Pointing Stability

The alignment of the laser beam with respect to mounting feet (pointing stability) changes a small amount during warm-up of the laser head. The alignment of the beam is stable once the laser head has reached thermal equilibrium (typically less than 30 minutes). This alignment change during warm-up of the laser head is less than 2 arc-minutes (typically 1 arc-minute).

When aligning the laser, optics or receiver, be sure the laser head has been powered-on for at least 10 minutes. This will assure proper alignment for subsequent power-ups.

The laser heads should not be exposed to ambient temperature change greater than ±5°C during operation to keep pointing stability variations to within a few arc-seconds during measurements.

OPTICS

Plane of Orientation with Respect to Laser Head

The mounting plane tolerance of the optics to the laser head is the same as discussed in the paragraph titled "Mounting Plane Tolerance — Laser Heads". That is, the bottom or sides of the interferometers should be parallel to within ±1° of the plane defined by the laser head's three mounting feet.

Optics Effects on Measurement Direction Sense

The orientation and the configuration of the interferometers also affects the measurement direction sense. The direction sense depends on which frequency is in the measurement path of the interferometer. For example, if F1 (lower frequency) is in the measurement path and F2 (higher frequency) is in the reference path and the optics are moving away from each other, the fringe counts will be INCREASING. This corresponds to using an HP 5517A Laser Head (mounting feet in horizontal plane) with an HP 10702A Linear Interferometer mounted with labels facing up and down (*Figure 2-8*). Interchanging F1 and F2 (e.g., rotating interferometer 90°) in this example will result in the fringe counts DECREASING.

The optical schematics for the interferometers, in Section II, show which frequency polarizations are in the measurement path.

As with the laser heads, when the interferometers are rotated 90°, the measurement direction sense will change. This rotation causes switching of frequencies in the measurement path.

CONFIGURATION EFFECTS

All of the interferometers can be configured to turn the beam at right angles. When configuring the linear, single-beam and plane mirror interferometers to turn the beam, the measurement direction sense will be changed. This is because the measurement and reference paths are switched on the interferometers therefore changing the direction sense.

HP 10715A DIFFERENTIAL INTERFEROMETER CONFIGURATION

For purposes of convention, aperture B will be considered the input aperture when referring to all configurations. Note that the choice of input aperture is one of the configuration variables that affects the direction sense.

The differential interferomter is available in two configurations; the HP 10715A and the HP 10715A Option 001. Both have the same direction sense, however it may change depending on the mounting and orientation as shown in *Table 5-1*.

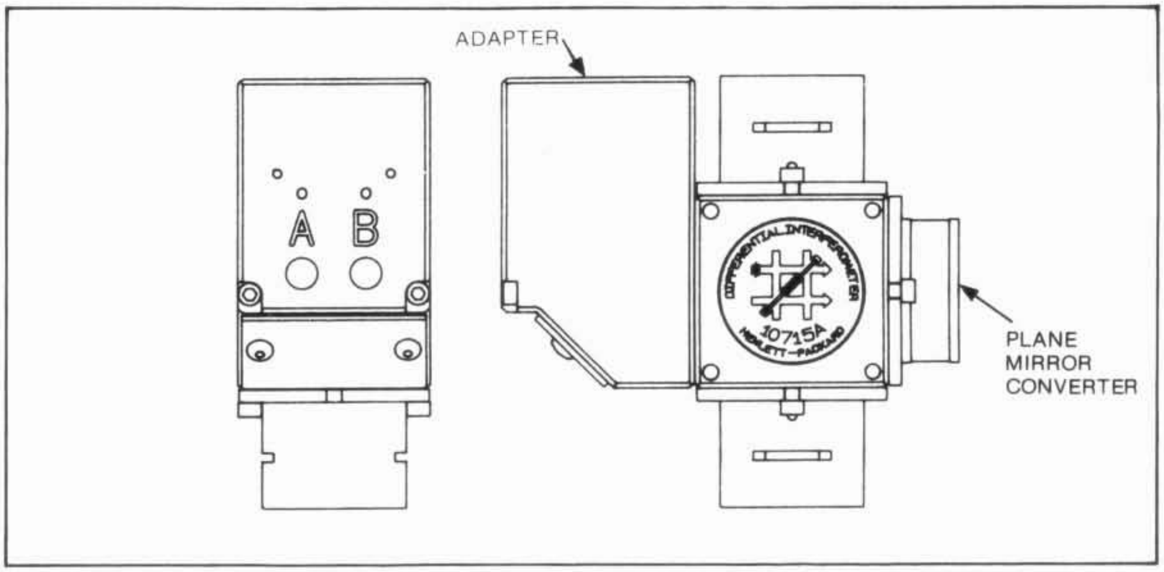


Figure 5-4. HP 10715A Standard Configuration

Configurations With the Same Direction Sense.

- STANDARD CONFIGURATION 10715A (*Figure 5-4*)

  The HP 10715A is assembled and shipped in the "Standard" configuration.

- TURNED CONFIGURATION 10715A (Option 001 (*Figure 5-5*)

  The primary reason for using the HP 10715A Option 001 is to turn the beam. In the "Standard" configuration, the beam is not turned (it passes straight through the interferometer).

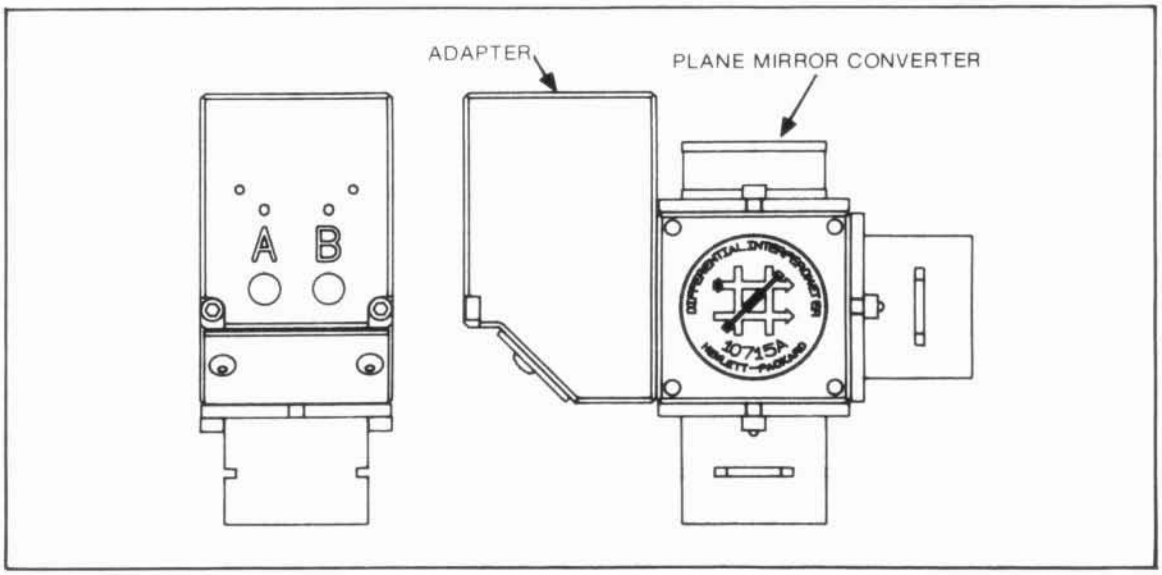


Figure 5-5. HP 10715A Option 001 In Turned Configuration

- HP 10715A UPSIDE DOWN

  Mounting the HP 10715A in this manner has no effect on the direction sense. (Assuming the same input aperture is used).

Table 5-1 shows the direction sense for various optical configurations.

Configurations that Change the Direction Sense

- HP 10715A INPUT AND OUTPUT APERTURES

  The laser beam may enter either one of the two apertures on the HP 10715A or HP 10715A Option 001. These apertures are labeled A and B. If aperture A is used as the input, then aperture B is the output aperture and vice-versa. Functionally, it is arbitrary which aperture is the input aperture. However, the choice of A or B does determine which frequency is passed to the measurement mirror and thereby determines the direction sense.

- HP 10715A ORIENTATION — HORIZONTAL OR VERTICAL

  The HP 10715A may be mounted to a horizontal suface or a vertical surface. The direction sense will be different for each orientation.

If any **two** of these effects, including the laser head orientation, are changed, there is no net change in the direction sense.

Table 5-1. HP 10715A Direction Sense

Laser Head	Laser Head Orientation Horizontal or Rolled 90° About Beam	HP 10715A Input Aperture A or B	HP 10715A Orientation Horizontal or Vertical	F1 Path
HP 5517A/B HP 5518A F1 Horizontal F2 Vertical	Horizontal	A	Horizontal	Ref
			Vertical	Meas
		B	Horizontal	Meas
			Vertical	Ref
	Rotated 90°	A	Horizontal	Meas
			Vertical	Ref
		B	Horizontal	Ref
			Vertical	Meas

HP 10717A WAVELENGTH TRACKER

The orientation of the laser head with respect to the HP 10717A and the selection of the input aperture on the Wavelength Tracker's differential interferometer, affect the direction sense of the compensation output. The correct direction sense of the Wavelength Tracker signal occurs when the compensation number gets larger as the wavelength-of-light increases. Refer to the "System Accuracy" paragraphs that appear later in this section for a discussion on atmospheric compensation.

The direction sense of the Wavelength Tracker signal may be changed on the HP 10946B Automatic Compensation Board by modifying the sign of the *WRL value. Refer to Section IV-K of this manual for details. *Table 5-1A* gives the correct sign of the *WRL value for various system configurations.

Table 5-1A. HP 10717A Direction Sense

Laser Head	Laser Head Orientation Horizontal or Rotated 90°	HP 10717A Input Aperture A or B	HP 10717A Orientation Horizontal or Rotated 90° About Etalon Axis	Sign of *WRL Value
HP 5517A/B HP 5518A F1 Horizontal F2 Vertical	Horizontal	A	Horizontal	+
			Rotated 90°	-
		B	Horizontal	-
			Rotated 90°	+
	Rotated 90°	A	Horizontal	-
			Rotated 90°	+
		B	Horizontal	+
			Rotated 90°	-

This page left blank intentionally.

Vibration Isolation

Vibration of the optics in a direction parallel to the beam can cause the fringe count in the Laser Position Transducer system electronics to fluctuate rapidly, making it difficult to determine which number indicates the true position of the optics. In more extreme cases, the velocity of the optics may momentarily exceed the velocity limitation of the Laser Position Transducer system, causing an error.

When vibration occurs in a direction perpendicular to the beam, the beam signal power can fluctuate. If this fluctuation is too great, insufficient beam signal will arrive at the receivers, causing a "measurement signal error".

Loose mounting can cause the optics to move inappropriately during a measurement, causing a measurement error or loss of beam power.

Elastic mounting can have the same effect as loose mounting. It can also be responsible for a "sag" offset in the optics' positions. If there is vibration in the machine, an elastic mounting can transmit and amplify the vibration to the attached optic, possibly causing more errors.

Purpose of Adjustable Mounts

The optical elements inside the optical components of the HP 5527A Laser Position Transducer are not referenced to their housings. This was done to significantly reduce the cost of these components. Therefore, slight positioning adjustments of the interferometers, beam splitters, and beam benders are required for proper alignment.

Two adjustable mounts are available with the HP 5527A Laser Position Transducer, the HP 10710A and HP 10711A Adjustable Mounts. Both mounts provide the capability to adjust yaw and pitch of the optical components. Roll of the components is typically not required and can be avoided by following proper installation instructions.

The HP 10710A is the adjustable mount for the following components:

- HP 10700A 33% Beam Splitter
- HP 10701A 50% Beam Splitter
- HP 10705A Single Beam Interferometer
- HP 10707A Beam Bender

The HP 10711A is the adjustable mount for the following components:

- HP 10702A (and Option 001) Linear Interferometer
- HP 10706A Plane Mirror Interferometer
- HP 10715A Differential Interferometer

Fasteners

All optical components in the system are supplied with mounting screws to mount them to the appropriate adjustable mount.

Vacuum Applications

All of the optical components of the system are compatible with vacuum environments. The housings of these components are made of stainless steel and the optical elements are attached to these housings using a low volatility adhesive. See Section VIII (Specifications) for list of materials used in the optics.

USE THROUGH WINDOW

If the laser beam has to go through a window (for example into a vacuum chamber) the window must meet the following requirements:

a. A minimum window aperture of 25.4 mm (1 inch) with a minimum thickness of 8 mm (0.3 inch). If a larger window is used, they must be proportionally thicker to assure no distortion in the window when under differential pressures.

b. Flatness within $\lambda/20$ over a 23 mm (0.9 inch) diameter.

c. Parallelism of faces less than ± 2 arc-minutes, to reduce beam shifts.

d. Surface quality 60–40 per Mil-0-13830.

e. The window must be strain free.

Differential Measurements with Interferometers

The HP 5527A Laser Position Transducer has four different interferometers available. Each has the capability to make differential measurements.

A differential measurement is a measurement in which there is a path length change in both the reference and measurement beam paths of the interferometer. In a typical measurement configuration, the reference path length does not change because the reference reflector is fixed. When making differential measurements, the reference reflector moves along with the measurement reflector. The position information from this type of measurement is the difference between the motions of the reference and measurement paths.

Making differential measurements is useful when making measurements between the primary moving part and a reference point. For example, differential measurements can be made between a stage and an optical column or measurement head.

Caution should be used when configuring the measurement optics to do differential measurements because of tricky alignment and potential changes in deadpath errors. When making differential measurements both reflectors (reference and measurement) should be of the same type (cube corner or plane mirror).

WITH CUBE CORNER REFLECTORS

All standard configurations of the interferometers, except the HP 10715A, use a cube corner reflector in their reference path. This reference cube corner is typically attached to the housing of the interferometer. For differential measurements, this cube corner reflector is detached from the housing and mounted on a second surface. (See *Figure 5-7*).

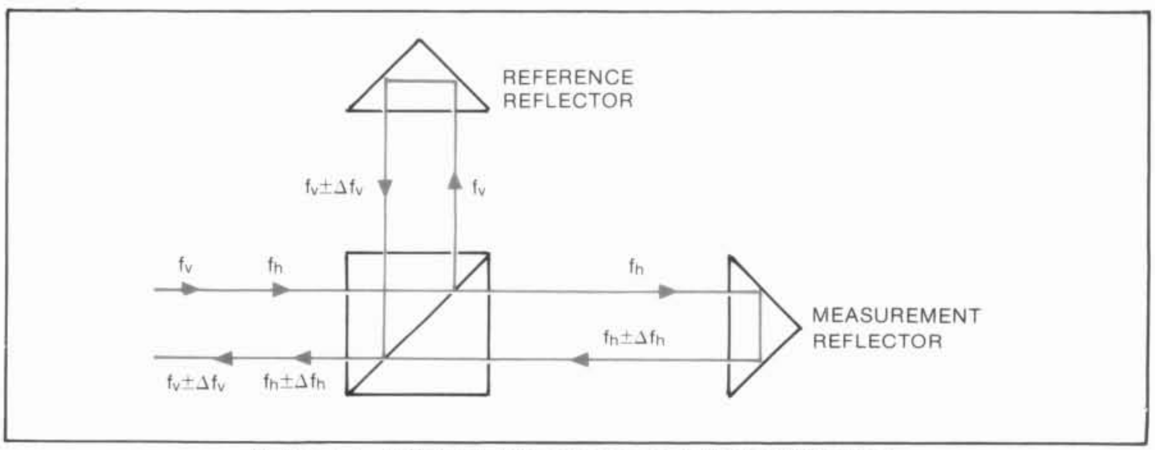


Figure 5-7. Differential Measurements with the HP 10702A

WITH PLANE MIRROR REFLECTORS

A plane mirror reference reflector is the standard configuration for the HP 10715A Differential Interferometer. This externally mounted plane mirror reference mirror provides the flexibility to mount the reference reflector on another surface.

With the HP 10706A Interferometer, a plane mirror reference mirror can be substituted for the reference cube corner. To use a plane mirror reference reflector with this interferometer, the reference cube corner is removed (not used) and an HP 10722A Plane Mirror Converter is substituted. Now a remotely mounted plane mirror can be used as the reference reflector (see *Figure 5-8*).

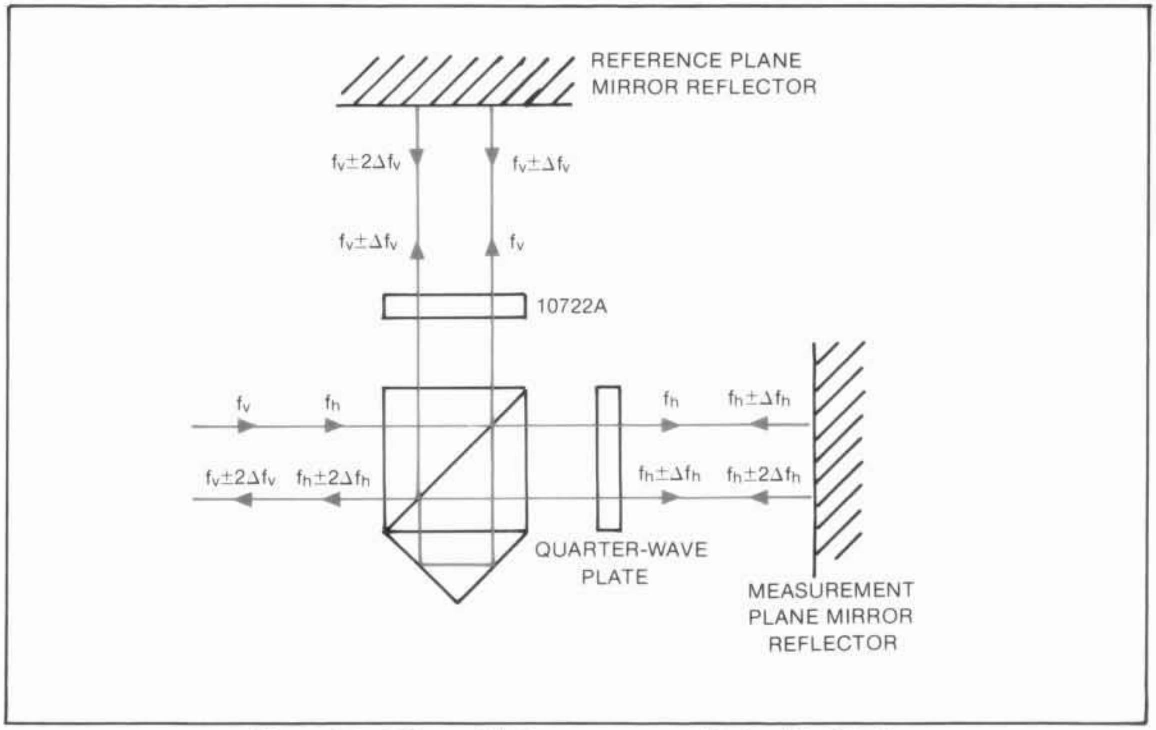


Figure 5-8. Differential Measurements with the HP 10706A

Moving Interferometer Instead of Reflector

When moving the interferometer is required instead of the measurement reflector, the HP 10702A Option 001 should be used. This is the only interferometer that can be moved while making measurements. For a detailed explanation of why this option is required, see *Figure 2-7* in Section II.

Beam Path Loss Computation

Multiaxis positioning systems must be designed with sufficient optical power reaching the HP 10780B Receiver. This section defines optical efficiency as it relates to the component loss. A method for computing the optical power loss in a system is described.

CONSIDERATIONS

The following considerations are important in designing a reliable multiaxis measuring system:

- Minimum laser output power is 120 microwatts for the laser heads. The typical laser output power is about 400 microwatts for the HP 5517A, HP 5517B, and HP 5518A. The output power is relatively constant over the life of the tube, and tends to drop off immediately at the end.

- Minimum required power at the HP 10780B Receiver is 1.5 microwatts. (Adjustment of the receiver's gain is required to obtain this sensitivity. See Section VI of this manual for the gain adjustment procedure.)
- The beam splitters have worst case as well as typical transmission and reflection specifications (see Section VIII).
- In addition, all optics have small reflection and absorption losses that occur at each internal interface or component, which is taken into account in their efficiency value.
- Fingerprints, dirt, or oil on a glass surface significantly reduce optical efficiency by increasing both reflection and absorption losses.
- System misalignment also reduces the amount of light reaching the receiver.
- Thermal gradients in the beam path area can bend the beam and distort the wave front, both of which reduce optical signal strength at the receiver.

CALCULATION

In order to assess the signal loss in a measurement system, each optical component has been characterized by both worst case and typical optical efficiencies. These efficiency values for each optical component are listed in Section VIII (Specifications).

Optical Efficiency is defined as:

$$\text{Efficiency} = \frac{\text{Optical Power Out}}{\text{Optical Power In}}$$

The optical efficiency for the interferometers are given with the respective measurement reflector efficiency included. For example, the HP 10702A Linear Interferometer efficiency includes the efficiency of the HP 10703A Retroreflector.

The combined optical efficiency of a given measurement axis is the product of the efficiencies of the individual optics in the beam path. This combined efficiency times the minimum laser output power in microwatts yields the worst case optical power at the receiver. This value must be at least 1.5 microwatts. A beam power safety factor of about three is recommended even though worst case laser and optics are assumed.

As an example, consider a typical installation with two measurement axes and a Wavelength Tracker axis (*Figure 5-9*). Assume differential interferometers, good optical alignment, 98% efficient plane mirrors (on the stage), comparable path lengths, and use of the HP 5517A Laser Head.

The three axes [X, Y, and Wavelength Tracker (WT)] have the following components:

AXIS	COMPONENT	COMPONENT EFFICIENCIES (WORST CASE)
X	HP 10700A (67% path)	61%
X	HP 10701A	39%
X	HP 10715A	25%
Y	HP 10700A (67% path)	61%
Y	HP 10701A	39%
Y	HP 10715A	25%
W	HP 10700A (33% path)	27%
W	HP 10707A	98%
W	HP 10717A	25%

Assuming a minimum laser power of 120 microwatts, the worst case power at the X, Y, and Wavelength Tracker receivers can be calculated by multiplying the product of the component efficiencies by the laser output power:

Power at X = 0.61 × 0.39 × 0.25 × 120 = 7.1

Power at Y = 0.61 × 0.39 × 0.25 × 120 = 7.1

Power at WT = 0.27 × 0.98 × 0.25 × 120 = 7.9

This system has a power safety factor of 4.7 at worst case for each axis resulting in reliable operation and easy alignment.

This safety factor can also be calculated using the typical optical efficiency values.

AXIS	COMPONENT	COMPONENT EFFICIENCIES (TYPICAL)
X	HP 10700A (67% path)	63%
X	HP 10701A	45%
X	HP 10715A	36%
Y	HP 10700A (67% path)	63%
Y	HP 10701A	45%
Y	HP 10715A	36%
W	HP 10700A (33% path)	30%
W	HP 10707A	99%
W	HP 10717A	36%

Using the typical laser power of 400 microwatts, the power at the X, Y, and Wavelength Tracker receivers can be calculated by multiplying the product of each component efficiency by the laser output power for each axis.

Power at X = 0.63 × 0.45 × 0.36 × 400 = 40.8

Power at Y = 0.63 × 0.45 × 0.36 × 400 = 40.8

Power at WT = 0.30 × 0.99 × 0.36 × 400 = 42.8

By using the typical efficiencies of the components, a safety factor greater than 28 is achieved.

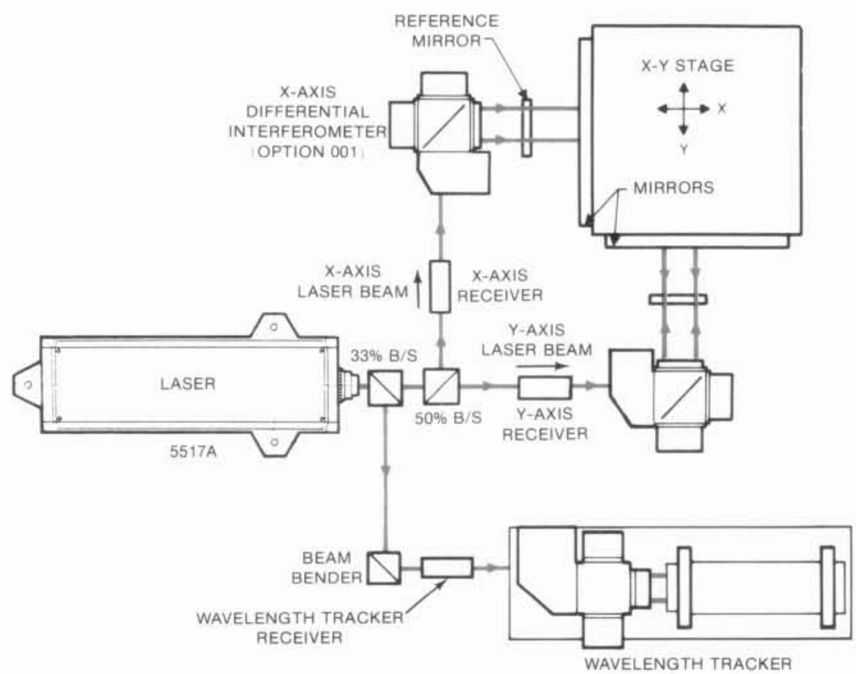


Figure 5-9. Two-axis Differential Interferometer with Wavelength Tracker

RECEIVER

General

When mounting the receiver keep the following points in mind:

a. At a 45 degree position (roll), the signal will go to zero.

b. The receiver dissipates a maximum of 2.7 Watts. Plastic pads keep an air gap around the receiver and act as thermal and electrical isolators.

CAUTION

Use Nylon screws only (HP 2360-0369). The receiver housing must be electrically isolated from the mounting fixture.

c. Allow a 5 cm space at the rear for the cable connection.

Clearance for Laser Beam

Figure 5-10 shows receiver and proper beam spacing.

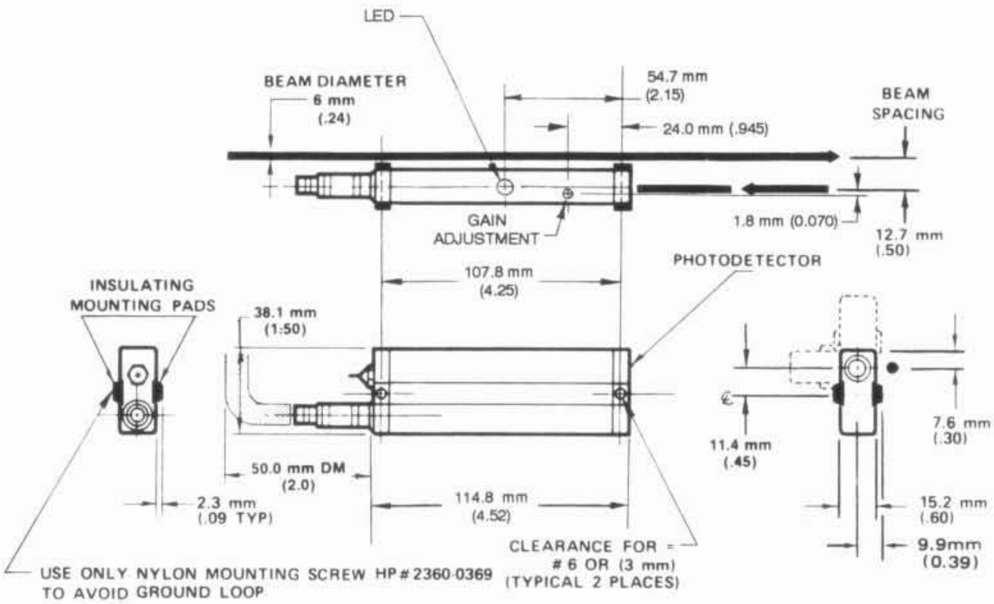


Figure 5-10. HP 10780B Receiver Dimensions

Alignment Adjustment Required

The HP 10780B Receiver requires an alignment to the input beam to maximize measurement signal. See Section VI for alignment procedures. See Alignment Specifications for the HP 10780B in Section VIII.

SYSTEM ACCURACY

The system accuracy is determined by adding the following terms:

- Laser Head Accuracy
- Electronics Accuracy (resolution increment)
- Automatic Compensation Accuracy (if used)
- Interferometer Nonlinearity
- Environmental Effects
- Optics Installation Effects

The first four terms are internal to the system, that is, there is a specification for each of these accuracy terms. These specifications are all given in Section VIII of this manual. The following items are important for these terms:

- Laser head and automatic compensation accuracies are presented in parts-per-million, which means the measurement error is a function of the distance measured.
- The electronics accuracy is the +/- one resolution count and is presented in units of distance.
- The interferometer nonlinearity is present in each different interferometer and is presented in units of distance. This nonlinearity occurs solely as a result of optical leakage of F1 into F2 or F2 into F1. This is caused by non-perfect separation of the two polarizations in the interferometer.
- The laser head accuracy term is not included in the overall system accuracy when Wavelength Tracking Compensation is used.

The remaining two terms, "Environmental Effects" and "Optics Installation Effects", are both external effects and are covered in the remainder of this section.

Environmental Effects

Interferometric measurements must be corrected for two potential sources of measurement error when highest accuracy is desired:

- The effect of atmosphere (gas temperature, pressure, compensation, and humidity) on the laser light wavelength.
- The effect of temperature on the size of the machine or measured part.

ATMOSPHERIC EFFECTS

Changes in air temperature, pressure and humidity change the density (and index of refraction) of air, which changes the wavelength of laser light. This, in turn, affects the accuracy of the HP 5527B Laser Position Transducer. 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, composition, 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 the measurements. The wavelength of the laser light can change by one-part-per-million, affecting measurement accuracy by the same amount, from any one of the following conditions:

- a 1°C (2°F) change in air temperature,
- a 2.5 mm (0.1 inch) of mercury change in air pressure,
- an 80% change in relative humidity.

These approximations assume the composition of air to be standard and homogeneous.

NOTE

The HP 5517C Laser Head wavelength is about 2.5 parts in 10^8 shorter than that of the HP 5517A, HP 5517B, or HP 5518A Laser Heads. This is much smaller than wavelength changes due to changing atmospheric conditions (on the order of parts in 10^6). Therefore, for all measurement situations except measurements made in a vacuum, compensation values based on the HP 5517A, HP 5517B, or HP 5518A Laser Heads can also be used for HP 5517C measurements.

TEMPERATURE EFFECTS

Changes in the temperature of the machine or measured part will cause it to expand or contract, resulting in the measured value not equaling the standard temperature measurement. This measurement error is dependent on the material used and its coefficient of thermal expansion. *Figure 5-11* shows relative effect of the different environmental effects.

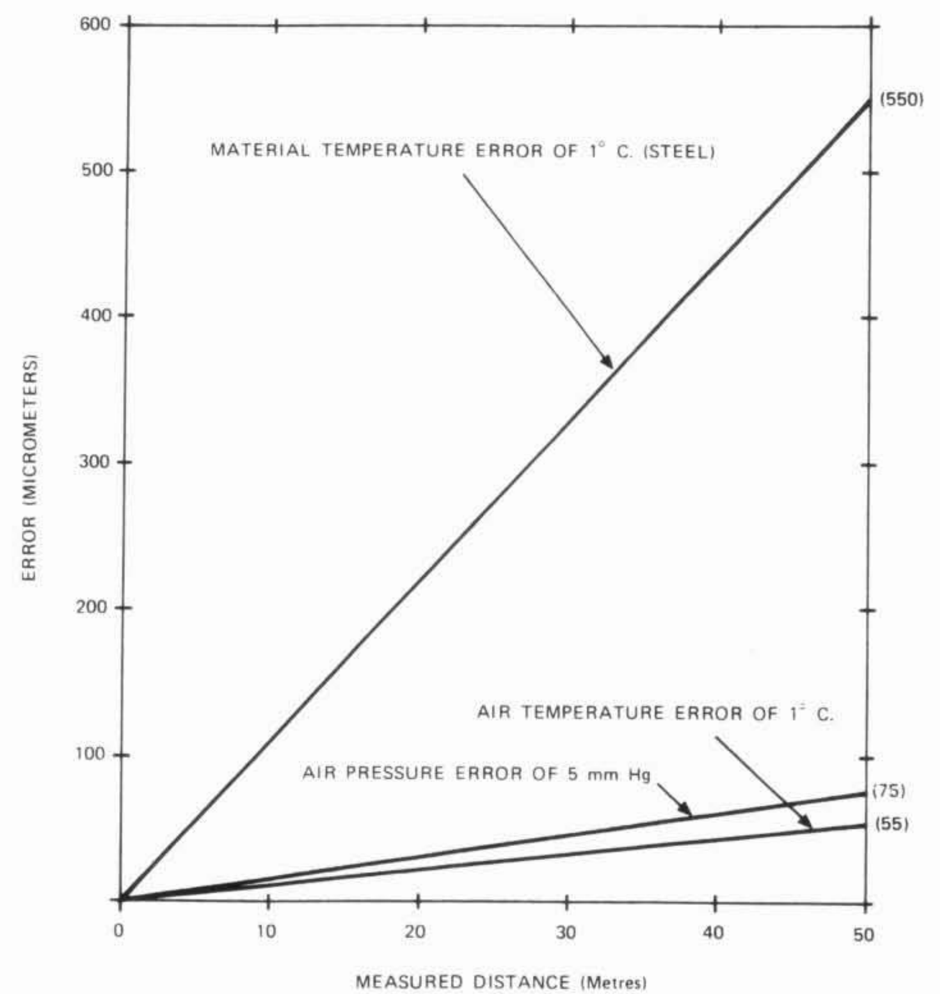


Figure 5-11. Relative Effect of Errors in Atmospheric and Material Temperature.

Measurement Correction By Compensation

These measurement errors can be corrected by using a compensation term. This compensation term is called the "Total Compensation Number" or "TCN". It contains a Wavelength of Light compensation term and a Material Temperature compensation term.

The Laser Position Transducer counts the number of wavelengths of motion traveled, the measurement can then be corrected by multiplying the distance by a correction factor:

Compensated Measurement (true position) = Wavelength Counts due to Motion X Vacuum Wavelength X TCN

where

$$\text{TCN} = \underbrace{\frac{\text{air wavelength}}{\text{vacuum wavelength}}}_{\text{Wavelength term}} \times \underbrace{[1 - (\text{Linear Thermal Coefficient}) \times (\text{Material Temperature} - \text{Standard Temperature})]}_{\text{Material Temperature term}}$$

The Wavelength of Light term compensates for changes in the laser wavelength. The material temperature term compensates for material changes due to thermal expansion.

WAVELENGTH OF LIGHT COMPENSATION

The wavelength of light compensation term is strictly the ratio of the air wavelength to the vacuum wavelength.

$$\text{Wavelength Compensation Term} = \frac{\text{air wavelength}}{\text{vacuum wavelength}}$$

Since the system counts the number of wavelengths of motion traveled, position can be compensated as follows:

$$\text{true position (compensated position)} = \text{(wavelength counts due to motion)} \times \frac{\text{air wavelength}}{\text{vacuum wavelength}} \times \text{vacuum wavelength}$$

NOTE

This equation ignores material temperature effects.

The information necessary for wavelength compensation can be obtained automatically by measurements of humidity, temperature and pressure using the HP 10946B/C Automatic Compensator board and associated sensors. Alternatively, the required information can be entered manually by inputing data from tables.

The wavelength value stored in the HP 5507B for use in measurements is the vacuum wavelength of the HP 5517A, HP 5517B, or HP 5518A Laser Heads. This value can also be used, without correction, for HP 5517C measurements made in air, since the effects of air on wavelength are so much greater than that resulting from the frequency difference between the HP 5517C and the other Laser Heads.

For measurements made in a vacuum, the

$$\frac{\text{air wavelength}}{\text{vacuum wavelength}}$$

term in the equations earlier on this page can be restated as:

$$\frac{\text{vacuum wavelength of Laser Head used}}{\text{wavelength value stored in HP 5507B}}$$

- For an HP 5517A, HP 5517B, or HP 5518A, this term is 1.
- For an HP 5517C, this term is 0.9999999747.

The HP 5517C Laser Head frequency is slightly higher than that of the HP 5517A, HP 5517B or HP 5518A Laser Heads. This will result in slightly more counts due to motion when a measurement is made using the HP 5517C than would occur with the other heads. In measurements made in air, the effects of changes in the air are so much greater than the differences due to the frequency difference that no correction is needed.

MATERIAL TEMPERATURE COMPENSATION

Previously discussed was compensation to eliminate errors due to a change in the laser wavelength. In addition, increased accuracy can be achieved by compensating for the expansion or contraction of the measured part or machine as the temperature changes.

Ideally, all distance measurements with the laser system would be made in a temperature controlled room held at exactly 20°C (68°F). Then the machine or part would be at their "true" size and the wavelength compensation number determined earlier could be used directly. For part temperatures other than 20°C (68°F), the best method of correction is to change the effective laser wavelength electronically (e.g., through the controller software) an amount sufficient to correct for thermal expansion or contraction.

The material temperature compensation term is a function of two factors:

a. The temperature of the part or machine

b. The thermal coefficient of expansion of the part or machine.

This compensation term is defined as:

Material Temperature Compensation $= 1 - \alpha\ (T - 20°C)$

α = Coefficient of Thermal Expansion

Therefore, the "true" (20°C) size of the part can be determined using the following relation:

Let

L_o= the size of the part at 20°C (68°F)
L_T= the size of the part at Temperature T
$\Delta T = T - 20°C$

then

$L_o = L_T\,(1 - \alpha\Delta T)$

HP 5527B Compensation Capability

The Laser Position Transducer has the capability to manually accept the Total Compensation Number (TCN) or automatically determine the TCN.

NOTE

The wavelength value stored in the HP 5507B for use in measurements is the vacuum wavelength of the HP 5517A, HP 5517B and HP 5518A Laser Heads. The HP 5517C operates at a frequency slightly higher than these laser heads; its vacuum wavelength is about 2.5 parts in 10^8 shorter than theirs. For measurements made in air, this difference is much smaller than the effects that changes in the air will have on the wavelength, so no additional correction need be made for the HP 5517C.

For measurements made in vacuum using the HP 5517C, a wavelength compensation value of 0.9999999747 should be entered to improve measurement accuracy.

MANUAL COMPENSATION

For manual compensation, the total compensation factor (TCN) is entered through the system controller to the HP 5507B Laser Position Transducer Electronics. The compensation number can be calculated by using the appropriate formulas for Wavelength and Material Temperature compensation. See Appendix E for Wavelength Compensation numbers and the method to calculate them.

Manual compensation can also be accomplished without deriving or looking up the factors, by using the Option 046 Automatic Compensation Board in the HP 5507B. This board computes compensation factors from the environmental data (atmosphere and machine or part) entered manually through the controller to the HP 5507B.

AUTOMATIC COMPENSATION

NOTE

Measurements made in a vacuum require no compensation for atmospheric effects.

However, because the HP 5517C vacuum wavelength is slightly shorter than the wavelength value stored in the HP 5507B, a wavelength compensation value of 0.9999999747 should be entered for measurements made in vacuum using the HP 5517C, to improve measurement accuracy.

With the Automatic Compensation Board, Option 046, and sensors, the Laser Position Transducer will automatically have an updated compensation number (TCN), ensuring more accurate wavelength and thermal expansion correction. Two products are available that provide wavelength compensation ("Wavelength" term); the HP 10751A/B Air Sensor and the HP 10717A Wavelength Tracker. The HP 10757A/B/C Material Temperature Sensor provides the temperature data for the "Material Temperature" term.

The HP 10751A/B Air Sensor supplies the HP 10946B/C Automatic Compensation Board with air temperature, pressure, and humidity information that is used to calculate the Wavelength Compensation number.

The HP 10717A Wavelength Tracker and its accompanying HP 10780B/C/F Receiver provide the HP 10946B/C Automatic Compensation Board with information indicating any changes in the laser wavelength. Unlike the Air Sensor, the Wavelength Tracker measures relative (differential) changes in the laser wavelength with respect to an initial value. The absolute accuracy is dependent on this initial value. Some methods of determining an initial compensation number are by:

- using an HP 10751A/B Air Sensor.
- using look-up tables (such as those found in Appendix E of this manual).
- measuring temperature, pressure and humidity, and then inputting these values into the Automatic Compensation board using mnemonics found in Section IV-K of this manual.
- measuring a known "standard" length.

To calculate the initial compensation number by measuring a known standard or artifact, use the following formula:

$$\text{Compensation Number} = \frac{\text{Measured length (from laser system on machine)}}{\text{Actual length (from a "Standards" laboratory)}}$$

NOTE

If relative compensation is satisfactory for your application, the default values (see Section IV-K of this manual) of initial compensation may be used.

Sensor Placement

To correct for the effects of air conditions on the laser reading, locate the HP 10717A or HP 10751A/B where it can accurately monitor the conditions influencing the laser beam. Either product should always be mounted as close as possible to the actual MEASUREMENT PATH, so as to monitor the condition of these laser beams.

HP 10717A WAVELENGTH TRACKER

The same mounting considerations as used with the other measurement optics should also be followed when using the Wavelength Tracker. That is, mount the unit on a stable surface so that alignment is maintained.

HP 10751A/B AIR SENSOR

The Air Sensor should not be placed underneath the measurement beam path because the heat from it will affect the laser beam. The HP 10751A/B Air Sensor base contains a magnet to aid in securing it to magnetic materials. For permanent mounting, secure the sensor using the #10-32 tapped hole on the bottom of the instrument.

NOTE
The Air Sensor should be mounted with its arrow pointing up, to maximize accuracy, as shown in *Figure 5-12*.

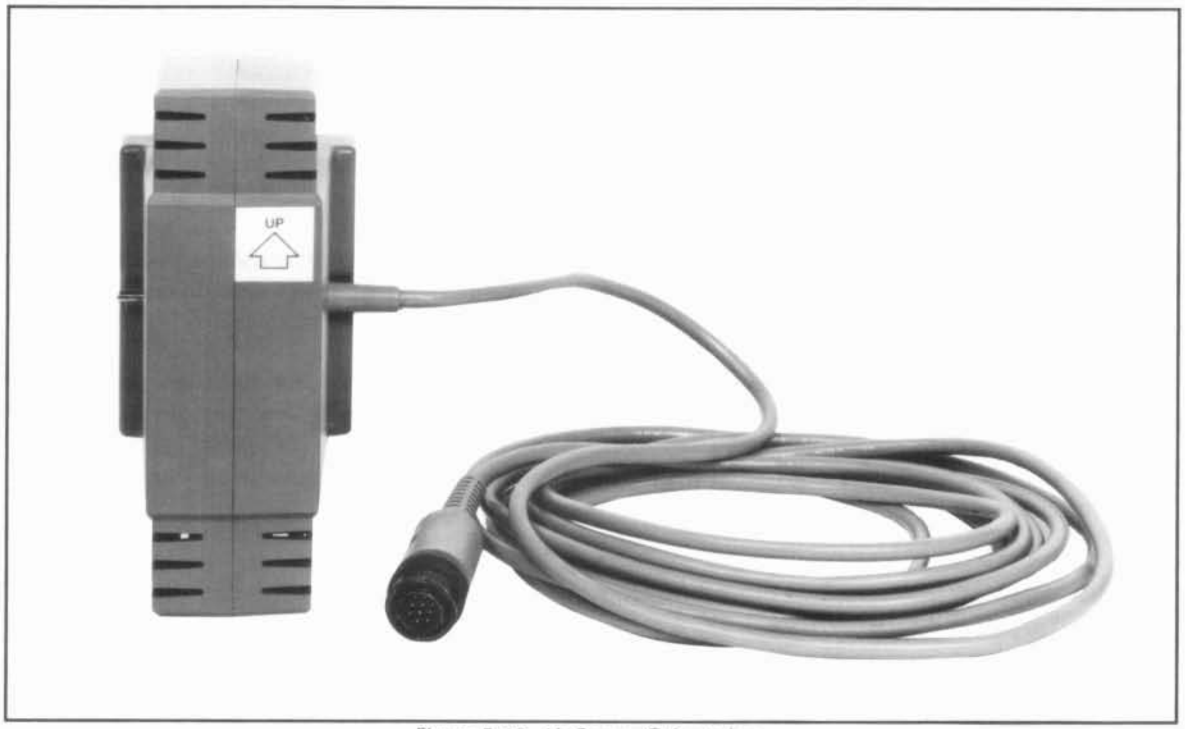


Figure 5-12. Air Sensor Orientation.

HP 10757A/B/C MATERIAL TEMPERATURE SENSOR

When monitoring material temperature to account for material expansion, the HP 10757A/B/C Material Temperature Sensor should be placed on the part of the machine closest to the workpiece.

The material temperature sensor contains a magnet to aid in securing it to ferrous materials. For permanent mounting, a clamp can be used to secure it. If two material temperature sensors are used, they should be placed to determine the average temperature of the workpiece. After attaching a probe to the workpiece, allow about 10 minutes for the probe temperature to stabilize at the workpiece temperature.

COMPENSATION METHOD COMPARISON

The method of atmospheric compensation used is significant in determining the overall laser system measurement accuracy. *Table 5-3* gives the laser system accuracy for various methods of atmospheric compensation as a function of different atmospheric conditions.

Table 5-3. Laser System Measurement Accuracy Comparison †

Environment:
Pressure: 760 mm Hg ±25 mm Hg
Relative Humidity: 50% ±10%

Temperature Control	**±0.1°C**	**±1.0°C**	**±5.0°C**
No Compensation †† (at 20°C)	±9.0 ppm	±9.9 ppm	±14.0 ppm
Compensation using HP 10751A/B Air Sensor (at 20°C)	±1.4 ppm	±1.5 ppm (typical)	±1.6 ppm
Wavelength Tracking Compensation †††	±0.15 ppm	±0.19 ppm	±0.44 ppm
Measurement in Vacuum	±0.1 ppm	±0.1 ppm	±0.1 ppm

† These accuracy specifications include the laser head term, but exclude electronics accuracy and interferometer nonlinearity terms.

†† No compensation means that no correction in compensation number occurs during environmental changes.

††† System accuracy equals these values (measurement repeatability) plus accuracy of initial compensation value.

NON-UNIFORM ENVIRONMENTS

Compensation for environmental effects is only practical when there is homogeneity in the atmosphere (around the measurement area) and in the temperature of the measured part or machine. Inhomogeneity can be caused by air turbulence and changing material temperature.

Changing Temperature Conditions

Note that material temperature compensation is accurate only under constant nonstandard conditions. Material Temperature Compensation can be used to correct for thermal expansion of the part only if the part and the machine are at thermal equilibrium with their surroundings. Changing temperature can result in changing thermal gradients in both the machine and the part. In this case, the primary machine errors are due to complex bending effects which distort machine geometry instead of simple thermal expansion. These effects are extremely difficult if not impossible to describe mathematically.

Therefore, if a machine is operated in a poor environment, its accuracy may be limited by its own geometry. In this case, the practical solution is to either improve the environment or make the machine less susceptible to environmental changes.

Air Turbulence

Another important factor to be considered during the installation of the Laser Position Transducer system is air turbulence. Air turbulence, or inhomogeneity of the air in the optical measuring path, is usually caused by variations in air temperature. The major effect of air turbulence is to reduce the amount of signal at the receiver. This reduction is due to either a physical deflection of the laser beam or a degradation of the coherence of the beam. If the air turbulence conditions become excessive, this could result in a complete loss of measurement signal. This loss of signal will be detected by the HP 10932A Axis Board which will output an error signal.

One application where serious consideration must be given to air turbulence is in temperature controlled environments. Although it would appear that such an environment would be ideal, temperature controlled areas often exhibit greater air turbulence than non-controlled areas. This turbulence is caused by incomplete mixing of new air from the temperature control unit with existing air, creating thermal gradients or pockets. Although such environments are good for a machine's thermal stability, the short term fluctuations can cause measurement signal degradation in the Laser Position Transducer system.

AIR TURBULENCE REDUCTION

In uncontrolled environments the effects of air turbulence can be minimized by protecting the laser beam with some type of cover. Since this would normally be done for protection against beam interruption, air turbulence effects will usually not be a significant installation factor in typical environments.

Protection against air turbulence problems which occur in controlled environments depend largely on the specific application. For systems such as integrated circuit lithography equipment in small closely controlled enclosures, it may be sufficient to provide constant air flow over the measurement paths. In other cases, such as large coordinate measuring machines, protecting the laser beams with covers prevents air turbulence effects from interfering with the measurement.

AVOIDING THERMAL GRADIENTS

One source of air turbulence which can affect not only the Laser Position Transducer but also the accuracy of the machine itself is thermal gradients created by localized heat sources (e.g., motors, electromagnetics, lamps, etc.) located on or near the machine. Every effort should be made to shield the measurement path from these types of heat sources. Note that a local heat source which can affect the Laser Position Transducer enough to cause measurement signal loss also tends to degrade the geometric accuracy of the machine through warping or bending. Therefore, consideration should be given to thermally isolating the heat source from the machine as well as the measurement path.

Optics Installation Effects

When planning the installation of the laser head and optics on a specific machine, a number of factors must be considered to maintain the system accuracy. The important points to consider are:

a. Installing the interferometer and retroreflector to minimize deadpath errors.

b. Align the laser beam path parallel to the axis of motion to minimize cosine errors.

c. Selecting the measurement paths to minimize Abbé error.

These effects are not a concern for the optical axis used for the HP 10717A Wavelength Tracker. The components of the Wavelength Tracker are aligned at the factory to minimize any cosine or Abbé errors.

In many cases, it may not be possible to completely eliminate these sources of error but every effort should be made to minimize them. The following paragraphs discuss methods of installing and compensating for these errors.

DEADPATH ERRORS

Deadpath is defined as the difference in optical path length of the Reference and Measurement components of the beam when the positioning stage or machine is at its zero position, as defined by the machine's coordinate system. Unequal beam components can produce an optical path length difference that will not be properly compensated during changing environmental conditions, resulting in a measurement error.

In simple terms, deadpath error is an error introduced due to an uncompensated length of laser light between the interferometer and the retroreflector when the machine is at its zero position.

Figure 5-13 shows a basic optical layout. In *Figure 5-13A* deadpath occurs as length "D" the distance between the interferometer and the zero point. *Figure 5-13B* shows how to minimize the deadpath error.

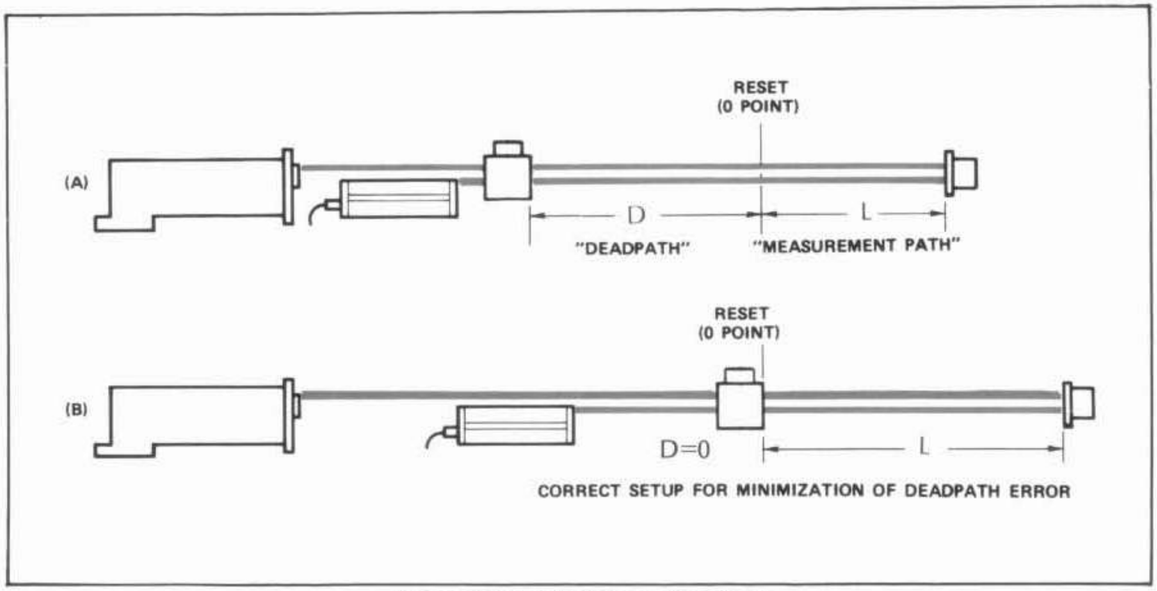


Figure 5-13. Minimizing Deadpath

Causes of Deadpath Error

There are two major components of deadpath:

- Unequal path lengths, and
- Unequal path treatment.

Unequal path lengths are described above as the difference in the path lengths of the reference and measurement components of the beam.

Unequal path treatment is the path length difference in these components caused by the beam components not passing through an equal amount of the same media. For example, if one component goes through more glass than the other.

Figure 5-14A shows the unequal path lengths in the case of the Linear Interferometer. The deadpath length is designated as "D". In this diagram the reference component is F_V and the measurement component is F_H. The component of F_H has a longer optical path length than component F_V by a distance "D". Now assume the retroreflector (*Figure 5-14B* moves a distance "L" to a new position and comes to rest. Assume while at rest the environmental conditions surrounding the laser beam change. The laser beam wavelength changes over the entire path (D + L) due to these environmental changes, and so should be compensated. Since our measurement technique only measures "wavelengths of motion" which involves only the distance "L", the system can make no correction for the wavelength change over "D" and the result is an apparent shift in the zero position on the machine. This error is deadpath error and occurs whenever environmental conditions change during a measurement.

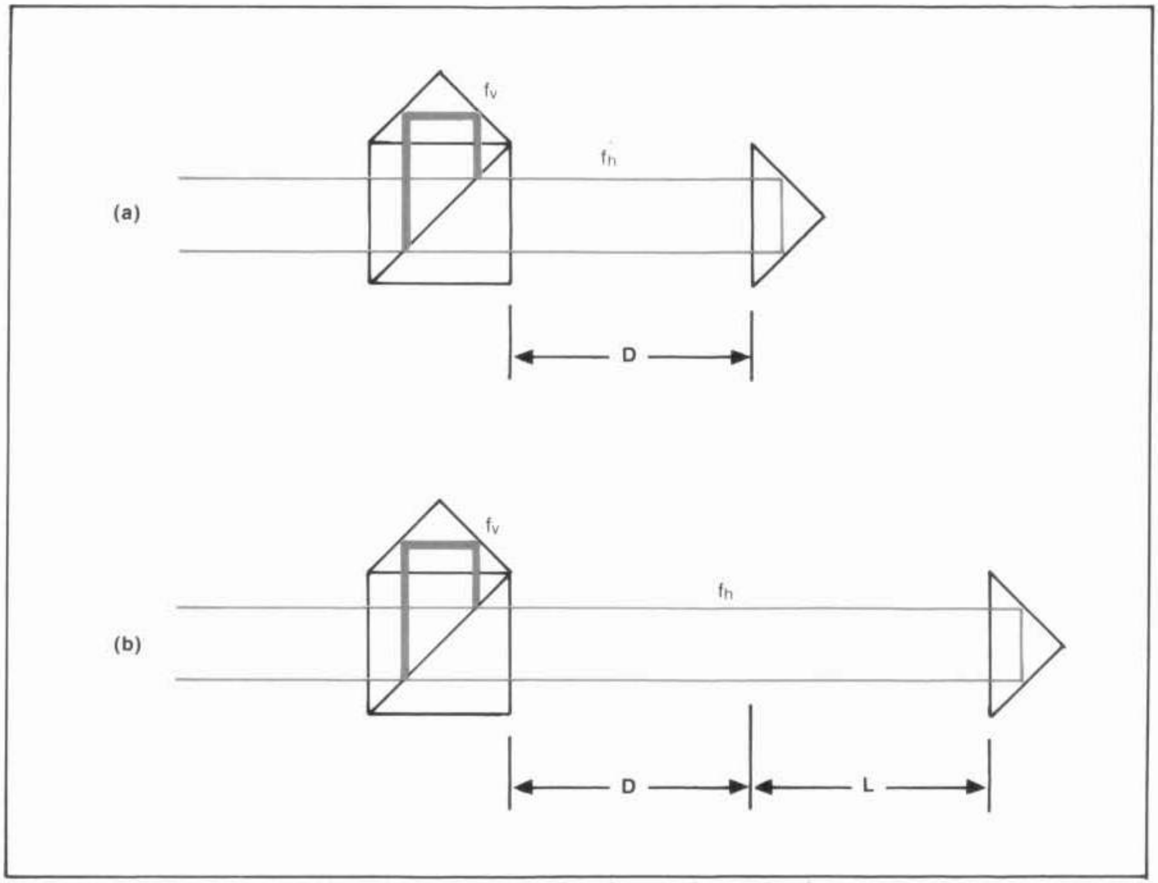


Figure 5-14. Unequal Path Length Deadpath

In *Figure 5-15* deadpath errors from unequal path treatment as well as unequal path lengths are shown. The illustrated application requires the addition of a glass window between the interferometer and the measurement retroreflector, which causes unequal treatment of F_V and F_H. In a similar manner, changing environmental conditions will have a different effect on F_H than F_V, resulting in a deadpath error because of the unequal path treatment of these beam components. Therefore in this example the total deadpath will be the sum of both the unequal path lengths and treatment affects.

For unequal path treatments, the changing optical path length is only a function of temperature, not wavelength of light.

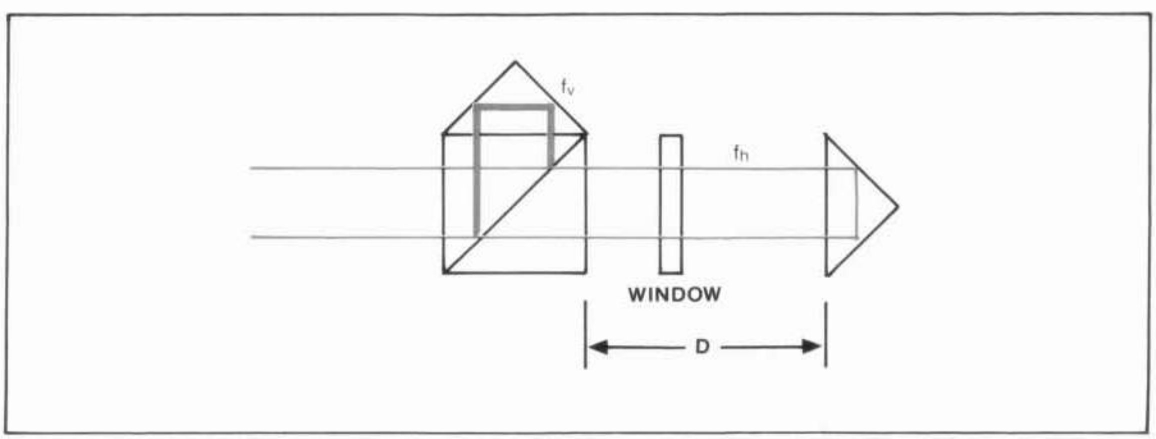


Figure 5-15. Unequal Path Treatment Deadpath.

How to Reduce Deadpath Errors

Deadpath errors can be minimized in most applications by a combination of the following:

a. By mechanically minimizing the distance "D". This is done by mounting the interferometer as close to the retroreflector as possible when the machine is at zero position as defined by its own coordinate system. This minimizes the unequal path length cases.

b. Minimize the unequal path treatments as much as possible, that is, minimize the use of transmitting the measurement beam through a window.

c. By using the HP 10715A Differential Interferometer.

d. By correcting for the residual distance "D" in software in the controller (See section IV).

e. Equalize the path lengths of F_V and F_H, thereby reducing deadpath error, by moving the reference cube-corner a distance "D" from the interferometer (See *Figure 5-16*). Assuming the atmospheric conditions are equivalent and the distances between the cube-corners and the interferometer are equal, this configuration would not have deadpath errors due to unequal path lengths. Care must be taken when using this method of reducing deadpath because any drift in the position of the reference cube-corner will also show up as a measurement error. This drift can occur from non-rigid mounting and thermal expansion, for example.

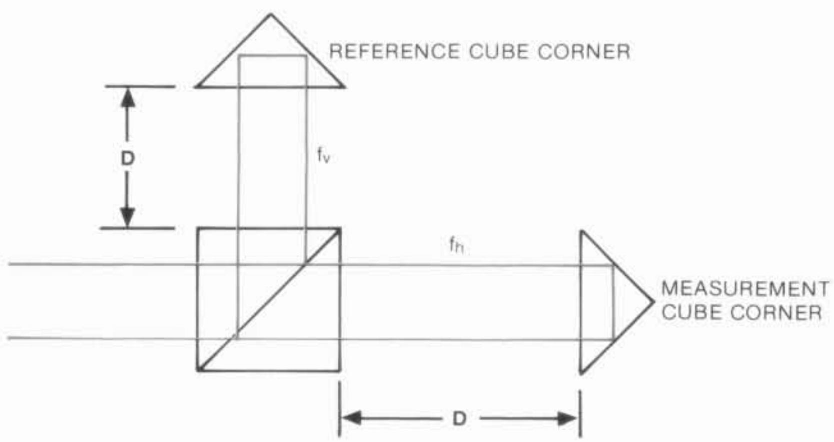


Figure 5-16. Equal Path Length Corrections

Some unequal path treatment can not be avoided with the HP 10706A Plane Mirror Interferometer. The other interferometers have negligible difference in their treatments. Note from *Figure 5-17* that component F_H travels through quite a bit more glass than does F_V. It makes twice as many trips through the interferometer as does F_H and also two round trips through the quarter-wave plate. This of course constitutes unequal treatment of F_H and F_V, and will cause deadpath errors under changing conditions.

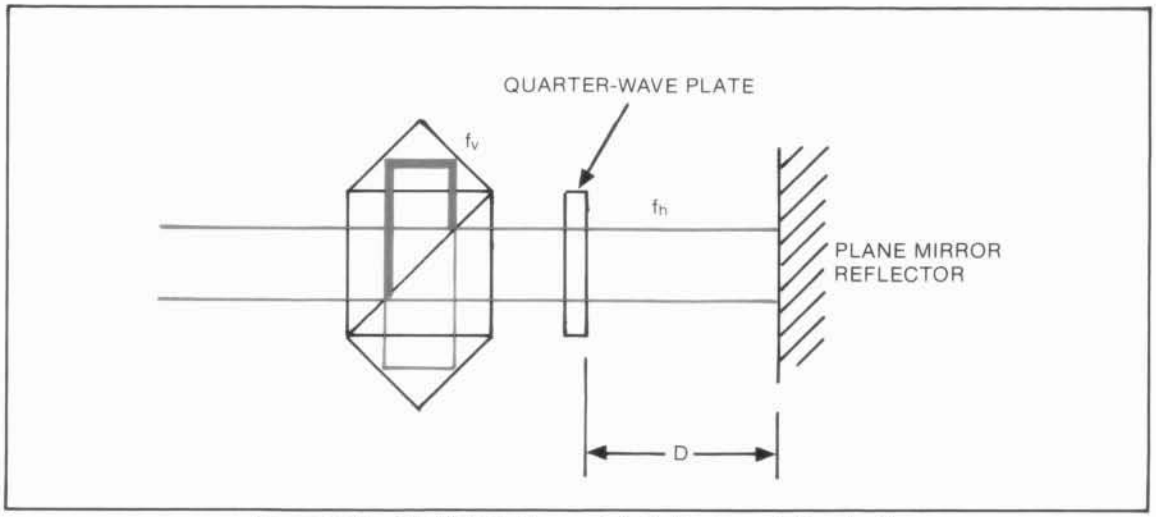


Figure 5-17. HP 10706A Unequal Path Treatment Deadpath.

To model this effect and compensate for it would be very difficult so the user should determine if this error source is significant in their particular application, given the temperature stability. The approximate deadpath error due just to this on the HP 10706A would be:

ΔT Since Measurement Reset	**Deadpath Error (shift of zero position)**
1°C	0.5 microns
2°C	1.0 microns

This deadpath is inherent in the design of this interferometer. If this error is excessive then it is recommended that the user consider using the HP 10715A Differential Interferometer or HP 10706B High Stability Plane Mirror Interferometer instead. See Section 8 for specifications of the HP 10706B.

COMPENSATION FOR DEADPATH ERRORS

Correction for deadpath error (unequal path length) is only necessary if there is a change in the laser wavelength due to environmental conditions. Compensation for deadpath error can be done by correcting for the deadpath distance "D" in software in the controller. In this case the general relation;

True Position = Wavelength counts due to motion × vacuum wavelength × TCN

is expanded to be:

True Position =

[(Accumulated Counts + Deadpath Counts) × Wavelength Conversion Factor × TCN] − (Deadpath in selected units)

Accumulated raw counts is the actual output from the electronics rather than the number of wavelengths. When using the HP 10715A Differential Interferometer or the HP 10706A/B Plane Mirror Interferometer an actual displacement count is equal to $\lambda/128$, where λ is the wavelength of the laser in air. For the other interferometers, a displacement count equals $\lambda/64$.

Deadpath counts is the deadpath length "D" in terms of counts. These counts have to be appropriate for the optics being used.

You must input the terms "Deadpath Counts" and "deadpath in selected units" with the correct conversion factor. These terms can be determined as follows:

For λ/128 Optics:

$$\text{Deadpath Counts} = \frac{(2.0221444 \times 10^5)}{(\text{Initial TCN})} D \text{ (if D is in millimetres)}$$

For λ/64 Optics:

$$\text{Deadpath Counts} = \frac{(1.0110722 \times 10^5)}{(\text{Initial TCN})} D \text{ (if D is in millimetres)}$$

where D is the deadpath distance.

The wavelength conversion factor is also dependent on which measurement optics are used.

For λ/128 optics:

$$\text{Wavelength Conversion Factor} = 4.9452451 \times 10^{-6} \frac{\text{millimetres}}{\text{count}}$$

For λ/64 optics:

$$\text{Wavelength Conversion Factor} = 9.8904902 \times 10^{-6} \frac{\text{millimetres}}{\text{count}}$$

The deadpath distance (D) need not be measured with precision. The error in measuring "D" simply shows up as an uncompensated deadpath (ΔD). This value would be much smaller than the error due to D.

The ability to correct for deadpath error in software does not eliminate the necessity of minimizing deadpath by proper location of the interferometer wherever possible. If the deadpath (D) is large compared to the distance traveled (L), then the predominant error is a zero shift due to uncertainty in determining the change in air wavelength and this error cannot be eliminated in software.

COSINE ERROR

Misalignment of the laser beam path to the axis of motion of the translation stage results in an error between the measured distance and the actual distance traveled. This is referred to as cosine error because the magnitude of the error is proportional to the cosine of the angle of misalignment. Cosine error can be visualized as shown in *Figure 5-18*.

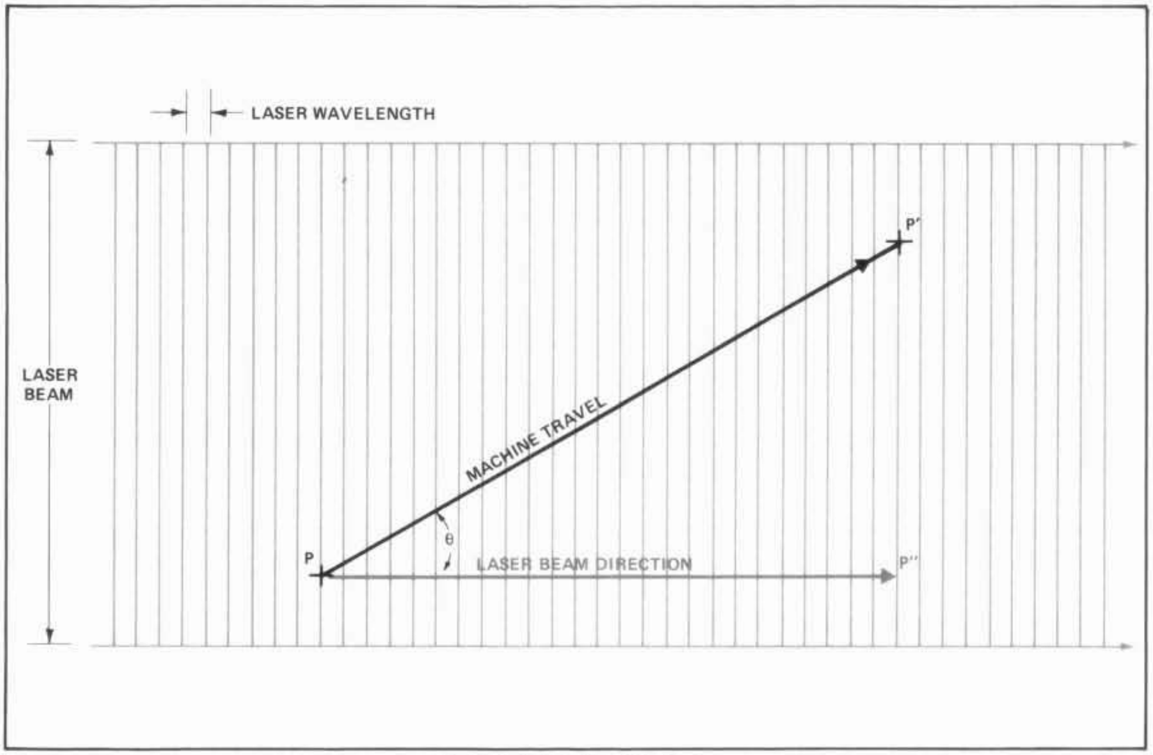


Figure 5-18. Cosine Error

The equally spaced vertical lines (*Figure 5-18*) can be thought of as lines on a conventional scale. As a point on the machine travels along the laser beam, the interferometer counts the number of wavefronts intercepted by the point during its travel. If the point travels along the path P-P′ as shown, the interferometer counts the number of wavefronts intercepted and measures the distance P-P″. In other words, the interferometer measures the component of motion in the direction of the laser beam.

Calculation

The two paths are related as follows:

$$P\text{-}P'' = P\text{-}P' \cos\theta$$

(where θ = angle of misalignment between laser beam and machine axis of motion)

Therefore the cosine error can be represented, in parts per million as:

$$\text{cosine error} = (1-\cos\theta) \times 10^6$$

It is obvious from *Figure 5-18* that the measured P-P″ is shorter than the actual distance traveled P-P′. Note that cosine error always causes the interferometer to read short of the actual distance traveled. *Table 5-4* shows some typical cosine errors for the angle θ.

Table 5-4. Angle θ Versus Cosine Error

θ (deg)	θ (rad)	COSINE ERROR
.001	1.7×10^{-5}	1.52×10^{-10}
.01	1.7×10^{-4}	1.52×10^{-8}
.08	1.4×10^{-3}	1.00×10^{-6}
.1	1.7×10^{-3}	1.52×10^{-6}
1	1.7×10^{-2}	1.52×10^{-4}

Minimizing Cosine Errors

Cosine error is reduced by making the laser beam parallel to the actual travel of the axis. Care in aligning the laser head and optics should be taken to minimize the possibility of cosine error. Section VI describes in detail the alignment techniques for the different optical configurations available. These techniques will help in minimizing cosine errors.

ABBÉ ERROR

Abbé offset error occurs when the measuring point of interest is displaced from the actual measuring scale location and there are angular errors in the positioning system.

A very important advantage of the Laser Position Transducer system is that the Abbé error evident in almost all positioning systems is very easily reduced.

Abbé offset error will make indicated position either shorter or longer than the actual position, depending on the angular offset. The amount of measurement error resulting from Abbé offset is:

Offset distance × tangent of offset angle

Figures 5-19 show some general examples of Abbé error and illustrate the requirement for minimizing angular error and placement of the measurement path. In *Figure 5-19A*, the measurement axis is coincident with the leadscrew centerline and is measuring a displacement of the carriage at the leadscrew. This figure illustrates the displacement error E which is generated at the measurement probe tip due to angular motion (θ) of the carriage. *Figure 5-19B* shows the same carriage motion as *Figure 5-19A* but with the measurement axis coincident with the probe path. In this case the measurement system measures the actual displacement and there is no offset error.

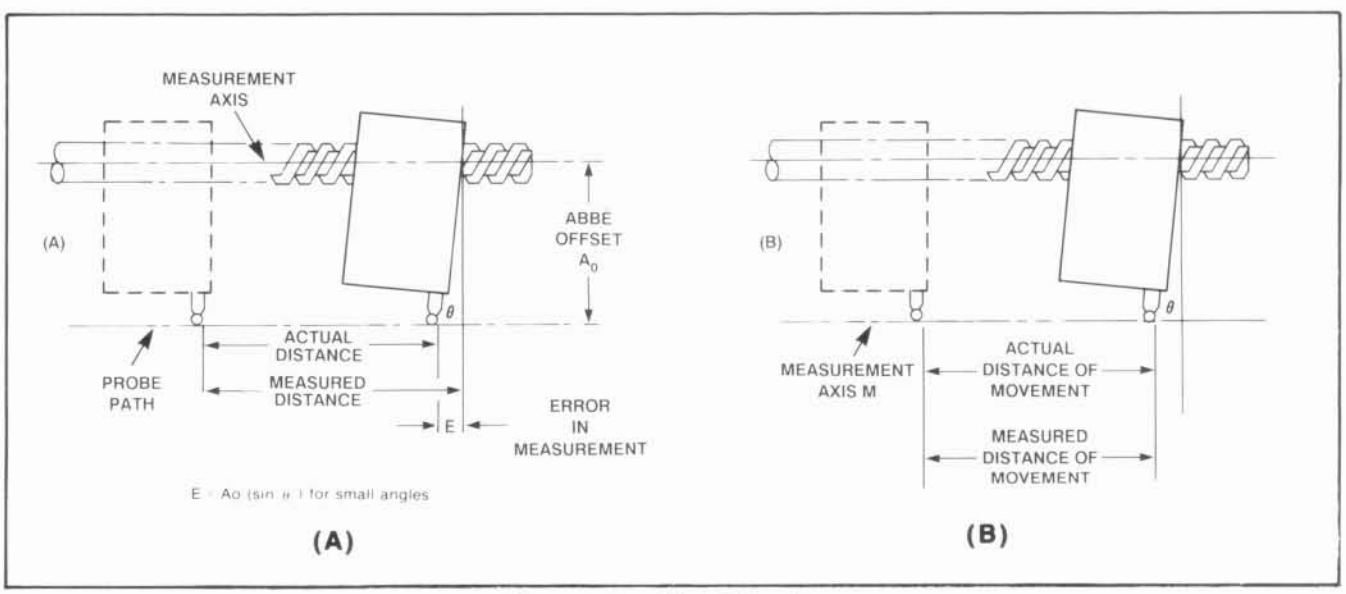


Figure 5-19. Abbé Offset Error

NOTE

A helpful rule of thumb for approximating the error attributable to angular motion is that for each arcsecond of angular motion, the error introduced is approximately 0.1 microns per 20 mm of offset (5 microinches per inch of offset).

Minimizing Abbé Error

When considering a specific application, make every effort to direct the measurement path as close as possible to the actual work area where the measurement process takes place. In *Figure 5-20*, a machine slide is shown with the interferometer and retroreflector placed to minimize Abbé error. The measurement axis is placed at approximately the same level as the work table and is also measuring down the center of the machine slide.

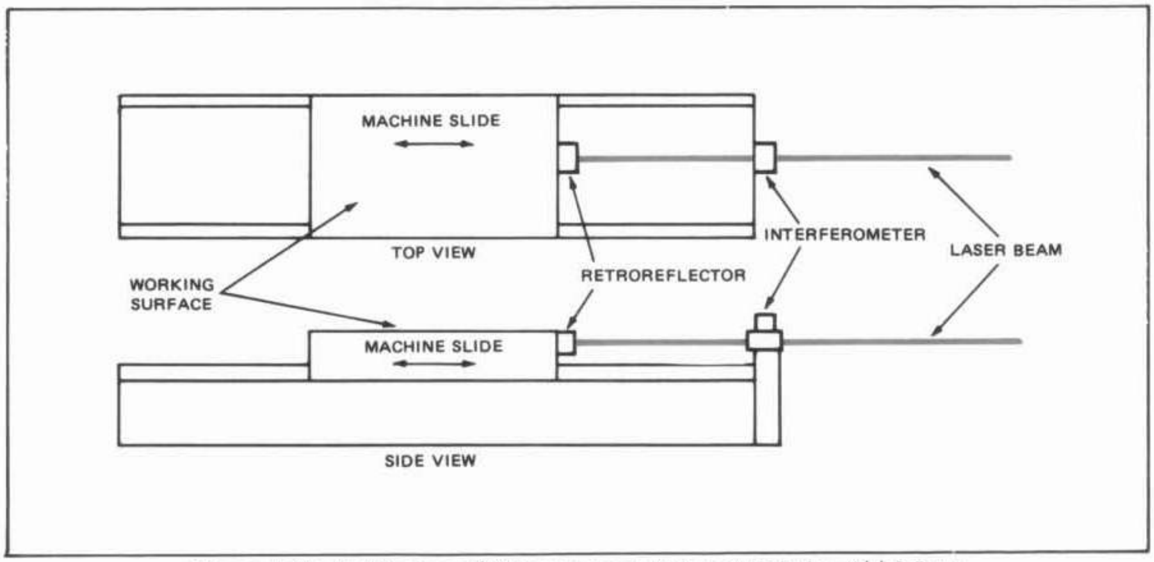


Figure 5-20. Positioning of Measurement Axis to Minimize Abbé Error

Using Plane Mirror Measurement Optics

For X-Y stage applications, the Laser Position Transducer system can minimize Abbé errors. The HP 10706A Plane Mirror Interferometer or HP 10715A Differential Interferometer used with plane mirrors, mounted at 90° to each other on the top edges of an X-Y stage, create a very accurate positioning system which eliminates Abbé error. *Figure 5-21* shows a typical installation for an X-Y stage. The principal advantage of this type of positioning system is that the measurement in both X and Y axes takes place at the work surface plane. If there are angular errors in the cross slides of the stage, any displacement of the work surface due to these errors is measured by the Laser Position Transducer.

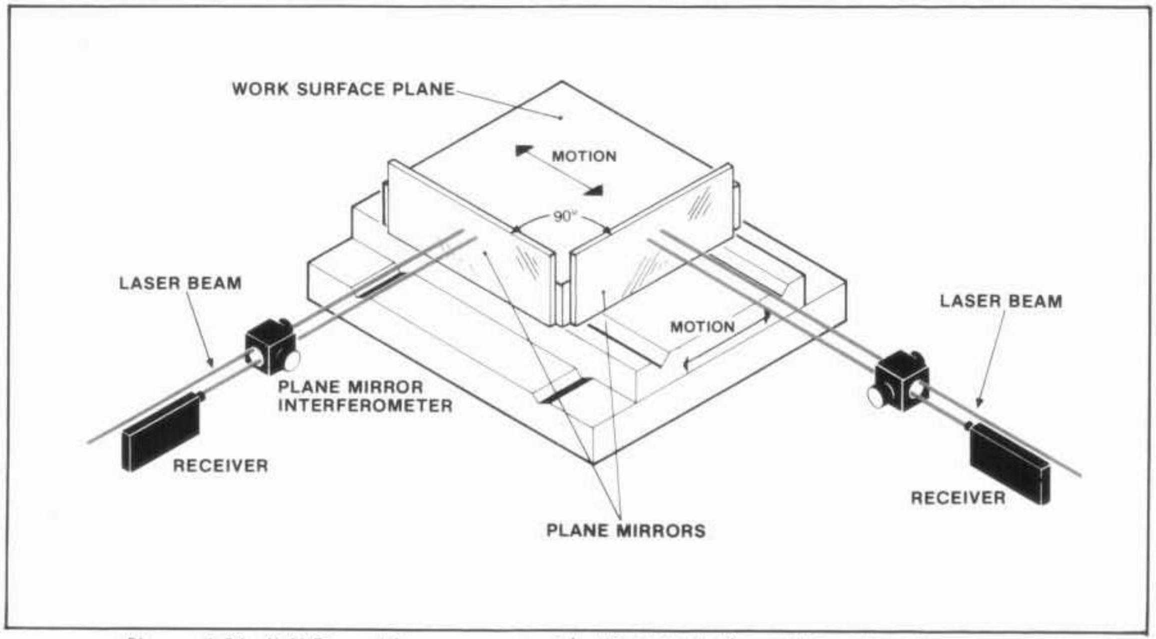


Figure 5-21. X-Y Stage Measurement with HP 10706A Plane Mirror Interferometer

In addition, if the mirrors are aligned at exactly 90° to each other, orthogonality of the positioning system is determined by the mirrors and not the X-Y slides. *Figure 5-22* illustrates the actual measurement which takes place if there are any geometric errors in the X-Y stage.

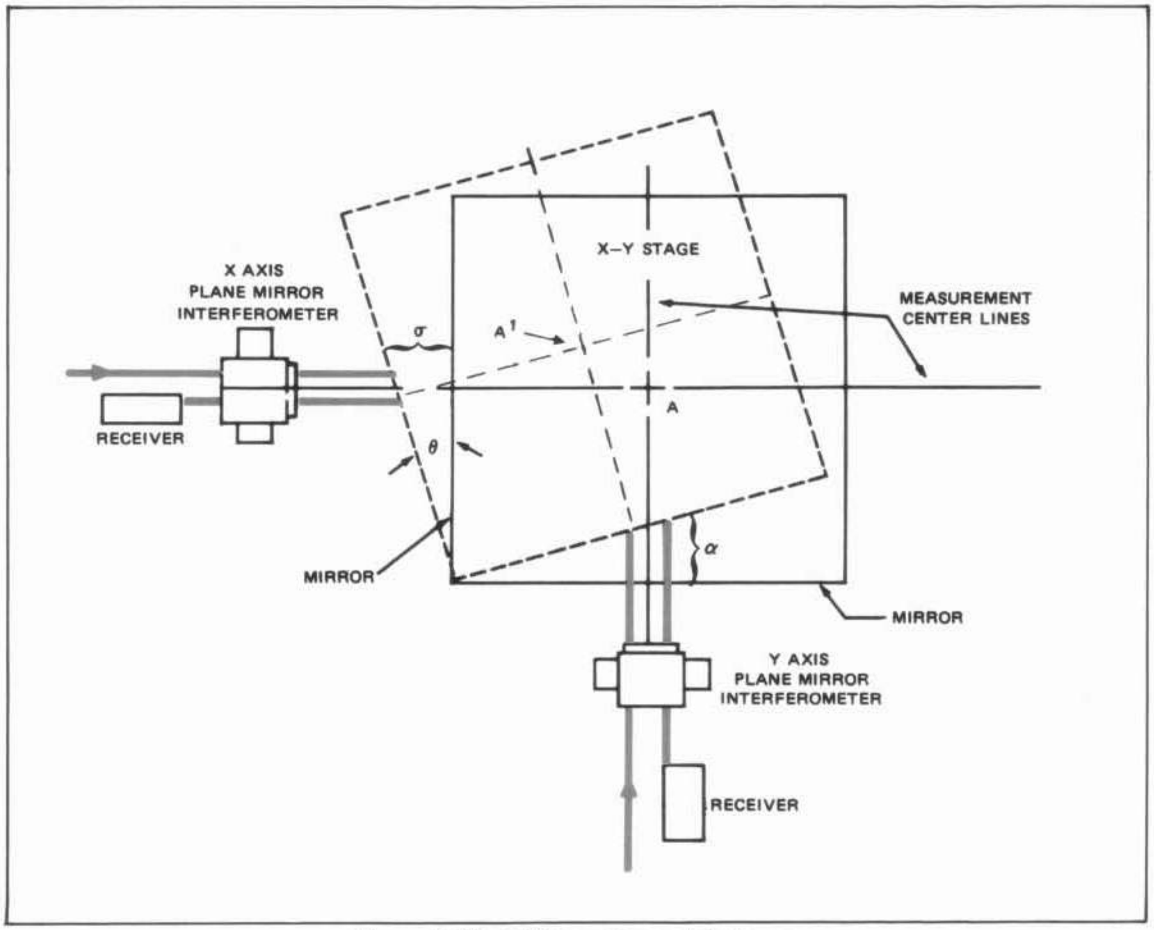


Figure 5-22. X-Y Stage Geometric Errors

If the HP 10706A Plane Mirror Interferometers or HP 10715A Differential Interferometers are installed with their measurement centerlines intersecting on the axis of the fixed cutting tool, measuring probe, lens centerline, etc., (Point A), then X-Y position errors due to any yaw angle errors can be corrected. For example, if the X-Y stage undergoes an angular error (θ), then the point of interest A is displaced to A^1. Since this angular error also generates an X- and Y- axis position error of σ and α in the X and Y directions respectively, point A^1 can be moved back to point A which will be the correct position.

This page left blank intentionally.

SECTION VI
INSTALLATION AND OPTICAL ALIGNMENT

SECTION VI CONTENTS

This page left blank intentionally.

SECTION VI
INSTALLATION AND OPTICAL ALIGNMENT

INTRODUCTION

This section provides the information necessary to install the Laser Position Transducer into a machine. The section has the following organization:

- Preinstallation Checklist
- Installation of the Electronics (HP 5507A)
- Installation of the Laser Heads and Receiver
- Installation of Optics
- Alignment Procedures for the different Interferometers
- Installation and Alignment of the Wavelength Tracker

PREINSTALLATION CHECKLIST

Besides reading Sections I through V, the following items should be completed before attempting to install the Laser Position Transducer into any application.

___ Complete Beam Path Loss Calculation (See Section V.)

___ If using HP 10706A or HP 10715A, you have supplied the Plane Mirror Reflectors. See Section VIII for specifications.

___ If using HP 10715A Differential Interferometer, you have supplied an adjustable mount for the reference mirror.

___ Orientation of laser head and interferometer determined for required direction sense. (See Sections II and V.)

___ Provisions made for alignment of the optics, laser head and receiver(s) on the machine.

___ Transmitted beam offset of beam splitters (HP 10700A and HP 10701A) taken into account in design. (See Section VIII for offset specifications.)

UNPACKING, INSPECTION, AND RESHIPMENT

The following paragraphs contain information for unpacking and inspection, warranty claims, laser tube shipment, tagging for service, and packaging for reshipment.

WARNING

TO AVOID HAZARDOUS ELECTRIC SHOCK, DO NOT PERFORM ELECTRICAL TESTS WHEN THERE ARE SIGNS OF SHIPPING DAMAGE TO ANY PORTION OF THE OUTER ENCLOSURE (COVERS, PANELS, METERS).

Unpacking and Inspection

Inspect the shipping container for damage. If the shipping container or cushioning material is damaged, it should be kept until the contents of the shipment have been checked for completeness and the instrument has been checked mechanically and electrically.

If the contents are incomplete, if there is mechanical damage or defect, or if the instrument or some component fails, notify the nearest Hewlett-Packard Office. If the shipping container is damaged, or the cushioning material shows signs of stress, notify the carrier as well as the Hewlett-Packard office. Keep the shipping materials for the carrier's inspection. The HP office will arrange for repair or replacement at HP's option without waiting for a claim settlement.

Warranty Claims

Contact the nearest HP Sales and Service Office (see manual back cover) for information relative to warranty claims.

Laser Tube Shipment

NOTE

The laser tube assembly MUST be shipped in an approved HP container.

The laser tube assembly should only be shipped in an HP container designed for that purpose. In addition, the container must indicate that the laser tube contains magnetic material. If it is necessary to ship a laser tube, contact your nearest HP Sales and Service Office for an approved container.

Tagging for Service

If the instrument is being returned to Hewlett-Packard for service, please complete one of the blue repair tags located at the end of this manual and attach it to the instrument.

Packaging for Reshipment

1. Original Packaging
   a. The same containers and materials used in factory packaging can be obtained through Hewlett-Packard Sales and Service Offices listed at the rear of this manual.
   b. If an instrument is being returned to Hewlett-Packard for service, attach a tag indicating the type of service required, return address, and model number. Mark the container FRAGILE to assure careful handling.
   c. In any correspondence refer to the equipment by model number.
2. Other Packaging Methods
   a. If it becomes necessary to reship equipment, good commercial packing should be used. Contract packaging companies can provide dependable custom packaging on short notice. The following general instructions should be followed when repackaging with commercially available materials.
   b. If shipping to a Hewlett-Packard Service Office or Center, attach a tag indicating the type of service required, return address, and model number.
   c. Wrap the equipment in heavy paper or plastic.
   d. Use a strong shipping container. A double-wall carton made of 350 pound test material is adequate.
   e. Use enough shock-absorbing material (three to four inch layer) around all sides of the equipment to provide a firm cushion and prevent movement inside the container.
   f. Seal the shipping container securely.
   g. Mark the shipping container FRAGILE to assure careful handling.

ELECTRONICS

Configuration

Generally, the HP 5507A will be shipped ready to connect to receivers, laser head and controller. But, when non-standard configurations, the prototyping kit, or field-installed boards are used, the following paragraphs should be read.

PC BOARD INSTALLATION

Tools Required - Pozidriv screwdrivers
9/16" Hex Nut Driver (0.75" deep)
7 mm Hex Nut Driver

WARNING

100/240 VOLTS AC MAY BE PRESENT IN THE HP 5507A. USE EXTREME CAUTION WHEN WORKING ON OR NEAR THE PRIMARY POWER WIRING. THERE IS EXPOSED LINE VOLTAGE BENEATH THE POWER SUPPLY COVER. TO PREVENT ELECTRIC SHOCK, REMOVE AC POWER CORD PRIOR TO REMOVING COVER. CONTACT WITH PRIMARY POWER VOLTAGE COULD CAUSE SERIOUS PERSONAL INJURY.

CAUTION

The HP 5507A must be turned off prior to inserting or removing any pc board. Expensive damage to both the instrument and the pc board may result if power is left on.

CAUTION

Some circuits on the HP 5507A plug-in boards are susceptible to damage from electrostatic discharge. Use an anti-static work station and ground straps when handling printed circuit assemblies during assembly or disassembly.

1. Remove the top cover which is held in place by a captive screw (*Figure 6-1*) at rear of instrument.
2. Remove the pc board retainer which is held in place by a screw at each side of the instrument.
3. Remove the appropriate rear panel access covers for the desired pc board location. (The slot furthest from the power supply is reserved for compensation boards).

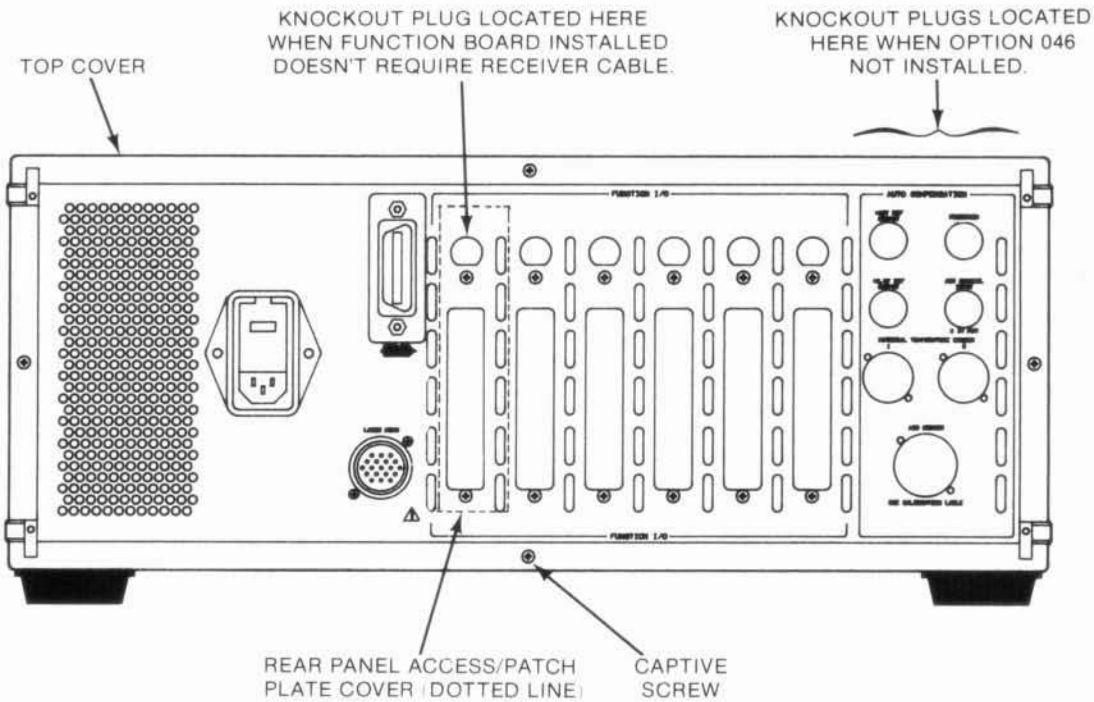


Figure 6-1. HP 5507A Rear Panel, Knockout and Access Plates

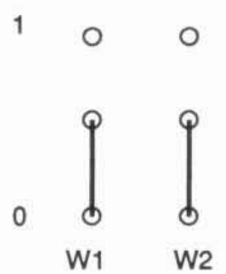
4. Select the desired address for the board from Table 6-1 and set switches accordingly.

CAUTION

Each board must be set to a unique address. Failure to do so will result in improper operation or circuit damage.

Table 6- 1. Backplane Addresses

Address (** = Factory Setting)	jumper or Switch Setting		Board
K			
L			RESERVED FOR FUTURE USE
M			
N			
O**	W1-0	W2-0	
P	W1-1	W2-0	HP 10941A
Q	W1-0	W2-1	PROTOTYPING BOARD
R	W1-1	W2-1	
S	00		
T	01		HP 10946B/C
U	10		AUTOMATIC COMPENSATION
V**	11		BOARD
S	000		
T	001		HP 10932A/B AXIS BOARD
U	010		OR
V	011		HP 10934A A-QUAD-B
W	100		AXIS BOARD
X	101		OR
Y	110		HP 10936A/B SERVO-AXIS BOARD
Z	111		



ADDRESS	JUMPER WIRES W1	W2
O	0	0
P	1	0
Q	0	1
R	1	1

MPBA_C4I

Figure 6-2. Prototyping Board Address Jumpers

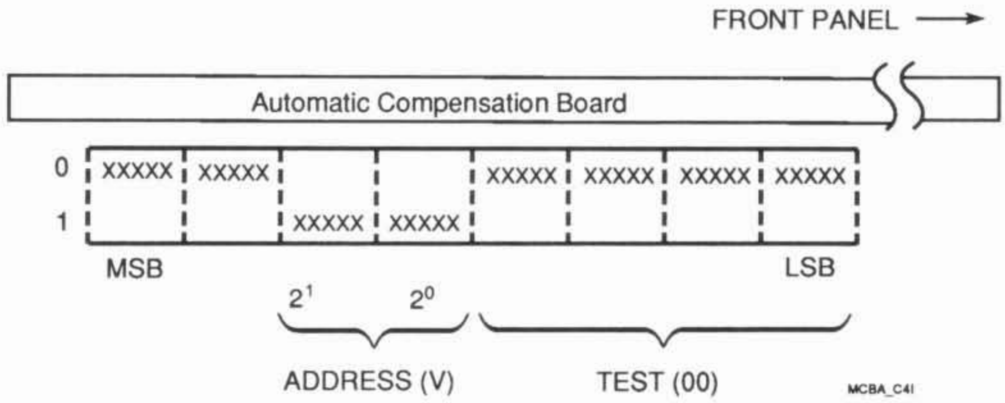


Figure 6-3. Compensation Board Address Switches

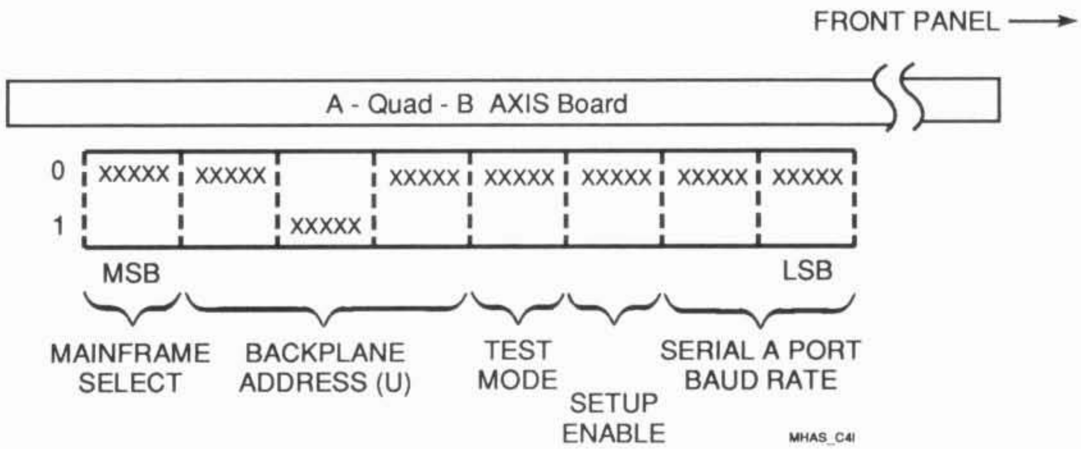


Figure 6-3a. A-Quad-B Axis Board Switches

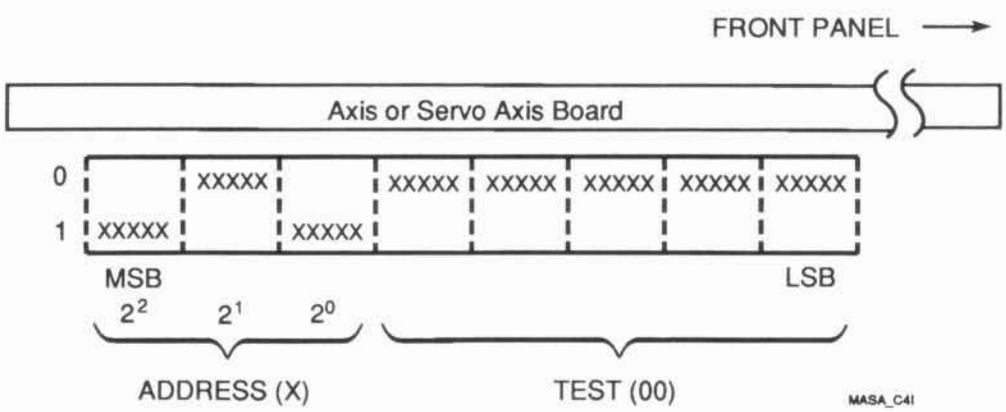


Figure 6-4. Axis and Servo-Axis Address Switches

5. Automatic Compensation board Only. Position Compensation Connector board assembly in rear panel so that all contacts protrude. Fasten in place with six 4-40 x 1/4" screws and three 5/16" nuts and lockwashers. Align compensation board with slot in Compensation Connector board and card guide on backplane, and plug board into backplane connector. Carefully connect flexible flat cable to Automatic Compensation board (do not crease cable).

6a. If HP 10932-60101 cable assembly is supplied with a board (HP 10932A/B, HP 10934A, HP 10936A/B, and HP 10946B/C only), then position cable's BNC connector in rear panel and fasten in place with 1/2" nut and lockwasher. Ensure that the flat side of the BNC connector is aligned with the flat side in the rear-panel hole, and that the BNC connector is fully seated. Otherwise install the supplied hole-plug in place of the cable connector.

6b. Connect HP 10932-60101 cable assembly to board and connect cable into plastic cable clamp. For HP 10932A/B Axis boards, this cable connects into the 4-pin male connector A2J4. On the HP 10934A A-Quad-B Axis Board, this cable connects to the 4-pin male connector A16J4. On the HP 10936A/B Servo-Axis board this cable connects to the 4-pin male connector Al5J4. On the HP 10946B/C Automatic Compensation board, this cable connects into 4-pin male connector A8J3.

7. Non-Compensation Board Only. Place shield over 50-pin connector, push connector through rear panel opening and seat board onto selected backplane connector (*Figure 6-5*). Place 50-pin adapter plate over connector and secure in place with the two supplied screws. Make sure connector is centered in opening.

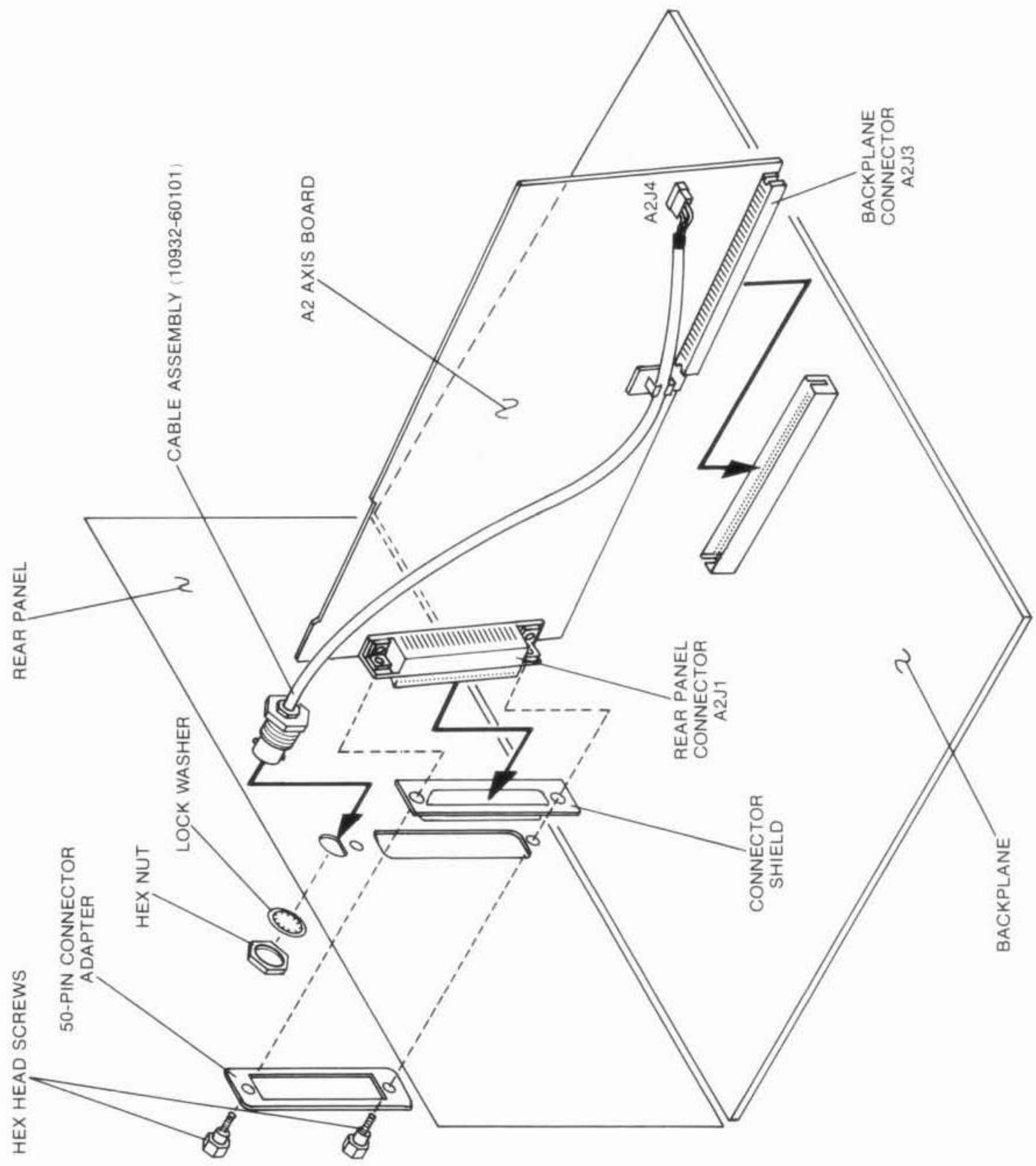


Figure 6-5. HP 5507A Board Installation, Exploded View

8. Non-Compensation Board Only. Install any required ribbon cables to adjacent boards. Make sure connectors are fully mated and retaining snaps fit over top of connector (*Figure 6-6*).

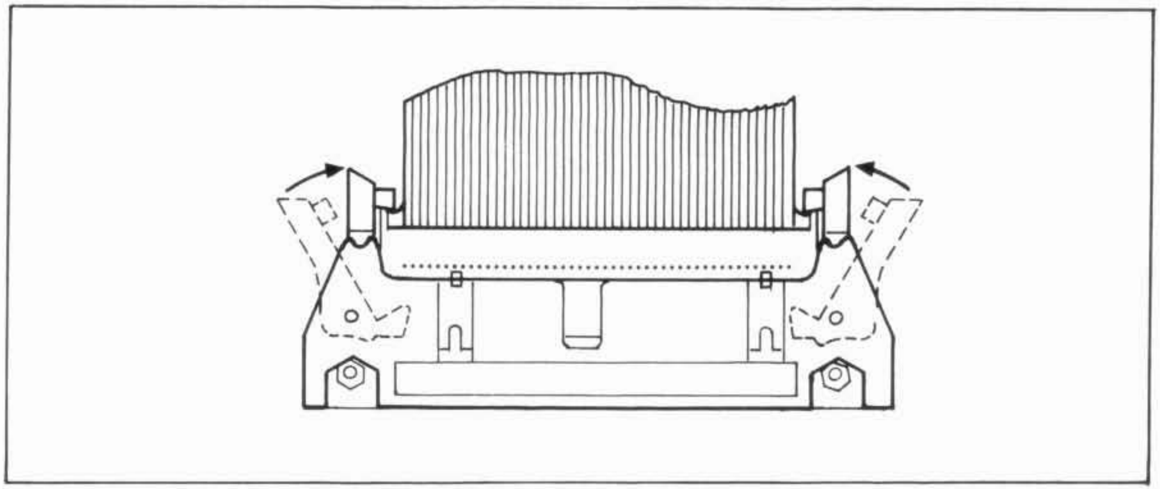


Figure 6-6. HP 5507A Intercard Connector

9. Reinstall pc board retainer being careful to line up each circuit board with the slots in the retainer.

10. Reinstall top cover.

ADDRESS CONFIGURATION

If non-standard addresses (function board or HP-IB) are desired, the factory settings may be changed by following steps 1, 4, and 10 above.

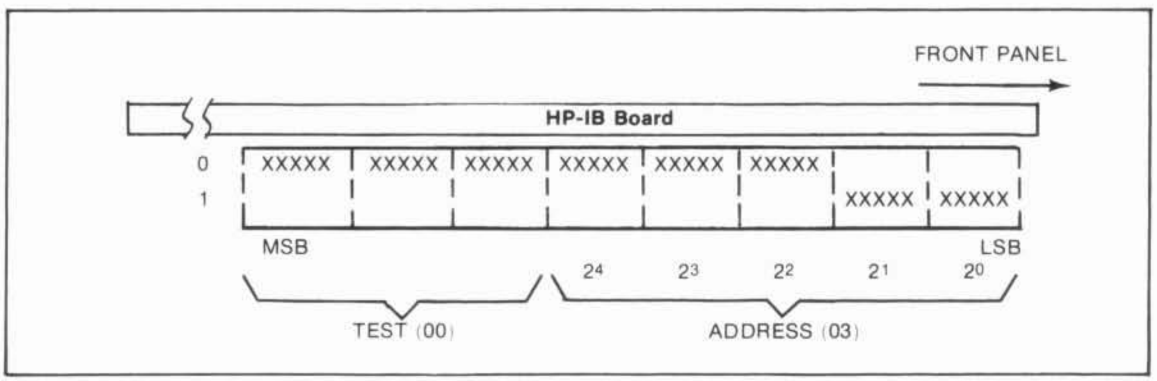


Figure 6-7. HP-IB Address Switches

Table 6-2. HP-IB Addresses

Address Characters		Address Code	Address Switch Settings				
Listen	**Talk**	**Decimal**	**(5)**	**(4)**	**(3)**	**(2)**	**(1)**
Space	@	0	0	0	0	0	0
!	A	1	0	0	0	0	1
"	B	2	0	0	0	1	0
#	C	3	0	0	0	1	1
$	D	4	0	0	1	0	0
%	E	5	0	0	1	0	1
&	F	6	0	0	1	1	0
'	G	7	0	0	1	1	1
(	H	8	0	1	0	0	0
)	I	9	0	1	0	0	1
*	J	10	0	1	0	1	0
+	K	11	0	1	0	1	1
,	L	12	0	1	1	0	0
-	M	13	0	1	1	0	1
.	N	14	0	1	1	1	0
/	O	15	0	1	1	1	1
0	P	16	1	0	0	0	0
1	Q	17	1	0	0	0	1
2	R	18	1	0	0	1	0
3	S	19	1	0	0	1	1
4	T	20	1	0	1	0	0
5	U	21	1	0	1	0	1
6	V	22	1	0	1	1	0
7	W	23	1	0	1	1	1
8	X	24	1	1	0	0	0
9	Y	25	1	1	0	1	0
:	Z	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

**Unlisten and Untalk Commands. Do not set to this address.

FAN DIRECTION

The HP 5507A is shipped from the factory with the fan forcing air into the instrument through the front grille filter. The air flow can be reversed if desired, however, the rear panel should be exposed to filtered air (rack mounted in a cabinet with a filtered air supply) to minimize problems with dust accumulation. If it is necessary to reverse the direction of air flow, proceed as follows:

WARNING

100/240 VOLTS AC MAY BE PRESENT IN THE HP 5507A. USE EXTREME CAUTION WHEN WORKING ON OR NEAR THE PRIMARY POWER WIRING. THERE IS EXPOSED LINE VOLTAGE BENEATH THE POWER SUPPLY COVER. TO PREVENT ELECTRIC SHOCK, REMOVE AC POWER CORD PRIOR TO REMOVING COVER. CONTACT WITH PRIMARY POWER VOLTAGE COULD CAUSE SERIOUS PERSONAL INJURY.

CAUTION

The HP 5507A must be turned off prior to inserting or removing any pc board. Expensive damage to both the instrument and the pc board may result if power is left on.

CAUTION

Some circuits on the HP 5507A plug-in boards are susceptible to damage from electrostatic discharge. Use an anti-static work station and ground straps when handling printed circuit assemblies during assembly or disassembly.

1. Remove the top cover which is held in place by a captive screw at rear of instrument.
2. Remove power supply cover secured by two 8-32 screws.
3. Disconnect fan by unplugging connector located at front right of backplane circuit board.
4. Remove front grille secured by two M5 × 0.8 screws.
5. Remove four screws securing fan in place.
6. Turn fan around and reinstall four fastening screws.
7. Reinstall front grille with two M5 × 0.8 screws. (For slightly improved air flow, the filter may be removed prior to reinstallation.)
8. Reconnect fan to backplane circuit board (connector is polarized).
9. Reinstall power supply cover using two 8-32 screws.
10. Replace top cover.

FAN MAINTENANCE

The filter should be cleaned or replaced yearly or as required in dusty environments. Follow steps 4 and 7 above to remove or replace front grille. Clean filter by blowing compressed air through the filter in a direction opposite to the fan direction. If filter is removed from front grille, be sure its air flow orientation is not changed when reinstalled.

Rack Mounting

CAUTION

Ambient temperature in a rack installation containing an HP 5507A should not exceed 40°C. Be sure that the position of the HP 5507A allows sufficient air circulation and that nearby equipment does not discharge hot air directly on the instrument.

To mount the HP 5507A in a rack, install Rack Flange Kit (HP Part Number 5061-9678). This is available with initial orders as Option 908. Installation instructions are supplied with the kit.

Grounding

The HP 5507A is grounded through the line cord. Additional grounding of the chassis is not required, but doing so shouldn't interfere with normal operation.

External Cabling

The following paragraphs cover all external connections to the HP 5507A. Each instrument is shipped with a set of color coded labels. These can be used to label both the cables and their respective rear panel connectors for easy identification.

LASER HEAD CABLES

To HP 5517A/5517B/5518A Laser Head

The HP 5517A/5517B/5518A Laser Head has only one connector on its rear panel. The HP 10793A/B/C cable connects the HP 5517A/5517B/5518A to the HP 5507A Laser Position Transducer Electronics. The connectors on this cable are identical on either end. The connectors on the cable, laser head and HP 5507A Electronics are "keyed" to go together only one way. The HP logo will be "up" on each connector "boot" when the connections are correctly made. The cable connectors have locking rings, which take about 1/3 turn clockwise to secure the cable to the mating connectors.

RECEIVER CABLE (Measurement and Wavelength Tracker Axes)

CAUTION

Each connector on the HP 10790A/B/C has both a male and female half. Before making a connection, be sure the male half of the cable connector is properly aligned with the female half of the mating connector. Failure to align the pins prior to mating the connectors may result in damaged pins.

The HP 10790A/B/C Receiver Cable is used to connect the HP 10780B Receiver to the HP 5507A Laser Position Transducer Electronics for both measurement and Wavelength Tracker axes. This cable's connectors are identical on either end. The connectors on the cable and on the receiver and HP 5507A electronics are "keyed" to go together only one way. The connectors on the cable each have a locking ring, which take a 1/4 turn clockwise to secure the cable to the mating connector.

HP-IB CABLE

The HP-IB connector is located on the rear panel and connects to any standard HP-IB (IEEE-488) cable. A number of lengths are available from HP (consult HP sales rep for part numbers and lengths). If an HP-IB address other than 03 is desired, then follow steps 1, 4, and 10 in the pc board installation above.

REAR PANEL FUNCTION BOARD CONNECTIONS

All function boards have a 50-pin rear panel connector for connection to external equipment. (See Section III for pinouts). The following connectors can be used when fabricating a cable to make these connections:

Amp: Champ® Connectors

3M: Delta Ribbon Connectors

T & B: Ansley® Ribbon Connectors

®Champ is a registered trademark of Amp
®Ansley is a registered trademark of T & B

To ensure reliable contacts, use two M3.5 × 0.6 screws 8 mm long to securely fasten connectors together.

AIR AND MATERIAL SENSORS (HP 10946B or HP 5507A OPTION 046 ONLY)

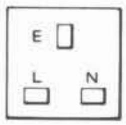
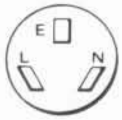
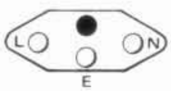
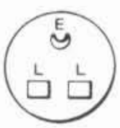
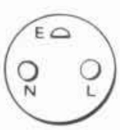
One 10-pin and two 6-pin circular connectors are available for use with an HP 10751A/B Air Sensor and two HP 10757A/B/C Material Temperature Sensors respectively. The connectors are "keyed" to go together only one way (HP logo will be "up"). Each cable's connector also has a locking ring which takes about 1/3 turn clockwise to secure the cable to the rear panel connector.

⚠ Power Cable

WARNING

BEFORE APPLYING POWER TO THIS INSTRUMENT, THE PROTECTIVE EARTH TERMINAL OF THIS INSTRUMENT MUST BE CONNECTED TO THE PROTECTIVE CONDUCTOR OF THE (MAINS) POWER CORD. THE MAINS PLUG SHALL BE INSERTED ONLY IN A SOCKET OUTLET PROVIDED WITH A PROTECTIVE EARTH CONTACT. THE PROTECTIVE ACTION MUST NOT BE NEGATED BY THE USE OF AN EXTENSION CORD (POWER CABLE) WITHOUT A PROTECTIVE EARTH CONDUCTOR.

The HP 5507A is shipped with a three-wire power cable. When the cable is connected to an appropriate ac power source, this cable connects the chassis to earth ground. The type of power cable shipped with each instrument depends on the country of destination. Refer to *Figure 6-8* for the part numbers of the power cable and plug configurations available.

PLUG TYPE	CABLE HP PART NO.	*CD	PLUG DESCRIPTION	CABLE LENGTH (INCHES)	CABLE COLOR	FOR USE IN COUNTRY
250V 	8120-1351 8120-1703	0 6	Straight **BS1363A 90°	90 90	Mint Gray Mint Gray	United Kingdom, Cyprus, Nigeria Rhodesia, Singapore
250V 	8120-1369 8120-0696	0 4	Straight **NZSS198/ASC112 90°	79 87	Gray Gray	Australia, New Zealand
250V 	8120-1689 8120-1692	7 2	Straight **CEE7-Y11 90°	79 79	Mint Gray Mint Gray	East and West Europe, Saudi Arabia, Egypt, So Africa, India (Unpolarized in many nations)
125V 	8120-1348 8120-1398 8120-1754 8120-1378 8120-1521 8120-1676	5 5 7 1 6 2	Straight **NEMA5-15P 90° Straight **NEMA5-15P Straight **NEMA5-15P 90° Straight **NEMA5-15P	80 80 36 80 80 30	Black Black Black Jade Gray Jade Gray Jade Gray	United States, Canada, Japan (100V or 200V), Mexico, Philippines, Taiwan
250V 	8120-2104	3	Straight **SEV1011 1959-24507 Type 12	79	Gray	Switzerland
250V 	8120-0698	6	Straight **NEMA6-15P			United States, Canada
220V 	8120-2956 8120-2957	2 3	Straight **DHCK 107 90°	79 79	Gray Gray	Denmark

*CD = Check Digit (refer to Section VI).
**Part number shown for plug is industry identifier for plug only. Number shown for cable is HP Part Number for complete cable including plug.
E = Earth Ground   L = Line   N = Neutral

Figure 6-8. AC Power Cables Available

LINE VOLTAGE SELECTION AND FUSE REPLACEMENT

The line voltage selector and power line fuse are contained in the Power Line Module on the rear panel of the HP 5507A. The line voltage selector must be set to match the line voltage that will be connected to the module and the proper value fuse must be selected as described and illustrated below:

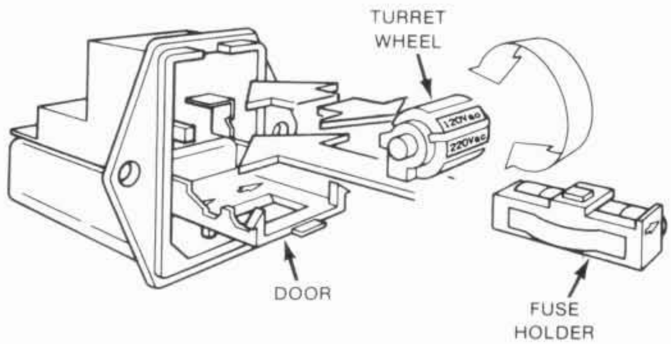


Figure 6-9. AC Line Voltage Selection and Fuse Replacement

1. Remove ac power cord from rear panel to gain access to the fuse compartment.
2. Using a small common-blade (slot) screwdriver, carefully open the fuse compartment access door.
3. To change the line voltage selector, remove the turret wheel before turning it to the desired line voltage. DO NOT turn turret wheel while installed in module. Push wheel firmly into module slot.
4. To replace the fuse, pull the fuse cartridge out of the module and install the correct value fuse. For a 115 Vac supply source, use a 5 amp line fuse, and for a 230 Vac supply source, use a 3.0 amp fuse (HP Part No.'s 2110-0010 and 2110-0003 respectively).
5. Insert the fuse cartridge in the right fuse compartment making sure the arrow points to your right ("→").
6. Snap the fuse compartment access door shut. The selected operating voltage is shown in module window.
7. Reconnect ac power cord.

System Power-Up and Verification

When the equipment is connected as outlined above, the HP 5507A may be turned on. It will initially go through a self test lasting about 20 seconds. (See Section III, IV, and VII for details and error indications). After self test, the Talk, Listen, and SRQ LED's will sequence until the laser head outputs a stable reference signal. When this occurs, the green Laser Locked LED will illuminate. If the optics are not aligned , then the Red System Error and Measurement Error LED's will also illuminate.

The following program (written in HP Basic 3.0 for Series 200 Computers) may be run initially to help align the optics and verify proper system operation.

```
10          REM  HP 5527A LASER POSITION TRANSDUCER VERIFICATION PROGRAM
20          REM  DECEMBER 11,1985 - Modified for 10946B on JULY 27, 1987
21          REM                     - Modified for 10936A on NOV 11, 1988
30          REM
40          REM  RUNS UNDER HP BASIC 3.0 USING THE FOLLOWING BIN FILES:
50          REM       ERR, HPIB, IO, AND CLOCK.
60          REM
70          REM  DISPLAY SHOULD BE CLEARED BEFORE RUNNING PROGRAM
80          REM
100 Set_up: !**********************  DECLARE VARIABLES  *********************
110         OPTION BASE 1
120         DIM  Response$[80],Axis_format$[80],Proto_format$[80],Comp_format$[
80],Srvo_format$[80]
130         DIM  Axis_addr$(6)[1],Proto_addr$(4)[1],Comp_addr$(4)[1],Srvo_addr$
(6)[1]
140         DIM  Position(6),Stat(6),Input_value(8)
150         Axis_format$="/,2A,""AXIS POSITION(mm) = "",6D.7D,10X,""STATUS = "
",3D"
155         Srvo_format$="/,2A,""SERVO POSITION(mm) = "",6D.7D,10X,""STATUS =
"",3D"
160         Proto_format$="/,2A,""PROTO BOARD INPUTS A THRU H"",8(3X,3D)"
165         Comp_format$="2X,2A,3A,""  ="",12A,4X,#"
170         Port_addr$="ABCDEFGH"
180         Ten_min$="00:10:00"
185 ! **  CHANGE 703 TO 7xx IF HP 5507A's HP-IB ADDRESS IS CHANGED TO xx  **
190         ASSIGN @Lsr TO 703
200 Start:  !****  DETERMINE CONFIGURATION AND FUNCTION BOARD ADDRESSES  *****
210         DISP "WAITING FOR POWER UP SELF TEST TO FINISH"
220         ON TIMEOUT 7,32 GOTO Hpib_down
230         OUTPUT @Lsr;"CNFG?"
240         ENTER @Lsr;Response$
250         PRINT "HP 5507A CONFIGURATION - ";Response$
260         IF POS(Response$,"—")0 THEN GOTO Pwr_up_err
270         CALL  Address(Axis_addr$(*),"AXIS",Response$,Nmbr_axis)
275         CALL  Address(Srvo_addr$(*),"SRVO",Response$,Nmbr_srvo)
280         CALL  Address(Proto_addr$(*),"PROT",Response$,Nmbr_prot)
290         CALL  Address(Comp_addr$(*),"COMP",Response$,Nmbr_comp)
300         IF Nmbr_comp0 THEN
310            OUTPUT @Lsr;Comp_addr$(1)&"REV?"
320            ENTER @Lsr;Comp_rev
330         END IF
500 Warm_up:!****************  WAIT FOR LASER HEAD TO WARM UP  ***************
510         Time_zero=TIMEDATE
520         REPEAT
530            Delta_time$=TIME$(TIMEDATE-Time_zero)
540            DISP "LASER HEAD WARMING UP       ELAPSED TIME ";Delta_time$
550         UNTIL SPOLL(@Lsr)0 OR Delta_time$Ten_min$
560         IF Delta_time$Ten_min$ THEN GOTO Lsr_hd_err
570         DISP "    LASER READY"
580         BEEP 500,2
```

```
1000 Loop:   !************ MAIN LOOP TO READ ALL BOARDS IN HP 5507A ***********
1010           LOOP
1020              PRINT TABXY(1,3)
1030              RESTORE Loop
1040              DATA  APV,MT1,CNV,ATV,MT2,WTE,AHV,MTA,WTC
1100 Read_comp:   IF Nmbr_comp0 THEN
1105                FOR I=1 TO 9
1110                   READ Comp_cmd$
1115                   IF Comp_revö AND (I=6 OR I=9) THEN Next_cmd
1120                   OUTPUT  @Lsr;Comp_addr$(1)&Comp_cmd$&"?"
1125                   ENTER @Lsr;Data_value$
1130                   PRINT  USING  Comp_format$;Comp_addr$(1);Comp_cmd$;Data_value$
1135                   IF Wte=0 AND I=3 THEN Comp_num=VAL(Data_value$)
1140                   IF Wte=1 AND I=9 THEN Comp_num=VAL(Data_value$)
1145 Next_cmd:            IF (I MOD 3)=0 THEN PRINT
1150                NEXT I
1155              END IF
1200 Read_axis:     FOR I=1 TO Nmbr_axis
1201                OUTPUT  @Lsr;Axis_addr$(I)&"TCN";Comp_num
1202                OUTPUT  @Lsr;Axis_addr$(I)&"POS?"
1203                ENTER @Lsr;Position(I)
1204                OUTPUT  @Lsr;Axis_addr$(I)&"STA?"
1205                ENTER @Lsr;Stat(I)
1206                PRINT USING  Axis_format$;Axis_addr$(I),Position(I),Stat(I)
1207              NEXT I
1270 Read_srvo: FOR I=1 TO Nmbr_srvo
1271                OUTPUT  @Lsr;Srvo_addr$(I)&"TCN";Comp_num
1272                OUTPUT  @Lsr;Srvo_addr$(I)&"POS?"
1273                ENTER @Lsr;Position(I)
1274                OUTPUT  @Lsr;Srvo_addr$(I)&"STA?"
1275                ENTER @Lsr;Stat(I)
1276                PRINT USING  Srvo_format$;Srvo_addr$(I),Position(I),Stat(I)
1277              NEXT I
1300 Read_proto: FOR I=1 TO Nmbr_prot
1310                FOR J=1 TO 8
1320                   OUTPUT  @Lsr;Proto_addr$(I)&"BY"&Port_addr$[J,J]&"?"
1330                   ENTER @Lsr;Input_value(J)
1340                NEXT J
1350                PRINT USING  Proto_format$;Proto_addr$(I),Input_value(*)
1360              NEXT I
1400 Read_errm: OUTPUT @Lsr;"ERRM?"
1410              ENTER @Lsr;Response$
1420              DISP Response$
1500 Read_ista: OUTPUT @Lsr;"ISTA?"
1510              ENTER @Lsr;Lsr_stat
1520              IF BIT(Lsr_stat,5) THEN
1530                OUTPUT @Lsr;"ERST"
1540                BEEP 800,.5
1550              END IF
1600            END LOOP  ! ***************** END OF MAIN LOOP *****************
```

```
2000             REM
2010             REM  FATAL ERRORS
2020             REM
2100 Pwr_up_err  REM  POWER UP SELF TEST FAILURE
2110             BEEP
2120             DISP "POWER UP SELF TEST FAILURE — SEE MANUAL SECTIONS 4 & 7"
2130             STOP
2200 Lsr_hd_err  REM  LASER HEAD FAILURE TO WARM UP
2210             BEEP
2220             DISP "LASER HEAD FAILURE — SEE LASER HEAD MANUAL"
2230             STOP
2300 Hpib_down:  REM  HP-IB TIMEOUT
2310             BEEP
2320             DISP "HP5507A NOT RESPONDING TO HP-IB — CHECK CABLES & ADDRESS"
2330             STOP
4000          END   ! ******************** END OF PROGRAM *********************
5000          REM
5010          REM  Subroutine "Address" fills the array "Addr$(*)" with the
5020          REM      addresses of any boards who's name in the "Search$"
5030          REM      string match the "Test_value$" string.  "Nmbr_found"
5040          REM      indicates how many matches were found.  A board's
5050          REM      address will be separated from its name by a space
5060          REM      in "Search$" ( ie. V COMP  X AXIS ).
5070          REM
5100          SUB  Address(Addr$(*),Test_value$,Search$,Nmbr_found)
5110             Last_pos=1
5120             LOOP
5130                Pos_found=POS(Search$[Last_pos+4],Test_value$)
5140             EXIT IF Pos_found=0
5150                Last_pos=Last_pos+Pos_found+1
5160                Nmbr_found=Nmbr_found+1
5170                Addr$(Nmbr_found)=Search$[Last_pos;1]
5180             END LOOP
5190          SUBEND
```

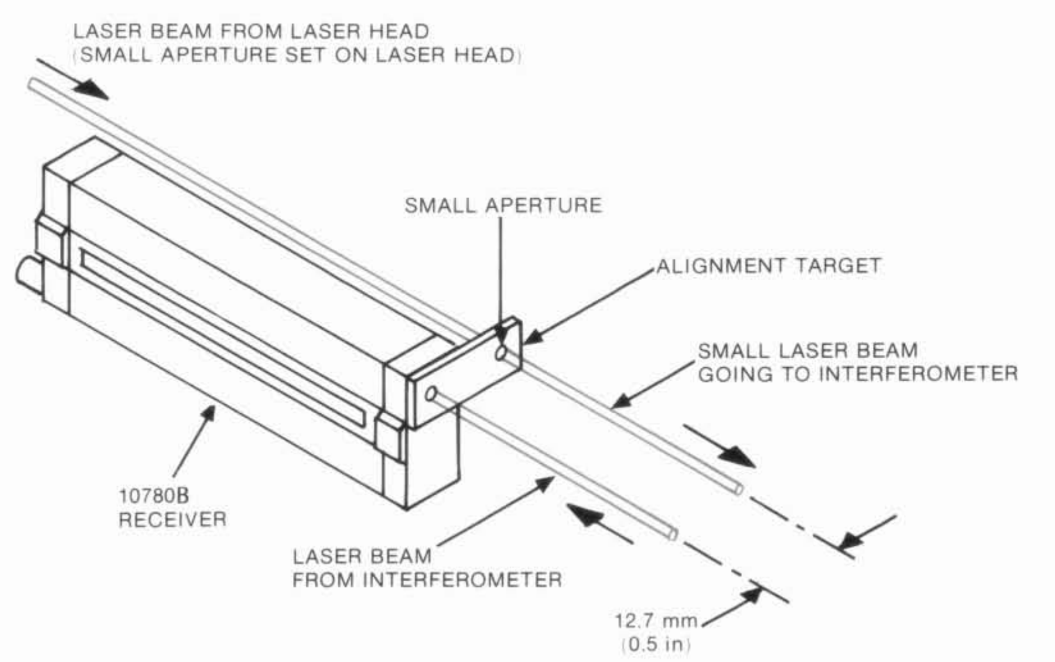


Figure 6-10. HP 10780B Receiver Alignment Target

OPTICS

Adjustable Mounts

The HP 10710A and HP 10711A Adjustable Mounts provide a convenient means of mounting, aligning, and securely locking in position the optical accessories to the Laser Position Transducer (see *Figure 6-11*). Since both mounts allow some tilt and yaw adjustment, the need for custom fixturing is minimized on most installations. A unique feature of these mounts allows the component being adjusted to be rotated about its optical centerline providing simplified installation. The HP 10710A Adjustable Mount will accept the HP 10700A and HP 10701A Beam Splitters, the HP 10705A Single Beam Interferometer, and the HP 10707A Beam Bender. The HP 10711A Adjustable Mount will accept the HP 10702A Linear Interferometer, HP 10706A Plane Mirror Interferometer, and the HP 10715A Differential Interferometer.

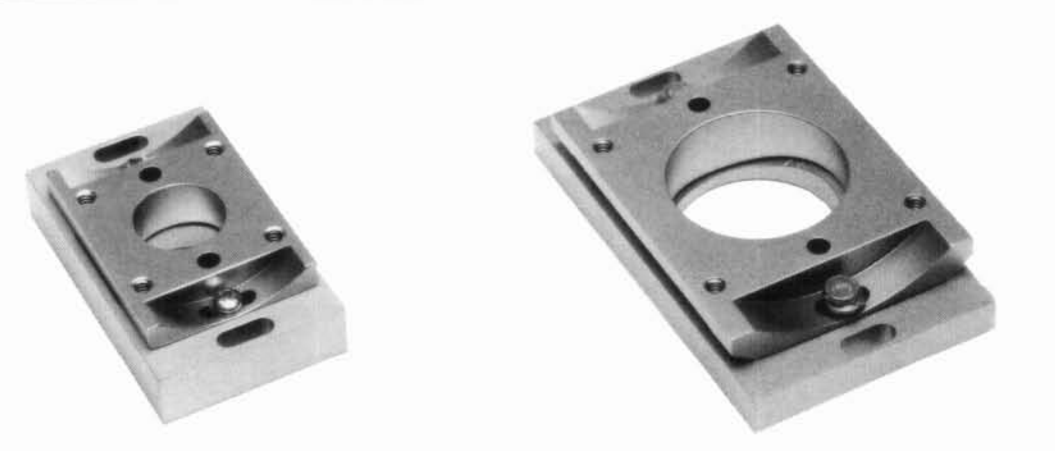


Figure 6-11. HP 10710 and HP 10711A Adjustable Mounts

LASER HEAD

The laser head is mounted in the orientation needed in your application, following the considerations in Section V. It is secured through the mounting feet using its respective hardware.

Be sure the plane defined by the laser head's three mounting feet is aligned to within ±1° to either the bottom or sides of the interferometers.

Cable Connections — See Electronics, External Cabling

Grounding

Since the system ground is defined at the HP 5507A, it is recommended to electrically isolate the laser head. (See Section V for further details.)

RECEIVER

Each axis of the Laser Position Transducer has an HP 10780B Receiver. It should be positioned to receive maximum signal. This is typically done by positioning it so that the two polarization vectors from the laser head are parallel or perpendicular to the plane defined by the centerlines of the two mounting holes (within ± 3°).

Cable Connection — See Electronics, External Cabling

Fasteners — Grounding

The supplied nylon screws must be used to assure that the receiver housing is electrically isolated from the mounting fixture.

Alignment — Principle

The alignment of the receiver is done by translating it perpendicularly and angularly, relative to the beam axis. This alignment is done during the optical system procedure (discussed later in this section). The translation is done to center the impinging beam on the lens, at the front of the receiver. The detailed alignment and gain adjustment procedures can be found in the "Installation and Alignment" and "Receiver — Alignment and Gain Adjustment Procedure" paragraphs (Wavelength Tracker and Receiver respectively) that follow later in this section.

Alignment Aid

With each HP 10780B Receiver, an alignment aid is supplied. This alignment target (P/N 10780-40003) helps align the receiver to the center of the incident beam. It is also used to adjust the proper spacing between the beam going to the interferometer and the beam impinging on the receiver (See *Figure 6-10*). The alignment target is slipped onto the front end of the receiver.

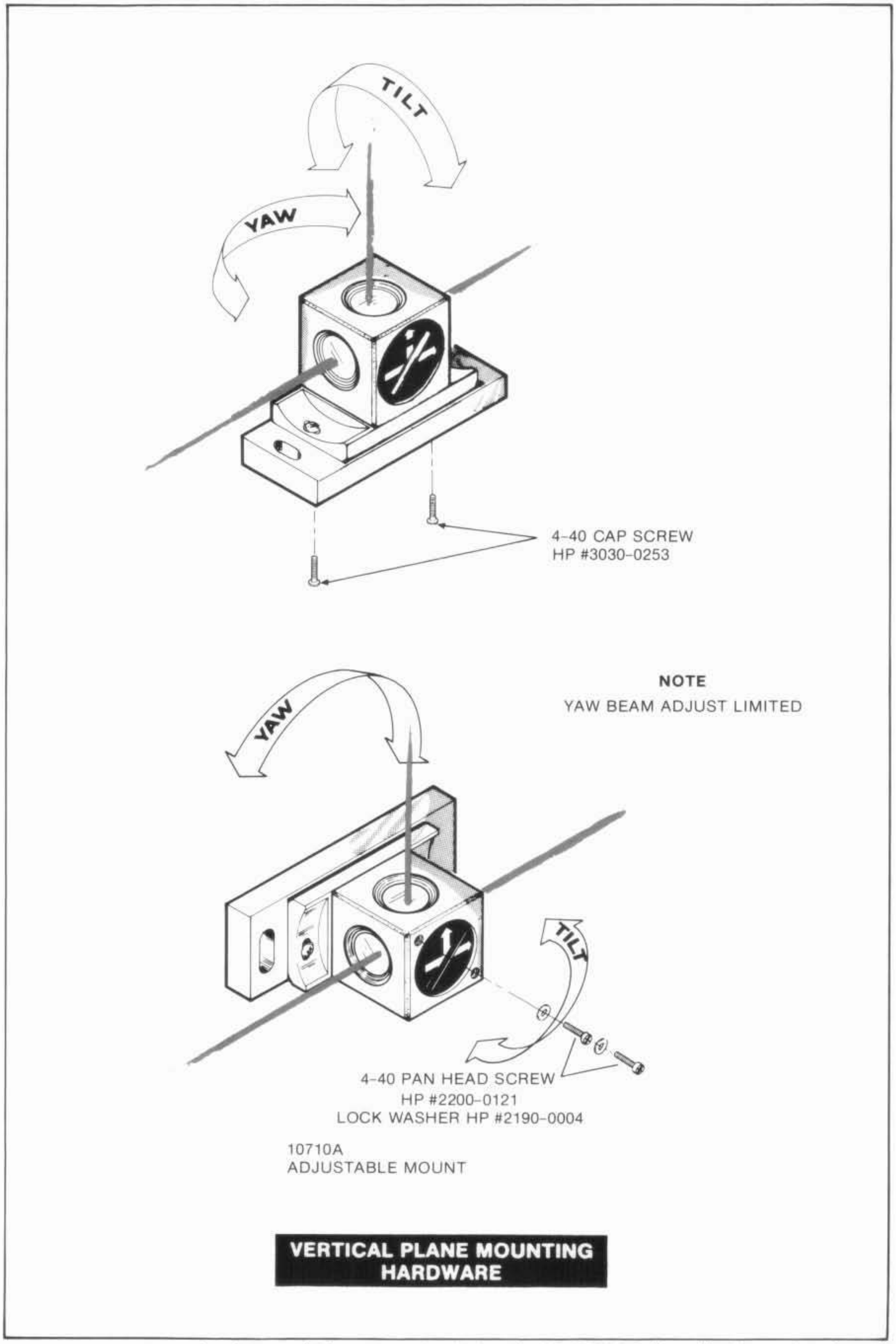


Figure 6-12. Horizontal and Vertical Plane Mounting Using the HP 10710A Adjustable Mount (continued)

Both mounts are made of 416 stainless steel. Its magnetic properties can be helpful at the design stage if magnetic clamps are used. However, in final installation, secure the mount with the screws provided.

Typical Mounting of Optics

The following figures show some methods of mounting the optics using the adjustable mounts:

a. *Figure 6-12* shows how to mount the splitting and bending optics or the single beam interferometer in the horizontal and vertical planes using the HP 10710A Adjustable Mount.

b. *Figure 6-13* shows how to mount the linear, plane mirror, or differential interferometer in the horizontal plane using the HP 10711A Adjustable Mount.

c. *Figure 6-14* shows how to mount the linear, plane mirror, or differential interferometer in the vertical plane using the HP 10711A Adjustable Mount.

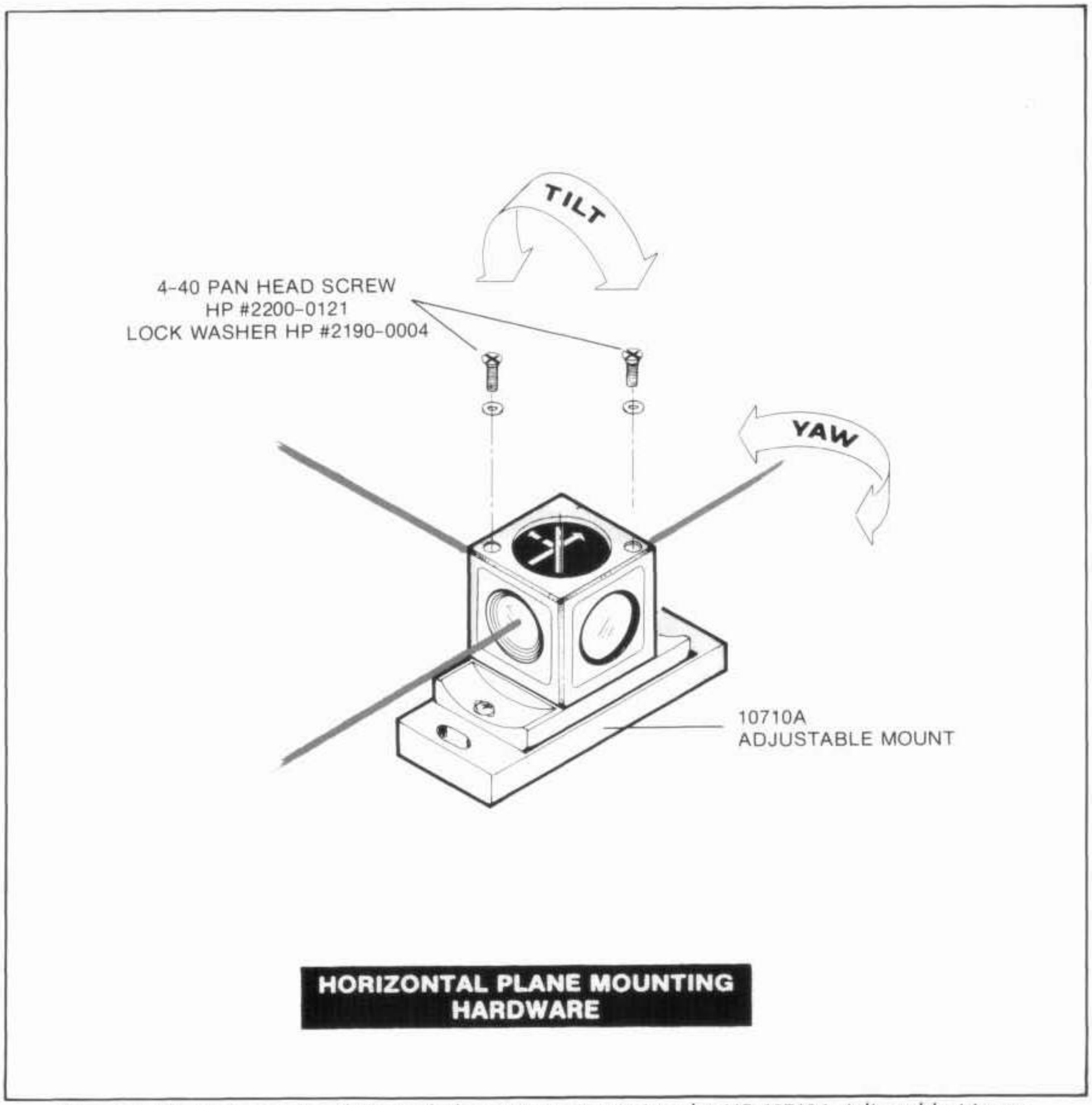


Figure 6-12. Horizontal and Vertical Plane Mounting Using the HP 10710A Adjustable Mount

Fasteners

All of the optical components are supplied with English mounting hardware. The screws supplied with each optical component are those required to mount to their respective adjustable mount.

Multi-Axis Configuration

As previously discussed, the system can measure up to four independent axes of displacement using one laser head. When installing the laser head on a machine, one of the prime considerations is to direct the laser beam to the point where the measurement actually takes place. By using the proper combination of beam splitters, beam benders, and interferometers, the measurement axes can be established with a minimum number of components. The following paragraphs discuss several examples of how the laser beam can be routed for multiaxis measurement configurations.

FOUR-AXIS LINEAR CONFIGURATION

In *Figure 6-15*, a four-axis measurement configuration is shown with all components aligned in one plane. Note that any of the components (beam benders, beam splitters, or interferometers) could be rotated in increments of 90° to provide a three-dimensional configuration. Since the interferometers can also bend the laser beam through 90°, the number of components used can be minimized.

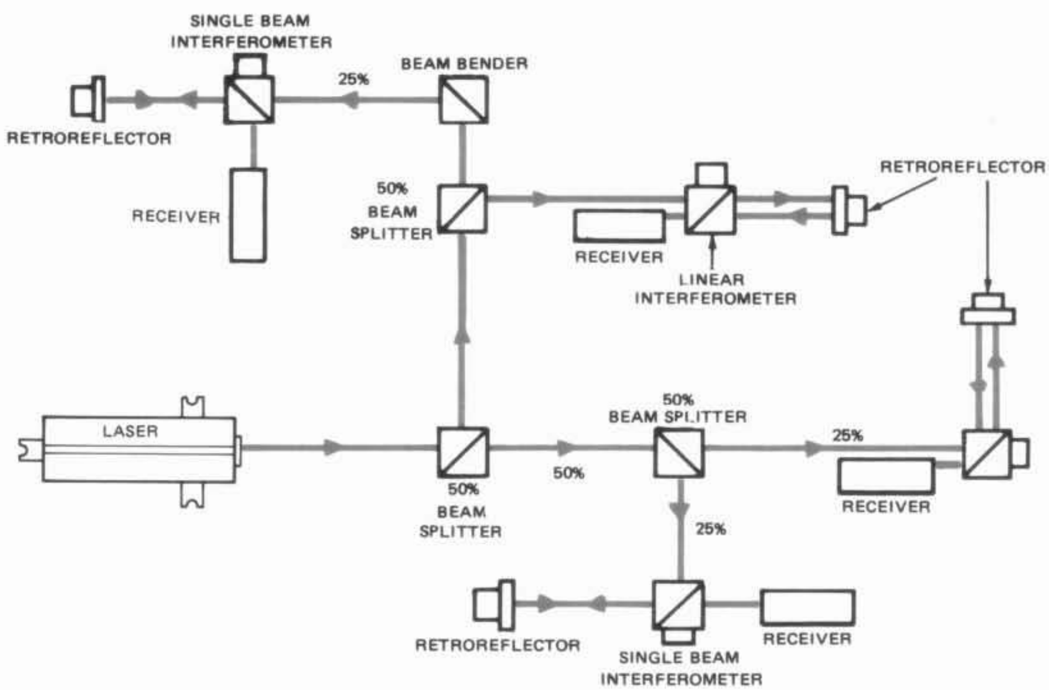


Figure 6-15. Four-Axis Configuration

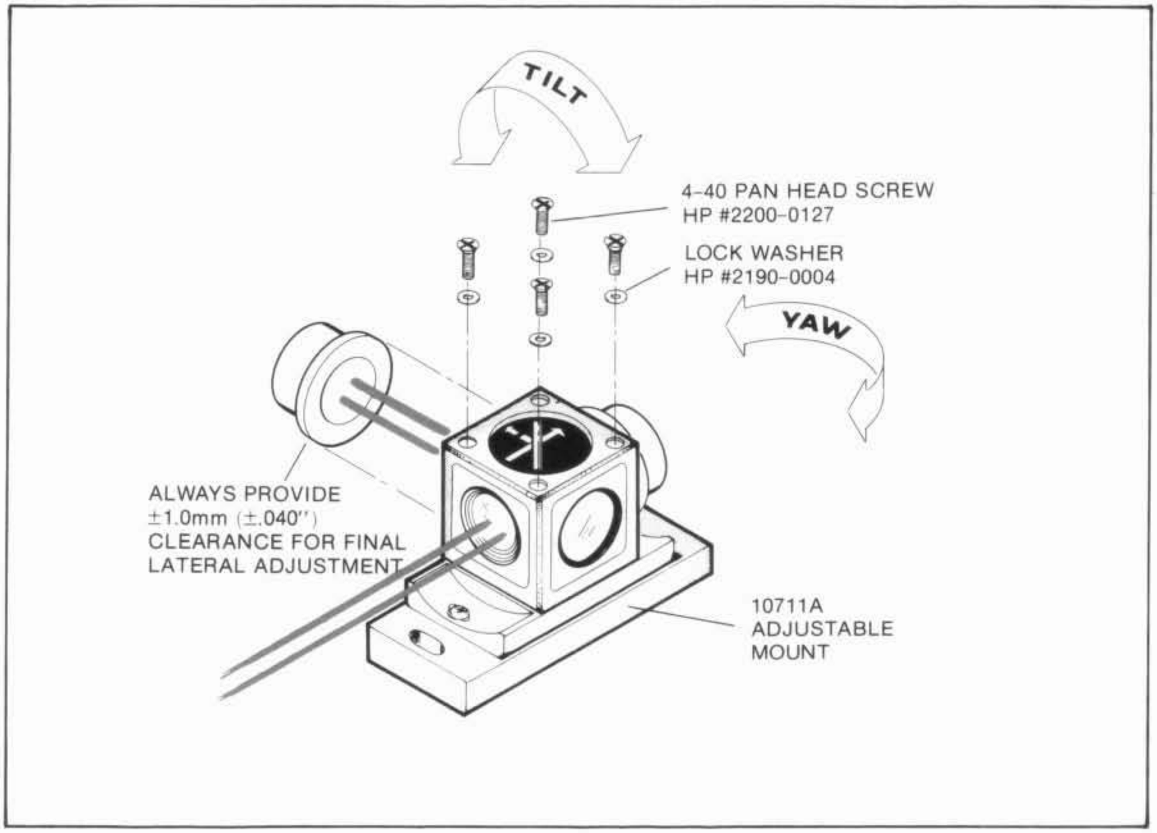


Figure 6-13. Horizontal Plane Mounting Using the HP 10711A Adjustable Mount

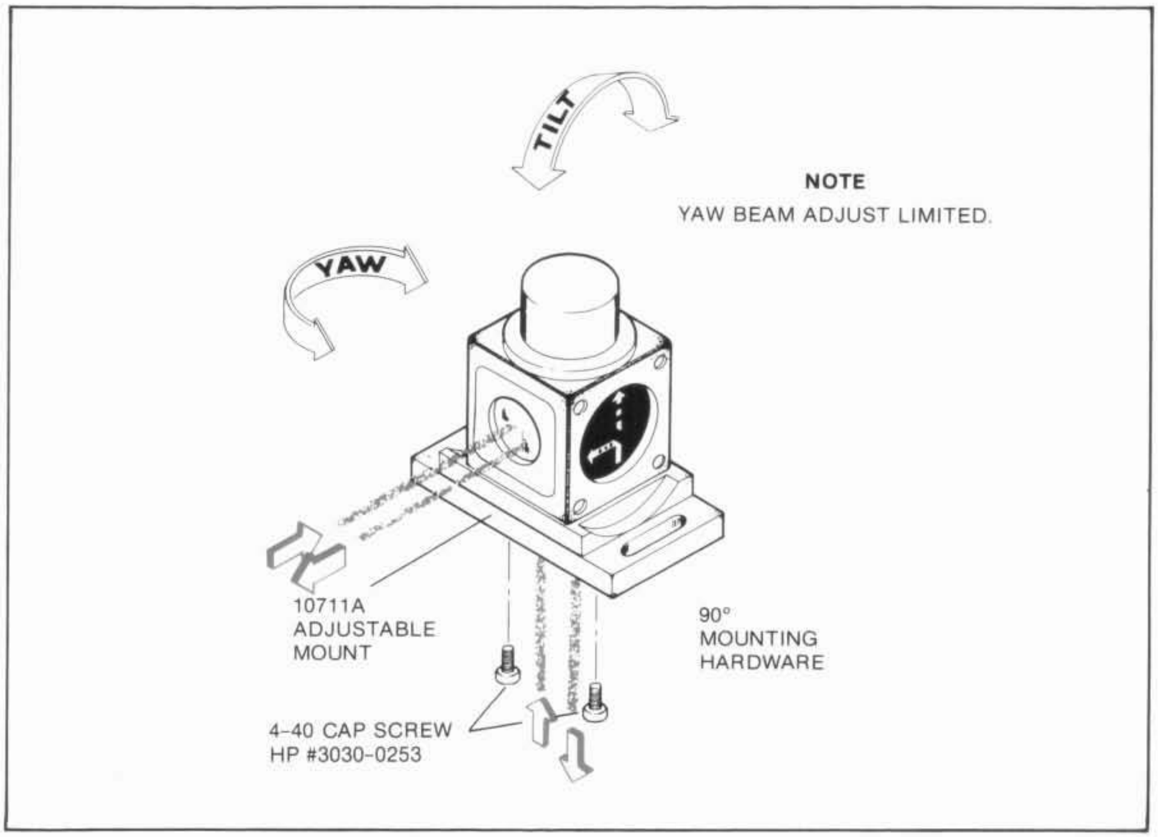


Figure 6-14. Vertical Plane Mounting Using the HP 10711A Adjustable Mount

TWO-AXIS PLANE MIRROR IN A VACUUM

In applications where the X-Y stage is installed in a vacuum chamber or sealed chamber, the configuration in *Figure 6-16* may not be suitable. *Figure 6-17* shows a configuration where the laser beam can enter and exit the chamber through one window. This allows the receivers to remain outside the chamber and leaves only the optics inside. For window specifications, refer to Section V. The HP 10567A Dual Beam Beam-Splitter is shown in this application, which allows the use of a single window. If the HP 10567A is not used, then two windows would be required with possibly additional beam splitters and benders.

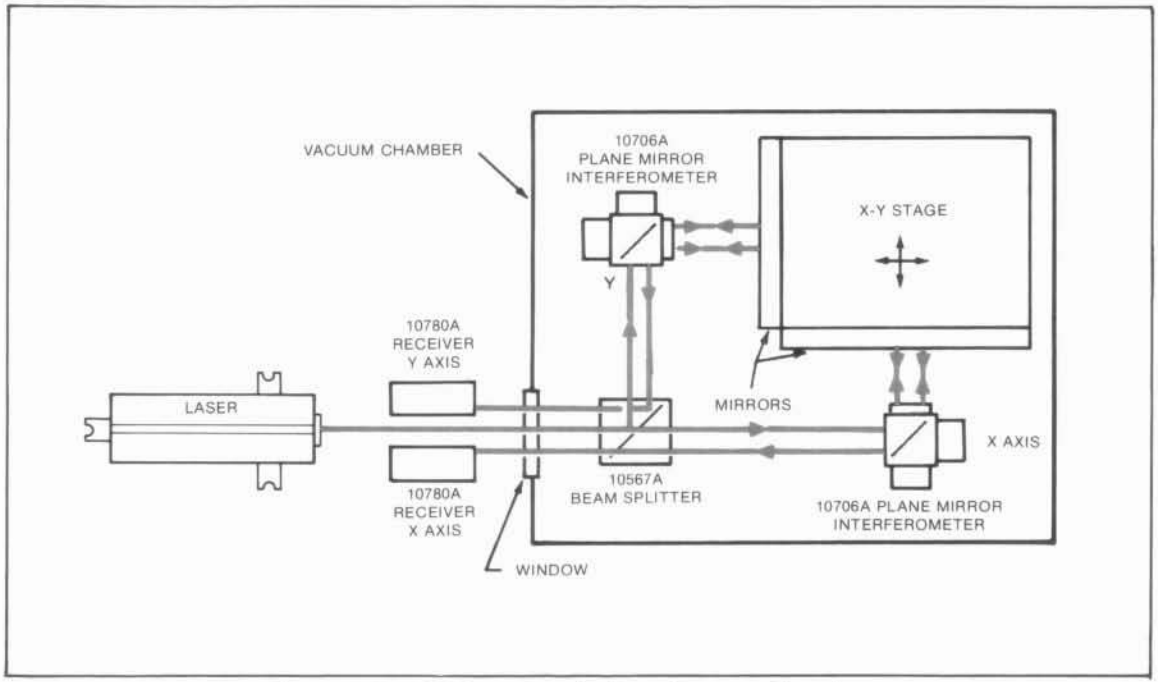


Figure 6-17. X-Y Stage Installed in a Vacuum Chamber

NOTE

In an application where the HP 10702A Linear Interferometer is the moving component and the HP 10703A Retroreflector is the fixed reference, the HP 10702A Linear Interferometer Option 001 must be used to eliminate alignment errors. When using the HP 10705A Single Beam Interferometer along with the HP 10704A Retroreflector, the interferometer must be the fixed component with only the retroreflector allowed to move. If a right angle beam bend is made through the HP 10702A then it can not be the moving component.

TWO-AXIS PLANE MIRROR

In *Figure 6-16*, an X-Y stage measurement configuration utilizing the HP 10706A Plane Mirror Interferometer is illustrated. The X-Y stage has plane mirrors mounted at 90° to each other on the upper portion of the stage which serve as the reflectors for the plane mirror interferometer. The advantages of this configuration were discussed in Section V. The HP 10706A Plane Mirror Interferometer is used to bend the laser beam to the correct orientation.

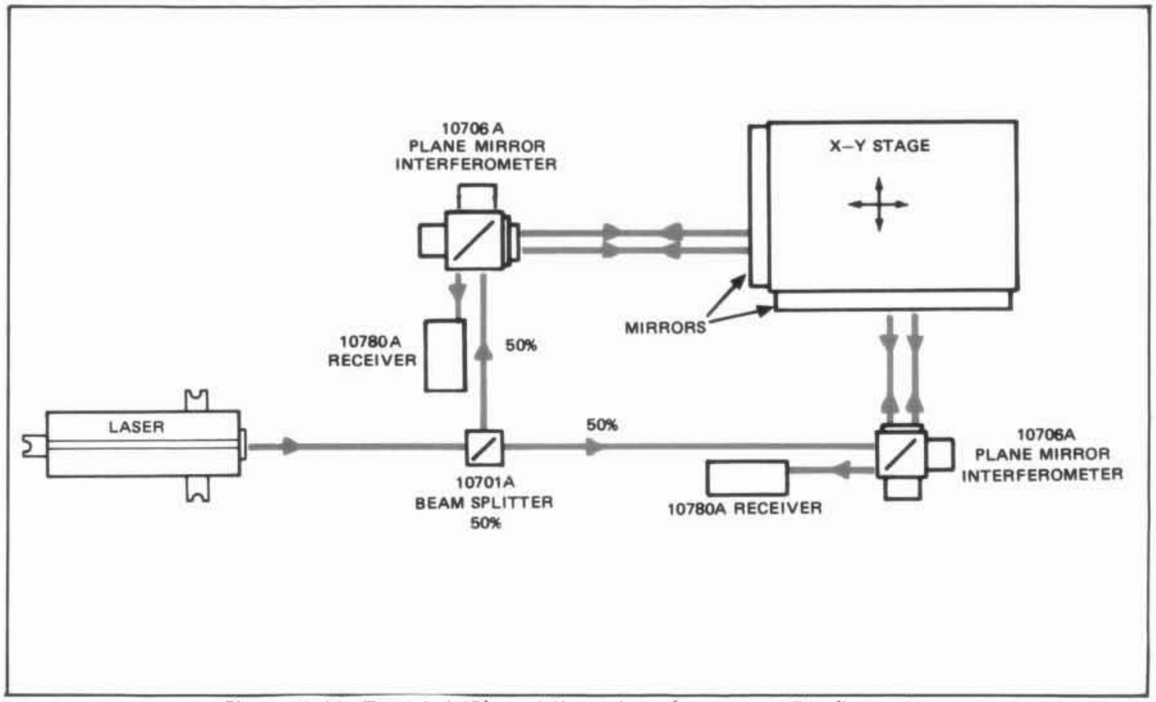


Figure 6-16. Two-Axis Plane Mirror Interferometer Configuration

THREE-AXIS PLANE MIRROR (YAW)

Some X-Y stage applications require measurement or control of the stage's yaw. Yaw is defined as angular rotation about an axis perpendicular to the plane of the stage.

With two interferometers (HP 10706A or HP 10715A) on one axis of the stage, angular motion can be calculated. In *Figure 6-19*, the yaw angle, θ is measured using axes Y and Y'. θ is calculated as follows:

$$\theta = \arctan \frac{(y-y')}{D}$$

The resulting angular measurement will only be as accurate as the measured distance "D". However, even if "D" is not known precisely, this technique can provide high resolution relative angular changes.

The angular rotation of the measurement mirror is limited to the "Alignment Requirement vs Distance" value for the interferometer. (See Section VIII for these specifications.)

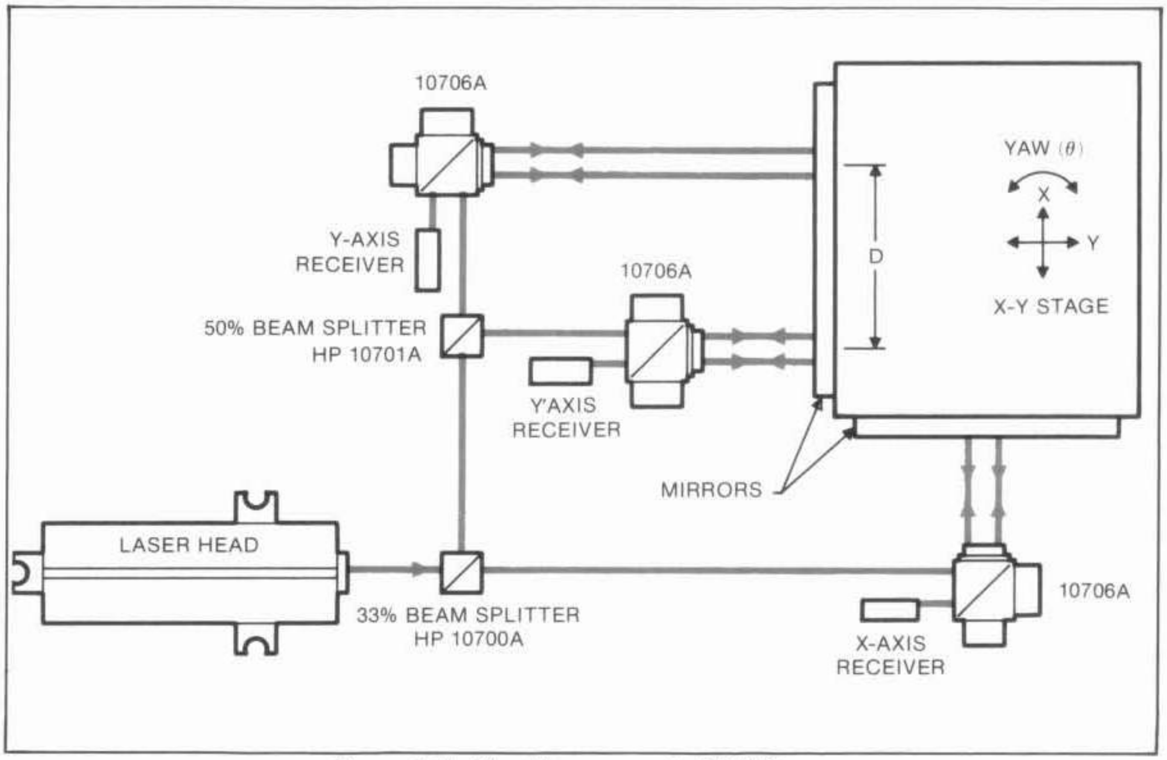


Figure 6-19. Yaw Measurement of X-Y Stage

When yaw control of a stage needs to be done at high speeds using a closed-loop control system, the (Y-Y') value needs to be obtained quickly. If this difference is calculated in software in the controller, it may be too slow. There are two methods to achieve a high-speed (y-y') output:

- Electronically
- Optically

TWO-AXIS DIFFERENTIAL INTERFEROMETER

In X-Y stage applications where the maximum performance, that is measurement accuracy and stability, are required, the HP 10715A Differential Interferometer should be used instead of the HP 10706A Plane Mirror Interferometer. In *Figure 6-18*, an X-Y stage using the HP 10715A's is illustrated. As with the Plane Mirror Interferometer, the reflectors are plane mirrors mounted at 90° to each other on the stage.

Using the differential interferometer also requires mounting the reference mirror (mirror supplied with the HP 10715-20205) between the interferometer and measurement reflector. Mounting instructions for the reference mirror will be discussed later in this section.

The HP 10715A Option 001 interferometer is used to turn the beam as shown in *Figure 6-18*. This configuration requires use of opposite input aperatures for each interferometer resulting in different direction senses for the X and Y axes (must be corrected by software). Note that the receivers for each axis are above the input beams.

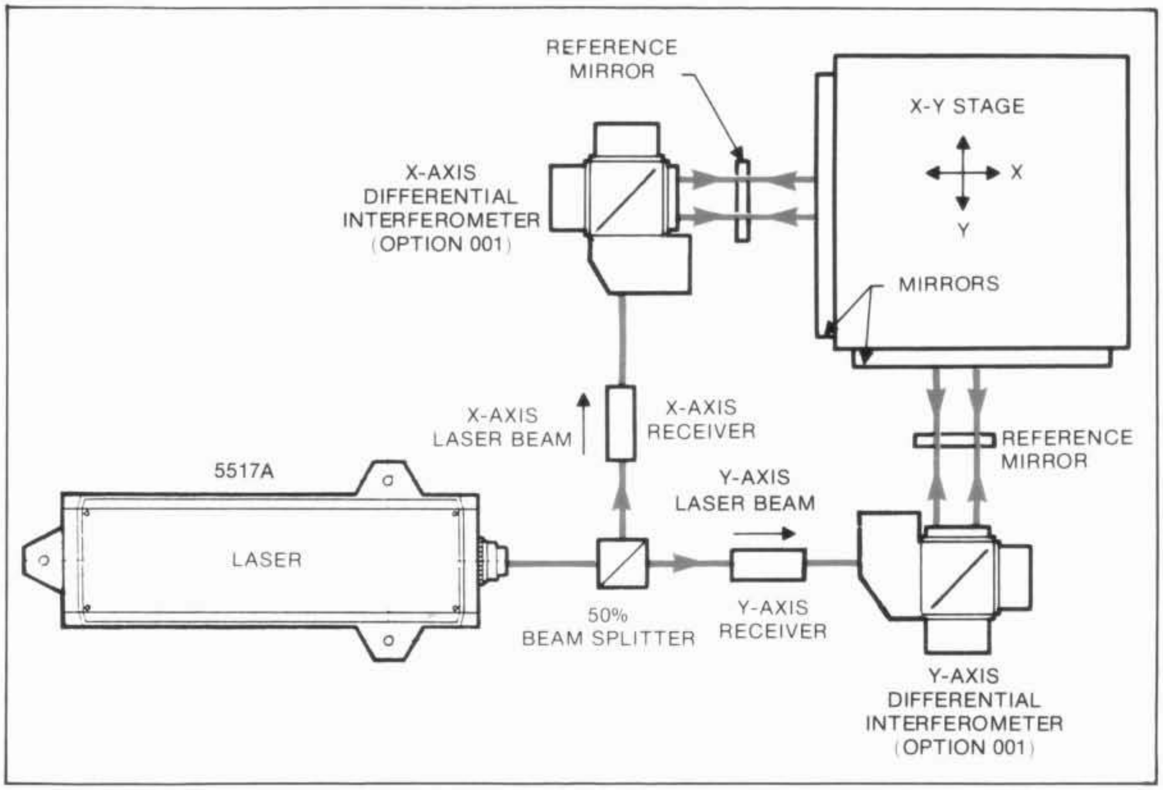


Figure 6-18. Two-Axis Differential Interferometer

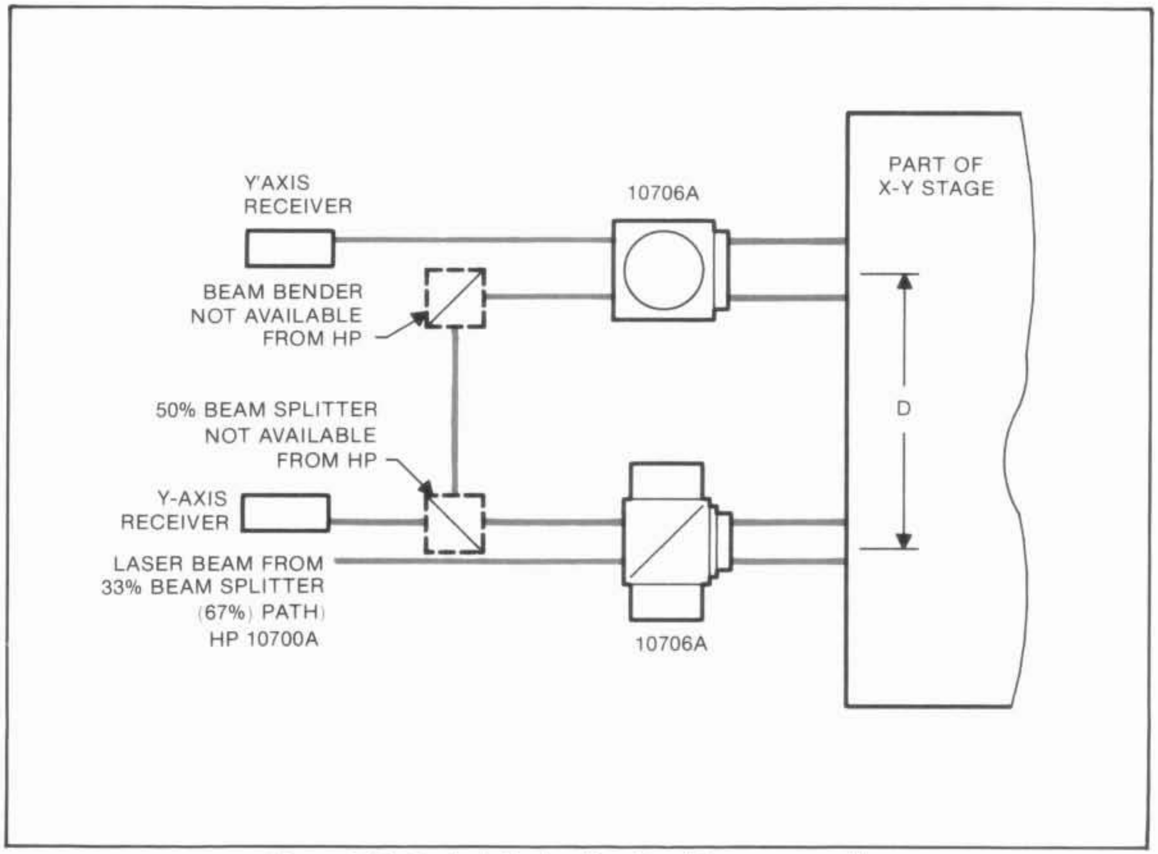


Figure 6-21. Optical Method for Yaw Measurement (2)

Electronic Yaw Calculation Method

This difference calculation can be done in hardware for both y and y' axis. A custom servo board could be designed to accept position information from both y and y' and perform a fast angular calculation, yielding an input for the yaw servo. See Section III (Hardware) for servo-loop interfacing.

Optical Yaw Calculation Method

There are optical configurations that will allow direct output of the difference between y and y', for example on the y' axis receiver. This is shown in *Figures 6-20* and *6-21*, both using the HP 10706A Plane Mirror Interferometer. Similar approaches can be done using the HP 10715A Differential Interferometer.

This is done by splitting off part of the Y-axis combined measurement signal (after going completely through the interferometer) and using this as the input beam to the y' axis interferometer. This technique outputs directly (y-y') information on the y'-axis receiver.

Both of these optical configurations require some special optical components not available through Hewlett-Packard. In both Figures, a small 50% non-polarizing beam splitter is required. This beam splitter has to be very small, so as not to block or clip the adjacent beam. This also holds true for the beam bender required on the configuration shown in *Figure 6-21*.

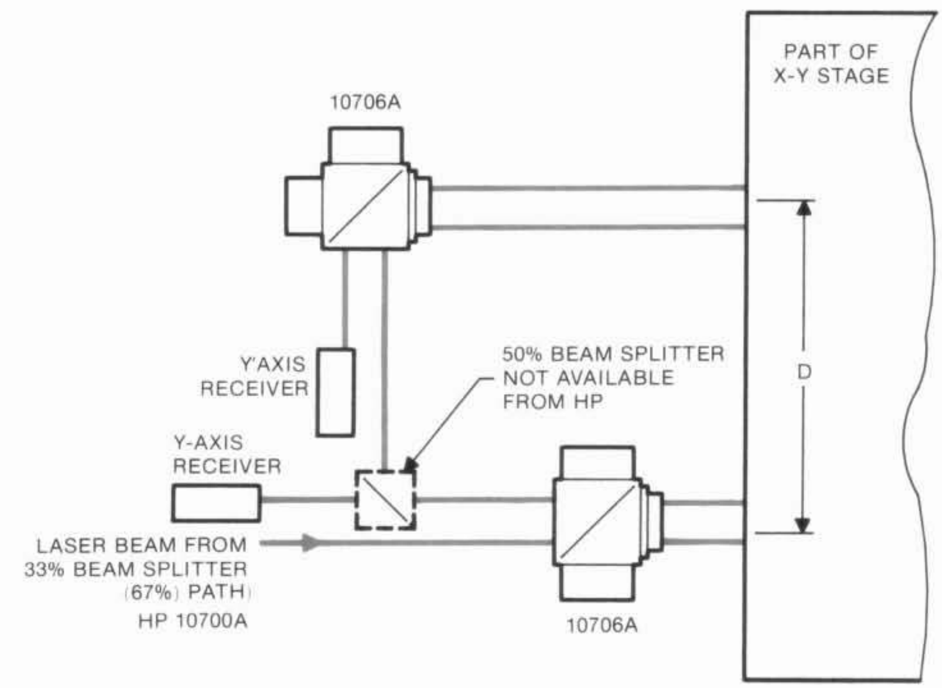


Figure 6-20. Optical Method for Yaw Measurement (1)

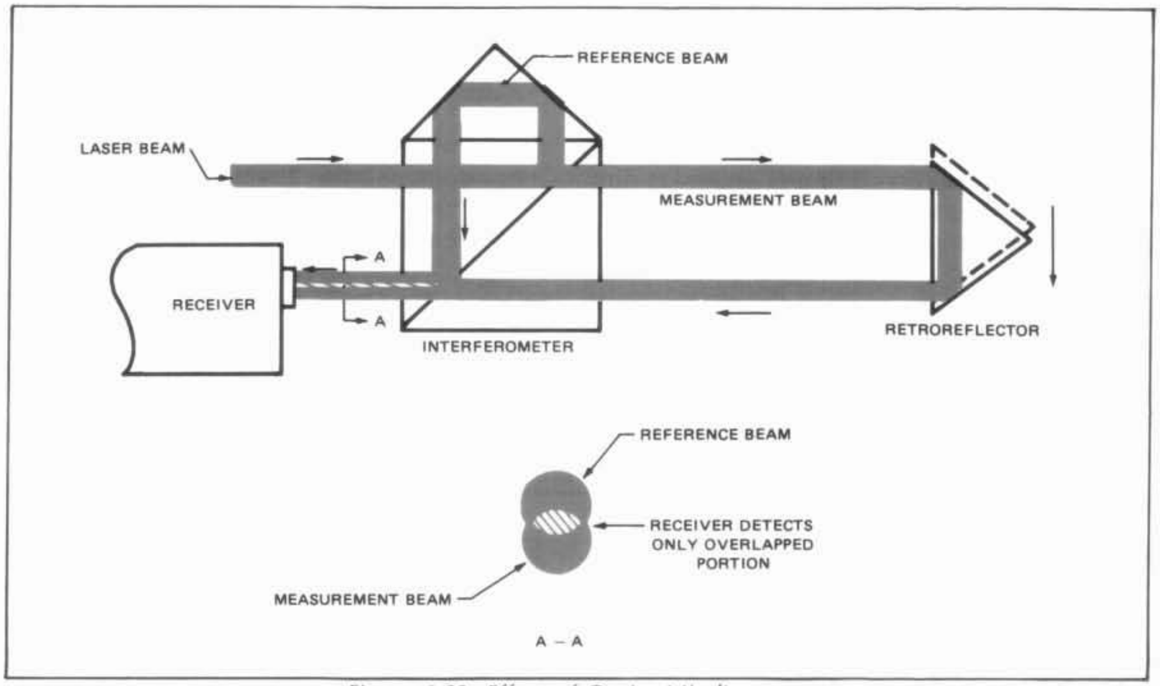


Figure 6-23. Effect of Optics Misalignment

Typically, a lateral offset between the beams, of ±1.5 mm (±0.06 inch) is allowable for adequate measurement signal. Every effort should be made to optimize the laser beam overlap for maximum performance.

If the measurement beam is not angularly aligned parallel to the direction of travel of the retroreflector, there are two effects. First, a cosine error is generated in the measurement of a magnitude directly related to the angle of misalignment. (For a complete description of cosine error, refer to Accuracy Considerations, Section V.) Second, the angular misalignment also causes a lateral displacement of the measurement beam with respect to the reference beam at recombination when movement between the interferometer and reflector occur. This results in additional signal loss. *Figure 6-24* illustrates the result of angular misalignment.

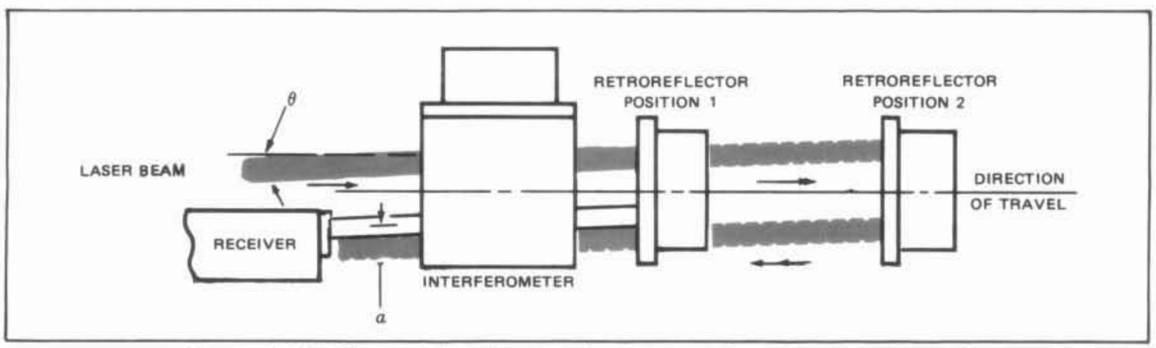


Figure 6-24. Effects of Angular Misalignment to the Direction of Travel

NOTE

The presence of measurement signal through the total length of travel does not guarantee that the measurement axis is aligned for minimum cosine error. Also, any angular misalignment of the laser beam to the direction of travel causes a decrease in the measurement signal.

OPTICS ALIGNMENT

General

When installing any displacement transducer in a positioning system, the transducer must be aligned to ensure correct operation and minimum measurement error. The two major objectives in aligning the Laser Position Transducer are to maximize the measurement signal at the receiver and to minimize cosine error. These objectives are achieved by proper alignment of the system.

In general, the laser beam in the measurement axis is required to be parallel to the motion of travel to minimize cosine error, and the optical components and receiver are required to have a specific spatial relationship to maximize the measurement signal. *Figure 6-22* shows a measurement axis where the laser beam is aligned parallel to the mechanical motion of travel of the retroreflector, and thus optimized for maximum measurement signal.

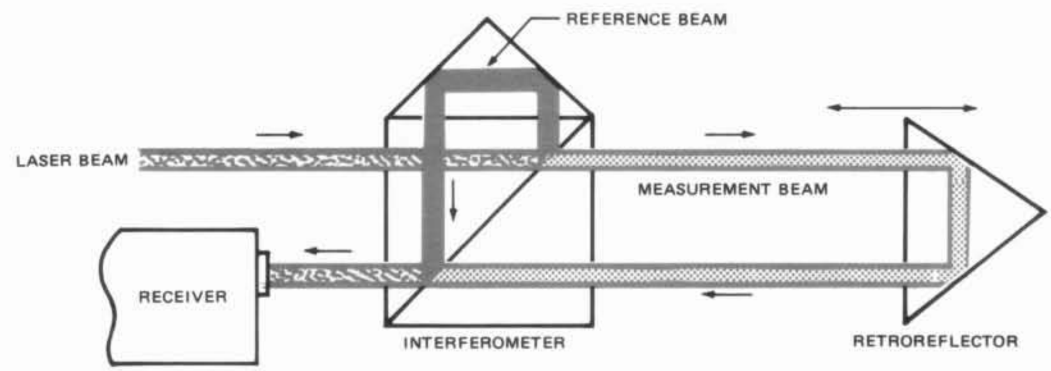


Figure 6-22. Optimum Alignment

For maximum signal, the interferometer and retroreflector are aligned laterally to each other such that the interferometer and the measurement beam from the retroreflector exactly overlap each other upon recombination. These recombined laser beams then enter the receiver in the center of the lens aperture. It is obvious from *Figure 6-22*, that if the recombined laser beams entering the receiver are not centered on the photodetector, measurement signal loss will occur. If either the interferometer or the retroreflector are misadjusted with respect to one another (*Figure 6-23*), then the reference and measurement beams no longer overlap completely resulting in signal loss. The receiver photodetector only measures the overlapping portion of the laser beams.

Linear and Single Beam Interferometer

The alignment techniques for both the linear and single beam interferometers are nearly the same. They both use a retroreflector (cube-corner) as the measurement reflector. There are two general techniques for aligning these measurement optics; they are

- Overlapping Dots method, and
- Autoreflection method.

Both of these methods are used to maximize return measurement signal power and to minimize cosine error. The Overlapping Dots method should be used when the measurement distance is over 0.5 metre (20 inches). The Autoreflection method should be used for less than 0.5 metre measurement distances and can also be used for distances over 0.5 metre.

The choice of method used depends on convenience and the nature of the application. The goal for both of these alignment methods is to have the reference and measurement beams be coincident at the receiver throughout the measurement.

ALIGNMENT AIDS

To help in aligning these interferometers, an alignment aid is included with each. They are:

- For HP 10702A and HP 10702A Opt 001 — Alignment Target (HP Part Number 10702-60001) (See *Figure 6-25A*).
- For HP 10705A — Alignment Target (HP Part Number 10705-60001) (see *Figure 6-25B*).

Both alignment aids are magnetic to simplify positioning them on the interferometer. They are used on the input side of the interferometer to properly position the beam.

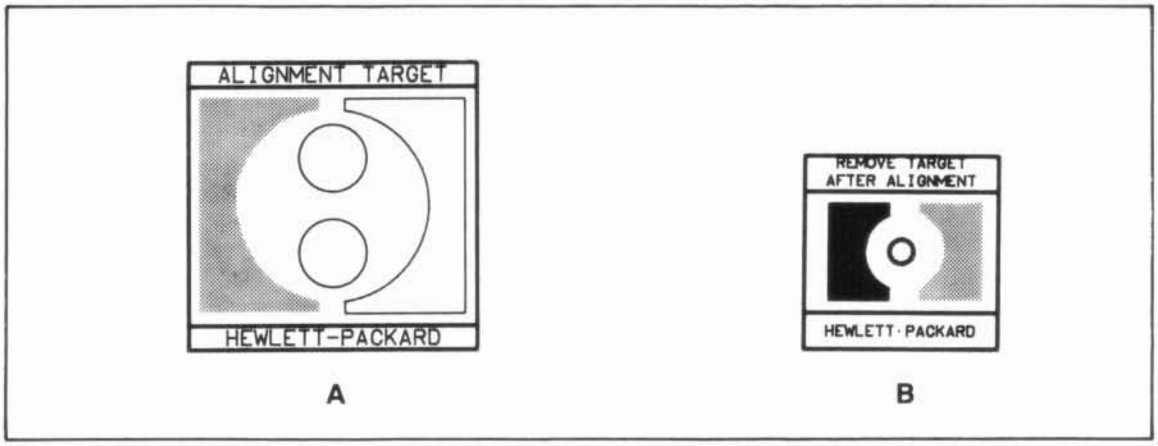


Figure 6-25. Linear and Single-Beam Interferometer Alignment Aids

OVERLAPPING DOTS METHOD

The overlapping dots method of alignment relies on the principle that if the measurement beam to the retroreflector is not parallel to the direction of travel, it is offset upon recombination with the reference beam of the interferometer (see *Figure 6-24*). When motion occurs between the retroreflector and interferometer along the measurement path, any angular misalignment causes a displacement (at the receiver) of one laser beam with respect to the other which can be visually observed. Since the human eye can resolve a displacement of the beam of approximately 300 micrometres (0.01 inch), this technique can be applied to reduce cosine error for measurement

Alignment Principles

Prior to beginning any alignment procedure, a basic understanding of principles will make the procedure easier to perform. The following information is intended as a concise summary of the various factors that affect the optical alignment of the Laser Position Transducer. While performing the alignment procedure, keep the following points in mind:

a. In order to achieve maximum accuracy, the laser beam must be parallel to each axis of travel.

b. Start the alignment at the laser head and move out one component at a time until the last component on an axis is aligned and the laser beam impinges on the receiver aperture.

c. The angular direction of the beam can be aligned by moving the laser head or adjusting a beam bender. The reflected beam can be aligned by adjusting a beam splitter or interferometer.

d. The angular direction of the beam will not be changed by adjusting a retroreflector. Similarly, the angular direction of a beam transmitted through a beam splitter or interferometer will not be changed by adjusting that particular component.

NOTE

There will be up to a 30-arcminute deviation of the beam when passing through any interferometer except the HP 10702A Option 001. (See Section VIII for Specifications).

e. The retroreflectors (cube corners) do not change the angular direction of the beam. However, they do displace the beam and reverse the direction. The laser beam remains parallel to its original path. In the case of the HP 10705A Single Beam Interferometer reference cube-corner and the HP 10704A Retroreflector, the displacement is zero because the beam hits the center of the cube-corner.

f. On multi-axis configurations, the first axis to be adjusted is the axis where angular adjustment of the laser beam requires adjustment of the laser head. After the first axis is aligned, the laser head is locked down and any angular adjustment of the laser beam in the other measurement axes is accomplished by rotating the optical components.

g. Properly aligned interferometers exhibit less sensitivity to temperature. See Dead Path Errors for details.

h. Setup multiaxis systems with all legs of the laser beam orthogonal to each other and the measurement mirrors. For ease of optical layout and alignment, keep the laser beams horizontal or vertical.

i. Define all beam legs (plane and direction) against machined surfaces known to be parallel or perpendicular to the stage plane. Use an auto reflection mirror with square sides (e.g., a metrologist's "true square").

j. It is suggested before installing the optics to define all beam bends (location and angle) with an optical square (pentaprism). This ensures the best possible starting point for the final adjustment of the laser system optics.

ALIGNMENT PROCEDURES

Basic Alignment Techniques

There are two basic alignment techniques used with the Laser Position Transducer: Overlapping Dots, which is a very satisfactory method in applications involving relatively long travel; and Autoreflection, which is used for short travel applications, measurements where cosine error must be reduced to the absolute minimum possible and when plane mirror reflectors are used. In general, regardless of the techniques used, alignments are performed with all optical components in place.

e. *Figure 6-27* illustrates a typical two-dot pattern on the receiver that is seen after the optics move. Now adjust the laser beam by angularly moving the beam until the dots again overlap at the receiver. This adjustment of the laser beam can be done by moving the laser head, beam bender or interferometer depending on the optical layout.

NOTE

Some translations of either the laser head or interferometer may also be necessary to achieve alignment.

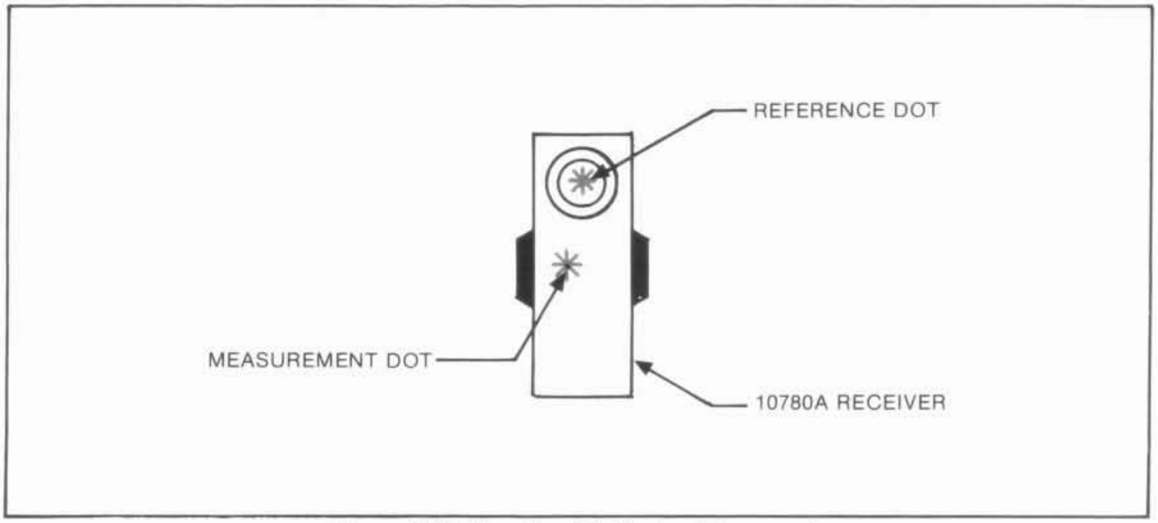


Figure 6-27. Results of Reflector Movement

Alignment Procedure (Overlapping Dots)

The following alignment procedure describes the overlapping dots methods used on a two-axis configuration. *Figure 6-28* is a typical measurement configuration which includes a linear interferometer and a single beam interferometer. In general, when the optical components are installed on the machine, their optical centerlines will be nominally in the correct relationship and only minor adjustments should be required.

NOTE

Steps 1 through 10 constitute the X-axis "Overlapping Dot" alignment procedure.

1. Place the interferometer alignment target on the laser side of the X-axis interferometer and place the receiver alignment target on the receiver so that it is not in the laser beam (see *Figure 6-28*, position 1). Place a piece of opaque material between the interferometer and retroreflector.

travel of 0.5 metres (20 inches) or longer. For travel less than this, the sensitivity of this technique is normally not sufficient and autoreflection should be used. The cosine error (E) in parts per million (ppm) can be calculated from the following formula:

$$E = \frac{S^2}{8D^2}$$

Where D is the distance measured in millimetres (inches) and S is the lateral offset of the returning beam in micrometres (thousands of an inch). For example, if the distance measured is 600 mm and this results in an offset of the return beam of 1.2 mm then:

$$E = \frac{(1200)^2}{(8) \times (600)^2} \text{ 0.5 ppm or 0.5 micrometre per metre of travel}$$

The following are the principle steps used for the "Overlapping Dots" method of alignment, followed by a detailed alignment procedure for a specific configuration.

a. The laser head and optics are mounted in their desired location.

b. Select the small beam aperture on the laser head.

c. With the retroreflector as close as possible to the interferometer, adjust any component (laser head, interferometer, or retroreflector) to get the dots (reference and measurement beams) to overlap at the receiver.

NOTE

Placing a piece of translucent tape over the receiver lense will help in observing the impinging beams.

d. Move the retroreflector away from the interferometer. If the laser beam is not parallel to the axis of travel, the measurement beam dot will begin to move away from the reference beam dot. The dot will move until the beam is cut off by the edge of the interferometer's aperture. Stop moving the retroreflector before the beam is thus blocked, or when the end of travel is reached. *Figure 6- 26* shows why the measurement dot moves.

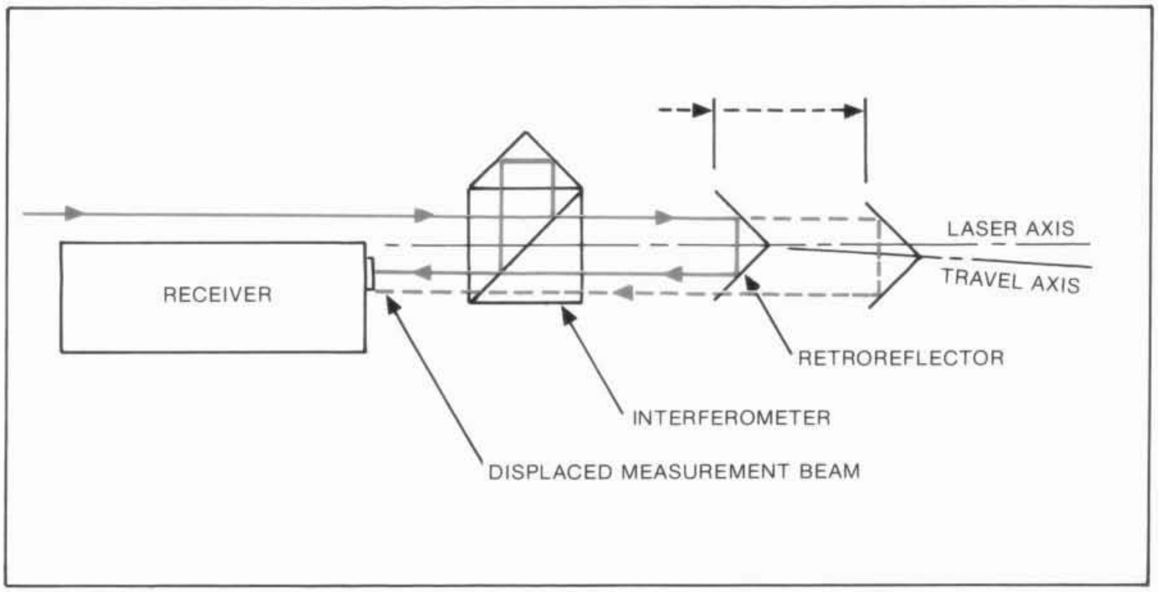


Figure 6-26. Measurement Beam Dot Movement

8. Repeat steps 4 through 7 until the return beam is centered on the receiver alignment target at both ends of travel. A lateral offset of 500 micrometres over a 0.5 metre travel is equal to a cosine error of 0.12 parts per million or 0.12 microns per metre of travel (0.12 microinches per inch).

9. If the reference beam returning from the interferometer is not centered on the receiver target, adjust the interferometer until both the reference and measurement beams are centered.

NOTE

In step 10, make sure the alignment is not disturbed.

10. Lock the laser head and X-axis optics down securely. Remove the receiver alignment target. Verify that the LED indicator on the receiver is illuminated and the voltage at the receiver test point is between 0.6 and 1.3 Vdc.

NOTE

Steps 11 through 20 constitute the Y-axis "Overlapping Dot" alignment procedure.

11. Place the alignment target on the Y-axis single beam interferometer and on the Y-axis receiver. Place a piece of opaque material between the single beam interferometer and the retroreflector.

12. Adjust the 50% beam splitter angularly until the reflected laser beam is centered in the beam bender entrance aperture. Slight lateral adjustments of the 50% beam splitter may be necessary to ensure there is no beam clipping. Lock down the 50% beam splitter securely.

13. Adjust the beam bender until the reflected beam is centered on the alignment target installed on the single beam interferometer. Lock the beam bender securely in place.

14. With the single beam interferometer and retroreflector at the closest point, adjust the single beam interferometer until the reference beam is centered on the receiver alignment target. Remove the opaque material.

15. Adjust the Y-axis retroreflector until the measurement beam is centered on the receiver alignment target.

16. Traverse the retroreflector to its furthest point of travel.

17. Angularly adjust the single beam interferometer to center the return beam from the retroreflector on the receiver alignment target. When adjusting the single beam interferometer angularly, it may also be necessary to make slight lateral adjustments to ensure that the reference beam from the single beam interferometer is also centered on the receiver alignment target.

18. Return the retroreflector to the closest point to the single beam interferometer.

2. With the retroreflector and interferometer at this closest point, adjust the laser head until the laser beam passes through the 50% Beam Splitter, enters one hole of the alignment target on the interferometer, and exits the other to impinge on the receiver alignment target centered on the hole over the photodetector. A slight lateral adjustment of the interferometer or laser head may be required.

3. Remove the opaque material from between the retroreflector and interferometer and rotate the receiver alignment target to position 2 (see *Figure 6-28*).

4. Adjust the retroreflector to center the return measurement beam on the receiver alignment target.

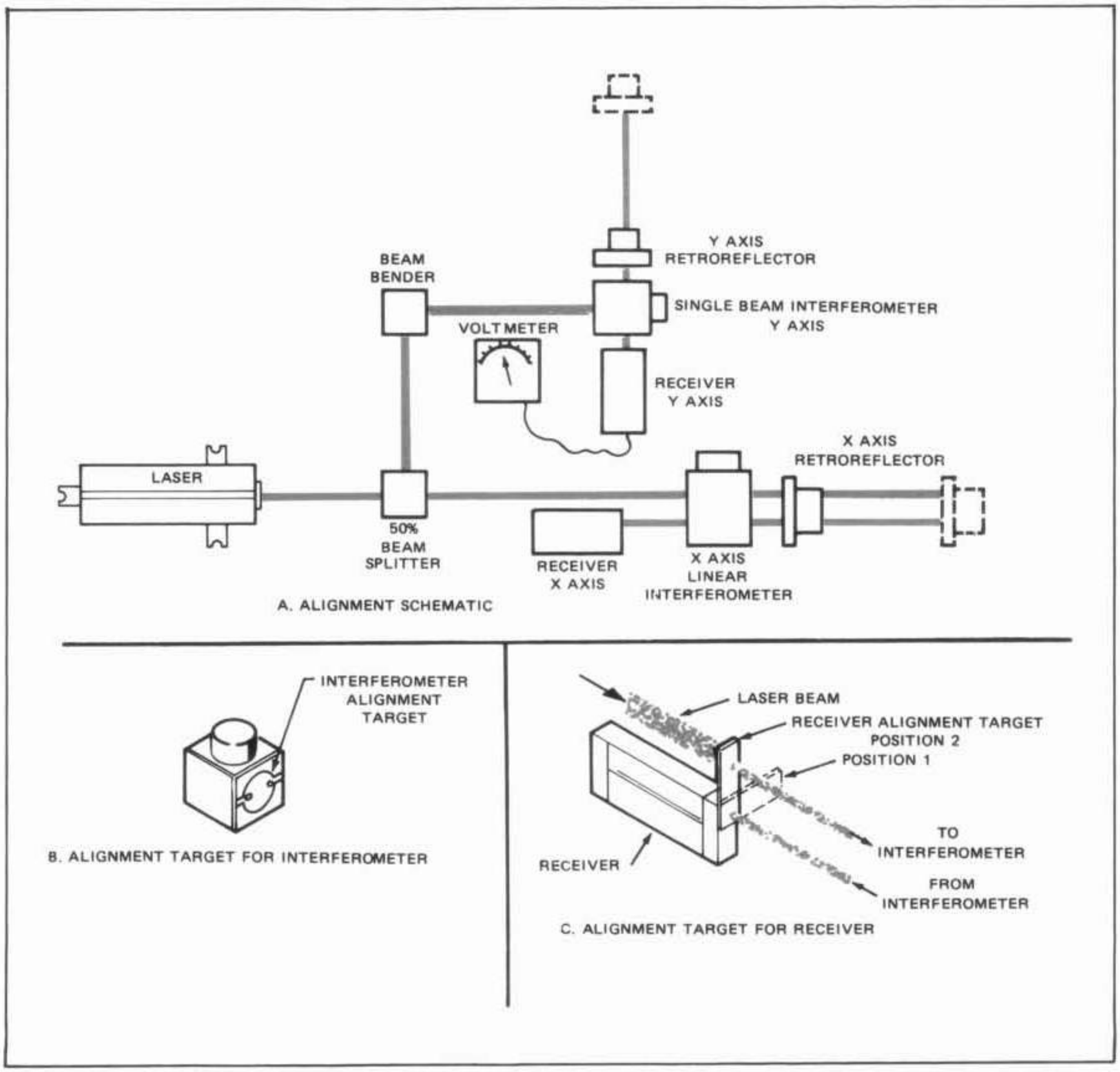


Figure 6-28. Overlapping Dot Alignment

5. Traverse the retroreflector to its furthest point.

6. Adjust the laser head angularly to center the return beam on the receiver alignment target.

7. Return the retroreflector to the closest point to the interferometer.

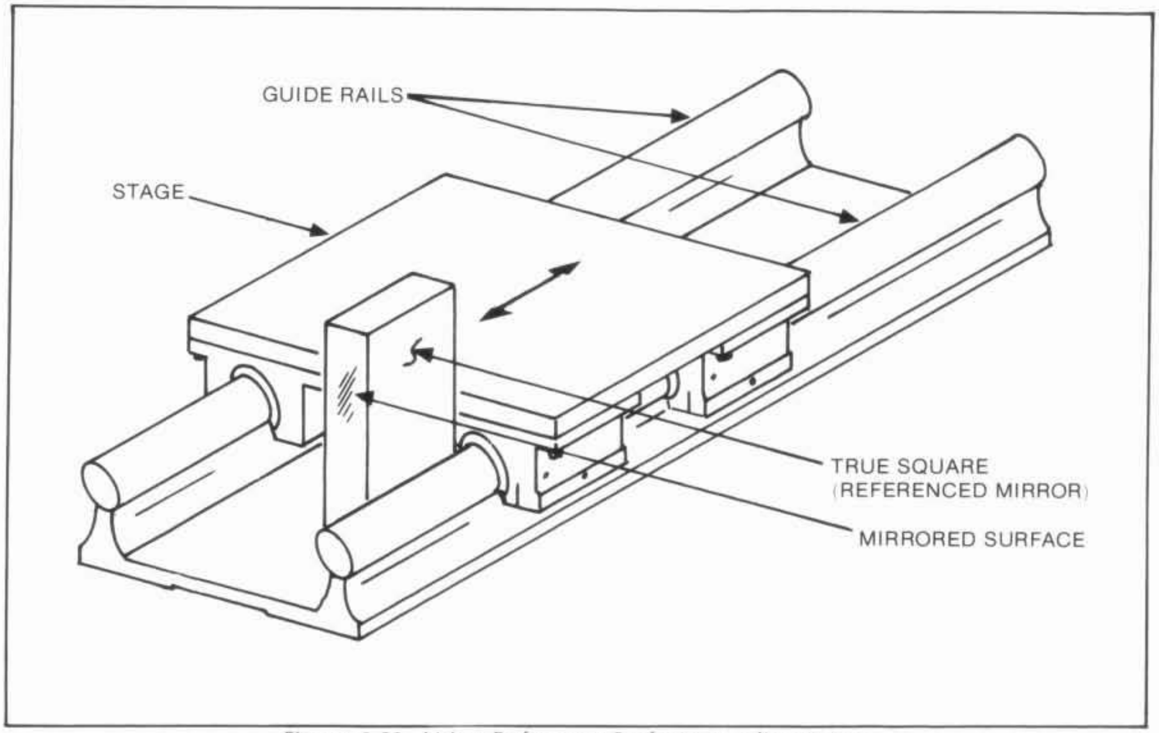


Figure 6-29. Using Reference Surfaces to Align Mirror

Alignment Procedure (Autoreflection)

The following procedure describes the autoreflection alignment method used on a two-axis system.

Figure 6-30 shows a measurement setup similar to *Figure 6-28* except that the referenced mirrors are included.

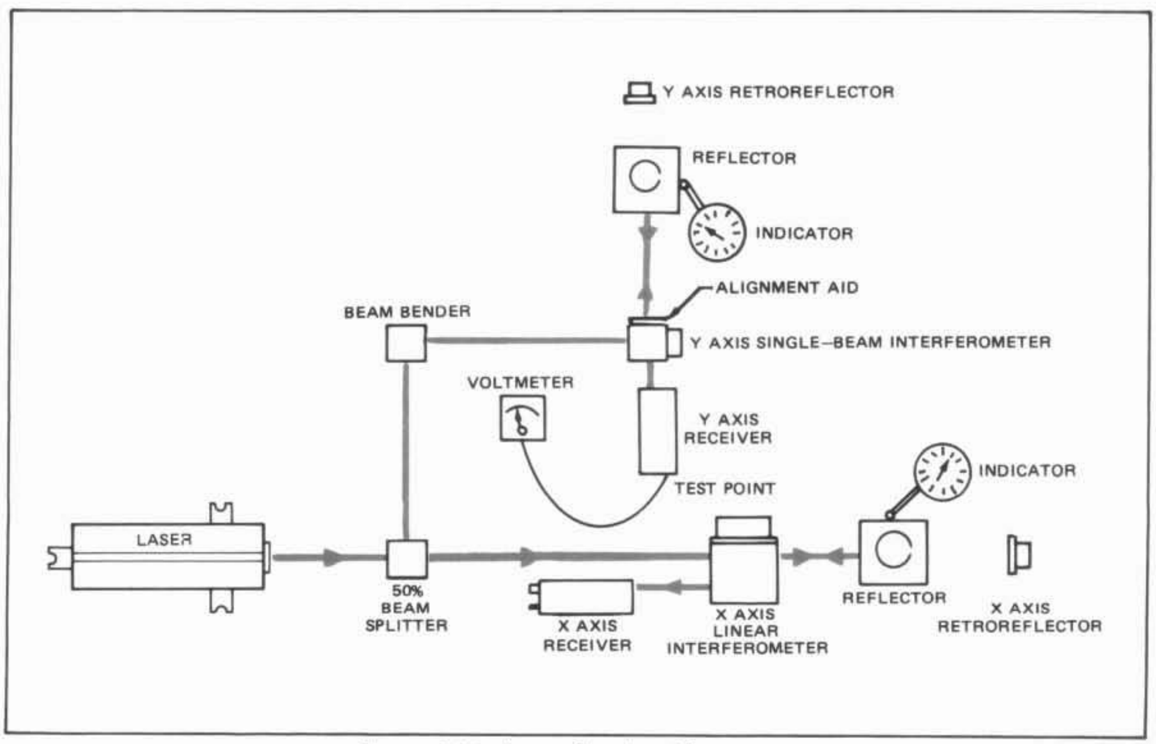


Figure 6-30. Autoreflection Alignment

19. Repeat steps 15 through 18 until the return beam from the retroreflector is centered on the receiver alignment target. Lock down the single beam interferometer securely making sure the alignment is not disturbed.

20. Remove the single beam alignment target and the receiver alignment target. Verify that the LED indicator on the receiver is illuminated and the voltage at the receiver test point is between 0.6 and 1.3 Vdc.

AUTOREFLECTION METHOD

The autoreflection method of alignment is used in short travel applications of less than 0.5 metre (20 inches). It is based on the principle of aligning a mirrored surface normal to the direction of travel and aligning the laser beam perpendicular to this mirrored surface (i.e., parallel to the direction of travel) to minimize cosine error. This technique is fast and is the best way to eliminate cosine error.

The following are the principle steps used for the "Autoreflection" method of alignment, followed by a detailed alignment procedure for a specific configuration.

a. The laser head and optics are mounted in the desired locations and the laser beam is roughly aligned parallel to the axes.

b. Provide a mirror, perpendicular to the axis of travel. Place the mirrored surface between the interferometer and retroreflector.

NOTE

Typical reflectors having required mirror flatness and referenced sides for autoreflection are

- True Square
- Other precision angle plates or squares with a gage block wrung to the appropriate surface.

The mirrored surface should be perpendicular to its sides (or angle plate) within 15 arcseconds.

Typical means for making the mirrored surface perpendicular to the axis of travel are:

- Locating the mirror reference surfaces against fixed reference surfaces on the machine's positioning system. (e.g., ways, rails, guides) (See *Figure 6-29*).
- Indicating the reference surfaces on the mirror/true square/gauge block with a dial indicator, and adjusting the angular position of the mirror surface.

c. Place the perpendicular mirrored surface at the far end of travel.

d. Select the small aperture on the laser head by rotating the front turret.

e. Adjust the laser beam so that the beam is reflected by the mirror back upon itself. Alignment is made when the (small) return beam is centered on the small laser head aperture. This adjustment of the laser beam can be done by moving the laser head, beam bender or interferometer, depending on the optical layout.

7. With a fast responding voltmeter (preferably a meter type) attached to the receiver test point and receiver case ground. Angularly fine adjust the laser beam (laser head or interferometer on this axis) until a signal is received on the receiver. (The voltmeter will suddenly jump to some value greater than 0.25 volts.) This is a critical adjustment and may initially require great care to achieve the desired result.

8. Peak the voltmeter reading (which will be fluctuating) by fine adjusting the laser beam in both angular axes. Now carefully readjust the interferometer until the voltage reading suddenly drops back down to about 0.3 Volts.

NOTE

The alignment should be so that the voltage reading from the receiver test point is just below the sudden jump up in voltage. If the alignment is fixed to sustain this peaked voltage then system operation will be degraded.

This will align the laser beam to within ±1.2 arcminutes to the direction of travel, resulting in a cosine error of approximately 0.05 parts per million. That is 0.05 micrometre per metre of travel (0.05 microinches per inch) of cosine error.

9. Lock down the laser head and interferometer securely. Make sure the alignment is not disturbed. Remove the referenced mirror and the opaque material.

10. Reposition the retroreflector until the return measurement beam is centered on the receiver alignment target and overlaps the reference beam from the interferometer.

NOTE

Placing a piece of translucent tape over the receiver lens will help in observing the impinging beams.

11. Verify that the LED indicator on the receiver is illuminated and the voltage at the receiver test point is between 0.6 and 1.3 Vdc.

NOTE

Steps 12 through 21 constitute the Y-axis autoreflection alignment.

12. Adjust the 50% beam splitter angularly until the reflected laser beam is centered on the beam bender aperture. Slight lateral adjustments of the 50% beam splitter may be necessary to ensure there is no beam clipping. Lock down the 50% beam splitter securely.

13. Adjust the beam bender until the reflected beam is centered on the aperture of the single beam interferometer. The single beam interferometer alignment target can be used as an aid and then removed. Lock down the beam bender securely.

14. Place the receiver alignment target on the receiver and rotate the turret of the laser head to select the small aperture.

NOTE

Steps 1 through 11 constitute the X-axis autoreflection alignment procedure.

1. With all optical components in place, install the alignment targets on the interferometer and the receiver (*Figure 6-28*, position 1). Place a piece of opaque material in front of the retroreflector.

2. With the laser beam passing through the 50% beam splitter, adjust the laser head and interferometer until the laser beam enters one hole of the alignment target and exits the other to impinge on the receiver alignment target centered on the hole over the photodetector.

NOTE

This is the reference beam that impinges on the receiver.

3. Place a referenced mirror between the interferometer and retroreflector so that the measurement beam from the interferometer strikes its reflective surface.

   Align the referenced mirror with a precision indicator until its reflective surface is perpendicular to the direction of travel.

4. Turn the front turret of the laser head to select the small aperture.

NOTE

If the distance between the laser head and the reflector is 0.5 metres (20 inches) or more, the formula given in the paragraph on Overlapping Dots determines the cosine error based on the offset of the return beam at the laser head. For example, a distance between the laser head and reflector of 0.5 metres and an offset of the return beam at the small aperture of the laser of 500 micrometres (0.0202 inches) the cosine error is approximately 0.12 parts per million.

5. Adjust the laser head angularly until the beam reflects back on itself from the referenced mirror and is centered on the small aperture of the laser head. Slight lateral translations of the interferometer may be required to ensure that the reference beam from the interferometer is centered on the receiver alignment target.

NOTE

For high accuracy alignment or for installations where there is less than 0.5 metre (20 inches) between the laser head and reflector, perform steps 6 through 8.

6. Remove the receiver alignment target and interferometer alignment target and rotate the turret of the laser head to select the large aperture.

22. Verify that the LED indicator on the receiver is illuminated and the voltage at the receiver test point is between 0.6 and 1.3 Vdc.

Plane Mirror Interferometer

This procedure covers specifically the alignment of the HP 10706A Plane Mirror Interferometer as applied to an X-Y positioning system using flat mirrors as measurement reflectors. In this procedure it is assumed that the mirror surfaces are flat to within the tolerances required for operation of the plane mirror interferometer (refer to the specifications in Section VIII) and they have been aligned perpendicular to each other and their respective directions of travel. *Figure 6-33* illustrates the most common 2-axis plane mirror interferometer installation. The interferometers have been configured to turn the beam in this example.

The alignment of the plane mirror interferometer is very similar to the autoreflection alignment technique previously described. In most cases, the accuracy demands of the X-Y positioning devices used, along with the relatively short travels encountered, dictate that the high accuracy alignment technique described in the autoreflection alignment procedure be used.

Before proceeding with the alignment procedure, reconfiguring the HP 10706A and alignment aids for this interferometer will be covered.

TURNED CONFIGURATION

To reduce the number of beam benders for this application, the interferometer can be configured to turn the beam. This is done by interchanging the reference cube corner and the plane mirror converter. *Figure 6-31* shows a reconfigured Plane Mirror Interferometer to turn the beam. Note the location of the plane mirror converter with respect to the arrows on the label.

In this configuration (*Figure 6-31*) the laser measurement beam is turned to the left. When the measurement beam needs to be turned to the right (as in *Figure 6-33*, X-axis) the interferometer is rotated 180° about the incoming optical axis.

NOTE

With this change in configuration the measurement direction sense will change (see Section V).

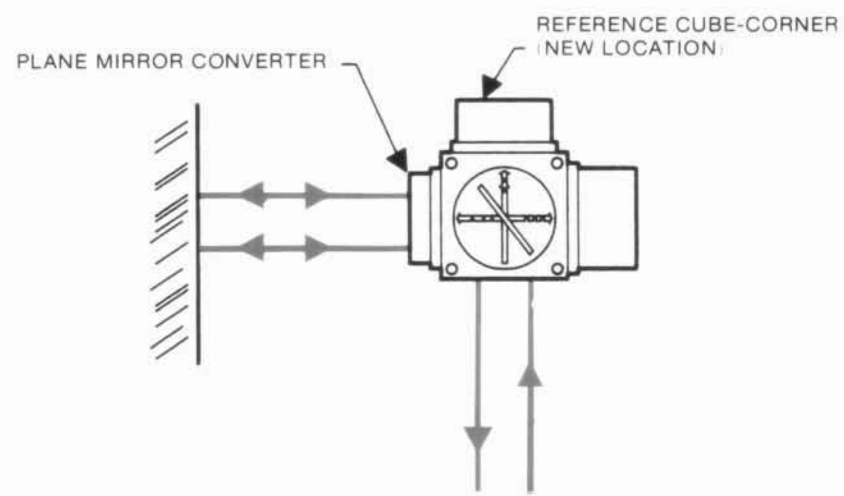


Figure 6-31. HP 10706A Turned Configuration

15. Place a referenced mirror between the interferometer and the retroreflector so that the measurement beam from the interferometer strikes its reflective surface. Align the referenced mirror with a precision indicator until its reflective surface is perpendicular to the direction of travel in both angular axes (<15 arcseconds).

16. Place a single beam interferometer alignment aid on the output side of the interferometer and adjust the single beam interferometer angularly until the beam reflects back on itself and is centered on the small aperture of the laser head. Slight lateral translations of the interferometer may be required to ensure that the reference beam from the interferometer is still centered on the receiver alignment target. Do not adjust the laser head.

NOTE

For high accuracy alignment or for installations where there is less than 0.5 metre (20 inches) between the laser head and reflector, perform steps 17 through 19.

17. Remove the receiver alignment target and interferometer alignment target and rotate the turret of the laser head to select the large aperture.

18. With a fast responding voltmeter attached to the receiver test point, angularly fine adjust the laser beam (interferometer or beam bender on this axis), until a signal is received on the receiver. (The voltmeter will suddenly jump to some value greater than 0.25 Volts.) This is a critical adjustment and may initially require great care to achieve the desired result.

19. Peak the voltmeter reading (which will be fluctuating) by fine adjusting the laser beam in both angular axes. Now carefully readjust the interferometer until the voltage reading suddenly drops back down to about 0.3 Volts.

NOTE

The alignment should be so that the voltage reading from the receiver test point is just below the sudden jump up in voltage. If the alignment is fixed to sustain this peaked voltage then system operation will be degraded.

This will align the laser beam to within ±1.2 arcminutes to the direction of travel, resulting in a cosine error of approximately 0.05 parts per million. That is 0.05 micrometre per metre of travel (0.05 microinches per inch) of cosine error.

20. Lock down the single beam interferometer and beam bender securely making sure the alignment is not disturbed. Remove the reflector.

21. Adjust the retroreflector until the return measurement beam is centered on the receiver and overlaps the reference beam from the interferometer.

NOTE

Placing a piece of translucent tape over the receiver lens will help in observing the impinging beams.

ALIGNMENT PROCEDURE (Plane Mirror Interferometer)

The following procedure describes the alignment of plane mirror interferometers used on an X-Y stage application. (See *Figure 6-33.*)

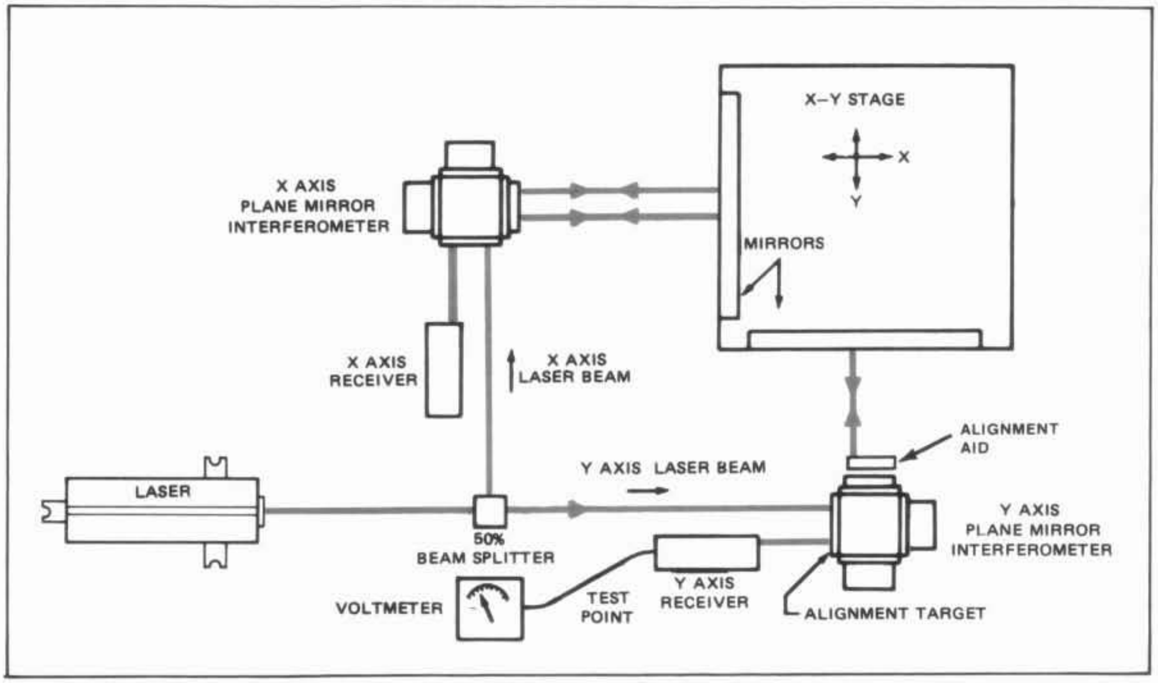


Figure 6-33. Plane Mirror Interferometer Alignment

NOTE

Steps 1 through 10 constitute the Y-axis alignment.

1. Place the interferometer alignment target on the laser side of the Y-axis plane mirror interferometer and the receiver alignment target on the receiver (*Figure 6-28*, position 1). Place a piece of opaque material between the Y-axis plane mirror interferometer and the mirror.

2. Adjust the laser head until the laser beam passes through the 50% beam splitter, enters one hole of the interferometer alignment target, and exits the other centered on the receiver alignment target. Lock down the laser head securely.

3. Select the small aperture of the front turret of the laser head and install the alignment aid on the output of the plane mirror interferometer in the correct orientation. Remove the opaque material from between the plane mirror interferometer and the mirror.

4. The laser beam will now exit the interferometer and be reflected by the mirror upon itself back into the interferometer. Angularly adjust the plane mirror interferometer until the beam reflected from the mirror returns upon itself through the plane mirror interferometer and back to the small aperture of the laser head. Slight lateral translations of the plane mirror interferometer may be required to ensure that the reference beam is still centered on the receiver alignment target. If the distance between the mirror and the laser head is at least 0.5 metres (20 inches) then the formula given in the section on Overlapping Dots determines the cosine error based on the offset of the return beam at the laser head.

ALIGNMENT AIDS

Figure 6-32 shows the two alignment aids supplied with the HP 10706A Plane Mirror Interferometer.

- Alignment Target, HP P/N 10702-60001
- Alignment Aid, HP P/N 10706-60001

Both aids are magnetic to simplify positioning on the interferometer.

Alignment Target (P/N 10702-60001) is used on the input side of the interferometer to properly position the beam in the aperture.

Alignment Aid (P/N 10706-60001) is placed on the exit aperture of the interferometer to allow autoreflection. This aid contains a quarter-wave plate to reflect the measurement beam back on itself and return it to the laser head without offset.

The Alignment Aid must be positioned to receive the primary measurement beam. This is the first of the two measurement beams that travel between the HP 10706A and the plane mirror reflector. To identify the primary beam, block one of the two measurement beams and if the other disappears, then the one blocked is the primary measurement beam.

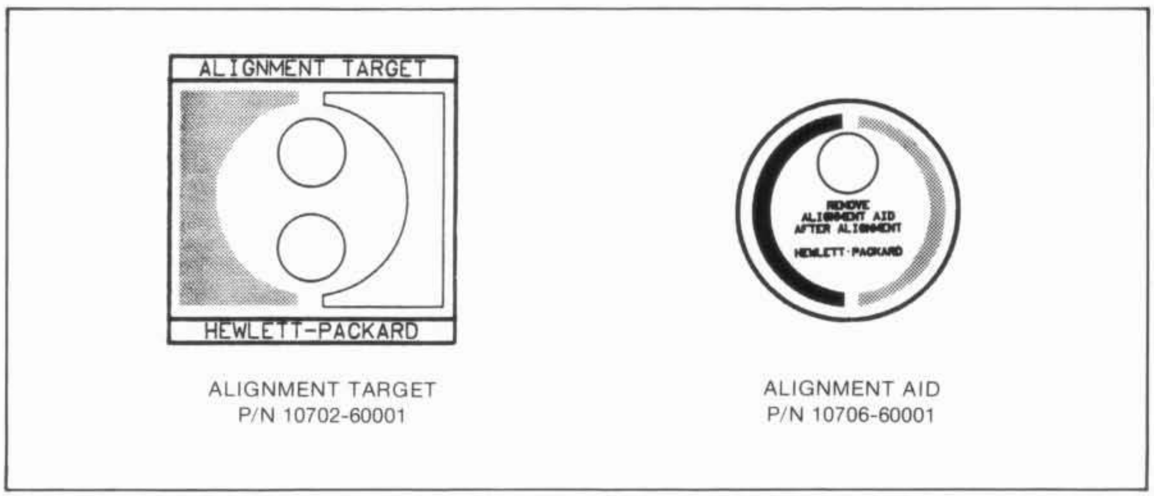


Figure 6-32. HP 10706A Alignment Aids

13. Angularly adjust the 50% beam splitter until the laser beam enters one hole of the plane mirror interferometer alignment target and exits the other, centered on the receiver alignment target (do not adjust the laser head). Slight lateral translations of the 50% beam splitter may be necessary to ensure there is no beam clipping. Lock down the 50% beam splitter securely.

14. Select the small aperture on the front turret of the laser head and install the alignment aid on the output of the plane mirror interferometer in the correct orientation. Remove the opaque material from between the plane mirror interferometer and the mirror.

15. The laser beam now exits the interferometer and is reflected by the mirror back upon itself into the interferometer. Angularly adjust the plane mirror interferometer until the beam reflected from the mirror returns through the plane mirror interferometer and back to the small aperture of the laser head. Slight, lateral translations of the plane mirror interferometer may be required to ensure that the reference beam is still centered on the receiver alignment target. If the distance between the mirror and the laser head is at least 0.5 metres (20 inches) then the formula given in the Section on Overlapping Dots will determine the cosine error based on the offset of the return beam at the laser.

NOTE

For high accuracy alignment or for installation where there is less than 0.5 metres (20 inches) between the laser and mirror, perform steps 15 through 17.

16. Remove the receiver alignment target and plane mirror interferometer alignment target and rotate the turret of the laser head to select the large aperture. Do not remove the plane mirror interferometer alignment aid on the output side of the plane mirror interferometer.

17. With a fast responding voltmeter attached to the receiver test point, fine adjust the plane mirror interferometer angularly until a signal is received on the receiver. (The voltmeter will suddenly jump to some value greater than 0.25 volts.) This is a critical adjustment and may initially require great care to achieve the desired result.

18. Peak the voltmeter reading (which will be fluctuating) by fine adjusting the plane mirror interferometer in both angular axes. Now carefully readjust the interferometer until the voltage reading suddenly drops back down to about 0.3 Volts.

NOTE

The alignment should be so that the voltage reading from the receiver test point is just below the sudden jump up in voltage. If the alignment is fixed to sustain this peaked voltage then system operation will be degraded.

This aligns the laser beam to within ±1.2 arcminutes to the direction of travel, resulting in a cosine error of approximately 0.05 parts per million. That is 0.05 micrometre per metre of travel (0.05 microinches per inch) of cosine error.

19. Lock down the plane mirror interferometer (X-axis) securely. Make sure the alignment is not disturbed.

NOTE

For high accuracy alignment or for installations where there is less than 0.5 metres (20 inches) between the laser and mirror, perform steps 5 through 7.

5. Remove the receiver target and plane mirror interferometer alignment target and rotate the turret of the laser head to select the large aperture. Do not remove the plane mirror interferometer alignment aid on the output side of the plane mirror interferometer.

6. With a fast responding voltmeter (preferably a meter type) attached to the receiver test point, fine adjust the plane mirror interferometer angularly until a signal is received on the receiver. (The voltmeter will suddenly jump to some value greater than 0.25 volts.) This is a critical adjustment and may initially require great care to achieve the desired result.

7. Peak the voltmeter reading (which will be fluctuating) by fine adjusting the plane mirror interferometer in both angular axes. Now carefully readjust the interferometer until the voltage reading suddenly drops back down to about 0.3 Volts.

NOTE

The alignment should be so that the voltage reading from the receiver test point is just below the sudden jump up in voltage. If the alignment is fixed to sustain this peaked voltage then system operation will be degraded.

This aligns the laser beam to within ±1.2 arcminutes to the direction of travel, resulting in a cosine error of approximately 0.05 parts per million. That is 0.05 micrometre per metre of travel (0.05 microinches per inch) of cosine error.

8. Lock down the plane mirror interferometer (Y-axis) securely, making sure the alignment is not disturbed.

9. Monitor the voltage reading along the complete travel of the stage (y-axis). The voltage should not jump up to the previously peaked voltage reading. If so, readjust the interferometer until the voltage reading suddenly drops back down to about 0.3 volts.

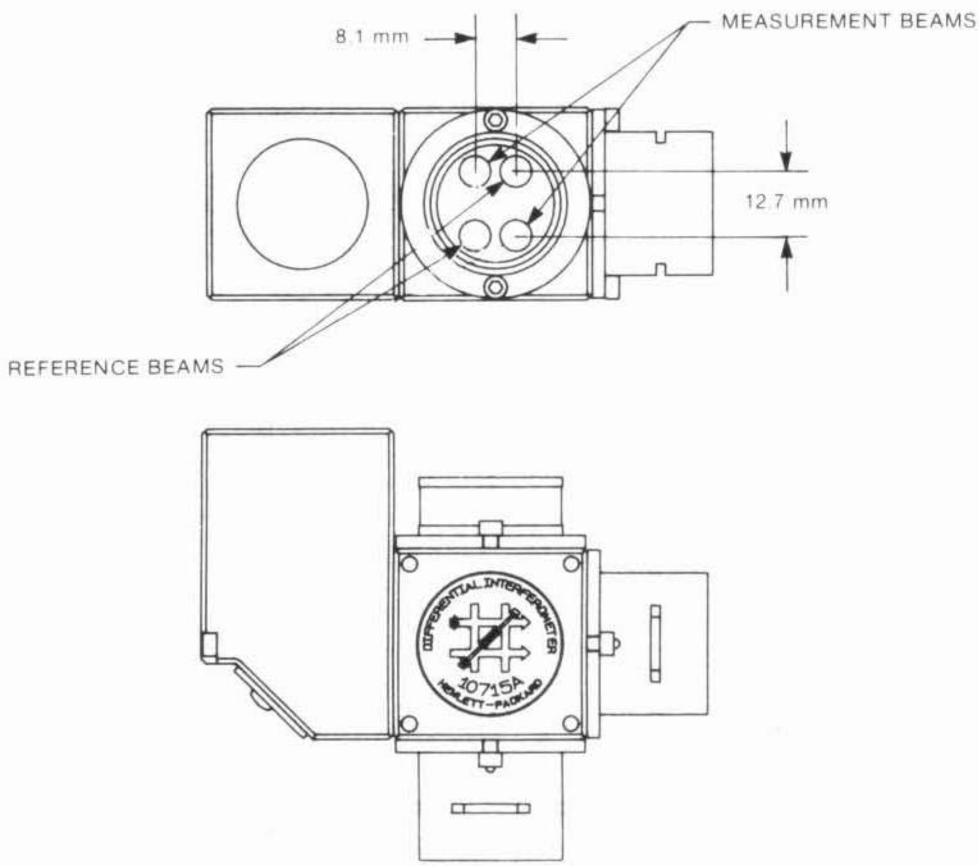
10. Remove the plane mirror interferometer alignment target and alignment aid. The reference beam and the measurement beam must be centered on the receiver alignment target.

11. Remove the receiver alignment aids and rotate the turret on the laser head to the large aperture. Verify that the LED indicator on the receiver is illuminated and the voltage at the receiver test point is between 0.6 and 1.3 Vdc.

NOTE

Steps 11 through 20 constitute the X-axis alignment.

12. With the laser head turret in the large aperture position, place the plane mirror interferometer alignment target on the laser head side of the X-axis plane mirror interferometer and the receiver alignment target on the receiver (*Figure 6-28*, position 1). Place a piece of opaque material between the X-axis plane mirror interferometer and the mirror.



B. TURNED CONFIGURATION (OPTION 001)

Figure 6-34. Beam Locations for HP 10715A Configurations (Continued)

20. Monitor the voltage reading along the complete travel of the stage (x-axis). The voltage should not jump up to the previously peaked voltage reading. If so, readjust the interferometer until the voltage reading suddenly drops down to about 0.3 volts.

21. Remove the plane mirror interferometer alignment target and alignment aid. The reference beam and the measurement beam must be centered on the receiver alignment target.

22. Remove the receiver alignment aids and rotate the turret on the laser head to the large aperture. Verify the LED indicator on the receiver is illuminated and the voltage at the receiver test point is between 0.6 and 1.3 Vdc.

Differential Interferometer

The Differential Interferometer is the most difficult HP interferometer to align because a reference mirror also has to be aligned.

Before describing the alignment procedure for this interferometer, details on beam locations and reference mirror mounting will be covered.

CONFIGURATIONS

There are two configurations available for the Differential Interferometer allowing flexibility in optical layout of a measurement system. They are:

- Standard
- Turned (Option 001)

Figure 6-34 illustrates the location of the measurement and reference beams for each configuration, both using input aperture B. The beams are switched if input aperature A is used.

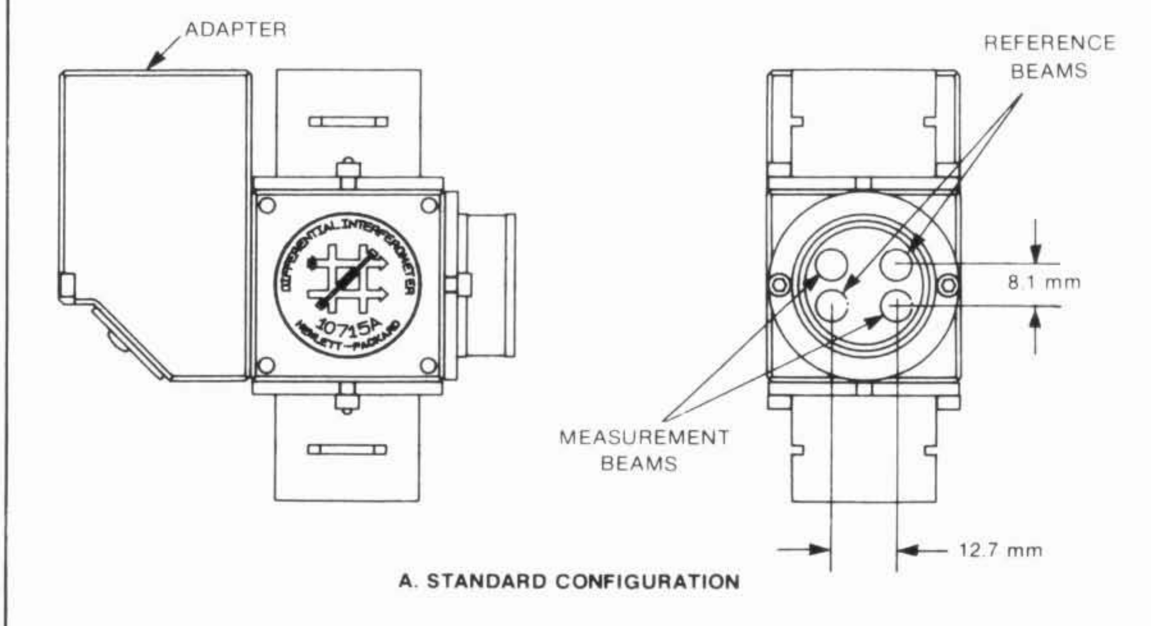


Figure 6-34. Beam Locations for HP 10715A Configurations

The following alignment procedure is for the "Standard Configuration" with the laser beam entering the interferometer in aperture B. The alignment procedure for the "Turned Configuration" is similar except it is more senstive to angular alignment of the interferometer.

a. Select the small aperture on the laser head.

b. The laser beam for each axis should be roughly aligned perpendicular to the measurement mirror. This is done by autoreflecting off this mirror and adjusting the laser head or beam bender until the reflected beam is centered in the small aperture on the laser head.

c. Translate the interferometer so that the laser beam enters the input aperture (aperture B, this example).

d. Place a rectangular gage block over the input aperture so that it reflects the laser beam back toward the laser. (See *Figure 6-36.*)

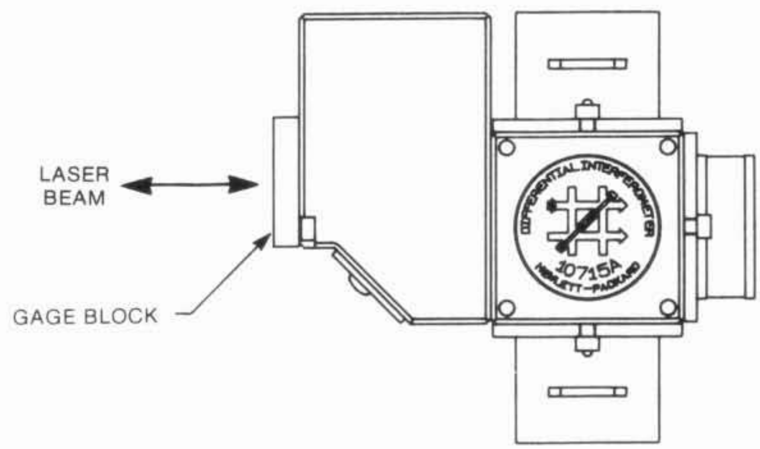


Figure 6-36. HP 10715A with Gage Block Attached

e. Adjust the Differential Interferometer in pitch and yaw until the laser beam is autoreflected back into the laser head. This insures proper angular alignment. It may be necessary to translate the interferometer again to center the laser beam on the input aperture (aperture B). Use a piece of translucent tape to help observe the beam.

f. Once the autoreflection alignment of the interferometer is complete, remove the gage block and select the large aperture on the laser head. Two parallel unclipped beams should now leave the interferometer. (See *Figure 6-37.*)

It should be noted that the previous autoreflection procedure is used only to reduce clipping and is not as critical as the autoreflection procedure used to reduce cosine error. As long as the two beams are not clipped, the alignment of the interferometer is adequate.

One of the two beams will be directed to the measurement mirror and the other will be directed to the stationary reference mirror. It does not matter which beam goes to which mirror. This only affects the direction sense. (Discussed in Section V.)

REFERENCE MIRROR MOUNTING

The differential Interferometer is supplied with a small reference plane mirror (see *Figure 6-35*). The mirror should be mounted on an adjustable mount so that proper alignment can be achieved. Once alignment is made, the position of the mirror needs to be rigidly fixed. The mirror needs to be attached to the mount and the recommended method is to use an adhesive. This adhesive should not induce stress into the glass during curing. The mirror/mount assembly should be located as close as possible to the near end of travel of the stage to reduce potential deadpath errors.

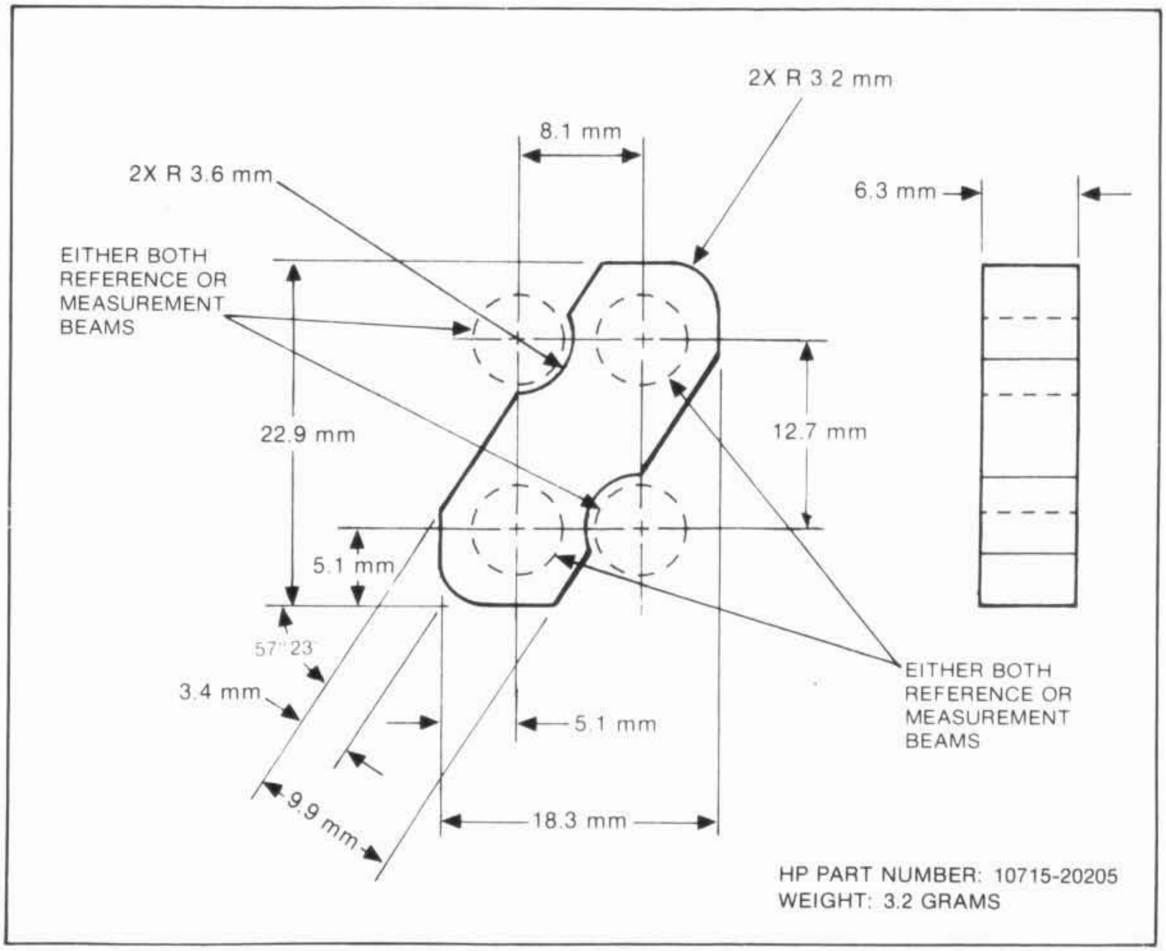


Figure 6-35. HP 10715A Reference Mirror

ALIGNMENT AIDS

To aid in aligning the HP 10715A, the Alignment Aid (P/N 10706-60001) is included. This is the same alignment aid used on the HP 10706A Plane Mirror Interferometer. See the previous section on Alignment Aids for the Plane Mirror Interferometer, for a discussion on its use.

ALIGNMENT PROCEDURE (Differential Interferometer)

The alignment procedure for the HP 10715A Differential Interferometer is similar to the alignment procedure for the Plane Mirror Interferometer. The principal difference is that in the Differential Interferometer, the laser beam must pass through small apertures. This requires fairly precise adjustment of the interferometer to avoid clipping part of the beam. It is assumed that the measurement mirror(s) has been aligned perpendicular to the axis of travel.

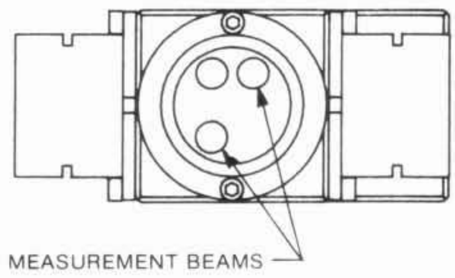


Figure 6- 39. Differential Interferometer as Viewed from Plane Mirrors with Measurement Beams Aligned

j. Switch to the large aperture on the laser head.

k. Check to ensure that both measurement beams pass clear of the stationary reference mirror. If necessary, translate the reference mirror until both measurement beams pass clear. The return beam should now pass unclipped to the receiver.

l. Replace the alignment aid over the output aperture of the Differential Interferometer such that the beam going to the reference mirror, (Reference beam) passes through the alignment aid. (See *Figure 6-40.*)

Figure 6-40. Alignment Aid Attached Over Reference Beam

The full Reference beam should strike the reference mirror. Select the small aperture on the laser head. If the reference mirror is parallel to the movable mirror, the reference beam will now be reflected back to the small aperture on the laser head. If not, the reference mirror must be adjusted in pitch and yaw until the reference beam is centered on the small aperture.

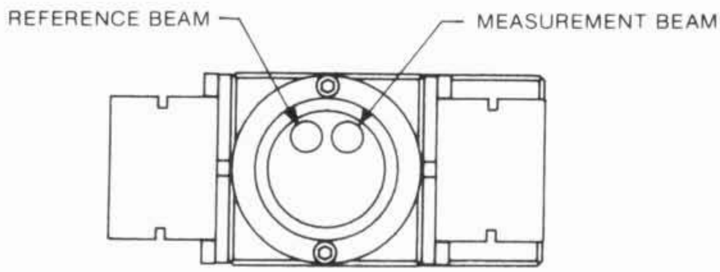


Figure 6-37. Differential Interferometer as Viewed from Plane Mirrors

Since it is most important that the beam going to the measurement mirror be properly aligned (this can cause cosine error), this alignment will be performed first. It is an iterative step because both the incoming beam and the interferometer require adjustment.

g. Place the alignment aid over the output aperture (plane mirror converter) of the Differential Interferometer such that the beam going to the measurement mirror (measurement beam) passes through the alignment target. (See *Figure 6-38.*)

Figure 6-38. HP 10715A with Alignment Aid Attached Over Measurement Beam

h. This beam should clear the reference mirror and strike the measurement mirror. Select the small aperture on the front turret of the laser head. Adjust the laser beam until the laser beam is autoreflected back through the small aperture of the laser head. This ensures that the beam is perpendicular to the measurement mirror. This step requires pitching and yawing the laser head, beam benders, or beam splitters depending on optical layout. Steps d and e should be performed after each adjustment to prevent the interferometer from clipping the laser beam.

i. Remove the alignment aid. The laser beam should now exit the interferometer aperture in two diametrically opposite positions (measurement beams). (See *Figure 6-39.*)

Wavelength Tracker

This procedure describes the installation and alignment of the HP 10717A Wavelength Tracker and HP 10780B Receiver. *Figure 6-42* shows an X-Y stage application using a Wavelength Tracking Compensation system. The components that comprise the Wavelength Tracking Compensation system are as follows:

- HP 10717A Wavelength Tracker
- Beam Bender/Splitter (see "Optics" paragraphs in this section for installation and alignment procedures)
- HP 10710A Adjustable Mounts (for mounting beam bender/splitter)
- HP 10780B Receiver
- HP 10790A/B/C Receiver Cable (see "Electronics" paragraphs in this section for installation procedures)
- HP 10946B or HP5507A Option 046 (see "Electronics" paragraphs in this section for installation procedures)

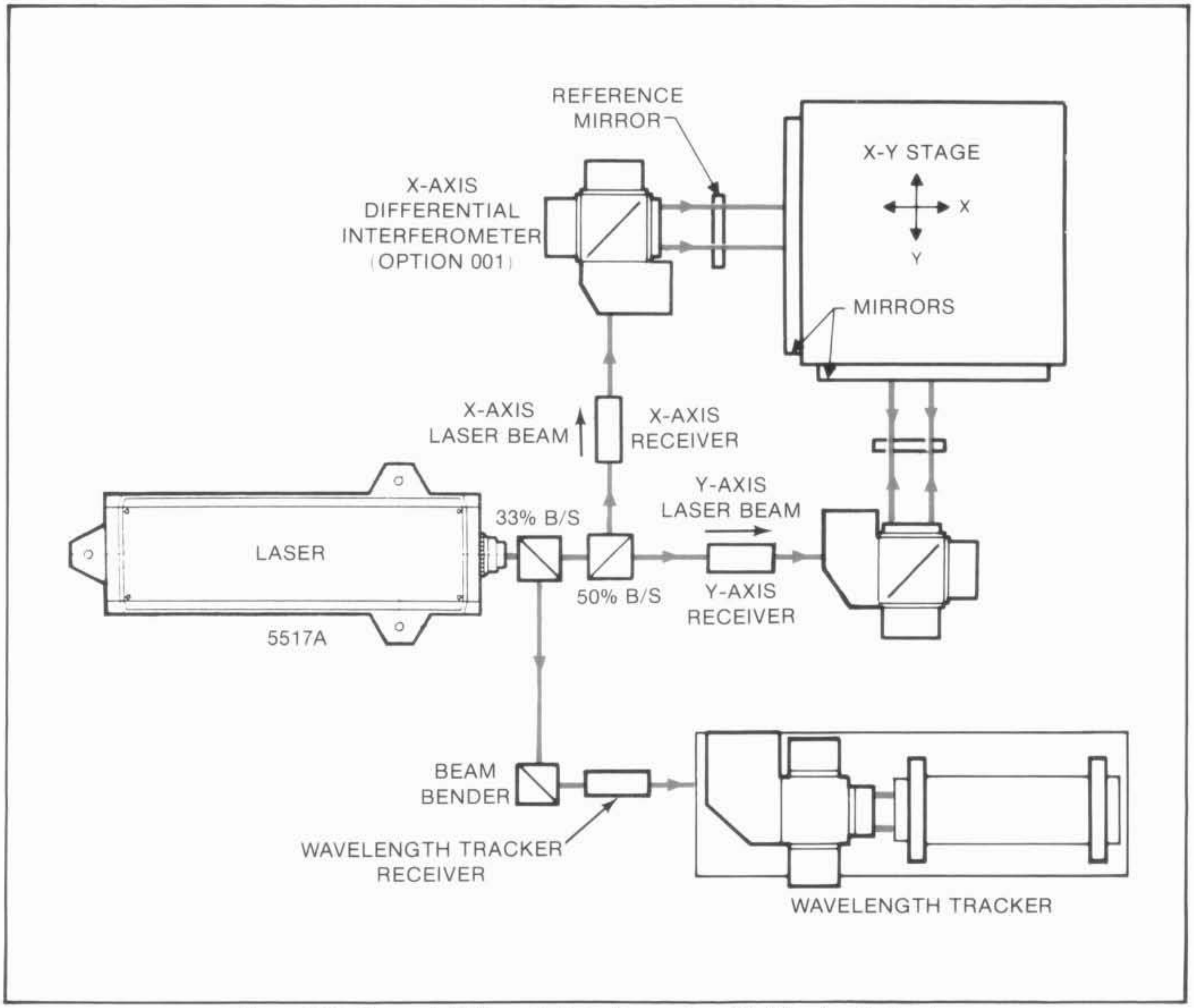


Figure 6-42. Two-axis Differential Interferometer with Wavelength Tracker

m. Remove the alignment aid. Both measurement and reference beams should now exit the interferometer aperture in diametrically opposite positions. Switch to large aperture. (See *Figure 6-41*.)

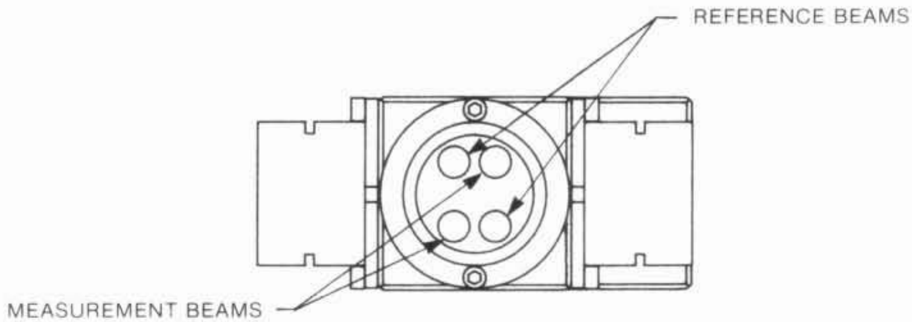


Figure 6-41. Differential Interferometer as Viewed from Plane Mirrors with Proper Alignment

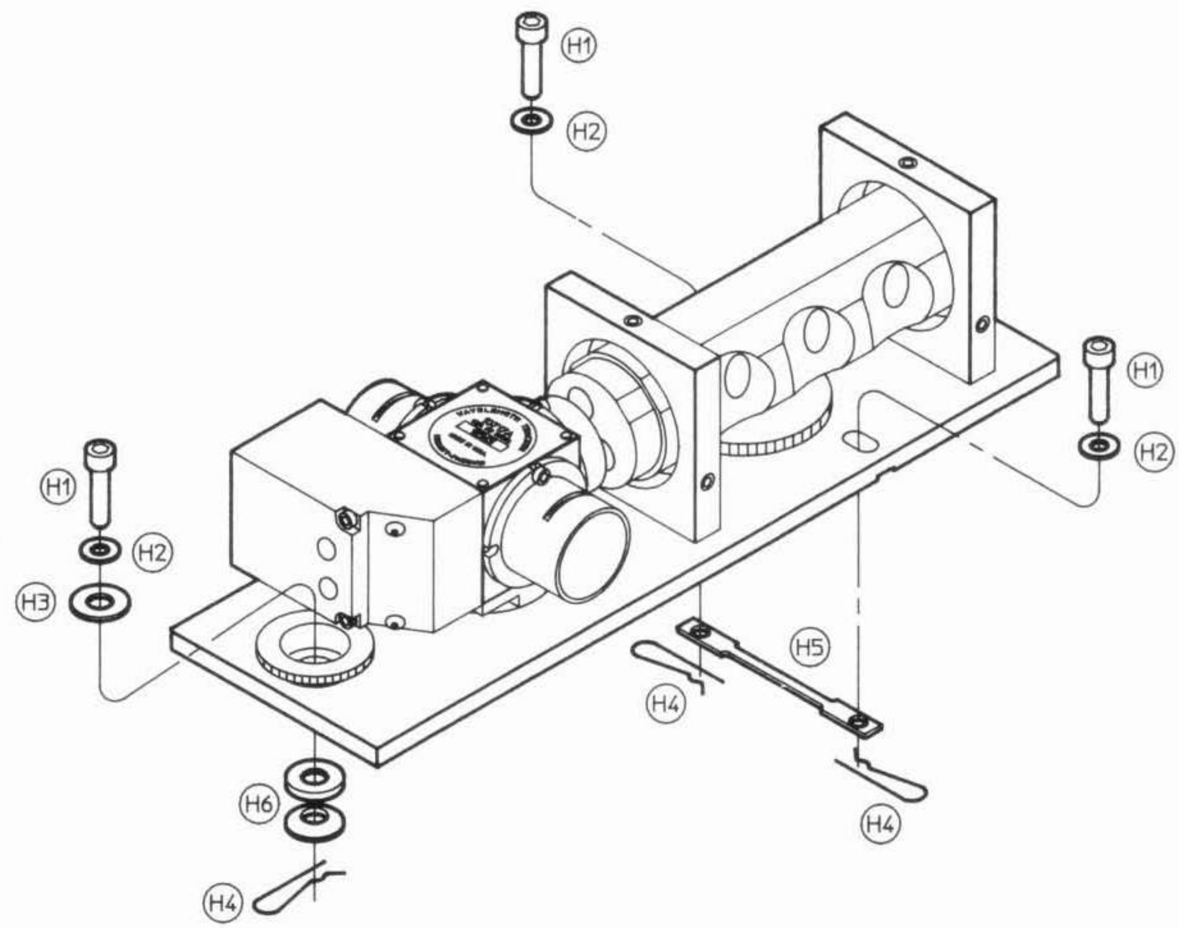
Both measurement and reference beams should pass unclipped to the receiver. Verify this by checking that these beams are centered in the output aperture (aperture A). Use a piece of translucent tape to help observe the laser beam.

1. Set Wavelength Tracker over the tapped holes on your equipment.

NOTE

Do not remove red tape and hitch-pin clips at this time.

2. Engage 3 to 4 threads of the three mounting screws (see *Figure 6-44*) by rotating each one 3 to 4 revolutions using the hex-ball driver supplied.



Reference Designator	Description	Part no.
H1	Screw - HD cap 10-32 .75 in-lg	3030-0182
H2	Washer - spring	3050-1274
H3	Washer - flat 1/4 in. .281 in-lg	3050-0583
H4	Hitch-pin Clip	1480-0694
H5	Subplate	10717-20209
H6	Washer - 2 Part Spherical	3050-1272

Figure 6-43. Wavelength Tracker Mounting Hardware

ALIGNMENT AID

To help in aligning the HP 10717A Wavelength Tracker, the Alignment Aid (P/N 10706-60001) is included. This is the same alignment aid used on the HP 10706A Plane Mirror Interferometer and HP 10715A Differential Interferometer. Refer to "Alignment Aids" in this section for further discussion on its use.

INSTALLATION AND ALIGNMENT PROCEDURE

The following procedure describes the installation and alignment of the Wavelength Tracker axis. The two units that require alignment (relative to one another and to the system in which they are installed) are the HP 10717A Wavelength Tracker and the HP 10780B Receiver. The HP 10717A Wavelength Tracker unit itself is pre-aligned at the factory and consequently requires no independent alignment. The Wavelength Tracking Compensation system should be installed and aligned with the following considerations in mind:

- HP 10717A Wavelength Tracker should be installed so that the air it samples is the same air through which the measurement axes' beam passes.
- HP 10717A Wavelength Tracker should be aligned to obtain maximum laser beam signal at the receiver. (See "Multi-Axis Configuration" paragraphs found in this section.)
- HP 10780B Receiver should be mounted in such a way that its LED indicator and gain adjustment potentiometer are accessible.
- HP 10780B Receiver will be properly aligned when the laser beam is centered in the receiver's aperture, the LED indicator on top of the receiver is on, and the voltage at the receiver's test point measures greater than +0.7 Vdc. See the receiver alignment procedure discussed earlier in this section for proper alignment techniques.
- No more than 6 measurement axes are installed in addition to the Wavelength Tracker.

As with any measurement axis, alignment starts at the laser head and moves out one component at a time (laser head, beam bending/splitting optics, Wavelength Tracker, and then receiver) until the last component of the Wavelength Tracking Compensation system is aligned and the laser beam impinges on the receiver's aperture. The following alignment procedure has the laser beam entering the HP 10717A's differential interferometer through aperture A.

NOTE

Do not remove the red tape and three hitch-pin clips until instructed to do so in the following procedure. These "clips" make installation of the Wavelength Tracker easier. The red tape and clips (see *Figure 6-43*, item H4) keep the three mounting screws in place during installation, and allow installation of the unit at any angle without having to physically hold the three mounting screws in place. After installation is complete, the clips are removed by pulling on the red tape. Also, if the red tape and mounting hardware are removed or lost prior to the Wavelength Tracker's installation, refer to *Figure 6-43* for an exploded view of the tracker's hardware and a listing of their respective HP part numbers.