.3	771.7	772.1	772.5	772.9
657	766.9	767.3	767.7	768.1	768.5	768.9	769.3	769.7	770.1	770.5	770.9	771.3	771.7	772.1	772.5	772.9	773.2
656	767.3	767.7	768.1	768.5	768.9	769.3	769.7	770.1	770.5	770.9	771.3	771.6	772.0	772.4	772.8	773.2	773.6
655	767.6	768.0	768.4	768.8	769.2	769.6	770.0	770.4	770.8	771.2	771.6	772.0	772.4	772.8	773.2	773.5	773.9
654	768.0	768.4	768.8	769.2	769.6	770.0	770.4	770.8	771.2	771.6	772.0	772.3	772.7	773.1	773.5	773.9	774.3
653	768.4	768.8	769.2	769.6	769.9	770.3	770.7	771.1	771.5	771.9	772.3	772.7	773.1	773.5	773.9	774.2	774.6
652	768.7	769.1	769.5	769.9	770.3	770.7	771.1	771.5	771.9	772.3	772.7	773.0	773.4	773.8	774.2	774.6	775.0
651	769.1	769.5	769.9	770.3	770.7	771.0	771.4	771.8	772.2	772.6	773.0	773.4	773.8	774.2	774.5	774.9	775.3
650	769.4	769.8	770.2	770.6	771.0	771.4	771.8	772.2	772.6	773.0	773.4	773.7	774.1	774.5	774.9	775.3	775.7
649	769.8	770.2	770.6	771.0	771.4	771.8	772.1	772.5	772.9	773.3	773.7	774.1	774.5	774.9	775.2	775.6	776.0
648	770.1	770.5	770.9	771.3	771.7	772.1	772.5	772.9	773.3	773.7	774.0	774.4	774.8	775.2	775.6	776.0	776.3
647	770.5	770.9	771.3	771.7	772.1	772.5	772.9	773.2	773.6	774.0	774.4	774.8	775.2	775.6	775.9	776.3	776.7
646	770.8	771.2	771.6	772.0	772.4	772.8	773.2	773.6	774.0	774.4	774.7	775.1	775.5	775.9	776.3	776.7	777.0
645	771.2	771.6	772.0	772.4	772.8	773.2	773.5	773.9	774.3	774.7	775.1	775.5	775.9	776.2	776.6	777.0	777.4
644	771.5	771.9	772.3	772.7	773.1	773.5	773.9	774.3	774.7	775.1	775.4	775.8	776.2	776.6	777.0	777.4	777.7
643	771.9	772.3	772.7	773.1	773.5	773.9	774.3	774.6	775.0	775.4	775.8	776.2	776.6	777.0	777.3	777.7	778.1
642	772.3	772.7	773.0	773.4	773.8	774.2	774.6	775.0	775.4	775.8	776.1	776.5	776.9	777.3	777.7	778.0	778.4
641	772.6	773.0	773.4	773.8	774.2	774.6	775.0	775.3	775.7	776.1	776.5	776.9	777.3	777.6	778.0	778.4	778.8
640	773.0	773.4	773.8	774.1	774.5	774.9	775.3	775.7	776.1	776.5	776.8	777.2	777.6	778.0	778.4	778.7	779.1

Table 19-11. Metric — High Alt, High-Mid Temp, Low Humidity
(Temp = 30.5 to 38.5°C , Press = 640 to 720 mm, 20% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

	30.5	31.0	31.5	32.0	32.5	33.0	33.5	34.0	34.5	35.0	35.5	36.0	36.5	37.0	37.5	38.0	38.5
720	751.9	752.3	752.7	753.1	753.6	754.0	754.4	754.8	755.2	755.6	756.0	756.4	756.9	757.3	757.7	758.1	758.5
719	752.3	752.6	753.1	753.5	753.9	754.3	754.7	755.1	755.5	755.9	756.4	756.8	757.2	757.6	758.0	758.4	758.9
718	752.6	753.0	753.4	753.8	754.2	754.7	755.1	755.5	755.9	756.3	756.7	757.1	757.5	757.9	758.3	758.7	759.1
717	752.9	753.3	753.8	754.2	754.6	755.0	755.4	755.8	756.2	756.6	757.0	757.4	757.8	758.2	758.6	759.0	759.4
716	753.3	753.7	754.1	754.5	754.9	755.3	755.8	756.2	756.6	757.0	757.4	757.8	758.2	758.6	759.0	759.4	759.8
715	753.6	754.0	754.4	754.9	755.3	755.7	756.1	756.5	756.9	757.3	757.7	758.1	758.5	758.9	759.3	759.7	760.1
714	754.0	754.4	754.8	755.2	755.6	756.0	756.4	756.8	757.2	757.6	758.1	758.5	758.9	759.3	759.7	760.1	760.5
713	754.3	754.7	755.1	755.5	756.0	756.4	756.8	757.2	757.6	758.0	758.4	758.8	759.2	759.6	760.0	760.4	760.8
712	754.6	755.1	755.5	755.9	756.3	756.7	757.1	757.5	757.9	758.3	758.8	759.2	759.6	760.0	760.4	760.8	761.2
711	754.9	755.4	755.7	756.2	756.6	757.1	757.5	757.9	758.3	758.7	759.1	759.5	759.9	760.3	760.7	761.1	761.5
710	755.1	755.7	756.2	756.6	757.0	757.5	757.8	758.2	758.7	759.0	759.4	759.8	760.2	760.6	761.0	761.4	761.8
709	755.7	756.1	756.5	756.9	757.3	757.7	758.1	758.5	758.9	759.3	759.7	760.1	760.5	760.9	761.3	761.7	762.1
708	756.0	756.4	756.8	757.2	757.7	758.1	758.5	758.9	759.3	759.7	760.1	760.5	760.9	761.3	761.7	762.1	762.5
707	756.4	756.8	757.2	757.6	758.0	758.4	758.8	759.2	759.6	760.0	760.4	760.8	761.2	761.6	762.0	762.4	762.8
706	756.7	757.1	757.5	757.9	758.4	758.8	759.2	759.6	760.0	760.4	760.8	761.2	761.6	762.0	762.4	762.8	763.2
705	757.1	757.5	757.9	758.3	758.7	759.1	759.5	759.9	760.3	760.7	761.1	761.5	761.9	762.3	762.7	763.1	763.5
704	757.4	757.8	758.2	758.6	759.0	759.4	759.9	760.3	760.7	761.1	761.5	761.9	762.3	762.7	763.1	763.5	763.9
703	757.7	758.2	758.6	759.0	759.4	759.8	760.2	760.6	761.0	761.4	761.8	762.2	762.6	763.0	763.4	763.9	764.3
702	758.1	758.5	758.9	759.3	759.7	760.1	760.5	760.9	761.3	761.7	762.1	762.5	762.9	763.3	763.7	764.1	764.5
701	758.4	758.8	759.3	759.7	760.1	760.5	760.9	761.3	761.7	762.1	762.5	762.9	763.3	763.7	764.1	764.5	764.9
700	758.7	759.2	759.6	760.0	760.4	760.8	761.2	761.6	762.0	762.4	762.8	763.2	763.6	764.0	764.4	764.8	765.2
699	759.1	759.5	759.9	760.3	760.8	761.2	761.6	762.0	762.4	762.8	763.2	763.6	764.0	764.4	764.8	765.2	765.6
698	759.4	759.9	760.3	760.7	761.1	761.5	761.9	762.3	762.7	763.1	763.5	763.9	764.3	764.7	765.1	765.5	765.9
697	759.8	760.2	760.6	761.0	761.4	761.9	762.3	762.7	763.1	763.5	763.9	764.3	764.7	765.1	765.5	765.9	766.3
696	760.2	760.6	761.0	761.4	761.8	762.2	762.6	763.0	763.4	763.8	764.2	764.6	765.0	765.4	765.8	766.2	766.6
695	760.5	760.9	761.3	761.7	762.1	762.5	762.9	763.3	763.7	764.1	764.5	764.9	765.3	765.7	766.1	766.5	766.9
694	760.9	761.3	761.7	762.1	762.5	762.9	763.3	763.7	764.1	764.5	764.9	765.3	765.7	766.0	766.4	766.8	767.2
693	761.2	761.6	762.0	762.4	762.8	763.2	763.6	764.0	764.4	764.8	765.2	765.6	766.0	766.4	766.8	767.2	767.6
692	761.5	761.9	762.4	762.8	763.2	763.6	764.0	764.4	764.8	765.2	765.6	766.0	766.4	766.8	767.2	767.6	768.0
691	761.9	762.3	762.7	763.1	763.5	763.9	764.3	764.7	765.1	765.5	765.9	766.3	766.7	767.1	767.5	767.9	768.3
690	762.2	762.6	763.0	763.4	763.8	764.2	764.6	765.0	765.4	765.8	766.2	766.6	767.0	767.4	767.8	768.2	768.6
689	762.6	763.0	763.4	763.8	764.2	764.6	765.0	765.4	765.8	766.2	766.6	767.0	767.4	767.8	768.2	768.6	769.0
688	762.9	763.3	763.7	764.1	764.5	764.9	765.3	765.7	766.1	766.5	766.8	767.2	767.6	768.0	768.4	768.8	769.2
687	763.3	763.7	764.1	764.5	764.9	765.3	765.7	766.1	766.5	766.8	767.2	767.6	768.0	768.4	768.8	769.2	769.6
686	763.6	764.0	764.4	764.8	765.2	765.6	766.0	766.4	766.8	767.2	767.6	768.0	768.4	768.8	769.2	769.6	770.0
685	764.0	764.4	764.8	765.2	765.6	766.0	766.3	766.7	767.1	767.5	767.9	768.3	768.7	769.1	769.5	769.9	770.3
684	764.3	764.7	765.1	765.5	765.9	766.3	766.7	767.1	767.5	767.9	768.3	768.7	769.0	769.4	769.8	770.2	770.6
683	764.6	765.0	765.4	765.8	766.2	766.6	767.0	767.4	767.8	768.2	768.6	769.0	769.4	769.8	770.1	770.5	770.9
682	765.0	765.4	765.8	766.2	766.6	767.0	767.4	767.8	768.2	768.6	769.0	769.4	769.8	770.1	770.5	770.9	771.3
681	765.3	765.7	766.1	766.5	766.9	767.3	767.7	768.1	768.5	768.9	769.1	769.7	770.1	770.4	770.9	771.2	771.6
680	765.7	766.1	766.5	766.9	767.3	767.7	768.1	768.5	768.9	769.2	769.6	770.0	770.4	770.8	771.2	771.6	772.0
679	766.0	766.4	766.8	767.2	767.6	768.0	768.4	768.8	769.2	769.6	770.0	770.4	770.8	771.2	771.6	772.0	772.4
678	766.4	766.8	767.2	767.6	768.0	768.4	768.8	769.2	769.6	770.0	770.3	770.7	771.1	771.5	771.9	772.3	772.7
677	766.7	767.1	767.5	767.9	768.3	768.7	769.1	769.5	769.9	770.2	770.6	771.0	771.4	771.8	772.2	772.6	773.0
676	767.1	767.5	767.9	768.2	768.6	769.0	769.4	769.8	770.2	770.6	771.0	771.4	771.8	772.2	772.6	773.0	773.4
675	767.4	767.8	768.2	768.6	769.0	769.4	769.8	770.2	770.5	770.9	771.3	771.7	772.1	772.5	772.9	773.3	773.7
674	767.8	768.2	768.5	768.9	769.3	769.7	770.1	770.5	770.9	771.3	771.7	772.0	772.4	772.8	773.2	773.6	774.0
673	768.1	768.5	768.9	769.3	769.7	770.1	770.5	770.9	771.3	771.7	772.0	772.4	772.8	773.2	773.6	774.0	774.4
672	768.4	768.8	769.2	769.6	770.0	770.4	770.8	771.2	771.6	771.9	772.3	772.7	773.1	773.5	773.9	774.3	774.7
671	768.8	769.2	769.6	770.0	770.4	770.8	771.2	771.6	771.9	772.3	772.7	773.1	773.5	773.9	774.2	774.6	775.0
670	769.1	769.5	769.9	770.3	770.7	771.1	771.5	771.9	772.3	772.7	773.1	773.5	773.8	774.2	774.6	775.0	775.4
669	769.5	769.9	770.3	770.7	771.0	771.4	771.8	772.2	772.6	773.0	773.4	773.8	774.2	774.6	775.0	775.4	775.8
668	769.8	770.2	770.6	771.0	771.4	771.8	772.2	772.6	772.9	773.3	773.7	774.1	774.5	774.9	775.3	775.7	776.1
667	770.2	770.6	771.0	771.4	771.7	772.1	772.5	772.9	773.3	773.6	774.0	774.4	774.8	775.2	775.6	776.0	776.4
666	770.5	770.9	771.3	771.7	772.1	772.5	772.9	773.2	773.6	774.0	774.4	774.7	775.1	775.5	775.9	776.3	776.7
665	770.9	771.3	771.6	772.0	772.4	772.8	773.2	773.6	774.0	774.3	774.7	775.1	775.5	775.9	776.3	776.7	777.0
664	771.2	771.6	772.0	772.4	772.8	773.1	773.5	773.9	774.3	774.7	775.1	775.5	775.8	776.2	776.6	777.0	777.4
663	771.6	771.9	772.3	772.7	773.1	773.5	773.9	774.2	774.6	775.0	775.4	775.8	776.2	776.6	777.0	777.4	777.8
662	771.9	772.3	772.7	773.1	773.5	773.8	774.2	774.6	775.0	775.4	775.7	776.1	776.5	776.9	777.3	777.7	778.1
661	772.2	772.6	773.0	773.4	773.8	774.2	774.5	774.9	775.3	775.7	776.1	776.4	776.8	777.2	777.6	778.0	778.4
660	772.6	773.0	773.4	773.7	774.1	774.5	774.9	775.3	775.6	776.0	776.4	776.8	777.2	777.5	777.9	778.3	778.7
659	772.9	773.3	773.7	774.1	774.5	774.9	775.2	775.6	776.0	776.4	776.8	777.1	777.5	777.9	778.3	778.7	779.0
658	773.3	773.7	774.0	774.4	774.8	775.2	775.6	776.0	776.3	776.7	777.1	777.5	777.8	778.2	778.6	779.0	779.4
657	773.6	774.0	774.4	774.8	775.2	775.5	775.9	776.3	776.7	777.0	777.4	777.8	778.2	778.6	778.9	779.3	779.7
656	774.0	774.4	774.7	775.1	775.5	775.9	776.3	776.6	777.0	777.4	777.8	778.1	778.5	778.9	779.3	779.6	780.0
655	774.3	774.7	775.1	775.5	775.8	776.2	776.6	777.0	777.4	777.7	778.1	778.5	778.9	779.2	779.6	780.0	780.3
654	774.7	775.0	775.4	775.8	776.2	776.6	776.9	777.3	777.7	778.1	778.4	778.8	779.2	779.6	779.9	780.3	780.7
653	775.0	775.4	775.8	776.1	776.5	776.9	777.3	777.7	778.0	778.4	778.8	779.2	779.5	779.9	780.3	780.6	781.0
652	775.3	775.7	776.1	776.5	776.9	777.2	777.6	778.0	778.4	778.7	779.1	779.5	779.8	780.2	780.6	781.0	781.3
651	775.7	776.1	776.5	776.8	777.2	777.6	778.0	778.3	778.7	779.1	779.5	779.8	780.2	780.6	780.9	781.3	781.7
650	776.0	776.4	776.8	777.2	777.6	777.9	778.3	778.7	779.1	779.4	779.8	780.2	780.5	780.9	781.3	781.6	782.0
649	776.4	776.8	777.1	777.5	777.9	778.3	778.6	779.0	779.4	779.8	780.1	780.5	780.9	781.2	781.6	782.0	782.4
648	776.7	777.1	777.5	777.9	778.2	778.6	779.0	779.3	779.7	780.1	780.4	780.8	781.2	781.6	781.9	782.3	782.7
647	777.1	777.5	777.8	778.2	778.6	779.0	779.3	779.7	780.1	780.4	780.8	781.2	781.5	781.9	782.3	782.7	783.0
646	777.4	777.8	778.2	778.6	778.9	779.3	779.7	780.0	780.4	780.8	781.2	781.5	781.9	782.3	782.6	783.0	783.4
645	777.8	778.1	778.5	778.9	779.3	779.6	780.0	780.4	780.8	781.1	781.5	781.9	782.2	782.6	783.0	783.3	783.7
644	778.1	778.5	778.9	779.2	779.6	780.0	780.4	780.7	781.1	781.5	781.8	782.2	782.6	782.9	783.3	783.7	784.0
643	778.5	778.8	779.2	779.6	780.0	780.3	780.7	781.1	781.4	781.8	782.2	782.5	782.9	783.3	783.6	784.0	784.4
642	778.8	779.2	779.6	779.9	780.3	780.7	781.0	781.4	781.8	782.1	782.5	782.9	783.2	783.6	784.0	784.3	784.7
641	779.1	779.5	779.9	780.3	780.6	781.0	781.4	781.8	782.1	782.5	782.9	783.2	783.6	784.0	784.3	784.7	785.0
640	779.5	779.9	780.2	780.6	781.0	781.4	781.7	782.1	782.5	782.8	783.2	783.6	783.9	784.3	784.7	785.0	785.4

Table 19-12. Metric — *Low Alt, Low Temp, Med Humidity*
(Temp = 5 to 13°C , Press = 720 to 800 mm, 50% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

Table 19-13. Metric — Low Alt, Low-Mid Temp, Med Humidity
(Temp = 13.5 to 21.5°C , Press = 720 to 800 mm, 50% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5
800	707.3	708.1	708.8	709.6	710.4	711.2	711.9	712.7	713.5	714.3	715.0	715.8	716.6	717.4	718.1	718.9	719.7
799	708.2	708.9	709.7	710.4	711.2	712.0	712.8	713.5	714.3	715.1	715.8	716.6	717.4	718.1	718.9	719.7	720.4
798	709.0	709.8	710.5	711.3	712.0	712.8	713.6	714.3	715.1	715.9	716.6	717.4	718.2	718.9	719.7	720.5	721.2
797	709.9	710.6	711.4	712.1	712.9	713.7	714.4	715.2	716.0	716.7	717.5	718.3	719.0	719.8	720.6	721.3	722.1
796	710.7	711.5	712.2	713.0	713.8	714.5	715.3	716.1	716.8	717.6	718.4	719.1	719.9	720.7	721.4	722.2	723.0
795	711.6	712.3	713.1	713.9	714.6	715.4	716.2	716.9	717.7	718.5	719.2	720.0	720.8	721.5	722.3	723.1	723.8
794	712.4	713.2	713.9	714.7	715.5	716.2	717.0	717.8	718.5	719.3	720.1	720.8	721.6	722.4	723.1	723.9	724.7
793	713.3	714.0	714.8	715.5	716.3	717.1	717.8	718.6	719.4	720.1	720.9	721.7	722.4	723.2	724.0	724.7	725.5
792	714.1	714.9	715.6	716.4	717.2	717.9	718.7	719.4	720.2	721.0	721.7	722.5	723.3	724.0	724.8	725.6	726.3
791	715.0	715.7	716.5	717.2	718.0	718.8	719.5	720.3	721.0	721.8	722.6	723.3	724.1	724.9	725.6	726.4	727.2
790	715.8	716.6	717.3	718.1	718.9	719.6	720.4	721.1	721.9	722.7	723.4	724.2	725.0	725.7	726.5	727.3	728.0
789	716.7	717.4	718.2	718.9	719.7	720.5	721.2	722.0	722.8	723.5	724.3	725.1	725.8	726.6	727.4	728.1	728.9
788	717.5	718.3	719.0	719.8	720.6	721.3	722.1	722.8	723.6	724.4	725.1	725.9	726.7	727.4	728.2	729.0	729.7
787	718.4	719.1	719.9	720.6	721.4	722.2	722.9	723.7	724.5	725.2	726.0	726.8	727.5	728.3	729.1	729.8	730.6
786	719.2	720.0	720.7	721.5	722.3	723.0	723.8	724.5	725.3	726.1	726.8	727.6	728.4	729.1	729.9	730.7	731.4
785	720.1	720.8	721.6	722.3	723.1	723.9	724.6	725.4	726.2	726.9	727.7	728.5	729.2	730.0	730.8	731.5	732.3
784	720.9	721.7	722.4	723.2	724.0	724.7	725.5	726.3	727.0	727.8	728.6	729.3	730.1	730.9	731.6	732.4	733.2
783	721.8	722.5	723.3	724.0	724.8	725.6	726.3	727.1	727.9	728.6	729.4	730.2	730.9	731.7	732.5	733.2	734.0
782	722.6	723.4	724.1	724.9	725.7	726.4	727.2	728.0	728.7	729.5	730.3	731.0	731.8	732.6	733.3	734.1	734.9
781	723.5	724.2	725.0	725.8	726.5	727.3	728.1	728.8	729.6	730.4	731.1	731.9	732.7	733.4	734.2	735.0	735.7
780	724.3	725.1	725.8	726.6	727.4	728.1	728.9	729.7	730.4	731.2	732.0	732.7	733.5	734.3	735.0	735.8	736.6
779	725.2	725.9	726.7	727.4	728.2	729.0	729.7	730.5	731.3	732.0	732.8	733.6	734.3	735.1	735.9	736.6	737.4
778	726.0	726.8	727.5	728.3	729.1	729.8	730.6	731.4	732.1	732.9	733.7	734.4	735.2	736.0	736.7	737.5	738.3
777	726.9	727.6	728.4	729.2	729.9	730.7	731.4	732.2	733.0	733.7	734.5	735.3	736.0	736.8	737.6	738.3	739.1
776	727.7	728.5	729.2	730.0	730.8	731.5	732.3	733.1	733.8	734.6	735.4	736.1	736.9	737.7	738.4	739.2	740.0
775	728.6	729.3	730.1	730.9	731.6	732.4	733.2	733.9	734.7	735.5	736.2	737.0	737.8	738.5	739.3	740.1	740.8
774	729.4	730.2	731.0	731.7	732.5	733.3	734.0	734.8	735.6	736.3	737.1	737.9	738.6	739.4	740.2	740.9	741.7
773	730.3	731.0	731.8	732.6	733.3	734.1	734.9	735.6	736.4	737.2	737.9	738.7	739.5	740.2	741.0	741.8	742.5
772	731.1	731.9	732.7	733.4	734.2	735.0	735.7	736.5	737.3	738.0	738.8	739.6	740.3	741.1	741.9	742.6	743.4
771	732.0	732.7	733.5	734.3	735.0	735.8	736.6	737.3	738.1	738.9	739.6	740.4	741.2	741.9	742.7	743.5	744.2
770	732.8	733.6	734.4	735.1	735.9	736.7	737.4	738.2	739.0	739.7	740.5	741.3	742.0	742.8	743.6	744.3	745.1
769	733.7	734.4	735.2	736.0	736.7	737.5	738.3	739.0	739.8	740.6	741.3	742.1	742.9	743.6	744.4	745.2	745.9
768	734.5	735.3	736.1	736.8	737.6	738.4	739.1	739.9	740.7	741.4	742.2	743.0	743.7	744.5	745.3	746.0	746.8
767	735.4	736.2	736.9	737.7	738.4	739.2	740.0	740.7	741.5	742.3	743.0	743.8	744.6	745.3	746.1	746.9	747.6
766	736.2	737.0	737.8	738.5	739.3	740.1	740.8	741.6	742.4	743.1	743.9	744.7	745.4	746.2	747.0	747.7	748.5
765	737.1	737.9	738.6	739.4	740.2	740.9	741.7	742.4	743.2	744.0	744.7	745.5	746.3	747.0	747.8	748.6	749.3
764	737.9	738.7	739.5	740.2	741.0	741.8	742.5	743.3	744.1	744.8	745.6	746.4	747.1	747.9	748.7	749.4	750.2
763	738.8	739.6	740.3	741.1	741.9	742.6	743.4	744.2	744.9	745.7	746.5	747.2	748.0	748.8	749.5	750.3	751.0
762	739.7	740.4	741.2	742.0	742.7	743.5	744.3	745.0	745.8	746.6	747.3	748.1	748.9	749.6	750.4	751.2	751.9
761	740.5	741.3	742.0	742.8	743.6	744.3	745.1	745.9	746.6	747.4	748.2	748.9	749.7	750.5	751.2	752.0	752.8
760	741.4	742.1	742.9	743.7	744.4	745.2	746.0	746.7	747.5	748.3	749.0	749.8	750.6	751.3	752.1	752.9	753.6
759	742.2	743.0	743.8	744.5	745.3	746.1	746.8	747.6	748.4	749.1	749.9	750.7	751.4	752.2	753.0	753.7	754.5
758	743.1	743.9	744.6	745.4	746.2	746.9	747.7	748.5	749.2	750.0	750.8	751.5	752.3	753.1	753.8	754.6	755.4
757	744.0	744.7	745.5	746.2	747.0	747.8	748.5	749.3	750.1	750.8	751.6	752.4	753.1	753.9	754.7	755.4	756.2
756	744.8	745.6	746.3	747.1	747.9	748.6	749.4	750.2	750.9	751.7	752.5	753.2	754.0	754.8	755.5	756.3	757.1
755	745.7	746.4	747.2	747.9	748.7	749.5	750.2	751.0	751.8	752.5	753.3	754.1	754.8	755.6	756.4	757.1	757.9
754	746.5	747.3	748.0	748.8	749.6	750.3	751.1	751.9	752.6	753.4	754.2	754.9	755.7	756.5	757.2	758.0	758.8
753	747.4	748.1	748.9	749.7	750.4	751.2	752.0	752.7	753.5	754.3	755.0	755.8	756.6	757.3	758.1	758.9	759.6
752	748.2	749.0	749.8	750.5	751.3	752.1	752.8	753.6	754.4	755.1	755.9	756.7	757.4	758.2	759.0	759.7	760.5
751	749.1	749.9	750.6	751.4	752.2	752.9	753.7	754.5	755.2	756.0	756.8	757.5	758.3	759.1	759.8	760.6	761.4
750	750.0	750.7	751.5	752.2	753.0	753.8	754.5	755.3	756.1	756.8	757.6	758.4	759.1	759.9	760.7	761.4	762.2
749	750.8	751.6	752.3	753.1	753.9	754.6	755.4	756.2	756.9	757.7	758.5	759.2	760.0	760.8	761.5	762.3	763.1
748	751.7	752.4	753.2	753.9	754.7	755.5	756.2	757.0	757.8	758.5	759.3	760.1	760.8	761.6	762.4	763.1	763.9
747	752.5	753.3	754.0	754.8	755.6	756.3	757.1	757.9	758.6	759.4	760.2	760.9	761.7	762.5	763.2	764.0	764.8
746	753.4	754.1	754.9	755.6	756.4	757.2	757.9	758.7	759.5	760.2	761.0	761.8	762.5	763.3	764.1	764.8	765.6
745	754.2	755.0	755.7	756.5	757.3	758.0	758.8	759.6	760.3	761.1	761.9	762.6	763.4	764.2	764.9	765.7	766.5
744	755.1	755.8	756.6	757.3	758.1	758.9	759.6	760.4	761.2	761.9	762.7	763.5	764.2	765.0	765.8	766.5	767.3
743	755.9	756.7	757.4	758.2	759.0	759.7	760.5	761.3	762.0	762.8	763.6	764.3	765.1	765.9	766.6	767.4	768.2
742	756.8	757.5	758.3	759.0	759.8	760.6	761.3	762.1	762.9	763.6	764.4	765.2	765.9	766.7	767.5	768.2	769.0
741	757.6	758.4	759.1	759.9	760.7	761.4	762.2	763.0	763.7	764.5	765.3	766.0	766.8	767.6	768.3	769.1	769.8
740	758.5	759.2	760.0	760.7	761.5	762.3	763.0	763.8	764.6	765.3	766.1	766.9	767.6	768.4	769.2	769.9	770.7
739	759.3	760.1	760.8	761.6	762.4	763.1	763.9	764.7	765.4	766.2	767.0	767.7	768.5	769.3	770.0	770.8	771.5
738	760.2	760.9	761.7	762.4	763.2	764.0	764.7	765.5	766.3	767.0	767.8	768.6	769.3	770.1	770.9	771.6	772.4
737	761.0	761.8	762.5	763.3	764.1	764.8	765.6	766.4	767.1	767.9	768.7	769.4	770.2	771.0	771.7	772.5	773.2
736	761.9	762.6	763.4	764.1	764.9	765.7	766.4	767.2	768.0	768.7	769.5	770.3	771.0	771.8	772.6	773.3	774.1
735	762.7	763.5	764.2	765.0	765.8	766.5	767.3	768.1	768.8	769.6	770.4	771.1	771.9	772.7	773.4	774.2	775.0
734	763.6	764.3	765.1	765.8	766.6	767.4	768.1	768.9	769.7	770.4	771.2	772.0	772.7	773.5	774.3	775.0	775.8
733	764.4	765.2	765.9	766.7	767.5	768.2	769.0	769.8	770.5	771.3	772.1	772.8	773.6	774.4	775.1	775.9	776.7
732	765.3	766.0	766.8	767.5	768.3	769.1	769.8	770.6	771.4	772.1	772.9	773.7	774.4	775.2	776.0	776.7	777.5
731	766.1	766.9	767.6	768.4	769.2	769.9	770.7	771.5	772.2	773.0	773.8	774.5	775.3	776.1	776.8	777.6	778.4
730	767.0	767.7	768.5	769.2	770.0	770.8	771.5	772.3	773.1	773.8	774.6	775.4	776.1	776.9	777.7	778.4	779.2
729	767.8	768.6	769.3	770.1	770.9	771.6	772.4	773.2	773.9	774.7	775.5	776.2	777.0	777.8	778.5	779.3	780.1
728	768.7	769.4	770.2	770.9	771.7	772.5	773.2	774.0	774.8	775.5	776.3	777.1	777.8	778.6	779.4	780.1	780.9
727	769.5	770.3	771.0	771.8	772.6	773.3	774.1	774.9	775.6	776.4	777.2	777.9	778.7	779.5	780.2	781.0	781.8
726	770.4	771.1	771.9	772.6	773.4	774.2	774.9	775.7	776.5	777.2	778.0	778.8	779.5	780.3	781.1	781.8	782.6
725	771.2	772.0	772.7	773.5	774.3	775.0	775.8	776.6	777.3	778.1	778.9	779.6	780.4	781.2	781.9	782.7	783.5
724	772.1	772.8	773.6	774.3	775.1	775.9	776.6	777.4	778.2	778.9	779.7	780.5	781.2	782.0	782.8	783.5	784.3
723	772.9	773.7	774.4	775.2	776.0	776.7	777.5	778.3	779.0	779.8	780.6	781.3	782.1	782.9	783.6	784.4	785.2
722	773.8	774.5	775.3	776.0	776.8	777.6	778.3	779.1	779.9	780.6	781.4	782.2	782.9	783.7	784.5	785.2	786.0
721	774.6	775.4	776.1	776.9	777.7	778.4	779.2	780.0	780.7	781.5	782.3	783.0	783.8	784.6	785.3	786.1	786.9
720	775.5	776.2	777.0	777.7	778.5	779.3	780.0	780.8	781.6	782.3	783.1	783.9	784.6	785.4	786.2	786.9	787.7

Table 19-14 Metric — Low Alt, Mid Temp, Med Humidity
(Temp = 22 to 30°C , Press = 720 to 800 mm, 50% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
800	716.5	717.0	717.5	718.0	718.5	719.0	719.5	720.0	720.4	720.8	721.4	721.8	722.4	722.8	723.4	723.9	724.3
799	716.4	716.3	716.8	717.3	717.8	718.3	718.8	719.3	719.8	720.3	720.8	721.3	721.8	722.3	722.7	723.2	723.7
798	715.2	715.7	716.2	716.7	717.2	717.7	718.2	718.7	719.2	719.7	720.2	720.7	721.1	721.6	722.1	722.6	723.1
797	714.1	714.6	715.1	715.6	716.1	716.6	717.1	717.6	718.1	718.6	719.1	719.6	720.0	720.5	721.0	721.5	722.0
796	712.9	713.4	713.9	714.4	714.9	715.4	715.9	716.4	716.9	717.4	717.9	718.4	718.9	719.4	719.9	720.4	720.9
795	711.8	712.3	712.8	713.3	713.8	714.3	714.8	715.3	715.8	716.3	716.8	717.3	717.8	718.3	718.8	719.3	719.8
794	710.6	711.1	711.6	712.1	712.6	713.1	713.6	714.1	714.6	715.1	715.6	716.1	716.6	717.1	717.6	718.1	718.6
793	709.5	710.0	710.5	711.0	711.5	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5	717.0	717.5
792	708.3	708.8	709.3	709.8	710.3	710.8	711.3	711.8	712.3	712.8	713.3	713.8	714.3	714.8	715.3	715.8	716.3
791	707.2	707.7	708.2	708.7	709.2	709.7	710.2	710.7	711.2	711.7	712.2	712.7	713.2	713.7	714.2	714.7	715.2
790	706.0	706.5	707.0	707.5	708.0	708.5	709.0	709.5	710.0	710.5	711.0	711.5	712.0	712.5	713.0	713.5	714.0
789	704.8	705.3	705.8	706.3	706.8	707.3	707.8	708.3	708.8	709.3	709.8	710.3	710.8	711.3	711.8	712.3	712.8
788	703.7	704.2	704.7	705.2	705.7	706.2	706.7	707.2	707.7	708.2	708.7	709.2	709.7	710.2	710.7	711.2	711.7
787	702.5	703.0	703.5	704.0	704.5	705.0	705.5	706.0	706.5	707.0	707.5	708.0	708.5	709.0	709.5	710.0	710.5
786	701.3	701.8	702.3	702.8	703.3	703.8	704.3	704.8	705.3	705.8	706.3	706.8	707.3	707.8	708.3	708.8	709.3
785	700.2	700.7	701.2	701.7	702.2	702.7	703.2	703.7	704.2	704.7	705.2	705.7	706.2	706.7	707.2	707.7	708.2
784	699.0	699.5	700.0	700.5	701.0	701.5	702.0	702.5	703.0	703.5	704.0	704.5	705.0	705.5	706.0	706.5	707.0
783	697.8	698.3	698.8	699.3	699.8	700.3	700.8	701.3	701.8	702.3	702.8	703.3	703.8	704.3	704.8	705.3	705.8
782	696.7	697.2	697.7	698.2	698.7	699.2	699.7	700.2	700.7	701.2	701.7	702.2	702.7	703.2	703.7	704.2	704.7
781	695.5	696.0	696.5	697.0	697.5	698.0	698.5	699.0	699.5	700.0	700.5	701.0	701.5	702.0	702.5	703.0	703.5
780	694.3	694.8	695.3	695.8	696.3	696.8	697.3	697.8	698.3	698.8	699.3	699.8	700.3	700.8	701.3	701.8	702.3
779	693.2	693.7	694.2	694.7	695.2	695.7	696.2	696.7	697.2	697.7	698.2	698.7	699.2	699.7	700.2	700.7	701.2
778	692.0	692.5	693.0	693.5	694.0	694.5	695.0	695.5	696.0	696.5	697.0	697.5	698.0	698.5	699.0	699.5	700.0
777	690.8	691.3	691.8	692.3	692.8	693.3	693.8	694.3	694.8	695.3	695.8	696.3	696.8	697.3	697.8	698.3	698.8
776	689.7	690.2	690.7	691.2	691.7	692.2	692.7	693.2	693.7	694.2	694.7	695.2	695.7	696.2	696.7	697.2	697.7
775	688.5	689.0	689.5	690.0	690.5	691.0	691.5	692.0	692.5	693.0	693.5	694.0	694.5	695.0	695.5	696.0	696.5
774	687.3	687.8	688.3	688.8	689.3	689.8	690.3	690.8	691.3	691.8	692.3	692.8	693.3	693.8	694.3	694.8	695.3
773	686.2	686.7	687.2	687.7	688.2	688.7	689.2	689.7	690.2	690.7	691.2	691.7	692.2	692.7	693.2	693.7	694.2
772	685.0	685.5	686.0	686.5	687.0	687.5	688.0	688.5	689.0	689.5	690.0	690.5	691.0	691.5	692.0	692.5	693.0
771	683.8	684.3	684.8	685.3	685.8	686.3	686.8	687.3	687.8	688.3	688.8	689.3	689.8	690.3	690.8	691.3	691.8
770	682.7	683.2	683.7	684.2	684.7	685.2	685.7	686.2	686.7	687.2	687.7	688.2	688.7	689.2	689.7	690.2	690.7
769	681.5	682.0	682.5	683.0	683.5	684.0	684.5	685.0	685.5	686.0	686.5	687.0	687.5	688.0	688.5	689.0	689.5
768	680.3	680.8	681.3	681.8	682.3	682.8	683.3	683.8	684.3	684.8	685.3	685.8	686.3	686.8	687.3	687.8	688.3
767	679.2	679.7	680.2	680.7	681.2	681.7	682.2	682.7	683.2	683.7	684.2	684.7	685.2	685.7	686.2	686.7	687.2
766	678.0	678.5	679.0	679.5	680.0	680.5	681.0	681.5	682.0	682.5	683.0	683.5	684.0	684.5	685.0	685.5	686.0
765	676.8	677.3	677.8	678.3	678.8	679.3	679.8	680.3	680.8	681.3	681.8	682.3	682.8	683.3	683.8	684.3	684.8
764	675.7	676.2	676.7	677.2	677.7	678.2	678.7	679.2	679.7	680.2	680.7	681.2	681.7	682.2	682.7	683.2	683.7
763	674.5	675.0	675.5	676.0	676.5	677.0	677.5	678.0	678.5	679.0	679.5	680.0	680.5	681.0	681.5	682.0	682.5
762	673.3	673.8	674.3	674.8	675.3	675.8	676.3	676.8	677.3	677.8	678.3	678.8	679.3	679.8	680.3	680.8	681.3
761	672.2	672.7	673.2	673.7	674.2	674.7	675.2	675.7	676.2	676.7	677.2	677.7	678.2	678.7	679.2	679.7	680.2
760	671.0	671.5	672.0	672.5	673.0	673.5	674.0	674.5	675.0	675.5	676.0	676.5	677.0	677.5	678.0	678.5	679.0
759	669.8	670.3	670.8	671.3	671.8	672.3	672.8	673.3	673.8	674.3	674.8	675.3	675.8	676.3	676.8	677.3	677.8
758	668.7	669.2	669.7	670.2	670.7	671.2	671.7	672.2	672.7	673.2	673.7	674.2	674.7	675.2	675.7	676.2	676.7
757	667.5	668.0	668.5	669.0	669.5	670.0	670.5	671.0	671.5	672.0	672.5	673.0	673.5	674.0	674.5	675.0	675.5
756	666.3	666.8	667.3	667.8	668.3	668.8	669.3	669.8	670.3	670.8	671.3	671.8	672.3	672.8	673.3	673.8	674.3
755	665.2	665.7	666.2	666.7	667.2	667.7	668.2	668.7	669.2	669.7	670.2	670.7	671.2	671.7	672.2	672.7	673.2
754	664.0	664.5	665.0	665.5	666.0	666.5	667.0	667.5	668.0	668.5	669.0	669.5	670.0	670.5	671.0	671.5	672.0
753	662.8	663.3	663.8	664.3	664.8	665.3	665.8	666.3	666.8	667.3	667.8	668.3	668.8	669.3	669.8	670.3	670.8
752	661.7	662.2	662.7	663.2	663.7	664.2	664.7	665.2	665.7	666.2	666.7	667.2	667.7	668.2	668.7	669.2	669.7
751	660.5	661.0	661.5	662.0	662.5	663.0	663.5	664.0	664.5	665.0	665.5	666.0	666.5	667.0	667.5	668.0	668.5
750	659.3	659.8	660.3	660.8	661.3	661.8	662.3	662.8	663.3	663.8	664.3	664.8	665.3	665.8	666.3	666.8	667.3
749	658.2	658.7	659.2	659.7	660.2	660.7	661.2	661.7	662.2	662.7	663.2	663.7	664.2	664.7	665.2	665.7	666.2
748	657.0	657.5	658.0	658.5	659.0	659.5	660.0	660.5	661.0	661.5	662.0	662.5	663.0	663.5	664.0	664.5	665.0
747	655.8	656.3	656.8	657.3	657.8	658.3	658.8	659.3	659.8	660.3	660.8	661.3	661.8	662.3	662.8	663.3	663.8
746	654.7	655.2	655.7	656.2	656.7	657.2	657.7	658.2	658.7	659.2	659.7	660.2	660.7	661.2	661.7	662.2	662.7
745	653.5	654.0	654.5	655.0	655.5	656.0	656.5	657.0	657.5	658.0	658.5	659.0	659.5	660.0	660.5	661.0	661.5
744	652.3	652.8	653.3	653.8	654.3	654.8	655.3	655.8	656.3	656.8	657.3	657.8	658.3	658.8	659.3	659.8	660.3
743	651.2	651.7	652.2	652.7	653.2	653.7	654.2	654.7	655.2	655.7	656.2	656.7	657.2	657.7	658.2	658.7	659.2
742	650.0	650.5	651.0	651.5	652.0	652.5	653.0	653.5	654.0	654.5	655.0	655.5	656.0	656.5	657.0	657.5	658.0
741	648.8	649.3	649.8	650.3	650.8	651.3	651.8	652.3	652.8	653.3	653.8	654.3	654.8	655.3	655.8	656.3	656.8
740	647.7	648.2	648.7	649.2	649.7	650.2	650.7	651.2	651.7	652.2	652.7	653.2	653.7	654.2	654.7	655.2	655.7
739	646.5	647.0	647.5	648.0	648.5	649.0	649.5	650.0	650.5	651.0	651.5	652.0	652.5	653.0	653.5	654.0	654.5
738	645.3	645.8	646.3	646.8	647.3	647.8	648.3	648.8	649.3	649.8	650.3	650.8	651.3	651.8	652.3	652.8	653.3
737	644.2	644.7	645.2	645.7	646.2	646.7	647.2	647.7	648.2	648.7	649.2	649.7	650.2	650.7	651.2	651.7	652.2
736	643.0	643.5	644.0	644.5	645.0	645.5	646.0	646.5	647.0	647.5	648.0	648.5	649.0	649.5	650.0	650.5	651.0
735	641.8	642.3	642.8	643.3	643.8	644.3	644.8	645.3	645.8	646.3	646.8	647.3	647.8	648.3	648.8	649.3	649.8
734	640.7	641.2	641.7	642.2	642.7	643.2	643.7	644.2	644.7	645.2	645.7	646.2	646.7	647.2	647.7	648.2	648.7
733	639.5	640.0	640.5	641.0	641.5	642.0	642.5	643.0	643.5	644.0	644.5	645.0	645.5	646.0	646.5	647.0	647.5
732	638.3	638.8	639.3	639.8	640.3	640.8	641.3	641.8	642.3	642.8	643.3	643.8	644.3	644.8	645.3	645.8	646.3
731	637.2	637.7	638.2	638.7	639.2	639.7	640.2	640.7	641.2	641.7	642.2	642.7	643.2	643.7	644.2	644.7	645.2
730	636.0	636.5	637.0	637.5	638.0	638.5	639.0	639.5	640.0	640.5	641.0	641.5	642.0	642.5	643.0	643.5	644.0
729	634.8	635.3	635.8	636.3	636.8	637.3	637.8	638.3	638.8	639.3	639.8	640.3	640.8	641.3	641.8	642.3	642.8
728	633.7	634.2	634.7	635.2	635.7	636.2	636.7	637.2	637.7	638.2	638.7	639.2	639.7	640.2	640.7	641.2	641.7
727	632.5	633.0	633.5	634.0	634.5	635.0	635.5	636.0	636.5	637.0	637.5	638.0	638.5	639.0	639.5	640.0	640.5
726	631.3	631.8	632.3	632.8	633.3	633.8	634.3	634.8	635.3	635.8	636.3	636.8	637.3	637.8	638.3	638.8	639.3
725	630.2	630.7	631.2	631.7	632.2	632.7	633.2	633.7	634.2	634.7	635.2	635.7	636.2	636.7	637.2	637.7	638.2
724	629.0	629.5	630.0	630.5	631.0	631.5	632.0	632.5	633.0	633.5	634.0	634.5	635.0	635.5	636.0	636.5	637.0
723	627.8	628.3	628.8	629.3	629.8	630.3	630.8	631.3	631.8	632.3	632.8	633.3	633.8	634.3	634.8	635.3	635.8
722	626.7	627.2	627.7	628.2	628.7	629.2	629.7	630.2	630.7	631.2	631.7	632.2	632.7	633.2	633.7	634.2	634.7
721	625.5	626.0	626.5	627.0	627.5	628.0	628.5	629.0	629.5	630.0	630.5	631.0	631.5	632.0	632.5	633.0	633.5
720	624.3	624.8	625.3	625.8	626.3	626.8	627.3	627.8	628.3	628.8	629.3	629.8	630.3	630.8	631.3	631.8	632.3

Table 19-15. Metric — Low Alt, High-Mid Temp, Med Humidity
(Temp = 30.5 to 38.5°C , Press = 720 to 800 mm, 50% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY	30.5	31.0	31.5	32.0	32.5	33.0	33.5	34.0	34.5	35.0	35.5	36.0	36.5	37.0	37.5	38.0	38.5
800	724.8	725.3	725.8	726.3	726.7	727.2	727.7	728.2	728.7	729.1	729.6	730.1	730.5	731.0	731.4	731.9	732.4
799	725.2	725.6	726.1	726.6	727.1	727.6	728.0	728.5	729.0	729.5	729.9	730.4	730.9	731.4	731.9	732.4	732.8
798	725.6	726.0	726.5	727.0	727.5	727.9	728.4	728.9	729.4	729.8	730.3	730.8	731.3	731.7	732.2	732.7	733.2
797	725.9	726.3	726.8	727.3	727.8	728.3	728.7	729.2	729.7	730.1	730.6	731.1	731.6	732.0	732.5	733.0	733.4
796	726.2	726.7	727.2	727.6	728.1	728.6	729.1	729.5	730.0	730.5	731.0	731.4	731.9	732.4	732.8	733.3	733.8
795	726.5	727.0	727.5	728.0	728.5	728.9	729.4	729.9	730.4	730.8	731.3	731.8	732.2	732.7	733.2	733.7	734.1
794	726.9	727.4	727.9	728.3	728.8	729.3	729.7	730.2	730.7	731.2	731.6	732.1	732.6	733.0	733.5	734.0	734.5
793	727.2	727.7	728.2	728.7	729.1	729.6	730.1	730.6	731.0	731.5	732.0	732.4	732.9	733.4	733.9	734.3	734.8
792	727.6	728.1	728.5	729.0	729.5	730.0	730.4	730.9	731.4	731.9	732.3	732.8	733.3	733.8	734.2	734.7	735.2
791	727.9	728.4	728.8	729.4	729.9	730.3	730.8	731.3	731.7	732.2	732.7	733.2	733.6	734.1	734.6	735.0	735.5
790	728.3	728.7	729.2	729.7	730.2	730.7	731.2	731.6	732.1	732.6	733.1	733.5	734.0	734.5	735.0	735.4	735.9
789	728.6	729.1	729.6	730.1	730.5	731.0	731.5	732.0	732.4	732.9	733.4	733.9	734.3	734.8	735.3	735.8	736.2
788	729.0	729.4	729.9	730.4	730.9	731.3	731.8	732.3	732.8	733.2	733.7	734.2	734.7	735.1	735.6	736.1	736.6
787	729.3	729.8	730.3	730.7	731.2	731.7	732.2	732.6	733.1	733.6	734.1	734.5	735.0	735.5	736.0	736.4	736.9
786	729.7	730.1	730.6	731.1	731.6	732.0	732.5	733.0	733.5	733.9	734.4	734.9	735.4	735.8	736.3	736.8	737.3
785	730.0	730.5	730.9	731.4	731.9	732.4	732.8	733.3	733.8	734.3	734.8	735.2	735.7	736.2	736.7	737.1	737.6
784	730.4	730.8	731.3	731.8	732.2	732.7	733.2	733.7	734.2	734.7	735.2	735.6	736.1	736.6	737.0	737.5	738.0
783	730.7	731.2	731.7	732.1	732.6	733.1	733.6	734.1	734.6	735.0	735.5	736.0	736.5	736.9	737.4	737.9	738.4
782	731.0	731.5	732.0	732.4	732.9	733.4	733.9	734.4	734.9	735.4	735.9	736.3	736.8	737.3	737.8	738.2	738.7
781	731.4	731.8	732.3	732.8	733.3	733.8	734.3	734.8	735.2	735.7	736.2	736.7	737.2	737.6	738.1	738.6	739.1
780	731.7	732.2	732.7	733.1	733.6	734.1	734.6	735.1	735.6	736.1	736.5	737.0	737.5	738.0	738.4	738.9	739.4
779	732.1	732.5	733.0	733.5	734.0	734.5	734.9	735.4	735.9	736.4	736.9	737.3	737.8	738.3	738.8	739.3	739.7
778	732.4	732.9	733.4	733.8	734.3	734.8	735.3	735.8	736.3	736.8	737.2	737.7	738.2	738.7	739.2	739.6	740.1
777	732.8	733.2	733.7	734.2	734.6	735.1	735.6	736.1	736.6	737.1	737.6	738.0	738.5	739.0	739.5	739.9	740.4
776	733.1	733.6	734.0	734.5	735.0	735.4	735.9	736.4	736.9	737.4	737.9	738.3	738.8	739.3	739.7	740.2	740.7
775	733.4	733.9	734.4	734.8	735.3	735.8	736.2	736.7	737.2	737.7	738.2	738.7	739.1	739.6	740.1	740.5	741.0
774	733.8	734.3	734.7	735.2	735.7	736.1	736.6	737.0	737.5	738.0	738.5	739.0	739.4	739.9	740.4	740.8	741.3
773	734.1	734.6	735.1	735.5	736.0	736.5	736.9	737.4	737.8	738.3	738.8	739.3	739.8	740.3	740.8	741.2	741.7
772	734.5	734.9	735.4	735.9	736.3	736.8	737.3	737.7	738.2	738.7	739.2	739.7	740.2	740.6	741.1	741.6	742.1
771	734.8	735.3	735.8	736.2	736.7	737.1	737.6	738.1	738.5	739.0	739.5	740.0	740.5	741.0	741.4	741.9	742.4
770	735.2	735.6	736.1	736.6	737.0	737.5	737.9	738.4	738.9	739.4	739.9	740.4	740.9	741.3	741.8	742.3	742.7
769	735.5	736.0	736.4	736.9	737.4	737.8	738.3	738.8	739.2	739.7	740.2	740.7	741.2	741.7	742.2	742.6	743.1
768	735.9	736.3	736.8	737.3	737.7	738.2	738.7	739.1	739.6	740.1	740.6	741.1	741.6	742.0	742.5	743.0	743.4
767	736.2	736.7	737.1	737.6	738.1	738.5	739.0	739.4	739.9	740.4	740.9	741.4	741.8	742.3	742.8	743.3	743.8
766	736.6	737.0	737.5	737.9	738.4	738.9	739.3	739.8	740.3	740.8	741.3	741.8	742.3	742.7	743.2	743.7	744.2
765	736.9	737.4	737.8	738.3	738.8	739.2	739.7	740.2	740.6	741.1	741.6	742.1	742.6	743.1	743.6	744.0	744.5
764	737.3	737.7	738.2	738.6	739.1	739.6	740.0	740.5	741.0	741.5	742.0	742.5	743.0	743.5	743.9	744.4	744.9
763	737.6	738.0	738.5	739.0	739.4	739.9	740.4	740.8	741.3	741.8	742.3	742.8	743.3	743.7	744.2	744.7	745.2
762	737.9	738.4	738.9	739.3	739.8	740.3	740.7	741.2	741.7	742.2	742.7	743.2	743.6	744.1	744.6	745.1	745.6
761	738.3	738.7	739.2	739.7	740.1	740.6	741.1	741.6	742.0	742.5	743.0	743.5	744.0	744.5	745.0	745.4	745.9
760	738.6	739.1	739.5	740.0	740.5	740.9	741.4	741.9	742.4	742.8	743.3	743.8	744.3	744.8	745.3	745.8	746.3
759	739.0	739.4	739.9	740.4	740.8	741.3	741.8	742.3	742.7	743.2	743.7	744.2	744.7	745.2	745.7	746.2	746.7
758	739.3	739.8	740.3	740.7	741.2	741.7	742.2	742.6	743.1	743.6	744.1	744.6	745.1	745.6	746.1	746.6	747.1
757	739.7	740.2	740.6	741.1	741.6	742.0	742.5	743.0	743.4	743.9	744.4	744.9	745.4	745.9	746.4	746.9	747.4
756	740.0	740.5	740.9	741.4	741.9	742.4	742.8	743.3	743.8	744.3	744.8	745.2	745.7	746.2	746.7	747.2	747.7
755	740.4	740.8	741.3	741.7	742.2	742.6	743.1	743.6	744.0	744.5	745.0	745.5	746.0	746.5	747.0	747.5	748.0
754	740.7	741.2	741.6	742.1	742.5	743.0	743.4	743.9	744.4	744.8	745.3	745.8	746.3	746.8	747.3	747.8	748.3
753	741.0	741.5	742.0	742.4	742.9	743.3	743.8	744.3	744.8	745.2	745.7	746.2	746.7	747.1	747.6	748.1	748.6
752	741.4	741.8	742.3	742.7	743.2	743.6	744.1	744.6	745.1	745.6	746.0	746.5	746.9	747.4	747.9	748.4	748.9
751	741.7	742.2	742.6	743.1	743.5	744.0	744.4	744.9	745.3	745.8	746.2	746.7	747.2	747.7	748.1	748.6	749.1
750	742.1	742.5	743.0	743.4	743.9	744.3	744.8	745.2	745.7	746.1	746.6	747.0	747.5	747.9	748.4	748.9	749.3
749	742.4	742.9	743.3	743.8	744.2	744.7	745.1	745.6	746.0	746.5	746.9	747.4	747.9	748.3	748.8	749.3	749.8
748	742.8	743.2	743.7	744.1	744.6	745.0	745.5	745.9	746.4	746.8	747.3	747.7	748.2	748.7	749.1	749.6	750.1
747	743.1	743.6	744.0	744.5	744.9	745.4	745.8	746.3	746.7	747.2	747.6	748.1	748.6	749.0	749.5	749.9	750.4
746	743.5	743.9	744.4	744.8	745.3	745.7	746.2	746.6	747.1	747.5	748.0	748.5	748.9	749.4	749.8	750.3	750.8
745	743.8	744.3	744.7	745.2	745.6	746.0	746.5	746.9	747.4	747.8	748.3	748.7	749.2	749.7	750.1	750.6	751.1
744	744.2	744.6	745.0	745.5	745.9	746.4	746.8	747.3	747.7	748.2	748.6	749.1	749.6	750.0	750.5	751.0	751.4
743	744.5	744.9	745.4	745.8	746.3	746.7	747.2	747.6	748.1	748.5	749.0	749.4	749.8	750.3	750.7	751.2	751.6
742	744.9	745.3	745.7	746.2	746.6	747.1	747.5	748.0	748.4	748.9	749.3	749.8	750.2	750.7	751.2	751.6	752.1
741	745.2	745.6	746.1	746.5	747.0	747.4	747.9	748.3	748.8	749.2	749.6	750.1	750.5	751.0	751.4	751.9	752.3
740	745.6	746.0	746.4	746.9	747.3	747.8	748.2	748.6	749.1	749.5	750.0	750.4	750.9	751.3	751.8	752.2	752.7
739	745.9	746.3	746.8	747.2	747.7	748.1	748.5	749.0	749.4	749.9	750.3	750.8	751.2	751.6	752.1	752.5	753.0
738	746.3	746.7	747.1	747.5	748.0	748.4	748.9	749.3	749.8	750.2	750.7	751.1	751.5	752.0	752.4	752.8	753.3
737	746.6	747.0	747.5	747.9	748.3	748.8	749.2	749.7	750.1	750.6	751.0	751.4	751.9	752.3	752.7	753.2	753.6
736	746.9	747.4	747.8	748.2	748.7	749.1	749.6	750.0	750.5	750.9	751.3	751.8	752.2	752.6	753.1	753.5	754.0
735	747.3	747.7	748.1	748.6	749.0	749.5	749.9	750.4	750.8	751.2	751.7	752.1	752.5	753.0	753.4	753.9	754.3
734	747.6	748.0	748.5	748.9	749.4	749.8	750.3	750.7	751.1	751.6	752.0	752.4	752.9	753.3	753.8	754.2	754.6
733	747.9	748.4	748.8	749.3	749.7	750.2	750.6	751.0	751.5	751.9	752.3	752.8	753.2	753.7	754.1	754.5	755.0
732	748.3	748.7	749.2	749.6	750.1	750.5	750.9	751.4	751.8	752.3	752.7	753.1	753.6	754.0	754.5	754.9	755.4
731	748.6	749.1	749.5	750.0	750.4	750.8	751.3	751.7	752.2	752.6	753.0	753.5	753.9	754.4	754.8	755.2	755.7
730	749.0	749.4	749.9	750.3	750.7	751.2	751.6	752.1	752.5	752.9	753.4	753.8	754.3	754.7	755.1	755.6	756.0
729	749.3	749.8	750.2	750.6	751.1	751.5	752.0	752.4	752.8	753.3	753.7	754.2	754.6	755.0	755.5	755.9	756.3
728	749.7	750.1	750.5	751.0	751.4	751.9	752.3	752.7	753.2	753.6	754.0	754.5	754.9	755.3	755.8	756.2	756.6
727	750.0	750.5	750.9	751.3	751.8	752.2	752.6	753.1	753.5	754.0	754.4	754.8	755.3	755.7	756.1	756.6	757.0
726	750.4	750.8	751.2	751.7	752.1	752.5	753.0	753.4	753.9	754.3	754.7	755.2	755.6	756.0	756.5	756.9	757.3
725	750.7	751.1	751.6	752.0	752.5	752.9	753.3	753.8	754.2	754.6	755.1	755.5	755.9	756.4	756.8	757.2	757.7
724	751.1	751.5	751.9	752.4	752.8	753.2	753.7	754.1	754.5	755.0	755.4	755.8	756.3	756.7	757.1	757.6	758.0
723	751.4	751.8	752.3	752.7	753.1	753.6	754.0	754.4	754.9	755.3	755.7	756.2	756.6	757.0	757.5	757.9	758.3
722	751.7	752.2	752.6	753.0	753.5	753.9	754.4	754.8	755.2	755.7	756.1	756.5	756.9	757.4	757.8	758.2	758.7
721	752.1	752.5	753.0	753.4	753.8	754.3	754.7	755.1	755.6	756.0	756.4	756.8	757.3	757.7	758.1	758.6	759.0
720	752.4	752.9	753.3	753.7	754.2	754.6	755.0	755.5	755.9	756.3	756.8	757.2	757.6	758.1	758.5	758.9	759.3

Table 19-16. Metric — High Alt, Low Temp, Med Humidity
(Temp = 5 to 13°C , Press = 640 to 720 mm, 50% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

Table 19-17. Metric — High Alt, Low-Mid Temp, Med Humidity
(Temp = 13.5 to 21.5°C , Press = 640 to 720 mm, 50% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

	13.5	14.0	14.5	15.0	15.4	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5
720	737.1	737.5	738.0	738.4	738.9	739.4	739.8	740.3	740.9	741.3	741.8	742.2	742.6	743.1	743.7	744.1	744.4
719	736.4	737.0	737.4	737.8	738.3	738.8	739.2	739.7	740.2	740.7	741.2	741.6	742.1	742.5	743.0	743.5	743.8
718	735.9	736.3	736.7	737.2	737.7	738.2	738.7	739.1	739.6	740.1	740.6	741.0	741.5	741.9	742.4	742.9	743.2
717	735.3	735.8	736.2	736.7	737.1	737.6	738.1	738.5	739.0	739.5	740.0	740.4	740.9	741.3	741.8	742.3	742.7
716	734.8	735.2	735.7	736.1	736.6	737.0	737.5	738.0	738.4	738.9	739.4	739.8	740.3	740.7	741.2	741.7	742.1
715	734.2	734.7	735.1	735.6	736.0	736.5	736.9	737.4	737.9	738.3	738.8	739.2	739.7	740.2	740.6	741.1	741.5
714	733.7	734.1	734.6	735.0	735.5	735.9	736.4	736.8	737.3	737.8	738.2	738.7	739.1	739.6	740.1	740.5	741.0
713	733.1	733.6	734.0	734.5	734.9	735.4	735.8	736.3	736.7	737.2	737.7	738.1	738.6	739.0	739.5	740.0	740.4
712	732.6	733.0	733.5	733.9	734.4	734.8	735.3	735.7	736.2	736.7	737.1	737.6	738.0	738.5	739.0	739.4	739.9
711	732.0	732.5	732.9	733.4	733.8	734.3	734.7	735.2	735.6	736.1	736.6	737.0	737.5	737.9	738.4	738.9	739.3
710	731.5	731.9	732.4	732.8	733.3	733.7	734.2	734.6	735.1	735.5	736.0	736.5	736.9	737.4	737.8	738.3	738.8
709	730.9	731.4	731.8	732.3	732.7	733.2	733.6	734.1	734.5	735.0	735.5	735.9	736.4	736.8	737.3	737.8	738.2
708	730.4	730.8	731.3	731.7	732.2	732.6	733.1	733.5	734.0	734.5	734.9	735.4	735.8	736.3	736.7	737.2	737.6
707	729.8	730.3	730.7	731.2	731.6	732.1	732.5	733.0	733.4	733.9	734.3	734.8	735.2	735.7	736.2	736.6	737.1
706	729.3	729.7	730.2	730.6	731.1	731.5	732.0	732.4	732.9	733.3	733.8	734.2	734.7	735.1	735.6	736.0	736.5
705	728.7	729.2	729.6	730.1	730.5	731.0	731.4	731.9	732.3	732.8	733.2	733.7	734.1	734.6	735.0	735.5	735.9
704	728.2	728.6	729.1	729.5	730.0	730.4	730.9	731.3	731.8	732.2	732.7	733.1	733.6	734.0	734.5	734.9	735.4
703	727.6	728.1	728.5	729.0	729.4	729.9	730.3	730.8	731.2	731.7	732.1	732.6	733.0	733.5	733.9	734.4	734.8
702	727.1	727.5	728.0	728.4	728.9	729.3	729.8	730.2	730.7	731.1	731.6	732.0	732.5	732.9	733.4	733.8	734.3
701	726.5	727.0	727.4	727.9	728.3	728.8	729.2	729.7	730.1	730.6	731.0	731.5	731.9	732.4	732.8	733.3	733.7
700	726.0	726.4	726.9	727.3	727.8	728.2	728.7	729.1	729.6	730.0	730.5	730.9	731.4	731.8	732.3	732.7	733.2
699	725.4	725.9	726.3	726.8	727.2	727.7	728.1	728.6	729.0	729.5	729.9	730.4	730.8	731.3	731.7	732.2	732.6
698	724.9	725.3	725.8	726.2	726.7	727.1	727.6	728.0	728.5	728.9	729.4	729.8	730.3	730.7	731.2	731.6	732.1
697	724.3	724.8	725.2	725.7	726.1	726.6	727.0	727.5	727.9	728.4	728.8	729.3	729.7	730.2	730.6	731.1	731.5
696	723.8	724.2	724.7	725.1	725.6	726.0	726.5	726.9	727.4	727.8	728.3	728.7	729.2	729.6	730.1	730.5	731.0
695	723.2	723.7	724.1	724.6	725.0	725.5	725.9	726.4	726.8	727.3	727.7	728.2	728.6	729.1	729.5	730.0	730.4
694	722.7	723.1	723.6	724.0	724.5	724.9	725.4	725.8	726.3	726.7	727.2	727.6	728.1	728.5	729.0	729.4	729.9
693	722.1	722.6	723.0	723.5	723.9	724.4	724.8	725.3	725.7	726.2	726.6	727.1	727.5	728.0	728.4	728.9	729.3
692	721.6	722.0	722.5	722.9	723.4	723.8	724.3	724.7	725.2	725.6	726.1	726.5	727.0	727.4	727.9	728.3	728.8
691	721.0	721.5	721.9	722.4	722.8	723.3	723.7	724.2	724.6	725.1	725.5	726.0	726.4	726.9	727.3	727.8	728.2
690	720.5	720.9	721.4	721.8	722.3	722.7	723.2	723.6	724.1	724.5	725.0	725.4	725.9	726.3	726.8	727.2	727.7
689	719.9	720.4	720.8	721.3	721.7	722.2	722.6	723.1	723.5	724.0	724.4	724.9	725.3	725.8	726.2	726.7	727.1
688	719.4	719.8	720.3	720.7	721.2	721.6	722.1	722.5	723.0	723.4	723.9	724.3	724.8	725.2	725.7	726.1	726.6
687	718.8	719.3	719.7	720.2	720.6	721.1	721.5	722.0	722.4	722.9	723.3	723.8	724.2	724.7	725.1	725.6	726.0
686	718.3	718.7	719.2	719.6	720.1	720.5	721.0	721.4	721.9	722.3	722.8	723.2	723.7	724.1	724.6	725.0	725.5
685	717.7	718.2	718.6	719.1	719.5	720.0	720.4	720.9	721.3	721.8	722.2	722.7	723.1	723.6	724.0	724.5	724.9
684	717.2	717.6	718.1	718.5	719.0	719.4	719.9	720.3	720.8	721.2	721.7	722.1	722.6	723.0	723.5	723.9	724.4
683	716.6	717.1	717.5	718.0	718.4	718.9	719.3	719.8	720.2	720.7	721.1	721.6	722.0	722.5	722.9	723.4	723.8
682	716.1	716.5	717.0	717.4	717.9	718.3	718.8	719.2	719.7	720.1	720.6	721.0	721.5	721.9	722.4	722.8	723.3
681	715.5	716.0	716.4	716.9	717.3	717.8	718.2	718.7	719.1	719.6	720.0	720.5	720.9	721.4	721.8	722.3	722.7
680	715.0	715.4	715.9	716.3	716.8	717.2	717.7	718.1	718.6	719.0	719.5	719.9	720.4	720.8	721.3	721.7	722.2
679	714.4	714.9	715.3	715.8	716.2	716.7	717.1	717.6	718.0	718.5	718.9	719.4	719.8	720.3	720.7	721.2	721.6
678	713.9	714.3	714.8	715.2	715.7	716.1	716.6	717.0	717.5	717.9	718.4	718.8	719.3	719.7	720.2	720.6	721.1
677	713.3	713.8	714.2	714.7	715.1	715.6	716.0	716.5	716.9	717.4	717.8	718.3	718.7	719.2	719.6	720.1	720.5
676	712.8	713.2	713.7	714.1	714.6	715.0	715.5	715.9	716.4	716.8	717.3	717.7	718.2	718.6	719.1	719.5	720.0
675	712.2	712.7	713.1	713.6	714.0	714.5	714.9	715.4	715.8	716.3	716.7	717.2	717.6	718.1	718.5	719.0	719.4
674	711.7	712.1	712.6	713.0	713.5	713.9	714.4	714.8	715.3	715.7	716.2	716.6	717.1	717.5	718.0	718.4	718.9
673	711.1	711.6	712.0	712.5	712.9	713.4	713.8	714.3	714.7	715.2	715.6	716.1	716.5	717.0	717.4	717.9	718.3
672	710.6	711.0	711.5	711.9	712.4	712.8	713.3	713.7	714.2	714.6	715.1	715.5	716.0	716.4	716.9	717.3	717.8
671	710.0	710.5	710.9	711.4	711.8	712.3	712.7	713.2	713.6	714.1	714.5	715.0	715.4	715.9	716.3	716.8	717.2
670	709.5	709.9	710.4	710.8	711.3	711.7	712.2	712.6	713.1	713.5	714.0	714.4	714.9	715.3	715.8	716.2	716.7
669	708.9	709.4	709.8	710.3	710.7	711.2	711.6	712.1	712.5	713.0	713.4	713.9	714.3	714.8	715.2	715.7	716.1
668	708.4	708.8	709.3	709.7	710.2	710.6	711.1	711.5	712.0	712.4	712.9	713.3	713.8	714.2	714.7	715.1	715.6
667	707.8	708.3	708.7	709.2	709.6	710.1	710.5	711.0	711.4	711.9	712.3	712.8	713.2	713.7	714.1	714.6	715.0
666	707.3	707.7	708.2	708.6	709.1	709.5	710.0	710.4	710.9	711.3	711.8	712.2	712.7	713.1	713.6	714.0	714.5
665	706.7	707.2	707.6	708.1	708.5	709.0	709.4	709.9	710.3	710.8	711.2	711.7	712.1	712.6	713.0	713.5	713.9
664	706.2	706.6	707.1	707.5	708.0	708.4	708.9	709.3	709.8	710.2	710.7	711.1	711.6	712.0	712.5	712.9	713.4
663	705.6	706.1	706.5	707.0	707.4	707.9	708.3	708.8	709.2	709.7	710.1	710.6	711.0	711.5	711.9	712.4	712.8
662	705.1	705.5	706.0	706.4	706.9	707.3	707.8	708.2	708.7	709.1	709.6	710.0	710.5	710.9	711.4	711.8	712.3
661	704.5	705.0	705.4	705.9	706.3	706.8	707.2	707.7	708.1	708.6	709.0	709.5	709.9	710.4	710.8	711.3	711.7
660	704.0	704.4	704.9	705.3	705.8	706.2	706.7	707.1	707.6	708.0	708.5	708.9	709.4	709.8	710.3	710.7	711.2
659	703.4	703.9	704.3	704.8	705.2	705.7	706.1	706.6	707.0	707.5	707.9	708.4	708.8	709.3	709.7	710.2	710.6
658	702.9	703.3	703.8	704.2	704.7	705.1	705.6	706.0	706.5	706.9	707.4	707.8	708.3	708.7	709.2	709.6	710.1
657	702.3	702.8	703.2	703.7	704.1	704.6	705.0	705.5	705.9	706.4	706.8	707.3	707.7	708.2	708.6	709.1	709.5
656	701.8	702.2	702.7	703.1	703.6	704.0	704.5	704.9	705.4	705.8	706.3	706.7	707.2	707.6	708.1	708.5	709.0
655	701.2	701.7	702.1	702.6	703.0	703.5	703.9	704.4	704.8	705.3	705.7	706.2	706.6	707.1	707.5	708.0	708.4
654	700.7	701.1	701.6	702.0	702.5	702.9	703.4	703.8	704.3	704.7	705.2	705.6	706.1	706.5	707.0	707.4	707.9
653	700.1	700.6	701.0	701.5	701.9	702.4	702.8	703.3	703.7	704.2	704.6	705.1	705.5	706.0	706.4	706.9	707.3
652	699.6	700.0	700.5	700.9	701.4	701.8	702.3	702.7	703.2	703.6	704.1	704.5	705.0	705.4	705.9	706.3	706.8
651	699.0	699.5	699.9	700.4	700.8	701.3	701.7	702.2	702.6	703.1	703.5	704.0	704.4	704.9	705.3	705.8	706.2
650	698.5	698.9	699.4	699.8	700.3	700.7	701.2	701.6	702.1	702.5	703.0	703.4	703.9	704.3	704.8	705.2	705.7
649	697.9	698.4	698.8	699.3	699.7	700.2	700.6	701.1	701.5	702.0	702.4	702.9	703.3	703.8	704.2	704.7	705.1
648	697.4	697.8	698.3	698.7	699.2	699.6	700.1	700.5	701.0	701.4	701.9	702.3	702.8	703.2	703.7	704.1	704.6
647	696.8	697.3	697.7	698.2	698.6	699.1	699.5	700.0	700.4	700.9	701.3	701.8	702.2	702.7	703.1	703.6	704.0
646	696.3	696.7	697.2	697.6	698.1	698.5	699.0	699.4	699.9	700.3	700.8	701.2	701.7	702.1	702.6	703.0	703.5
645	695.7	696.2	696.6	697.1	697.5	698.0	698.4	698.9	699.3	699.8	700.2	700.7	701.1	701.6	702.0	702.5	702.9
644	695.2	695.6	696.1	696.5	697.0	697.4	697.9	698.3	698.8	699.2	699.7	700.1	700.6	701.0	701.5	701.9	702.4
643	694.6	695.1	695.5	696.0	696.4	696.9	697.3	697.8	698.2	698.7	699.1	699.6	700.0	700.5	700.9	701.4	701.8
642	694.1	694.5	695.0	695.4	695.9	696.3	696.8	697.2	697.7	698.1	698.6	699.0	699.5	699.9	700.4	700.8	701.3
641	693.5	694.0	694.4	694.9	695.3	695.8	696.2	696.7	697.1	697.6	698.0	698.5	698.9	699.4	699.8	700.3	700.7
640	693.0	693.4	693.9	694.3	694.8	695.2	695.7	696.1	696.6	697.0	697.5	697.9	698.4	698.8	699.3	699.7	700.2

Table 19-18 Metric — High Alt, Mid Temp, Med Humidity
(Temp = 22 to 30°C , Press = 640 to 720 mm, 50% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

Table 19-19. Metric — High Alt, High-Mid Temp, Med Humidity
(Temp = 30.5 to 38.5°C , Press = 640 to 720 mm, 50% Humidity)

TEMPERATURE IN DEGREES CELSIUS

	30.5	31.0	31.5	32.0	32.5	33.0	33.5	34.0	34.5	35.0	35.5	36.0	36.5	37.0	37.5	38.0	38.5
720	752.4	752.9	753.3	753.7	754.2	754.6	755.0	755.5	755.9	756.3	756.8	757.2	757.6	758.1	758.5	758.9	759.3
719	752.9	753.2	753.6	754.1	754.5	754.9	755.4	755.8	756.2	756.7	757.1	757.5	758.0	758.4	758.8	759.2	759.7
718	753.3	753.6	754.0	754.4	754.9	755.3	755.7	756.2	756.6	757.0	757.4	757.9	758.3	758.7	759.2	759.6	760.0
717	753.5	753.9	754.3	754.8	755.2	755.6	756.1	756.5	756.9	757.4	757.8	758.2	758.6	759.1	759.5	759.9	760.3
716	753.9	754.2	754.7	755.1	755.5	756.0	756.4	756.8	757.3	757.7	758.1	758.5	759.0	759.4	759.8	760.3	760.7
715	754.2	754.6	755.0	755.5	755.9	756.3	756.7	757.2	757.6	758.0	758.4	758.9	759.3	759.7	760.2	760.6	761.0
714	754.6	754.9	755.4	755.8	756.2	756.7	757.1	757.5	757.9	758.4	758.8	759.2	759.7	760.1	760.5	760.9	761.4
713	754.9	755.3	755.7	756.1	756.6	757.0	757.4	757.9	758.3	758.7	759.1	759.6	760.0	760.4	760.8	761.3	761.7
712	755.2	755.6	756.1	756.5	756.9	757.3	757.8	758.2	758.6	759.1	759.5	759.9	760.3	760.8	761.2	761.6	762.0
711	755.6	756.0	756.4	756.8	757.3	757.7	758.1	758.5	759.0	759.4	759.8	760.2	760.7	761.1	761.5	761.9	762.4
710	755.9	756.3	756.7	757.2	757.6	758.0	758.5	758.9	759.3	759.8	760.2	760.6	761.0	761.5	761.9	762.3	762.7
709	756.2	756.7	757.1	757.5	757.9	758.4	758.8	759.2	759.6	760.1	760.5	760.9	761.3	761.8	762.2	762.6	763.0
708	756.6	757.0	757.4	757.9	758.3	758.7	759.1	759.6	760.0	760.4	760.8	761.3	761.7	762.1	762.5	763.0	763.4
707	756.9	757.3	757.8	758.2	758.6	759.1	759.5	759.9	760.3	760.8	761.2	761.6	762.0	762.4	762.9	763.3	763.7
706	757.3	757.7	758.1	758.5	759.0	759.4	759.8	760.2	760.7	761.1	761.5	762.0	762.4	762.8	763.2	763.6	764.0
705	757.6	758.0	758.5	758.9	759.3	759.7	760.2	760.6	761.0	761.4	761.9	762.3	762.7	763.1	763.5	764.0	764.4
704	758.0	758.4	758.8	759.2	759.7	760.1	760.5	760.9	761.4	761.8	762.2	762.6	763.0	763.5	763.9	764.3	764.7
703	758.3	758.7	759.1	759.6	760.0	760.4	760.9	761.3	761.7	762.1	762.5	763.0	763.4	763.8	764.2	764.6	765.1
702	758.6	759.1	759.5	759.9	760.3	760.8	761.2	761.6	762.0	762.5	762.9	763.3	763.7	764.1	764.6	765.0	765.4
701	759.0	759.4	759.8	760.3	760.7	761.1	761.5	762.0	762.4	762.8	763.2	763.7	764.1	764.5	765.0	765.4	765.8
700	759.3	759.8	760.2	760.6	761.0	761.4	761.9	762.3	762.7	763.1	763.6	764.0	764.4	764.8	765.2	765.7	766.1
699	759.7	760.1	760.5	760.9	761.4	761.8	762.2	762.6	763.0	763.5	763.9	764.3	764.7	765.1	765.6	766.0	766.4
698	760.0	760.4	760.9	761.3	761.7	762.1	762.6	763.0	763.4	763.8	764.2	764.6	765.1	765.5	765.9	766.3	766.7
697	760.4	760.8	761.2	761.6	762.1	762.5	762.9	763.3	763.7	764.2	764.6	765.0	765.4	765.8	766.2	766.6	767.1
696	760.7	761.1	761.6	762.0	762.4	762.8	763.2	763.7	764.1	764.5	764.9	765.3	765.7	766.2	766.6	767.0	767.4
695	761.1	761.4	761.9	762.3	762.7	763.2	763.6	764.0	764.4	764.9	765.3	765.7	766.1	766.5	766.9	767.3	767.7
694	761.4	761.8	762.2	762.7	763.1	763.5	763.9	764.3	764.8	765.2	765.6	766.0	766.4	766.8	767.3	767.7	768.1
693	761.7	762.2	762.6	763.0	763.4	763.8	764.3	764.7	765.1	765.5	765.9	766.3	766.8	767.2	767.6	768.0	768.4
692	762.1	762.5	762.9	763.4	763.8	764.2	764.6	765.0	765.4	765.9	766.3	766.7	767.1	767.5	767.9	768.3	768.8
691	762.4	762.9	763.3	763.7	764.1	764.5	764.9	765.4	765.8	766.2	766.6	767.0	767.4	767.8	768.3	768.7	769.1
690	762.8	763.2	763.6	764.0	764.4	764.8	765.3	765.7	766.1	766.5	766.9	767.3	767.8	768.2	768.6	769.0	769.4
689	763.1	763.5	764.0	764.4	764.8	765.2	765.6	766.0	766.5	766.9	767.3	767.7	768.1	768.5	769.0	769.4	769.8
688	763.5	763.9	764.3	764.7	765.1	765.6	766.0	766.4	766.8	767.2	767.6	768.0	768.5	768.9	769.3	769.7	770.1
687	763.8	764.2	764.7	765.1	765.5	765.9	766.3	766.7	767.1	767.6	768.0	768.4	768.8	769.2	769.6	770.0	770.4
686	764.2	764.6	765.0	765.4	765.8	766.2	766.7	767.1	767.5	767.9	768.3	768.7	769.1	769.5	769.9	770.3	770.8
685	764.5	764.9	765.3	765.8	766.2	766.6	767.0	767.4	767.8	768.2	768.6	769.0	769.4	769.8	770.3	770.7	771.1
684	764.9	765.3	765.7	766.1	766.5	766.9	767.3	767.8	768.2	768.6	769.0	769.4	769.8	770.2	770.6	771.0	771.4
683	765.2	765.6	766.0	766.4	766.9	767.3	767.7	768.1	768.5	768.9	769.3	769.7	770.1	770.5	771.0	771.4	771.8
682	765.5	766.0	766.4	766.8	767.2	767.6	768.0	768.4	768.9	769.3	769.7	770.1	770.5	770.9	771.3	771.7	772.1
681	765.9	766.3	766.7	767.1	767.5	768.0	768.4	768.8	769.2	769.6	770.0	770.4	770.8	771.2	771.6	772.0	772.5
680	766.2	766.6	767.1	767.5	767.9	768.3	768.7	769.1	769.5	769.9	770.3	770.8	771.2	771.6	772.0	772.4	772.8
679	766.6	767.0	767.4	767.8	768.2	768.6	769.0	769.5	769.9	770.3	770.7	771.1	771.5	771.9	772.3	772.7	773.1
678	766.9	767.3	767.7	768.2	768.6	769.0	769.4	769.8	770.2	770.6	771.0	771.4	771.8	772.2	772.6	773.1	773.5
677	767.3	767.7	768.1	768.5	768.9	769.3	769.7	770.1	770.5	771.0	771.4	771.8	772.2	772.6	773.0	773.4	773.8
676	767.6	768.0	768.4	768.8	769.3	769.7	770.1	770.5	771.0	771.4	771.8	772.2	772.5	772.9	773.3	773.7	774.1
675	768.0	768.4	768.8	769.2	769.6	770.0	770.4	770.8	771.2	771.6	772.0	772.4	772.9	773.3	773.7	774.1	774.5
674	768.3	768.7	769.2	769.6	770.0	770.4	770.8	771.2	771.6	772.0	772.4	772.8	773.2	773.6	774.0	774.4	774.8
673	768.7	769.1	769.5	769.9	770.3	770.7	771.1	771.5	771.9	772.3	772.7	773.1	773.5	773.9	774.3	774.7	775.1
672	769.0	769.4	769.8	770.2	770.6	771.0	771.4	771.8	772.3	772.7	773.1	773.5	773.9	774.3	774.8	775.2	775.5
671	769.3	769.7	770.2	770.6	771.0	771.4	771.8	772.2	772.6	773.0	773.4	773.8	774.2	774.6	775.0	775.4	775.8
670	769.7	770.1	770.5	770.9	771.3	771.7	772.1	772.5	772.9	773.3	773.7	774.1	774.5	774.9	775.3	775.7	776.1
669	770.0	770.4	770.8	771.3	771.7	772.1	772.5	772.9	773.3	773.7	774.1	774.5	774.9	775.3	775.7	776.1	776.5
668	770.4	770.8	771.2	771.6	772.0	772.4	772.8	773.2	773.6	774.0	774.4	774.8	775.2	775.6	776.0	776.4	776.8
667	770.7	771.1	771.5	771.9	772.3	772.7	773.1	773.6	774.0	774.4	774.8	775.2	775.6	776.0	776.4	776.8	777.2
666	771.1	771.5	771.9	772.3	772.7	773.1	773.5	773.9	774.4	774.7	775.1	775.5	775.9	776.3	776.7	777.1	777.5
665	771.4	771.8	772.2	772.6	773.0	773.4	773.8	774.2	774.6	775.0	775.4	775.8	776.2	776.6	777.0	777.5	777.9
664	771.8	772.2	772.6	773.0	773.4	773.8	774.2	774.6	775.0	775.4	775.9	776.3	776.8	777.2	777.6	778.0	778.4
663	772.1	772.5	772.9	773.3	773.7	774.1	774.5	774.9	775.3	775.7	776.1	776.5	776.9	777.3	777.7	778.1	778.5
662	772.5	772.9	773.3	773.7	774.1	774.5	774.9	775.3	775.7	776.1	776.5	776.9	777.3	777.7	778.0	778.4	778.8
661	772.9	773.2	773.6	774.0	774.4	774.8	775.2	775.6	776.0	776.4	776.8	777.2	777.6	778.0	778.4	778.8	779.2
660	773.1	773.5	773.9	774.3	774.7	775.1	775.5	775.9	776.3	776.7	777.1	777.5	777.9	778.3	778.7	779.1	779.5
659	773.5	773.9	774.3	774.7	775.1	775.5	775.9	776.3	776.7	777.1	777.5	777.9	778.3	778.7	779.1	779.5	779.8
658	773.8	774.2	774.6	775.0	775.4	775.8	776.2	776.6	777.0	777.4	777.8	778.2	778.6	779.0	779.4	779.8	780.2
657	774.2	774.6	775.0	775.4	775.8	776.2	776.6	777.0	777.4	777.8	778.2	778.5	778.9	779.3	779.7	780.1	780.5
656	774.5	774.9	775.3	775.7	776.1	776.5	776.9	777.3	777.7	778.1	778.5	778.9	779.3	779.7	780.1	780.5	780.9
655	774.9	775.3	775.7	776.1	776.5	776.9	777.2	777.6	778.0	778.4	778.8	779.2	779.6	780.0	780.4	780.8	781.2
654	775.2	775.6	776.0	776.4	776.8	777.2	777.6	778.0	778.4	778.8	779.2	779.6	780.0	780.4	780.8	781.1	781.5
653	775.6	776.0	776.3	776.7	777.1	777.5	777.9	778.3	778.7	779.1	779.5	779.9	780.3	780.7	781.1	781.5	781.9
652	775.9	776.3	776.7	777.1	777.5	777.9	778.3	778.7	779.1	779.5	779.9	780.3	780.7	781.0	781.4	781.8	782.2
651	776.2	776.6	777.0	777.4	777.8	778.2	778.6	779.0	779.4	779.8	780.2	780.6	781.0	781.4	781.8	782.1	782.5
650	776.6	777.0	777.4	777.8	778.2	778.6	779.0	779.4	779.7	780.1	780.5	780.9	781.3	781.7	782.1	782.5	782.9
649	776.9	777.3	777.7	778.1	778.5	778.9	779.3	779.7	780.1	780.5	780.9	781.3	781.6	782.0	782.4	782.8	783.2
648	777.3	777.7	778.1	778.5	778.9	779.3	779.6	780.0	780.4	780.8	781.2	781.6	782.0	782.4	782.8	783.2	783.5
647	777.6	778.0	778.4	778.8	779.2	779.6	780.0	780.4	780.8	781.2	781.5	781.9	782.3	782.7	783.1	783.5	783.9
646	778.0	778.4	778.8	779.1	779.5	779.9	780.3	780.7	781.1	781.5	781.9	782.3	782.7	783.1	783.5	784.0	784.4
645	778.3	778.7	779.1	779.5	779.9	780.3	780.7	781.1	781.5	781.9	782.2	782.6	783.0	783.4	783.8	784.2	784.6
644	778.7	779.1	779.4	779.8	780.2	780.6	781.0	781.4	781.8	782.2	782.6	783.0	783.4	783.8	784.2	784.5	784.9
643	779.0	779.4	779.8	780.2	780.6	781.0	781.4	781.8	782.2	782.6	782.9	783.3	783.7	784.1	784.5	784.9	785.3
642	779.4	779.7	780.1	780.5	780.9	781.3	781.7	782.1	782.5	782.9	783.3	783.6	784.0	784.4	784.8	785.2	785.6
641	779.7	780.1	780.5	780.9	781.3	781.6	782.0	782.4	782.8	783.2	783.6	784.0	784.4	784.7	785.1	785.5	785.9
640	780.1	780.4	780.8	781.2	781.6	782.0	782.4	782.8	783.2	783.5	783.9	784.3	784.7	785.1	785.5	785.9	786.2

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

Table 19-20. Metric — Low Alt, Low Temp, High Humidity
(Temp = 5 to 13°C , Press = 720 to 800 mm, 80% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

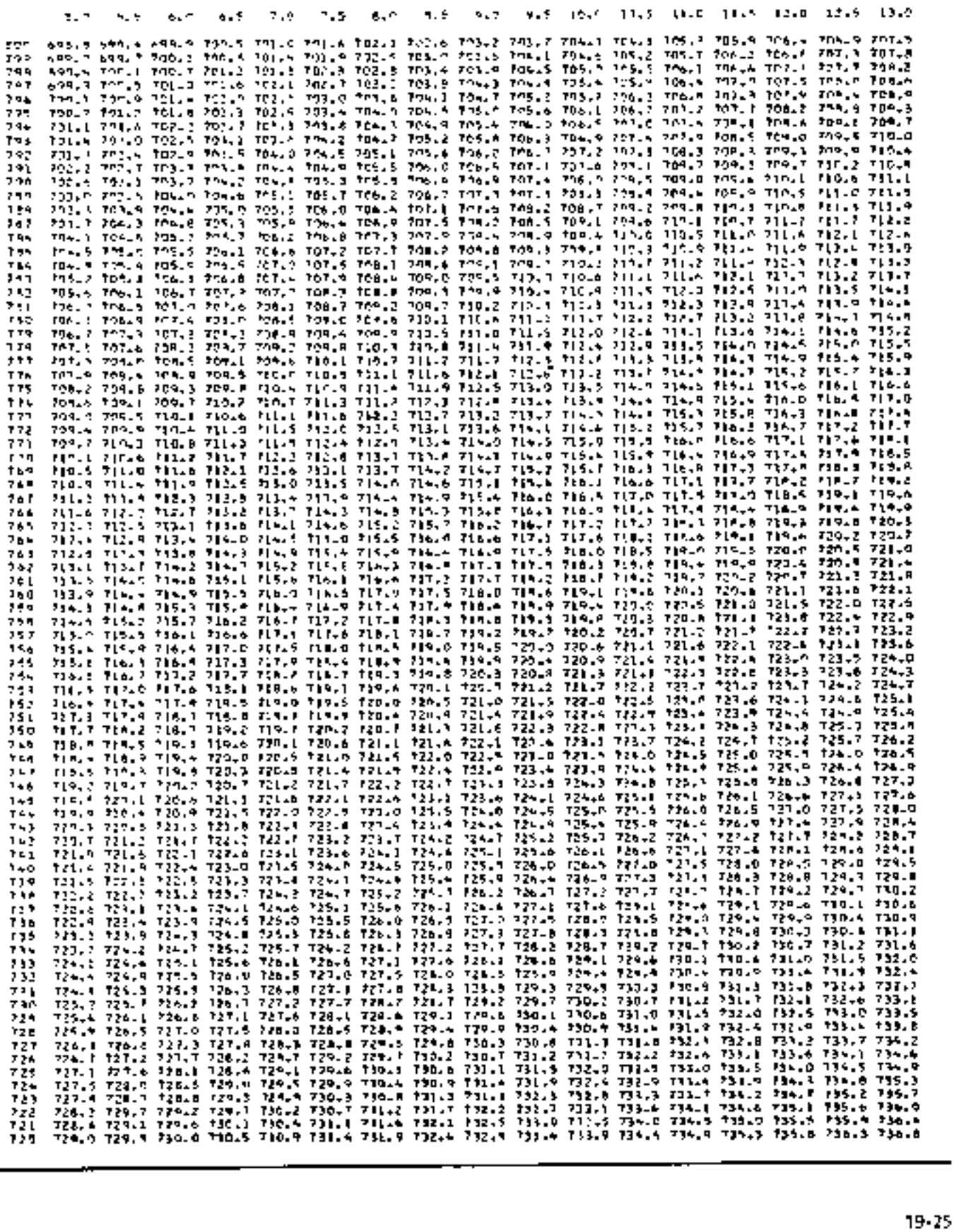


Table 19-21. Metric — Low Alt, Low-Mid Temp, High Humidity
(Temp = 13.5 to 21.5°C , Press = 720 to 800 mm, 80% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5
800	708.4	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.7	712.2	712.7	713.2	713.7	714.2	714.8	715.3	715.8	716.3
798	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.1	713.6	714.1	714.6	715.1	715.6	716.2	716.7
796	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
794	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
792	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
790	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
788	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
786	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
784	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
782	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
780	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
778	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
776	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
774	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
772	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
770	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
768	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
766	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
764	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
762	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
760	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
758	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
756	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
754	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
752	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
750	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
748	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
746	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
744	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
742	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
740	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
738	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
736	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
734	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
732	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
730	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
728	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
726	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
724	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
722	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5
720	708.4	708.4	708.4	708.4	710.1	710.6	711.1	711.6	712.0	712.5	713.0	713.5	714.0	714.5	715.0	715.5	716.0	716.5

Table 19-22. Metric — Low Alt, Mid Temp, High Humidity
(Temp = 22 to 30°C , Press = 720 to 800 mm, 80% Humidity)

TEMPERATURE IN DEGREES CELSIUS

	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
800	716.9	717.2	717.8	718.3	718.8	719.4	719.9	720.4	720.9	721.4	721.9	722.4	722.9	723.4	723.8	724.4	724.9
799	717.1	717.7	718.2	718.7	719.2	719.7	720.2	720.7	721.2	721.7	722.2	722.7	723.2	723.7	724.2	724.7	725.2
798	717.5	718.0	718.5	719.0	719.6	720.1	720.6	721.1	721.6	722.1	722.6	723.1	723.6	724.1	724.6	725.1	725.6
797	717.9	718.4	718.9	719.4	719.9	720.4	720.9	721.4	721.9	722.4	722.9	723.4	723.9	724.4	724.9	725.4	725.9
796	718.2	718.7	719.2	719.8	720.3	720.8	721.3	721.8	722.3	722.8	723.3	723.8	724.3	724.8	725.3	725.8	726.3
795	718.6	719.1	719.6	720.1	720.6	721.1	721.6	722.1	722.6	723.1	723.6	724.1	724.6	725.1	725.6	726.1	726.6
794	718.9	719.5	720.0	720.5	721.0	721.5	722.0	722.5	723.0	723.5	724.0	724.5	725.0	725.5	726.0	726.5	727.0
793	719.3	719.8	720.3	720.8	721.3	721.8	722.3	722.8	723.3	723.8	724.3	724.8	725.3	725.8	726.3	726.8	727.3
792	719.7	720.2	720.7	721.2	721.7	722.2	722.7	723.2	723.7	724.2	724.7	725.2	725.7	726.2	726.6	727.1	727.6
791	720.0	720.5	721.0	721.5	722.0	722.5	723.0	723.5	724.0	724.5	725.0	725.5	726.0	726.5	727.0	727.5	728.0
790	720.4	720.9	721.4	721.9	722.4	722.9	723.4	723.9	724.4	724.9	725.4	725.9	726.4	726.9	727.3	727.8	728.3
789	720.7	721.2	721.7	722.2	722.7	723.2	723.7	724.2	724.7	725.2	725.7	726.2	726.7	727.2	727.7	728.2	728.7
788	721.1	721.6	722.1	722.6	723.1	723.6	724.1	724.6	725.1	725.6	726.1	726.6	727.0	727.5	728.0	728.5	729.0
787	721.4	721.9	722.4	722.9	723.4	723.9	724.4	724.9	725.4	725.9	726.4	726.9	727.4	727.9	728.4	728.9	729.4
786	721.8	722.3	722.8	723.3	723.8	724.3	724.8	725.3	725.8	726.3	726.8	727.3	727.7	728.2	728.7	729.2	729.7
785	722.1	722.6	723.1	723.6	724.1	724.6	725.1	725.6	726.1	726.6	727.1	727.6	728.1	728.6	729.1	729.6	730.1
784	722.5	723.0	723.5	724.0	724.5	725.0	725.5	726.0	726.5	727.0	727.5	727.9	728.4	728.9	729.4	729.9	730.4
783	722.9	723.4	723.9	724.3	724.8	725.3	725.8	726.3	726.8	727.3	727.8	728.3	728.8	729.3	729.8	730.3	730.9
782	723.2	723.7	724.2	724.7	725.2	725.7	726.2	726.7	727.2	727.7	728.2	728.7	729.1	729.6	730.1	730.6	731.1
781	723.6	724.1	724.6	725.1	725.5	726.0	726.5	727.0	727.5	728.0	728.5	729.0	729.5	730.0	730.5	731.0	731.4
780	724.0	724.4	724.9	725.4	725.9	726.4	726.9	727.4	727.9	728.4	728.9	729.3	729.8	730.3	730.8	731.3	731.8
779	724.3	724.8	725.3	725.8	726.3	726.7	727.2	727.7	728.2	728.7	729.2	729.7	730.2	730.7	731.2	731.6	732.1
778	724.7	725.2	725.7	726.2	726.7	727.1	727.6	728.1	728.6	729.1	729.6	730.0	730.5	731.0	731.5	732.0	732.5
777	725.0	725.5	726.0	726.5	727.0	727.5	727.9	728.4	728.9	729.4	729.9	730.4	730.9	731.4	731.9	732.3	732.8
776	725.4	725.9	726.3	726.8	727.3	727.8	728.3	728.8	729.3	729.8	730.3	730.7	731.2	731.7	732.2	732.7	733.2
775	725.7	726.2	726.7	727.2	727.7	728.2	728.6	729.1	729.6	730.1	730.6	731.1	731.6	732.1	732.5	733.0	733.5
774	726.0	726.5	727.0	727.5	728.0	728.5	729.0	729.5	730.0	730.5	730.9	731.4	731.9	732.4	732.9	733.4	733.9
773	726.4	726.9	727.4	727.9	728.4	728.9	729.3	729.8	730.3	730.8	731.3	731.8	732.3	732.8	733.2	733.7	734.2
772	726.8	727.3	727.8	728.2	728.7	729.2	729.7	730.2	730.7	731.2	731.6	732.1	732.6	733.1	733.6	734.1	734.6
771	727.1	727.6	728.1	728.6	729.1	729.6	730.1	730.5	731.0	731.5	732.0	732.5	733.0	733.5	733.9	734.4	734.9
770	727.5	728.0	728.5	728.9	729.4	729.9	730.4	730.9	731.4	731.9	732.3	732.8	733.3	733.8	734.3	734.8	735.2
769	727.9	728.3	728.8	729.3	729.8	730.3	730.8	731.2	731.7	732.2	732.7	733.2	733.7	734.1	734.6	735.1	735.6
768	728.2	728.7	729.2	729.6	730.1	730.6	731.1	731.6	732.1	732.6	733.1	733.5	734.0	734.5	735.0	735.5	735.9
767	728.6	729.0	729.5	730.0	730.5	731.0	731.5	731.9	732.4	732.9	733.4	733.9	734.4	734.8	735.3	735.8	736.3
766	729.0	729.4	729.9	730.4	730.8	731.3	731.8	732.3	732.8	733.3	733.7	734.2	734.7	735.2	735.7	736.1	736.6
765	729.3	729.7	730.2	730.7	731.2	731.7	732.2	732.6	733.1	733.6	734.1	734.6	735.1	735.5	736.0	736.5	737.0
764	729.6	730.1	730.6	731.1	731.5	732.0	732.5	733.0	733.5	734.0	734.4	734.9	735.4	735.9	736.4	736.8	737.3
763	730.0	730.4	730.9	731.4	731.9	732.4	732.9	733.4	733.8	734.3	734.8	735.3	735.7	736.2	736.7	737.2	737.7
762	730.3	730.8	731.3	731.8	732.3	732.7	733.2	733.7	734.2	734.7	735.1	735.6	736.1	736.6	737.1	737.5	738.0
761	730.7	731.2	731.6	732.1	732.6	733.1	733.6	734.0	734.5	735.0	735.5	736.0	736.4	736.9	737.4	737.9	738.4
760	731.0	731.5	732.0	732.5	733.0	733.4	733.9	734.4	734.9	735.4	735.8	736.3	736.8	737.3	737.7	738.2	738.7
759	731.4	731.9	732.3	732.8	733.3	733.8	734.3	734.8	735.2	735.7	736.2	736.7	737.1	737.6	738.1	738.6	739.0
758	731.7	732.2	732.7	733.2	733.7	734.1	734.6	735.1	735.6	736.1	736.5	737.0	737.5	738.0	738.4	738.9	739.4
757	732.1	732.6	733.1	733.5	734.0	734.5	735.0	735.5	735.9	736.4	736.9	737.4	737.8	738.3	738.8	739.3	739.7
756	732.4	732.9	733.4	733.9	734.4	734.8	735.3	735.8	736.3	736.8	737.2	737.7	738.2	738.7	739.1	739.6	740.1
755	732.8	733.3	733.8	734.2	734.7	735.2	735.7	736.2	736.6	737.1	737.6	738.1	738.5	739.0	739.5	740.0	740.4
754	733.1	733.6	734.1	734.6	735.1	735.6	736.0	736.5	737.0	737.5	737.9	738.4	738.9	739.4	739.8	740.3	740.8
753	733.5	734.0	734.5	734.9	735.4	735.9	736.4	736.9	737.3	737.8	738.3	738.8	739.2	739.7	740.2	740.6	741.1
752	733.9	734.3	734.8	735.3	735.8	736.3	736.7	737.2	737.7	738.2	738.6	739.1	739.6	740.1	740.5	741.0	741.5
751	734.2	734.7	735.2	735.7	736.1	736.6	737.1	737.6	738.0	738.5	739.0	739.5	739.9	740.4	740.9	741.3	741.8
750	734.6	735.1	735.5	736.0	736.5	737.0	737.4	737.9	738.4	738.9	739.3	739.8	740.3	740.7	741.2	741.7	742.2
749	734.9	735.4	735.9	736.4	736.8	737.3	737.8	738.3	738.8	739.2	739.7	740.2	740.6	741.1	741.6	742.0	742.5
748	735.3	735.8	736.2	736.7	737.2	737.7	738.1	738.6	739.1	739.6	740.0	740.5	741.0	741.4	741.9	742.4	742.8
747	735.6	736.1	736.6	737.1	737.5	738.0	738.5	739.0	739.4	739.9	740.4	740.8	741.3	741.8	742.3	742.7	743.2
746	736.0	736.4	736.9	737.4	737.9	738.4	738.8	739.3	739.8	740.3	740.7	741.2	741.7	742.2	742.6	743.1	743.5
745	736.3	736.8	737.3	737.8	738.2	738.7	739.2	739.7	740.1	740.6	741.1	741.5	742.0	742.5	742.9	743.4	743.9
744	736.7	737.2	737.7	738.1	738.6	739.1	739.5	740.0	740.5	741.0	741.4	741.9	742.4	742.8	743.3	743.8	744.2
743	737.1	737.5	738.0	738.5	738.9	739.4	739.9	740.4	740.8	741.3	741.8	742.2	742.7	743.2	743.6	744.1	744.6
742	737.4	737.9	738.4	738.8	739.3	739.8	740.2	740.7	741.2	741.7	742.1	742.6	743.1	743.5	744.0	744.5	744.9
741	737.8	738.2	738.7	739.2	739.7	740.1	740.6	741.1	741.5	742.0	742.5	742.9	743.4	743.9	744.3	744.8	745.3
740	738.1	738.6	739.1	739.5	740.0	740.5	741.0	741.4	741.9	742.4	742.8	743.3	743.8	744.2	744.7	745.1	745.6
739	738.5	739.0	739.4	739.9	740.4	740.8	741.3	741.8	742.2	742.7	743.2	743.6	744.1	744.6	745.0	745.5	746.0
738	738.8	739.3	739.8	740.2	740.7	741.2	741.7	742.1	742.6	743.1	743.5	744.0	744.5	744.9	745.4	745.8	746.3
737	739.2	739.7	740.1	740.6	741.1	741.5	742.0	742.5	742.9	743.4	743.9	744.3	744.8	745.3	745.7	746.2	746.7
736	739.6	740.0	740.5	741.0	741.4	741.9	742.4	742.8	743.3	743.8	744.2	744.7	745.1	745.6	746.1	746.5	747.0
735	739.9	740.4	740.9	741.3	741.8	742.2	742.7	743.2	743.6	744.1	744.6	745.0	745.5	746.0	746.4	746.9	747.3
734	740.3	740.7	741.2	741.7	742.1	742.6	743.1	743.5	744.0	744.5	744.9	745.4	745.8	746.3	746.8	747.2	747.7
733	740.6	741.1	741.6	742.0	742.5	743.0	743.4	743.9	744.4	744.8	745.3	745.7	746.2	746.7	747.1	747.6	748.0
732	741.0	741.4	741.9	742.4	742.8	743.3	743.8	744.2	744.7	745.2	745.6	746.1	746.5	747.0	747.5	747.9	748.4
731	741.3	741.8	742.3	742.7	743.2	743.7	744.1	744.6	745.0	745.5	746.0	746.4	746.9	747.3	747.8	748.3	748.7
730	741.7	742.1	742.6	743.1	743.6	744.0	744.5	745.0	745.4	745.9	746.3	746.8	747.2	747.7	748.2	748.6	749.1
729	742.0	742.5	743.0	743.4	743.9	744.4	744.8	745.3	745.7	746.2	746.7	747.1	747.6	748.0	748.5	749.0	749.4
728	742.4	742.8	743.3	743.8	744.2	744.7	745.2	745.6	746.1	746.6	747.0	747.5	747.9	748.4	748.8	749.3	749.8
727	742.7	743.2	743.7	744.1	744.6	745.1	745.5	746.0	746.5	746.9	747.4	747.8	748.3	748.7	749.2	749.7	750.1
726	743.1	743.6	744.0	744.5	744.9	745.4	745.9	746.3	746.8	747.3	747.7	748.2	748.6	749.1	749.5	750.0	750.5
725	743.5	743.9	744.4	744.8	745.3	745.8	746.2	746.7	747.1	747.6	748.1	748.5	749.0	749.4	749.9	750.3	750.8
724	743.8	744.3	744.7	745.2	745.7	746.1	746.6	747.0	747.5	748.0	748.4	748.9	749.3	749.8	750.2	750.7	751.2
723	744.2	744.6	745.1	745.5	746.0	746.5	746.9	747.4	747.8	748.3	748.8	749.2	749.7	750.1	750.6	751.0	751.5
722	744.5	745.0	745.4	745.9	746.4	746.8	747.3	747.7	748.2	748.7	749.1	749.6	750.0	750.5	750.9	751.4	751.8
721	744.9	745.3	745.8	746.3	746.7	747.2	747.6	748.1	748.6	749.0	749.5	749.9	750.4	750.8	751.3	751.7	752.2
720	745.2	745.7	746.1	746.6	747.1	747.5	748.0	748.4	748.9	749.4	749.8	750.3	750.7	751.2	751.6	752.1	752.5

RADIOMETRIC PRESSURE IN MILLIMETERS OF MERCURY

Table 19-23. Metric — Low Alt, High-Mid Temp, High Humidity
(Temp = 30.5 to 38.5°C , Press = 720 to 800 mm, 80% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

	30.5	31.0	31.5	32.0	32.5	33.0	33.5	34.0	34.5	35.0	35.5	36.0	36.5	37.0	37.5	38.0	38.5
800	725.4	725.9	726.4	726.9	727.4	727.9	728.3	728.9	729.1	729.8	730.3	730.8	731.3	731.8	732.3	732.8	733.3
799	725.7	726.2	726.7	727.2	727.7	728.2	728.7	729.2	729.7	730.2	730.7	731.2	731.7	732.2	732.6	733.1	733.6
798	726.1	726.6	727.1	727.5	728.0	728.5	729.0	729.5	730.0	730.5	731.0	731.5	732.0	732.5	733.0	733.4	734.0
797	726.4	726.9	727.4	727.9	728.4	728.9	729.4	729.9	730.4	730.9	731.4	731.9	732.4	732.8	733.3	733.8	734.3
796	726.7	727.2	727.7	728.2	728.7	729.2	729.7	730.2	731.7	731.2	731.7	732.2	732.7	733.2	733.7	734.1	734.6
795	727.1	727.6	728.1	728.6	729.1	729.6	730.1	730.6	731.1	731.6	732.1	732.6	733.1	733.6	734.1	734.5	735.0
794	727.4	727.9	728.4	728.9	729.4	729.9	730.4	730.9	731.4	731.9	732.4	732.9	733.4	733.9	734.3	734.8	735.3
793	727.8	728.3	728.8	729.3	729.8	730.2	730.7	731.2	731.7	732.2	732.7	733.2	733.7	734.2	734.7	735.2	735.7
792	728.1	728.6	729.1	729.6	730.1	730.6	731.1	731.6	732.1	732.6	733.0	733.5	734.0	734.5	735.0	735.5	736.0
791	728.5	729.0	729.5	730.0	730.4	730.9	731.4	731.9	732.4	732.9	733.4	733.9	734.4	734.9	735.3	735.8	736.3
790	728.8	729.3	729.8	730.3	730.8	731.3	731.8	732.3	732.7	733.2	733.7	734.2	734.7	735.2	735.7	736.2	736.7
789	729.2	729.7	730.1	730.6	731.1	731.6	732.1	732.6	733.1	733.6	734.1	734.6	735.0	735.5	736.0	736.5	737.0
788	729.5	730.0	730.5	731.0	731.5	732.0	732.5	733.0	733.5	733.9	734.4	734.9	735.4	735.9	736.4	736.8	737.3
787	729.9	730.3	730.8	731.3	731.8	732.3	732.8	733.3	733.8	734.3	734.7	735.2	735.7	736.2	736.7	737.2	737.7
786	730.2	730.7	731.2	731.7	732.2	732.6	733.1	733.6	734.1	734.6	735.1	735.6	736.1	736.5	737.0	737.5	738.0
785	730.5	731.0	731.5	732.0	732.5	733.0	733.5	734.0	734.4	734.9	735.4	735.9	736.4	736.9	737.4	737.9	738.3
784	730.9	731.4	731.9	732.4	732.8	733.3	733.8	734.2	734.8	735.3	735.8	736.3	736.8	737.3	737.8	738.2	738.7
783	731.2	731.7	732.2	732.7	733.2	733.7	734.2	734.6	735.1	735.6	736.1	736.6	737.1	737.6	738.0	738.5	739.0
782	731.6	732.1	732.6	733.0	733.5	734.0	734.5	735.0	735.5	736.0	736.4	736.9	737.4	737.9	738.4	738.8	739.3
781	731.9	732.4	732.9	733.4	733.9	734.4	734.9	735.3	735.8	736.3	736.9	737.3	737.8	738.2	738.7	739.2	739.7
780	732.3	732.8	733.2	733.7	734.2	734.7	735.2	735.7	736.2	736.6	737.1	737.6	738.1	738.6	739.1	739.5	740.0
779	732.6	733.1	733.6	734.1	734.6	735.0	735.5	736.0	736.5	737.0	737.5	737.9	738.4	738.9	739.4	739.9	740.4
778	733.0	733.4	733.9	734.4	734.9	735.4	735.9	736.3	736.8	737.3	737.8	738.3	738.8	739.3	739.7	740.2	740.7
777	733.3	733.8	734.3	734.8	735.2	735.7	736.2	736.7	737.2	737.7	738.1	738.6	739.1	739.6	740.1	740.5	741.0
776	733.7	734.1	734.6	735.1	735.6	736.1	736.6	737.0	737.5	738.0	738.5	739.0	739.4	739.9	740.4	740.9	741.4
775	734.0	734.5	735.0	735.4	735.9	736.4	736.9	737.4	737.9	738.3	738.8	739.3	739.8	740.3	740.8	741.2	741.7
774	734.3	734.8	735.3	735.8	736.3	736.8	737.2	737.7	738.2	738.7	739.2	739.6	740.1	740.6	741.1	741.6	742.0
773	734.7	735.2	735.7	736.1	736.6	737.1	737.6	738.1	738.5	739.0	739.5	740.0	740.5	740.9	741.4	741.9	742.4
772	735.0	735.5	736.0	736.5	737.0	737.4	737.9	738.4	738.9	739.4	739.9	740.3	740.8	741.3	741.8	742.3	742.7
771	735.4	735.9	736.4	736.8	737.3	737.8	738.3	738.8	739.3	739.7	740.2	740.7	741.2	741.6	742.1	742.6	743.0
770	735.7	736.2	736.7	737.2	737.6	738.1	738.6	739.1	739.6	740.0	740.5	741.0	741.5	741.9	742.4	742.9	743.4
769	736.1	736.5	737.0	737.5	738.0	738.5	738.9	739.4	739.9	740.4	740.9	741.3	741.8	742.3	742.8	743.2	743.7
768	736.4	736.9	737.4	737.8	738.3	738.8	739.3	739.8	740.2	740.7	741.2	741.7	742.1	742.6	743.1	743.6	744.1
767	736.8	737.2	737.7	738.2	738.7	739.1	739.6	740.1	740.6	741.1	741.6	742.0	742.5	743.0	743.4	743.9	744.4
766	737.1	737.6	738.1	738.5	739.0	739.5	740.0	740.4	740.9	741.4	741.9	742.3	742.8	743.3	743.8	744.3	744.7
765	737.5	737.9	738.4	738.9	739.4	739.8	740.3	740.8	741.3	741.7	742.2	742.7	743.2	743.6	744.1	744.6	745.1
764	737.8	738.3	738.8	739.2	739.7	740.2	740.7	741.2	741.6	742.1	742.6	743.0	743.5	744.0	744.5	744.9	745.4
763	738.1	738.6	739.1	739.6	740.0	740.5	741.0	741.5	741.9	742.4	742.9	743.4	743.8	744.3	744.8	745.3	745.7
762	738.5	739.0	739.4	739.9	740.4	740.9	741.3	741.8	742.3	742.8	743.2	743.7	744.2	744.7	745.1	745.6	746.1
761	738.9	739.3	739.8	740.3	740.7	741.2	741.7	742.2	742.6	743.1	743.6	744.0	744.5	745.0	745.5	745.9	746.4
760	739.2	739.6	740.1	740.6	741.1	741.5	742.0	742.5	743.0	743.4	743.9	744.4	744.9	745.3	745.8	746.3	746.7
759	739.5	740.0	740.5	740.9	741.4	741.9	742.4	742.8	743.3	743.8	744.2	744.7	745.2	745.7	746.1	746.6	747.1
758	739.9	740.3	740.8	741.3	741.8	742.2	742.7	743.2	743.6	744.1	744.6	745.1	745.6	746.0	746.5	746.9	747.4
757	740.2	740.7	741.2	741.6	742.1	742.6	743.0	743.5	744.0	744.5	744.9	745.4	745.9	746.3	746.8	747.3	747.8
756	740.6	741.0	741.5	742.0	742.4	742.9	743.4	743.9	744.3	744.8	745.3	745.7	746.2	746.7	747.1	747.6	748.1
755	741.0	741.4	741.9	742.3	742.8	743.3	743.7	744.2	744.7	745.1	745.6	746.1	746.6	747.0	747.5	748.0	748.5
754	741.3	741.7	742.2	742.7	743.1	743.6	744.1	744.5	745.0	745.5	745.9	746.4	746.9	747.4	747.8	748.3	748.8
753	741.6	742.1	742.5	743.0	743.5	743.9	744.4	744.9	745.3	745.8	746.3	746.8	747.2	747.7	748.2	748.6	749.1
752	741.9	742.4	742.9	743.3	743.8	744.3	744.8	745.2	745.7	746.2	746.6	747.1	747.6	748.0	748.5	749.0	749.4
751	742.3	742.7	743.2	743.7	744.2	744.6	745.1	745.6	746.0	746.5	747.0	747.4	747.9	748.4	748.8	749.3	749.8
750	742.6	743.1	743.6	744.0	744.5	745.0	745.4	745.9	746.4	746.8	747.3	747.8	748.2	748.7	749.2	749.6	750.1
749	743.0	743.4	743.9	744.4	744.8	745.3	745.8	746.2	746.7	747.2	747.6	748.1	748.6	749.0	749.5	750.0	750.4
748	743.3	743.8	744.3	744.7	745.2	745.7	746.1	746.6	747.1	747.5	748.0	748.5	748.9	749.4	749.8	750.3	750.8
747	743.7	744.1	744.6	745.1	745.5	746.0	746.5	746.9	747.4	747.9	748.3	748.8	749.3	749.7	750.2	750.7	751.1
746	744.0	744.5	744.9	745.4	745.9	746.3	746.8	747.3	747.7	748.2	748.7	749.1	749.6	750.1	750.5	751.0	751.5
745	744.4	744.8	745.3	745.7	746.2	746.7	747.1	747.6	748.1	748.6	749.0	749.5	749.9	750.4	750.9	751.3	751.8
744	744.7	745.2	745.6	746.1	746.6	747.0	747.5	748.0	748.4	748.9	749.3	749.8	750.3	750.7	751.2	751.7	752.1
743	745.0	745.5	746.0	746.4	746.9	747.4	747.8	748.3	748.8	749.2	749.7	750.1	750.6	751.1	751.5	752.0	752.5
742	745.4	745.9	746.3	746.8	747.2	747.7	748.2	748.6	749.1	749.6	750.0	750.5	750.9	751.4	751.9	752.3	752.8
741	745.7	746.2	746.7	747.1	747.6	748.0	748.5	749.0	749.4	749.9	750.4	750.8	751.3	751.7	752.2	752.7	753.1
740	746.1	746.5	747.0	747.5	747.9	748.4	748.9	749.3	749.8	750.2	750.7	751.2	751.6	752.1	752.6	753.0	753.5
739	746.4	746.9	747.3	747.8	748.3	748.7	749.2	749.7	750.1	750.6	751.0	751.5	752.0	752.4	752.9	753.4	753.8
738	746.8	747.2	747.7	748.2	748.6	749.1	749.6	750.0	750.5	750.9	751.4	751.8	752.3	752.8	753.2	753.7	754.1
737	747.1	747.6	748.0	748.5	749.0	749.4	749.9	750.3	750.8	751.3	751.7	752.2	752.7	753.1	753.6	754.0	754.5
736	747.5	747.9	748.4	748.8	749.3	749.8	750.2	750.7	751.1	751.6	752.1	752.5	753.0	753.5	753.9	754.4	754.8
735	747.8	748.3	748.7	749.2	749.6	750.1	750.6	751.0	751.5	751.9	752.4	752.9	753.3	753.8	754.2	754.7	755.2
734	748.1	748.6	749.1	749.5	750.0	750.4	750.9	751.4	751.8	752.3	752.7	753.2	753.7	754.1	754.6	755.0	755.5
733	748.5	749.0	749.4	749.9	750.3	750.8	751.2	751.7	752.2	752.6	753.1	753.5	754.0	754.4	754.9	755.4	755.8
732	748.8	749.3	749.8	750.2	750.7	751.2	751.6	752.0	752.5	753.0	753.4	753.9	754.3	754.8	755.2	755.7	756.2
731	749.2	749.6	750.1	750.6	751.0	751.5	751.9	752.4	752.8	753.3	753.8	754.2	754.7	755.1	755.6	756.0	756.5
730	749.5	750.0	750.4	750.9	751.4	751.8	752.3	752.7	753.2	753.6	754.1	754.6	755.0	755.5	755.9	756.4	756.8
729	749.9	750.3	750.8	751.2	751.7	752.2	752.6	753.1	753.5	754.0	754.4	754.9	755.3	755.8	756.3	756.7	757.2
728	750.2	750.7	751.1	751.6	752.0	752.5	753.0	753.4	753.9	754.3	754.8	755.2	755.7	756.1	756.6	757.0	757.5
727	750.6	751.0	751.5	751.9	752.4	752.8	753.3	753.8	754.2	754.7	755.1	755.6	756.0	756.5	756.9	757.4	757.8
726	750.9	751.4	751.8	752.3	752.7	753.2	753.6	754.1	754.5	755.0	755.5	755.9	756.4	756.8	757.3	757.7	758.2
725	751.3	751.7	752.2	752.6	753.1	753.5	754.0	754.4	754.9	755.3	755.8	756.2	756.7	757.2	757.6	758.1	758.5
724	751.6	752.1	752.5	753.0	753.4	753.9	754.3	754.8	755.2	755.7	756.1	756.6	757.0	757.5	757.9	758.4	758.8
723	751.9	752.4	752.9	753.3	753.8	754.2	754.7	755.1	755.6	756.0	756.5	756.9	757.4	757.8	758.3	758.7	759.2
722	752.3	752.7	753.2	753.6	754.1	754.6	755.0	755.5	755.9	756.4	756.8	757.3	757.7	758.2	758.6	759.1	759.5
721	752.6	753.1	753.5	754.0	754.4	754.9	755.3	755.8	756.2	756.7	757.2	757.6	758.1	758.5	759.0	759.4	759.9
720	753.0	753.4	753.9	754.3	754.8	755.2	755.7	756.1	756.6	757.0	757.5	757.9	758.4	758.8	759.3	759.7	760.2

Table 19-24. Metric — High Air, Low Temp, High Humidity
(Temp = 5 to 13°C , Press = 640 to 720 mm, 80% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

Table 19-25. Metric — High Alt, Low-Mid Temp, High Humidity
(Temp = 13.5 to 21.5°C , Press = 640 to 720 mm, 80% Humidity)

TEMPERATURE IN DEGREES CELSIUS

BAROMETRIC PRESSURE IN MILLIMETERS OF MERCURY

	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5
720	737.3	737.7	738.2	738.7	739.2	739.6	740.1	740.6	741.0	741.5	742.0	742.4	742.9	743.4	743.8	744.3	744.8
719	737.6	738.1	738.6	739.0	739.5	740.0	740.5	740.9	741.4	741.9	742.3	742.8	743.3	743.7	744.2	744.7	745.1
718	738.0	738.5	738.9	739.4	739.9	740.4	740.8	741.3	741.8	742.2	742.7	743.2	743.6	744.1	744.6	745.0	745.5
717	738.4	738.8	739.3	739.8	740.2	740.7	741.2	741.7	742.1	742.6	743.1	743.5	744.0	744.5	744.9	745.4	745.8
716	738.7	739.2	739.7	740.1	740.6	741.1	741.5	742.0	742.5	743.0	743.4	743.9	744.3	744.8	745.3	745.7	746.2
715	739.1	739.6	740.0	740.5	741.0	741.5	741.9	742.4	742.8	743.3	743.8	744.2	744.7	745.2	745.6	746.1	746.5
714	739.5	739.9	740.4	740.9	741.3	741.8	742.3	742.7	743.2	743.7	744.1	744.6	745.1	745.5	746.0	746.4	746.9
713	739.9	740.3	740.8	741.2	741.7	742.2	742.6	743.1	743.6	744.0	744.5	745.0	745.4	745.9	746.3	746.8	747.3
712	740.2	740.7	741.1	741.6	742.1	742.5	743.0	743.5	743.9	744.4	744.9	745.3	745.8	746.2	746.7	747.2	747.6
711	740.6	741.0	741.5	742.0	742.4	742.9	743.4	743.8	744.3	744.8	745.2	745.7	746.1	746.6	747.1	747.5	748.0
710	740.9	741.4	741.9	742.3	742.8	743.3	743.7	744.2	744.7	745.1	745.6	746.0	746.5	747.0	747.4	747.9	748.4
709	741.3	741.7	742.2	742.7	743.2	743.6	744.1	744.5	745.0	745.5	745.9	746.4	746.9	747.3	747.8	748.2	748.7
708	741.6	742.1	742.6	743.0	743.5	744.0	744.4	744.9	745.4	745.8	746.3	746.8	747.2	747.7	748.1	748.6	749.0
707	742.0	742.5	742.9	743.4	743.9	744.3	744.8	745.3	745.7	746.2	746.7	747.1	747.6	748.0	748.5	748.9	749.4
706	742.4	742.8	743.3	743.8	744.2	744.7	745.2	745.6	746.1	746.6	747.0	747.5	747.9	748.4	748.8	749.3	749.7
705	742.7	743.2	743.7	744.1	744.6	745.1	745.5	746.0	746.5	746.9	747.4	747.8	748.3	748.7	749.2	749.6	750.1
704	743.1	743.6	744.0	744.5	745.0	745.4	745.9	746.4	746.8	747.3	747.7	748.2	748.6	749.1	749.6	750.0	750.5
703	743.5	743.9	744.4	744.9	745.3	745.8	746.3	746.7	747.2	747.6	748.1	748.5	749.0	749.5	749.9	750.4	750.8
702	743.9	744.3	744.8	745.2	745.7	746.2	746.6	747.1	747.5	748.0	748.4	748.9	749.4	749.8	750.3	750.7	751.2
701	744.2	744.7	745.1	745.6	746.1	746.5	747.0	747.4	747.9	748.4	748.8	749.3	749.7	750.2	750.6	751.1	751.5
700	744.6	745.0	745.5	746.0	746.4	746.9	747.3	747.8	748.3	748.7	749.2	749.6	750.1	750.5	751.0	751.4	751.9
699	744.9	745.4	745.9	746.3	746.8	747.2	747.7	748.2	748.6	749.1	749.5	750.0	750.4	750.9	751.3	751.8	752.2
698	745.3	745.8	746.2	746.7	747.1	747.6	748.1	748.5	749.0	749.4	749.9	750.3	750.8	751.2	751.7	752.1	752.6
697	745.7	746.1	746.6	747.1	747.5	748.0	748.4	748.9	749.3	749.8	750.2	750.7	751.1	751.6	752.0	752.5	752.9
696	746.0	746.5	747.0	747.4	747.9	748.3	748.8	749.2	749.7	750.2	750.6	751.1	751.5	752.0	752.4	752.9	753.3
695	746.4	746.9	747.3	747.8	748.2	748.7	749.1	749.6	750.1	750.5	751.0	751.4	751.9	752.3	752.8	753.2	753.7
694	746.8	747.2	747.7	748.1	748.6	749.1	749.5	750.0	750.4	750.9	751.3	751.8	752.2	752.7	753.1	753.6	754.0
693	747.1	747.6	748.0	748.5	749.0	749.4	749.9	750.3	750.8	751.2	751.7	752.1	752.6	753.0	753.5	753.9	754.4
692	747.5	748.0	748.4	748.9	749.3	749.8	750.2	750.7	751.1	751.6	752.0	752.5	752.9	753.4	753.8	754.3	754.7
691	747.9	748.3	748.8	749.2	749.7	750.1	750.6	751.0	751.5	752.0	752.4	752.8	753.3	753.7	754.2	754.6	755.1
690	748.2	748.7	749.1	749.6	750.1	750.5	751.0	751.4	751.9	752.3	752.8	753.2	753.7	754.1	754.6	755.0	755.4
689	748.6	749.1	749.5	750.0	750.4	750.9	751.3	751.8	752.2	752.7	753.1	753.6	754.0	754.5	754.9	755.3	755.8
688	749.0	749.4	749.9	750.3	750.8	751.2	751.7	752.1	752.6	753.0	753.5	753.9	754.3	754.8	755.2	755.7	756.1
687	749.3	749.8	750.2	750.7	751.1	751.6	752.0	752.5	752.9	753.4	753.8	754.2	754.7	755.1	755.6	756.0	756.5
686	749.7	750.1	750.6	751.0	751.5	751.9	752.4	752.8	753.3	753.7	754.2	754.6	755.0	755.5	755.9	756.4	756.8
685	750.1	750.5	751.0	751.4	751.9	752.3	752.8	753.2	753.7	754.1	754.6	755.0	755.4	755.9	756.3	756.8	757.2
684	750.4	750.9	751.3	751.8	752.2	752.7	753.1	753.6	754.0	754.5	754.9	755.4	755.8	756.2	756.7	757.1	757.6
683	750.8	751.2	751.7	752.1	752.6	753.0	753.5	753.9	754.4	754.8	755.3	755.7	756.2	756.6	757.0	757.5	757.9
682	751.2	751.6	752.1	752.5	753.0	753.4	753.9	754.3	754.7	755.2	755.6	756.1	756.5	757.0	757.4	757.8	758.3
681	751.5	752.0	752.4	752.9	753.3	753.8	754.2	754.7	755.1	755.6	756.0	756.4	756.9	757.3	757.8	758.2	758.6
680	751.9	752.3	752.8	753.2	753.7	754.1	754.6	755.0	755.5	755.9	756.4	756.8	757.2	757.7	758.1	758.6	759.0
679	752.3	752.7	753.2	753.6	754.0	754.5	754.9	755.4	755.8	756.3	756.7	757.2	757.6	758.0	758.5	758.9	759.4
678	752.6	753.1	753.5	754.0	754.4	754.9	755.3	755.7	756.2	756.6	757.1	757.5	758.0	758.4	758.8	759.3	759.7
677	753.0	753.4	753.9	754.3	754.8	755.2	755.7	756.1	756.5	757.0	757.4	757.9	758.3	758.8	759.2	759.6	760.1
676	753.3	753.8	754.2	754.7	755.1	755.6	756.0	756.5	756.9	757.4	757.8	758.2	758.7	759.1	759.5	760.0	760.4
675	753.7	754.2	754.6	755.1	755.5	756.0	756.4	756.8	757.3	757.7	758.2	758.6	759.0	759.5	759.9	760.3	760.8
674	754.1	754.5	755.0	755.4	755.9	756.3	756.7	757.2	757.6	758.1	758.5	758.9	759.4	759.8	760.3	760.7	761.1
673	754.4	754.9	755.3	755.8	756.2	756.7	757.1	757.6	758.0	758.4	758.9	759.3	759.7	760.2	760.6	761.1	761.5
672	754.8	755.3	755.7	756.1	756.6	757.0	757.5	757.9	758.4	758.8	759.2	759.7	760.1	760.5	761.0	761.4	761.8
671	755.1	755.6	756.0	756.5	757.0	757.4	757.8	758.3	758.7	759.2	759.6	760.0	760.5	760.9	761.3	761.9	762.2
670	755.5	756.0	756.4	756.9	757.3	757.8	758.2	758.6	759.1	759.5	759.9	760.4	760.8	761.3	761.7	762.1	762.6
669	755.9	756.4	756.8	757.2	757.7	758.1	758.6	759.0	759.4	759.9	760.3	760.7	761.2	761.6	762.0	762.5	762.9
668	756.3	756.7	757.2	757.6	758.0	758.5	758.9	759.4	759.8	760.2	760.7	761.1	761.5	762.0	762.4	762.8	763.3
667	756.6	757.1	757.5	758.0	758.4	758.8	759.3	759.7	760.2	760.6	761.0	761.5	761.9	762.3	762.8	763.2	763.6
666	757.0	757.4	757.9	758.3	758.8	759.2	759.6	760.1	760.5	761.0	761.4	761.8	762.3	762.7	763.1	763.5	764.0
665	757.4	757.8	758.3	758.7	759.1	759.6	760.0	760.4	760.9	761.3	761.7	762.2	762.6	763.0	763.4	763.9	764.3
664	757.7	758.2	758.6	759.1	759.5	759.9	760.4	760.8	761.2	761.7	762.1	762.5	763.0	763.4	763.8	764.3	764.7
663	758.1	758.5	759.0	759.4	759.8	760.3	760.7	761.2	761.6	762.0	762.5	762.9	763.3	763.8	764.2	764.6	765.0
662	758.5	758.9	759.3	759.8	760.2	760.7	761.1	761.5	762.0	762.4	762.8	763.3	763.7	764.1	764.6	765.0	765.4
661	758.8	759.3	759.7	760.1	760.6	761.0	761.5	761.9	762.3	762.8	763.2	763.6	764.0	764.5	764.9	765.3	765.8
660	759.2	759.6	760.1	760.5	760.9	761.4	761.8	762.2	762.7	763.1	763.5	764.0	764.4	764.8	765.3	765.7	766.1
659	759.5	760.0	760.4	760.9	761.3	761.7	762.2	762.6	763.0	763.5	763.9	764.3	764.8	765.2	765.6	766.0	766.5
658	759.9	760.4	760.8	761.2	761.7	762.1	762.5	763.0	763.4	763.8	764.3	764.7	765.1	765.5	766.0	766.4	766.8
657	760.3	760.7	761.2	761.6	762.0	762.5	762.9	763.3	763.8	764.2	764.6	765.0	765.4	765.9	766.3	766.8	767.2
656	760.7	761.1	761.5	762.0	762.4	762.8	763.3	763.7	764.1	764.6	765.0	765.4	765.8	766.3	766.7	767.1	767.5
655	761.0	761.5	761.9	762.3	762.8	763.2	763.6	764.1	764.5	764.9	765.3	765.8	766.2	766.6	767.0	767.5	767.9
654	761.4	761.8	762.3	762.7	763.1	763.6	764.0	764.4	764.8	765.3	765.7	766.1	766.5	767.0	767.4	767.8	768.2
653	761.8	762.2	762.6	763.1	763.5	763.9	764.4	764.8	765.2	765.6	766.1	766.5	766.9	767.3	767.8	768.2	768.6
652	762.1	762.6	763.0	763.4	763.9	764.3	764.7	765.1	765.6	766.0	766.4	766.8	767.3	767.7	768.1	768.5	769.0
651	762.5	762.9	763.4	763.8	764.2	764.6	765.1	765.5	765.9	766.4	766.8	767.2	767.6	768.0	768.5	768.9	769.3
650	762.9	763.3	763.7	764.1	764.6	765.0	765.4	765.9	766.3	766.7	767.1	767.6	768.0	768.4	768.8	769.2	769.7
649	763.2	763.7	764.1	764.5	764.9	765.4	765.8	766.2	766.6	767.1	767.5	767.9	768.3	768.8	769.2	769.6	770.0
648	763.6	764.0	764.4	764.9	765.3	765.7	766.2	766.6	767.0	767.4	767.9	768.3	768.7	769.1	769.5	770.0	770.4
647	764.0	764.4	764.8	765.2	765.7	766.1	766.5	766.9	767.4	767.8	768.2	768.6	769.1	769.5	769.9	770.3	770.7
646	764.3	764.7	765.2	765.6	766.0	766.4	766.9	767.3	767.7	768.2	768.6	769.0	769.4	769.9	770.3	770.7	771.1
645	764.7	765.1	765.5	766.0	766.4	766.8	767.2	767.7	768.1	768.5	768.9	769.4	769.8	770.2	770.6	771.0	771.4
644	765.1	765.5	765.9	766.3	766.8	767.2	767.6	768.0	768.5	768.9	769.3	769.7	770.1	770.6	771.0	771.4	771.8
643	765.4	765.8	766.3	766.7	767.1	767.5	768.0	768.4	768.8	769.2	769.7	770.1	770.5	770.9	771.3	771.7	772.2
642	765.8	766.2	766.6	767.1	767.5	767.9	768.3	768.8	769.2	769.6	770.0	770.4	770.8	771.3	771.7	772.1	772.5
641	766.1	766.6	767.0	767.4	767.8	768.3	768.7	769.1	769.5	770.0	770.4	770.8	771.2	771.6	772.0	772.5	772.9
640	766.5	766.9	767.4	767.8	768.2	768.6	769.1	769.5	769.9	770.3	770.7	771.1	771.4	772.0	772.4	772.8	773.2

Table 19-26. Metric — High Alt, Mid Temp, High Humidity
(Temp = 22 to 30°C , Press = 640 to 720 mm, 80% Humidity)

TEMPERATURE IN DEGREES CELSIUS

	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
720	745.2	745.7	746.1	746.6	747.1	747.5	748.0	748.4	748.9	749.4	749.8	750.3	750.7	751.2	751.6	752.1	752.6
719	745.4	746.0	746.4	746.9	747.4	747.9	748.3	748.8	749.2	749.7	750.2	750.6	751.1	751.6	752.0	752.5	752.9
718	745.9	746.4	746.9	747.3	747.8	748.2	748.7	749.1	749.6	750.1	750.5	751.0	751.4	751.9	752.4	752.8	753.3
717	746.1	746.6	747.2	747.7	748.1	748.6	749.0	749.5	749.9	750.4	750.9	751.3	751.8	752.2	752.7	753.1	753.6
716	746.6	747.1	747.6	748.0	748.5	749.0	749.4	749.9	750.3	750.8	751.3	751.7	752.2	752.7	753.1	753.6	754.0
715	747.0	747.5	747.9	748.4	748.9	749.3	749.8	750.2	750.7	751.1	751.6	752.1	752.5	753.0	753.4	753.9	754.3
714	747.4	747.9	748.3	748.8	749.2	749.7	750.1	750.6	751.0	751.5	751.9	752.4	752.8	753.2	753.7	754.2	754.6
713	747.7	748.2	748.6	749.1	749.6	750.0	750.4	750.9	751.3	751.8	752.2	752.7	753.2	753.6	754.0	754.5	754.9
712	748.1	748.5	749.0	749.4	749.9	750.3	750.8	751.2	751.7	752.1	752.6	753.0	753.5	753.9	754.4	754.8	755.3
711	748.4	748.9	749.3	749.8	750.2	750.7	751.1	751.6	752.0	752.5	752.9	753.4	753.8	754.3	754.7	755.2	755.6
710	748.9	749.3	749.7	750.1	750.6	751.0	751.5	751.9	752.4	752.8	753.3	753.7	754.2	754.6	755.1	755.5	756.0
709	749.3	749.8	750.2	750.6	751.0	751.4	751.8	752.3	752.7	753.2	753.6	754.1	754.5	755.0	755.4	755.9	756.3
708	749.5	749.9	750.4	750.8	751.3	751.7	752.2	752.6	753.1	753.5	754.0	754.4	754.9	755.3	755.8	756.2	756.7
707	749.8	750.3	750.7	751.2	751.7	752.1	752.6	753.0	753.4	753.9	754.3	754.8	755.2	755.7	756.1	756.6	757.0
706	750.2	750.7	751.1	751.6	752.0	752.5	752.9	753.4	753.8	754.3	754.7	755.1	755.6	756.0	756.5	756.9	757.4
705	750.6	751.0	751.5	751.9	752.4	752.8	753.3	753.7	754.2	754.6	755.0	755.5	755.9	756.4	756.8	757.3	757.7
704	750.9	751.4	751.8	752.3	752.7	753.2	753.6	754.1	754.5	754.9	755.4	755.8	756.3	756.7	757.2	757.6	758.1
703	751.3	751.7	752.2	752.6	753.1	753.5	754.0	754.4	754.9	755.3	755.7	756.2	756.6	757.1	757.5	758.0	758.4
702	751.6	752.1	752.5	753.0	753.4	753.9	754.3	754.8	755.2	755.6	756.1	756.5	757.0	757.4	757.9	758.3	758.8
701	752.0	752.4	752.9	753.3	753.8	754.2	754.7	755.1	755.6	756.0	756.4	756.9	757.3	757.8	758.2	758.7	759.1
700	752.3	752.8	753.2	753.7	754.1	754.6	755.0	755.5	755.9	756.3	756.8	757.2	757.7	758.1	758.6	759.0	759.4
699	752.7	753.1	753.6	754.0	754.5	754.9	755.4	755.8	756.3	756.7	757.1	757.6	758.0	758.5	758.9	759.3	759.8
698	753.0	753.5	753.9	754.4	754.8	755.3	755.7	756.2	756.6	757.0	757.5	757.9	758.4	758.8	759.3	759.7	760.1
697	753.4	753.8	754.3	754.7	755.2	755.6	756.1	756.5	757.0	757.4	757.8	758.3	758.7	759.2	759.6	760.0	760.5
696	753.7	754.2	754.6	755.1	755.5	756.0	756.4	756.9	757.3	757.7	758.2	758.6	759.1	759.5	759.9	760.4	760.8
695	754.1	754.6	755.0	755.4	755.9	756.3	756.8	757.2	757.7	758.1	758.5	759.0	759.4	759.9	760.3	760.8	761.2
694	754.5	754.9	755.3	755.8	756.2	756.7	757.1	757.6	758.0	758.4	758.9	759.3	759.8	760.2	760.6	761.1	761.5
693	754.8	755.3	755.7	756.1	756.6	757.0	757.5	757.9	758.4	758.8	759.2	759.7	760.1	760.5	761.0	761.4	761.9
692	755.2	755.6	756.1	756.5	757.0	757.4	757.9	758.3	758.7	759.2	759.6	760.0	760.5	760.9	761.3	761.8	762.2
691	755.5	756.0	756.4	756.9	757.3	757.7	758.2	758.6	759.1	759.5	759.9	760.4	760.8	761.2	761.7	762.1	762.5
690	755.9	756.3	756.8	757.2	757.6	758.1	758.5	759.0	759.4	759.8	760.3	760.7	761.2	761.6	762.0	762.5	762.9
689	756.2	756.7	757.1	757.6	758.0	758.4	758.9	759.3	759.8	760.2	760.6	761.1	761.5	761.9	762.4	762.8	763.2
688	756.6	757.0	757.5	757.9	758.4	758.8	759.2	759.7	760.1	760.5	761.0	761.4	761.8	762.3	762.7	763.2	763.6
687	756.9	757.4	757.8	758.3	758.7	759.1	759.6	760.0	760.4	760.9	761.3	761.8	762.2	762.6	763.1	763.5	763.9
686	757.3	757.7	758.2	758.6	759.1	759.5	759.9	760.4	760.8	761.2	761.7	762.1	762.5	763.0	763.4	763.8	764.3
685	757.7	758.1	758.5	759.0	759.4	759.8	760.3	760.7	761.2	761.6	762.0	762.5	762.9	763.3	763.8	764.2	764.6
684	758.0	758.5	758.9	759.3	759.8	760.2	760.6	761.1	761.5	761.9	762.4	762.8	763.2	763.7	764.1	764.5	765.0
683	758.4	758.8	759.2	759.7	760.1	760.6	761.0	761.4	761.8	762.3	762.7	763.2	763.6	764.0	764.4	764.9	765.3
682	758.7	759.2	759.6	760.0	760.5	760.9	761.3	761.8	762.2	762.6	763.1	763.5	763.9	764.4	764.8	765.2	765.7
681	759.1	759.5	760.0	760.4	760.8	761.3	761.7	762.1	762.5	763.0	763.4	763.8	764.3	764.7	765.1	765.6	766.0
680	759.4	759.9	760.3	760.7	761.2	761.6	762.0	762.5	762.9	763.3	763.8	764.2	764.6	765.1	765.5	765.9	766.4
679	759.8	760.2	760.7	761.1	761.5	762.0	762.4	762.8	763.3	763.7	764.1	764.6	765.0	765.4	765.8	766.3	766.7
678	760.1	760.6	761.0	761.4	761.9	762.3	762.7	763.2	763.6	764.0	764.5	764.9	765.3	765.8	766.2	766.6	767.0
677	760.5	760.9	761.4	761.8	762.2	762.7	763.1	763.5	764.0	764.4	764.8	765.3	765.7	766.1	766.5	767.0	767.4
676	760.9	761.3	761.7	762.2	762.6	763.0	763.4	763.9	764.3	764.7	765.2	765.6	766.0	766.5	766.9	767.3	767.7
675	761.2	761.6	762.1	762.5	762.9	763.4	763.8	764.2	764.7	765.1	765.5	765.9	766.4	766.8	767.2	767.7	768.1
674	761.6	762.0	762.4	762.9	763.3	763.7	764.2	764.6	765.0	765.4	765.9	766.3	766.7	767.2	767.6	768.0	768.4
673	761.9	762.4	762.8	763.2	763.6	764.1	764.5	764.9	765.4	765.8	766.2	766.6	767.1	767.5	767.9	768.4	768.8
672	762.3	762.7	763.1	763.6	764.0	764.4	764.9	765.3	765.7	766.1	766.6	767.0	767.4	767.8	768.3	768.7	769.1
671	762.6	763.1	763.5	763.9	764.4	764.8	765.2	765.6	766.1	766.5	766.9	767.3	767.8	768.2	768.6	769.0	769.5
670	763.0	763.4	763.8	764.3	764.7	765.1	765.6	766.0	766.4	766.8	767.3	767.7	768.1	768.6	769.0	769.4	769.8
669	763.3	763.8	764.2	764.6	765.1	765.5	765.9	766.3	766.8	767.2	767.6	768.0	768.5	768.9	769.3	769.7	770.2
668	763.7	764.1	764.6	765.0	765.4	765.8	766.3	766.7	767.1	767.5	768.0	768.4	768.8	769.2	769.7	770.1	770.5
667	764.0	764.5	764.9	765.3	765.8	766.2	766.6	767.0	767.5	767.9	768.3	768.7	769.2	769.6	770.0	770.4	770.9
666	764.4	764.8	765.3	765.7	766.1	766.5	767.0	767.4	767.8	768.2	768.7	769.1	769.5	769.9	770.4	770.8	771.2
665	764.8	765.2	765.6	766.0	766.5	766.9	767.3	767.7	768.2	768.6	769.0	769.4	769.9	770.3	770.7	771.1	771.5
664	765.1	765.5	766.0	766.4	766.8	767.2	767.7	768.1	768.5	768.9	769.4	769.8	770.2	770.6	771.0	771.5	771.9
663	765.5	765.9	766.3	766.7	767.2	767.6	768.0	768.4	768.9	769.3	769.7	770.1	770.6	771.0	771.4	771.8	772.2
662	765.8	766.3	766.7	767.1	767.5	767.9	768.4	768.8	769.2	769.6	770.0	770.5	770.9	771.3	771.7	772.2	772.6
661	766.2	766.6	767.0	767.5	767.9	768.3	768.7	769.1	769.6	770.0	770.4	770.8	771.2	771.7	772.1	772.5	772.9
660	766.6	767.0	767.4	767.8	768.2	768.7	769.1	769.5	769.9	770.3	770.8	771.2	771.6	772.0	772.4	772.8	773.3
659	767.0	767.3	767.7	768.2	768.6	769.0	769.4	769.9	770.3	770.7	771.1	771.5	771.9	772.4	772.8	773.2	773.6
658	767.3	767.7	768.1	768.5	768.9	769.4	769.8	770.2	770.6	771.0	771.5	771.9	772.3	772.7	773.1	773.5	774.0
657	767.6	768.0	768.4	768.8	769.3	769.7	770.1	770.5	771.0	771.4	771.8	772.2	772.6	773.1	773.5	773.9	774.3
656	768.0	768.4	768.8	769.2	769.6	770.1	770.5	770.9	771.3	771.7	772.2	772.6	773.0	773.4	773.8	774.2	774.7
655	768.3	768.7	769.2	769.6	770.0	770.4	770.8	771.2	771.7	772.1	772.5	772.9	773.3	773.8	774.2	774.6	775.0
654	768.7	769.1	769.5	769.9	770.3	770.8	771.2	771.6	772.0	772.4	772.9	773.3	773.7	774.1	774.5	774.9	775.3
653	769.0	769.4	769.9	770.3	770.7	771.1	771.5	772.0	772.4	772.8	773.2	773.6	774.0	774.4	774.8	775.3	775.7
652	769.4	769.8	770.2	770.6	771.1	771.5	771.9	772.3	772.7	773.1	773.6	774.0	774.4	774.8	775.2	775.6	776.0
651	769.7	770.1	770.6	771.0	771.4	771.8	772.2	772.7	773.1	773.5	773.9	774.3	774.7	775.1	775.5	776.0	776.4
650	770.1	770.5	770.9	771.3	771.8	772.2	772.6	773.0	773.4	773.8	774.2	774.7	775.1	775.5	775.9	776.3	776.7
649	770.4	770.9	771.3	771.7	772.1	772.5	772.9	773.4	773.8	774.2	774.6	775.0	775.4	775.8	776.2	776.7	777.1
648	770.8	771.2	771.6	772.0	772.5	772.9	773.3	773.7	774.1	774.5	774.9	775.4	775.8	776.2	776.6	777.0	777.4
647	771.2	771.6	772.0	772.4	772.8	773.2	773.6	774.1	774.5	774.9	775.3	775.7	776.1	776.5	776.9	777.4	777.8
646	771.5	771.9	772.3	772.8	773.2	773.6	774.0	774.4	774.9	775.3	775.7	776.1	776.5	776.9	777.4	777.8	778.2
645	771.9	772.3	772.7	773.1	773.5	773.9	774.3	774.8	775.2	775.6	776.0	776.4	776.8	777.2	777.6	778.0	778.5
644	772.2	772.6	773.0	773.5	773.9	774.3	774.7	775.1	775.5	775.9	776.4	776.8	777.2	777.6	778.0	778.4	778.9
643	772.6	773.0	773.4	773.8	774.2	774.6	775.0	775.5	775.9	776.3	776.7	777.1	777.5	778.0	778.4	778.8	779.1
642	772.9	773.3	773.8	774.2	774.6	775.0	775.4	775.8	776.2	776.6	777.0	777.5	777.9	778.3	778.7	779.1	779.5
641	773.3	773.7	774.1	774.5	774.9	775.3	775.8	776.2	776.6	777.0	777.4	777.8	778.2	778.6	779.0	779.4	779.8
640	773.6	774.0	774.5	774.9	775.3	775.7	776.1	776.5	776.9	777.3	777.7	778.1	778.6	779.0	779.4	779.8	780.2

Table 19-27. Metric — High Alt, High-Mid Temp, High Humidity
(Temp = 30.5 to 38.5°C , Press = 640 to 720 mm, 80% Humidity)

TEMPERATURE IN DEGREES CELSIUS

PRESSURE IN MILLIMETERS OF MERCURY	30.5	31.0	31.5	32.0	32.5	33.0	33.5	34.0	34.5	35.0	35.5	36.0	36.5	37.0	37.5	38.0	38.5
720	754.0	753.4	753.9	754.4	754.8	754.2	753.7	754.1	754.6	754.0	753.5	753.9	754.3	754.8	754.2	753.7	753.2
719	753.4	753.9	754.2	754.7	755.1	754.6	754.0	754.5	754.9	754.4	753.8	754.2	754.7	755.2	754.6	754.1	753.6
718	753.2	754.1	754.6	755.0	755.5	755.0	754.4	754.9	755.4	754.8	754.3	754.8	755.2	755.7	755.1	754.6	754.1
717	754.2	754.7	755.1	755.6	756.1	755.5	755.0	755.4	755.9	755.4	754.8	755.3	755.8	756.2	755.7	755.2	754.7
716	754.8	755.3	755.8	755.7	756.2	756.6	756.1	756.5	756.0	755.5	755.0	755.4	755.9	756.4	756.8	756.3	755.8
715	756.1	755.2	755.6	756.1	756.5	756.0	755.4	755.9	756.4	755.9	755.3	755.8	756.2	756.7	757.2	756.7	756.2
714	755.1	755.5	755.9	756.4	756.8	757.3	756.7	757.2	756.6	756.1	755.6	756.0	756.5	757.0	757.4	756.9	756.4
713	755.4	755.8	756.3	756.7	757.2	757.6	758.1	757.5	757.0	756.5	756.0	756.4	756.9	757.4	757.8	757.3	756.8
712	756.1	756.7	757.1	757.5	758.0	758.4	757.9	758.3	757.8	757.3	756.8	757.2	757.7	758.1	758.6	758.1	757.6
711	756.1	756.5	757.0	757.4	757.9	758.3	758.8	758.2	757.7	757.2	756.7	757.1	757.6	758.1	758.5	758.0	757.5
710	756.4	756.9	757.3	757.8	758.2	758.7	759.1	758.6	758.1	757.6	757.1	757.5	758.0	758.5	758.9	758.4	757.9
709	756.8	757.3	757.7	758.1	758.6	759.0	759.4	759.0	758.4	757.9	757.4	757.9	758.3	758.8	759.2	758.7	758.2
708	757.1	757.6	758.0	758.5	758.9	759.3	759.8	759.2	758.7	758.2	757.7	758.1	758.6	759.0	759.5	759.0	758.5
707	757.5	757.9	758.4	758.8	759.2	759.7	760.1	759.6	759.0	758.5	758.0	758.5	758.9	759.4	759.8	759.3	758.8
706	757.9	758.3	758.8	759.2	759.6	760.0	760.5	760.0	759.4	758.9	758.4	758.8	759.3	759.7	760.2	759.7	759.2
705	758.2	758.6	759.0	759.5	759.9	760.4	760.8	760.3	759.7	759.2	758.7	759.2	759.6	760.1	760.5	760.0	759.5
704	758.6	759.0	759.4	759.8	760.3	760.7	761.2	760.6	760.1	759.6	759.1	759.5	760.0	760.4	760.9	760.4	759.9
703	759.0	759.4	759.7	760.2	760.6	761.1	761.5	761.0	760.4	759.9	759.4	759.9	760.3	760.8	761.2	760.7	760.2
702	759.2	759.6	760.1	760.5	761.0	761.4	761.9	761.3	760.8	760.3	759.8	760.2	760.7	761.1	761.6	761.1	760.6
701	759.5	760.0	760.4	760.9	761.3	761.8	762.2	761.7	761.2	760.7	760.2	760.6	761.1	761.5	762.0	761.5	761.0
700	759.9	760.3	760.8	761.2	761.7	762.1	762.6	762.1	761.5	761.0	760.5	761.0	761.4	761.9	762.3	761.8	761.3
699	760.3	760.7	761.1	761.6	762.0	762.5	762.9	762.4	761.9	761.4	760.9	761.3	761.8	762.2	762.7	762.2	761.7
698	760.6	761.0	761.5	761.9	762.4	762.8	763.3	762.8	762.2	761.7	761.2	761.7	762.1	762.6	763.0	762.5	762.0
697	760.9	761.4	761.8	762.3	762.7	763.2	763.6	763.1	762.6	762.1	761.6	762.0	762.5	762.9	763.4	762.9	762.4
696	761.3	761.7	762.2	762.6	763.0	763.5	763.9	763.4	762.9	762.4	761.9	762.3	762.8	763.2	763.7	763.2	762.7
695	761.6	762.0	762.5	762.9	763.4	763.8	764.3	763.8	763.2	762.7	762.2	762.7	763.1	763.6	764.0	763.5	763.0
694	762.0	762.4	762.8	763.3	763.7	764.2	764.6	764.0	763.5	763.0	762.5	763.0	763.4	763.9	764.3	763.8	763.3
693	762.3	762.7	763.2	763.6	764.0	764.5	764.9	764.4	763.8	763.3	762.8	763.2	763.7	764.2	764.6	764.1	763.6
692	762.6	763.1	763.5	764.0	764.4	764.8	765.3	764.7	764.2	763.7	763.2	763.6	764.1	764.5	765.0	764.5	763.9
691	763.0	763.4	763.9	764.3	764.7	765.2	765.6	765.0	764.5	764.0	763.5	763.9	764.4	764.8	765.3	764.8	764.2
690	763.3	763.8	764.2	764.7	765.1	765.5	766.0	765.4	764.9	764.4	763.8	764.3	764.7	765.2	765.6	765.1	764.6
689	763.7	764.1	764.5	765.0	765.4	765.9	765.3	765.8	765.2	764.7	764.2	764.6	765.1	765.5	766.0	765.4	764.9
688	764.0	764.5	764.9	765.4	765.8	766.2	766.6	766.1	765.6	765.0	764.5	765.0	765.4	765.9	766.3	765.8	765.3
687	764.4	764.8	765.2	765.7	766.1	766.5	767.0	766.4	765.9	765.4	764.8	765.3	765.7	766.2	766.6	766.1	765.6
686	764.7	765.1	765.6	766.0	766.4	766.9	767.3	766.8	766.2	765.7	765.2	765.6	766.1	766.5	767.0	766.5	765.9
685	765.1	765.5	765.9	766.4	766.8	767.2	767.6	767.1	766.6	766.0	765.5	766.0	766.4	766.9	767.3	766.8	766.3
684	765.4	765.8	766.3	766.7	767.1	767.6	768.0	767.4	766.9	766.4	765.8	766.3	766.7	767.2	767.6	767.1	766.6
683	765.7	766.2	766.6	767.0	767.5	767.9	768.3	767.8	767.2	766.7	766.2	766.6	767.1	767.5	768.0	767.5	766.9
682	766.1	766.5	767.0	767.4	767.8	768.2	768.7	768.1	767.6	767.1	766.5	767.0	767.4	767.9	768.3	767.8	767.3
681	766.4	766.9	767.3	767.7	768.2	768.6	769.0	768.4	767.9	767.4	766.8	767.3	767.7	768.2	768.6	768.1	767.6
680	766.8	767.2	767.6	768.1	768.5	768.9	769.4	768.8	768.3	767.7	767.2	767.6	768.1	768.5	769.0	768.5	767.9
679	767.1	767.6	768.0	768.4	768.8	769.3	769.7	769.1	768.6	768.0	767.5	768.0	768.4	768.9	769.3	768.8	768.3
678	767.5	767.9	768.3	768.8	769.2	769.6	770.0	769.5	769.0	768.4	767.9	768.3	768.8	769.2	769.7	769.2	768.6
677	767.8	768.2	768.7	769.1	769.5	770.0	770.4	769.8	769.3	768.7	768.2	768.7	769.1	769.6	770.0	769.5	769.0
676	768.2	768.6	769.0	769.4	769.9	770.3	770.7	770.2	769.6	769.1	768.6	769.0	769.5	769.9	770.4	769.9	769.3
675	768.5	768.9	769.4	769.8	770.2	770.6	771.1	770.5	770.0	769.4	768.9	769.4	769.8	770.3	770.7	770.2	769.7
674	768.9	769.3	769.7	770.2	770.6	771.0	771.4	770.9	770.3	769.8	769.3	769.7	770.2	770.6	771.1	770.6	770.0
673	769.2	769.6	770.1	770.5	771.0	771.3	771.7	771.2	770.6	770.1	769.6	770.0	770.5	770.9	771.4	770.9	770.4
672	769.6	770.0	770.4	770.8	771.2	771.7	772.1	771.5	771.0	770.4	769.9	770.4	770.8	771.3	771.7	771.2	770.7
671	769.9	770.3	770.7	771.2	771.6	772.0	772.4	771.9	771.3	770.7	770.2	770.7	771.1	771.6	772.0	771.5	771.0
670	770.2	770.7	771.1	771.5	771.9	772.4	772.8	772.2	771.6	771.1	770.6	771.0	771.5	771.9	772.4	771.8	771.3
669	770.6	771.0	771.4	771.8	772.3	772.7	773.1	772.5	772.0	771.4	770.9	771.4	771.8	772.3	772.7	772.2	771.7
668	770.9	771.3	771.8	772.2	772.6	773.0	773.5	772.9	772.4	771.8	771.3	771.7	772.2	772.6	773.1	772.5	772.0
667	771.3	771.7	772.1	772.5	773.0	773.4	773.8	773.2	772.6	772.1	771.5	772.0	772.4	772.9	773.3	772.8	772.3
666	771.6	772.0	772.5	772.9	773.3	773.7	774.1	773.6	773.0	772.4	771.9	772.3	772.8	773.2	773.7	773.1	772.6
665	772.0	772.4	772.8	773.2	773.6	774.0	774.5	773.9	773.3	772.8	772.2	772.7	773.1	773.6	774.0	773.5	772.9
664	772.3	772.7	773.1	773.6	774.0	774.4	774.8	774.2	773.7	773.1	772.6	773.0	773.5	773.9	774.4	773.8	773.3
663	772.7	773.1	773.5	773.9	774.3	774.7	775.2	774.6	774.0	773.5	773.0	773.4	773.8	774.3	774.7	774.2	773.6
662	773.0	773.4	773.9	774.3	774.7	775.1	775.5	775.0	774.4	773.8	773.3	773.7	774.2	774.6	775.1	774.5	774.0
661	773.3	773.8	774.2	774.6	775.0	775.4	775.9	775.3	774.7	774.2	773.6	774.1	774.5	775.0	775.4	774.9	774.3
660	773.7	774.1	774.5	774.9	775.4	775.8	776.2	775.6	775.1	774.5	774.0	774.4	774.9	775.3	775.8	775.2	774.7
659	774.0	774.5	774.9	775.3	775.7	776.1	776.5	776.0	775.4	774.8	774.3	774.8	775.2	775.7	776.1	775.6	775.0
658	774.4	774.8	775.2	775.6	776.0	776.5	776.9	776.3	775.7	775.2	774.6	775.1	775.5	776.0	776.4	775.9	775.3
657	774.7	775.1	775.6	776.0	776.4	776.8	777.2	776.6	776.0	775.5	774.9	775.4	775.8	776.3	776.7	776.2	775.6
656	775.1	775.5	775.9	776.3	776.7	777.1	777.6	776.9	776.4	775.8	775.2	775.7	776.1	776.6	777.0	776.5	775.9
655	775.4	775.8	776.2	776.7	777.1	777.5	777.9	777.3	776.7	776.2	775.6	776.0	776.5	776.9	777.4	776.8	776.2
654	775.8	776.2	776.6	777.0	777.4	777.8	778.2	777.6	777.1	776.5	775.9	776.4	776.8	777.3	777.7	777.2	776.6
653	776.1	776.5	776.9	777.3	777.8	778.2	778.6	778.0	777.4	776.8	776.3	776.7	777.2	777.6	778.0	777.5	776.9
652	776.4	776.8	777.3	777.7	778.1	778.5	778.9	778.4	777.8	777.2	776.7	777.1	777.5	778.0	778.4	777.8	777.3
651	776.8	777.2	777.6	778.0	778.4	778.9	779.3	778.7	778.1	777.5	777.0	777.4	777.9	778.3	778.7	778.2	777.6
650	777.1	777.6	778.0	778.4	778.8	779.2	779.6	779.0	778.4	777.9	777.3	777.8	778.2	778.6	779.1	778.5	778.0
649	777.5	777.9	778.3	778.7	779.1	779.5	779.9	779.4	778.8	778.2	777.7	778.1	778.5	779.0	779.4	778.9	778.3
648	777.8	778.2	778.7	779.1	779.5	779.9	780.4	779.8	779.2	778.7	778.1	778.5	779.0	779.4	779.8	779.3	778.7
647	778.1	778.6	779.0	779.4	779.8	780.2	780.6	780.1	779.5	779.0	778.4	778.9	779.3	779.7	780.2	779.6	779.1
646	778.5	778.9	779.3	779.7	780.2	780.6	781.0	780.5	779.9	779.4	778.8	779.2	779.7	780.1	780.5	780.0	779.4
645	778.8	779.3	779.7	780.1	780.5	780.9	781.3	780.8	780.2	779.7	779.1	779.6	780.0	780.4	780.9	780.3	779.8
644	779.2	779.6	780.0	780.4	780.8	781.3	781.7	781.2	780.6	780.1	779.5	780.0	780.4	780.8	781.3	780.7	780.2
643	779.6	780.0	780.4	780.8	781.2	781.6	782.0	781.5	780.9	780.4	779.8	780.3	780.7	781.2	781.6	781.1	780.5
642	779.9	780.3	780.7	781.1	781.5	781.9	782.3	781.8	781.2	780.7	780.2	780.6	781.1	781.5	781.9	781.4	780.8
641	780.2	780.7	781.1	781.5	781.9	782.3	782.7	782.1	781.5	781.0	780.5	780.9	781.4	781.8	782.2	781.7	781.1
640	780.6	781.0	781.4	781.8	782.2	782.6	783.0	782.4	781.8	781.3	780.8	781.2	781.7	782.1	782.5	782.0	781.4

Table 19-28. English — Wide-Range
(Temp = 40 to 120°F , Press = 20 to 31 inches, 50% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	95.0	100.0	105.0	110.0	115.0	120.0
31.00	700.0	707.0	714.0	721.0	728.0	735.0	742.0	749.0	756.0	763.0	770.0	777.0	784.0	791.0	798.0	805.0	812.0
30.80	696.0	703.0	710.0	717.0	724.0	731.0	738.0	745.0	752.0	759.0	766.0	773.0	780.0	787.0	794.0	801.0	808.0
30.60	692.0	699.0	706.0	713.0	720.0	727.0	734.0	741.0	748.0	755.0	762.0	769.0	776.0	783.0	790.0	797.0	804.0
30.40	688.0	695.0	702.0	709.0	716.0	723.0	730.0	737.0	744.0	751.0	758.0	765.0	772.0	779.0	786.0	793.0	800.0
30.20	684.0	691.0	698.0	705.0	712.0	719.0	726.0	733.0	740.0	747.0	754.0	761.0	768.0	775.0	782.0	789.0	796.0
30.00	680.0	687.0	694.0	701.0	708.0	715.0	722.0	729.0	736.0	743.0	750.0	757.0	764.0	771.0	778.0	785.0	792.0
29.80	676.0	683.0	690.0	697.0	704.0	711.0	718.0	725.0	732.0	739.0	746.0	753.0	760.0	767.0	774.0	781.0	788.0
29.60	672.0	679.0	686.0	693.0	700.0	707.0	714.0	721.0	728.0	735.0	742.0	749.0	756.0	763.0	770.0	777.0	784.0
29.40	668.0	675.0	682.0	689.0	696.0	703.0	710.0	717.0	724.0	731.0	738.0	745.0	752.0	759.0	766.0	773.0	780.0
29.20	664.0	671.0	678.0	685.0	692.0	699.0	706.0	713.0	720.0	727.0	734.0	741.0	748.0	755.0	762.0	769.0	776.0
29.00	660.0	667.0	674.0	681.0	688.0	695.0	702.0	709.0	716.0	723.0	730.0	737.0	744.0	751.0	758.0	765.0	772.0
28.80	656.0	663.0	670.0	677.0	684.0	691.0	698.0	705.0	712.0	719.0	726.0	733.0	740.0	747.0	754.0	761.0	768.0
28.60	652.0	659.0	666.0	673.0	680.0	687.0	694.0	701.0	708.0	715.0	722.0	729.0	736.0	743.0	750.0	757.0	764.0
28.40	648.0	655.0	662.0	669.0	676.0	683.0	690.0	697.0	704.0	711.0	718.0	725.0	732.0	739.0	746.0	753.0	760.0
28.20	644.0	651.0	658.0	665.0	672.0	679.0	686.0	693.0	700.0	707.0	714.0	721.0	728.0	735.0	742.0	749.0	756.0
28.00	640.0	647.0	654.0	661.0	668.0	675.0	682.0	689.0	696.0	703.0	710.0	717.0	724.0	731.0	738.0	745.0	752.0
27.80	636.0	643.0	650.0	657.0	664.0	671.0	678.0	685.0	692.0	699.0	706.0	713.0	720.0	727.0	734.0	741.0	748.0
27.60	632.0	639.0	646.0	653.0	660.0	667.0	674.0	681.0	688.0	695.0	702.0	709.0	716.0	723.0	730.0	737.0	744.0
27.40	628.0	635.0	642.0	649.0	656.0	663.0	670.0	677.0	684.0	691.0	698.0	705.0	712.0	719.0	726.0	733.0	740.0
27.20	624.0	631.0	638.0	645.0	652.0	659.0	666.0	673.0	680.0	687.0	694.0	701.0	708.0	715.0	722.0	729.0	736.0
27.00	620.0	627.0	634.0	641.0	648.0	655.0	662.0	669.0	676.0	683.0	690.0	697.0	704.0	711.0	718.0	725.0	732.0
26.80	616.0	623.0	630.0	637.0	644.0	651.0	658.0	665.0	672.0	679.0	686.0	693.0	700.0	707.0	714.0	721.0	728.0
26.60	612.0	619.0	626.0	633.0	640.0	647.0	654.0	661.0	668.0	675.0	682.0	689.0	696.0	703.0	710.0	717.0	724.0
26.40	608.0	615.0	622.0	629.0	636.0	643.0	650.0	657.0	664.0	671.0	678.0	685.0	692.0	699.0	706.0	713.0	720.0
26.20	604.0	611.0	618.0	625.0	632.0	639.0	646.0	653.0	660.0	667.0	674.0	681.0	688.0	695.0	702.0	709.0	716.0
26.00	600.0	607.0	614.0	621.0	628.0	635.0	642.0	649.0	656.0	663.0	670.0	677.0	684.0	691.0	698.0	705.0	712.0
25.80	596.0	603.0	610.0	617.0	624.0	631.0	638.0	645.0	652.0	659.0	666.0	673.0	680.0	687.0	694.0	701.0	708.0
25.60	592.0	599.0	606.0	613.0	620.0	627.0	634.0	641.0	648.0	655.0	662.0	669.0	676.0	683.0	690.0	697.0	704.0
25.40	588.0	595.0	602.0	609.0	616.0	623.0	630.0	637.0	644.0	651.0	658.0	665.0	672.0	679.0	686.0	693.0	700.0
25.20	584.0	591.0	598.0	605.0	612.0	619.0	626.0	633.0	640.0	647.0	654.0	661.0	668.0	675.0	682.0	689.0	696.0
25.00	580.0	587.0	594.0	601.0	608.0	615.0	622.0	629.0	636.0	643.0	650.0	657.0	664.0	671.0	678.0	685.0	692.0
24.80	576.0	583.0	590.0	597.0	604.0	611.0	618.0	625.0	632.0	639.0	646.0	653.0	660.0	667.0	674.0	681.0	688.0
24.60	572.0	579.0	586.0	593.0	600.0	607.0	614.0	621.0	628.0	635.0	642.0	649.0	656.0	663.0	670.0	677.0	684.0
24.40	568.0	575.0	582.0	589.0	596.0	603.0	610.0	617.0	624.0	631.0	638.0	645.0	652.0	659.0	666.0	673.0	680.0
24.20	564.0	571.0	578.0	585.0	592.0	599.0	606.0	613.0	620.0	627.0	634.0	641.0	648.0	655.0	662.0	669.0	676.0
24.00	560.0	567.0	574.0	581.0	588.0	595.0	602.0	609.0	616.0	623.0	630.0	637.0	644.0	651.0	658.0	665.0	672.0
23.80	556.0	563.0	570.0	577.0	584.0	591.0	598.0	605.0	612.0	619.0	626.0	633.0	640.0	647.0	654.0	661.0	668.0
23.60	552.0	559.0	566.0	573.0	580.0	587.0	594.0	601.0	608.0	615.0	622.0	629.0	636.0	643.0	650.0	657.0	664.0
23.40	548.0	555.0	562.0	569.0	576.0	583.0	590.0	597.0	604.0	611.0	618.0	625.0	632.0	639.0	646.0	653.0	660.0
23.20	544.0	551.0	558.0	565.0	572.0	579.0	586.0	593.0	600.0	607.0	614.0	621.0	628.0	635.0	642.0	649.0	656.0
23.00	540.0	547.0	554.0	561.0	568.0	575.0	582.0	589.0	596.0	603.0	610.0	617.0	624.0	631.0	638.0	645.0	652.0
22.80	536.0	543.0	550.0	557.0	564.0	571.0	578.0	585.0	592.0	599.0	606.0	613.0	620.0	627.0	634.0	641.0	648.0
22.60	532.0	539.0	546.0	553.0	560.0	567.0	574.0	581.0	588.0	595.0	602.0	609.0	616.0	623.0	630.0	637.0	644.0
22.40	528.0	535.0	542.0	549.0	556.0	563.0	570.0	577.0	584.0	591.0	598.0	605.0	612.0	619.0	626.0	633.0	640.0
22.20	524.0	531.0	538.0	545.0	552.0	559.0	566.0	573.0	580.0	587.0	594.0	601.0	608.0	615.0	622.0	629.0	636.0
22.00	520.0	527.0	534.0	541.0	548.0	555.0	562.0	569.0	576.0	583.0	590.0	597.0	604.0	611.0	618.0	625.0	632.0
21.80	516.0	523.0	530.0	537.0	544.0	551.0	558.0	565.0	572.0	579.0	586.0	593.0	600.0	607.0	614.0	621.0	628.0
21.60	512.0	519.0	526.0	533.0	540.0	547.0	554.0	561.0	568.0	575.0	582.0	589.0	596.0	603.0	610.0	617.0	624.0
21.40	508.0	515.0	522.0	529.0	536.0	543.0	550.0	557.0	564.0	571.0	578.0	585.0	592.0	599.0	606.0	613.0	620.0
21.20	504.0	511.0	518.0	525.0	532.0	539.0	546.0	553.0	560.0	567.0	574.0	581.0	588.0	595.0	602.0	609.0	616.0
21.00	500.0	507.0	514.0	521.0	528.0	535.0	542.0	549.0	556.0	563.0	570.0	577.0	584.0	591.0	598.0	605.0	612.0
20.80	496.0	503.0	510.0	517.0	524.0	531.0	538.0	545.0	552.0	559.0	566.0	573.0	580.0	587.0	594.0	601.0	608.0
20.60	492.0	499.0	506.0	513.0	520.0	527.0	534.0	541.0	548.0	555.0	562.0	569.0	576.0	583.0	590.0	597.0	604.0
20.40	488.0	495.0	502.0	509.0	516.0	523.0	530.0	537.0	544.0	551.0	558.0	565.0	572.0	579.0	586.0	593.0	600.0
20.20	484.0	491.0	498.0	505.0	512.0	519.0	526.0	533.0	540.0	547.0	554.0	561.0	568.0	575.0	582.0	589.0	596.0
20.00	480.0	487.0	494.0	501.0	508.0	515.0	522.0	529.0	536.0	543.0	550.0	557.0	564.0	571.0	578.0	585.0	592.0

Table 19-29. English — Low Alt, Low Temp, Low Humidity
(Temp = 40 to 56°F , Press = 27 to 31 inches, 20% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

	40.0	41.0	42.0	43.0	44.0	45.0	46.0	47.0	48.0	49.0	50.0	51.0	52.0	53.0	54.0	55.0	56.0
31.00	702.9	703.6	704.4	705.4	706.2	707.2	708.4	709.0	709.5	710.1	710.7	711.3	711.9	712.4	713.0	713.5	714.0
30.95	703.3	704.0	704.8	705.8	706.7	707.7	708.8	709.4	709.9	710.5	711.1	711.7	712.3	712.8	713.4	713.9	714.4
30.90	703.8	704.4	705.2	706.2	707.1	708.1	709.2	709.8	710.4	710.9	711.5	712.1	712.7	713.2	713.8	714.3	714.8
30.85	704.2	704.8	705.6	706.6	707.5	708.5	709.6	710.2	710.8	711.3	711.9	712.5	713.1	713.6	714.2	714.7	715.2
30.80	704.7	705.3	706.1	707.1	708.0	709.0	710.0	710.6	711.2	711.8	712.4	713.0	713.5	714.1	714.6	715.1	715.6
30.75	705.2	705.8	706.6	707.5	708.4	709.4	710.5	711.1	711.7	712.2	712.8	713.4	714.0	714.5	715.1	715.6	716.1
30.70	705.7	706.3	707.1	708.0	708.9	709.9	711.0	711.5	712.1	712.7	713.3	713.8	714.4	714.9	715.5	716.0	716.5
30.65	706.2	706.7	707.5	708.4	709.3	710.3	711.4	712.0	712.5	713.1	713.7	714.2	714.8	715.3	715.9	716.4	716.9
30.60	706.6	707.2	707.9	708.8	709.8	710.8	711.8	712.4	713.0	713.5	714.1	714.7	715.2	715.7	716.3	716.8	717.3
30.55	707.1	707.7	708.4	709.3	710.3	711.3	712.3	712.9	713.4	714.0	714.6	715.1	715.6	716.2	716.7	717.2	717.7
30.50	707.6	708.2	708.8	709.8	710.8	711.8	712.7	713.3	713.9	714.4	715.0	715.5	716.0	716.6	717.1	717.6	718.1
30.45	708.1	708.7	709.3	710.2	711.2	712.2	713.2	713.8	714.3	714.9	715.4	715.9	716.4	716.9	717.5	718.0	718.5
30.40	708.6	709.1	709.8	710.7	711.7	712.7	713.6	714.2	714.8	715.3	715.8	716.3	716.8	717.4	717.9	718.4	718.9
30.35	709.0	709.6	710.2	711.2	712.1	713.1	714.1	714.7	715.2	715.7	716.2	716.7	717.2	717.8	718.3	718.8	719.3
30.30	709.5	710.1	710.7	711.6	712.6	713.6	714.5	715.1	715.6	716.1	716.6	717.1	717.6	718.2	718.7	719.2	719.7
30.25	710.0	710.6	711.2	712.1	713.1	714.0	715.0	715.5	716.0	716.5	717.0	717.5	718.0	718.6	719.1	719.6	720.1
30.20	710.5	711.1	711.6	712.6	713.5	714.5	715.4	716.0	716.5	717.0	717.5	718.0	718.5	719.0	719.5	720.0	720.5
30.15	711.0	711.6	712.1	713.0	714.0	714.9	715.9	716.4	716.9	717.4	717.9	718.4	718.9	719.4	720.0	720.5	721.0
30.10	711.4	712.0	712.6	713.5	714.4	715.4	716.3	716.9	717.4	717.9	718.4	718.9	719.4	719.9	720.4	720.9	721.4
30.05	711.9	712.5	713.1	714.0	714.9	715.8	716.8	717.3	717.8	718.3	718.8	719.3	719.8	720.3	720.8	721.3	721.8
30.00	712.4	713.0	713.5	714.4	715.4	716.3	717.2	717.8	718.3	718.8	719.3	719.8	720.3	720.8	721.2	721.7	722.2
29.95	712.9	713.4	714.0	714.9	715.8	716.7	717.7	718.2	718.7	719.2	719.7	720.2	720.7	721.2	721.7	722.2	722.7
29.90	713.3	713.9	714.5	715.3	716.2	717.2	718.1	718.7	719.2	719.7	720.2	720.7	721.2	721.7	722.2	722.7	723.2
29.85	713.8	714.4	715.0	715.8	716.7	717.6	718.6	719.2	719.7	720.2	720.7	721.2	721.7	722.2	722.7	723.2	723.7
29.80	714.3	714.9	715.5	716.3	717.2	718.1	719.1	719.6	720.1	720.6	721.1	721.6	722.1	722.6	723.1	723.6	724.2
29.75	714.8	715.4	715.9	716.8	717.7	718.6	719.5	720.1	720.6	721.1	721.6	722.1	722.6	723.1	723.6	724.1	724.7
29.70	715.3	715.8	716.4	717.2	718.2	719.1	720.0	720.5	721.0	721.5	722.0	722.5	723.0	723.5	724.0	724.6	725.1
29.65	715.7	716.3	716.8	717.7	718.6	719.5	720.4	721.0	721.5	722.0	722.5	723.0	723.5	724.0	724.5	725.1	725.6
29.60	716.2	716.8	717.4	718.2	719.1	720.0	720.9	721.4	721.9	722.5	723.0	723.5	724.0	724.5	725.0	725.6	726.1
29.55	716.7	717.3	717.8	718.6	719.5	720.4	721.3	721.9	722.4	722.9	723.4	723.9	724.4	725.0	725.5	726.0	726.5
29.50	717.2	717.8	718.3	719.1	720.0	720.9	721.8	722.3	722.8	723.4	723.9	724.4	724.9	725.4	726.0	726.5	727.0
29.45	717.7	718.2	718.8	719.6	720.4	721.3	722.2	722.8	723.3	723.8	724.3	724.9	725.4	725.9	726.4	727.0	727.5
29.40	718.1	718.7	719.3	720.1	720.9	721.8	722.7	723.2	723.8	724.3	724.8	725.3	725.9	726.4	726.9	727.4	728.0
29.35	718.6	719.2	719.8	720.5	721.4	722.2	723.1	723.7	724.2	724.8	725.3	725.8	726.3	726.9	727.4	727.9	728.4
29.30	719.1	719.7	720.2	721.0	721.8	722.7	723.6	724.1	724.7	725.2	725.8	726.3	726.8	727.4	727.9	728.4	728.9
29.25	719.6	720.1	720.7	721.4	722.3	723.1	724.0	724.6	725.1	725.7	726.2	726.7	727.3	727.8	728.3	728.9	729.4
29.20	720.0	720.6	721.2	721.8	722.7	723.6	724.5	725.0	725.6	726.1	726.7	727.2	727.8	728.3	728.8	729.4	729.9
29.15	720.5	721.1	721.7	722.2	723.2	724.0	724.9	725.5	726.0	726.6	727.1	727.7	728.2	728.8	729.3	729.8	730.4
29.10	721.0	721.6	722.1	722.7	723.6	724.5	725.4	726.0	726.5	727.1	727.6	728.2	728.7	729.2	729.8	730.3	730.8
29.05	721.5	722.1	722.6	723.2	724.1	724.9	725.9	726.4	727.0	727.5	728.1	728.6	729.2	729.7	730.2	730.8	731.3
29.00	722.0	722.5	723.1	723.7	724.5	725.4	726.4	726.9	727.5	728.0	728.6	729.1	729.6	730.2	730.7	731.2	731.8
28.95	722.5	723.0	723.6	724.1	724.9	725.9	726.8	727.4	727.9	728.4	729.0	729.5	730.1	730.6	731.2	731.7	732.3
28.90	722.9	723.5	724.0	724.6	725.4	726.3	727.3	727.8	728.4	728.9	729.4	730.0	730.5	731.1	731.6	732.2	732.7
28.85	723.4	724.0	724.5	725.1	725.9	726.8	727.7	728.3	728.8	729.3	729.9	730.4	731.0	731.5	732.1	732.6	733.2
28.80	723.9	724.5	725.0	725.6	726.4	727.2	728.2	728.7	729.3	729.8	730.3	730.9	731.4	732.0	732.5	733.1	733.6
28.75	724.4	724.9	725.5	726.0	726.8	727.7	728.6	729.2	729.7	730.3	730.8	731.3	731.9	732.4	733.0	733.5	734.1
28.70	724.9	725.4	726.0	726.5	727.3	728.2	729.2	729.7	730.2	730.8	731.3	731.8	732.4	732.9	733.5	734.0	734.6
28.65	725.3	725.9	726.4	727.0	727.8	728.7	729.6	730.2	730.7	731.2	731.8	732.3	732.9	733.4	734.0	734.5	735.1
28.60	725.8	726.4	726.9	727.5	728.3	729.2	730.1	730.7	731.2	731.7	732.3	732.8	733.4	733.9	734.5	735.0	735.6
28.55	726.3	726.9	727.4	727.9	728.8	729.6	730.6	731.1	731.7	732.2	732.7	733.3	733.8	734.4	734.9	735.5	736.0
28.50	726.8	727.3	727.9	728.4	729.2	730.1	731.1	731.6	732.1	732.7	733.2	733.8	734.3	734.8	735.4	735.9	736.5
28.45	727.2	727.8	728.4	728.9	729.7	730.6	731.5	732.1	732.6	733.2	733.7	734.2	734.8	735.3	735.9	736.4	737.0
28.40	727.7	728.3	728.8	729.4	730.2	731.0	732.0	732.5	733.1	733.6	734.2	734.7	735.3	735.8	736.4	736.9	737.5
28.35	728.2	728.8	729.3	729.9	730.7	731.5	732.5	733.0	733.6	734.1	734.7	735.2	735.8	736.3	736.9	737.4	738.0
28.30	728.7	729.2	729.8	730.3	731.1	732.0	732.9	733.5	734.0	734.6	735.1	735.7	736.2	736.8	737.3	737.9	738.4
28.25	729.2	729.7	730.3	730.8	731.6	732.4	733.4	734.0	734.5	735.1	735.6	736.2	736.7	737.3	737.8	738.4	738.9
28.20	729.7	730.2	730.7	731.3	732.0	732.9	733.8	734.4	735.0	735.5	736.1	736.6	737.2	737.7	738.3	738.8	739.4
28.15	730.1	730.7	731.2	731.8	732.5	733.3	734.3	734.9	735.4	736.0	736.5	737.1	737.6	738.2	738.7	739.3	739.8
28.10	730.6	731.2	731.7	732.2	732.9	733.8	734.7	735.3	735.9	736.4	737.0	737.5	738.1	738.6	739.2	739.7	740.3
28.05	731.1	731.6	732.2	732.7	733.3	734.2	735.2	735.8	736.3	736.9	737.4	738.0	738.5	739.1	739.6	740.2	740.7
28.00	731.6	732.1	732.7	733.2	733.7	734.6	735.6	736.2	736.8	737.3	737.9	738.4	739.0	739.5	740.1	740.6	741.2
27.95	732.1	732.6	733.1	733.7	734.2	735.1	736.1	736.7	737.2	737.8	738.3	738.9	739.4	740.0	740.5	741.1	741.6
27.90	732.5	733.1	733.6	734.1	734.7	735.5	736.5	737.1	737.7	738.2	738.7	739.3	739.8	740.4	740.9	741.5	742.0
27.85	733.0	733.6	734.1	734.6	735.2	736.0	737.0	737.6	738.1	738.7	739.2	739.8	740.3	740.9	741.4	742.0	742.5
27.80	733.5	734.0	734.6	735.1	735.6	736.4	737.4	738.0	738.6	739.1	739.7	740.2	740.8	741.3	741.9	742.4	743.0
27.75	734.0	734.5	735.0	735.6	736.1	736.9	737.9	738.5	739.0	739.6	740.1	740.7	741.2	741.8	742.3	742.9	743.4
27.70	734.5	735.0	735.5	736.1	736.6	737.5	738.4	739.0	739.5	740.1	740.6	741.2	741.7	742.3	742.8	743.4	743.9
27.65	734.9	735.5	736.0	736.6	737.1	737.9	738.9	739.5	740.0	740.6	741.1	741.7	742.2	742.8	743.3	743.9	744.4
27.60	735.4	735.9	736.5	737.0	737.5	738.4	739.4	740.0	740.5	741.1	741.6	742.2	742.7	743.3	743.8	744.4	744.9
27.55	735.9	736.4	737.0	737.5	738.0	738.9	739.9	740.5	741.0	741.6	742.1	742.7	743.2	743.8	744.3	744.9	745.4
27.50	736.4	736.9	737.4	738.0	738.5	739.4	740.4	741.0	741.5	742.1	742.6	743.2	743.7	744.3	744.8	745.4	745.9
27.45	736.8	737.4	737.9	738.4	739.0	739.9	740.9	741.5	742.0	742.6	743.1	743.7	744.2	744.8	745.3	745.9	746.4
27.40	737.3	737.9	738.4	738.9	739.4	740.4	741.4	742.0	742.5	743.1	743.6	744.2	744.7	745.3	745.8	746.4	746.9
27.35	737.8	738.3	738.9	739.4	739.9	740.9	741.9	742.5	743.0	743.6	744.1	744.7	745.2	745.8	746.3	746.9	747.4
27.30	738.3	738.8	739.3	739.9	740.4	741.4	742.4	743.0	743.5	744.1	744.6	745.2	745.7	746.3	746.8	747.4	747.9
27.25	738.8	739.3	739.8	740.3	740.9	741.9	742.9	743.4	744.0	744.6	745.1	745.7	746.2	746.8	747.3	747.9	748.4
27.20	739.2	739.8	740.3	740.8	741.3	742.4	743.4	743.9	744.5	745.1	745.6	746.2	746.7	747.3	747.8	748.4	748.9
27.15	739.7	740.3	740.8	741.3	741.8	742.9	743.9	744.4	745.0	745.6	746.1	746.7	747.2	747.8	748.3	748.9	749.4
27.10	740.2	740.7	741.3	741.8	742.3	743.4	744.4	744.9	745.5	746.1	746.6	747.2	747.7	748.3	748.8	749.4	749.9
27.05	740.7	741.2	741.7	742.2	742.8	743.9	744.9	745.4	746.0	746.6	747.1	747.7	748.2	748.8	749.3	749.9	750.4
27.00	741.2	741.7	742.2	742.7	743.2	744.3	745.4	745.9	746.5	747.1	747.6	748.2	748.7	749.3	749.8	750.4	750.9

Table 19-30. English — Low Alt, Low-Mid Temp, Low Humidity
(Temp = 57 to 73°F , Press = 27 to 31 inches, 20% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

	57.1	58.0	59.0	60.0	61.0	62.0	63.0	64.0	65.0	66.0	67.0	68.0	69.0	70.0	71.0	72.0	73.0
30.00	712.1	713.4	713.9	714.4	714.7	715.4	716.0	716.6	717.1	717.7	718.2	718.8	719.3	719.8	720.4	720.9	721.5
30.05	712.2	712.7	713.1	713.6	714.0	714.5	715.1	715.6	716.1	716.7	717.2	717.8	718.3	718.8	719.4	719.9	720.4
30.10	711.3	711.8	712.2	712.7	713.1	713.6	714.2	714.7	715.2	715.8	716.3	716.8	717.4	717.9	718.4	719.0	719.5
30.15	710.4	710.9	711.3	711.8	712.2	712.7	713.3	713.8	714.3	714.8	715.4	715.9	716.4	716.9	717.5	718.0	718.5
30.20	709.5	710.0	710.4	710.9	711.3	711.8	712.4	712.9	713.4	713.9	714.5	715.0	715.5	716.0	716.6	717.1	717.6
30.25	708.6	709.1	709.5	710.0	710.4	710.9	711.5	712.0	712.5	713.0	713.6	714.1	714.6	715.1	715.7	716.2	716.7
30.30	707.7	708.2	708.6	709.1	709.5	710.0	710.6	711.1	711.6	712.1	712.7	713.2	713.7	714.2	714.8	715.3	715.8
30.35	706.8	707.3	707.7	708.2	708.6	709.1	709.7	710.2	710.7	711.2	711.8	712.3	712.8	713.3	713.9	714.4	714.9
30.40	705.9	706.4	706.8	707.3	707.7	708.2	708.8	709.3	709.8	710.3	710.9	711.4	711.9	712.4	713.0	713.5	714.0
30.45	705.0	705.5	705.9	706.4	706.8	707.3	707.9	708.4	708.9	709.4	710.0	710.5	711.0	711.5	712.1	712.6	713.1
30.50	704.1	704.6	705.0	705.5	705.9	706.4	707.0	707.5	708.0	708.5	709.1	709.6	710.1	710.6	711.2	711.7	712.2
30.55	703.2	703.7	704.1	704.6	705.0	705.5	706.1	706.6	707.1	707.6	708.2	708.7	709.2	709.7	710.3	710.8	711.3
30.60	702.3	702.8	703.2	703.7	704.1	704.6	705.2	705.7	706.2	706.7	707.3	707.8	708.3	708.8	709.4	709.9	710.4
30.65	701.4	701.9	702.3	702.8	703.2	703.7	704.3	704.8	705.3	705.8	706.4	706.9	707.4	707.9	708.5	709.0	709.5
30.70	700.5	701.0	701.4	701.9	702.3	702.8	703.4	703.9	704.4	704.9	705.5	706.0	706.5	707.0	707.6	708.1	708.6
30.75	699.6	700.1	700.5	701.0	701.4	701.9	702.5	703.0	703.5	704.0	704.6	705.1	705.6	706.1	706.7	707.2	707.7
30.80	698.7	699.2	699.6	700.1	700.5	701.0	701.6	702.1	702.6	703.1	703.7	704.2	704.7	705.2	705.8	706.3	706.8
30.85	697.8	698.3	698.7	699.2	699.6	700.1	700.7	701.2	701.7	702.2	702.8	703.3	703.8	704.3	704.9	705.4	705.9
30.90	696.9	697.4	697.8	698.3	698.7	699.2	699.8	700.3	700.8	701.3	701.9	702.4	702.9	703.4	704.0	704.5	705.0
30.95	696.0	696.5	696.9	697.4	697.8	698.3	698.9	699.4	699.9	700.4	701.0	701.5	702.0	702.5	703.1	703.6	704.1
31.00	695.1	695.6	696.0	696.5	696.9	697.4	698.0	698.5	699.0	699.5	700.1	700.6	701.1	701.6	702.2	702.7	703.2

Table 19-31. English — Low Alt, Mid Temp, Low Humidity
(Temp = 74 to 90°F, Press = 27 to 31 inches, 20% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0	90.0
31.00	734.7	732.1	729.6	727.1	724.7	722.3	719.9	717.6	715.3
30.92	732.1	729.5	727.0	724.6	722.2	719.8	717.5	715.2	712.9
30.84	729.5	727.0	724.5	722.1	719.7	717.4	715.1	712.8	710.5
30.76	726.9	724.4	722.0	719.6	717.2	714.9	712.6	710.4	708.1
30.68	724.3	721.8	719.4	717.0	714.7	712.4	710.2	707.9	705.7
30.60	721.7	719.3	716.8	714.5	712.2	709.9	707.7	705.5	703.3
30.52	719.2	716.7	714.3	711.9	709.7	707.5	705.3	703.1	700.9
30.44	716.6	714.1	711.7	709.4	707.2	705.0	702.8	700.7	698.5
30.36	714.0	711.6	709.2	706.8	704.7	702.6	700.4	698.3	696.2
30.28	711.4	709.0	706.6	704.3	702.1	700.1	698.0	695.9	693.8
30.20	708.8	706.5	704.1	701.7	699.6	697.7	695.6	693.5	691.4
30.12	706.3	703.9	701.5	699.2	697.0	695.2	693.2	691.1	689.0
30.04	703.7	701.4	699.0	696.6	694.5	692.7	690.7	688.7	686.7
29.96	701.1	698.8	696.4	694.1	692.0	690.2	688.3	686.3	684.3
29.88	698.5	696.2	693.9	691.5	689.4	687.7	685.8	683.9	682.0
29.80	695.9	693.7	691.3	689.0	686.9	685.2	683.4	681.5	679.6
29.72	693.4	691.1	688.8	686.4	684.3	682.7	681.0	679.2	677.3
29.64	690.8	688.5	686.2	683.9	681.8	680.2	678.5	676.8	675.0
29.56	688.2	685.9	683.7	681.3	679.2	677.7	676.1	674.4	672.7
29.48	685.6	683.4	681.1	678.8	676.7	675.2	673.7	672.0	670.4
29.40	683.1	680.8	678.6	676.3	674.2	672.7	671.2	669.7	668.1
29.32	680.5	678.3	676.0	673.7	671.7	670.2	668.8	667.3	665.8
29.24	677.9	675.7	673.5	671.2	669.1	667.7	666.3	664.9	663.5
29.16	675.3	673.2	670.9	668.7	666.6	665.2	663.9	662.5	661.2
29.08	672.8	670.6	668.4	666.2	664.1	662.7	661.4	660.2	658.9
29.00	670.2	668.1	665.9	663.7	661.6	660.3	659.0	657.8	656.6
28.92	667.6	665.5	663.4	661.2	659.1	657.8	656.6	655.4	654.3
28.84	665.0	663.0	660.8	658.7	656.6	655.4	654.2	653.1	651.9
28.76	662.5	660.4	658.3	656.2	654.2	653.0	651.8	650.7	649.6
28.68	659.9	657.9	655.8	653.7	651.7	650.6	649.4	648.4	647.3
28.60	657.3	655.3	653.3	651.2	649.3	648.2	647.1	646.0	645.0
28.52	654.7	652.8	650.7	648.7	646.8	645.8	644.7	643.7	642.7
28.44	652.2	650.2	648.2	646.2	644.4	643.4	642.4	641.4	640.4
28.36	649.6	647.7	645.7	643.8	642.0	641.0	640.0	639.1	638.1
28.28	647.0	645.1	643.2	641.3	639.5	638.6	637.7	636.8	635.8
28.20	644.4	642.6	640.7	638.9	637.1	636.2	635.3	634.4	633.5
28.12	641.9	640.0	638.2	636.4	634.7	633.8	632.9	632.1	631.2
28.04	639.3	637.5	635.7	634.0	632.3	631.4	630.6	629.7	628.9
27.96	636.7	634.9	633.2	631.5	629.8	629.0	628.2	627.4	626.6
27.88	634.1	632.4	630.7	629.0	627.4	626.6	625.8	625.0	624.3
27.80	631.5	629.8	628.2	626.6	625.0	624.2	623.4	622.7	621.9
27.72	629.0	627.3	625.7	624.1	622.5	621.8	621.0	620.3	619.6
27.64	626.4	624.8	623.2	621.7	620.1	619.4	618.7	617.9	617.2
27.56	623.8	622.2	620.7	619.2	617.7	617.0	616.3	615.6	614.9
27.48	621.2	619.7	618.2	616.7	615.3	614.6	613.9	613.2	612.5
27.40	618.7	617.1	615.7	614.3	612.9	612.2	611.5	610.8	610.2
27.32	616.1	614.6	613.2	611.8	610.4	609.8	609.1	608.5	607.8
27.24	613.5	612.0	610.7	609.3	608.0	607.4	606.7	606.1	605.5
27.16	610.9	609.5	608.2	606.8	605.6	605.0	604.4	603.8	603.1
27.08	608.4	607.0	605.7	604.4	603.2	602.6	602.0	601.4	600.8
27.00	605.8	604.5	603.2	602.0	600.8	600.2	599.7	599.1	598.5

Table 19-32. English — Low Alt, High-Mid Temp, Low Humidity
(Temp = 91 to 107°F, Press = 27 to 31 inches, 20% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-33. English — High Alt, Low Temp, Low Humidity
(Temp = 40 to 56°F , Press = 23 to 27 inches, 20% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-34. English — High Alt, Low-Mid Temp, Low Humidity
(Temp = 57 to 73°F, Press = 23 to 27 inches, 20% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

	57.0	58.0	59.0	60.0	61.0	62.0	63.0	64.0	65.0	66.0	67.0	68.0	69.0	70.0	71.0	72.0	73.0
27.00	749.9	750.3	750.6	751.3	751.7	752.2	752.6	753.2	753.7	754.3	754.6	755.3	755.6	755.9	756.4	757.0	757.4
26.95	750.3	750.7	751.2	751.7	752.0	752.7	753.0	753.4	754.1	754.6	755.1	755.7	756.0	756.5	757.1	757.6	757.9
26.90	750.7	751.2	751.7	752.3	752.7	753.1	753.6	754.1	754.6	755.1	755.5	755.9	756.5	756.9	757.4	757.8	758.3
26.85	751.1	751.7	752.2	752.6	753.1	753.6	754.1	754.6	755.0	755.5	756.0	756.5	756.9	757.4	757.8	758.3	758.8
26.80	751.6	752.1	752.6	753.1	753.6	754.1	754.5	755.0	755.5	756.0	756.4	756.9	757.3	757.8	758.3	758.8	759.3
26.75	752.1	752.6	753.1	753.5	754.0	754.5	755.1	755.6	756.0	756.4	756.9	757.4	757.8	758.3	758.8	759.3	759.7
26.70	752.6	753.1	753.5	754.0	754.5	755.0	755.5	755.9	756.4	756.9	757.3	757.8	758.4	758.7	759.2	759.7	760.1
26.65	753.0	753.5	754.0	754.5	755.0	755.4	755.9	756.4	756.8	757.3	757.8	758.3	758.7	759.2	759.7	760.1	760.6
26.60	753.5	754.0	754.5	754.9	755.4	755.9	756.4	756.9	757.3	757.8	758.1	758.7	759.2	759.7	760.1	760.6	761.0
26.55	754.0	754.4	754.9	755.4	755.9	756.4	756.8	757.3	757.8	758.3	758.7	759.1	759.5	760.1	760.6	761.0	761.5
26.50	754.4	754.9	755.4	755.9	756.3	756.8	757.1	757.5	758.2	758.7	759.1	759.6	760.1	760.6	761.0	761.5	761.9
26.45	754.9	755.4	755.9	756.3	756.5	757.3	757.7	758.2	758.7	759.1	759.6	760.1	760.5	761.0	761.5	761.9	762.4
26.40	755.4	755.9	756.3	756.8	757.3	757.7	758.2	758.7	759.1	759.6	760.1	760.5	761.0	761.5	761.9	762.4	762.8
26.35	755.8	756.3	756.8	757.2	757.7	758.2	758.7	759.1	759.6	760.1	760.5	761.0	761.4	761.9	762.4	762.8	763.3
26.30	756.3	756.8	757.2	757.7	758.2	758.7	759.1	759.6	760.1	760.5	761.0	761.4	761.9	762.4	762.8	763.3	763.7
26.25	756.7	757.2	757.7	758.2	758.6	759.1	759.6	760.0	760.5	761.0	761.4	761.9	762.3	762.8	763.3	763.7	764.2
26.20	757.2	757.7	758.2	758.6	759.1	759.6	760.0	760.5	761.0	761.4	761.9	762.4	762.8	763.3	763.7	764.2	764.6
26.15	757.7	758.1	758.6	759.1	759.6	760.0	760.5	761.0	761.4	761.9	762.3	762.8	763.3	763.7	764.2	764.6	765.1
26.10	758.1	758.6	759.1	759.5	760.0	760.5	761.0	761.4	761.9	762.3	762.8	763.3	763.7	764.2	764.6	765.1	765.5
26.05	758.6	759.1	759.5	760.0	760.5	760.9	761.4	761.9	762.3	762.8	763.2	763.7	764.2	764.6	765.1	765.5	766.0
26.00	759.1	759.5	760.0	760.5	760.9	761.4	761.9	762.3	762.8	763.3	763.7	764.2	764.6	765.1	765.5	766.0	766.4
25.95	759.5	760.0	760.5	760.9	761.4	761.8	762.3	762.8	763.3	763.7	764.2	764.6	765.1	765.5	766.0	766.4	766.9
25.90	760.0	760.5	760.9	761.4	761.9	762.3	762.8	763.3	763.7	764.2	764.6	765.1	765.5	766.0	766.4	766.9	767.3
25.85	760.4	760.9	761.4	761.9	762.3	762.8	763.2	763.7	764.2	764.6	765.1	765.5	766.0	766.4	766.9	767.3	767.8
25.80	760.9	761.4	761.8	762.3	762.8	763.2	763.1	764.2	764.6	765.1	765.5	766.0	766.4	766.9	767.3	767.8	768.2
25.75	761.4	761.9	762.3	762.8	763.2	763.7	764.2	764.6	765.1	765.5	766.0	766.4	766.9	767.3	767.8	768.2	768.7
25.70	761.8	762.3	762.8	763.2	763.7	764.2	764.6	765.1	765.5	766.0	766.4	766.9	767.3	767.8	768.2	768.7	769.1
25.65	762.3	762.8	763.2	763.7	764.2	764.6	765.1	765.5	766.0	766.4	766.9	767.3	767.8	768.2	768.7	769.1	769.6
25.60	762.8	763.2	763.7	764.2	764.6	765.1	765.5	766.0	766.4	766.9	767.3	767.8	768.2	768.7	769.1	769.6	770.0
25.55	763.2	763.7	764.2	764.6	765.1	765.5	766.0	766.4	766.9	767.3	767.8	768.3	768.7	769.1	769.6	770.0	770.5
25.50	763.7	764.2	764.6	765.1	765.5	766.0	766.5	766.9	767.4	767.8	768.3	768.7	769.2	769.6	770.1	770.5	771.0
25.45	764.2	764.6	765.1	765.5	766.0	766.5	766.9	767.4	767.8	768.3	768.7	769.2	769.6	770.1	770.5	771.0	771.4
25.40	764.6	765.1	765.5	766.0	766.5	766.9	767.4	767.8	768.3	768.7	769.2	769.6	770.1	770.5	771.0	771.4	771.9
25.35	765.1	765.5	766.0	766.5	766.9	767.4	767.8	768.3	768.7	769.2	769.6	770.1	770.5	771.0	771.4	771.9	772.3
25.30	765.6	766.0	766.5	766.9	767.4	767.8	768.3	768.7	769.2	769.6	770.1	770.5	771.0	771.4	771.9	772.3	772.7
25.25	766.0	766.5	766.9	767.4	767.8	768.3	768.7	769.2	769.6	770.1	770.5	771.0	771.4	771.9	772.3	772.7	773.2
25.20	766.5	766.9	767.4	767.8	768.3	768.8	769.2	769.7	770.1	770.6	771.0	771.5	771.9	772.3	772.8	773.2	773.6
25.15	766.9	767.4	767.9	768.3	768.8	769.2	769.7	770.1	770.6	771.0	771.5	771.9	772.3	772.8	773.2	773.6	774.1
25.10	767.4	767.9	768.3	768.8	769.2	769.7	770.1	770.6	771.0	771.5	771.9	772.3	772.8	773.2	773.7	774.1	774.5
25.05	767.9	768.3	768.8	769.2	769.7	770.1	770.6	771.0	771.5	771.9	772.4	772.8	773.2	773.7	774.1	774.5	775.0
25.00	768.3	768.8	769.2	769.7	770.1	770.6	771.0	771.5	771.9	772.4	772.8	773.2	773.7	774.1	774.6	775.0	775.4
24.95	768.8	769.2	769.7	770.2	770.6	771.0	771.5	771.9	772.4	772.8	773.3	773.7	774.1	774.6	775.0	775.4	775.9
24.90	769.3	769.7	770.2	770.6	771.1	771.5	771.9	772.4	772.8	773.3	773.7	774.2	774.6	775.0	775.5	775.9	776.3
24.85	769.7	770.2	770.6	771.1	771.5	772.0	772.4	772.9	773.3	773.7	774.2	774.6	775.0	775.5	775.9	776.3	776.8
24.80	770.2	770.6	771.1	771.5	772.0	772.4	772.9	773.3	773.8	774.2	774.6	775.1	775.5	775.9	776.4	776.8	777.2
24.75	770.7	771.1	771.5	772.0	772.4	772.9	773.3	773.8	774.2	774.6	775.1	775.5	776.0	776.4	776.8	777.2	777.7
24.70	771.1	771.6	772.0	772.5	772.9	773.3	773.8	774.2	774.7	775.1	775.5	776.0	776.4	776.8	777.3	777.7	778.1
24.65	771.6	772.0	772.5	772.9	773.4	773.8	774.2	774.7	775.1	775.6	776.0	776.4	776.9	777.3	777.7	778.1	778.6
24.60	772.0	772.5	772.9	773.4	773.8	774.3	774.7	775.1	775.6	776.0	776.4	776.9	777.3	777.7	778.2	778.6	779.0
24.55	772.5	772.9	773.4	773.8	774.3	774.7	775.2	775.6	776.0	776.4	776.9	777.3	777.8	778.2	778.6	779.0	779.5
24.50	773.0	773.4	773.9	774.3	774.7	775.2	775.6	776.1	776.5	776.9	777.4	777.8	778.2	778.6	779.1	779.5	779.9
24.45	773.4	773.9	774.3	774.8	775.2	775.6	776.1	776.5	776.9	777.4	777.8	778.2	778.7	779.1	779.5	779.9	780.4
24.40	773.9	774.3	774.8	775.2	775.7	776.1	776.5	777.0	777.4	777.8	778.3	778.7	779.1	779.6	780.0	780.4	780.9
24.35	774.4	774.8	775.2	775.7	776.1	776.6	777.0	777.4	777.9	778.3	778.7	779.1	779.6	780.0	780.4	780.9	781.3
24.30	774.8	775.3	775.7	776.1	776.6	777.0	777.5	777.9	778.3	778.7	779.2	779.6	780.0	780.5	780.9	781.3	781.7
24.25	775.3	775.7	776.2	776.6	777.0	777.5	777.9	778.4	778.8	779.2	779.6	780.1	780.5	780.9	781.3	781.8	782.2
24.20	775.8	776.2	776.6	777.1	777.5	777.9	778.4	778.8	779.2	779.7	780.1	780.5	780.9	781.4	781.8	782.2	782.6
24.15	776.2	776.7	777.1	777.5	778.0	778.4	778.8	779.3	779.7	780.1	780.6	781.0	781.4	781.8	782.3	782.7	783.1
24.10	776.7	777.1	777.6	778.0	778.4	778.9	779.3	779.7	780.1	780.6	781.0	781.4	781.9	782.3	782.7	783.1	783.5
24.05	777.2	777.6	778.0	778.5	778.9	779.3	779.7	780.2	780.6	781.0	781.5	781.9	782.3	782.7	783.1	783.6	784.0
24.00	777.6	778.0	778.5	778.9	779.4	779.8	780.2	780.6	781.1	781.5	781.9	782.3	782.7	783.2	783.6	784.0	784.4
23.95	778.1	778.5	778.9	779.4	779.8	780.2	780.7	781.1	781.5	781.9	782.4	782.8	783.2	783.6	784.0	784.5	784.9
23.90	778.5	779.0	779.4	779.8	780.3	780.7	781.1	781.5	782.0	782.4	782.8	783.2	783.7	784.1	784.5	784.9	785.3
23.85	779.0	779.4	779.9	780.3	780.7	781.2	781.6	782.0	782.4	782.8	783.3	783.7	784.1	784.5	784.9	785.4	785.8
23.80	779.5	779.9	780.3	780.8	781.2	781.6	782.0	782.5	782.9	783.3	783.7	784.1	784.6	785.0	785.4	785.8	786.2
23.75	779.9	780.4	780.8	781.2	781.6	782.1	782.5	782.9	783.3	783.8	784.2	784.6	785.0	785.4	785.8	786.3	786.7
23.70	780.4	780.8	781.2	781.7	782.1	782.5	783.0	783.4	783.8	784.2	784.6	785.1	785.5	785.9	786.3	786.7	787.1
23.65	780.9	781.3	781.7	782.1	782.6	783.0	783.4	783.8	784.3	784.7	785.1	785.5	785.9	786.3	786.7	787.2	787.6
23.60	781.3	781.8	782.2	782.6	783.0	783.4	783.9	784.3	784.7	785.1	785.5	786.0	786.4	786.8	787.2	787.6	788.0
23.55	781.8	782.2	782.6	783.1	783.5	783.9	784.3	784.7	785.2	785.6	786.0	786.4	786.8	787.2	787.6	788.1	788.5
23.50	782.3	782.7	783.1	783.5	783.9	784.4	784.8	785.2	785.6	786.0	786.5	786.9	787.3	787.7	788.1	788.5	788.9
23.45	782.7	783.1	783.6	784.0	784.4	784.8	785.2	785.7	786.1	786.5	786.9	787.3	787.7	788.1	788.6	789.0	789.4
23.40	783.2	783.6	784.0	784.4	784.9	785.3	785.7	786.1	786.5	787.0	787.4	787.8	788.2	788.6	789.0	789.4	789.8
23.35	783.6	784.1	784.5	784.9	785.3	785.7	786.2	786.6	787.0	787.4	787.8	788.2	788.6	789.0	789.5	789.9	790.3
23.30	784.1	784.5	784.9	785.4	785.8	786.2	786.6	787.0	787.4	787.9	788.3	788.7	789.1	789.5	789.9	790.3	790.7
23.25	784.6	785.0	785.4	785.8	786.2	786.7	787.1	787.5	787.9	788.3	788.7	789.1	789.5	790.0	790.4	790.8	791.2
23.20	785.0	785.4	785.9	786.3	786.7	787.1	787.5	788.0	788.4	788.8	789.2	789.6	790.0	790.4	790.8	791.2	791.6
23.15	785.5	785.9	786.3	786.7	787.2	787.6	788.0	788.4	788.8	789.2	789.6	790.0	790.5	790.9	791.3	791.7	792.1
23.10	786.0	786.4	786.8	787.2	787.6	788.0	788.5	788.9	789.3	789.7	790.1	790.5	790.9	791.3	791.7	792.1	792.5
23.05	786.4	786.8	787.3	787.7	788.1	788.5	788.9	789.3	789.7	790.1	790.5	791.0	791.4	791.8	792.2	792.6	793.0
23.00	786.9	787.3	787.7	788.1	788.5	789.0	789.4	789.8	790.2	790.6	791.0	791.4	791.8	792.2	792.6	793.0	793.4

Table 19-35. English — High Alt, Mid Temp, Low Humidity
(Temp = 74 to 90°F, Press = 23 to 27 inches, 20% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-36 English — High Alt, High-Mid Temp, Low Humidity
(Temp = 91 to 107°F , Press = 23 to 27 inches, 20% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

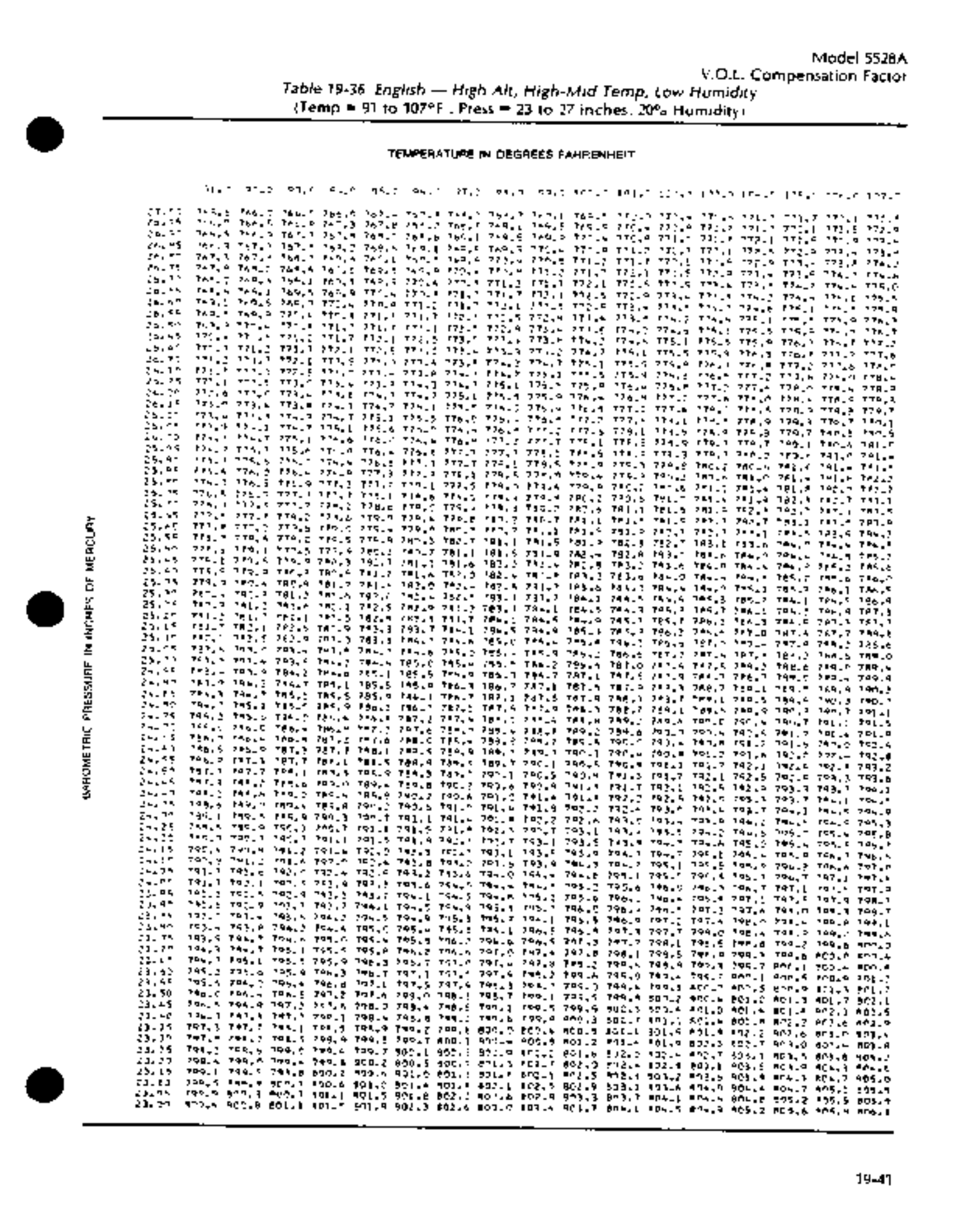


Table 19-37. English — Low Alt, Low Temp, Med Humidity
(Temp = 40 to 56°F , Press = 27 to 31 inches, 50% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-38. English — Low Alt, Low-Mid Temp, Med Humidity
(Temp = 57 to 73°F , Press = 27 to 31 inches, 50% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-39. English — Low Alt, Mid Temp, Med Humidity
(Temp = 74 to 90°F , Press = 27 to 31 inches, 50% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-40. English — Low Alt, High-Mid Temp, Med Humidity
(Temp = 91 to 107°F , Press = 27 to 31 inches, 50% Humidity:

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table T9-41 English — High Alt, Low Temp, Med Humidity
(Temp = 40 to 56°F , Press = 23 to 27 inches, 50% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-42. English — High Alt, Low-Mid Temp, Med Humidity
(Temp = 57 to 73°F , Press = 23 to 27 inches, 50% Humidity

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-43. English — High Alt. Mid Temp, Med Humidity
(Temp = 74 to 90°F , Press = 23 to 27 inches, 50% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-44 English — High Alt, High-Mid Temp, Med Humidity
(Temp = 91 to 107°F , Press = 23 to 27 inches, 50% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-45. English — Low Alt, Low Temp, High Humidity
(Temp = 40 to 56°F, Press = 27 to 31 inches, 80% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-46. English — Low Alt, Low-Mid Temp, High Humidity
(Temp = 57 to 73°F , Press = 27 to 31 inches, 60% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-47. English — Low Alt, Mid Temp, High Humidity
(Temp = 74 to 90°F , Press = 27 to 31 inches, 80% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

	74.0	75.0	76.0	77.0	78.0	79.0	80.0	81.0	82.0	83.0	84.0	85.0	86.0	87.0	88.0	89.0	90.0
31.00	722.7	723.5	723.5	724.4	724.9	725.5	726.0	726.4	727.1	727.7	728.2	728.9	729.1	729.9	730.4	731.0	731.5
30.95	723.2	723.7	724.3	724.9	725.4	725.9	726.5	727.0	727.6	728.1	728.7	729.2	729.8	730.3	730.9	731.4	731.9
30.90	723.6	724.2	724.7	725.3	725.9	726.4	726.9	727.5	728.0	728.6	729.1	729.7	730.2	730.8	731.3	731.8	732.4
30.85	724.1	724.6	725.2	725.7	726.3	726.8	727.4	727.9	728.5	729.0	729.6	730.2	730.7	731.2	731.8	732.3	732.8
30.80	724.5	725.1	724.6	726.2	726.7	727.3	727.8	728.4	729.0	729.5	730.1	730.6	731.1	731.7	732.2	732.7	733.3
30.75	725.0	725.5	726.1	726.6	727.2	727.7	728.3	728.9	729.4	729.9	730.4	731.0	731.5	732.1	732.6	733.1	733.7
30.70	725.4	726.0	726.5	727.1	727.6	728.2	728.7	729.2	729.8	730.3	730.9	731.4	732.0	732.5	733.0	733.6	734.1
30.65	725.9	726.4	727.0	727.5	728.1	728.6	729.1	729.7	730.2	730.8	731.3	731.9	732.4	732.9	733.5	734.0	734.6
30.60	726.3	726.9	727.4	728.0	728.5	729.0	729.6	730.1	730.7	731.2	731.8	732.3	732.8	733.4	734.0	734.5	735.0
30.55	726.8	727.3	727.9	728.4	728.9	729.5	730.0	730.6	731.1	731.7	732.2	732.7	733.3	733.8	734.4	734.9	735.4
30.50	727.2	727.8	728.3	728.9	729.4	729.9	730.5	731.1	731.6	732.1	732.6	733.2	733.7	734.3	734.8	735.3	735.9
30.45	727.7	728.2	728.7	729.3	729.8	730.4	730.9	731.5	732.0	732.5	733.1	733.6	734.2	734.7	735.2	735.8	736.3
30.40	728.1	728.7	729.2	729.7	730.3	730.8	731.4	732.0	732.5	733.0	733.5	734.1	734.6	735.1	735.7	736.2	736.7
30.35	728.6	729.1	729.6	730.2	730.7	731.3	731.8	732.4	732.9	733.4	734.0	734.5	735.0	735.6	736.1	736.6	737.2
30.30	729.0	729.5	730.1	730.6	731.2	731.7	732.3	732.8	733.3	733.9	734.4	734.9	735.5	736.0	736.5	737.1	737.6
30.25	729.4	730.0	730.5	731.1	731.6	732.2	732.7	733.2	733.8	734.3	734.8	735.4	735.9	736.4	737.0	737.5	738.0
30.20	729.9	730.4	731.0	731.5	732.1	732.6	733.1	733.7	734.2	734.7	735.3	735.8	736.4	736.9	737.4	738.0	738.5
30.15	730.3	730.9	731.4	732.0	732.5	733.0	733.6	734.1	734.7	735.2	735.7	736.3	736.8	737.3	737.9	738.4	738.9
30.10	730.8	731.3	731.9	732.4	733.0	733.5	734.0	734.6	735.1	735.6	736.2	736.7	737.2	737.8	738.3	738.8	739.4
30.05	731.2	731.8	732.3	732.9	733.4	733.9	734.5	735.0	735.5	736.1	736.6	737.1	737.7	738.2	738.7	739.3	739.8
30.00	731.7	732.2	732.8	733.3	733.9	734.4	734.9	735.4	736.0	736.5	737.0	737.6	738.1	738.6	739.2	739.7	740.2
29.95	732.1	732.7	733.2	733.8	734.3	734.8	735.4	735.9	736.4	737.0	737.5	738.0	738.5	739.1	739.6	740.1	740.7
29.90	732.6	733.1	733.7	734.2	734.7	735.3	735.8	736.3	736.9	737.4	737.9	738.5	739.0	739.5	740.0	740.6	741.1
29.85	733.0	733.6	734.1	734.6	735.2	735.7	736.2	736.8	737.3	737.8	738.4	738.9	739.4	740.0	740.5	741.0	741.5
29.80	733.5	734.0	734.6	735.1	735.6	736.2	736.7	737.2	737.8	738.3	738.8	739.4	739.9	740.4	740.9	741.4	742.0
29.75	733.9	734.5	735.0	735.5	736.1	736.6	737.1	737.7	738.2	738.7	739.2	739.8	740.3	740.8	741.4	741.9	742.4
29.70	734.4	734.9	735.5	736.0	736.5	737.0	737.6	738.1	738.6	739.2	739.7	740.2	740.7	741.3	741.8	742.3	742.8
29.65	734.8	735.4	735.9	736.4	737.0	737.5	738.0	738.6	739.1	739.6	740.1	740.7	741.2	741.7	742.2	742.8	743.3
29.60	735.3	735.8	736.3	736.9	737.4	737.9	738.5	739.0	739.5	740.1	740.6	741.1	741.6	742.2	742.7	743.2	743.7
29.55	735.7	736.3	736.8	737.3	737.9	738.4	738.9	739.4	740.0	740.5	741.0	741.5	742.1	742.6	743.1	743.6	744.1
29.50	736.2	736.7	737.2	737.8	738.3	738.8	739.4	739.9	740.4	740.9	741.5	742.0	742.5	743.0	743.5	744.1	744.6
29.45	736.6	737.2	737.7	738.2	738.7	739.3	739.8	740.3	740.8	741.4	741.9	742.4	742.9	743.5	744.0	744.5	745.0
29.40	737.1	737.6	738.1	738.7	739.2	739.7	740.2	740.8	741.3	741.8	742.3	742.8	743.4	743.9	744.4	744.9	745.5
29.35	737.5	738.1	738.6	739.1	739.6	740.2	740.7	741.2	741.7	742.3	742.8	743.3	743.8	744.3	744.9	745.4	745.9
29.30	738.0	738.5	739.0	739.6	740.1	740.6	741.1	741.7	742.2	742.7	743.2	743.7	744.3	744.8	745.3	745.8	746.3
29.25	738.4	739.0	739.5	740.0	740.5	741.1	741.6	742.1	742.6	743.1	743.7	744.2	744.7	745.2	745.7	746.2	746.8
29.20	738.9	739.4	739.9	740.5	741.0	741.5	742.0	742.5	743.1	743.6	744.1	744.6	745.1	745.6	746.2	746.7	747.2
29.15	739.3	739.9	740.4	740.9	741.4	741.9	742.5	743.0	743.5	744.0	744.5	745.1	745.6	746.1	746.6	747.1	747.6
29.10	739.8	740.3	740.8	741.3	741.9	742.4	742.9	743.4	744.0	744.5	745.0	745.5	746.0	746.5	747.0	747.6	748.1
29.05	740.2	740.7	741.3	741.8	742.3	742.8	743.4	743.9	744.4	744.9	745.4	745.9	746.4	747.0	747.5	748.0	748.5
29.00	740.7	741.2	741.7	742.2	742.8	743.3	743.8	744.3	744.8	745.3	745.8	746.4	746.9	747.4	747.9	748.4	748.9
28.95	741.1	741.6	742.2	742.7	743.2	743.7	744.2	744.8	745.3	745.8	746.3	746.8	747.3	747.8	748.3	748.8	749.4
28.90	741.6	742.1	742.6	743.1	743.6	744.2	744.7	745.2	745.7	746.2	746.7	747.2	747.7	748.2	748.7	749.2	749.7
28.85	742.0	742.5	743.1	743.6	744.1	744.6	745.1	745.7	746.2	746.7	747.2	747.7	748.2	748.7	749.2	749.7	750.2
28.80	742.5	743.0	743.5	744.0	744.5	745.1	745.6	746.1	746.6	747.1	747.6	748.1	748.6	749.2	749.7	750.2	750.7
28.75	742.9	743.4	744.0	744.5	745.0	745.5	746.0	746.5	747.0	747.5	748.1	748.6	749.1	749.6	750.1	750.6	751.1
28.70	743.4	743.9	744.4	744.9	745.4	745.9	746.5	747.0	747.5	748.0	748.5	749.0	749.5	750.0	750.5	751.0	751.6
28.65	743.8	744.3	744.8	745.4	745.9	746.4	746.9	747.4	747.9	748.4	748.9	749.4	750.0	750.5	751.0	751.5	752.0
28.60	744.3	744.8	745.3	745.8	746.3	746.8	747.3	747.8	748.3	748.8	749.3	749.8	750.3	750.8	751.3	751.8	752.4
28.55	744.7	745.2	745.7	746.3	746.8	747.3	747.8	748.3	748.8	749.3	749.8	750.3	750.8	751.3	751.8	752.3	752.8
28.50	745.2	745.7	746.2	746.7	747.2	747.7	748.2	748.7	749.2	749.7	750.2	750.7	751.2	751.7	752.2	752.7	753.2
28.45	745.6	746.1	746.6	747.1	747.7	748.2	748.7	749.2	749.7	750.2	750.7	751.2	751.7	752.2	752.7	753.2	753.7
28.40	746.1	746.6	747.1	747.6	748.1	748.6	749.1	749.6	750.1	750.6	751.1	751.6	752.1	752.6	753.1	753.6	754.1
28.35	746.5	747.0	747.5	748.0	748.5	749.1	749.6	750.1	750.6	751.1	751.6	752.1	752.6	753.1	753.6	754.1	754.6
28.30	747.0	747.5	748.0	748.5	749.0	749.5	750.0	750.5	751.0	751.5	752.0	752.5	753.0	753.5	754.0	754.5	755.0
28.25	747.4	747.9	748.4	748.9	749.4	749.9	750.4	750.9	751.4	751.9	752.4	752.9	753.4	753.9	754.4	754.9	755.4
28.20	747.9	748.4	748.9	749.4	749.9	750.4	750.9	751.4	751.9	752.4	752.9	753.4	753.9	754.4	754.9	755.4	755.9
28.15	748.3	748.8	749.3	749.8	750.3	750.8	751.3	751.8	752.3	752.8	753.3	753.8	754.3	754.8	755.3	755.8	756.3
28.10	748.8	749.3	749.8	750.3	750.8	751.3	751.8	752.3	752.8	753.3	753.8	754.3	754.8	755.3	755.8	756.3	756.8
28.05	749.2	749.7	750.2	750.7	751.2	751.7	752.2	752.7	753.2	753.7	754.2	754.7	755.2	755.7	756.2	756.7	757.2
28.00	749.6	750.2	750.7	751.2	751.7	752.2	752.7	753.2	753.7	754.2	754.7	755.2	755.7	756.2	756.7	757.2	757.7
27.95	750.1	750.6	751.1	751.6	752.1	752.6	753.1	753.6	754.1	754.6	755.1	755.6	756.1	756.6	757.1	757.6	758.1
27.90	750.5	751.1	751.6	752.1	752.6	753.1	753.6	754.1	754.6	755.1	755.6	756.1	756.6	757.1	757.6	758.1	758.6
27.85	751.0	751.5	752.0	752.5	753.0	753.5	754.0	754.5	755.0	755.5	756.0	756.5	757.0	757.5	758.0	758.5	759.0
27.80	751.4	751.9	752.4	752.9	753.4	753.9	754.4	754.9	755.4	755.9	756.4	756.9	757.4	757.9	758.4	758.9	759.4
27.75	751.8	752.4	752.9	753.4	753.9	754.4	754.9	755.4	755.9	756.4	756.9	757.4	757.9	758.4	758.9	759.4	759.9
27.70	752.3	752.8	753.3	753.8	754.3	754.8	755.3	755.8	756.3	756.8	757.3	757.8	758.3	758.8	759.3	759.8	760.3
27.65	752.7	753.3	753.8	754.3	754.8	755.3	755.8	756.3	756.8	757.3	757.8	758.3	758.7	759.2	759.7	760.2	760.7
27.60	753.2	753.7	754.2	754.7	755.2	755.7	756.2	756.7	757.2	757.7	758.2	758.7	759.2	759.7	760.2	760.7	761.2
27.55	753.7	754.2	754.7	755.2	755.7	756.2	756.7	757.2	757.7	758.2	758.7	759.2	759.7	760.2	760.7	761.2	761.7
27.50	754.1	754.6	755.1	755.6	756.1	756.6	757.1	757.6	758.1	758.6	759.1	759.6	760.1	760.6	761.1	761.6	762.1
27.45	754.6	755.1	755.6	756.1	756.6	757.1	757.5	758.0	758.5	759.0	759.5	760.0	760.5	761.0	761.5	762.0	762.5
27.40	755.0	755.5	756.0	756.5	757.0	757.5	758.0	758.5	759.0	759.5	760.0	760.5	761.0	761.5	762.0	762.5	763.0
27.35	755.5	756.0	756.5	757.0	757.5	757.9	758.4	758.9	759.4	759.9	760.4	760.9	761.4	761.9	762.4	762.9	763.5
27.30	755.9	756.4	756.9	757.4	757.9	758.4	758.9	759.4	759.9	760.4	760.9	761.4	761.9	762.4	762.9	763.4	763.9
27.25	756.4	756.9	757.4	757.9	758.5	758.9	759.4	759.9	760.4	760.8	761.3	761.8	762.3	762.8	763.3	763.8	764.3
27.20	756.8	757.3	757.8	758.3	758.8	759.3	759.8	760.3	760.8	761.3	761.8	762.3	762.7	763.2	763.7	764.2	764.7
27.15	757.3	757.8	758.3	758.8	759.3	759.7	760.2	760.7	761.2	761.7	762.2	762.6	763.1	763.6	764.1	764.6	765.1
27.10	757.7	758.2	758.7	759.2	759.7	760.2	760.7	761.2	761.6	762.1	762.6	763.1	763.6	764.0	764.5	765.0	765.5
27.05	758.2	758.7	759.2	759.6	760.1	760.6	761.1	761.6	762.1	762.6	763.0	763.5	764.0	764.5	765.0	765.4	765.9
27.00	758.6	759.1	759.6	760.1	760.6	761.1	761.5	762.0	762.5	763.0	763.5	764.0	764.4	764.9	765.4	765.9	766.4

Table 19-48. English — Low Alt, High-Mid Temp, High Humidity
(Temp = 91 to 107°F , Press = 27 to 31 inches, 80% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

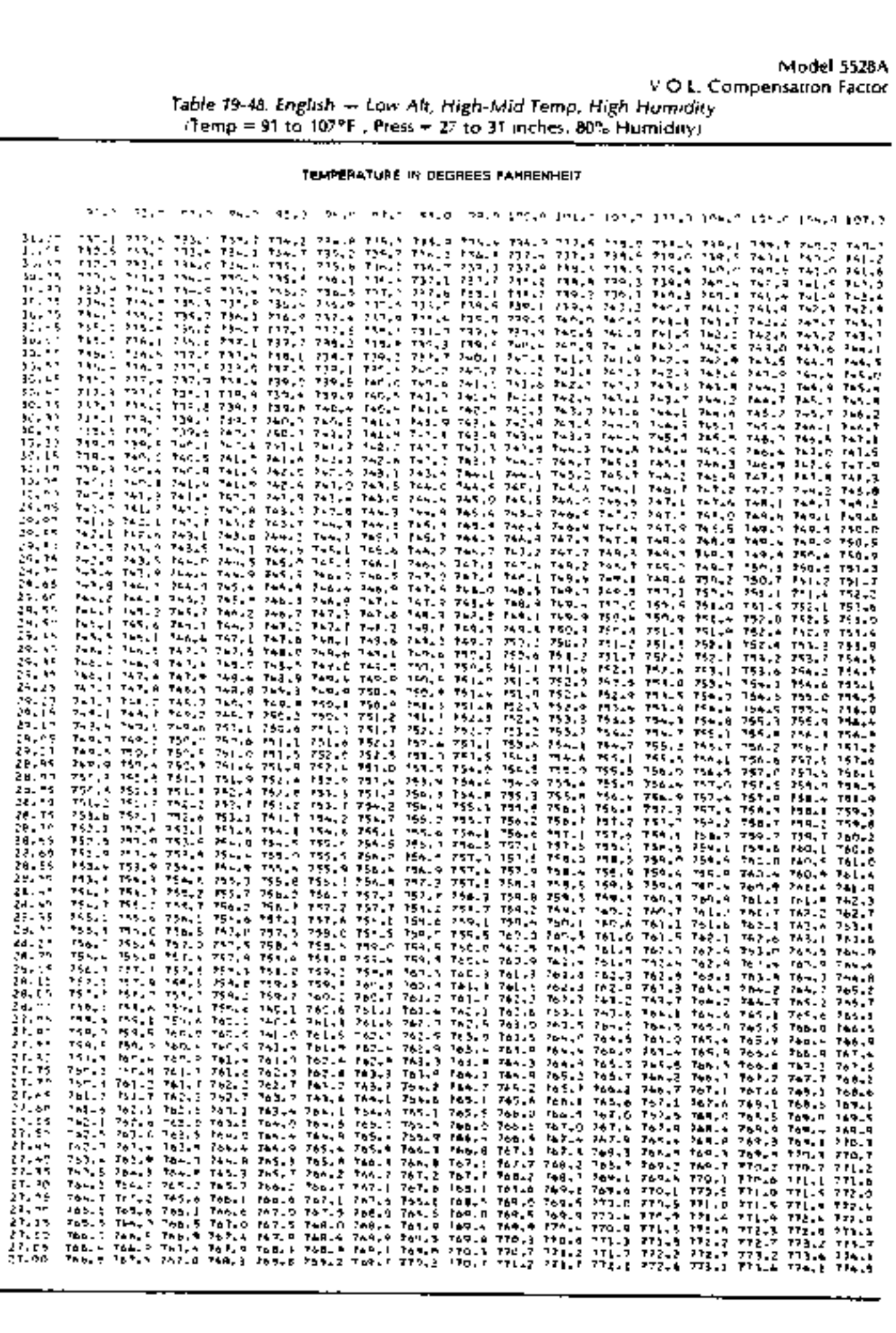


Table 19-49. English — High Alt, Low Temp, High Humidity
(Temp = 40 to 56°F , Press = 23 to 27 inches, 80% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-50. English — High Alt, Low-Mid Temp, High Humidity
(Temp = 57 to 73°F , Press = 23 to 27 inches, 80% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY

Table 19-51. English — High Alt, Mid Temp, High Humidity
(Temp = 74 to 90°F , Press = 23 to 27 inches, 80% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

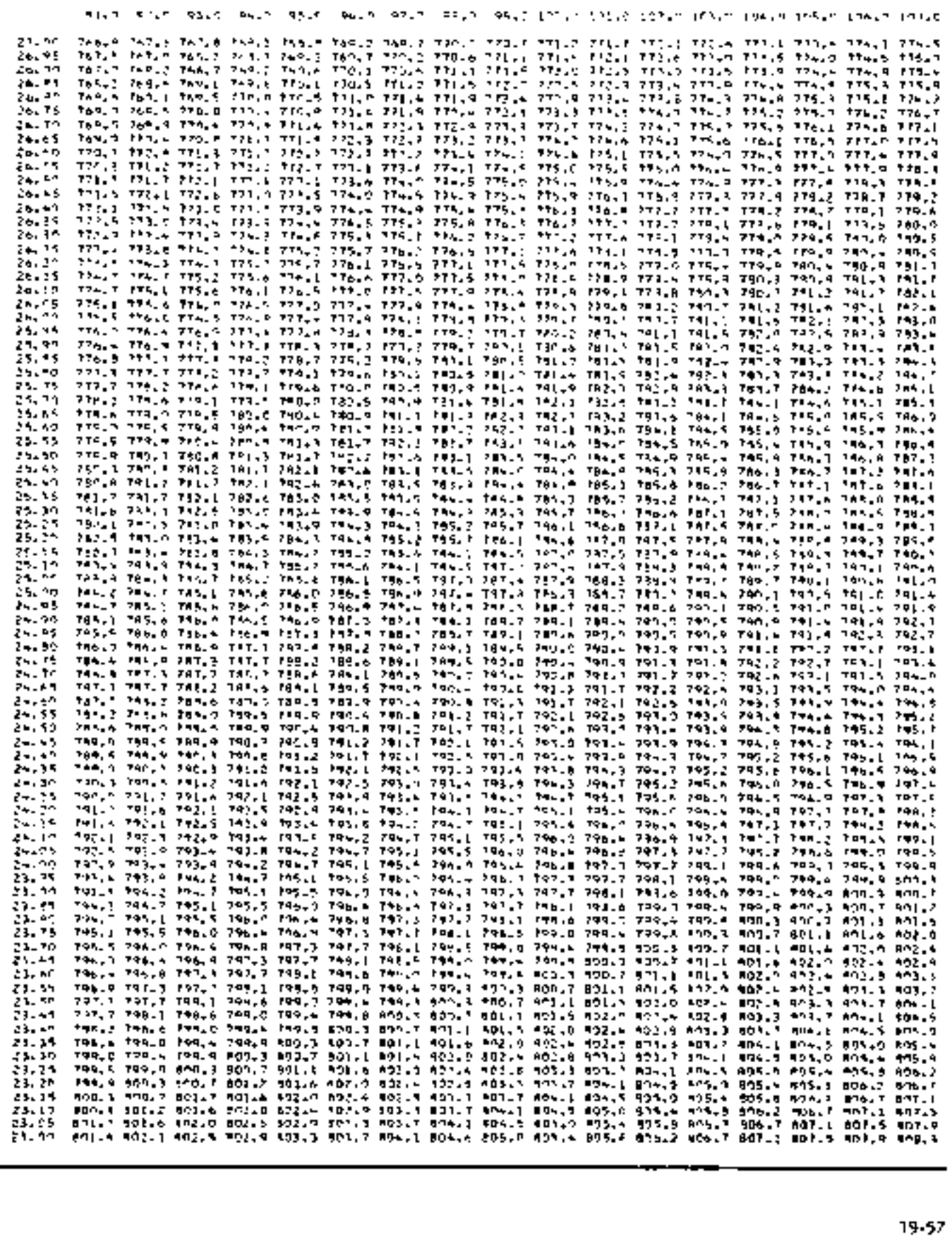
BAROMETRIC PRESSURE IN INCHES OF MERCURY

	74.0	75.0	76.0	77.0	78.0	79.0	80.0	81.0	82.0	83.0	84.0	85.0	86.0	87.0	88.0	89.0	90.0
27.00	759.5	759.1	758.6	758.1	757.6	757.1	756.5	756.0	755.4	754.9	754.3	753.7	753.1	752.5	751.9	751.3	750.6
27.05	759.6	759.2	758.7	758.2	757.7	757.2	756.6	756.1	755.5	755.0	754.4	753.8	753.2	752.6	752.0	751.4	750.7
27.10	759.8	759.3	758.8	758.3	757.8	757.3	756.7	756.2	755.6	755.1	754.5	753.9	753.3	752.7	752.1	751.5	750.8
27.15	760.0	759.5	759.0	758.4	757.9	757.4	756.8	756.3	755.7	755.2	754.6	754.0	753.4	752.8	752.2	751.6	750.9
27.20	760.1	759.6	759.1	758.6	758.1	757.5	757.0	756.4	755.8	755.3	754.7	754.1	753.5	752.9	752.3	751.7	751.0
27.25	760.3	759.8	759.3	758.8	758.2	757.7	757.1	756.6	756.0	755.4	754.8	754.2	753.6	753.0	752.4	751.8	751.1
27.30	760.5	760.0	759.5	758.9	758.4	757.8	757.3	756.7	756.1	755.6	755.0	754.4	753.8	753.2	752.6	752.0	751.3
27.35	760.7	760.2	759.6	759.1	758.5	758.0	757.4	756.9	756.3	755.7	755.1	754.5	753.9	753.3	752.7	752.1	751.4
27.40	760.8	760.3	759.8	759.2	758.7	758.1	757.6	757.0	756.4	755.9	755.3	754.7	754.1	753.5	752.9	752.3	751.6
27.45	761.0	760.5	759.9	759.4	758.8	758.3	757.7	757.2	756.6	756.0	755.4	754.8	754.2	753.6	753.0	752.4	751.7
27.50	761.2	760.7	760.1	759.6	759.0	758.4	757.9	757.3	756.7	756.2	755.6	755.0	754.4	753.8	753.2	752.6	751.9
27.55	761.4	760.8	760.3	759.7	759.2	758.6	758.0	757.5	756.9	756.3	755.7	755.1	754.5	753.9	753.3	752.7	752.0
27.60	761.5	761.0	760.4	759.9	759.3	758.8	758.2	757.6	757.0	756.5	755.9	755.3	754.7	754.1	753.5	752.9	752.2
27.65	761.7	761.2	760.6	760.1	759.5	758.9	758.4	757.8	757.2	756.6	756.0	755.4	754.8	754.2	753.6	753.0	752.3
27.70	761.9	761.3	760.8	760.2	759.6	759.1	758.5	757.9	757.3	756.8	756.2	755.6	755.0	754.4	753.8	753.2	752.5
27.75	762.1	761.5	761.0	760.4	759.8	759.3	758.7	758.1	757.5	756.9	756.3	755.7	755.1	754.5	753.9	753.3	752.6
27.80	762.2	761.7	761.1	760.5	760.0	759.4	758.8	758.2	757.6	757.1	756.5	755.9	755.3	754.7	754.1	753.5	752.8
27.85	762.4	761.8	761.3	760.7	760.1	759.6	759.0	758.4	757.8	757.2	756.6	756.0	755.4	754.8	754.2	753.6	752.9
27.90	762.6	762.0	761.4	760.8	760.3	759.7	759.1	758.5	757.9	757.4	756.8	756.2	755.6	755.0	754.4	753.8	753.1
27.95	762.7	762.2	761.6	761.0	760.4	759.8	759.3	758.7	758.1	757.5	756.9	756.3	755.7	755.1	754.5	753.9	753.2
28.00	762.9	762.3	761.7	761.2	760.6	760.0	759.4	758.8	758.2	757.6	757.1	756.5	755.9	755.3	754.7	754.1	753.4
28.05	763.1	762.5	762.0	761.4	760.8	760.2	759.6	759.0	758.4	757.8	757.2	756.6	756.0	755.4	754.8	754.2	753.5
28.10	763.2	762.7	762.1	761.5	760.9	760.3	759.7	759.1	758.5	758.0	757.4	756.8	756.2	755.6	755.0	754.4	753.7
28.15	763.4	762.8	762.2	761.7	761.1	760.5	759.9	759.3	758.7	758.1	757.5	756.9	756.3	755.7	755.1	754.5	753.8
28.20	763.5	763.0	762.4	761.8	761.2	760.6	760.0	759.4	758.8	758.3	757.7	757.1	756.5	755.9	755.3	754.7	753.9
28.25	763.7	763.1	762.5	762.0	761.4	760.8	760.2	759.6	759.0	758.4	757.8	757.2	756.6	756.0	755.4	754.8	754.1
28.30	763.8	763.3	762.7	762.1	761.5	760.9	760.3	759.7	759.1	758.6	758.0	757.4	756.8	756.2	755.6	755.0	754.2
28.35	764.0	763.4	762.8	762.3	761.7	761.1	760.5	759.9	759.3	758.7	758.1	757.5	756.9	756.3	755.7	755.1	754.4
28.40	764.1	763.6	763.0	762.4	761.8	761.2	760.6	760.0	759.4	758.9	758.3	757.7	757.1	756.5	755.9	755.3	754.5
28.45	764.3	763.7	763.1	762.5	762.0	761.4	760.8	760.2	759.6	759.0	758.4	757.8	757.2	756.6	756.0	755.4	754.7
28.50	764.4	763.9	763.3	762.7	762.1	761.5	760.9	760.3	759.7	759.2	758.6	758.0	757.4	756.8	756.2	755.6	754.8
28.55	764.6	764.0	763.4	762.8	762.3	761.7	761.1	760.5	759.9	759.3	758.7	758.1	757.5	756.9	756.3	755.7	755.0
28.60	764.7	764.2	763.6	763.0	762.4	761.8	761.2	760.6	760.0	759.5	758.9	758.3	757.7	757.1	756.5	755.9	755.1
28.65	764.9	764.3	763.7	763.2	762.6	762.0	761.4	760.8	760.2	759.6	759.0	758.4	757.8	757.2	756.6	756.0	755.3
28.70	765.0	764.5	763.9	763.3	762.7	762.1	761.5	761.0	760.4	759.8	759.2	758.6	758.0	757.4	756.8	756.2	755.4
28.75	765.2	764.6	764.0	763.5	762.9	762.3	761.7	761.1	760.5	759.9	759.3	758.7	758.1	757.5	756.9	756.3	755.6
28.80	765.3	764.8	764.2	763.6	763.0	762.4	761.8	761.2	760.7	760.1	759.5	758.9	758.3	757.7	757.1	756.5	755.7
28.85	765.5	764.9	764.3	763.8	763.2	762.6	762.0	761.4	760.8	760.2	759.6	759.0	758.4	757.8	757.2	756.6	755.9
28.90	765.6	765.1	764.5	763.9	763.3	762.7	762.1	761.5	761.0	760.4	759.8	759.2	758.6	758.0	757.4	756.8	756.0
28.95	765.8	765.2	764.6	764.1	763.5	762.9	762.3	761.7	761.1	760.5	759.9	759.3	758.7	758.1	757.5	756.9	756.2
29.00	765.9	765.4	764.8	764.2	763.6	763.0	762.4	761.8	761.2	760.7	760.1	759.5	758.9	758.3	757.7	757.1	756.3
29.05	766.1	765.5	765.0	764.4	763.8	763.2	762.6	762.0	761.4	760.8	760.2	759.6	759.0	758.4	757.8	757.2	756.5
29.10	766.2	765.7	765.1	764.5	763.9	763.3	762.7	762.1	761.5	761.0	760.4	759.8	759.2	758.6	758.0	757.4	756.6
29.15	766.4	765.8	765.3	764.7	764.1	763.5	762.9	762.3	761.7	761.1	760.5	759.9	759.3	758.7	758.1	757.5	756.8
29.20	766.5	766.0	765.4	764.8	764.2	763.6	763.0	762.4	761.8	761.2	760.7	760.1	759.5	758.9	758.3	757.7	756.9
29.25	766.7	766.1	765.5	765.0	764.4	763.8	763.2	762.6	762.0	761.4	760.8	760.2	759.6	759.0	758.4	757.8	757.1
29.30	766.8	766.3	765.7	765.1	764.5	763.9	763.3	762.7	762.1	761.5	761.0	760.4	759.8	759.2	758.6	758.0	757.2
29.35	767.0	766.4	765.8	765.3	764.7	764.1	763.5	762.9	762.3	761.7	761.1	760.5	759.9	759.3	758.7	758.1	757.4
29.40	767.1	766.6	766.0	765.4	764.8	764.2	763.6	763.0	762.4	761.8	761.2	760.7	760.1	759.5	758.9	758.3	757.5
29.45	767.3	766.7	766.1	765.6	765.0	764.4	763.8	763.2	762.6	762.0	761.4	760.8	760.2	759.6	759.0	758.4	757.7
29.50	767.4	766.9	766.3	765.7	765.1	764.5	763.9	763.3	762.7	762.1	761.5	761.0	760.4	759.8	759.2	758.6	757.8
29.55	767.6	767.0	766.4	765.9	765.3	764.7	764.1	763.5	762.9	762.3	761.7	761.1	760.5	759.9	759.3	758.7	758.0
29.60	767.7	767.2	766.6	766.0	765.4	764.8	764.2	763.6	763.0	762.4	761.8	761.2	760.7	760.1	759.5	758.9	758.1
29.65	767.9	767.3	766.7	766.2	765.6	765.0	764.4	763.8	763.2	762.6	762.0	761.4	760.8	760.2	759.6	759.0	758.3
29.70	768.0	767.5	766.9	766.3	765.7	765.1	764.5	763.9	763.3	762.7	762.1	761.5	761.0	760.4	759.8	759.2	758.4
29.75	768.2	767.6	767.0	766.5	765.9	765.3	764.7	764.1	763.5	762.9	762.3	761.7	761.1	760.5	759.9	759.3	758.6
29.80	768.3	767.8	767.2	766.6	766.0	765.4	764.8	764.2	763.6	763.0	762.4	761.8	761.2	760.7	760.1	759.5	758.7
29.85	768.5	767.9	767.3	766.8	766.2	765.6	765.0	764.4	763.8	763.2	762.6	762.0	761.4	760.8	760.2	759.6	758.9
29.90	768.6	768.1	767.5	766.9	766.3	765.7	765.1	764.5	763.9	763.3	762.7	762.1	761.5	761.0	760.4	759.8	759.0
29.95	768.8	768.2	767.6	767.1	766.5	765.9	765.3	764.7	764.1	763.5	762.9	762.3	761.7	761.1	760.5	759.9	759.2
30.00	768.9	768.4	767.8	767.2	766.6	766.0	765.4	764.8	764.2	763.6	763.0	762.4	761.8	761.2	760.7	760.1	759.3
30.05	769.1	768.5	768.0	767.4	766.8	766.2	765.6	765.0	764.4	763.8	763.2	762.6	762.0	761.4	760.8	760.2	759.5
30.10	769.2	768.7	768.1	767.5	766.9	766.3	765.7	765.1	764.5	764.0	763.4	762.8	762.2	761.6	761.0	760.4	759.6
30.15	769.4	768.8	768.3	767.7	767.1	766.5	765.9	765.3	764.7	764.1	763.5	762.9	762.3	761.7	761.1	760.5	759.8
30.20	769.5	769.0	768.4	767.8	767.2	766.6	766.0	765.4	764.8	764.2	763.6	763.0	762.4	761.8	761.2	760.7	759.9
30.25	769.7	769.1	768.5	768.0	767.4	766.8	766.2	765.6	765.0	764.4	763.8	763.2	762.6	762.0	761.4	760.8	760.1
30.30	769.8	769.3	768.7	768.1	767.5	766.9	766.3	765.7	765.1	764.5	764.0	763.4	762.8	762.2	761.6	761.0	760.2
30.35	770.0	769.4	768.8	768.3	767.7	767.1	766.5	765.9	765.3	764.7	764.1	763.5	762.9	762.3	761.7	761.1	760.4
30.40	770.1	769.6	769.0	768.4	767.8	767.2	766.6	766.0	765.4	764.8	764.2	763.6	763.0	762.4	761.8	761.2	760.5
30.45	770.3	769.7	769.1	768.6	768.0	767.4	766.8	766.2	765.6	765.0	764.4	763.8	763.2	762.6	762.0	761.4	760.7
30.50	770.4	769.9	769.3	768.7	768.1	767.5	766.9	766.3	765.7	765.1	764.5	764.0	763.4	762.8	762.2	761.6	760.8
30.55	770.6	770.0	769.4	768.9	768.3	767.7	767.1	766.5	765.9	765.3	764.7	764.1	763.5	762.9	762.3	761.7	761.0
30.60	770.7	770.2	769.6	769.0	768.4	767.8	767.2	766.6	766.0	765.4	764.8	764.2	763.6	763.0	762.4	761.8	761.1
30.65	770.9	770.3	769.7	769.2	768.6	768.0	767.4	766.8	766.2	765.6	765.0	764.4	763.8	763.2	762.6	762.0	761.3
30.70	771.0	770.5	769.9	769.3	768.7	768.1	767.5	766.9	766.3	765.7	765.1	764.5	764.0	763.4	762.8	762.2	761.5
30.75	771.2	770.6	770.0	769.5	768.9	768.3	767.7	767.1	766.5	765.9	765.3	764.7	764.1	763.5	762.9	762.3	761.6
30.80	771.3	770.8	770.2	769.6	769.0	768.4	767.8	767.2	766.6	766.0	765.4	764.8	764.2	763.6	763.0	762.4	761.8
30.85	771.5	770.9	770.3	769.8	769.2	768.6	768.0	767.4	766.8	766.2	765.6	765.0	764.4	763.8	763.2	762.6	761.9
30.90	771.6	771.1	770.5	769.9	769.3	768.7	768.1	767.5	766.9	766.3	765.7	765.1	764.5	764.0	763.4	762.8	762.1
30.95	771.8	771.2	770.6	770.1	769.5	768.9	768.3	767.7	767.1	766.5	765.9	765.3	764.7	764.1	763.5	762.9	762.2
31.00	771.9	771.4	770.8	770.2	769.6	769.0	768.4	767.8	767.2	766.6	766.0	765.4	764.8	764.2	763.6	763.0	762.4

Table 19-52 English — High Alt, High-Mid Temp, High Humidity
(Temp = 91 to 107°F , Press = 23 to 27 inches, 80% Humidity)

TEMPERATURE IN DEGREES FAHRENHEIT

BAROMETRIC PRESSURE IN INCHES OF MERCURY



SECTION 20
OPERATOR MAINTENANCE

INTRODUCTION

There are two maintenance procedures that should be performed periodically to keep your Laser Measurement System working its best for you.

These procedures are —

- Cleaning the air filter in the Measurement Display unit, —
- Calibrating the Air Sensor and Material Temperature Sensor(s), and related circuitry in the Measurement Display unit, if sensors are used in the system

In addition, foreign material (dirt, dust particles, other contaminants) may collect on the Optics and cause attenuation of the Laser beam. A procedure for cleaning the Optics is provided below.

CLEANING THE MEASUREMENT DISPLAY UNIT'S AIR FILTER

The air filter at the top of the Measurement Display unit's rear panel should be cleaned periodically or when it has collected excessive dirt. To clean the filter, —

a. Remove the POSIDRIV screw that fastens the right-hand side of the filter holder to the Measurement Display unit's rear panel. (This screw is just to the left of the RMT CONT connector.) Gently pull the right-hand side of the filter holder away from the rear panel; the left-hand side of the filter holder is held by a tab that slides into a slot in the panel.

b. Remove the filter from the holder and clean it by blowing compressed air through it from the inside out. If the filter is too dirty to clean with air, wash the filter element in hot water and a mild detergent. Dry the filter before reinstalling.

For the HP Part Number of a replacement filter element, see Section 3 of the Laser Measurement System's Service Manual.

CALIBRATION

Optionally, an Air Sensor and Material Temperature Sensor(s) can be connected to the Measurement Display unit for automatic compensation. In order to maintain the accuracy of a Laser Measurement System that includes these sensors, the sensors and the Measurement Display should be calibrated once a year or when required because of repair. Calibration procedures are provided in Section 4 of the Laser Measurement System's Service Manual.

If sensors are used with the system, two voltage references and an Analog-to-Digital Converter in the Measurement Display unit must be calibrated. However, if sensors are not used, this calibration is not needed.

Sensor calibration requires special equipment, so the sensors must be returned to Hewlett-Packard for this service.

Contact your local Hewlett-Packard Sales and Service office for more specific information.

CLEANING THE OPTICS

WARNING

THE FOLLOWING OPTICAL CLEANING PROCEDURES DO NOT APPLY TO THE OPTICS IN THE LASER HEAD. CLEANING OF THE LASER HEAD OPTICS REQUIRES ACCESS TO THE INTERIOR OF THE INSTRUMENT WHERE HIGH VOLTAGES CAN BE PRESENT. THUS ALL LASER HEAD MAINTENANCE SHOULD BE PERFORMED BY A QUALIFIED ELECTRONICS TECHNICIAN WHO IS AWARE OF THE HAZARDS INVOLVED.

A good rule for the exposed glass surfaces is NEVER LET ANYTHING TOUCH THEM. A fingerprint will collect dust and dirt which will reduce the beam intensity by attenuating and dispersing the beam.

Cleaning the optics should be avoided unless the signal intensity is noticeably reduced as indicated by the Beam Strength Meter.

If cleaning is necessary, you must be careful to avoid rubbing particles into the antireflective lens coating. Permanent reduction of the signal intensity will result. Particles can be rinsed with a gentle stream of pure industrial grade methanol from a squirt bottle. Avoid alcohol contamination with the following precautions —

1. Use only new, previously unopened containers. Alcohol absorbs water if left exposed to air. This will result in water spots when the alcohol evaporates.
2. Transfer the alcohol to a squeeze bottle that can be capped and made airtight.
3. Never transfer alcohol back into the original container.

SECTION 21
STRAIGHTNESS AND SQUARENESS CONSIDERATIONS

CONTENTS

INTRODUCTION
CALCULATION OF SLOPE
CALCULATION OF SQUARENESS
SQUARENESS SIGN CONVENTIONS

INTRODUCTION

This User's Guide Section provides the information you need in order to calculate and remove the slope from your Straighness measurements or to calculate the Squareness between two axes.

This Section will also help you determine the sign conventions on your Straghtness measurements so your Squareness calculation is correct, whether it is done manually or automatically (using the HP Dimensional Metrology Analysis System).

CALCULATION OF SLOPE

There are two methods used to remove the slope value from your data. The first method is called "End Point Fit", and the second is called "Least Squares Fit"

End Point Fit Method

To remove slope from your measurement data, using the "End Point Fit" method, you should —

a. Determine the slope of your data by subtracting the first reading from the last, and then dividing by the length of travel of the Optics.

$$m\ (slope) = \frac{\text{last measurement} - \text{first measurement}}{\text{length of travel of Optics}}$$

b Identify the equation of the line of your slope —

$$Y_{slope} = m\lambda + b,$$

where —

Y will be a calculated value,

λ is the distance travelled along the measorement path, and

b is the first Straightness reading.

c. Determine what "Y" should be for each "X" along your measurement path using the equation above. This will be —

$$Y_{slope}$$

d. Subtract all the values you calculated in step "c" from the values you actually measured with the Laser Measurement System, leaving you with "true" Straightness values —

$$Y_{true} = Y_{LMS} - Y_{slope}$$

Here is an example of calculating "slope" and then "true" Straightness values for two axes of measurement. We use values for two axes because we will use the "slope" values in our Squareness calculations later.

The important variables are —

m = slope of the misalignment axis

b = intercept of the misalignment axis

x = position of the machine along the axis of travel

Y_{slope} = value of the bias due to misalignment (slope) of the Optical straightedge axis with the axis of travel

Y_{true} = true value of the out-of-straightness of the machine

Y_{LMS} = reading on the laser display

For Axis 1 —

Our raw data is —

Y_{LMS} = −0.3, 0.9, 1.5, 2.5, 2.9, 3.6, 4.2, 5.1, 5.9, 7.2 (microns)

X = 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 (metres)

Number of points = 10

Calculations for Axis 1 —

Total distance travelled, ΔX = 0.9 metre

Slope $m_1 = \Delta Y/\Delta X = (7.2-(-0.3))/(0.9-0.0)$

= 8.33 microns/metre

Intercept = b_1 = −0.3 microns (at $X = 0$, you want $Y_{true} = 0$)

Therefore —

$Y_{slope} = m_1 X + b_1 = 8.33X - 3.3$

$Y_{true} = Y_{LMS} - Y_{slope}$

X =	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Y_{LMS} =	−0.3	0.9	1.5	2.5	2.9	3.6	4.2	5.1	5.9	7.2
Y_{slope} =	−0.3	0.5	1.4	2.2	3.0	3.9	4.7	5.5	6.4	7.2
Y_{true} =	0.0	0.4	0.1	0.3	−0.7	−0.3	−0.5	−0.4	−0.5	0.0 (microns

For Axis 2 —

Our raw data is —

Y_{LMS} = −0.5, −1.2, −2.5, −3.8, −4.0, −4.8, −5.9, −6.2, −7.4, −8.8 (microns)

X = 0.0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45 (metre)

Number of points = 10

Calculations for Axis 2 —

Total distance travelled: ΔX = 0.45 metre

Slope $m_2 = \Delta Y/\Delta X = |-8.8-|-0.5||/(0.45-0.0)$

$= -16.44$ microns/metre

Intercept = b_2 = −0.5 microns (at X = 0, you want Y_{true} = 0)

Therefore —

$Y_{slope} = m_1 X + b_1 = 20.67X - 0.5$

$Y_{true} = Y_{LMS} - Y_{slope}$

X =	0.0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45
Y_{LMS} =	−0.5	−1.2	−2.5	−3.8	−4.0	−4.8	−5.9	−6.2	−7.4	−8.8
Y_{slope} =	−0.5	−1.42	−2.34	−3.27	−4.19	−5.1	−6.03	−6.96	−7.88	−8.8
Y_{true} =	0.0	−0.22	−0.16	−0.53	0.19	0.31	0.13	0.76	0.48	0.0 (microns.

LEAST SQUARES FIT METHOD

To remove slope from your measurement data, using the Least Squares Fit Method, you should —

a. Determine both the slope (m) and the intercept (b) from calculations on your raw data.

b. Identify the equation of the line of your slope —

$Y_{slope} = mX + b.$

where —

Y will be a calculated value, and

X is the distance travelled along the measurement path.

c. Determine what "Y" should be for each "X" along your measurement path using the equation above. This will be —

$$Y_{slope}$$

d. Subtract all the values you calculated in step "c" from the values you actually measured with the Laser Measurement System, leaving you with "true" Straightness values —

$$Y_{true} = Y_{LMS} - Y_{slope}$$

Here is an example of calculating "slope" and then "true" Straightness values for two axes of measurement.

The important variables are —

m = slope of the misalignment axis

b = intercept of the misalignment axis

x = position of the machine along the axis of travel

Y_{slope} = value of the bias due to misalignment of the Optical straightedge axis with the axis of travel

Y_{true} = true value of the out-of-straightness of the machine

Y_{LMS} = reading on the laser display

The raw data is the same as the data used in the example for the "End Point Fit" method.

For Axis 7 —

Our raw data is —

Y_{LMS} = -0.3, 0.9, 1.5, 2.5, 2.9, 3.6, 4.2, 5.1, 5.9, 7.2 (microns)

X = 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 (metre)

Number of points = 10

Calculations for Axis 1 —

Equations used —

$$\text{Slope } m = \frac{\Sigma X \times \Sigma Y - N \times \Sigma XY}{(\Sigma X)^2 - N \times \Sigma X^2}$$

$$\text{Intercept } b = \frac{\Sigma X \times \Sigma XY - \Sigma Y \times \Sigma X^2}{(\Sigma X)^2 - N \times \Sigma X^2}$$

Axis 1 Data —

X	Y	X2	XY
0.0	-0.3	0	0.0
0.1	0.9	0.01	0.09
0.2	1.5	0.04	0.30
0.3	2.5	0.09	0.75
0.4	2.9	0.16	1.16
0.5	3.6	0.25	1.80
0.6	4.2	0.36	2.52
0.7	5.1	0.49	3.57
0.8	5.9	0.64	4.72
0.9	7.2	0.81	6.48
4.5	33.5	2.85	21.39

$$m_1 = \frac{|33.5||4.5| - (10)|21.39|}{|4.5|^2 - (10)|2.85|} = 7.65 \text{ microns/metre}$$

$$b_1 = \frac{(4.5)|21.39| - |33.5||2.85|}{|4.5|^2 - (10)|2.85|} = -0.095 \text{ micron}$$

therefore —

$$Y_{slope} = m_1 X + b_1 = 7.65X - 0.095$$

X =	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Y_{LMS} =	-0.3	0.9	1.5	2.5	2.9	3.6	4.2	5.1	5.9	7.2
Y_{slope} =	-0.1	0.7	1.4	2.2	3.0	3.7	4.5	5.3	6.0	6.8
Y_{true} =	0.2	0.2	0.1	0.3	-0.1	-0.1	-0.3	-0.2	-0.1	0.4 (microns)

For Axis 2 —

Our raw data is —

Y_{LMS} = −0.5, −1.2, −2.5, −3.8, −4.0, −4.8, −5.9, −6.2, −7.4, −8.8 (microns)

X = 0.0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45 (metre)

Number of points = 10

Calculations for Axis 2 —

Axis 2 Data —

X	Y	X^2	XY
0.0	0.5	0	0.0
0.05	−1.2	0.00025	−0.060
0.1	−2.5	0.010	−0.250
0.15	−3.8	0.0225	−0.570
0.2	−4.0	0.040	−0.800
0.25	−4.8	0.0625	−1.20
0.3	−5.9	0.090	−1.77
0.35	−6.2	0.1225	−2.17
0.4	−7.4	0.160	−2.96
0.45	−8.8	0.2025	−3.96
2.25	−45.1	0.7125	−13.74

$$m_2 = \frac{(-45.1)(2.25) - (10)(-13.74)}{(2.25)^2 - (10)(0.7125)} = -17.42 \text{ microns/metre}$$

$$b = \frac{(2.25)(-13.74) - (-45.1)(0.7125)}{(2.25)^2 - (10)(0.7125)} = 0.591 \text{ micron}$$

$$Y_{slope} = m_2 X + b_2 = -17.42X - 0.591 \text{ micron}$$

X =	0.0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45
Y_{LMS} =	0.5	−1.2	−2.5	−3.8	−4.0	−4.8	−5.9	−6.2	−7.4	−8.8
Y_{slope} =	−0.291	−1.46	−2.33	−3.2	−4.08	−4.95	−5.82	−6.69	−2.56	−8.43
Y_{true} =	0.09	−0.262	−0.167	−0.596	0.08	−0.146	−0.083	0.488	0.159	−0.37 (microns)

CALCULATION OF SQUARENESS

Squareness is determined by comparing the angles of misalignment for two Straightness measurements. This is what must be done —

1. For each axis, determine the angle of misalignment (θ).

   This is done by taking the arctangent of the slope (m) of each Straightness measurement and multiplying by 3600, to convert it to "arcseconds"

θ = [arctangent (m)] x 3600 (arcseconds)

Be sure your slope value is dimensionless, i.e., metre/metre or inch/inch.

This means dividing the previously-calculated slope values by one million (10^6). Using the values in our examples, you'll get —

Calculation Method	Term	Axis 1 Value	Axis 2 Value
End-point Fit	m	8.3×10^{-6}	-18.44×10^{-6}
	θ	1.7	-3.8
Least-square Fit	m	7.65×10^{-6}	-17.42×10^{-6}
	θ	1.6	-3.6

2. Determine the sign of each angle of misalignment by following the procedures on the following pages.

   This is very important since adding two angles will certainly produce a much different Squareness value than subtracting the same angles.

3. Calculate the total angle between the two axes by the following formula (refer to *Figure 21-1*) —

   Total angle = 324000 + θ_2 - θ_1 + Optical Square Error

   The value "324000" is the number of arcseconds in a right angle (90 x 3600).

   "Optical Square Error" is the number of arcseconds of error in the Optical Square; i.e., how far it is from being exactly 90 degrees (324000 arcseconds) square. This value is found printed on the surface of the Optical Square.

   Always add θ_2 and always subtract θ_1, regardless of their sign conventions. (See the example below.)

4. Calculate Squareness —

   Squareness = θ_2 - θ_1 + Optical Square Error

   If the Optical Square's error = 0.0, then the Squareness (using our previous calculations) is

Calculation Method	Squareness
End-point Fit	-5.5 arcseconds
Least-squares Fit	-5.2 arcseconds

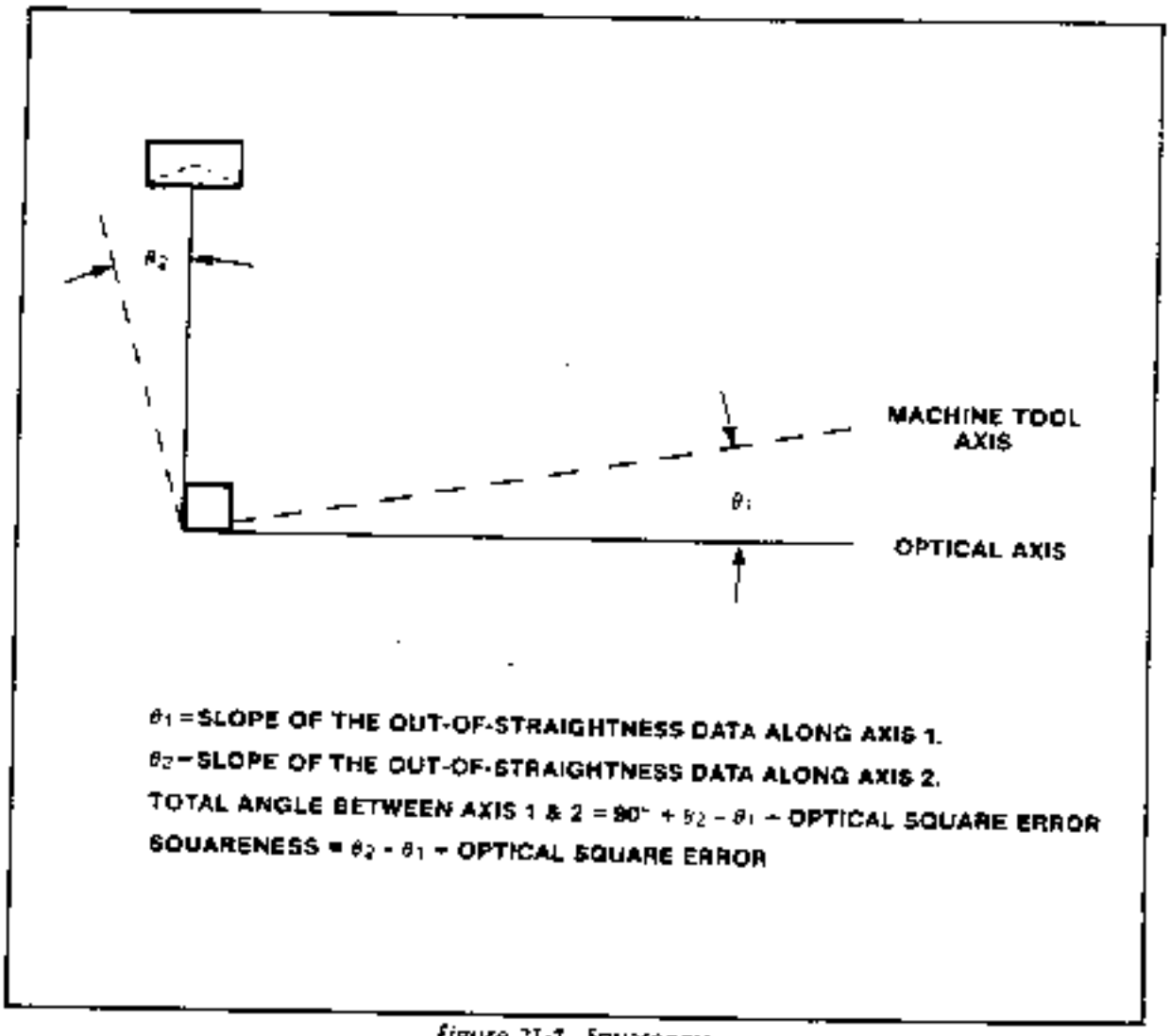


Figure 21-1. Squareness

Squareness Sign Conventions

When making a single Straightness measurement, you need not worry about the sign convention used, other than to relate positive values to one direction of the machine tool's movement.

However, when you are making a Squareness measurement, the sign convention is critical in making sure you have the correct sign and magnitude of the Squareness error.

Figure 21-1 shows how to obtain a squareness value. This is the same procedure the HP Dimensional Metrology Analysis System uses to define squareness.

Determining Sign Conventions

To determine the sign conventions for Straightness and Squareness, —

1. Draw the Squareness measurement you are going to take. Identify which direction along each of the two Straightness measurement paths will be "into" the square and which direction will be "out" of the square (See Figure 21-2).

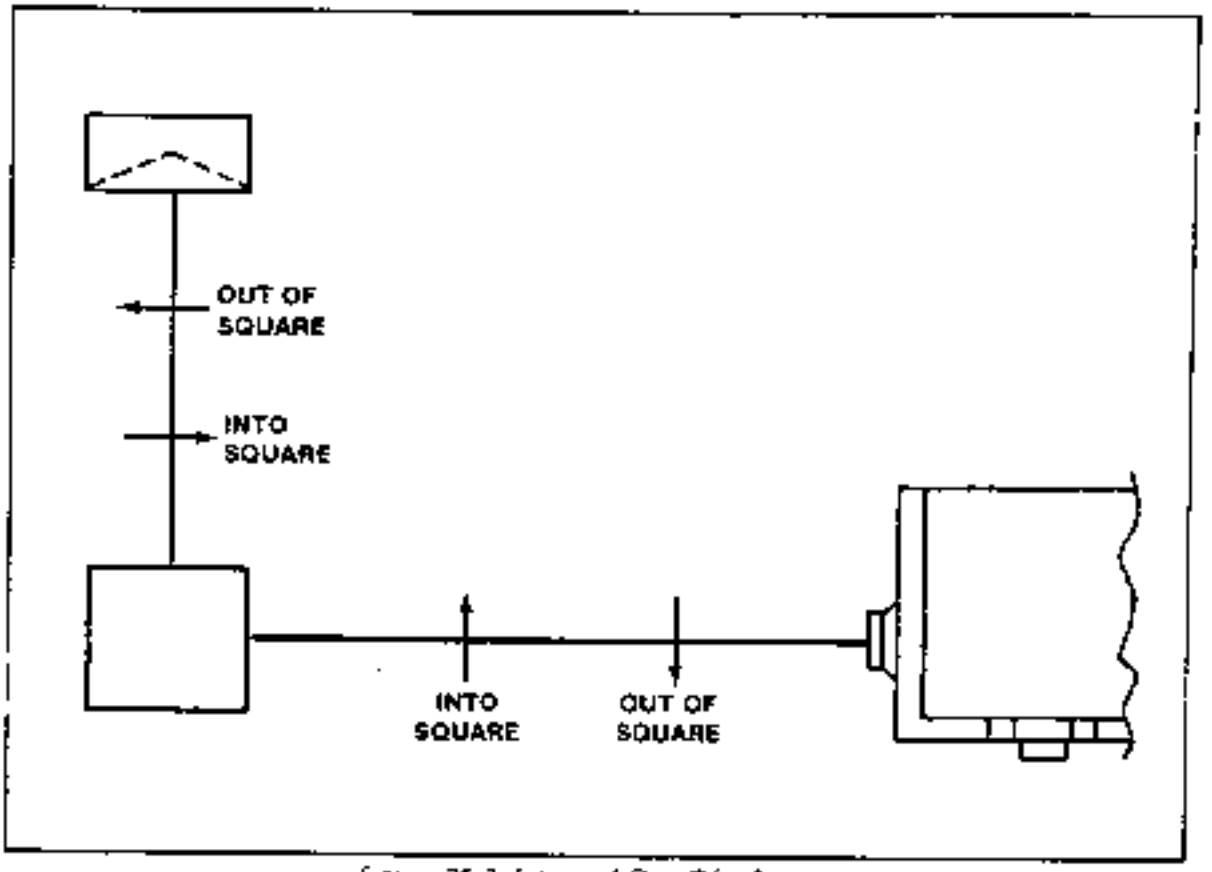


Figure 21-2 Into and Out Of a Square

2. For each axis, select the direction of travel which is more convenient for your setup. The moving optic can travel either towards or away from the Optical Square.
3. For each axis, set the DIR SENSE key on the Measurement Display according to the Squareness Convention Guide in *Figure 21-3*. Notice that the direction sense of the moving optic is determined by the direction of travel you selected in Step 2 above.

   Measure the axis perpendicular to the Straightness Reflector first, and the axis in line with the Straightness Reflector second. *Figure 21-5* shows the eight possible configurations.

NOTE

If you measure the axis in line with the Straightness Reflector first, then all direction senses are reversed. *Figure 21-6* shows these eight possible configurations.

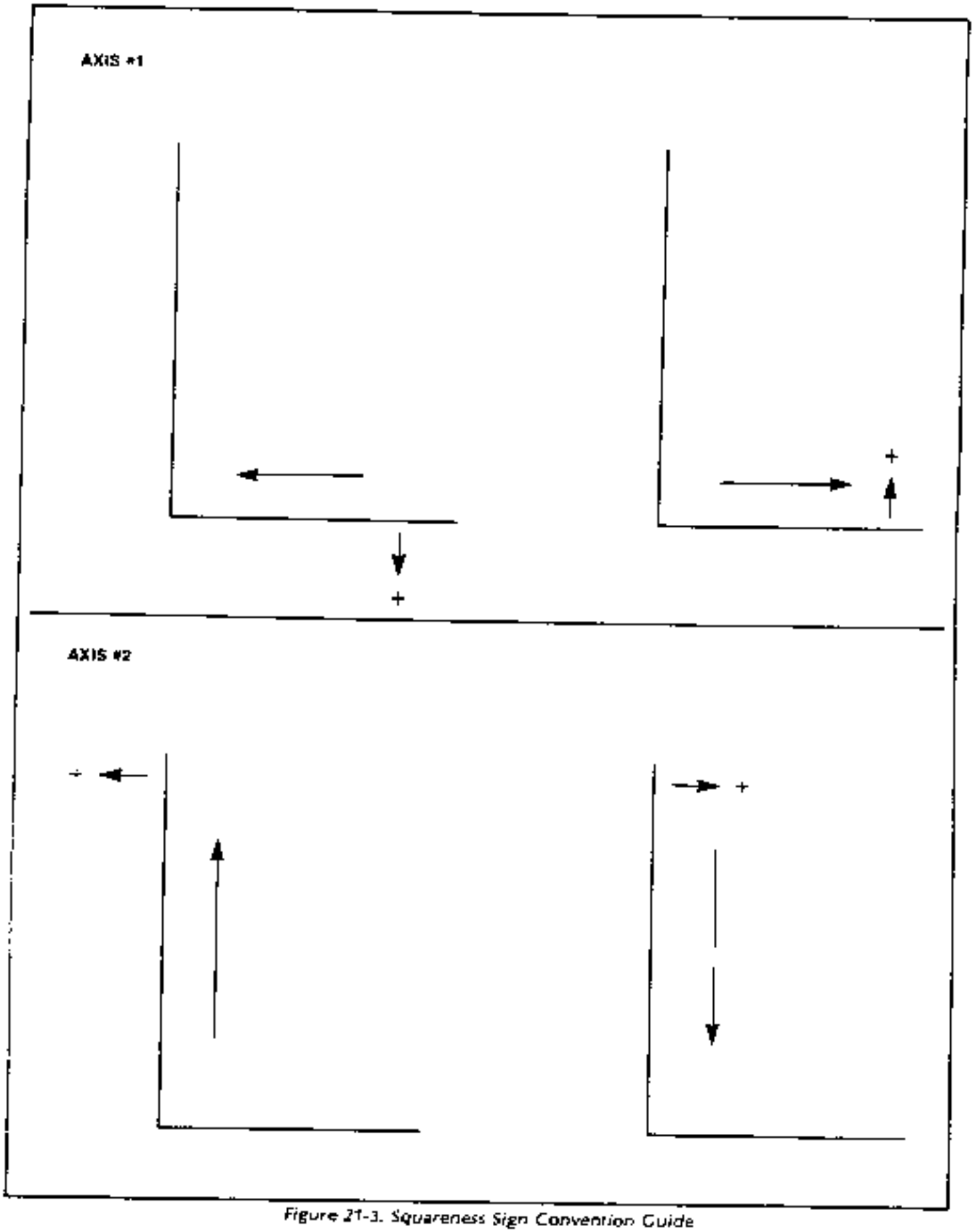
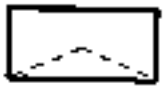


Figure 21-3. Squareness Sign Convention Guide

LEGEND FOR SQUARENESS SIGN CONVENTION CONFIGURATIONS



Straightness Reflector



Straightness Interferometer



Direction of travel of moving optic

1 — Starting point of Straightness measurement for first axis

2 — Starting point of Straightness measurement for second axis

\+ — Deviations of the moving optic in the direction of the + should result in an increasing positive reading on the Measurement Display

Figure 21-4. Legend for Squareness Sign Convention

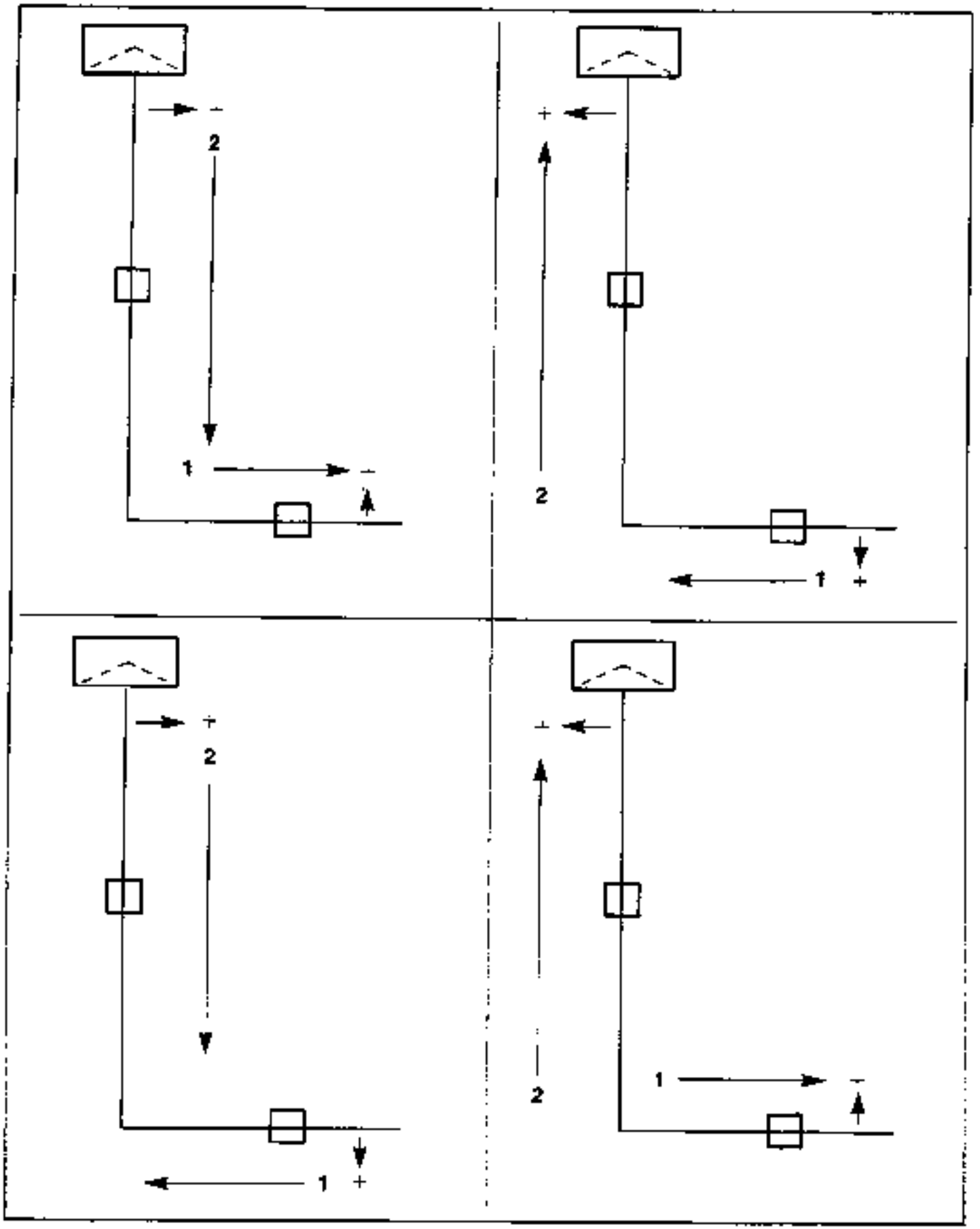


Figure 21-5. Squareness Sign Convention Configurations

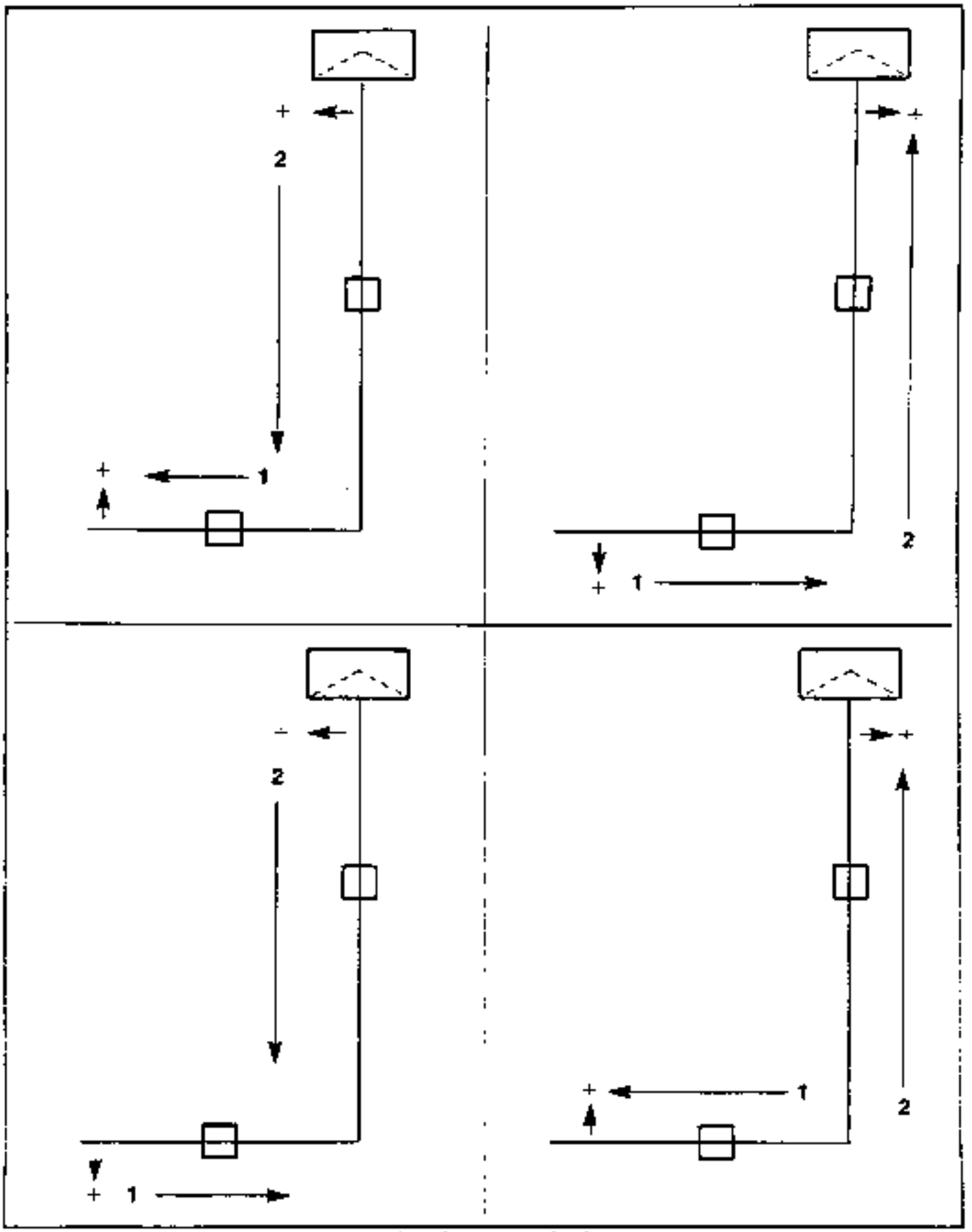


Figure 21-5. Squareness Sign Convention Configurations (Continued)

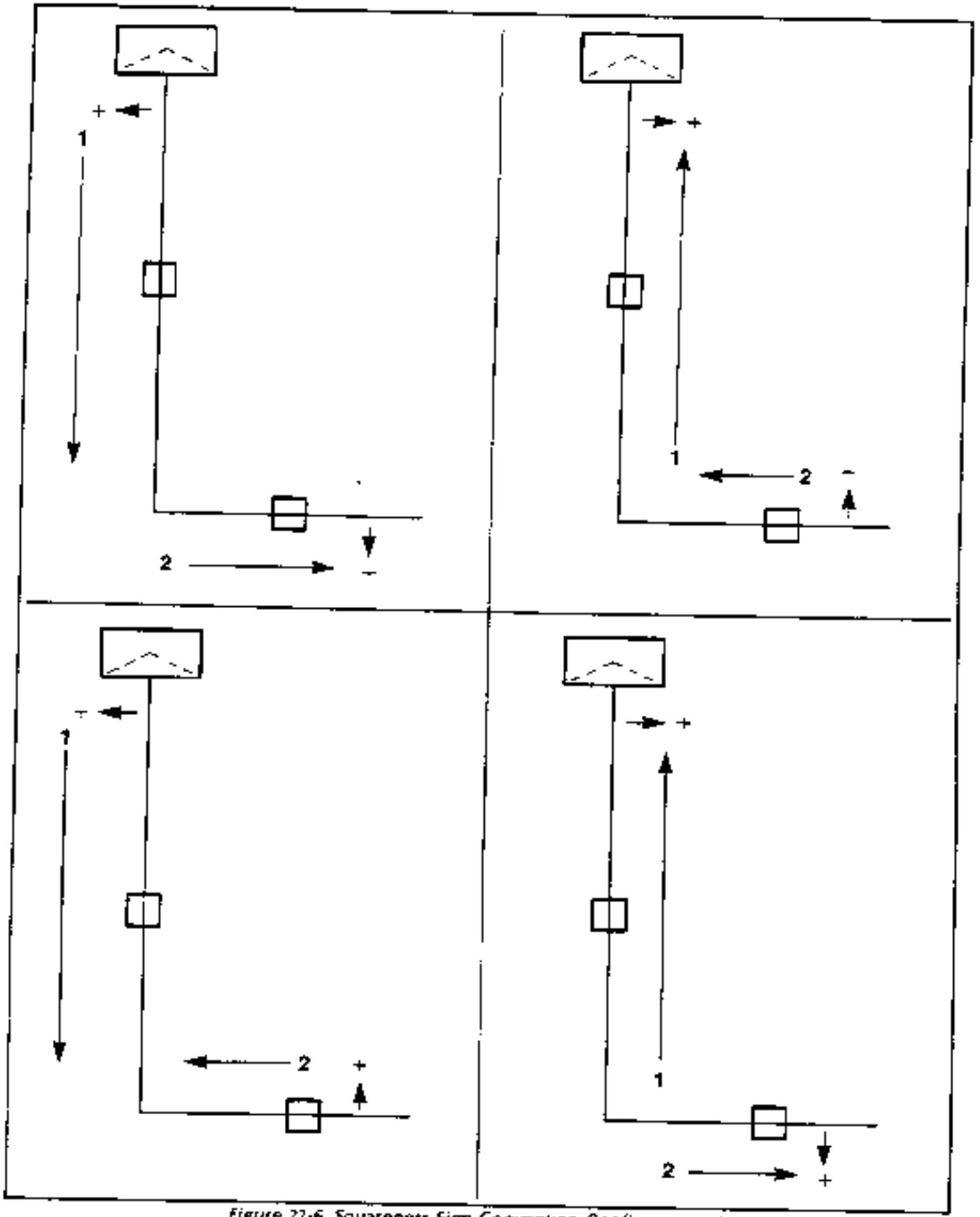


Figure 21-6 Squareness Sign Convention Configurations for First Axis Measurements In-line with the Reflector.

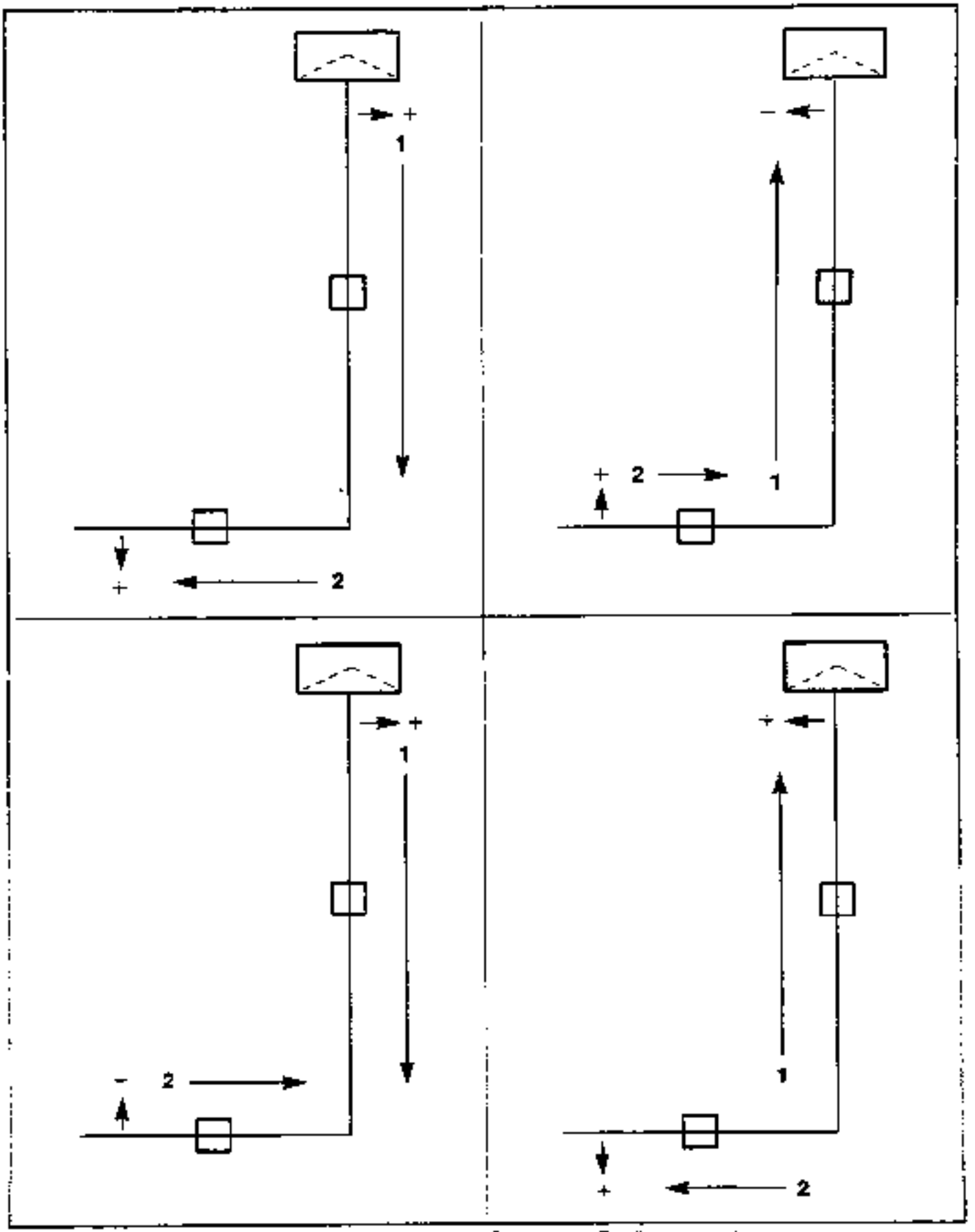


Figure 21-6 Squareness Sign Convention Configurations for First Axis Measurements In-line with the Reflector. (Continued)

A Principles of Operation

APPENDIX A
PRINCIPLES OF OPERATION

CONTENTS

INTRODUCTION
HARDWARE DESCRIPTIONS
- 5508A MEASUREMENT DISPLAY
- 5518A LASER HEAD
- 10751 AIR SENSOR
- 10757 MATERIAL SENSOR
- 10766A LINEAR INTERFEROMETER
- 10767A LINEAR RETROREFLECTOR
- 10770A ANGULAR INTERFEROMETER
- 10771A ANGULAR REFLECTOR
- 10774A AND 10775A STRAIGHTNESS INTERFEROMETER AND REFLECTOR

PRINCIPLES OF MEASUREMENTS
- GENERAL SYSTEM PRINCIPLES
- DISTANCE AND VELOCITY MEASUREMENTS
- ANGULAR MEASUREMENTS
- FLATNESS MEASUREMENTS
- STRAIGHTNESS MEASUREMENTS
- SQUARENESS MEASUREMENTS
- PARALLELISM MEASUREMENTS

INTRODUCTION

This User's Guide section —

- describes the major hardware pieces of the Laser Measurement System, and —
- presents the principles of operation of the Laser Measurement System

If you need more information than is presented in this Section, go to Section 8 of the Laser Measurement System's Service Manual. The Service Manual goes into greater depth, explaining exactly how the electronic functions are executed.

HARDWARE DESCRIPTIONS

5508A Measurement Display

The Measurement Display unit consists of —

- Measurement and Reference Counters.
- Analog-to-digital Converter circuits,

- HP-IB interface circuits,
- a Data Bus system,
- Keyboard-Display,
- Processor, and
- Power Supplies.

An extensive self-test feature built into the Measurement Display unit runs during the Laser Head warmup period, giving a high degree of confidence that the equipment is operating properly.

The Measurement Display unit's Processor also controls the timing and sequence of operations in the system. This includes transfer and routing of data, calculations, and the display timing and control functions.

The Measurement Display unit's front-panel display is an all-numeric LED (Light-Emitting Diode) readout consisting of nine digits plus a sign indicator.

The HP-IB (interface) circuits allow the Measurement Display unit to be interfaced with an external controller such as a calculator or computer. Data can be sent to or from the Measurement Display unit via the interface bus. The HP-IB also allows all front-panel keyboard functions to be remotely programmed. A "TALK-ONLY" mode allows transfer of data to a recording device such as a digital plotter without using a controller.

5518A Laser Head

The Laser Head contains —

- A thermally-tuned laser tube, —
- Control circuits, —
- A Reference Receiver, —
- A Measurement Receiver, and a —
- High-voltage Power Supply.

The Laser Head also contains a special Optic used for Straightness measurements. This Optic is moved into the Laser beam when the turret ring is switched to "STRAIGHT". For more information about this Optic, see the "STRAIGHTNESS MEASUREMENT" information, below.

10751 Air Sensor

The Air Sensor's air pressure output is an analog voltage that is controlled by the size of a small aneroid barometer contained in the sensor. The Measurement Display unit converts this analog voltage to a digital value that it uses in its Velocity-of-Light ("V.O.L.") calculation.

The Air Sensor's air temperature output is an analog voltage that is controlled by a temperature-sensitive element in the sensor. The Measurement Display unit converts this analog voltage to a digital voltage that it uses in its V.O.L. calculation.

The Air Sensor's humidity output is an analog voltage that is controlled by a three-position switch on the side of the sensor's housing. The Measurement Display unit converts this voltage into a digital value that it uses in its V.O.L. calculation

10757 Material Sensor

The Material Sensor's output is an analog voltage that is controlled by a temperature-sensitive element in the sensor. The Measurement Display unit converts this analog voltage to a digital voltage that it incorporates into its material expansion calculation.

10766A Linear Interferometer

The Interferometer used in Distance and Velocity measurements contains a polarized beam splitter. This is represented by a diagonal line in *Figure A-2*. The polarized beam splitter will reflect the f_1 component of the laser beam and let the f_2 component pass through. The best way to visualize this is to imagine that the polarized beam splitter is a vertical picket fence that lets the vertically polarized frequency component through, but reflects the horizontally polarized frequency component.

10767A Linear Retroreflector

The Retroreflector is an optically ground and polished glass trihedral (three-surface) prism (sometimes called a "cube corner"). It reflects the laser beam back along a line parallel to the original beam, but offset from it by twice the distance at which the incoming beam is offset from the corner apex.

10770A Angular Interferometer

The Angular Interferometer used in Angular and Flatness measurements is basically a Linear Interferometer with a Beam Bender located above it (see *Figure A-3*).

10771A Angular Reflector

The Angular Reflector contains two Retroreflectors spaced a precisely-known distance apart.

10774A and 10775A Straighiness Interferometer and Reflector

The Straighiness Interferometer and Reflector have the same instrument number because they are a matched pair. They must be matched to have the Reflector return the two frequency components of the Laser beam directly back into the Interferometer.

The Interferomter splits the two-frequency beam from the Laser Head into its two component parts, with each part leaving the Interferometer along a specific, precisely-controlled path. This is possible because the Interferometer contains a Wollaston prism, which has a different index of refraction for each of the two perpendicular polarities in the Laser beam. The Interferometer can be turned, so the plane established by the two exit paths can be rotated about the incoming Laser beam.

Each beam from the Straightness Interferometer is directed to one mirror of the Straightness Reflector. The Straightness Reflector consists of a pair of front-surface plane mirrors, rigidly mounted such that they reflect each beam back along its incoming path to the Interferometer.

PRINCIPLES OF MEASUREMENTS

General System Principles

A Helium-Neon gas laser in the Laser Head produces a coherent light beam (see *Figure A-1*). A cylindrical permanent magnet around the cavity causes the laser to oscillate at two slightly different frequencies. This is Zeeman splitting. The two components, F1 and F2 ("frequency 1" and "frequency 2") are distinguishable by their opposite circular polarizations.

From the laser tube, the beam containing both the F1 and the F2 frequencies passes through Optical glass quarter-wave and half-wave plates which change the circular polarizations of F1 and F2 to linear perpendicular polarizations, one vertical and the other horizontal. The linearly polarized beam is expanded in a collimating telescope, after which most of the beam is transmitted through a 45-degree beam splitter and out of the Laser Head.

From the 45-degree beam splitter, a portion of the beam is sampled. Most of this sample is fed into the Reference Receiver to detect the difference in frequency between the beam's two optical components (f_1 and f_2). This difference will be between 1.5 and 2.0 MHz, and is represented in *Figure A-1* as "$f_1 - f_2$". The remainder of the sampled beam controls the tuning of the laser, to keep the laser's output frequency constant.

During a measurement, the laser beam is directed through Optics in the measurement path and then returned to the Laser Head's Measurement Receiver. This receiver will detect part of the returning beam that will be $f_1 - f_2$ plus a Doppler-shifted frequency component, Δf, if there was any relative motion between the Optics in the measurement path.

The two frequencies do not interfere to form fringes until the beam reaches the demodulating polarizer mounted in front of the photodetector because their polarizations are orthogonal to each other.

The signals from each of the Laser Head's receivers (Reference Receiver and Measurement Receiver) are counted by the Measurement Display in two separate pulse counters, one for the Reference signal and one for the Measurement signal. These counters store absolute counts, although the frequency determines the rate at which the counts are accumulated. (See *Figure A-1*.)

The Measurement Display unit then —

a. Continously subtracts the Reference Counter's contents from the Measurement Counter's contents, —

   (The counters' contents, and the difference value, are numbers of wavelengths counted.)

b. Performs the necessary electronic functions to make the particular measurement calculations, —

c. Modifies the results of "b" with keyboard input data (values entered using SET UP keys) and compensation information from the Air Sensor and Material Sensor(s) (if used), and then —

d. Displays the computed measurement on the front-panel display.

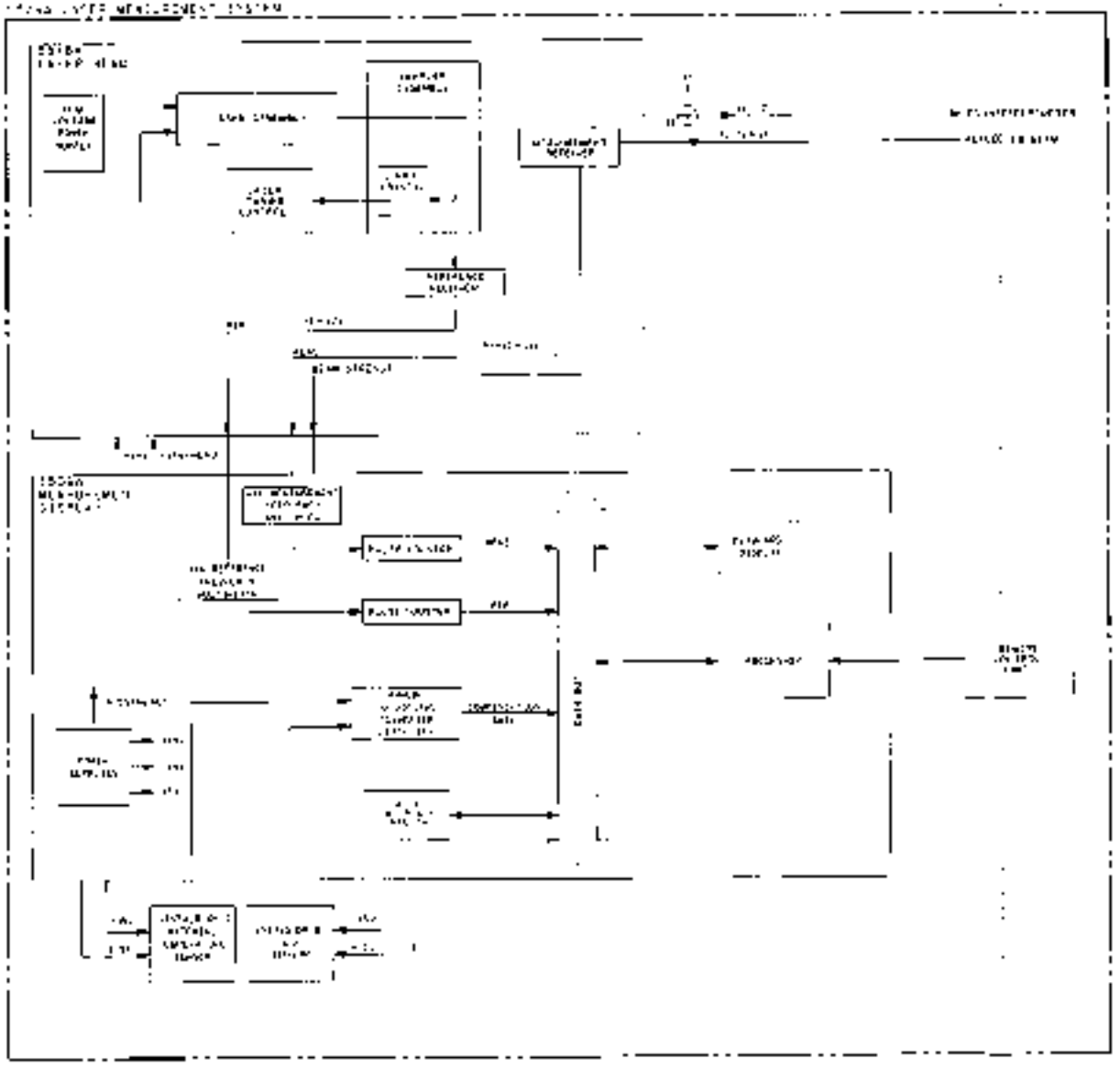


Figure A-1. Tone Measurement System — Simplified Block Diagram

Distance and Velocity Measurements

The F1 and F2 beams that leave the Laser Head are aimed at an Interferomter which splits F1 and F2 via a polarizing beam splitter (See Figure A-2). Component F1 becomes the fixed-distance path, and F2 is sent to a target which reflects it back to the Interferometer. Relative motion between the Interferometer and the remote Retroreflector causes a Doppler shift in the returned frequency. Therefore, the Measurement Receiver photodetector in the Laser Head sees a fringe difference given by F1 - F2 = ΔF2.

The F1 - F2 = ΔF2 signal that is returned from the external Interferometer is compared in the Measurement Display unit to the F1 - F2 Reference signal. The difference, ΔF2, is then related electronically to velocity and then to distance. This information is finally manipulated as described above under "GENERAL SYSTEM PRINCIPLES" to produce the correct output on the display.

Proper separation between outgoing and incoming laser beams is provided by each Retroreflector.

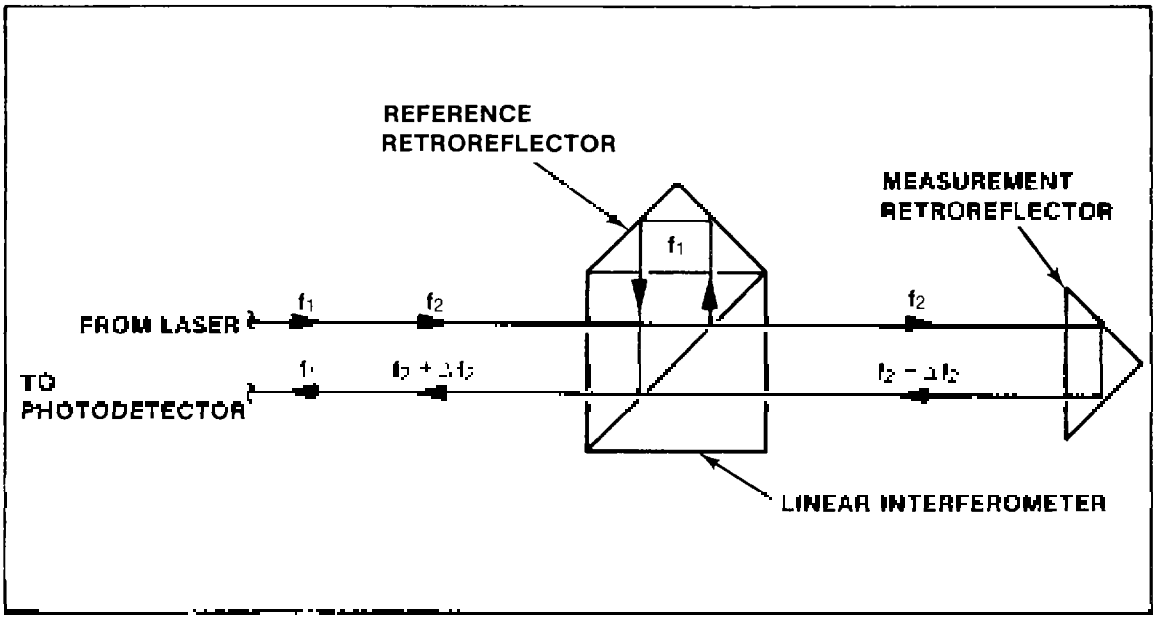


Figure A-2. Distance and Velocity Measurements

Angular Measurements

The set-up for making an Angular measurement is shown in Figure A-3.

The Angular Optics create two parallel beam paths between the Angular Interferometer and the Angular Reflector; one path is frequency f_1, the second path is frequency f_2. The distance between the two paths is precisely known, since the two Retroreflectors are precisely positioned within the Angular Reflector. Initially, the angle between the Angular Interferometer and the Angular Reflector is assumed to be "0", and the two paths between them have some relative length. If either the Angular Interferometer or the Angular Reflector is turned, the relative lengths of the two paths will change, this change will cause a Doppler-shifted frequency change in the beam that is returned from the Angular Interferometer to the Laser Head. The Laser Measurement System's Electronics hardware will calculate and display the angular change, using the new frequency count data and the spacing between the optical paths.

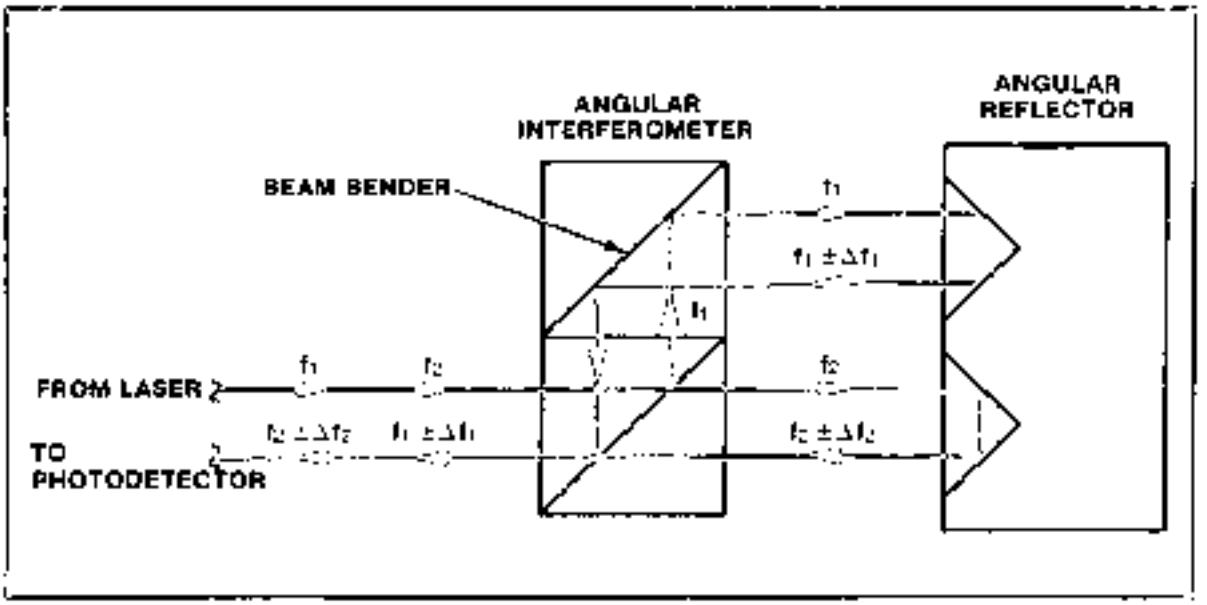


Figure A-3 Angular Measurements

Flatness Measurements

A Flatness measurement is made by integrating a series of Angular measurements taken as the Angular Optics follow the surface variations along a measurement path. *Figure A-4* shows the process of taking measurements for Flatness

Position "A" is the "RESET" position and relative "zero" elevation.

Position "B" is "one foot-pad-spacing" behind position "A". In this position, the Reflector's front foot is located where the back foot was in position "A". The height of the rear foot at position "B" is then determined, using the angle measurement and the length of the footspacer.

Similarly, position "C" is that position where the Reflector's front foot is at the same location as the rear foot was for position "B". The height of the rear foot for position "C" is determined, and algebraically added to the height at "B" and "A", if "A" has a value other than "zero", to find the total distance above or below zero. This process is continued to the end of the measurement path, each new foot height being algebraically added to the previous total.

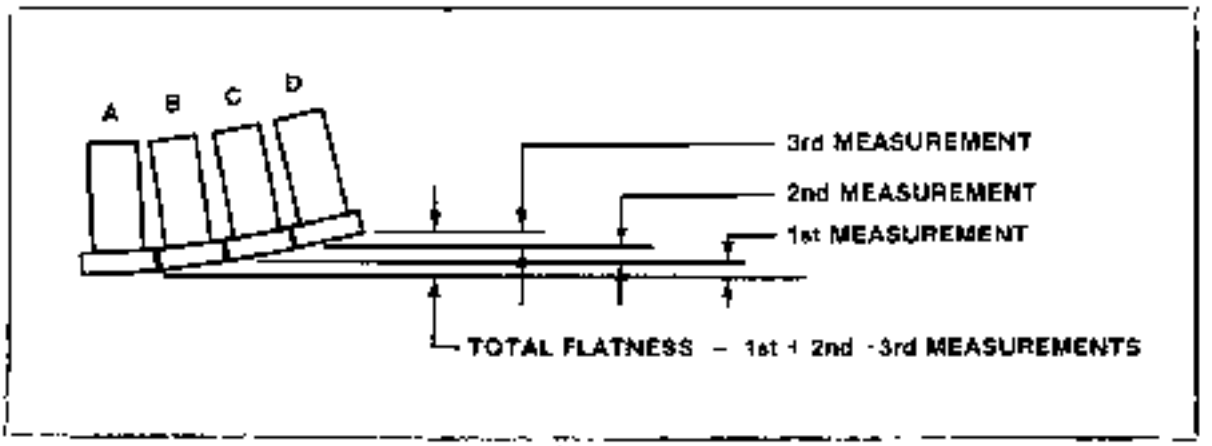


Figure A-4 Flatness Measurements

Straightness Measurements

In the following discussion, it will help to visualize the Straightness Reflector as a straightedge supported at one end, and the Straightness Interferometer as an indicator that runs along this straightedge.

Initially, the two paths from the Interferometer to the Reflector (l_1 and l_2) have some length relative to each other. If either the Straightness Interferometer or the Straightness Reflector is moved side-to-side (across the reference Straightedge), the relative lengths of the two beams will change. The change in accumulated fringe counts will be —

$$2D \sin(\theta/2),$$

where —

D = the distance of the offset, and —

θ = the angle between the two beams leaving the Interferometer.

θ is about 1.5 degrees for the Short-Range Interferometer, and about 0.15 degree for the Long Range Interferometer.

To provide the correct readout of the offset distance, the Electronic hardware automatically multiplies the fringe count by the reciprocal of $2 \sin(\theta/2)$.

Small pitch, yaw, or roll motions of the Interferometer do not create a path difference and therefore do not affect the measurement accuracy.

The two return beams from the Straightness Reflector combine in the prism, at the same point where the beam from the Laser Head was split. The combined beam is returned to the Laser Head along the same path as the Laser Head's exit beam. A beam bender at the Laser Head's Exit port, switched into position by setting the Laser Head's turret ring to "STRAIGHT", deflects the incoming beam from Straightness Interferometer down to the photodetector behind the Laser Head's normal Return port. (This offset in the return path is very much like that in a periscope or a pair of prism binoculars.)

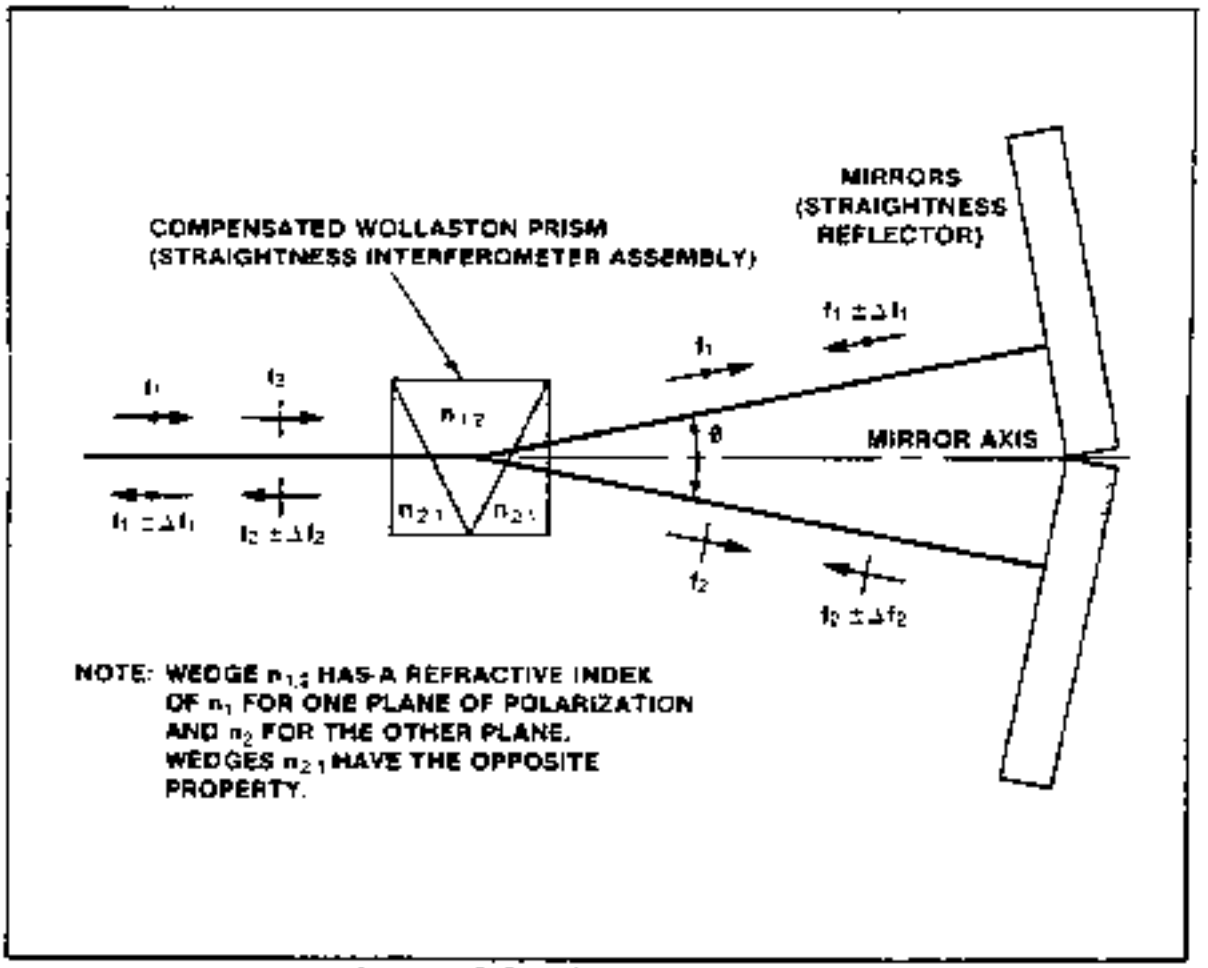


Figure A-5. Straightness Measurements

Squareness Measurements

A Squareness measurement consists of two perpendicular Straightness measurements made from the same Straightness Reflector. Perpendicularity is achieved using an Optical Square.

Squareness is calculated by adding or subtracting the slopes for each Straightness measurement to a right angle (provided by the Optical Square). Section 21 of this User's Guide shows how this is done.

Parallelism Measurements

A Parallelism measurement is similar to a Squareness measurement, except it does not use an Optical Square.

A Parallelism measurement consists of two Straightness measurements, made along the same axis from the same Straightness Reflector. (See Section 14 in this User's Guide.)

Parallelism is calculated by comparing the slopes of the two Straightness measurements, as described in Section 14 of this User's Guide.

B Measurement Considerations

APPENDIX B
MEASUREMENT CONSIDERATIONS

LASER SYSTEM MEASUREMENTS

To fully characterize machine geometry, you need to measure —

- The six degrees of freedom for each measurement axis, —
- Squareness between measurement axes, and —
- Parallelism between measurement axes.

The six degrees of freedom are —

1. Linear displacement
2. Angular displacement about the measurement axis —
   a. Pitch
   b. Yaw
   c. Roll
3. Displacement perpendicular to the measurement axis —
   a. Straightness in the vertical plane
   b. Straightness in the horizontal plane.

These six variables are used to break down the complex movements of a carriage traveling on a pair of ways into factors which can be more easily handled. (See *Figure B-1.*)

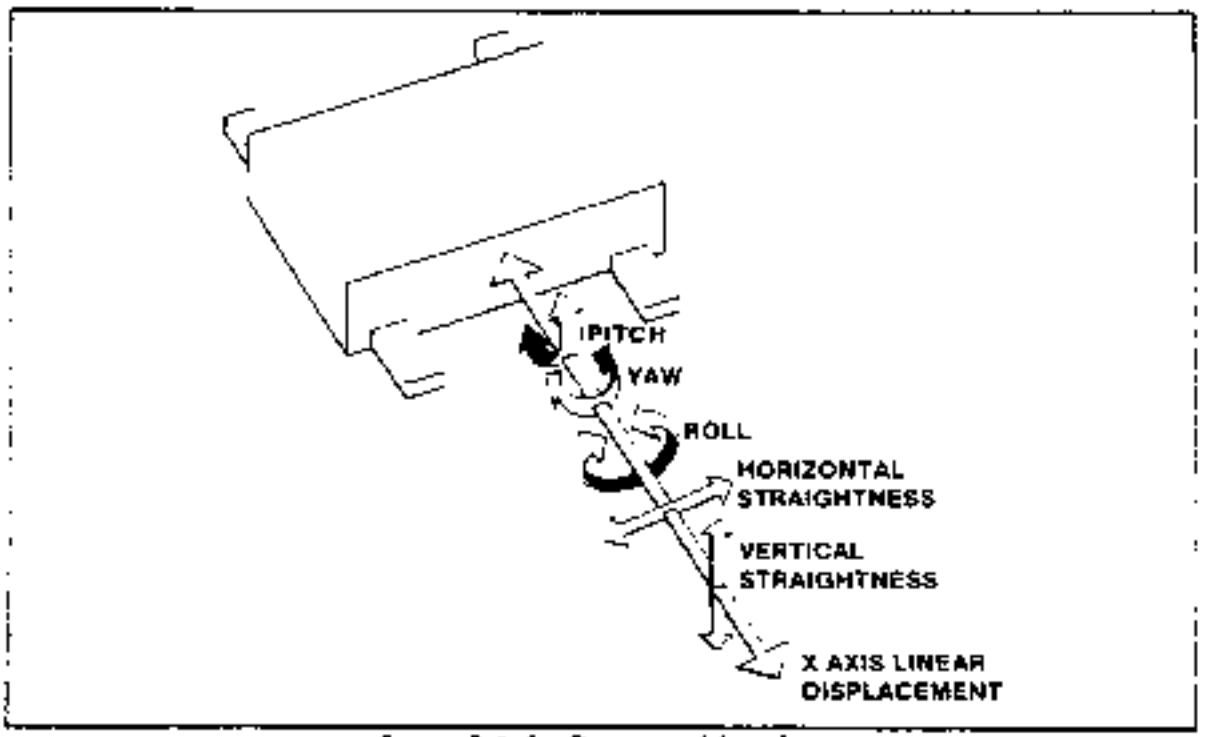


Figure B-1. Six Degrees of Freedom

Squareness and parallelism of travel between two axes characterize how any two axes are positioned relative to each other. Both measurements are accomplished by performing two Straightness measurements. (See *Figure B-2.*)

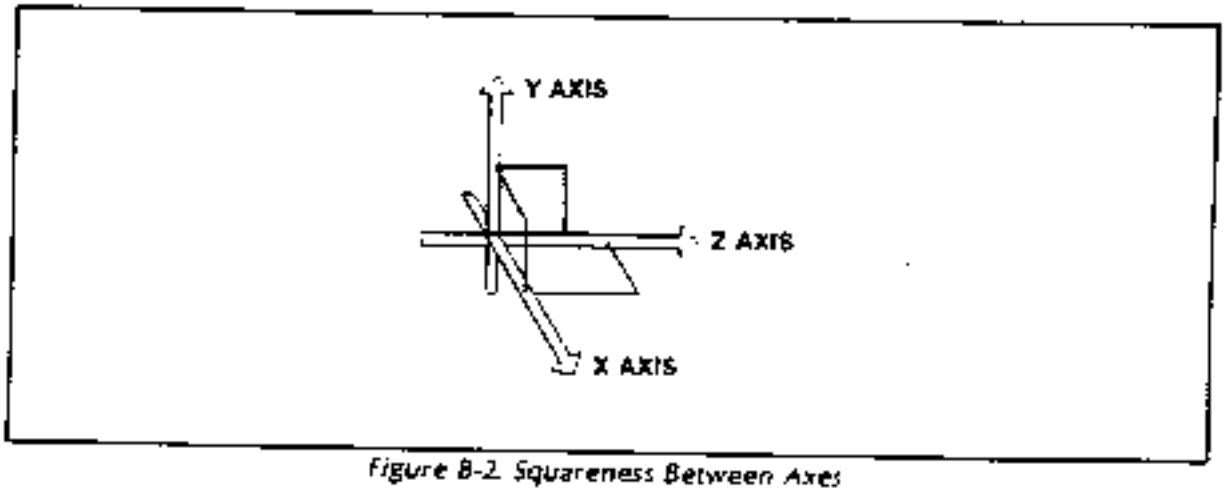


Figure B-2. Squareness Between Axes

Each of these characteristics contributes to positioning accuracy and precision at any point within the machine's work zone.

All of these measurements (except roll) can be made with the Laser Measurement System.

REPEATABILITY, ACCURACY, RESOLUTION

It is important that you understand the definitions of "repeatability", "accuracy", and "resolution"; these are common terms in industry, and are used throughout this User's Guide. THESE TERMS ARE NOT INTERCHANGEABLE.

REPEATABILITY is the range among a group of measurements at a target position.

Assume that a marksman is shooting at a target. The tightness of his shot pattern is a measure of his repeatability, using that gun, in that environment. (See *Figure B-3.*)

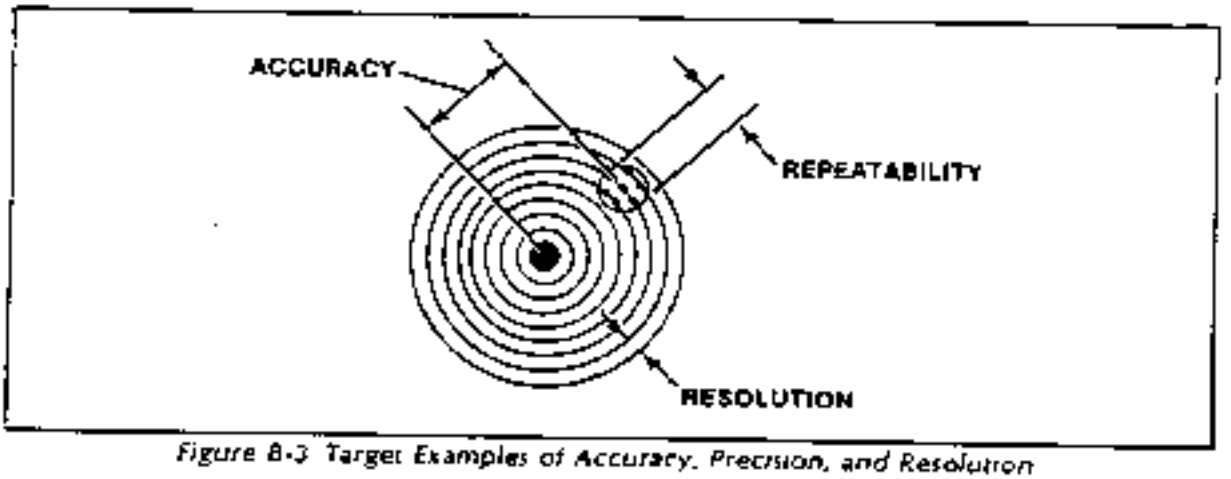


Figure B-3. Target Examples of Accuracy, Precision, and Resolution

You can think of repeatability in a similar way when making measurements with the laser. Operator skill, machine stability, machine geometry, and the environment affect repeatability.

ACCURACY is how closely the measurements agree to a given standard for the measurement. Repeatability, by comparison, is how close the measurements agree to each other.

In our example of the marksman, the closeness of his shots to the bull's eye is the measure of his accuracy. It is possible for all his shots to have been close together (repeatable), but to have been far from the bull's eye. Repeatability and accuracy are not the same.

Accuracy in linear positioning is the difference between the average position of a group of measurements and the location of the target position for those measurements. Accurate parts are exactly like the drawing for those parts. Repeatable parts are exactly like each other. A batch of parts, all rejected for the same flaw, are repeatable but not accurate.

RESOLUTION is the smallest increment of scale. In the target example, resolution is the distance between the rings in the target.

FACTORS AFFECTING ACCURACY AND PRECISION

The accuracy and precision of a measurement are influenced by many factors, which can be separated into two groups —

- Machine-related, and —
- Set-up-related.

Machine-related factors include —

- Machine geometry,
- Machine scale accuracy and precision,
- Machine environment, and —
- Machine response to the changing environment.

One set-up-related error is Abbe Error.

Machine-Related Factors

A machine calibration is more complex than checking positioning accuracy and precision. The accuracy and precision of the work a machine can be expected to turn out depends on —

- The machine's environment (including temperature and vibration), —
- The machine's response to changing operating and environmental conditions (Machine stability; —
- The accuracy and precision of the machine's geometry, and —
- The accuracy and precision of the machine's scale(s).

Each of these factors is equally important. Measurements of accuracy and precision have meaning only when the environment and geometry are known.

Abbe' Offset Error

Abbe' offset error can appear in a laser measurement as well as in a measurement made using a more traditional method. It results from the combination of —

1. An angular offset in the measurement system, and —
2. A linear offset between the measurement axis and the scale axis in the measurement system.

Abbe' offset error will make the indicated length either shorter or longer than the actual length, depending on the direction of the angular offset, as shown in *Figure B-4*.

The amount of measurement error resulting from Abbe' offset is —

Offset distance × tangent (offset angle)

For an angle of 20 degrees or less, the tangent of the angle divided by the size of the angle in arcseconds is between 5.05×10^{-6} and 4.84×10^{-6}. This means that you can get a very close approximation of the Abbe' offset error by multiplying the measurement offset distance by —

$$\frac{5 \times 10^{-6}}{\text{arcsec}} \times \text{the angle's size (in arcsec)}$$

The units of the error will be the same as the units of the measurement (and of the offset) (centimetres, inches, etc.), since the tangent value is dimensionless.

Abbe' offset error increases in proportion to the size of the angular offset and the distance of the linear offset, and is really a question of "what are you trying to measure?". For example, if you want to determine the accuracy of a machine tool's leadscrew or scale, you would make your measurement as closely as possible to the screw or scale, which would minimize the results of Abbe' offset. If, on the other hand, you wanted to know how accurately the machine positions its cutting tool, you would make your measurement along the tool's path; this would give you a true picture of the positioning accuracy, and would include compensation for geometric inaccuracies of the measurement system (including those due to Abbe' error).

As an example of Abbe' offset error, consider the caliper shown in *Figure B-4*.

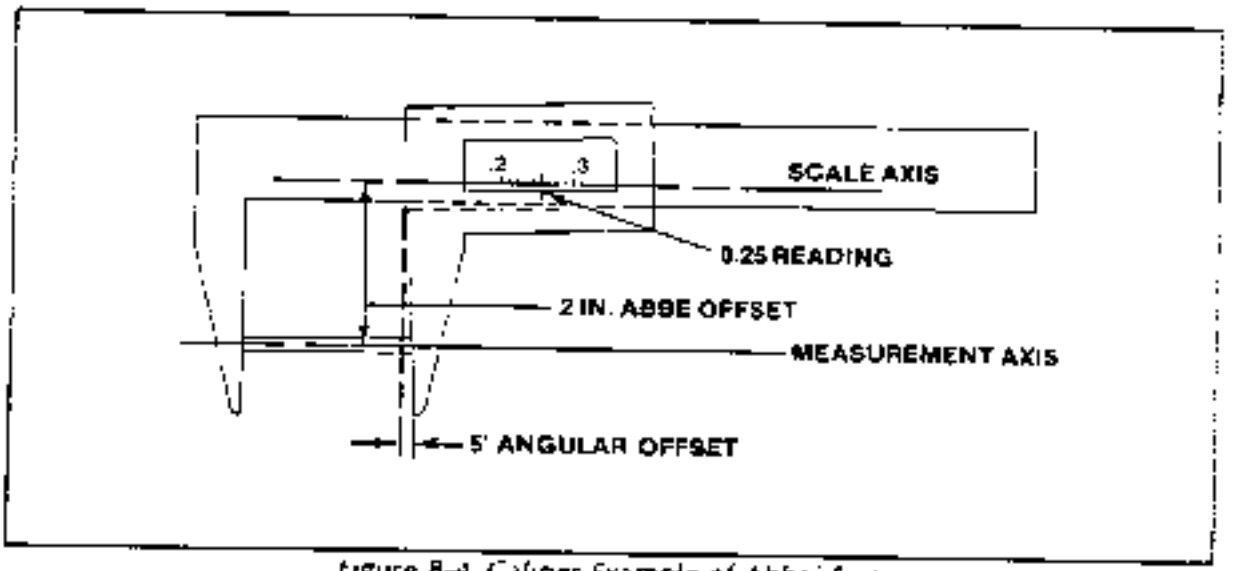


Figure B-4. Caliper Example of Abbe' Error

In the caliper example (*figure* B-4), the angular offset in the measurement system is 5 arcmin, and the linear offset between the measurement axis and the scale axis is 50 mm (2 inches). The error due to the offset between the measurement axis and the scale axis can be calculated as —

$$\text{error} = 50\ \text{mm} \times \frac{5 \times 10^{-6}}{\text{arcsec}} \times 5\ \text{arcmin} \times \frac{60\ \text{arcsec}}{\text{arcmin}}$$

$$= 50 \times 5 \times 10^{-6} \times 5 \times 60\ \text{mm}$$

$$= 75.0 \times 10^{-3}\ \text{mm}$$

$$= 0.075\ \text{mm}\ (0.003\ \text{in})$$

By minimizing the offset between the measurement and scale axes, the error is significantly reduced.

For example, if the offset distance is 10 mm (0.4 inch) instead of 50 mm (2 inches), the error in the reading due to Abbe' offset error is —

$$\text{error} = 10\ \text{mm} \times \frac{5 \times 10^{-6}}{\text{arcsec}} \times 300\ \text{arcsec}$$

$$= 10 \times 5 \times 10^{-6} \times 300\ \text{mm}$$

$$= 15.0 \times 10^{-3}\ \text{mm}\ (0.009\ \text{mm})$$

$$= 0.015\ \text{mm}\ (0.0006\ \text{inch})$$

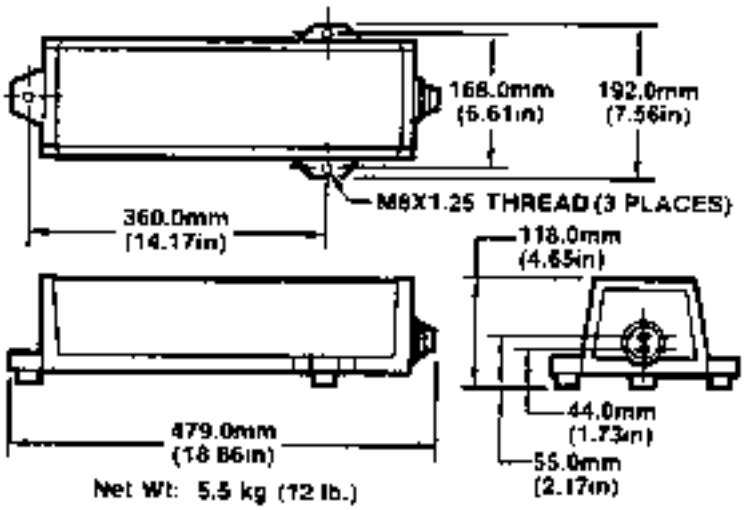
It may be worthwhile mentioning here that a micrometer wouldn't be subject to Abbe' offset error, since its measurement axis and its scale axis are the same.

Consider checking the positioning accuracy of a tool on a mill. To minimize the effect of Abbe' offset error on your measurement, you should set up the laser so that the optics will provide the exact information on how the tool is moving.

The calibration axes should be located in the most critical positioning area of the machine's working area. Once compensated, the machine will position accurately along the calibration axes. The worst accuracy will be at the greatest Abbe' offsets from the calibration axes.

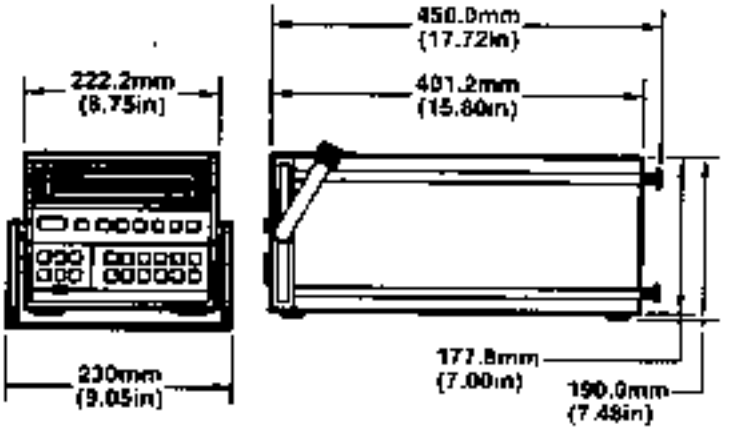
APPENDIX C
HARDWARE DIMENSIONS

HEAD/DISPLAY/TRIPOD



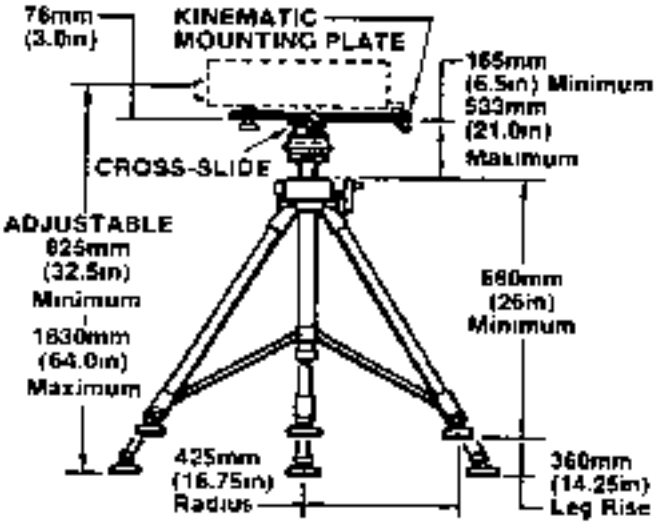
Net Wt: 5.5 kg (12 lb.)

5518A LASER HEAD



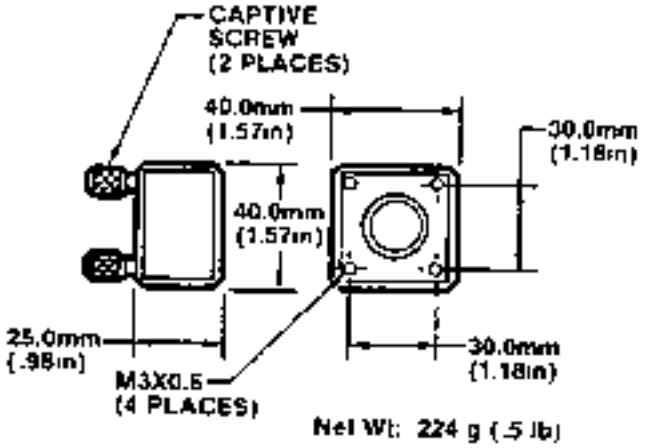
Net Wt: 6.7 kg (15 lb.)

5505A MEASUREMENT DISPLAY



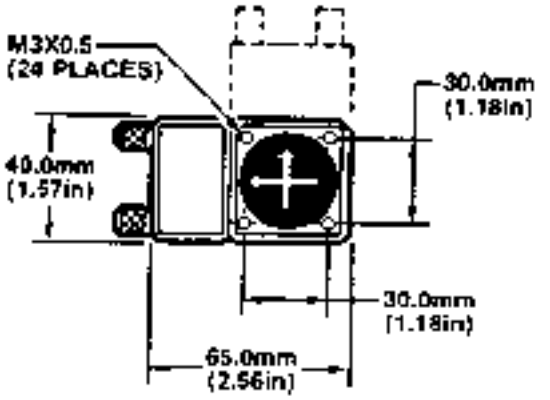
10753A LASER TRIPOD

LINEAR OPTICS



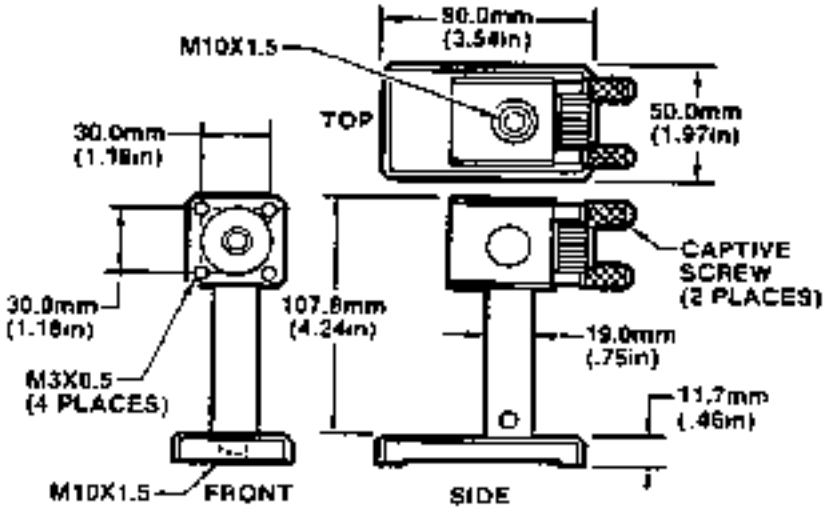
Net Wt: 224 g (.5 lb)

10767A
LINEAR RETROREFLECTOR



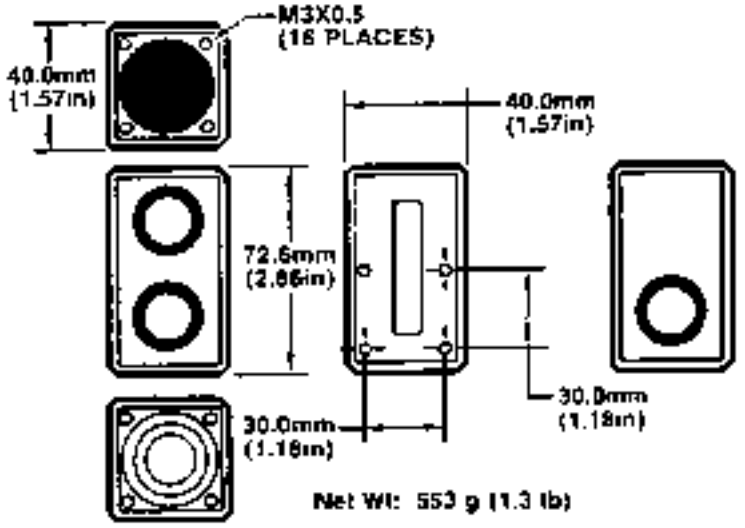
Net Wt: 536 g (1.2 lb)

10766A/10767A
INTERFEROMETER COMBINATION

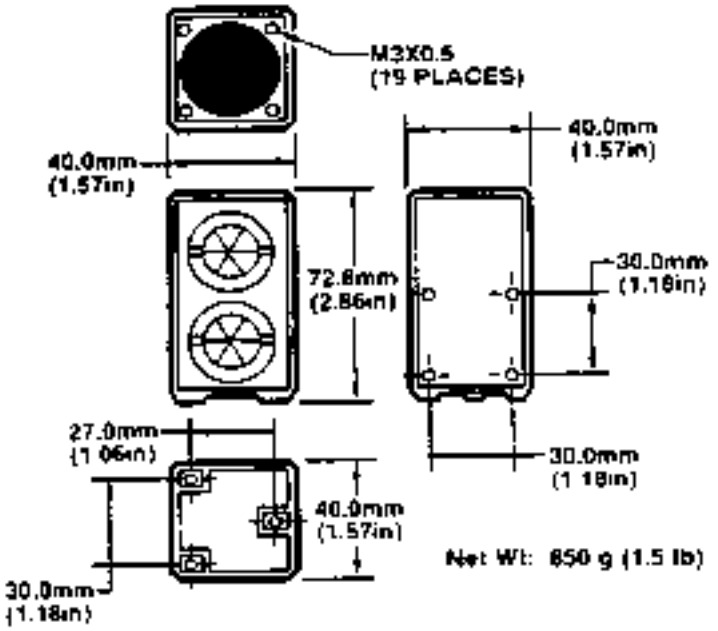


10785A HEIGHT ADJUSTER/POST
10784A BASE

ANGULAR OPTICS

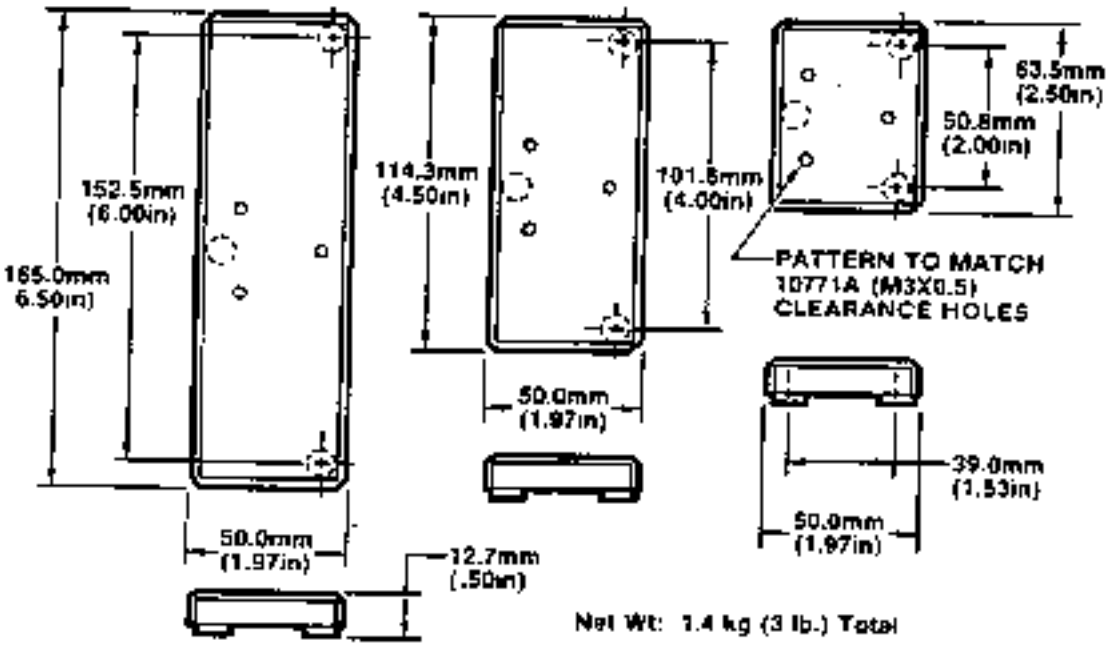


10770A
ANGULAR INTERFEROMETER

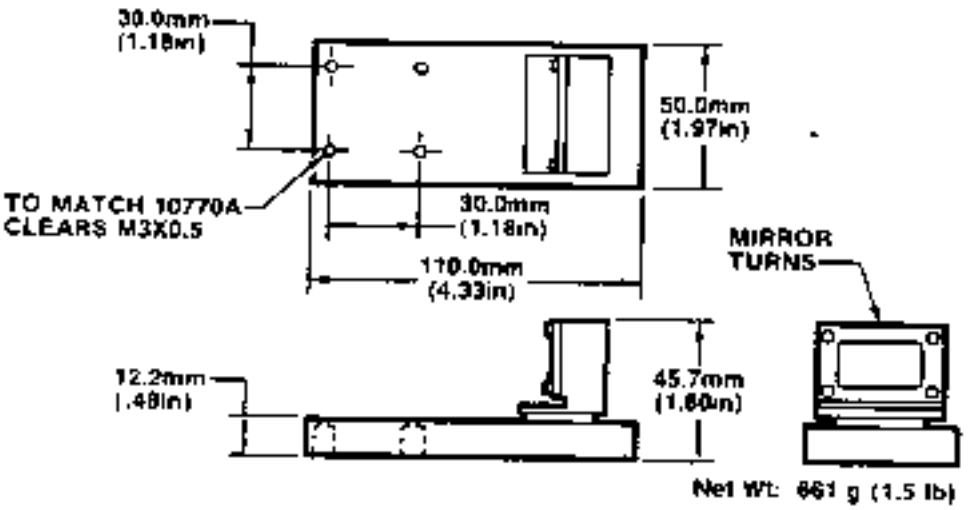


10771A
ANGULAR REFLECTOR

FLATNESS ACCESSORIES

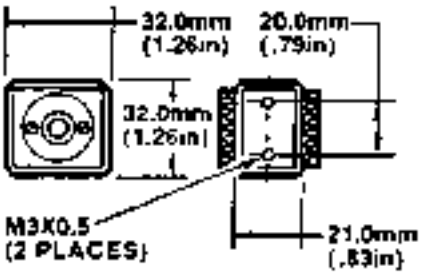


10769A
FOOT SPACING KIT



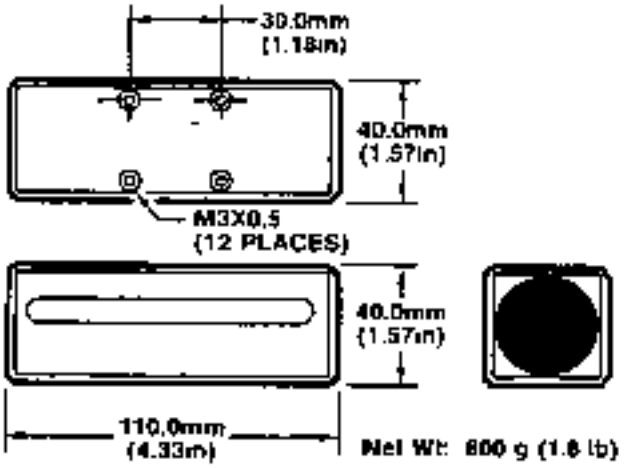
10773A
FLATNESS MIRROR

STRAIGHTNESS/SQUARENESS OPTICS



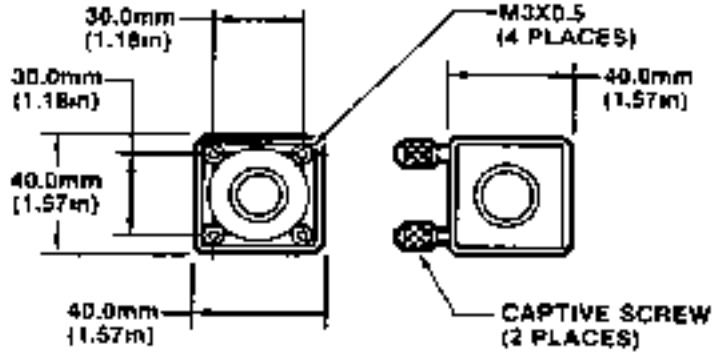
Net Wt: 164 g (0.36 lb)

STRAIGHTNESS INTERFEROMETER



Net Wt: 800 g (1.8 lb)

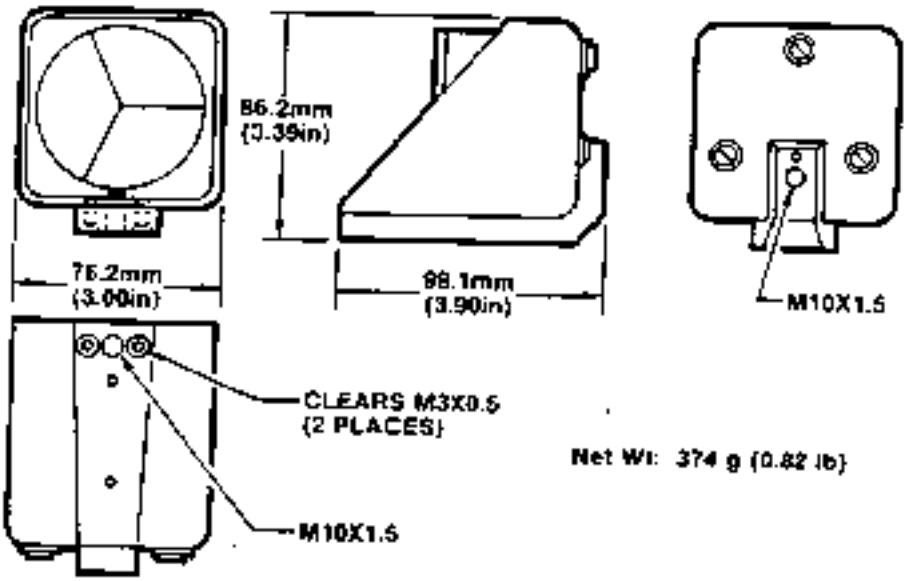
STRAIGHTNESS REFLECTOR



Net Wt: 510 g (1.2 lb) W/Mount

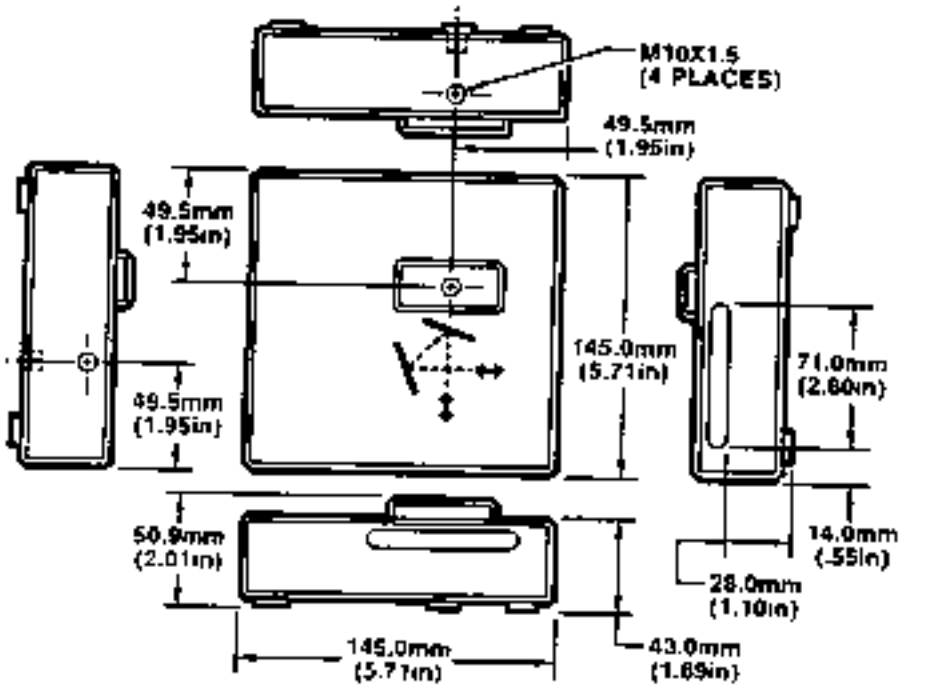
10772A
TURNING MIRROR

STRAIGHTNESS/SQUARENESS OPTICS (Cont'd)



Net Wt: 374 g (0.82 lb)

10776-67001
STRAIGHTNESS RETROREFLECTOR



Net Wt: 4.0 kg (8.9 lbs.) W/Mount

10777A
OPTICAL SQUARE

APPENDIX D
MEASUREMENTS USING AN HP 10706A PLANE MIRROR INTERFEROMETER

CONTENTS

INTRODUCTION
OPERATING SPECIFICATIONS
HARDWARE REQUIRED
OPTIONAL HARDWARE
REFERENCE MATERIAL
SETTING 5508A MEASUREMENT DISPLAY INTERNAL SWITCH
ASSEMBLY OF OPTICS
INSTALLATION AND ALIGNMENT OF OPTICS
DISTANCE MEASUREMENTS
VELOCITY MEASUREMENTS

INTRODUCTION

This User's Guide appendix provides instructions for making distance and velocity measurements with a plane mirror interferometer such as the HP 10706A. Although any HP 5528A system can be used to make measurements with a plane mirror interferometer, only those systems with an HP 5508A Measurement Display with serial prefix of 2732A or above, or units upgraded to this standard with EPROM Upgrade Kit p/n 05508-60211, will give the correct measurement on the display. Previous units must have the displayed distance or velocity value divided by 2 to get the correct answer.

The distance and velocity measurements are made by measuring the change in position of one of the optics while the other optic is held stationary. See Appendix A for a description of the principles on which this measurement is based.

To make a velocity measurement, begin as if you were making a distance measurement. Most instructions for the velocity measurement are identical to those for a distance measurement. Values for set-up keys will be different, and you'll have to push the VELOCITY key instead of the DISTANCE key. Details are in Section 7, Velocity Measurements.

OPERATING SPECIFICATIONS

Distance

Accuracy: Distance measurements are accurate within the following tolerances depending on the velocity of light compensation method and operating temperature. Values shown apply at a known material temperature with a known coefficient of expansion.

Operating Temperature Range[2]	Velocity of Light (VOL) Compensation Method	
	Manual (VOL Exactly Known in Beam Path)	Automatic[3] (Using 10751A/B Air Sensor)
19.5-20.5°C	±0.1 ppm	±1.5 ppm
15-25°C	± 0.1 ppm	±1.7 ppm
0-40°C	±0.1 ppm	± 3.0 ppm

1 If automatic material temperature sensing is used, the system error will be increased by Te (ppm).
Te (ppm) = coefficient of expansion in ppm/°C x average sensor error in °C.
(See 10752A/B Maximum Sensor Error Specification.)

2 Temperature of all system components are stabilized anywhere within the temperature range shown.

3 10751A/B mounted in recommended orientation, 12 month calibration interval used. Humidity switch set to position closest to actual humidity. If humidity switch set to 50%, tolerances are ±1.75 ppm at 20°C, 2.00 ppm at 15-25°C, and 3.70 ppm at 0-40°C. If 10751A/B mounted incorrectly, add 2 ppm.

Resolution: Metric Units Mode: 0.01 micron (0.00001mm)

English Units Mode: 1 microinch

Maximum Velocity: ±9000mm/minute (360 inches/minute)

Measurement Range: Maximum (with proper alignment, 15-25°C.) 20 metres (65 feet)

Velocity

Accuracy: ± 0.1% of displayed value

Resolution: ±0.1 mm/minute

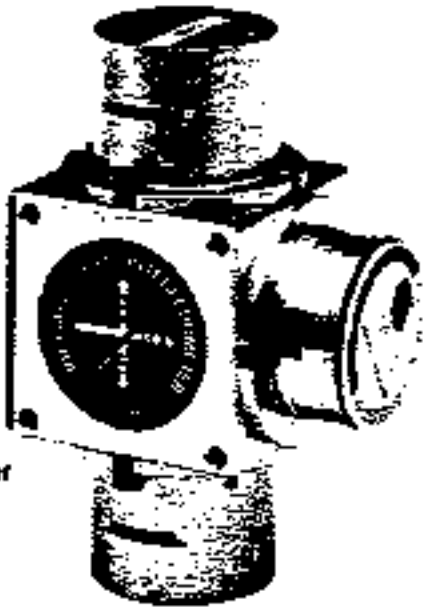
±0.01 in./minute

Maximum Velocity: same as distance measurement

Measurement Range: same as distance measurement

HARDWARE REQUIRED

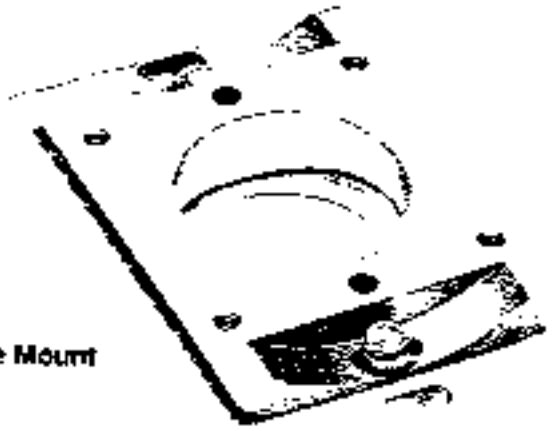
In addition to the hardware required for any measurement using the Laser Measurement System (see *Figure D-1*), distance or velocity measurements with plane mirror interferometers require the hardware shown in *Figure D-1*. Use of an adjustable mount, HP 10711A, is recommended for ease of alignment. It is recommended that the plane mirror used have the following specifications:



HP 10706A Plane Mirror Interferometer



HP 10773A Flatness Mirror



HP 10711A Adjustable Mount

Figure D-1. Distance or Velocity Measurement Hardware

Reflectance:	98% at 633 nm at normal incidence.
Flatness:	Flatness deviations will appear as measurement errors when the mirror is scanned perpendicular to the beam. The recommended range is 1/4 wavelength to 1/20 wavelength (0.16 to 0.03 microns, 6 to 1.2 microinches).
Optical Surface Quality:	60–40 per Mil O-13830.

The HP 10733A Flatness Mirror meets these specifications.

OPTIONAL HARDWARE

Optional hardware, shown in *Figure* 6-2, can be connected to your Laser Measurement System to allow measurements to be made more accurately.

REFERENCE MATERIAL

Setup of the Laser Head and Tripod . . . . . Section 4 Interconnections
Turn-on . . . . . Section 5 Alignment
Techniques (general) . . . . . Section 15

SETTING 5508A MEASUREMENT DISPLAY INTERNAL SWITCH

The HP 5508A Measurement Display normally uses the HP 10766A Linear Interferometer for distance and velocity measurements. To get the correct measurement displayed when using the HP 10706A Plane Mirror Interferometer, a switch setting in the HP 5508A must be changed.

To set the Measurement Display correctly for use with the plane mirror interferometer:

1. Set the front panel LINE switch to OFF.
2. Disconnect the line cord at the rear of the unit.
3. Using a POSIDRIV screwdriver, loosen the screw at the rear of the top cover.
4. Slide the top cover rearward and remove it.

Figure D-2 shows the location and proper setting of the A253 TEST SWITCH for use with the plane mirror interferometer. For normal operation, that is for use with the linear interferometer, set the switch to all zeros.

5. Set the TEST SWITCH to the setting shown in *Figure* D-2.
6. Replace the top cover and fasten the screw at the rear of the top cover.
7. Connect the line cord at the rear of the unit.
8. When ready to use the system, turn the LINE switch ON.

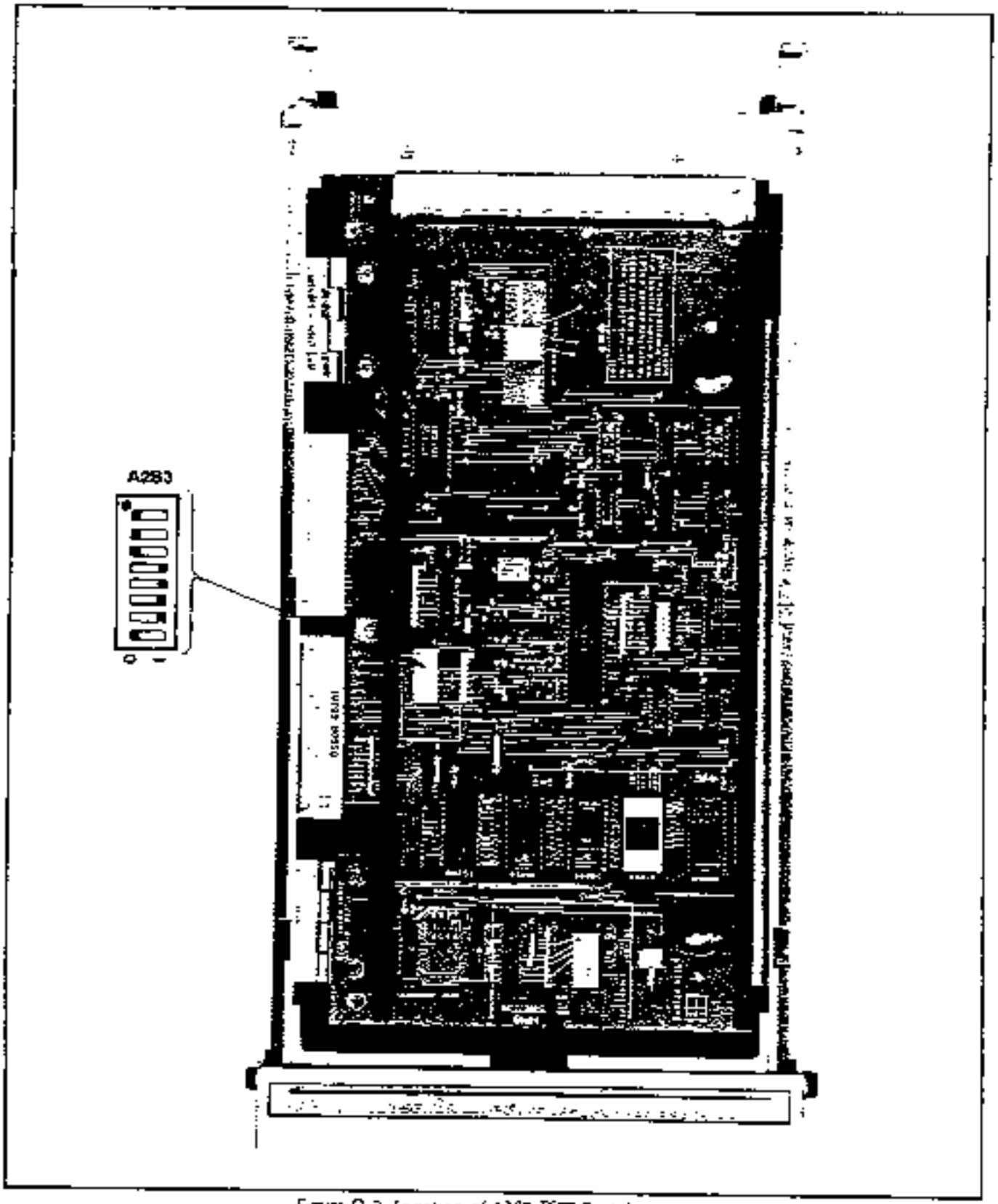


Figure D-2. Location of A2S3 TEST Switch

NOTE When the system is warming up, the display will indicate the various system self tests taking place. At the end of the initial sequence it will flash HI RES briefly on the display. This is the only external indication that the system is set for use with the plane mirror interferometer.

ASSEMBLY OF OPTICS

Refer to *Figure D-1*. Attach the interferometer to the mount with the screws provided.

INSTALLATION AND ALIGNMENT OF OPTICS

The alignment of the HP 10706A Plane Mirror Interferometer is very similar to the overlapping dots method for the linear interferometer. Before proceeding with the alignment procedure, reconfiguring the HP 10706A and alignment aids for this interferometer will be covered.

Turned Configuration

The interferometer can be configured to turn the beam. This is done by interchanging the reference cube corner and the plane mirror converter. *Figure D-3* shows a reconfigured HP 10706A Plane Mirror Interferometer that turns the beam. Note the location of the plane mirror converter with respect to the arrows on the label.

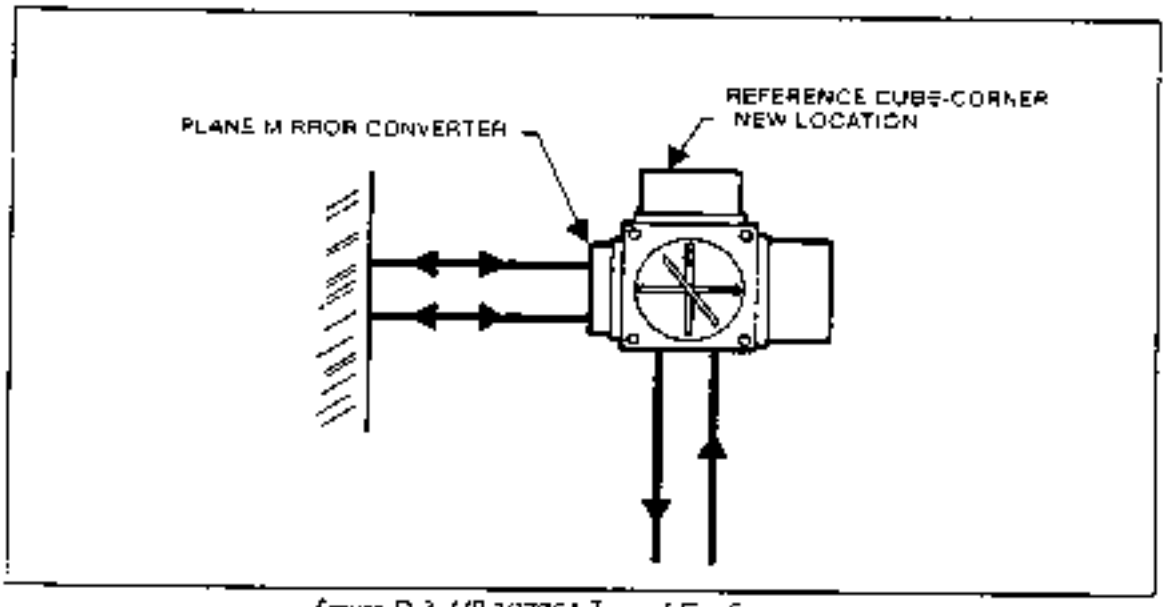


Figure D-3 HP 10706A Turned Configuration

In this configuration (*Figure D-3*) the laser measurement beam is turned to the left. When the measurement beam needs to be turned to the right, the interferometer is rotated 180 degrees about the incoming optical axis.

Alignment Aids

To help in aligning the plane mirror interferometer, two alignment aids are included. They are:

- Alignment Target (P/N 10702-60001) (See *Figure D-1*)
- Alignment Aid (P/N 10706-60001) (See *Figure D-1*)

Both alignment aids are magnetic to simplify positioning them on the interferometer.

The alignment target is used on the input side of the interferometer to properly position the beam in the input aperture.

The alignment aid is placed on the exit aperture (on the plane mirror converter) to allow using the autoreflection method of aligning the plane mirror interferometer. The alignment aid needs to be properly oriented so that the primary measurement beam goes through the hole on the alignment aid. The primary measurement beam is the first of two measurement beams that go between the interferometer and the plane mirror. To find the primary beam, block one of the two measurement beams and if the other disappears, then the one blocked is the primary measurement beam.

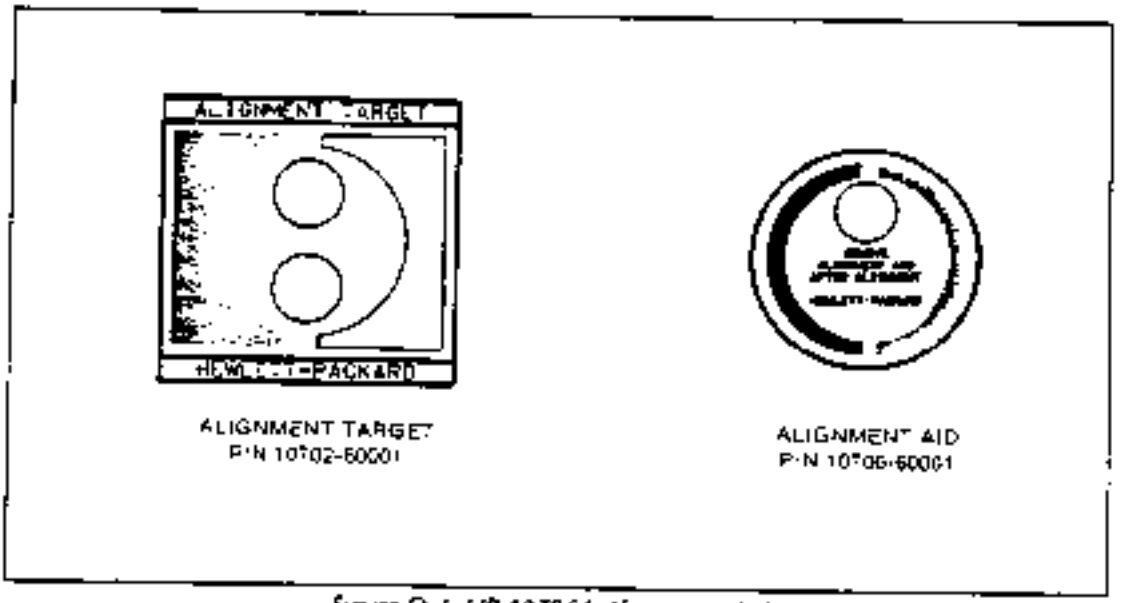


Figure D-1. HP 10706A Alignment Aids

Alignment Procedure

Refer to *Figure D-5* during this procedure. The procedure given is the overlapping dots method.

1. Align the plane mirror perpendicular to the axis of travel.
2. For straight through configurations, align the laser beam perpendicular to the plane mirror by autoreflection.

3. Insert the plane mirror interferometer into the laser beam and fasten to the mount.

4. Block the interferometer output beam. Select the small aperture of the laser head and the target on the receiver. Adjust the interferometer and the laser head (vertical and horizontal translation only) to get the reference return beam centered on the receiver.

5. Remove the beam block from the interferometer output. Adjust the interferometer to get both the reference and measurement return beams to overlap on the center of the receiver.

6. Check the alignment for cosine error. See page 6-14 for the procedure.

7. Select the large aperture on the laser head and rotate the receiver target out of the beam path

Distance Measurements

Distance measurements using a plane mirror interferometer are made the same way as with a linear interferometer, except that **the plane mirror interferometer cannot be the moving optic.** Refer to Section 6, Distance Measurements, for information about measurement display settings, sensor use, making a measurement, and what affects accuracy.

Velocity Measurements

Velocity measurements using a plane mirror interferometer are made the same way as with a linear interferometer, except that **the plane mirror interferometer cannot be the moving optic.** Refer to Section 6, Distance Measurements, and Section 7, Velocity Measurements, for information about measurement display settings, sensor use, making a measurement, and what affects accuracy. The limiting factor in the accuracy of velocity measurements is the accuracy of the electronics in the velocity measurement circuitry.

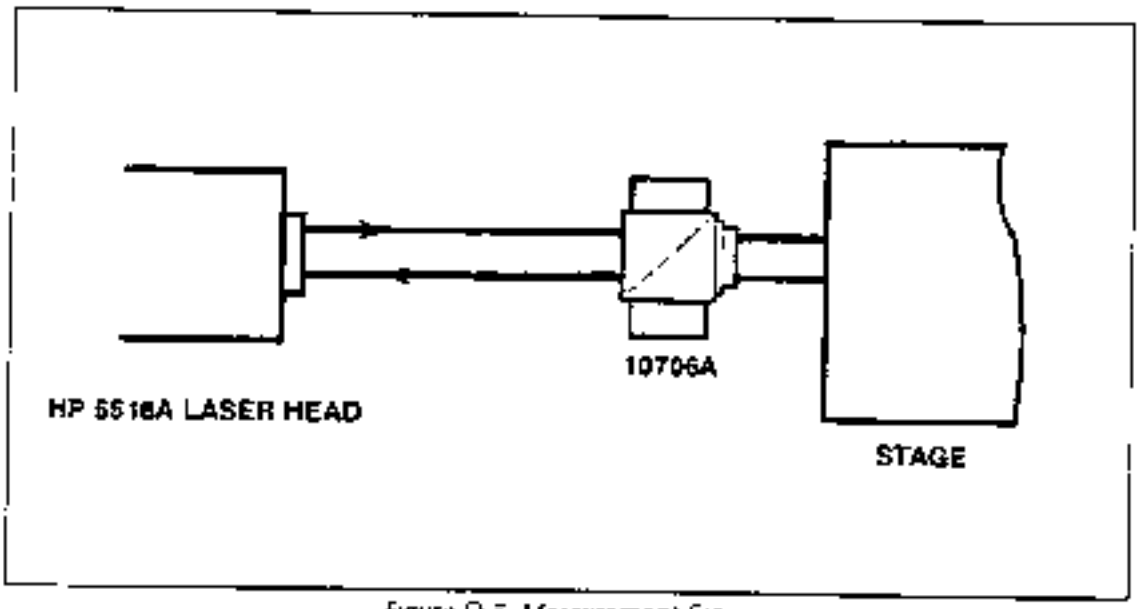


Figure D-5. Measurement Setup

GLOSSARY

Ambient: In the vicinity of; surrounding on all sides

Arcsec, Arcseconds (with or without hyphen): Your Angular measurements are displayed in units of "arc-seconds" ("ARC-SEC"), regardless of the setting of the Measurement Display's rear-panel "English/Metric" switch.

"Arcseconds" is a short way of saying "seconds of arc". One arcsecond equals 1/3600 of one degree of arc.

Another way to visualize an arcsecond is that it is equivalent to 0.000005 mm (or inches) for every mm (or inch) from your measurement axis. (This is the same as 0.5 mm in 100 metres, or about 0.3 inch in one mile.)

ASME: American Society of Mechanical Engineers

Coefficients of Thermal Expansion:

Material length varies with temperature per the following expansion coefficients:

Material	ppm/°C	ppm/°F
Aluminum	23.1	12.8
Brass	19.4	10.8
Steel	11.7	6.5
Granite	11.0	6.1
Cast Iron	10.5	5.7
Pyrex Glass	3.2	1.8
INVAR	1.2-2.0	0.7-1.1

"Standard" material temperature is 20°C (68°F).

Conversion Factors:

To Obtain	Multiply	By
Mils	Microns	0.039370
Inches	Millimetres	0.039370
Feet	Metres	3.280839
Microns	Mils	25.4
Millimetres	Inches	25.4
Metres	Feet	0.3048

$°F = 9/5(°C) + 32$ $°C = 5/9[(°F) - 32]$

Far End of Travel: The point in your measurement setup when the Optics are at their farthest distance apart during a measurement.

Hg: symbol for the chemical element Mercury.

Laser, LASER: An acronym of "Light Amplification caused by the Stimulated Emission of Radiation". Also, the device that produces light using this effect.

LED (Light-Emitting Diode): A semiconductor device that emits light when the correct voltage is applied.

Microinch: One millionth of an inch.

Micrometre: In this User's Guide, one millionth of a metre, or one thousandth of a millimetre (mm). Another name for micrometre is Micron.

Near End of Travel: The point in your measurement setup where your Optics are as close as they will ever be during a measurement.

Parts-per-million ("ppm"): a means of standardizing a changing quantity by comparing some number of your measurement units against one million of those units (sort of a high-resolution "percentage").

To use "ppm", multiply the value preceding the expression by the number of millions over which it applies. For example, if your measurement error is "10 ppm", and your measurement length is "100 mm" (4 inches), then your error will be —

$$100 \text{ mm} \times \frac{10 \text{ mm}}{1 \text{ million mm}} = \frac{1000 \text{ mm}}{1 \text{ million}} = 0.001000 \text{ mm}$$

or

$$4 \text{ inches} \times \frac{10 \text{ in}}{1 \text{ million in}} = \frac{40 \text{ inches}}{1 \text{ million}} = 0.000040 \text{ inch}$$

To give you an idea of how small this quantity can be, 1 ppm is —

One inch in about 15.8 miles.

One second in about 11.6 days.

One pound in the weight of about 6500 people.

One car-length in the distance from San Francisco to New York.

Pitch: Rotational movement about a side-to-side horizontal axis

Roll: Rotation about a lengthwise horizontal axis.

Rotation (of the Laser Head): An angular adjustment of the Laser Head's **orientation** to direct the laser beam as required for your measurement.

Translation (of the Laser Head): A straight-line adjustment of the Laser Head's **position** to direct the laser beam as required for your measurement.

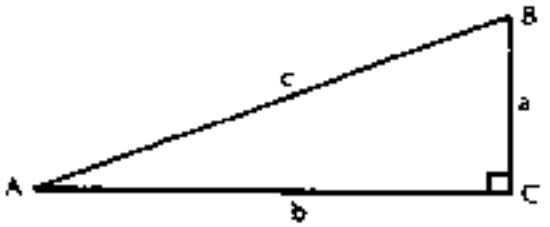
Trigonometry: An angle of one *degree* is an angle in which the rotation is 1/360 of one complete rotation. 1 degree = 60 *arc-minutes* = 3600 arc-seconds.

A *straight angle* is an angle of 180° (180 degrees).
A *right angle* is an angle of 90°C.
An *acute angle* is an angle between 0° and 90°.
An *obtuse angle* is an angle between 90° and 180°.

The Trigonometric Functions of an Acute Angle

In the right triangle *ABC*,

sine A = sin $A = a/c$ — cosecant A = csc $A = c/a$
cosine A = cos $A = b/c$ — secant A = sec $A = c/b$
tangent A = tan $A = a/b$ — cotangent A = cot A = ctn $A = b/a$



Wavelength: for light, equal to the velocity divided by the frequency; units are distance-per-cycle (although the "per-cycle" is normally omitted).

Yaw: Rotation about a vertical axis.

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