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MODEL 6000

Inchworm® Motor Controller

Instruction Manual

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Chapter 1 - Introduction

Burleigh Instruments Inc. thanks you for choosing our Model 6000 Inchworm® Motor Controller. It's design has been optimized for the operation of Burleigh's 700 series and LTS/LTO series Inchworm Motors.

Burleigh Instruments introduced Inchworm Motor systems in the early 1970's. These unique piezoelectric devices produce ultra-high resolution linear motion with no backlash or leadscrew errors. They have been found indispensable in a wide range of applications including fiber optic alignment, disk drive media verification, and cellular recording.

Please take time to familiarize yourself with the 6000 system by reading this manual and examining each of the system components as it is described. Failure to correctly install and operate the system may result in damage to the controller and/or motors and can create hazards to personnel.

CAUTION: The 6000 Controller is a high voltage, high current device. Contact with internal high voltage components can be extremely dangerous. **NEVER** service the controller, cabling, or other connected components with the line power connected.

CAUTION: The 6000 Controller will maintain high voltage levels for some time after the power is removed. Always wait at least 60 seconds after disconnecting power before removing any covers, circuit boards, cables, etc. for service.

CAUTION: During normal operation certain internal components of the 6000 Controller may become hot. Use care during service operations to avoid burns.

CAUTION: Never connect or disconnect ANY cables from the 6000 while the power is on. This includes Inchworm Motor cables, Encoder cables, Communication cables, etc. Failure to observe this caution may result in damage to the 6000 and/or associated computer systems. Burleigh Instruments assumes no liability for this type of damage which will additionally void the product warranty.

INITIAL TEST

IMPORTANT: Before plugging in the line cord confirm that the rear panel voltage selector position matches the available line voltage. Incorrect setting can cause permanent damage to the system.

Do NOT connect an Inchworm Motor to the Controller until you have read the Installation section of this manual and followed the instructions contained therein. This initial test is performed with *nothing but the line cord connected* to the Controller.

After connecting the line cord turn the instrument on using the toggle switch located on the rear panel. The POWER and HV LEDs on the front panel should be illuminated.

Should your instrument fail this initial check please contact Burleigh Instruments, Inc. or your local representative for further instructions.

BURLEIGH QUALITY CONTROL

Your Model 6000 Inchworm Controller has been inspected, tested, calibrated, and burned-in at elevated temperatures before shipment. It is conservatively designed and should provide years of trouble free operation. In the event of any problem please contact Burleigh for instructions. Our Customer Service Department is always ready to help with advice, parts, and repair services.

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Chapter 2 - System Overview

There are four general configurations of 6000 series Inchworm Motor Controllers, namely Open Loop, Level I Closed Loop, Level II Closed Loop, and OEM. They differ mainly in how they interface with control devices.

The first type of system is the Open Loop system, designated Model 6000. This system is interfaced via the Manual Port. Inputs to this port are TTL level signals which actuate the primitive Inchworm Motor operations. This port directly interfaces with the model 6003 Joystick and the model 6005 handset for manual control. Note that all clock signals controlling motor operation are generated externally to all 6000 series controllers. The Manual Port accepts inputs only. No data is output.

Closed Loop controllers accept input from a position encoding device which monitors displacements of an Inchworm Motor or the attached load. The systems permit taking steps of known length and the maintenance of position under varying load. The front panel buttons and display permit setting and monitoring the various parameters.

The Level 1 Closed Loop system is designated Model 6100. TTL control of primitive functions is similar to that described for the Model 6000 controller. Several additional input lines are provided on the Manual Port however communication is still unidirectional. External control capabilities in these two configurations are quite limited. For full external control the Level II system or one of the 7000 series controllers is recommended.

The Level II Closed Loop system is designated Model 6200. Level II is used only in the closed loop configuration as the enhanced interface would be of little benefit in an open loop configuration. Level II includes a more sophisticated port which allows bi-directional information transfer. An external control device can have greater control over the movements of the Inchworm Motor. In addition to receiving position information from the encoder the port permits monitoring of limit switches, Inchworm Motor status, jumper positions, and a number of other useful parameters.

Models 6100 and 6200 may be operated via signals provided by the Model 660 PCIC interface card which is easily installed in an IBM-PC/XT or compatible. In the case of a model 6200 controller this provides high level language control allowing the development of sophisticated motion control programs. Note that communication is performed over a Burleigh specified bus and that RS-232 or IEEE-488 communication is not available on the 6000 family of controllers (though these functions can often be obtained through the host computer if it is necessary to communicate with other equipment).

The fourth and final configuration of the 6000 Series Controllers is the OEM module form. The power supply and all cards are available separately for installation in OEM equipment. Many different configurations are possible. Contact Burleigh for more details.

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Chapter 3 - Installation

CAUTION: Never attach an Inchworm motor to a Controller with the power switched on. Permanent damage may occur to both systems.

CAUTION: Before switching on the Controller be sure that the proper line voltage selection has been made and that the proper fuse is installed.

LOCATION

The Model 6000 Inchworm Controller should be located in a convenient location observing the following restrictions:

1. Be sure that there is sufficient room around the chassis for proper cooling and that the vents are not blocked.

2. If the unit is to be operated with the Burleigh Model 6005 Handset or Model 6003 Joystick note that the cables for those devices are 6 feet in length. Locate the Controller, experiment, and operator positions to permit adequate access to all components.

3. Inchworm motors are supplied with 6 foot long cables. If the experiment requires that motors be operated at greater distances from the Controller a Model 7011-xx Motor Extension Cable must be used. 'xx' signifies cable length to a maximum of 50 feet. See the catalog for available lengths.

4. If Encoders are located more than 6 feet from the Controller the Remote Encoder Box Option must be used (Closed Loop systems only).

CONNECTING INCHWORM MOTORS

Turn off the power switch located on the rear panel of the controller. (This is the rocker switch on the lower left side of the rear panel when viewed from the rear.) Push the connector on the Inchworm motor's cable onto one of the connectors on the rear of the Controller marked DEVICE. Be sure to push the connectors fully together so that the latches on the connectors lock.

For Closed Loop systems push the connector on the Encoder's cable onto the rear panel chassis connector marked ENCODER. This connector is located adjacent to the DEVICE connector and under the label indicating an axis number.

CONNECTING THE MODEL 6003 JOYSTICK

Turn off power to the Controller. Plug one end of the cable into the Controller's rear panel MANUAL PORT connector and secure it using the two capture screws located on the connector. Plug the other end of the cable into the connector located at the rear of the Joystick and secure it in the same manner as the other cable end.

CONNECTING THE MODEL 6005 HANDSET

Turn off power to the Controller. Plug the connector on the Handset cable into the Controller's rear panel MANUAL PORT connector. Secure the connector with the two capture screws located on the connector.

INTERFACING TO ENCODERS

The Model 6000 Controller can interface with three different types of quadrature encoder signals, namely Differential TTL, Analog, and Single-Ended TTL. Quadrature Analog is standard with the other interfaces available from the factory or as user installed conversion kits.

NOTE: The rear panel connectors are labeled as to encoder type but are otherwise identical. It is important that the user check that the proper encoder/interface combinations are used.

DIFFERENTIAL QUADRATURE *ANALOG INTERFACE*

All Burleigh 0.5 micron encoders use this interface. The interface may be identified by observing that there is a piggyback circuit board installed on the Counter/CPU circuit board. In addition the back panel of the Controller may have an ANALOG label indicating the type of interface. Connection is made by plugging the encoder's 9 pin connector into the appropriately labeled rear panel connector on the Controller, as always with the power disconnected.

The maximum cable length from encoder to Controller is 2 meters. If the application requires distances in excess of this the Differential TTL Interface must be used along with the Model 7006 Remote Encoder Box and the necessary extension cable.

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DIFFERENTIAL QUADRATURE
TTL INTERFACE

This interface is used with all remote encoder installations and with all 0.1 micron Heidenhain systems. Both the Burleigh Remote Encoder Box and the Heidenhain EXE 702 Encoder Box have the same TTL output signals, and plug directly into this interface. The interface is identified by observing two DS8820A integrated circuits installed in sockets U18 and U19 on the Counter/CPU circuit board. The rear panel of the Controller will be labeled "DIF/QUAD" to indicate the presence of this interface.

Connections are made to the Remote Encoder Box as follows:

Turn off power to the controller. Identify the Encoder Extension Cable by it's 7007-x label and plug the female end of this cable into the ENCODER socket on the controller. Note that the connector polarity is always determined based on the presence of pins or sockets, NOT on the style of the housing. Plug the other end of the Encoder Extension Cable into the connector on the Remote Encoder Box. The encoder cable from the Inchworm motor is connected to the remaining connector on the Remote Encoder Box.

WARNING: Do NOT plug the Remote Encoder Box into a DEVICE connector on the controller. Connection to a DEVICE connector will result in damage to both the controller and the Remote Encoder Box. This type of damage is not covered under the device warranty.

Connection is made to the Heidenhain EXE 702 Encoder Box by simply plugging the cable from the Heidenhain into the DEVICE connector on the 6000.

SINGLE-ENDED QUADRATURE
TTL INTERFACE

This type of interface is used with ACCURITE 1 micron encoders. The interface is identified by observing that the sockets U18 and U19 on the Counter/CPU circuit board contain component headers labeled 04077-3. In addition the rear panel of the Controller will bear a SINGLE/QUAD label. Connection is made by removing power and then plugging the encoder cable into the ENCODER socket on the Controller.

SELECTING DISPLAY RESOLUTION

If a Closed Loop Controller is equipped with a Digital Display the resolution jumpers on the Counter/CPU circuit board must be configured to match the resolution of the encoder being used such that the digital display indicates the correct distances. The jumpers may be set for encoders with 0.01, 0.02, 0.05, 0.1, 0.2, 0.5, and 1.0 micron resolution. Note that the Differential Quadrature TTL Interface has the highest EMI rejection. See Appendix B for jumper locations and settings.

LINE VOLTAGE SELECTION

Line Voltage selection is made by means of a two position rotary switch located on the rear panel of the Controller. The switch is easily rotated with a coin or small screwdriver. Voltage selection is accomplished by rotating the slot in the switch such that it points toward the appropriate nominal line voltage as indicated on the label surrounding the switch.

NOTE: Model 6000 Controllers intended for sale in the USA and Europe have a sticker indicating nominal voltages of 118 and 236 volts. The range of line voltages permitted for these switch settings is 107-129 volts and 213-259 volts respectively.

NOTE: Model 6000 Controllers intended for sale in Japan have a sticker indicating nominal voltages of 100 and 200 volts. The permissible voltage ranges for these settings are 90-110 volts and 180-220 volts respectively.

LINE VOLTAGE CONVERSION

One can easily convert any Model 6000 Controller chassis for the alternate set of operating voltages. This is accomplished by changing the position of two of the wires on the transformer. The procedure is as follows:

1. Disconnect line power to the Controller. Wait at least 5 minutes before proceeding so stored electrical energy can dissipate.

2. Remove the screws securing the top cover of the Controller and lift the cover off.

3. With the front panel of the Controller facing you the Power Supply is located on the right side of the chassis. Locate the Transformer on the Power Supply and its lugs labeled P1, P2, P3, P4, P5, and P6. See Appendix B.

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NOTE: For either chassis configuration P3 and P6 will have blue and white wires connected respectively.

4a. For a chassis configuration to be used in Japan connect the black wire to P2 and the brown wire to P5.

4b. For a chassis configuration to be used in areas outside of Japan connect the black wire to P1 and the brown wire to P4.

5. Replace the blank connectors on the unused transformer terminals.

6. Replace the Controller's top cover and secure with the screws.

CAUTION: If the Controller chassis has been converted from its factory setting the sticker on the rear panel indicating voltage selections and fuse ratings will be incorrect. To avoid mistakenly damaging the unit be sure to correctly label the Controller.

NOTE: Contact Burleigh Instruments or your local representative for replacement labels.

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Chapter 4 - Operation

Model 6000 Controllers do not contain an internal clock for sequencing the piezoelectric elements contained in Inchworm motors. In order to operate the controller and thus the motors clock signals must be supplied by an external source such as a Model 6005 Handset, a Model 6003 Joystick, or user supplied TTL signals.

NOTE: Open Loop Controllers may only be operated via Joystick, Handset, or user supplied TTL signals. For more information please refer to Sections 5.B., 5.C., and 5.D.

FRONT PANEL

The front panel switches and displays of closed loop Controllers permit setting and/or reading a number of useful parameters.

SETTING TRAVEL

TRAVEL is the distance in user selected units of μM, MM, or IN that an Inchworm motor will move when a STEP is taken. It is set using the front panel switches as follows:

1. Repeatedly press the DISPLAY switch until the TRAVEL light is illuminated. The Controller is now in the input mode and the other switches have their alternate functions (as labeled under each button).

2. Pressing the up arrow switch will cause the right most digit to begin automatically incrementing in value. When the digit increments past '9' the digit to its left will increment by one while the first digit continues incrementing.

3. When the desired TRAVEL distance is indicated pressing the STOP switch will halt the incrementing.

4. If the display increments beyond the desired TRAVEL distance pressing the down arrow switch will cause the digit which is currently incrementing to begin decrementing instead.

5. The display can be cleared at any time by pressing the CLEAR switch.

6. In order to get the system into operating mode press the DISPLAY switch until the indicators are extinguished and motor position is displayed.

NOTE: The process just described is only suitable for setting relatively small values of TRAVEL since the rate of automatic incrementing is slow. The following method is suggested for setting large TRAVEL values.

1. Repeatedly press the DISPLAY switch until the TRAVEL light is illuminated. The Controller is now in the input mode and the other switches have their alternate functions.

2. Press the CLEAR switch to blank the display.

3. Repeatedly press the up arrow switch until the left most digit in the number to be input is illuminated and begins automatic incrementing.

NOTE: It is normal for digits to the right of the selected digit to be filled with ones or other numbers depending upon the rapidity with which the up arrow switch was pressed.

4. Press the CLEAR switch to clear the display. Note that the selected digit is still auto incrementing and that the numbers to the right of it are all zero.

5. When the selected digit is at the desired value press the STOP switch.

NOTE: If the selected digit proceeds beyond the desired number, before pressing the STOP switch pressing the down arrow switch will cause that digit to begin decrementing thus providing a second chance. Once again be sure to press the STOP switch when the desired value is displayed.

LOOP:

If you wish to set digits to the right of that already set proceed as follows, looping back to the start of the procedure until all of the desired digits are set.

1. Repeatedly press the up arrow switch until the left most digit remaining to be input is illuminated and begins automatic incrementing.

2. When the selected digit is at the desired value press the STOP switch.

NOTE: If the selected digit proceeds beyond the desired number, before pressing the STOP switch pressing the down arrow switch will cause that digit to begin decrementing thus providing a second chance. Once again be sure to press the STOP switch when the desired value is displayed.

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3. When the desired number is displayed in full press the DISPLAY switch until the M.SPEED, TRAVEL, and DWELL lights are off.

SETTING M.SPEED AND DWELL

NOTE: Values of M.SPEED and DWELL are factory preset to values suitable for most applications. Under ordinary circumstances it should not be necessary to reset their values.

If Inchworm motors are used to move large inertial loads it may be observed that when a motor is rapidly brought to rest it continually seeks to correct its position. This self correcting of position may interfere with your experiment and can be eliminated or reduced by adjusting M.SPEED and DWELL. When M.SPEED is reduced the speed of the Inchworm motor in making corrections is slowed thus minimizing inertial effects. In addition, if the load tends to 'ring' setting the DWELL time to a larger value will permit the system to settle before a correction is made.

CAUTION: M.SPEED and DWELL are adjusted by turning potentiometers inside the Controller while the power is on. High voltages are present inside the Controller when the adjustments are being made so care must be taken in keeping fingers, tools, and jewelry away from the Controller except as indicated in these instructions.

CAUTION: Do not work alone. High voltages are present whenever power is applied to the Controller.

To adjust the M.Speed and DWELL values proceed as follows:

1. Turn off power to the Controller.

2. Remove the screws securing the top cover of the Controller and lift off the cover.

3. Locate the M.SPEED and DWELL potentiometers on the circuit boards. See appendix B.

4. Turn on power to the Controller. Remember that HIGH VOLTAGE is present at this time.

NOTE: The following is written for adjusting M.SPEED. In order to set DWELL proceed in exactly the same manner substituting 'DWELL' for 'M.SPEED' in all that follows.

5. Repeatedly press the DISPLAY switch until the M.SPEED indicator is illuminated and its value is displayed.

6. Slowly rotate the M.SPEED potentiometer until the desired value is displayed.

CAUTION: In order to avoid electrical shock hazard be sure to use an electrically insulated screw driver or a special potentiometer adjusting tool.

7. Turn off power to the Controller and replace the cover securing it with the screws.

MODEL 6003 JOYSTICK

The Joystick permits independent or simultaneous operation of up to 3 Inchworm motors with a suitably configured Model 6000 Controller. It is connected to the Controller's rear panel MANUAL port.

Deflecting the Joystick forward or backward operates the Axis 1 motor while moving it side to side operates Axis 2. Actuation of Axis 3 is accomplished by rotating the knob located on the end of the Joystick shaft. In all cases the speed of the Inchworm motor is a function of the amount of deflection (or rotation) of the Joystick.

The SPEED switch selects the maximum speed which will be produced when the Joystick is fully activated. In the HIGH position the motor speed may be varied continuously from 0 to about 2mm/sec while in the LOW position motors can be run from 0 to about .016mm/sec.

NOTE: Although both switch settings will permit low speed motor operation the LOW setting provides much better Joystick resolution and therefore control when operating below .016mm/sec.

NOTE: When the Joystick is in its center position it generates the clock for the GO HOME function of the Controller. The frequency generated is 400-550 Khz and will drive the Inchworm at full speed.

The ON/OFF switch enables or disables all axes of Joystick operation. When 'OFF' the GO HOME clock is no longer asserted.

The directional sense of the Joystick may be changed such that Inchworm motors move in the 'logical' direction for a particular application. This is accomplished by changing the position of jumpers on the bottom of the Joystick's circuit board.

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To change the jumpers:

1. Turn off power to the Controller.

2. Remove the Model 7005 cable from the Joystick by loosening the capture screws located on the connector.

3. Remove the three socket head screws at the base of the Joystick and remove the Joystick cover assembly from the chassis.

4. The jumpers can be adjusted for each axis as shown in appendix B.

5. After setting the jumpers replace the socket head screws and the Model 7005 cable.

MODEL 6005 HANDSET

The Handset permits operation of a single Inchworm motor on any Controller axis. The axis which will be operated is selected with the three position switch located at the lower left of the Handset. The Handset is connected to the Controller's rear panel MANUAL port using its permanently connected cable.

The speed knob located at the upper right of the Handset controls the speed at which Inchworm motors will operate when the FORWARD or REVERSE buttons are pushed. With the control fully counterclockwise motor speed will be 4-40nm/sec. When the control is rotated fully clockwise motor speed will be about 2mm/sec.

The MODE switch, located adjacent to the FORWARD button provides access to three manual modes of operation:

JOG mode causes the selected Inchworm motor to run only when the FORWARD or REVERSE button is depressed.

OFF mode disables the Handset.

In STEP mode momentarily depressing the FORWARD or REVERSE button causes the appropriate Inchworm motor to move the distance selected by the Controller's TRAVEL function.
NOTE: The Handset generates a GO HOME clock which varies with Speed Knob position.

The directional sense of the Handset may be changed such that Inchworm motors move in the 'logical' direction for a particular application. This is accomplished by changing the position of jumpers on the bottom of the Handset's circuit board. See appendix B.

To change the jumpers:

1. Turn off power to the Controller.

2. Remove the four Phillips head screws located on the base of the Handset and then remove the case.

3. Change the jumper positions as indicated in the figure.

4. Replace the case and secure with the screws.

NOTE: The STEP function cannot be used with Open Loop systems.

NOTE: Changing the position of the Mode switch or the Axis Select switch while an Inchworm motor is operating will abort the operation and stop the Inchworm motor.

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Chapter 5 - Interfacing

LEVEL I TTL OPEN LOOP INTERFACE

The Level I TTL Open Loop Interface permits user supplied TTL level signals to control the primitive operations of Inchworm motors. These functions are the motor's speed, direction of travel, start, and stop. The Interface permits operation of as many as 3 Inchworm motors either individually or simultaneously.

The Interface is accessed through a 25 pin "D" type connector labeled MANUAL PORT which is located on the rear panel of the Controller. In addition to accepting TTL signals for motor control the Interface can supply +5 and +12 volts for use in powering external circuits. Two ground lines are also provided.

CONNECTOR PINOUT

1) +5 Volts	14) +5 Volts
2) Ground	15) Ground
3) -12 Volts	16) +12 Volts
4) Port OFF/ON*	17) Open Loop Status Axis 1
5) Reserved	18) ENABLE* Axis 1
6) HALT/RUN* Axis 1	19) FWD/REV* Axis 1
7) Clock Axis 1	20) Open Loop Status Axis 2
8) Reserved	21) ENABLE* Axis 2
9) HALT/RUN* Axis 2	22) FWD/REV* Axis 2
10) Clock Axis 2	23) Open Loop Status Axis 3
11) Reserved	24) ENABLE* Axis 3
12) HALT/RUN* Axis 3	25) FWD/REV* Axis 3
13) Clock Axis 3	

DESCRIPTION OF PIN FUNCTIONS

+5 VOLT POWER SUPPLY

The regulated power found on pins 1 and 14 of the interface connector are tied together and can supply the user with +5 volts ±4% with an absolute maximum current draw of 750 milliamps. Output ripple at 120 Hz will be no more than 800 microvolts. The output is both short circuit and thermally protected. Note that although this supply originates on the 601 driver board it is separate and distinct from the regulated +5 volts that powers the 601 board.

+12 VOLT POWER SUPPLY

The regulated supply found on pin 16 of the interface connector supplies the user with +12 volts ±4% with an absolute maximum current draw of 50 milliamps. The 120 Hz output ripple will be no more than 23 millivolts. The supply regulator is protected from thermal overload and short circuits. This supply also originates on the 601 driver board but it is separate and distinct from the regulated +12 volt supply that powers the 601 board.

-12 VOLT POWER SUPPLY

Pin 3 supplies a regulated -12 volts which will not vary more than ±4% with a maximum current draw of 45 milliamps. The 120 Hz output ripple will be no more that 4 millivolts. This supply is also protected from short circuit and thermal overload. Once again, this supply originates on the 601 driver board but it is a separate and distinct supply from the regulated -12 volts that powers the 601 board.

SUPPLY RETURN LINES

Pins 2 and 15 of the interface connector are the power supply return lines. They are common with circuit ground of the Controller circuitry. In all cases the user must connect his circuit common to these pins in order to properly operate the Controller through the Interface.

INPUT CLOCKS

The Interface provides the user with inputs to supply clock sources to the drive circuitry and thereby control the Inchworm motor shaft velocity. Separate clock inputs are provided for each axis of the Controller. Clock inputs for axes 1, 2, and 3 are located on pins 7, 10, and 13 respectively.

INPUT CLOCK CHARACTERISTICS

Each clock must be a TTL type signal with the following characteristics:

- Minimum high level input = 3.15 V
- Input current @ min high level input = -185μA
- Maximum low level input = 0.9 V
- Input current @ max low level input = -410μA
- Duty Cycle = 45% to 55%

NOTE: When referring to current a minus sign indicates current flowing out of signal pin. This convention will be followed throughout this document.

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INPUT CLOCK FREQUENCY

The maximum allowable input frequency is 500KHz. The nominal frequency in Hertz required for a desired Inchworm shaft velocity in millimeters/second is given by the following equation:

$$\text{Frequency (Hz)} = \tfrac{1}{2} \times \frac{1 \times 10^{3} \text{ steps/cycle}}{\dfrac{3.9 \times 10^{-3} \text{ mm/cycle}}{\text{Velocity (mm/sec)}} - 2 \times 10^{-4} \text{ sec/cycle}}$$

Conversely, the nominal motor shaft velocity in millimeters/second for a given input frequency in Hertz is given by the following equation:

$$\text{Velocity (mm/sec)} = \frac{3.9 \times 10^{-3} \text{ mm/cycle}}{\dfrac{1 \times 10^{3} \text{ steps/cycle}}{\text{(Frequency (Hz) } \times 2)} + 2 \times 10^{-4} \text{ sec/cycle}}$$

NOTE: Inchworm motors are individually factory tested to insure that they can achieve a minimum speed of 2 millimeter per second with a 1.5 Kg load. Maximum speed varies from motor to motor depending on load, motor efficiency, and the stability of the user input clock frequency. *Do not rely on the calculated speed if accuracy of speed is a critical factor.* Tests should be performed using the actual motors and controller channels that are intended for the final application. The Inchworm motor speed will vary over the life of the device along with several other factors. Consult the factory for more information.

INPUT CLOCK DUTY CYCLE

In order to maintain uniform shaft motion it is necessary that the duty cycle of the input clock be maintained within the boundary of 45% to 55%. The reason is that each transition of the input clock signal whether high-to-low or low-to-high will produce a clocking pulse in the 601 driver circuitry. Thus every clock transition will cause a single staircase step change. If the input clock duty cycle is not approximately 50% the staircase steps derived from input clock transitions will not occur at regular time intervals.

FORWARD/REVERSE* INPUTS

When describing the directions of forward and reverse the following convention is used:

FORWARD: Inchworm motor shaft extending out of housing.

REVERSE: Inchworm motor shaft retracting into housing.

The user can change the motion direction of the shaft by changing the state of the FORWARD/REVERSE* (F/R*) input line. A F/R* line is provided for each axis of the 6000. These are located on pins 19, 22, and 25 of the interface connector.

FORWARD/REVERSE* LINE CHARACTERISTICS

Each F/R* line must be a TTL type signal with the following characteristics:

- Minimum high level input = 3.15 V
- Input current @ min high level input = -150μA
- Maximum low level input = 0.9 V
- Input current @ max low level input = -410μA
- Minimum time signal must be high or low for level to be detected = 500nS

FORWARD/REVERSE* LINE FUNCTION

In order to cause the Inchworm motor shaft to move in the forward direction the F/R* line must be set to the logic "1" or "high" state. If the reverse direction is desired then the F/R* line is set to the logic "0" or "low" state.

FORWARD/REVERSE* INPUT FILTERING

Digital filtering is employed on the 601 Driver Board in order to reduce noise on the F/R* line. The filtering will discriminate between a valid input level and noise pulses up to 500nS in duration. To be detected the input level desired must be held at that level for at least 500nS. When a change in the state of the F/R* line occurs the actual change in Inchworm motor shaft direction will not occur until at least a 500nS time period plus the length of time it takes until the next input clock transition (after the 500nS time period) occurs.

HALT/RUN* INPUT LINE

The next input line to be discussed in the open loop section is the HALT/RUN* (H/R*) line. As the name implies this line is used to start and stop the Inchworm motor depending on the state of the line. Inputs are found on pins 6, 9, and 12 of the interface connector.

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HALT/RUN* LINE CHARACTERISTICS

Each H/R* line must be a TTL type signal with the following characteristics:

- Minimum high level input = 3.15 V
- Input current @ min high level input = -150μA
- Maximum low level input = 0.9 V
- Input current @ max low level input = -410μA
- Minimum time signal must be high or low for level to be detected = 500nS

HALT/RUN* LINE FUNCTION

To run the Inchworm motor one must set the H/R* line to a logic "0" or "low" state. In order to halt the motor the H/R* line must be set to the logic "1" or "high" state.

HALT/RUN* LINE INPUT FILTERING

Digital filtering is employed. The filtering discriminates between valid input levels and noise pulses up to 500nS in duration. Thus, the H/R* line must be at the desired level for at least 500nS in order for that level to be detected. Due to this filtering a delay of about 500 nS plus the time it takes after this 500nS time period for an input clock transition to take place will occur before a change in the state of the H/R* line will take affect.

HALT/RUN* LINE EMULATION
VIA CLOCK INPUT

One can use the clock input to emulate the HALT/RUN* line. With the HALT/RUN* line to the "RUN" mode one can start and stop the Inchworm motor by gating the input clock on and off. To run the Inchworm motor in this fashion the clock will operate as normal. To halt the clock line must be inhibited. This is an alternate method of starting and stopping the Inchworm motor.

ENABLE* INPUT LINES

Enable lines for the three axes are located on pins 18, 21, and 24 of the interface connector.

ENABLE* INPUT LINE CHARACTERISTICS

Each Enable line must be a TTL type signal with the following characteristics:

- Minimum high level input = 3.15 V
- Input current @ min high level input = -150μA
- Maximum low level input = 0.9 V
- Input current @ max low level input = -410μA

ENABLE* LINE FUNCTION

The ENABLE* input line is used to enable or disable an axis from running. To enable an axis its corresponding ENABLE* line must be tied to a logic low. A logic high will disable an axis from running.

The ENABLE* line can be used as an "emergency stop" for each axis or as a global "emergency stop" if all enable lines are tied together. The ENABLE* lines should not be used as a run/stop line since the ENABLE* lines have no digital filtering on their inputs as described in the Forward/REVERSE or the HALT/RUN* sections of 5.D. It is recommended that these lines be hard wired to the "enable" state and remain in that state for normal operation.

PORT OFF/ON*

The Port OFF/ON* line is an input line that enables and disables the Level One interface port. It is located on pin 4 of the interface connector.

PORT OFF/ON* INPUT
LINE CHARACTERISTICS

The Port OFF/ON* line must be a TTL type signal with the following characteristics:

- Minimum high level input = 3.15 V
- Input current @ min high level input = -150μA
- Maximum low level input = 0.9 V
- Input current @ max low level input = -410μA

PORT OFF/ON* FUNCTION

The Port OFF/ON* line is used to inhibit the entire Level One Open Loop Interface. When in the logic "0" or "low" state, the port is active and will operate as explained in this document. When the Port OFF/ON* line is in the logic "1" or "high" state the Port is inactive and any activity on the input lines will be ignored. However, the +5V, +12V and -12V supplies will function normally. This input must not be used as an "emergency stop" input. For open loop operation this input must be tied to a logic "0" (port "on") and remain there for proper operation.

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OPEN LOOP STATUS OUTPUT LINE

The OPEN LOOP STATUS line is an output that in the open loop mode will always be high. No active information is available on this line in the open loop mode.

LEVEL I CLOSED LOOP INTERFACE

The Level I Closed Loop Interface permits user supplied TTL level signals to control the primitive operations of Inchworm motors. These functions are the motor's speed, direction of travel, starting, and stopping. In addition, since the closed loop mode includes encoded information relative to the motor's shaft position it is possible in this mode to take known length steps and to maintain a position under changing load. The Interface permits operation of as many as 3 Inchworm motors either individually or simultaneously.

As with the Open Loop Interface described above the Closed loop Interface is accessed through a 25 pin "D" type connector labeled MANUAL PORT which is located on the rear panel of the Controller. In addition to accepting TTL signals for Inchworm motor control the Interface can supply +5 and +12 volts for powering external circuits. Two ground lines are also provided.

All of the closed loop functions are performed in hardware via the 605 counter/processor board (from now on referred to as the 'counter' board).

CONNECTOR PINOUT

The Level One Closed Loop Interface connector pinout is shown as follows:

1) +5 VOLTS	14) +5 VOLTS
2) GROUND	15) GROUND
3) -12 VOLTS	16) +12 VOLTS
4) PORT OFF/ON*	17) PROCESSOR ACTIVE* AXIS
5) TRIGGER AXIS 1	18) STEP AXIS 1
6) HALT/RUN* AXIS 1	19) FWD/REV* AXIS 1
7) CLOCK AXIS 1	20) PROCESSOR ACTIVE* AXIS
8) TRIGGER AXIS 2	21) STEP AXIS 2
9) HALT/RUN* AXIS 2	22) FWD/REV* AXIS 2
10) CLOCK AXIS 2	23) PROCESSOR ACTIVE* AXIS
11) TRIGGER AXIS 3	24) STEP AXIS 3
12) HALT/RUN* AXIS 3	25) FWD/REV* AXIS 3
13) CLOCK AXIS 3	

The following lines remain unchanged between Open Loop and Closed Loop Interfaces. The descriptions provided in the previous section still apply.

+5, +12, and -12 Volt Power Supplys

Supply Return Lines

Input Clocks

FORWARD/REVERSE* Inputs

Port OFF/ON*

The following lines have different functions from the Open Loop Interface, and are described below:

PROCESSOR ACTIVE* OUTPUT LINE

The PROCESSOR ACTIVE* (or PA*) line is an output signal from the counter board that alerts external circuitry connected to the Level One closed loop interface that a processor is present to oversee closed loop operations. There is a PROCESSOR ACTIVE* line for each axis of the controller. They are located on pins 17, 20, and 23 of the interface connector.

PROCESSOR ACTIVE* CHARACTERISTICS

Each PA* line is a TTL type signal with the following characteristics:

- Minimum high level output = 3.7 V
- Max. output @ min high level output = -7.9mA
- Maximum low level output = 0.4 V
- Max. output @ max low level output = 6 mA

HALT/RUN* Line Emulation Via Clock Input

WARNING: It is strongly suggested that one does not start and stop the motor in closed loop operation by tying the HALT/RUN* line to "run" and gating the clock on and off. Performing this action would start and stop the motor without performing a TRIGGER. This would confuse the processor as to what function is being performed and will result in unpredictable closed loop operation. Also, when an axis is in the closed loop configuration a software "stall test" is continuously performed. By gating the clock off to stop the motor the processor thinks the axis is still in the run mode. However, the axis has stopped due to the clock being gated off. After approximately 120 seconds the "stall routine" will display an error when in fact no stall error has occurred.

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STEP MODE INPUT

One of the unique functions of a closed loop positioning system is its ability to move preset distances (steps) upon command.

STEP MODE LINE CHARACTERISTICS

Each STEP line must be a TTL type signal with the following characteristics:

- Minimum high level input = 3.15 V
- Input current @ min high level input = -150μA
- Maximum low level input = 0.9 V
- Input current @ max low level input = -410μA

STEP INPUT LINE FUNCTION

The STEP input line gives the Controller the ability to perform a step function. When the STEP line is true which is a logic "1", the axis will be in the STEP mode of operation. If the STEP line is true and the HALT/RUN* line is "RUN", the next occurrence of TRIGGER will cause the axis to move to a new position based on the step size loaded into the front panel display in the direction selected by the FORWARD/REVERSE* line.

When the STEP input line is false (logic "0"), the axis will run or halt according to the HALT/RUN* line and TRIGGER line. It is not running to a target, merely obeying the HALT/RUN* line. The only closed loop operation that takes place when the STEP line is false is MAINTENANCE. MAINTENANCE is the function by which the Inchworm will maintain the position where it is halted. MAINTENANCE will also function when the STEP line is true.

NOTE: In closed loop mode every change of state of the control input lines must be accompanied by a valid TRIGGER (next section).

TRIGGER INPUT LINE

For the processor to oversee closed loop operations it must know the state of the input lines in order to determine the proper course of action. This is accomplished by using the TRIGGER input line.

The TRIGGER line is an edge sensitive input signal that is used to interrupt the processor in order to alert it to the fact that a change has occurred on the Level One closed loop input lines and that it must act upon the new input states.

A TRIGGER signal has no effect on the Controller when the PORT OFF/ON* input line is in the "off" state or when the PROCESSOR ACTIVE* output line is false (logic "1" or "high"). TRIGGER lines are located on pins 5, 8, and 11 of the interface connector.

TRIGGER INPUT LINE CHARACTERISTICS

The TRIGGER line is a TTL type signal with the following characteristics:

- Minimum high level input = 3.15 V
- Max. input @ min. high level input = -150 μA
- Maximum low level input = 0.9 V
- Max. input @ max. low level input = -410 μA

Each TRIGGER line connects directly to the processors interrupt input. This interrupt is a "transition-activated" interrupt with the active transition from high to low. The steady state level must be high. For proper detection the timing rules as shown in the figures must be observed.

TRIGGER INPUT LINE FUNCTION

In order to perform a closed loop function with the Level One closed loop interface the user must first establish the desired levels of the STEP line, the FORWARD/REVERSE* line, the HALT/RUN* line and the CLOCK input line. *(Keep in mind that each axis of the Controller has these signals along with its own TRIGGER line so different combinations of closed loop and open loop motions can be accomplished with each axis).* Next, the TRIGGER line goes active according to the rules described in the previous section. When the TRIGGER function is detected the processor is interrupted, reads the state of the input lines, and directs the counter hardware to perform the desired function as dictated by the input lines. The input lines can be set to their desired levels in any order as long as they are at the desired level when the TRIGGER line is detected.

TRIGGER EXAMPLE - RUN FUNCTION

Suppose one wants to run an Inchworm in the forward direction in closed loop mode. First, the external hardware must make sure that the PROCESSOR ACTIVE* line is true. Next, the STEP line is set false (logic "0"). The FORWARD/REVERSE* LINE is set to "forward" and the HALT/RUN* line is set to "run". An active edge on the TRIGGER input will initiate the "run" function.

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To stop the motor, the HALT/RUN* line is set to the "halt" state and the TRIGGER line once again receives an active edge to perform the "halt" function. If the motor reaches a limit, all one needs to do is change the state of the FORWARD/REVERSE* line and execute a TRIGGER.

TRIGGER EXAMPLE - STEP MODE

STEP mode differs from just running a motor using the HALT/RUN* line in that the Inchworm is searching for a target. This motion is actually a "move relative". The target is based on the position the Inchworm is in and the step size loaded into the axis before the step is executed. The step size is determined by the number that is loaded via the front panel display by the user. When a step is executed , the processor adds the step size to the current shaft position and loads this new number into the target register. This number is the new position the Inchworm will seek. The STEP function is a "move relative" motion type because the motor is moving a predetermined distance relative to the current shaft position.

STEP MODE SETUP

To place an axis in the step mode, the STEP line must be set to the logic "1" state.

NOTE: It is not necessary to set this input to the desired state before pulsing the TRIGGER line. It can be set at the same time as the other control inputs and read when a TRIGGER occurs.

STEP MODE EXECUTION

When step size is loaded and the STEP line set true, the remaining inputs (FORWARD/REVERSE*, HALT/RUN* AND CLOCK) can be set accordingly. Upon receiving a TRIGGER, the motor will move from its starting position in the direction given by the FORWARD/REVERSE* line by a distance given by the step size.

If additional TRIGGERS are executed before the motor reaches its original target, additional step sizes will be added to the ultimate target. The direction line determines whether the step size is added to the original target or subtracted from the original target.

HALTING IN THE MIDDLE OF A STEP

If the motor is executing a step and the HALT/RUN* line is set to the halt mode and TRIGGERed, the Inchworm motor will stop and maintain the position it was at when the halt TRIGGER was received. Any additional steps taken will be taken relative to this new maintained position.

HITTING A LIMIT IN STEP MODE

When a motor reaches a limit it is important to remember that as far as the closed loop hardware is concerned the motor is still running to a target. If during execution of step the motor reaches a limit before reaching its target the motor will obviously stop. However, if additional step triggers occur in the same direction as the limit these steps will be added to the target as if the motor were still running. The motor cannot move because the new target is physically outside its range of motion. In order to move the motor from the limit after this happens one must take the necessary number of steps in the opposite direction until the new target is within the range of the motor's physical limits.

LEVEL II CLOSED LOOP INTERFACE

The Level II interface provides additional functions and features not available with the Level 1 configuration. In addition to providing the primitive Inchworm motor control functions this interface permits bi-directional data transfers by means of a TTL bus. The bus is capable of multiple axis and multiple chassis control.

The Level II Option of the 6000 is configured in hardware by using a different Counter/CPU PCB as well as a piggyback PCB for the Motion Control/Driver PCB. This version of the Counter/CPU board contains all the hardware drivers/receivers and firmware for the micro-controller to provide an auxiliary TTL interface. The MC/HV piggyback PCB contains the hardware necessary for providing closed-loop velocity control.

The Level II option provides the following Level I control functions:

- Run forward, run reverse
- Halt
- Run mode/step mode
- Step forward, step reverse

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In addition the following functions are made available:

- Load absolute target value
- Load step size
- Read current position
- Read Inchworm motor & controller status
- True speed enable/disable
- Control maintenance mode
- Stall motor test function
- Zero reference & counter clear

OPERATION

The 6200 controller can be used with any host computer that has a TTL digital I/O interface by properly connecting the Auxiliary port to the host. The host can then control up to 3 axes per chassis, or by connecting multiple chassis together the host can control up to 15 axes. For long haul TTL interconnections (greater than 2 meters), the 6200(s) can be connected to the host by means of external differential line drivers/receivers. The software in the host must provide the proper timing signals to establish communication with the 6200. See the sections on Software Protocol Definitions, Hardware Protocol Definitions, and Pin Descriptions.
The 6200 controller can be used with or without a digital display front panel. All of the digital display functions may be accessed through the auxiliary port.

FRONT PANEL LIMIT DISPLAY

When using the Limit Display front panel the host can read both the position and the condition of the limits by means of the appropriate function codes. Travel Size can also be downloaded from the host to the 6200.

The Counter/CPU PCB has two test points for monitoring Mspeed (maintenance speed) and Dwell time. These are used with an oscilloscope as follows:

In the case of Mspeed the probe is connected to TP1 while adjusting pot RV1 for the required frequency. The resultant Mspeed can be calculated from the following formula:

$$\text{MSPEED } (\mu\text{M/sec}) = \frac{3.9\ \mu\text{M/cycle}}{\frac{1000\ \text{steps/cycle}}{2 \times f\ \text{steps/sec}} + .0002\ \text{sec/cycle}}$$

where f is the measured frequency at the test point TP1. The frequency can be adjusted down to zero to permanently turn off the maintenance function, but this is not recommended if using the Level II auxiliary port. The proper function code should be used to disable the maintenance function.

The Dwell time can be measured via the signal on test point TP2 while adjusting pot RV2 clockwise to increase the dwell time. The pulse is a positive signal and must be enabled with the proper function code to cause the dwell timer to be automatically triggered. Be sure to toggle the dwell test mode off before trying to operate an Inchworm motor.

DIGITAL DISPLAY FRONT PANEL

The digital display front panel operation is the same for all 6000 series controllers except for the Units function. All 6200 controllers have NVRAM (non-volatile RAM) which saves the current units of display when the controller is turned off. In addition all versions of ROM 2.xx or greater will allow the Units to be changed when in the Mspeed mode.

The digital display will also display four different flashing error messages.

1. "POS Error" will alternately flash with the position data to indicate that the position data may be in error due to EMI or encoder problems. This error message can only be cleared by resetting the counter.

2. "Error 01" will alternately flash with the position data to indicate that the CPU has detected a motor stall condition based on the current stall motor parameters. The drive signals to the motor will also b e turned off. This error message will be cleared by starting a new motor operation or clearing the counter.

3. "Error 02" will alternately flash with the position data to indicate that the NVRAM has a low battery condition and the data contained in the RAM may be corrupted. This error condition must be cleared by replacing the NVRAM IC U6.

4. "code Error" will alternately flash with the position data to indicate that the code ROM has detected a SUMCHECK error. This error condition can only be cleared by replacing the CPU ROM IC U5.

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AUXILIARY PORT

The 6200 controller can be interfaced with any host computer that has a TTL I/O capability. The host must have as a minimum one 8-bit TTL bi-directional port, one 8-bit TTL output port, and a single bit TTL input bit for a total of 17 interface signals. The bi-directional port is used for data transfer. The output port is used for 6 control lines and two strobe lines. The single input bit is the acknowledge handshake line for synchronizing the communication.

The maximum length recommended for the interface cable is 2 meters unless external RS-422 receivers/drivers (or equivalent) are used. An Output Control signal (pin 13) is available to control the receivers/drivers connected to the bi-directional port.

FUNCTIONS & FEATURES

The Level II hardware and software provide many features not available with the basic closed loop 6000. The 6100 system can only provide the step and maintenance functions with the added cost of an Encoder and Counter/CPU board.

Additional hardware in the 6200 provide a means of communicating data with a host. The components include NVRAM to store the configuration setup data.

An optional piggyback board on the Motion Control/Driver board is necessary to provide closed loop velocity control.

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FUNCTION TABLE

FUNCTION CODE DESCRIPTION

0 Execute Motor Operation
Reads three motor control lines and performs the operations:
1. Halt/Run
2. Forward/Reverse
3. Step Mode/Run Mode

1 Reset Counter
Clears the position counter. Loads a '0' into the target register for maintaining the zero position if maintenance is enabled.

2 Load Travel Size
Loads the new value into the travel (step) size register. This new value is saved in NVRAM. No motor operation takes place. Data received must be a 24 bit positive binary value.

3 Load a Target Value
Loads the new value into the target register and causes the motor to search for the target position. Data received must be a 24 bit two's complement binary value.

4 Read the Status Byte
Returns one to 4 bytes of information where each bit represents a different function such as: forward limit, reverse limit, position error, motor stall error, motor ready, and resolution. The bit values of all bytes are true high. The first byte is defined as follows:

BIT 0	position error
BIT 1	forward limit
BIT 2	reverse limit
BIT 3	motor ready
BIT 4, 5, 6	resolution
BIT 7	stall error

FUNCTION CODE DESCRIPTION

The second byte contains the following bit information:

BIT 0	manual port active
BIT 1	maintenance enabled
BIT 2	true speed enabled
BIT 3	stall test active
BIT 4	dwell test mode active
BIT 5	zero reference mark active
BIT 6, 7	unused

The third byte contains the following information:

BIT 0	rom sumcheck error status
BIT 1	low battery status NVRAM
BIT 2	unused
BIT 3	digital display units of in
BIT 4	digital display units of mm
BIT 5	digital display units of μm
BIT 6, 7	unused

The fourth byte is not used.

5 Read the Position
Returns a three byte value containing both the magnitude and sign of the current position (least to most) with the 24th bit being the sign bit. The data will be in the form of two's complement binary. A fourth byte if read is exactly the same as the first status byte in function code 4.

6 Enable Zero Reference Mark
Enables the zero reference mark on an encoder to reset the position counter and stop the motor.

7 Extended Function Code
Used to generate another function code table.

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EXTENDED FUNCTION TABLE

# EXT	FUNCTION CODE	DESCRIPTION
1	0	Maintenance Enable (Default) Enables the maintenance mode function. Whenever the motor is at the target position the closed loop control will maintain that position with zero tolerance at the user adjustable maintenance speed.
1	1	Maintenance Disable Disables the maintenance mode function. In this mode the controller will NOT maintain the target position.
1	2	True Speed Enable Enables the true speed function. The motor will begin running at a speed to match the encoder frequency with the input clock frequency if the piggyback option has been installed.
1	3	True Speed Disable (Default) Disables the true speed function. The motor will begin running at a speed determined by the input clock frequency.
1	4	Set Units Of Display On Front Panel This function is used to set the units of display on the front panel by sending a single byte data value of: 1 display units of Inches 2 display units of Millimeters 4 display units of Microns
1	5	Reserved
1	6	Set/Clear Dwell Test This is a toggle function to set/clear the dwell test mode. When the dwell test mode is active the dwell timer is repetitively triggered to aide in measuring the dwell time on the test point. Normal motor operations are disabled.
1	7	Second Extended Function Code Used to generate another function code table.

# EXT	FUNCTION CODE	DESCRIPTION
2	0	Stall Motor Test Enabled Enables the stall motor test operation. Whenever the motor is moving the micro controller will test the motion of the motor by determining the position of the motor to a tolerance and time interval. If the motor has not moved more than the specified tolerance during the specified time interval than the motor will be stopped and the stall motor error bit set in the status byte.
2	1	Stall Motor Test Disabled (Default) Disables the stall motor test function.
2	2	Set Stall Motor Test Parameters This function is used to specify the total time interval and tolerance for the stall motor test function. The first byte is the time interval between each stall test that is performed. The range of this value is 0 to 255 intervals of 10mS. The second byte is the number of consecutive times that the stall test must be true. The range of this byte is 0 to 255. The third and last byte is the tolerance of the stall motor test. The range of this byte is 0 to 255 encoder counts.
2	3	Returns the Version Number of the ROM
2	4	Reserved
2	5	Reserved
2	6	Reserved
2	7	Reserved

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SOFTWARE PROTOCOL DEFINITIONS

The following is a description of the software protocol necessary to communicate to the 6000 through the auxiliary port:

- The binary device address (axis number) must be setup on the lower four control lines (pins 14-17) with the least significant bit on pin 14.

- Next the device strobe (pin 20) is asserted and remains asserted until completion of the data transfer sequence.

- Next the function code (pins 14-16) and the motor control bits (which are required with function code 0 only) are setup on the 6 control lines. Pin 17 is the forward/reverse motor direction line, pin 18 is the motor halt/run line, and pin 19 is the step_mode/run_mode control.

- Next the data strobe (pin 21) is asserted and remains asserted until the handshake is received from the 6000.

- The 6000 micro controller processes the data and acknowledges the data transfer by asserting the ACK line (pin 12).

- The data strobe is negated after the acknowledge is received.

- If binary data is transferred to the 6000 then the byte of data is setup on the I/O bus (pins 4-11).

- Next the data strobe is again asserted until the acknowledge is received.

- The data strobe is again negated. This sequence of data setup, assertion of data strobe, acknowledge, and data strobe negation is repeated until all the data is transferred.

- The device strobe can be negated after all the bytes of data have been transferred.

- The sequence of transferring data from the 6000 to the host is similar. The same sequence is used for device address and function code. The 6000 will acknowledge the function code when it is ready to send the data.

- The data strobe is then asserted.

- The 6000 will assert the acknowledge (pin 12) when it has put the data byte on the I/O bus (pins 4-11).

- The host must read the data before negating the data strobe.

- The subsequent data bytes are transferred by using the same sequence as above.

- After all of the data has been transferred the device strobe is negated.

HARDWARE PROTOCOL DEFINITIONS

The diagrams on the following pages indicate the timing necessary to communicate with a particular axis.

INTERFACE CONNECTIONS

The interface connections are made by means of a DB-25 male connector located on the back panel and marked as Auxiliary Port. All inputs are TTL compatible and are internally bused to all axes. Each axis has a 10K ohm pull up on every input. All outputs are TTL compatible with Tri-state control.

PIN ASSIGNMENTS - DB25

PIN #	PIN DESCRIPTION	SIGNAL DIRECTION
1	/DT1 - dead time axis 1	output
2	/DT2 - dead time axis 2	output
3	/DT3 - dead time axis 3	output
4	DATA I/O bit 0	input/output
5	DATA I/O bit 1	input/output
6	DATA I/O bit 2	input/output
7	DATA I/O bit 3	input/output
8	DATA I/O bit 4	input/output
9	DATA I/O bit 5	input/output
10	DATA I/O bit 6	input/output
11	DATA I/O bit 7	input/output
12	/ACK - acknowledge	output
13	OUTPUT CONTROL	output
14	CONTROL bit 0	input
15	CONTROL bit 1	input
16	CONTROL bit 2	input
17	CONTROL bit 3	input
18	CONTROL bit 4	input
19	CONTROL bit 5	input
20	/DVSTB - device strobe	input
21	/DTSTB - data strobe	input
22	CLK1 - speed clock axis 1	input
23	CLK2 - speed clock axis 2	input
24	CLK3 - speed clock axis 3	input
25	LOGIC COMMON	—

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PIN DESCRIPTIONS

PINS 1-3:
are TTL compatible CMOS tri-state outputs, each with a 10K ohm pull-up resistor. Each high current output is capable of driving 15 LSTTL loads including the pull-up resistor. The outputs are in the tri-state condition until the axis number is selected by the mini jumps on the Counter/CPU board. The signal that is output from these pins is a real time indication of the dead time interval (clamp change interval) of the motor. A high level indicates no clamp change, while the low level indicates that a clamp change is in process. The duration of the low level is approximately 100 microseconds. The duration of the high level is dependent on the user adjustable speed and maintenance speed.

PINS 4-11:
are bi-directional data input/output signals which are TTL compatible CMOS. These signals are common to all axes and each axis is terminated with a 10K ohm pull-up resistor. Each high current output is capable of driving 15 LSTTL loads including the pull-up resistor.

PIN 12:
is a TTL compatible CMOS tri-state output and is the only handshake signal on the bus. This signal is bused together on all axes and is capable of driving 15 LSTTL loads including the 10K ohm pull-up resistor on each axis. The output is used to tell the host that the 6000 has responded to the data and is ready to accept additional instructions.

PIN 13 - OUTPUT CONTROL:
This pin is used to control differential drivers and receivers that can be connected to the bi-directional data input/output signals, pins 4-11, for long haul transmission lines (RS-232).

PINS 14-19:
are TTL compatible CMOS inputs and are bused together between all axes. Each axis input has a 10K ohm pull-up resistor. These signals are used to receive the device code, function code, and motor control data from the host.

PINS 20, 21:
are TTL compatible CMOS inputs and are bused together between all axes. Each axis input has a 10K ohm pull-up resistor. These two signals are used to strobe the device address (PIN 20 device strobe) and data (PIN 21 data strobe) in the 6000.

PINS 22-24:
are individual TTL compatible CMOS inputs each with a 10K ohm pull-up resistor. These clock inputs determine the speed at which each motor will run (PIN 22 axis 1, etc.).

PIN 25:
is used for signal returns (logic common).

CHANGES EFFECTING ALL 6000 CONTROLLERS

A SUMCHECK test is performed after every power up cycle to verify the integrity of the code in the ROM. If an error is detected the digital display may display the flashing error message "codE Error". The code ROM must be replaced to eliminate this condition. The Counter/CPU board now has the capability of operating as a counter only by converting the mode of operation to open loop. Contact the Burleigh Service Department for information on configuring the board.

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Chapter 6 - Troubleshooting

CAUTION: The internal voltages present in the 6000 Controller are extremely hazardous. All service operations described in this section are to be performed with the power OFF.

GENERAL TROUBLESHOOTING GUIDE

SYMPTOM	CHECK THE:
Front panel lights are off	line fuse
Inchworm does not make noise	HV fuse
Inchworm makes noise, but does not move	HV drive card HV drive card fuse
Position display does not indicate correctly	Resolution jumpers Interface type
Inchworm "runs away" in closed loop system	Direction jumpers
Low push force or slow speed	Clearance Compensation
Erratic operation with TTL	Not 50% clock signal
Erratic operation with high mass loads	Maintenance parameters
Inchworm moves when joystick is on center	Joystick zero adjustment (Consult factory)

GENERAL HIGH VOLTAGE CIRCUIT EVALUATION

The only portion of the 6000 series controller circuits that can be easily field serviced is the high voltage control section. The parts are usually easily available and the only equipment necessary is a good digital volt-ohm meter which uses low voltage to make it's resistance measurements. Beckman, Fluke, Keithley, and others make suitable units. It is assumed that the person servicing the instrument is versed in basic electronic troubleshooting techniques. If this is not the case please consult the factory before proceeding further.

If a problem in the high voltage section is suspected remove power from the controller, wait five minutes for any stored energy to dissipate, and then remove the instrument cover.

The next item to check is the fuse. It should be less than 20 ohms. The value is 63mA. Never substitute the fuse with any other value. Permanent damage to the controller or Inchworm motor could occur.

Locate the red high voltage circuit board(s). On the upper half of the board you will find eleven power resistors. Check the value of each and replace any which are open or out of tolerance. The values are marked on each resistor. (large "sand" resistors are 1K ohm, the two smaller resistors nearest the rear panel connector are 510K ohms, and the remaining four small resistors are 110K ohms)

Finally, check the FETs (lower row of heat sinks). The circuit board will have to be removed from the chassis, so be sure to note where the various connector are located. Each FET should be checked for resistance from gate to source and gate to drain. Several hundred K ohms should be observed. If any FET shows low resistance it should be replaced with an identical device (BUZ50B).

This covers most common problems in the high voltage circuits. If further problems are suspected please contact the Burleigh Customer Service Department. They will be able to provide the most current service recommendations, in addition to factory service with OEM parts.

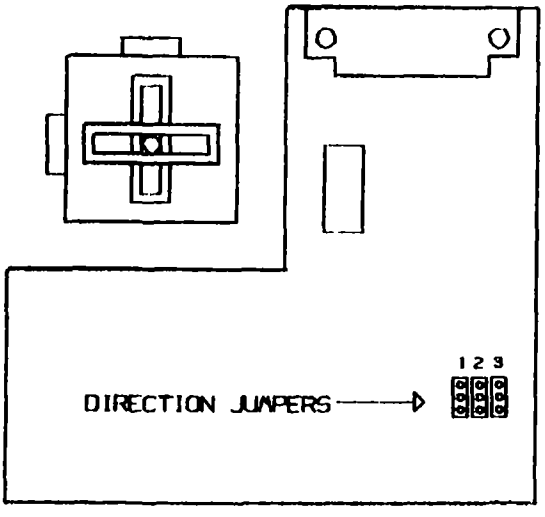
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Appendix A - Specifications

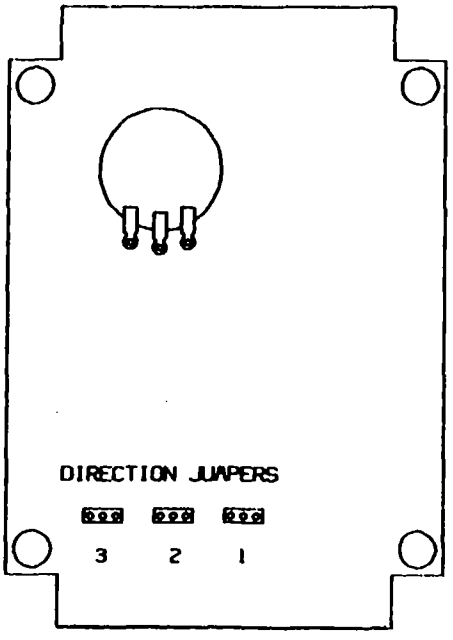
Line Frequency	50 to 60 Hertz
Line Voltage (Volts R.M.S.)	90-110 107-129 180-220 213-259
Fuse (Slow Blow Type)	4 A 3 A 4 A 3 A
Power Consumption (max. Watts RMS)	230
Temperature Range (storage)	-40 to +70 degrees Celsius
Temperature Range (operating)	0 to +50 degrees Celsius
Humidity Range	0 to 90% R.H. (non-condensing)
Environment	Normal laboratory (for mobile or airborne use consult factory)
Physical Size	
Height	7.2 inches (183 mm)
Width (w/o rack mount kit)	17.4 inches (442 mm)
Width (w/ rack mount kit)	19.0 inches (483 mm)
Depth (unit only)	14.7 inches (374 mm)
Depth (required, with cables)	20.7 inches (526 mm)
Weight 38 lbs. (17 Kg.)	
Construction finish.	Aluminum and steel chassis. Exterior coated with baked enamel
Maintenance maintenance is required.	Intake filter to be cleaned when visibly dirty. No other periodic
Reliability	3000 Hrs. MTBF (est.)

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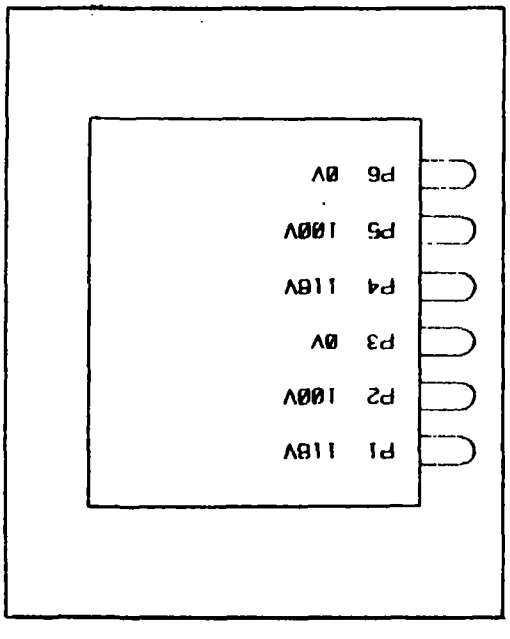
Appendix B - Hardware Configuration



6003 JOYSTICK
JUMPER LOCATIONS

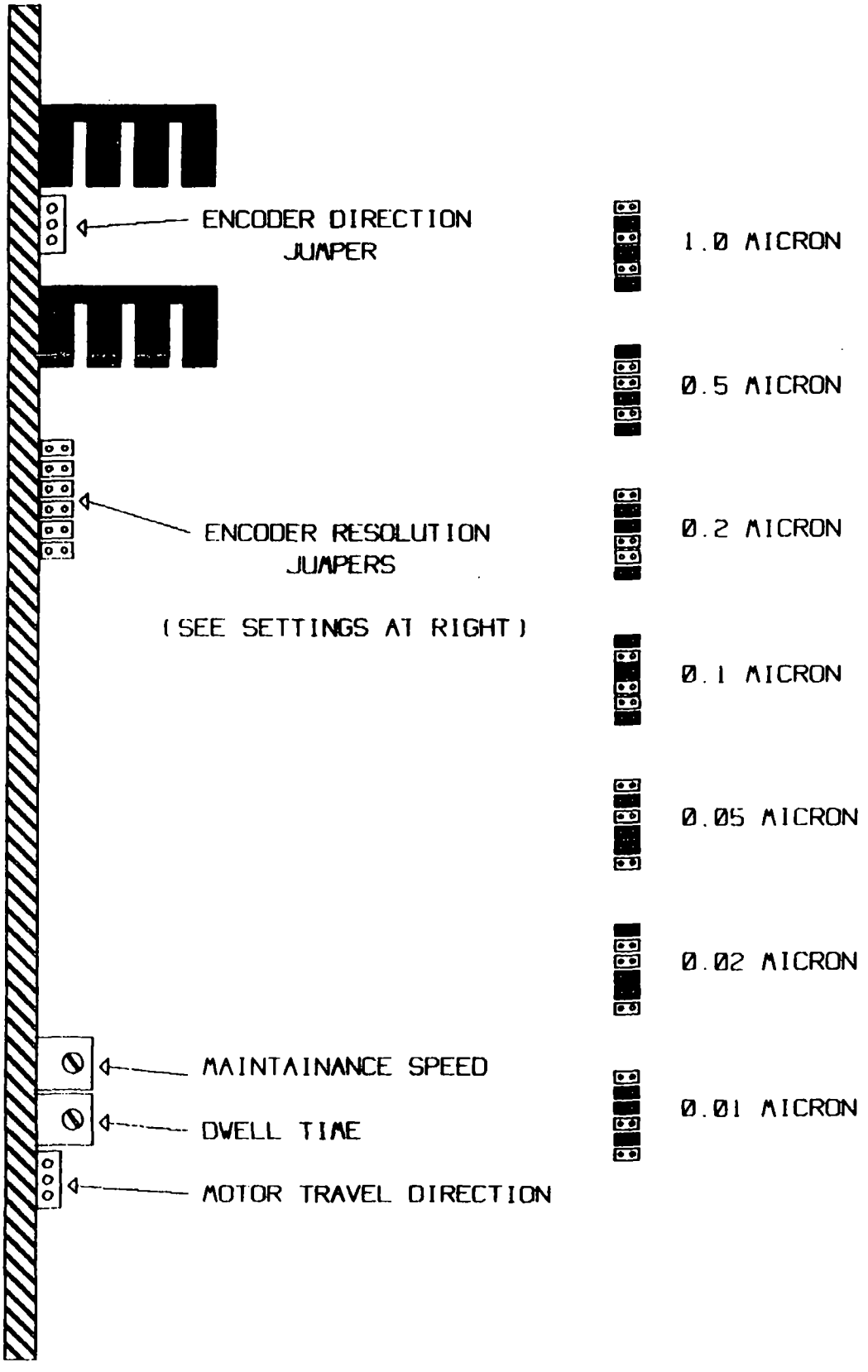


6005 HANDSET
JUMPER LOCATIONS



6000 POWER TRANSFORMER
TERMINAL LOCATIONS

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WARRANTY

Burleigh Model 6000 Inchworm Motor Controllers are warranted against defects in material and workmanship for a period of one year after date of delivery. Burleigh's warranty card must be returned within 30 days after date of delivery. During the warranty period, Burleigh will repair or, at its option, replace parts which prove to be defective when the instrument is returned prepaid to Burleigh Instruments, Inc. The warranty will not apply if the instrument has been damaged by accident, misuse, or as a result of modification by persons other than Burleigh personnel.

It is important to call Burleigh or your local representative for a Return Authorization Number (RA#) before returning any product. This will insure the prompt handling of the repair.

The liability of Burleigh (except as to title) arising out of supplying of said product, or its use, whether under the foregoing warranty, a claim of negligence, or otherwise, shall not in any case exceed the cost of correcting defects in the product as herein provided. Upon expiration of the warranty period specified herein, all liability shall terminate. The foregoing shall constitute the sole remedy of the buyer. In no event shall the seller be liable for consequential or special damages.

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51517-0

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Inchworm Motor Positioning System
The LSS-1000



25 mm travel	Ample range for slices and in-vivo preparations
Programmable step-sizes in 0.5 µm increments	Absolute control of microelectrode position
Solid state construction	Highest position stability and lowest vibration
High speed and acceleration	Clean cell penetrations
Ultra Low Noise (ULN) drive electronics	Negligible EMI noise in recording measurements

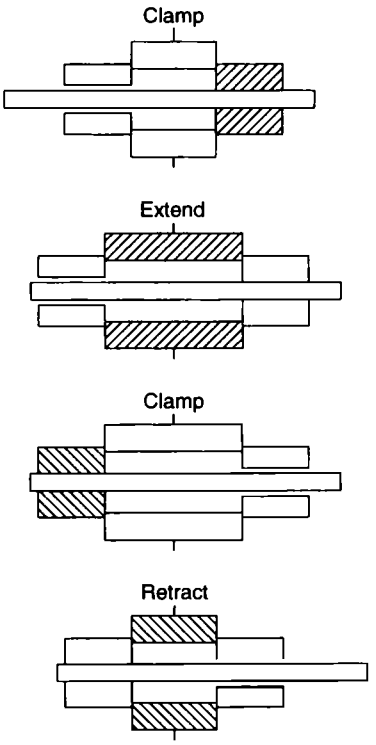


Figure 1. Inchworm Motor motion sequence.

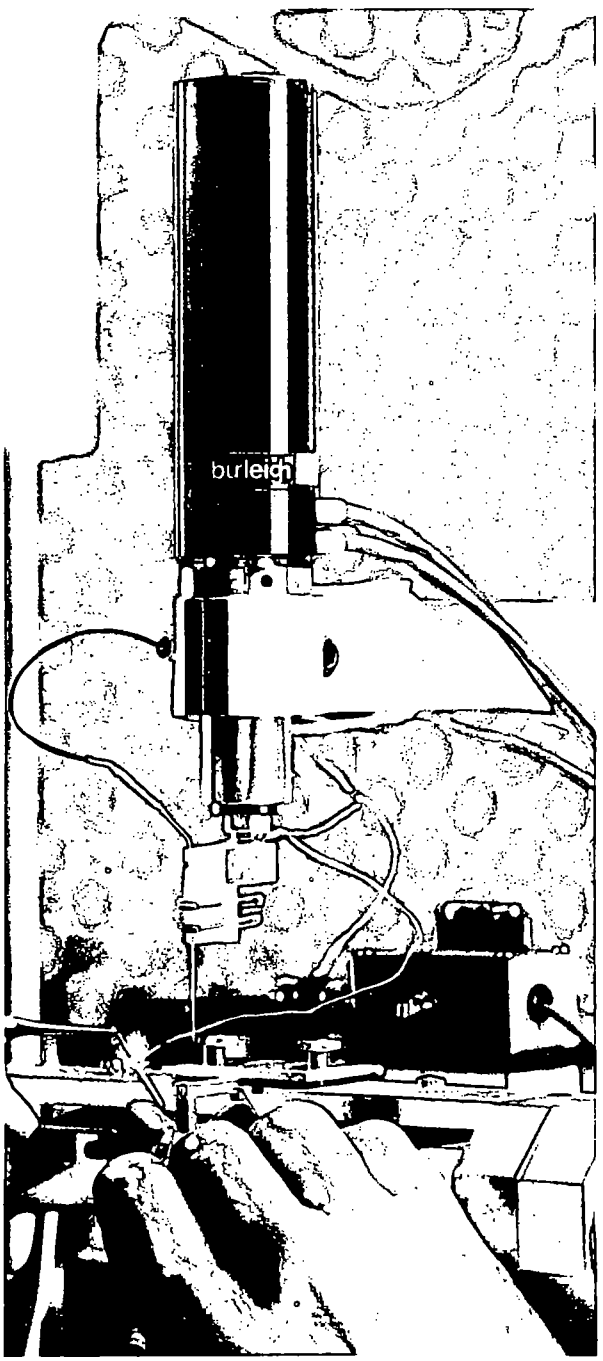
Positioning of microelectrodes for electrophysiology recordings requires micrometer scale control of high velocity-high acceleration steps. These steps must be achieved with minimum vibration to prevent damage to cells, their processes or connections. For almost 20 years, Burleigh has supplied Inchworm Motor Systems to help cell physiologists obtain clean penetrations and stable cell recordings.

One of the major goals in any research program is constantly improving productivity. In electrophysiological recording productivity translates into more clean cell penetrations for intracellular work and more cells per penetration for extracellular work while maintaining stable recording conditions.

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The Power of Precision
in Life Science.



LSS-1000
INCHWORM® MOTOR POSITIONING SYSTEM

Microelectrode positioner providing the highest precision, speed, and acceleration!

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INCHWORM TECHNOLOGY

The Inchworm Motor is a patented solid-state design that directly creates linear motion by sequential activation of three piezoelectric (PZT) elements. Piezoelectric material is an electrically active ceramic that changes dimension when a voltage is applied. The sequence of operation is shown in Figure 1.

Each clamp-extend-clamp-retract cycle of the Inchworm produces approximately 2 µm of linear motion. The signal driving the center element is divided into 500 1.0 volt steps. (Approximately 500 volts total.) Each 1.0 volt step produces a position step of approximately 4 nm.

The Inchworm motion sequence can be repeated any number of times to achieve a total travel limited only by the length of the motor shaft.

The maximum speed of the Inchworm is 2 mm per second and corresponds to a maximum clamp change frequency of approximately 1000 Hz.

POSITIONING PRECISION

The LSS-1000 System uses an optical position encoder to directly measure the Inchworm shaft position. The encoder counts and subdivides fringes produced by a Moiré interferometer using a proprietary Burleigh design. Absolute position measurement of the shaft compliments the outstanding resolution, stability, and acceleration of the Inchworm Motor to provide full closed loop position control. When compared with DC servo/stepper motors equipped with rotary encoders, Inchworm Motors eliminate errors derived from backlash and lead screws.

The absolute position of the Inchworm shaft is displayed with 0.5 µm resolution and ± 1 µm accuracy. The Inchworm resolution of 4 nm easily produces 0.5 µm position steps with very smooth motion and minimum overshoot. Step sizes can be programmed and commanded in any multiple of the encoder resolution (i.e. 0.5, 1, 1.5, 2 ....µm).

HIGH ACCELERATION & VELOCITY

Clean penetrations require a micro-positioner capable of high acceleration and velocity as well as rapid deceleration. The goal is to avoid membrane dimpling which can result in severe cell damage.

The Inchworm' s piezoelectric elements respond in microseconds with very high stiffness to achieve inherent high acceleration and velocity. The motor attains its top speed within one clamp change with a maximum velocity of 2 mm per second. When operating in step mode, the step size is programmable and the step speed is adjustable using the potentiometer on the Model 6005 Handset. When the programmed step is achieved the motion stops almost instantaneously yielding minimum overshoot and creep.

The dynamic velocity range is another important performance advantage. Speeds from 4 nm per second to 2 mm per second can be selected to allow full optimization of your experiment. In contrast, motor/lead screw systems suffer from "stick-slip" effects at very slow speeds that produce unstable motion.

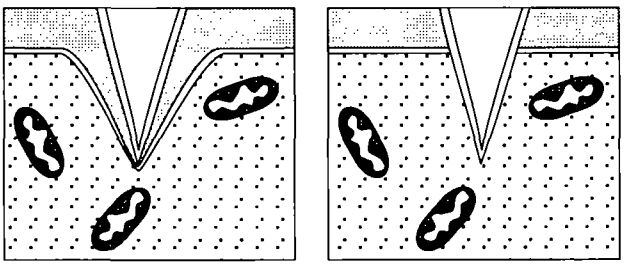


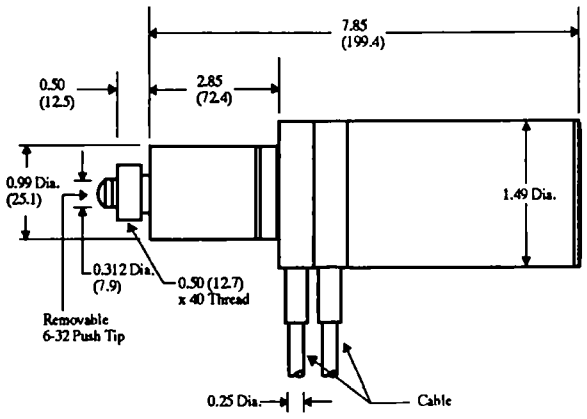
Figure 3. Inchworm Motors produce more clean punctures and avoid membrane dimpling and cell destruction.

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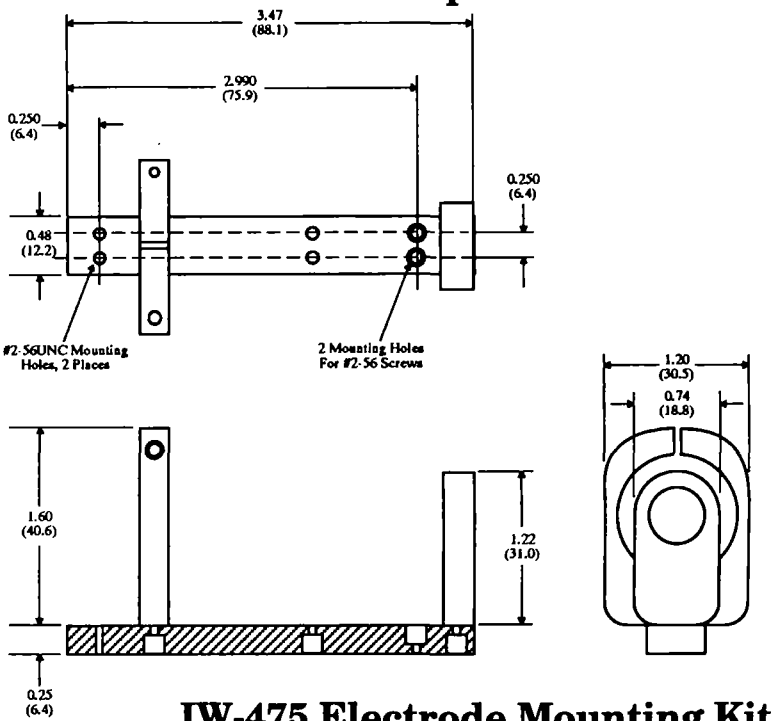
Outline Dimensions

Dimensions in Parentheses are in Millimeters

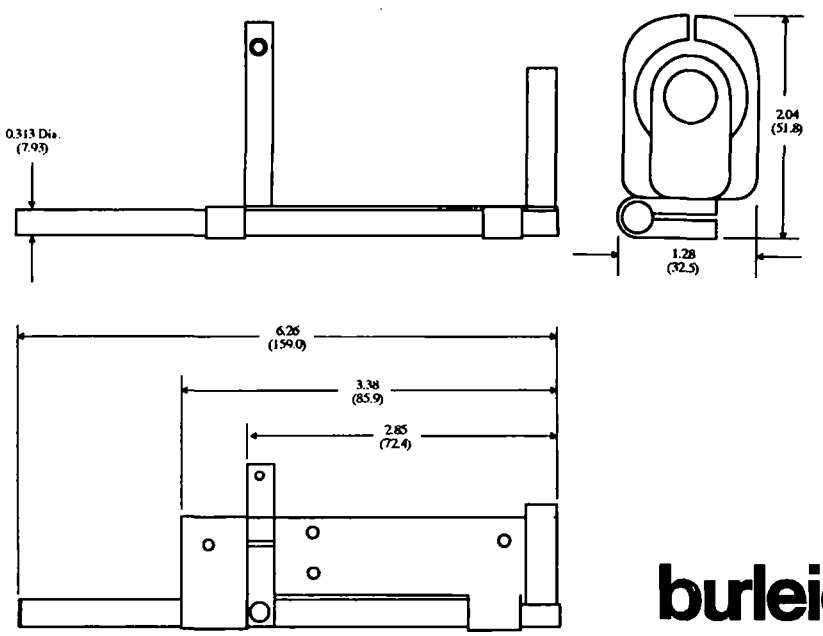
IW-711-01 Inchworm Motor



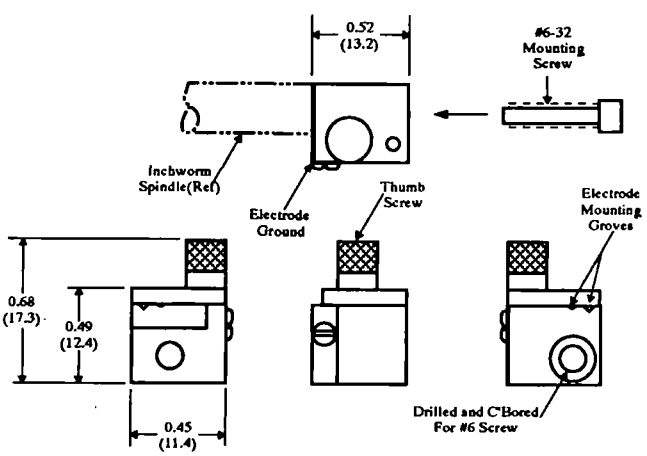
IW-450 Micromanipulator Mount



IW-460 Kopf Stereotaxic Mount



IW-475 Electrode Mounting Kit



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Fax. 44 (0) 1582 767888

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MINIMUM TIP VIBRATION

A Model IW-711-01 Inchworm Motor is used in the LSS-1000 System and incorporates a lateral stability option (LSO) on the output shaft to minimize lateral motion. This unique vibration damping system limits lateral wander of spindle tip to approximately 0.2 µm per piezoelectric clamp change during operation.

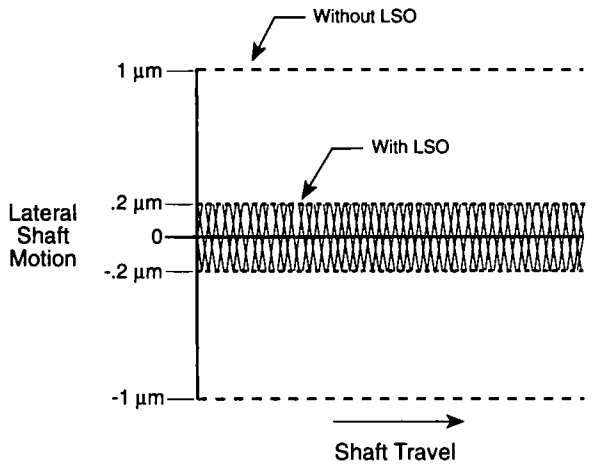


Figure 4. Inchworm Motor lateral shaft motion.

STABILITY

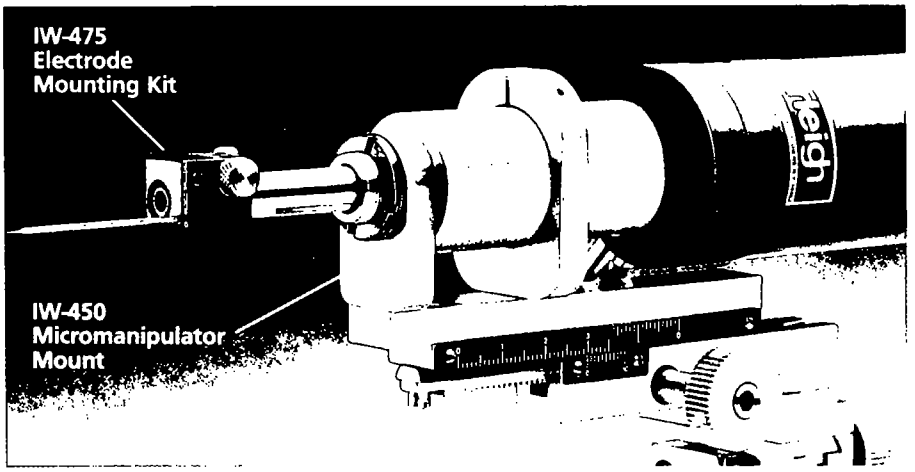
Once an electrode is in the desired position, stable recording conditions may be required for several hours. Position drift of the micropipette or microelectrode tip is not acceptable. The solid-state ceramic and metal construction of the Inchworm provides very high stiffness and low thermal drift. The thermal stability is further enhanced by the zero heat dissipation of the Inchworm when holding position.

The Inchworm Motor does not exhibit any drift typically associated with hydraulic systems. The closed loop encoder feedback ensures submicron stability of the electrode tip. Inchworm Systems simply hold cells longer!

ULTRA LOW NOISE MOTOR CONTROLLER

The LSS-1000 System uses a Model 6200ULN (Ultra Low Noise) Motor Controller and 6005 Handset. In 1992 the "ULN" version of the original 6000 Series Controller was developed. The 6200ULN drive signals have less than 5 mv RMS noise (more than an order of magnitude improvement over the original 6000) and an improved grounding/shielding design. These changes minimize any possible EMI interference in your electrical recordings and virtually eliminates position errors on the controller display.

The Model 6005 Handset uses push buttons and a potentiometer to control the direction, speed, starts and stops. Run/jog and step mode can be selected. Position set points and step sizes are programmed on the front panel of the 6200ULN Controller.



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The LSS-1000 System Configuration

Burleigh offers many Nanopositioning choices for cellular physiology to meet the requirements of your specific experimental technique. The LSS-1000 System is recommended for intracellular and extracellular recording in slices and in-vivo and is offered at a discounted price when compared to purchasing the components individually.

LSS-1000 Inchworm System includes:

- **Model IW-711-01, Inchworm Motor**: 25 mm travel, 0.5 µm encoder, and lateral stability option, 2 meter interconnect cables
- **Model 6200ULN-1-1, Ultra Low Noise Controller**: single-axis, closed loop, with position and limit displays
- **Model 6005, Handset** with cable

Other Options For Inchworm Systems

Burleigh offers many other options for Inchworm positioning systems that are compatible with electrophysiology. All systems must include an Inchworm Motor, controller, and user interface. These options include:

- 50 mm travel
- Longer interconnect cables
- PC computer interface
- Up to three axes of independent motor control in each 6200 chassis
- Model 6003 Joystick with cable
- Model 650 Status Port Option to monitor limits and clamp changes
- Mounting accessories

Please contact your Burleigh sales representative for more information on Nanopositioning and Life Science products.

ACCESSORIES

Mounting:

IW-450 Micromanipulator Mount
IW-460 Kopf Stereotaxic Mount
IW-475 Electrode Mounting Kit

Rack Mount Kit:

7009 Rack Mount Kit

Extension Cables:

7011-1 3 meter motor extension cable
7011-2 7.5 meter motor extension cable
7011-3 15 meter motor extension cable

7007-1 3 meter encoder extension cable
7007-2 7.5 meter encoder extension cable
7007-3 15 meter encoder extension cable

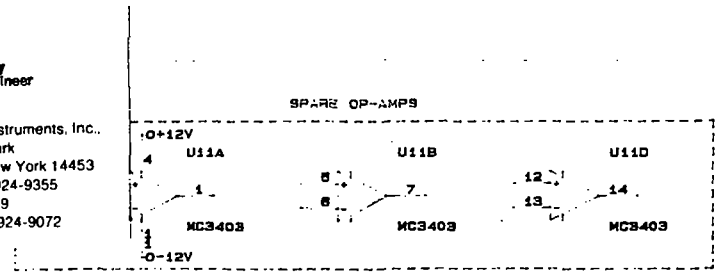
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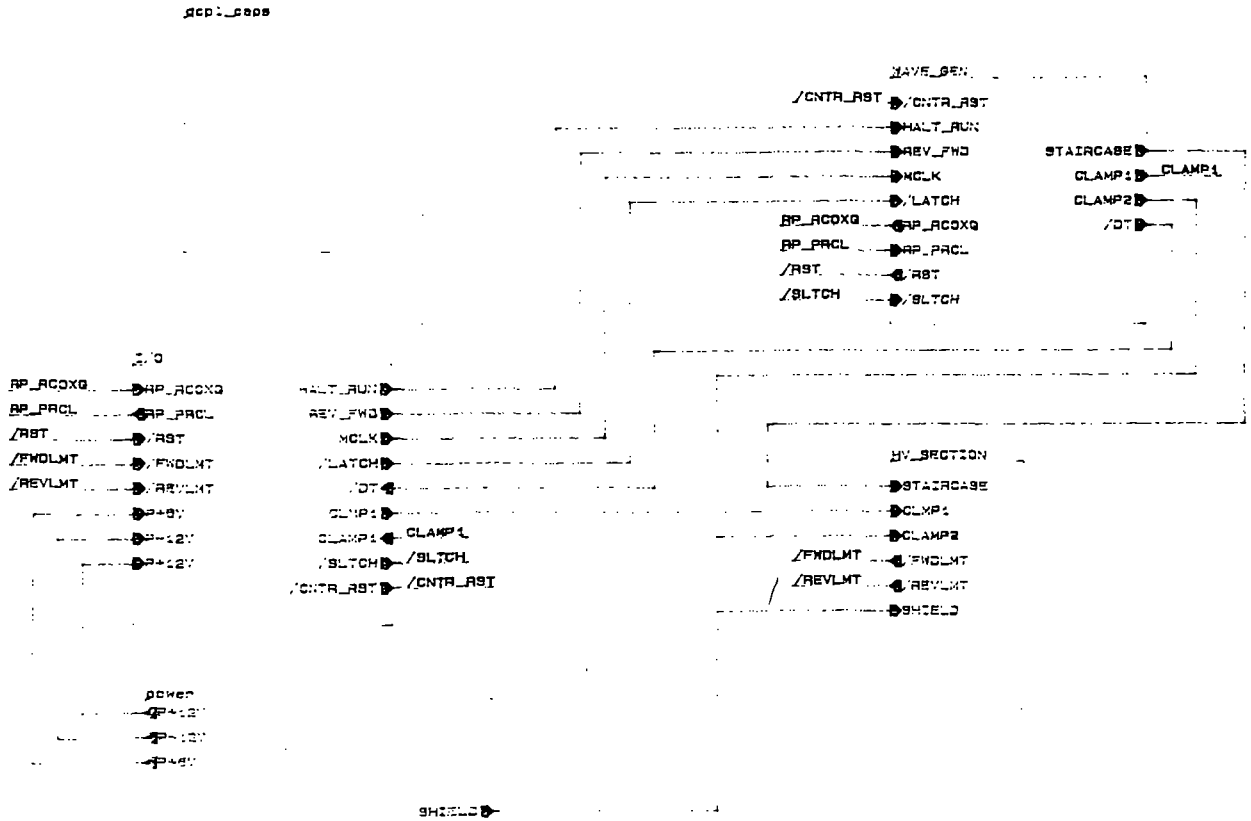
Paul A. Kruty
Service Engineer

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Fax. (716) 924-9072

AUTH	CHK	REV	DATE	DESCRIPTION	ECO #
RRB	RRB	-	10/28/88	RELEASE	1284
DJF	DJF	A	6-9-89	ADDITIVE SERVICE AND SCH. UPDATE	1375

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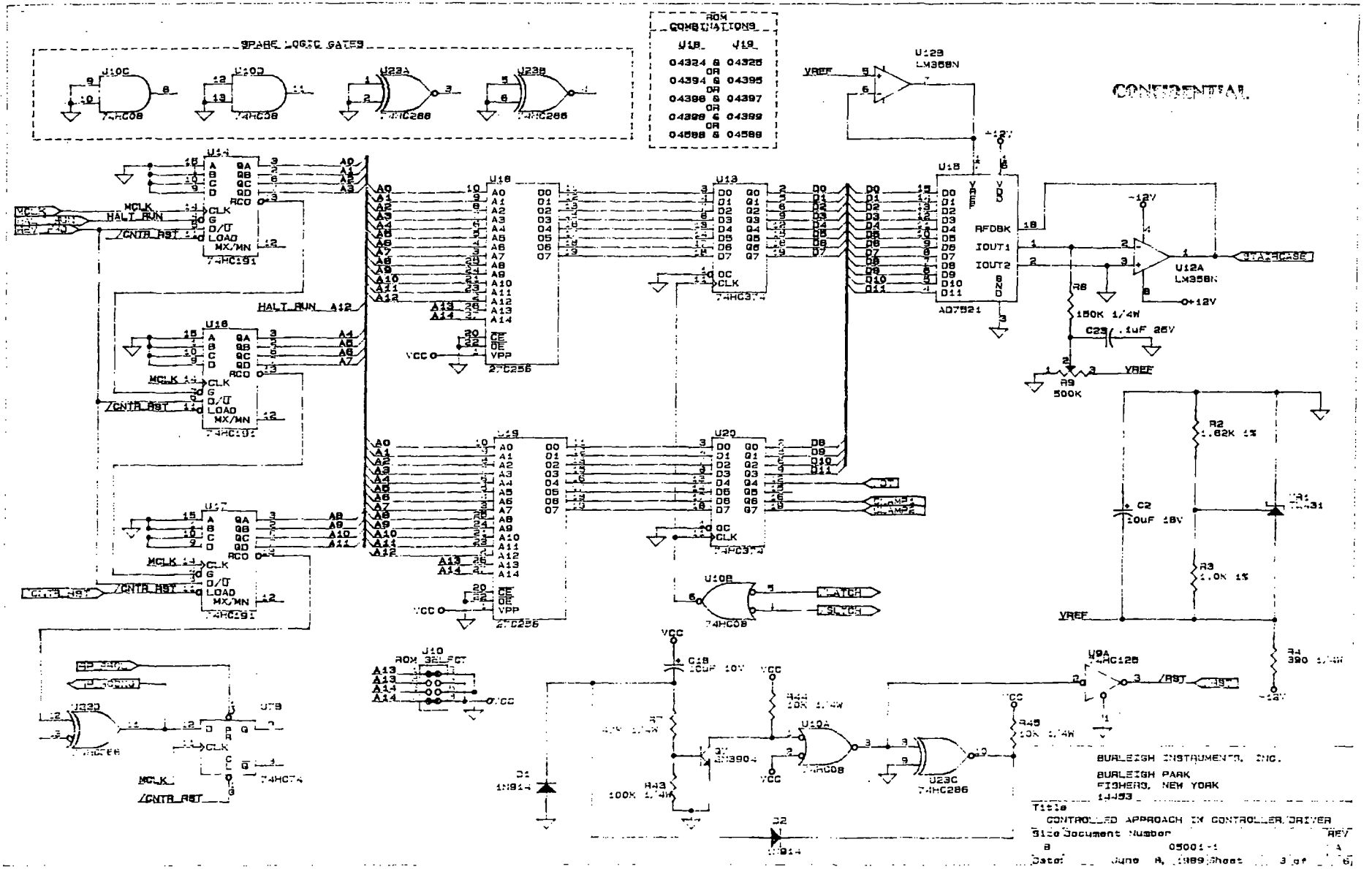
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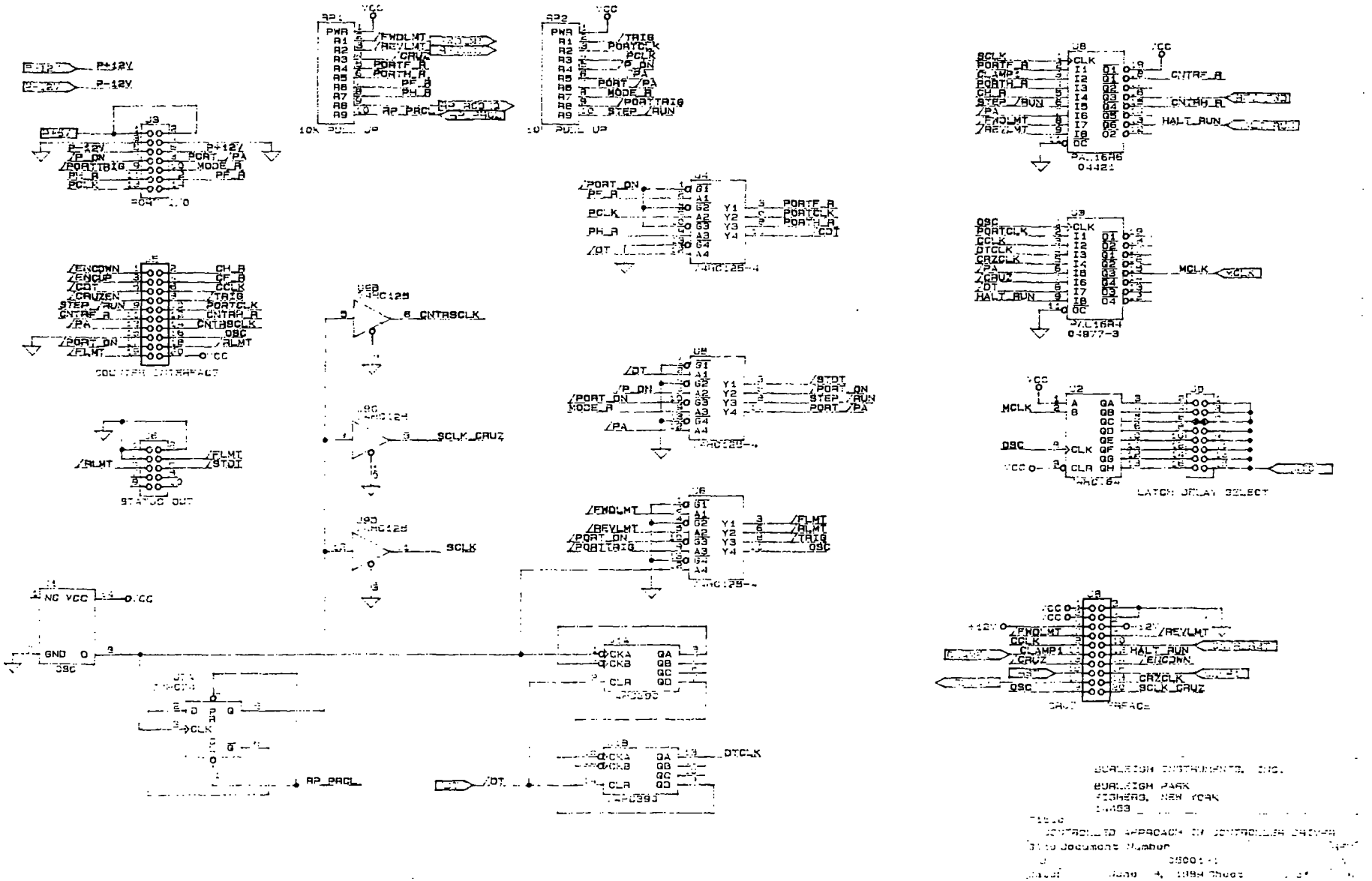
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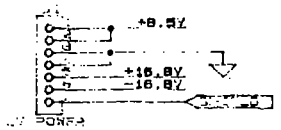


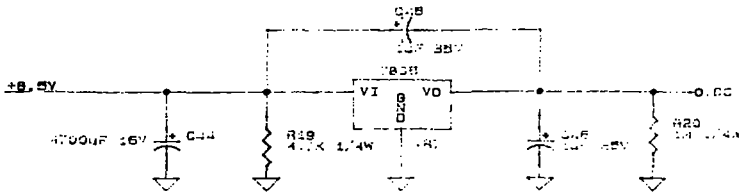
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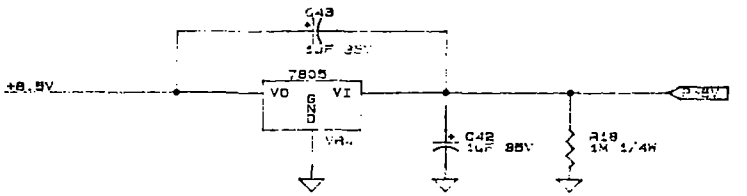


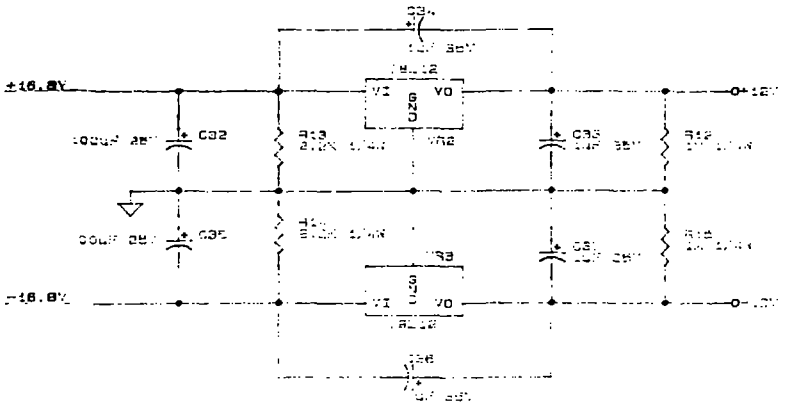
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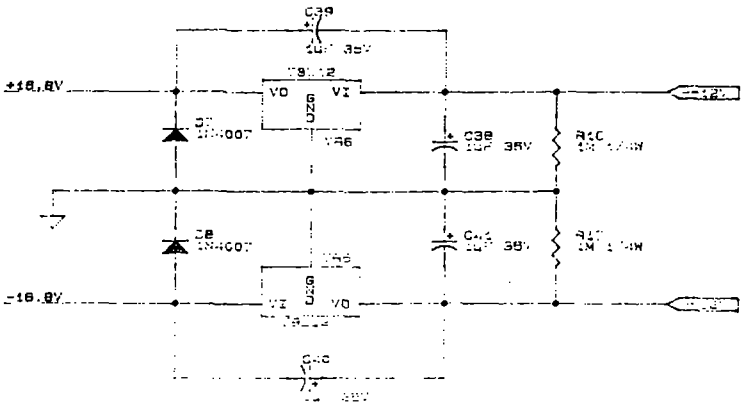
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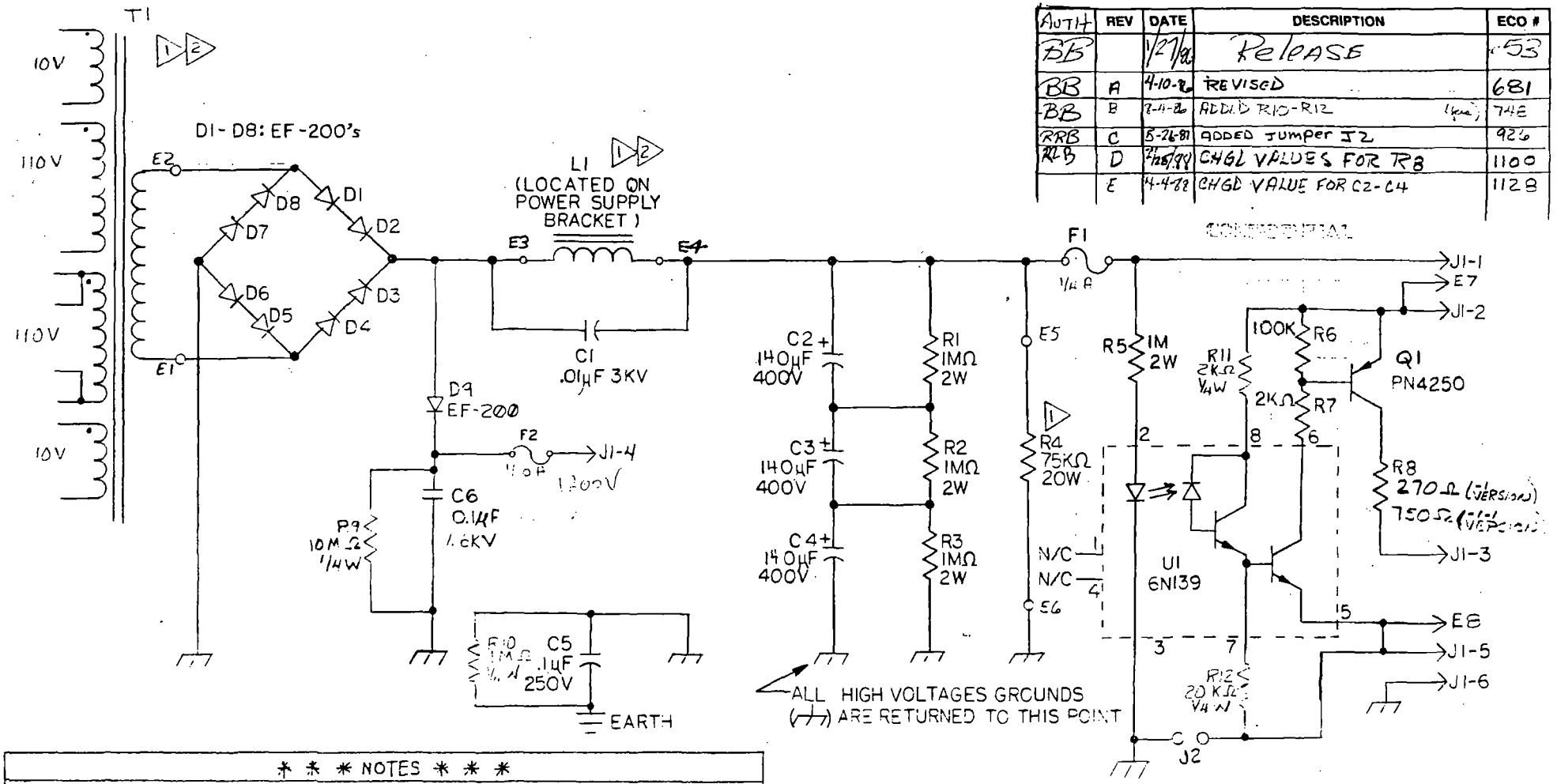


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Title
CONTROLLED APPROACH IN CONTROLLER/DRIVER

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Date: June 4, 1987 Sheet 5 of



AUTH	REV	DATE	DESCRIPTION	ECO #
BB		1/27/88	RELEASE	453
BB	A	4-10-86	REVISED	681
BB	B	7-11-86	ADDED R10-R12 (4pcs)	748
RRB	C	5-26-87	ADDED JUMPER J2	926
RLB	D	2/25/88	CHGL VALUES FOR R8	1100
	E	4-4-88	CHGD VALUE FOR C2-C4	1128

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*** * * NOTES * * ***

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   AND L1 = E1F-[illegible]
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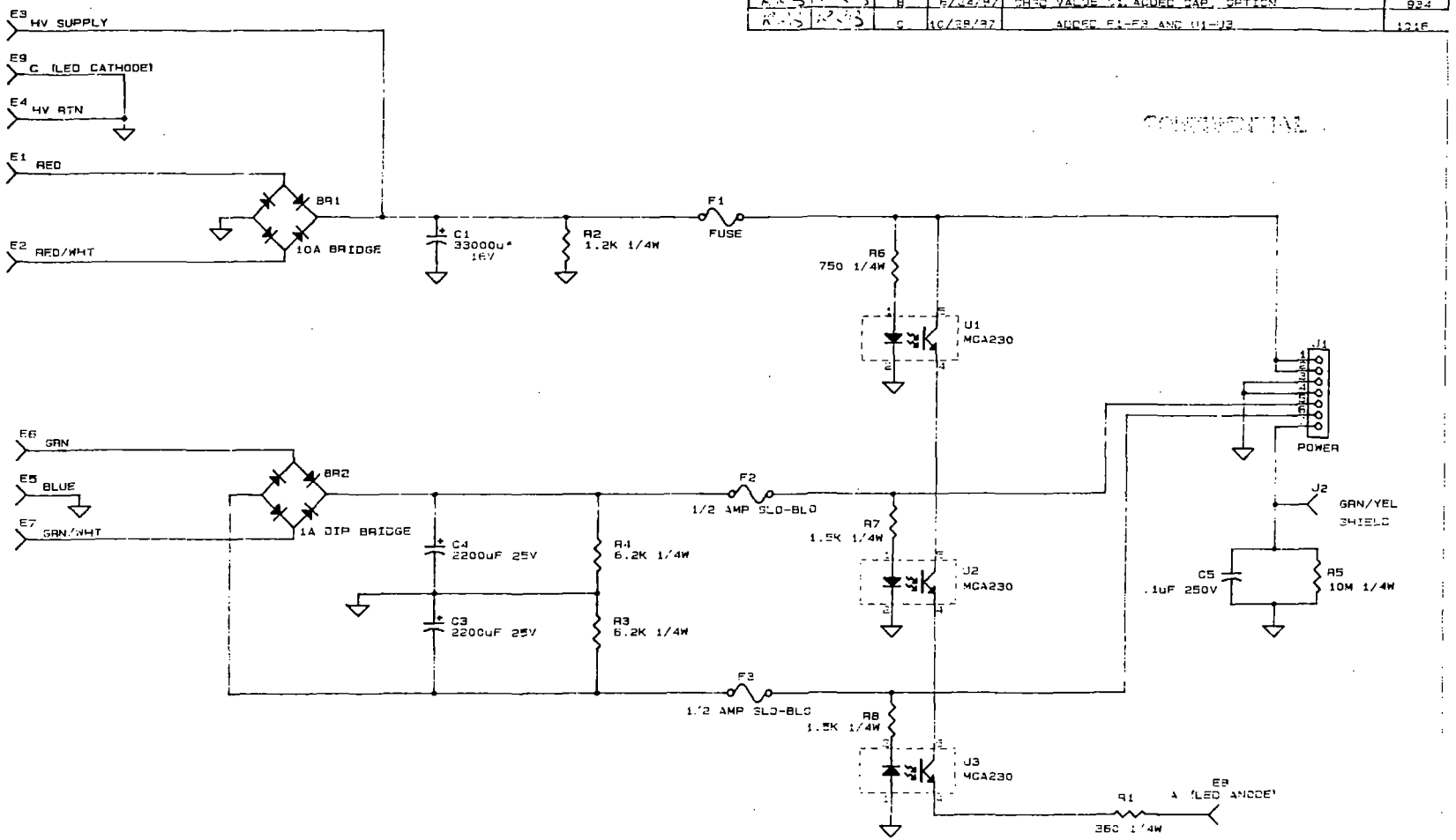
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CHEM FIN:	2 PLACE ± .010 3 PLACE ± .005 ANG ± SURF FIN

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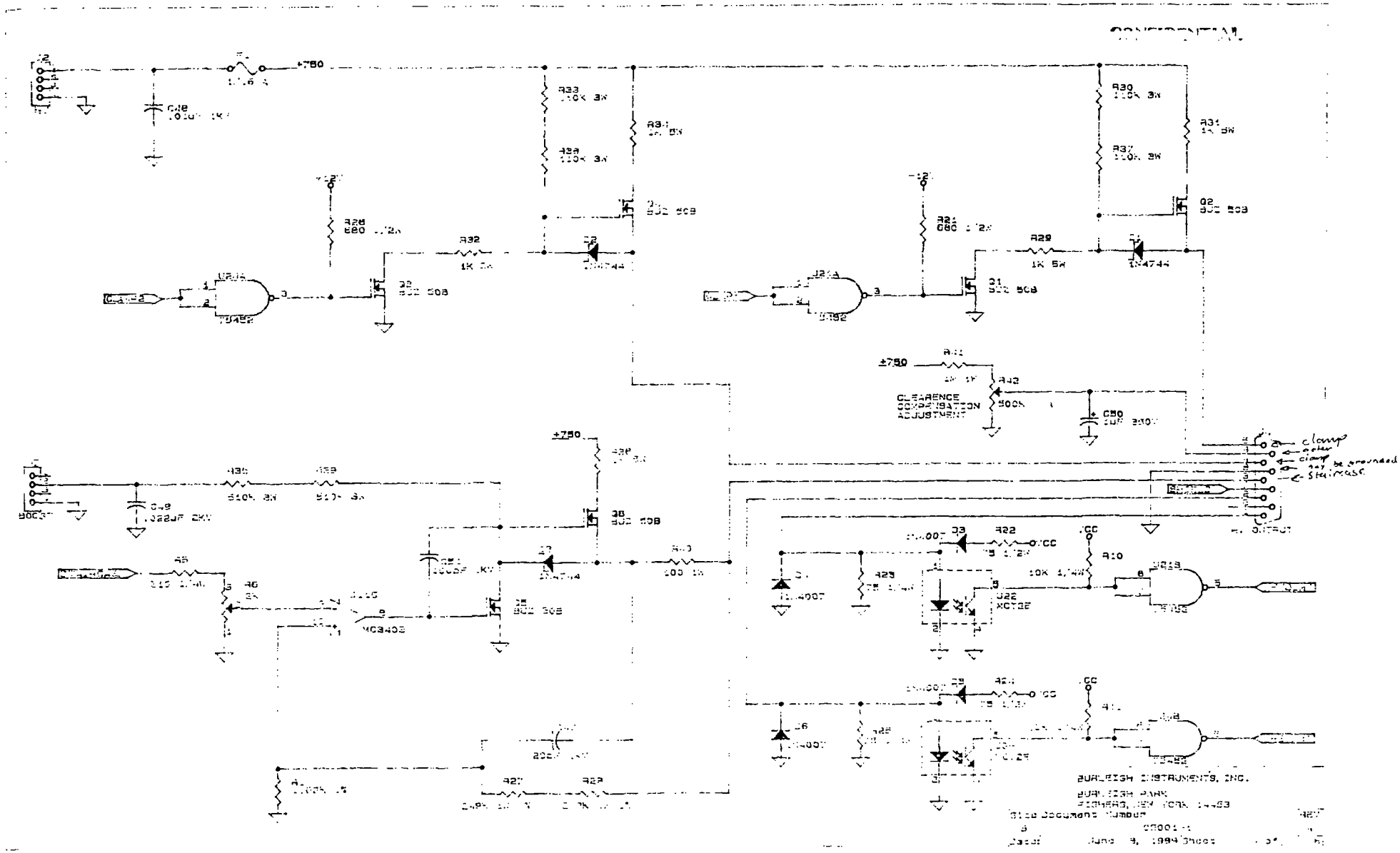
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B C3788-1/-1	SHEET 1 of 1.

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RRP	RRR	A	6/27/97	RELEASE	923
RRP	RRR	B	6/24/97	CHGD VALUE C1, ADDED CAP. OPTION	934
RRP	RRR	C	10/28/97	ADDED F1-F3 AND U1-U3	1216



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IW-700/710

INCHWORM MOTOR

INSTRUCTION MANUAL

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1. INTRODUCTION

Burleigh Instruments Inc. thanks you for choosing an IW-700 or 710 Series Inchworm® Motor. It's design has been optimized to meet your most rigorous micropositioning needs. These products are the culmination of over a decade of development in Inchworm technology, and incorporate significant improvements over earlier motors in smoothness of operation, speed under load, mechanical step resolution, reliability, and versatility. When operated by Burleigh control electronics they provide the highest mechanical resolution of any commercially available positioning systems.

Should any questions or problems arise with the Inchworm Motor please contact Burleigh's Customer Service Department at (716) 924-9355 or your local representative.

CAUTION: High voltages are present during normal operation of Inchworm Motors, even when they are not in motion. Do not disassemble the Motor or remove any covers. There are no user serviceable areas or parts inside. Also, use care not to damage the cables and plugs.

CAUTION: Inchworm Motors contain piezoelectric ceramics and their encoders contain glass scales, both of which can be damaged by rough handling or physical shock.

2. INITIAL INSPECTION

A. VISUAL

Inchworm Motors are packed in a special carton designed to provide maximum protection during shipment. Notify your shipping department if the outside of the shipping carton is damaged. They may wish to notify the carrier at this point.

If the shipping carton is undamaged externally remove the Inchworm Motor from the carton. If any damage is evident visually or if rattling can be heard when it is gently shaken notify your shipping department and Burleigh Instruments, Inc. or your local representative. Please save the special carton for future storage and transportation.

B. OPERATIONAL

Refer to section 4 for a discussion of normal operation of the IW-700 and 710 Series Inchworm Motors. If an Inchworm Motor fails to operate correctly contact the Burleigh Customer Service Department or your local representative at once.

CAUTION: Do not attempt to use an Inchworm Motor until you are familiar with the operation of the Controller. Refer to the Controller Manual for details.

C. QUALITY CONTROL

Inchworm Motors undergo several stages of inspection, test, and calibration before shipment including an extended run-in. They are designed to provide years of trouble-free operation. In the unlikely event that problems occur please contact Burleigh for instructions. Our Customer Service Department is ready to help with advice, parts, and repair services.

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3. DESCRIPTION

The Burleigh Inchworm Motor is a compact linear actuator. Its patented piezoelectric construction allows precise positioning with low compliance (high stiffness) and none of the backlash inherent in gear driven stepper or dc motor systems. Unlike magnetic motors the Inchworm Motor does not dissipate power when stopped. They have a mechanical resolution of 0.004 microns with a speed range of 0.004 μm/sec to greater than 2 mm/s. The shaft can generate a linear force of 1.5Kg. Construction for vacuum operation is available.

Inchworm Motors are available with nominal travel distances of 6.3, 25 and 50mm, with or without integral 0.5μm resolution encoders. Applications requiring longer travel or different mounting geometries may be satisfied with Burleigh LTO and LTS Series Motors. Contact Burleigh or your local representative for more information.

Burleigh IW-700 and IW-710 Series Inchworm Motors have identical motor components and positioning specifications. The IW-710 Series include an integral 0.5μm resolution encoder which is described in section 3-B.

For your convenience, a glossary of micropositioning terms is found in Section 11 of this manual.

NOTE: Although designed for operation by Burleigh 6000, 7000 and 7010 Series Controllers, IW-700 and 710 Series Motors may be operated with certain restrictions by CE-1000 and CE-2000 Controllers. Refer to Section 10 for details.

CAUTION: An electrical shock hazard can exist if an IW-700 or 710 Series Inchworm Motor is connected directly to a CE-1000 or CE-2000 Controller. If you have any questions, please contact the Burleigh Customer Service Department or your local representative.

A. INCHWORM MOTION

The principle of Inchworm motion is described below. See Figure 1.

Both outer elements, numbered 1 and 3 in the figure, contract when voltage is applied and firmly clamp onto the shaft. The center element, numbered 2, expands along the shaft with increasing voltage. All three elements operate independently.

The Controller sequences the clamp and center element voltages to generate Inchworm motion as follows:

- actuate clamp element 3
- extend center element 2, moving shaft to the right
- actuate clamp 1, release clamp 3
- contract center element, moving shaft further to the right
- actuate clamp 3, release clamp 1
- repeat sequence

Reverse travel is achieved by reversing the sequence for actuating the clamp elements.

Forward and reverse limit switches automatically halt further travel when either extreme of travel is reached. Extension or contraction of the center element causes about 2 microns of shaft movement between clamp changes.

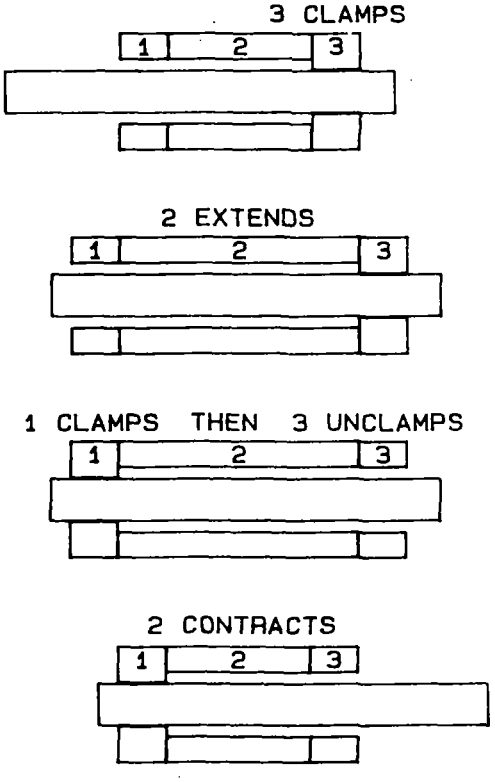


FIGURE 1
INCHWORM MOTION

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The voltage applied to the clamp elements has two levels: On (clamped) and Off (unclamped). The center element receives a 512 step voltage staircase for smooth motion. The slope of these ramp signals, coordinated with the clamp change frequency determines translation speed. Between clamp changes the voltage staircase may be halted at any level to achieve mechanical resolution of about 0.004 microns. See Figure 2.

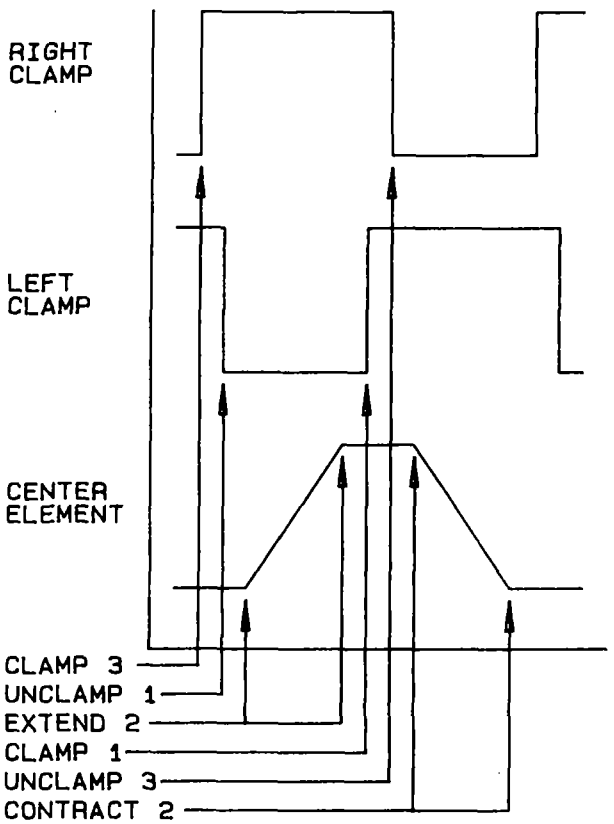


FIGURE 2
VOLTAGE SEQUENCE

The clamping and unclamping process generates a "discontinuity" in the motion which will vary slightly from motor to motor with a typical magnitude of less than 0.05μm under no-load conditions and 0.2μm with a 1.5Kg load. See Figure 3.

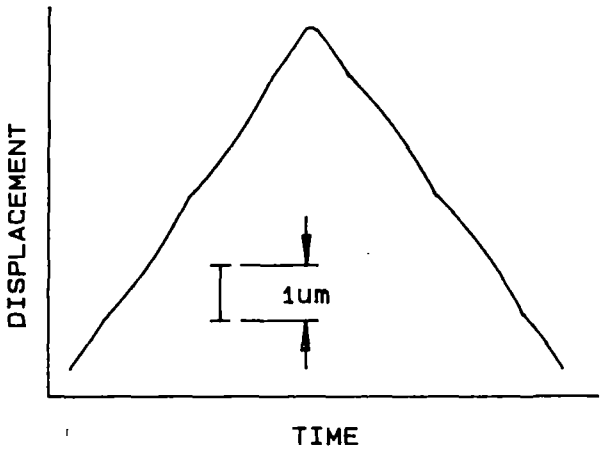


FIGURE 3
MOTION PROFILE

In applications where accurate, repeatable positioning is required best results are obtained by using the Inchworm Motor in closed-loop mode with a linear encoder providing position feedback. The IW-710 Series feature integral 0.5μm resolution encoders which are described in the following section. Alternatively, an IW-700 Series can be used with an externally mounted 0.1μm resolution encoder also available from Burleigh.

B. ENCODER

The IW-710 Series Inchworm Motor features an integral Moire fringe counting linear optical encoder mounted on the rear of the Motor shaft. It directly detects movement of the spindle and shaft with 0.5μm resolution and $\pm$1μm accuracy. The encoder provides feedback (direction and amount of motion) to the Controller for position display and closed-loop operation. Burleigh 0.5μm encoders do not have a reference mark.

The encoder is calibrated and aligned at the time of assembly and requires no user adjustment.

Refer to section 9-A for information on EN Series externally mounted 0.1μm resolution encoders.

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4. OPERATION

A. INCHWORM MOTOR

IW-700 and 710 Series Motors are designed for use with Burleigh 6000, 7000 and 7010 Series Controllers. Refer to section 10 for information on using these motors with Burleigh CE-1000 or CE-2000 Controllers.

Before connecting an Inchworm Motor to a Controller be sure that the Controller power is turned off. Plug the Inchworm Motor cable connector directly into the High Voltage Driver Output located on the rear of the Controller. For IW-710 Series Motors refer to the following section for connecting the encoder cable.

If the motor must be located beyond its standard six foot cable length from the Controller Burleigh Model 7011 Extension Cables must be used for the Motor. Although extension cables can be connected in series, do not exceed 50 feet in total length.

The novel piezoelectric construction of the Inchworm Motor results in unique operating characteristics. As the Motor moves a buzzing at high speeds and clicking at low speeds can be heard. This is due to the opening and closing of the clamp elements and is normal. When the Inchworm Motor is stopped one clamp firmly holds the shaft so the shaft is very stable and does not exhibit any vibration. In addition, since piezoelectric materials do not draw current when held at constant voltage Inchworm Motors do not dissipate heat when stopped. The fast response of piezoelectric materials give the Inchworm Motor very high acceleration and deceleration.

Some lateral motion occurs in the spindle when the piezoelectric clamps change, typically $\pm 1\mu$m or less at the tip of the spindle. For critical applications such as intracellular probing the Lateral Stability Option is of value. With this feature lateral motion at the spindle tip is reduced to approximately 0.2-0.4 micron. Refer to section 8.

Refer to the Controller manual for more information on using Inchworm Motors.

In any application:

- Make sure the Motor is protected from dust, dirt and debris.
- Avoid excessive relative humidity that may condense causing electrical arcing.
- Avoid shock loads which may damage the encoder glass scales and/or the Inchworm Motor.
- In operation any side loading (perpendicular to the direction of travel) of the spindle must be kept below 0.1Kg.
- Damage can result if the Inchworm Motor stalls repeatedly against a mechanical stop for periods greater than 5 minutes.

B. INTEGRAL ENCODER

The integral encoder of an IW-710 Series Inchworm motor has a separate cable for direct connection to the Encoder Input on the back of the Controller. If the encoder is located beyond its standard 6 foot cable length from the Controller a model 7006 Remote Encoder Box must be used. The encoder cable connects directly into this box. Burleigh Model 7007 Extension Cables are available in 10, 25,and 50 foot versions and connect the box to the Controller. Extension cables can be connected in series but should not exceed 50 feet in total length.

CAUTION: Use care in handling the Inchworm Motor, specifically avoiding shocking the motor/encoder body. Misalignment and/or breakage of the encoder reader and reticle scales could result.

NOTE: When routing cables from Inchworm Motors and encoders to the Controller be sure to separate the encoder and motor cables. Avoid coiling the cables together when cables are longer than necessary since unwanted signals can be generated resulting in incorrect encoder position readings.

The mechanical resolution of the Inchworm Motor is approximately 0.004μm. Since this is much smaller than the 0.5μm encoder measurement resolution the motor may be operated within this range ($<0.5\mu$m) without the encoder detecting any change in position.

Some applications may require externally mounted encoders, the choice based upon the need for a reference mark, higher resolution, or the need for a more direct measurement of the motion of interest. Externally mounted encoders may be used with IW-700 Series Inchworm Motors.
Refer to section 9-A.

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C. MOUNTING THE INCHWORM MOTOR

Important considerations:

- Use a rigid mount.
- Do not apply side loads greater than 0.1Kg

There are three methods for mounting IW-700 and IW-710 Series Inchworm Motors.

i. Mount the threaded front section of the Inchworm Motor through a clearance hole in a plate. For best results use a .500" diameter hole with a plate thickness less than or equal to .375". Use the retaining nut and spanner wrench supplied to secure the Inchworm Motor in place.

Under some conditions the retainer nut may bind and become difficult to turn. A few drops of isopropyl alcohol applied to the threads as a lubricant will alleviate the problem.

ii. Use a mount which threads onto the .5 × 40 pitch thread on the front housing. Thread the mount onto the Inchworm Motor. DO NOT thread the Inchworm Motor into the mount as there is a risk of loosening the housings.

iii. Insert the Inchworm Motor front housing into a 1.000" diameter clamp. Be careful to not over tighten the clamp. This method of mounting can provide the best stiffness.

NOTE: The rear housings do not provide a stable mounting surface and should not be used to mount Inchworm Motors.

The Burleigh IW-450 Mount was designed specifically for use with the Lateral Stability Option (LSO) Inchworm Motor but also provides a versatile mount for other applications. See Figure 4.

D. MOUNTING LOADS TO INCHWORM MOTORS

Important considerations:

- Couple loads to the spindle with care as lateral forces on the spindle (perpendicular to the travel direction) must be less than 0.1Kg.

- It is best to operate Inchworm Motors with as light a direct load as possible. This leads to smoother motion and minimizes differences in forward and reverse speeds. Spring loading does nothing to improve the stability of Inchworm Motors since they are very rigid and stable when stopped. In addition Inchworm Motors are clamped only when the controller is turned on. Rigid mounting provides less chance of slippage when power is turned off.

- Shaft-to-body axial alignment is very important. Misalignment can lead to motor damage and failure. Use Burleigh's Model LTO-H Alignment Hardware Kit to compensate for minor misalignments. See Figures 5 and 8.

- When power is turned off the Inchworm Motor holding force can momentarily drop to .5Kg or lower. It is best to remove any direct load (i.e. vertical mass, spring load, etc.) from the spindle before turning the power off.

Inchworm Motors are supplied with a rounded spindle tip. This can be used to couple to a load or can be removed to access the 6-32 tapped hole in the end of the spindle.

Several coupling methods can be used: See Figure 5.

i. The rounded spindle tip is used for pushing against a spring loaded flat surface. This is often the simplest method, but may not yield the best performance.

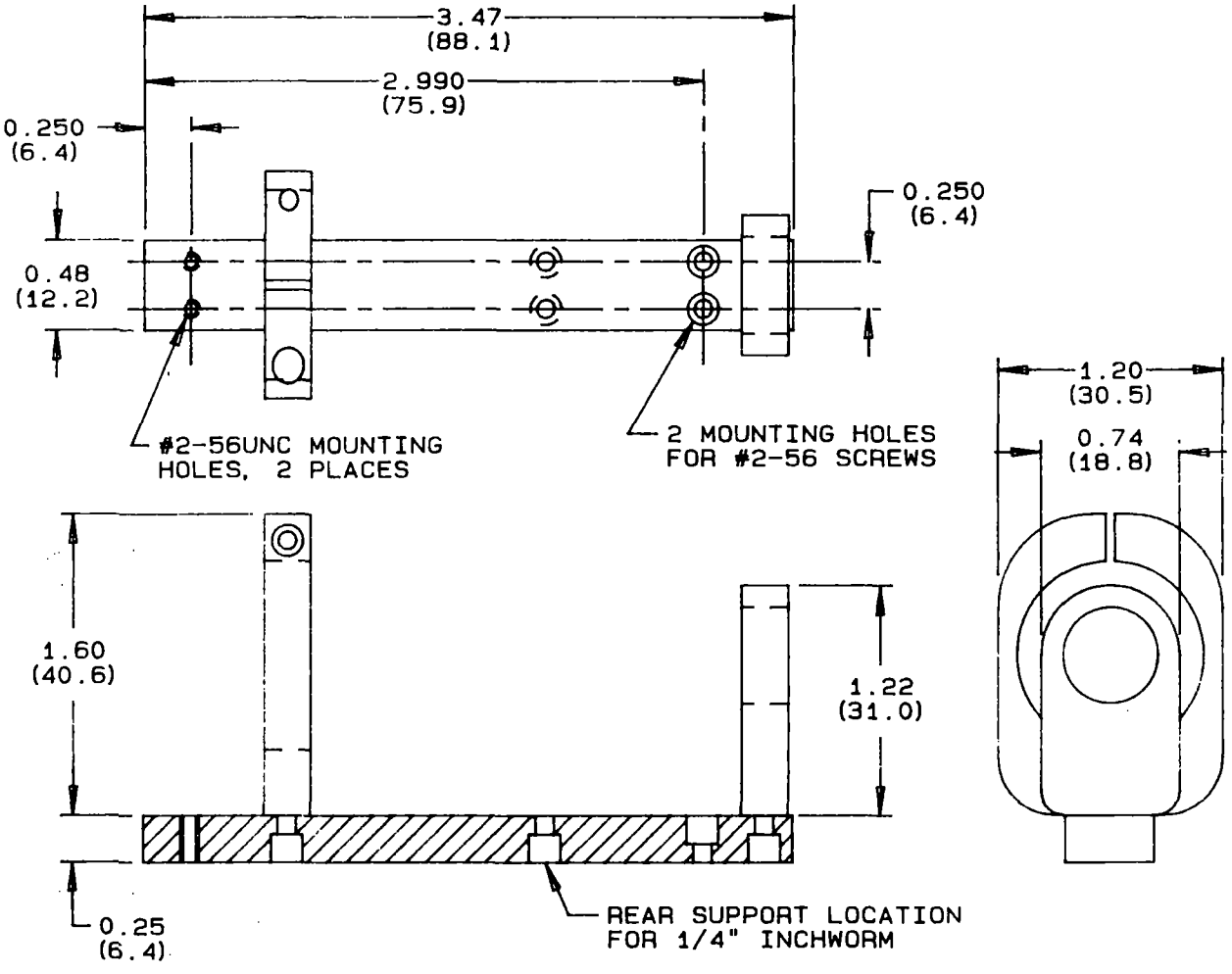
ii. Light objects may be mounted directly to the tapped hole in the spindle.

iii. Coupling may be accomplished by magnetic attraction by removing the non-magnetic spindle tip and replacing it with either a magnetic tip or a tip of ferromagnetic material that contacts a magnetic load.

iv. Burleigh's model IW-475 Electrode Mounting Kit may be used to attach small electrodes, pipettes, or other small loads to the spindle. It mounts directly to the spindle tip with a supplied 6-32 screw.

CAUTION: NEVER tighten or loosen the spindle tip (or any threaded object) on the spindle while holding the housing. This could damage the Inchworm Motor. Hold the spindle at the wrench flats located near the end of the spindle.

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FIGURE 4
IW-450 MOUNT

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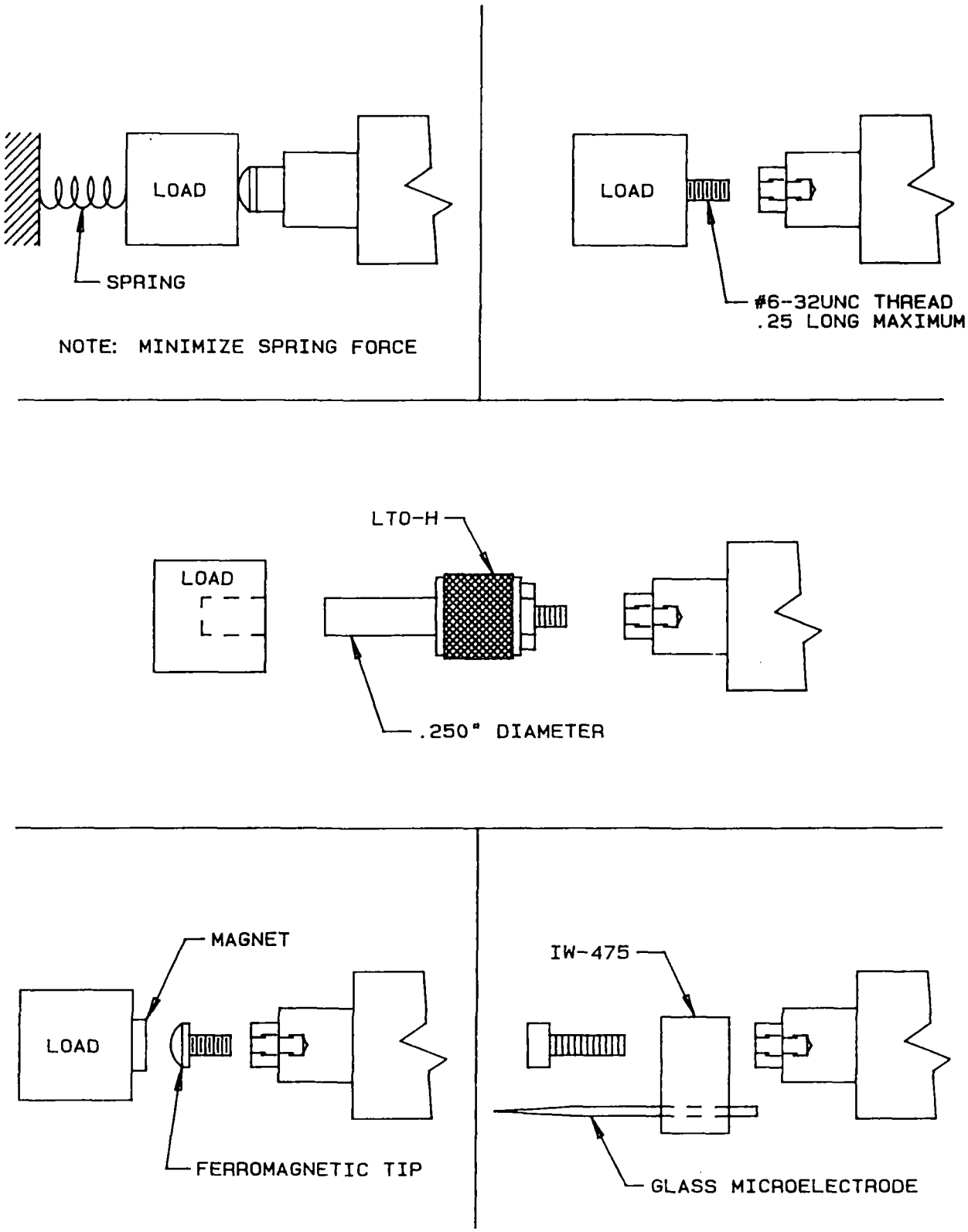


FIGURE 5
COUPLING METHODS

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5. SERVICE

Clearance Compensation is a bias level that sets the Off, or unclamped voltage for the clamp elements and determines the clearance between the clamp elements and the shaft. Burleigh sets this operating level at the factory. In normal use no adjustment should be necessary. However, under certain conditions the clearance between the shaft and clamps will change slightly resulting in a loss of push force. These conditions include:

- high ambient temperature
- large load combined with high duty cycle
- motor wear over a long period of time.

Please refer to your Inchworm Motor Controller Manual for instructions on adjusting the Clearance Compensation.

CAUTION: Excessive wear and damage to the Inchworm Motor can result if the Clearance Compensation is set too low.

There is no other user service or maintenance that can be done for the IW-700 or 710 Series Inchworm Motors. When any problems or questions arise please call the Burleigh Customer Service Department at:

Burleigh Instruments, Inc.
Burleigh Park
Fishers, New York 14453
Tel. (716)924-9355
Tlx. 97-8379
Fax. (716)924-9072

Or contact your local representative.

CAUTION: Do not open up an Inchworm Motor or remove any housing parts. High voltages may be exposed and the warranty will be voided!

6. SPECIFICATIONS

All Models:

Travel Distance	0.25(mm)	IW-700, IW-710
	25.0	IW-701, IW-711
	50.0	IW-702, IW-712

Speed	(minimum)	.004 micron/sec
	(maximum)	>2mm/sec.
Load	(maximum)	1.5Kg in direction of motion
		0.1Kg perpendicular to motion

Mechanical Resolution	4nm (typical)
Lateral Motion (maximum)	±1 microns at tip (6.25 and 25mm models)
	±2 microns at tip (50mm models)
Discontinuity at clamp change (typical)	<0.05 microns at no load
	<0.2 microns at 1.5 Kg. load
Temperature Range	Operation +10 to +50 degrees C.
	Storage 0 to +70 degrees C.
Force to move shaft (typical)	1.0to 1.5Kg Controller power off
	0.0 to 0.7Kg Power on (Free mode)

Encoder models:

Encoder Resolution	0.5μm
Encoder Accuracy	±1.0μm
	±2.0μm with LSO

Refer to Figure 7 for IW-700 and 710 Series outline dimensions.

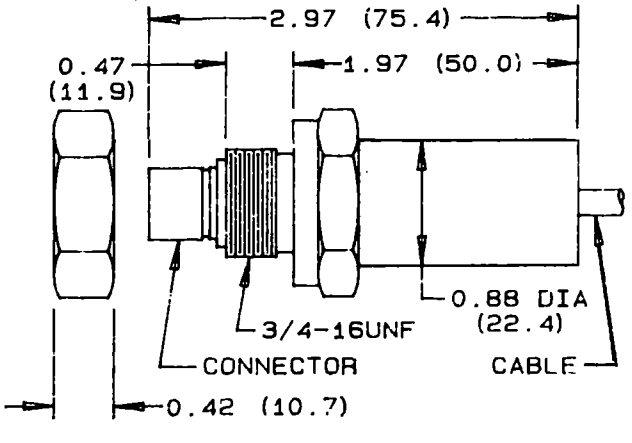
7. VACUUM OPERATION

A. DESCRIPTION

IW-700 and 710 Series Inchworm Motors are available with special assembly for vacuum use.

Important features are:

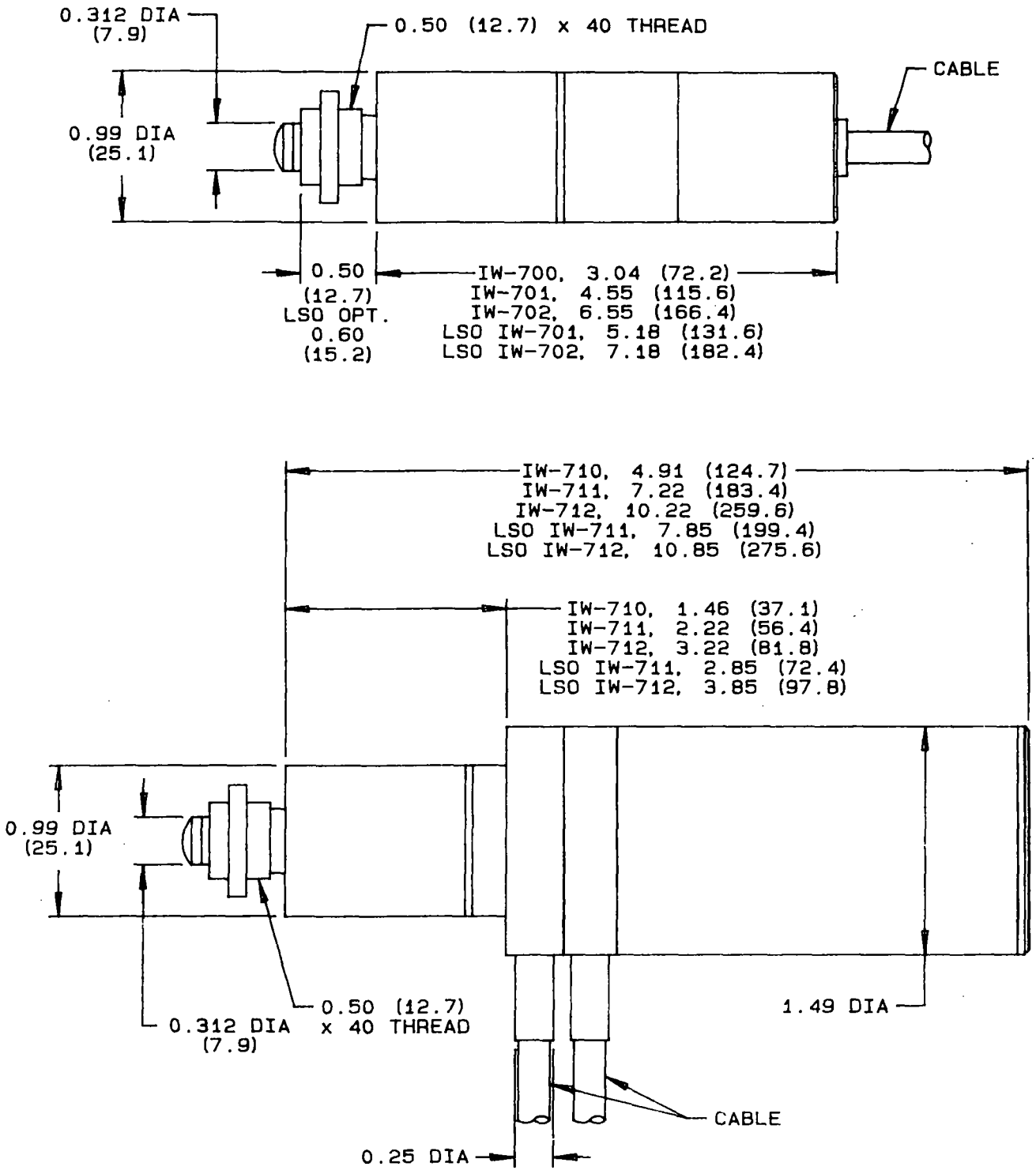
- Teflon motor and encoder cables.
- Bulkhead mount O-ring vacuum feedthroughs supplied for both Motor and encoder cables. (See Figure 6)
- Special cleaning in Freon to remove residual contaminants.
- All cavities vented to prevent trapping air.



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FIGURE 6
VACUUM FEEDTHROUGH

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FIGURE 7
IW-700/710 OUTLINE DIMENSIONS

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B. OPERATION

Excess heat generation during Inchworm Motor operation places a limitation on the product of duty cycle and speed. For vacuum use the recommended maximum is .25 × 100% duty cycle × 2mm/sec. In all cases the actual Motor temperature must be kept at or below 60^{O}C during operation.

When an Inchworm Motor is first run in vacuum self heating may cause some excess degassing which will result in a higher initial outgassing rate. The system will then return to outgassing rates listed below. The ultimate pressure obtainable depends on the pumping rate and background outgassing rate of the user's vacuum system. For ultra high vacuum applications contact Burleigh Instruments for information on UHV Series Inchworm Motors.

WARNING: The controller must be turned OFF when pumping through the corona region (.001 to 100 Torr). Failure to turn off the controller will result in permanent damage to the Inchworm motor, cabling, and controller. Inchworm motor replacement will likely be required. It is Burleigh's strongest recommendation that vacuum/power interlocks be installed to help prevent this type of damage.

CAUTION: The vacuum Inchworm uses a vented spindle tip. The threaded spindle hole is NOT vented. If the spindle tip is replaced, a vented screw design must be used.

C. SPECIFICATIONS

With the exception of the maximum product of duty cycle and speed as described above all positioning specifications are identical for vacuum and non-vacuum Inchworm Motors.

Vacuum range	10^{-6} to 10^{-7}Torr (typical)	
Bakeout temperature	- 70 C (maximum)	
Outgassing (typical)	Model	Outgassing rate
	IW-700	<1.0 (X10^{-6} T-L/s)
	IW-701	1.0
	IW-702	1.5
	IW-710	3.0
	IW-711	3.5
	IW-712	4.0

NOTE: (T-L/s = Torr-Liters/sec)

8. LATERAL STABILITY OPTION (LSO)

A. DESCRIPTION

The Lateral Stability Option reduces the sideways (lateral) motion of the Inchworm Motor spindle that occurs during a clamp change. This option is primarily of interest to neuroscientists who use the Inchworm Motor to probe or penetrate small cells (<20μm diameter).

The LSO is available for 25 and 50mm travel models only and is compatible with the encoder and vacuum options. The LSO adds approximately .63" to the length of the front housing of the Inchworm Motor. All other dimensions remain the same. Refer to Figure 7.

B. OPERATION

Cell penetration:

When the Inchworm Motor is moving there may be some vibration transmitted to the microelectrode, even with with LSO. Some Neuroscientists find this vibration or "ringing" helpful in making successful cell penetrations. Since this vibration is not a lateral motion of the spindle tip, but a resonant effect of the microelectrode it can be adjusted by varying the length of the pipette. Contact the Burleigh Customer Service Department or your local representative for more information.

Stability:

Due to its piezoelectric construction the Inchworm Motor is intrinsically very stable, showing little drift over many hours in a stopped condition.

For correct operation and to prevent unintended motions the Controller should be operated with the Maintenance function turned OFF. Refer to the Controller manual for further details.

C. SPECIFICATIONS

With the exception of encoder accuracy all positioning specifications are identical for LSO and non-LSO Inchworm Motors.

Lateral motion	<.2μm at clamp change (typical)
Lateral hysteresis	3μm maximum (see definition below)
Encoder accuracy	±2μm (IW-711 and IW-712 only)

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Lateral hysteresis is the net sideways motion of the spindle occurring when the Inchworm Motor reverses travel direction. This is a gradual motion with a sideways translation of 1-3μm occurring in a travel distance of 5-30μm. It is measured at the end of an approximately 3" long glass microelectrode mounted on the end of a fully extended Inchworm spindle.

D. ACCESSORIES

IW-475 ELECTRODE MOUNTING KIT

This kit provides the user a stable mount for 1mm diameter glass microelectrodes. The insulating Delrin block mounts to the threaded spindle end with a supplied 6-32 screw. See Figure 5.

IW-450 INCHWORM MOUNT

This mount is designed for use with LSO Inchworm Motors and provides a stable versatile platform for connecting to user supplied apparatus. The mount is provided with two tapped and two countersunk holes for mounting, or the user can tap or drill holes in the base as required. See Figure 4.

9. OPTIONS

A. EN SERIES ENCODERS

The EN Series encoders have travel distances of 12, 25 and 60mm, with 0.1μm resolution and $\pm$.5μm accuracy ($\pm$1μm accuracy for 60mm version). All three versions have an absolute reference position and are compatible with 6000, 7000, and 7010 Controllers. Hardware is available for mounting them to TS-100 Series stages. Contact the Burleigh Sales Department or your local representative for further details.

B. TS-100 TRANSLATION STAGES

The TS-100 Series offers a lightweight aluminum, high precision, crossed roller bearing stage designed for used with IW-700 and 710 Series Inchworm Motors. The basic stage has a 4" × 4" (101.6mm × 101.6mm) footprint with 50mm travel and is offered with or without a 1.75" diameter central through-hole, each in a standard or vacuum version. Counterbalanced vertical (Z-axis) versions are also available. Hardware is available for mounting EN Series encoders. Contact the Burleigh Sales Department or your local representative for further details.

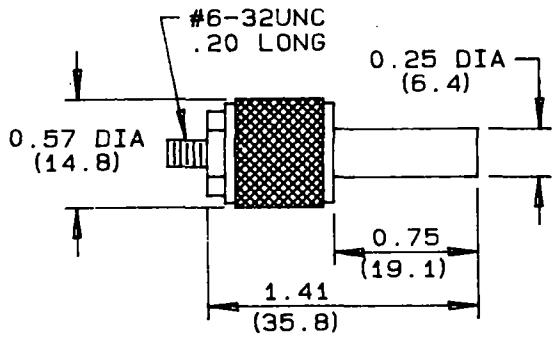
C. NON-MAGNETIC INCHWORM MOTOR

The standard IW-700 and 710 Series Motors use ferromagnetic shafts and screws. For applications requiring non-magnetic construction a ceramic shaft and stainless steel or brass screws can be substituted. For the IW-710 Series there are additional magnetic encoder parts that can be replaced depending on the degree of magnetism which can be tolerated. Contact the Burleigh Sales Department or your local representative for further details.

D. ACCESSORIES

LTO-H HARDWARE KIT

Burleigh's LTO-H Hardware Kit provides spring coupling directly to the spindle and provides a 0.25 inch diameter shaft for connection to the load. Each Kit has two spring loaded couplings. See Figures 5 and 8.



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FIGURE 8
LTO-H

CE-7 CABLE

This cable permits use of Inchworm Motors with CE-1000 & CE-2000 Controllers. See section 10.

10. OPERATION WITH CE-1000 AND CE-2000 CONTROLLERS

Restrictions:

i. A CE-7 Cable must be used (see below).
ii. Mechanical resolution is .01μm (typical).

As part of a design to improve noise immunity, Inchworm Motors designed for use the 6000, 7000 and 7010 Controllers use a different ground and

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shield pin configuration than those designed for use with the CE-1000 or CE-2000 Controllers. Thus the IW-700 and 710 Series are not directly compatible with Burleigh Model CE-1000 or CE-2000 Controllers, but require use of a CE-7 Adapter Cable between the Controller and the Inchworm Motor cable.

CAUTION: An electrical shock hazard can exist if a CE-1000 or CE-2000 Controller is used without a CE-7 cable. If you have any questions please contact the Burleigh Customer Service Department or your local representative.

EN Series 0.1μm resolution encoder operation:

A model EXE-710 interface box must be used. Contact the Burleigh Customer Service Department or your local representative for details.

Extension cables:

Motor: Use Model 7011 Extension cables. The maximum allowable length is 50 feet. First connect the CE-7 cable to the Controller then connect the extension cable.

Encoder:

0.5μm resolution - No extension cables permitted

0.1μm resolution - Use Model 7007 Extension cables. The maximum allowable length is 50 feet.

11. GLOSSARY

Accuracy - The veracity with which an instrument can determine the true value of a quantity measured.

Backlash - An error in gear trains and lead screw systems arising from mechanical tolerances. It is the "dead band" where no motion occurs when the direction of travel is reversed.

Closed loop control - Operation of a positioning system with position feedback. Positioning accuracy is dependent upon the encoder.

Encoder - A measuring device which outputs signals corresponding to position or change in position. Rotary or shaft encoders measure angles. Linear encoders measure distance along a straight line.

Feedback - In closed loop positioning systems this refers to the signals used by the controller to measure and maintain position.

Lateral motion - The rapid sideways net motion of the spindle which occurs during a clamp change.

Open loop control - Operation of a positioning system without position feedback. Accuracy depends on the drive system, stage and load.

Piezoelectric - A term used to describe a class of materials which expand or contract upon application of an electric field.

Repeatability - The variability experienced when a positioning system is repeatedly moved to some nominal location. Note that a system can be inaccurate, but very repeatable.

Resolution: measurement - The smallest increment of motion that the encoder or sensor can detect. In a closed-loop system this is also the smallest position step that can be taken under feedback control.

Resolution: mechanical - The smallest motion that an actuator can achieve.

12. WARRANTY

Burleigh 700 and 710 Series Inchworm Motors, when operated by Burleigh Control Electronics, are warranted against defects in material and workmanship for a period of one year after date of delivery. Burleigh's warranty card must be returned within 30 days after date of delivery. During the warranty period, Burleigh will repair or, at its option, replace parts which prove to be defective when the motor is returned prepaid to Burleigh Instruments, Inc. The warranty will not apply if the motor has been damaged by accident, misuse, or as a result of modification by persons other than Burleigh personnel.

It is important to call Burleigh or your local representative for a Return Authorization Number (RA#) before returning any product. This will insure the prompt handling of the repair.

The liability of Burleigh (except as to title) arising out of supplying of said product, or its use, whether under the foregoing warranty, a claim of negligence, or otherwise, shall not in any case exceed the cost of correcting defects in the product as herein provided. Upon expiration of the warranty period specified herein, all liability shall terminate. The foregoing shall constitute the sole remedy of the buyer. In no event shall the seller be liable for consequential or special damages.

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1	03992-3-07	IW-711-01, 25MM ENC LSO	65	2	2	EA	16-Oct-91	2	
2	04649-3	IW-475, ELECTRODE MOUNTING KIT	65	2	2	EA	16-Oct-91	2	
3	04745-3	IW-450, MOUNT, MICROMANIPULATOR	65	2	2	EA	16-Oct-91	2	
4		SPECIAL 6200-2-3-1-3 SEE SPECIAL SHEET	67	1	1	EA	16-Oct-91	1	
5	04629-3	6005, HANDSET	67	1	1	EA	16-Oct-91	1	

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WARRANTY

Burleigh products are guaranteed to be free from defects in material and workmanship for a period of one year from date of delivery. Optical components carry a 90 day warranty. Laser crystals are warranteed for one year.

You qualify for this warranty by filling out and returning this postage paid warranty sheet within 30 days.

All products are fully tested at the factory and carefully packaged for shipment. If there are any problems, please contact us immediately. Shipping damages must be quickly reported to the carrier to receive full consideration.

Thank you for your order. We hope to do business with you again in the near future.

Specifier or User

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Company _____

Street _____

Dept. or Ms. _____

City _____ State _____ Zip _____

Phone _____

Purchasing Agent

Name _____

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Dept. or Ms. _____

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Do you have any comments on our products? _____

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LTO/LTS
INCHWORM® MOTOR
Instruction Manual

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1. INTRODUCTION

Burleigh Instruments Inc. thanks you for choosing an LTO or LTS Series Inchworm® Motor. It has been designed and optimized to meet your most rigorous micropositioning needs. LTO and LTS Series Inchworm motors are the culmination of over a decade of development in piezoelectric technology. They incorporate significant improvements over earlier systems in smoothness of operation, speed under load, mechanical step resolution, reliability, and versatility. Operated by Burleigh control electronics these devices provide the highest mechanical resolution of any commercial positioning system.

Should any questions or problems arise with the Inchworm motor please contact Burleigh's Customer Service Department at (716) 924-9355 or your local representative.

CAUTION: High voltages are present during normal operation of Inchworm Motors even when they are not in motion. Do not disassemble nor remove any covers as there are no user serviceable areas or parts inside. Use care not to damage the cables and plugs.

CAUTION: Inchworm Motors contain piezoelectric ceramics which can be damaged by rough handling or physical shock.

2. INITIAL INSPECTION

A. VISUAL

Inchworm Motors are packed in a special carton designed to give maximum protection during shipment. If the outside of the shipping carton is damaged notify your shipping department immediately. They may wish to notify the carrier at this time.

If the shipping carton is undamaged externally remove the motor from the carton. If any damage is visually evident or if rattling can be heard when the motor is gently shaken, notify your shipping department and Burleigh Instruments or your local representative immediately. Please save the special carton for future storage and transportation.

B. OPERATIONAL

Refer to Section 4 for a discussion of normal operation of the LTO and LTS Series Inchworm motors. In the event of abnormal operation contact Burleigh's Customer Service Department or your local representative at once.

CAUTION: Do not attempt to use an Inchworm Motor until you are familiar with the operation of the Controller. Refer to the Controller Manual for details.

CAUTION: Do not attempt to run an LTS Series Inchworm motor until it is correctly mounted and the shipping bar removed. Failure to follow these instructions will result in damage.

C. QUALITY CONTROL

LTO and LTS Series Inchworm motors undergo several stages of inspection, test, and calibration before shipment including an extended run-in. They are designed to provide years of trouble free operation. In the unlikely event that problems occur please contact Burleigh or your local representative for instructions. Our Customer Service Department is ready to help with advice, parts, and repair services.

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3. DESCRIPTION

The Burleigh Inchworm Motor is a compact linear actuator. Its patented piezoelectric construction allows precise positioning with low compliance (high stiffness) and none of the backlash inherent in gear driven stepper or dc motor systems. Unlike magnetic motors the Inchworm Motor does not dissipate power when stopped. When used with a Burleigh Controller it has a mechanical resolution of 0.004 microns with a speed range of 0.004μm/sec to greater than 2mm/s. The shaft can generate a linear force of 1.5Kg. Construction for vacuum operation is available.

LTO Series motors have travel distances of 0.25, 1, 2, 4, 6 and 8 inches. They are the simplest and most compact conventional Inchworm Motors, consisting of a compact body with the shaft extending through it and out both ends. It contains no built-in limit switches.

LTS Series Inchworm motors have travel distances of 4, 6, and 8 inches. Their construction is similar to LTO Series motors, but they are designed for mounting on Burleigh's line of long travel stages. The user can attach them to other manufacturers' stages if necessary. LTS Series Inchworm motors include stage mounting hardware and built-in, adjustable limit switches which stop travel when actuated.

MODEL NUMBERS

LTO-XXX-A LTS-YYY-A

XXX	Travel	YYY	Travel
025	0.25	400	4.00
100	1.00	600	6.00
200	2.00	800	8.00
400	4.00		
600	6.00		
800	8.00		

A = 0 - Standard
= 1 - Vacuum option

NOTE: LTO and LTS Series Inchworm motors are designed for operation by Burleigh 6000, 7000 and 7010 Series Controllers. With certain restrictions they may be operated by CE-1000 and CE-2000 Controllers. Refer to Section 8 for details.

CAUTION: An electrical shock hazard can exist if an LTO or LTS Series Inchworm motor is connected directly to a CE-1000 or CE-2000 Controller. If you have any questions please contact the Burleigh Customer Service Department or your local representative.

For your convenience a glossary of micropositioning terms is found in Section 9 of this manual.

INCHWORM MOTION

The principle of Inchworm motor motion is described below. See Figure 1.

Both outer elements, numbered 1 and 3 in the figure, contract when voltage is applied and firmly clamp onto the shaft. The center element, numbered 2, expands along the shaft with increasing voltage. All three elements operate independently.

The Controller sequences the clamp and center element voltages to generate Inchworm Motor motion as follows:

- actuate clamp element 3
- extend center element 2, moving shaft to the right
- actuate clamp 1, then release clamp 3
- contract center element, moving shaft further to the right
- actuate clamp 3, then release clamp 1
- repeat sequence

Reverse travel is achieved by reversing this sequence. Forward and reverse limit switches automatically halt further travel when either extreme of travel is reached. Extension or contraction of the center element causes about 2 microns of shaft movement between clamp changes.

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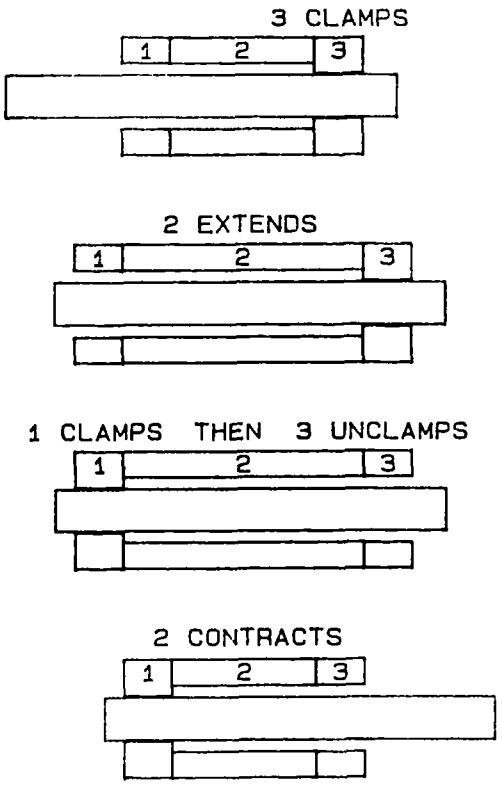


FIGURE 1
INCHWORM MOTOR MOTION

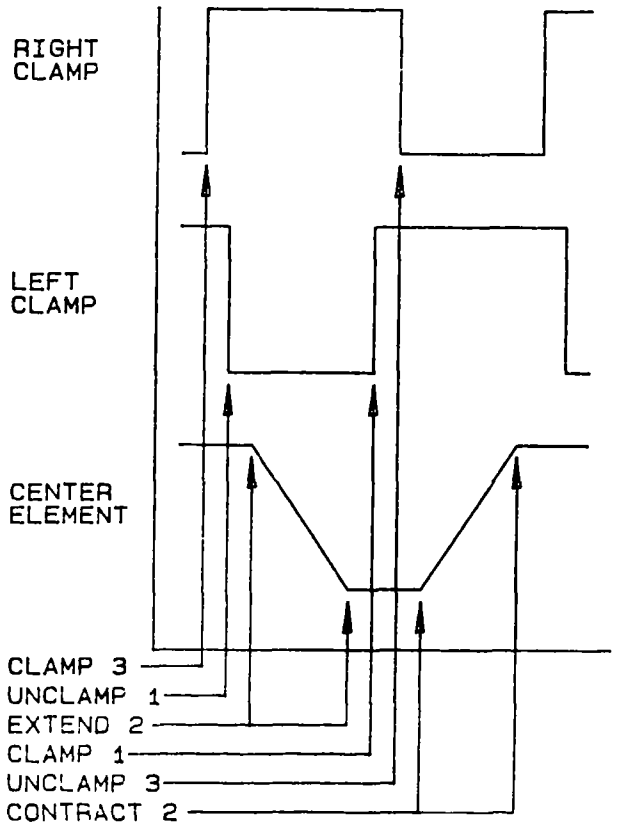


FIGURE 2
VOLTAGE SEQUENCES

The voltage applied to the clamp elements has two levels - On (clamped) and Off (unclamped). The center element receives a positive or negative sloped voltage ramp (staircase) for smooth motion. The slope of these ramp signals coordinated with the clamp change frequency determines translation speed. See Figure 2.

The ramp is electronically divided into 512 discrete levels between clamp changes and may be halted at any level to achieve mechanical resolution of about 0.004 microns. The clamping and unclamping process generates a "discontinuity" in the motion which will vary slightly from system to system with a typical magnitude of less than 0.05μm under no load conditions and 0.2μm with a 1.5Kg load.
See Figure 3.

In applications where accurate, repeatable positioning is required best results are obtained by using the Inchworm motor in a closed-loop mode with a linear encoder for position feedback. Optical encoders are available from Burleigh with travel ranges from 0.5" to 8.25". It is also possible to interface encoders from other manufacturers. Refer to the Controller manual for details.

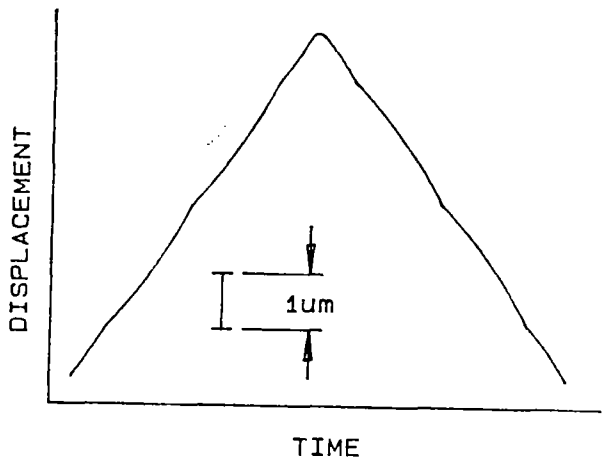


FIGURE 3
TYPICAL MOTION PROFILE

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4. OPERATION

A. MOUNTING LTO SERIES INCHWORM MOTORS

LTO Series Inchworm motors may be mounted with the body stationary and the shaft moving through it or with the shaft stationary and the body moving along it. The LTO may be mounted in any orientation. Attachment to the body is made with the two #6-32 by 0.25 inch deep tapped holes located in the center part of the body. The shaft has a #6-32 tapped hole, 0.25 inch deep at each end for mounting. See Figure 4.

WARNING: During the process of mounting an LTO series Inchworm motor observe the following cautions:

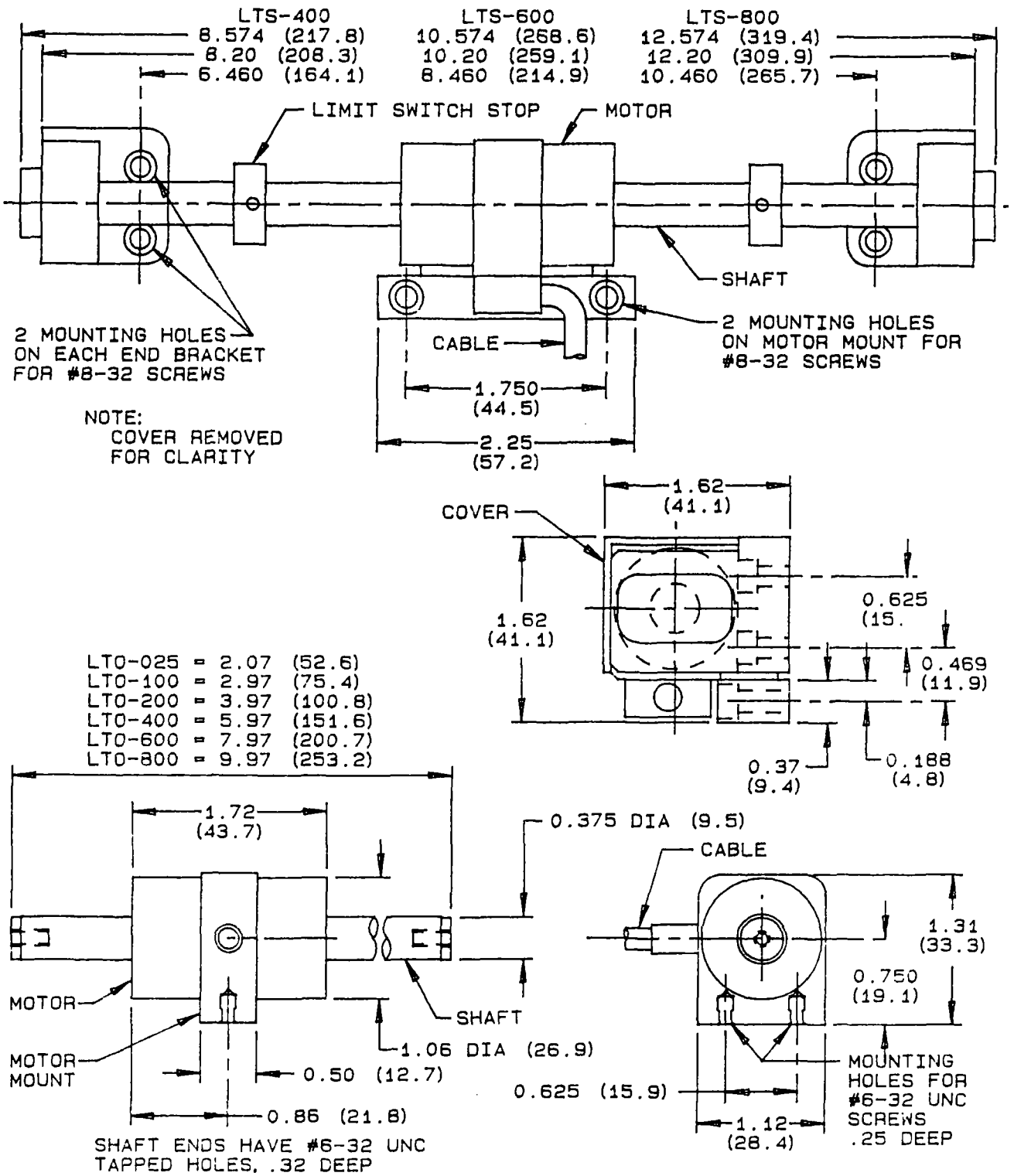
- **The Inchworm motor is fragile to shocks and shock loads.**
- **Side loading or misalignment during installation can break the piezoelectric ceramic elements. Do not attach the Inchworm motor or shaft rigidly until proper alignment is verified.**

When mounting LTO Series motors, please consider the following:

- Never remove the shaft from the body.
- Protect the Inchworm motors' body and shaft from dust, dirt, and debris. If these get inside they will shorten its life.
- Excessive relative humidity may condense and cause electrical arcing subsequent failure.
- Shaft-to-body axial alignment is very important. Misalignment can lead to severe damage and failure. Use Burleigh's Model LTO-H Alignment Hardware Kit to compensate for minor misalignment. Each Kit has two spring loaded end pieces that screw into the shaft ends. A 0.25 inch diameter shaft extends from each piece for mounting. See Section 7.
- For the 6" and 8" travel models if the Inchworm Motor is mounted horizontally the shaft must be supported along its length to prevent its weight from causing damage.
- In operation any side loading (perpendicular to the direction of travel) of the shaft or Inchworm motor must be kept below 0.1Kg.
- During operation the shaft may rotate randomly. Do not, however, attach the shaft to a rotating device as excessive wear or damage can result.

There are no built-in limit switches in LTO Series Inchworm motors so they will not stop actuating when a physical travel limit is reached. Damage can result if the Inchworm motor stalls repeatedly against a mechanical stop for periods greater than 5 minutes.

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FIGURE 4
MOUNTING LTO/LTS INCHWORM MOTORS

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B. MOUNTING LTS SERIES INCHWORM MOTORS

Burleigh LTS Series Inchworm motors are designed to be mounted on translation stages and are supplied with the required mounting brackets, hardware, and tools. See Figure 4.

Special instructions for mounting the LTS to user-supplied stages:

The end brackets and body mounting bracket have counterbored holes which will accept either an 8-32 or M4 socket head screw. For the user's convenience the necessary 8-32 screws are provided. Four tapped holes are required in the side of the stage top where the end brackets mount. Two tapped holes are required in the side of the stage bottom where the body mounting bracket attaches. These should be at the center of stage travel. Locate all six of these holes to a tolerance of ±0.005 inches to give proper shaft alignment. See Figure 5.

CAUTION: Each LTS Inchworm Motor is shipped in proper alignment with a mounting bar attached. Do not remove this bar until instructed to do so.

CAUTION: Avoid side or shock loads to the shaft during the mounting procedure. These can cause permanent damage.

1. Attach the Inchworm motor assembly to the stage top slide by fastening the End Brackets with the four #8-32 by 0.75" long screws. Two screws hold each End Bracket. Loosely attach these screws for now; do not tighten them. Position the top of the mounting bar parallel to the stage top surface within 0.002" (.05mm) over its entire length, then tighten the four screws securely. See Figure 5.

2. Check that the two screws holding the Mounting Block to the Inchworm Motor Block are loose. This permits some mounting allowance while attaching the Mounting Block. Attach the Inchworm Motor Mounting Block to the stage bottom slide with the two 8-32 by 0.5" long screws. Tighten these two screws securely. Next securely tighten the two screws holding Inchworm Motor Mounting Block to the Inchworm Motor Block.

   Once installed the shaft alignment can be checked by removing the end caps from both End Brackets. Remove the two screws in each end cap, take the end caps off and remove the plunger from each end. One end also has a small spring that is removed with the plunger. Look down the bore of the end brackets and observe that the Inchworm motor shaft is centered in the bore. Reassemble the End Brackets.

3. When all screws are securely tightened remove the six screws holding the mounting bar to the Inchworm Motor Block and End Brackets. Remove the bar and save it and its screws for future disassembly.

4. The two collars on the Inchworm motor shaft are adjustable stops for the travel limit switches. One collar is located on each end of the shaft between the Inchworm Motor Block and the End Bracket. Each is held in position by a set screw and can be positioned anywhere along the shaft as long as they are not outside the travel of the stage.

5. Place the Cover over the End Brackets so the shaft and Inchworm Motor Block are protected. Secure it with the four 6-32 by 0.25 inch long screws provided.

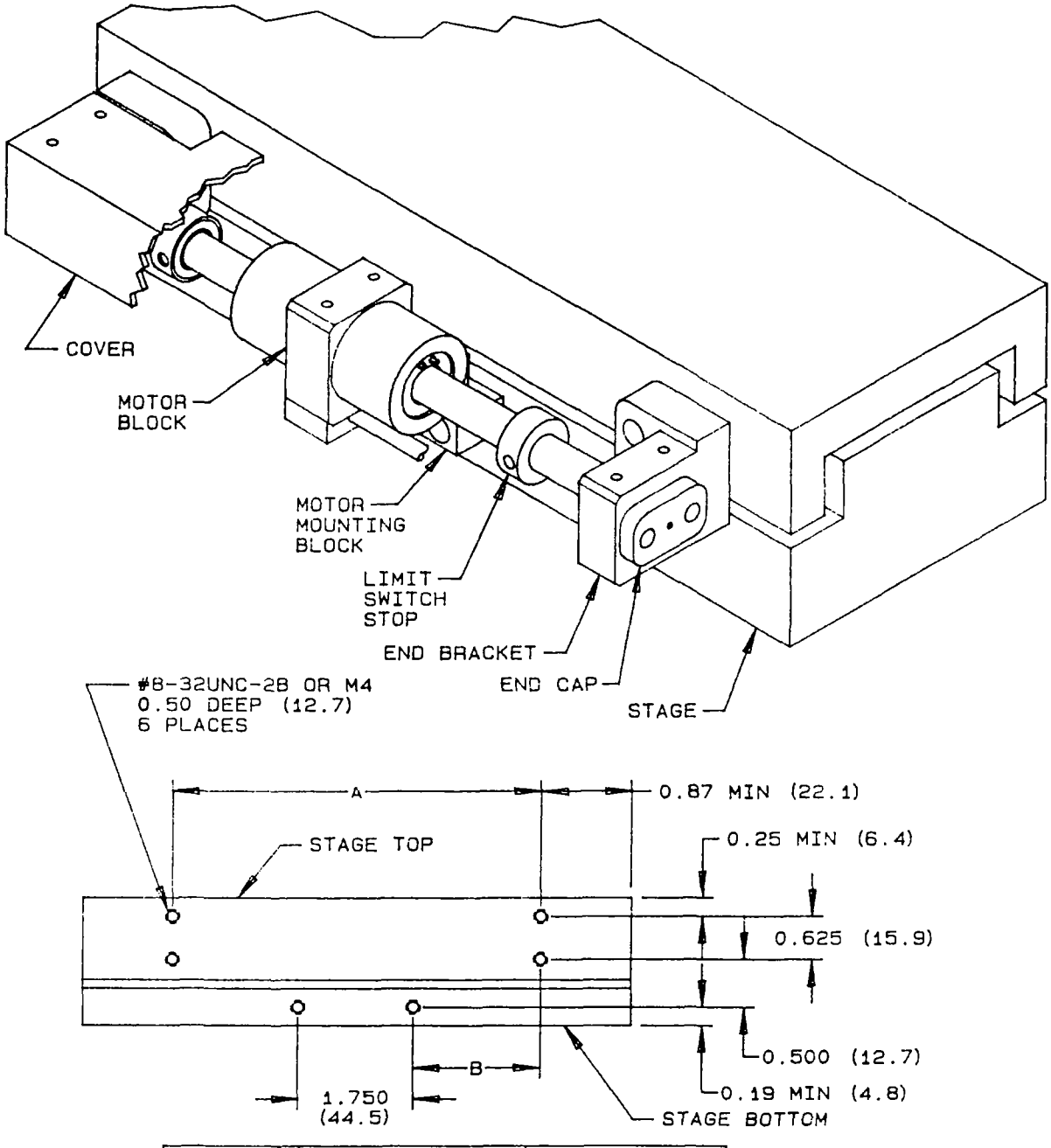
WHEN MOUNTING LTS MOTORS PLEASE CONSIDER THE FOLLOWING:

- Never remove the shaft from the body.

- Protect the Inchworm motor body and shaft from dust, dirt and debris. If these get inside they will shorten its life.

- Avoid excessive relative humidity that may condense and cause electrical arcing and ultimate failure.

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PRODUCT	A	B
LTS-400	6.460 (164.1)	2.34 (59.4)
LTS-600	8.460 (214.9)	3.34 (84.8)
LTS-800	10.460 (265.7)	4.34 (110.2)

NOTE:
DIMENSIONS SHOWN IN PARENTHESES ARE IN MILIMETERS.

FIGURE 5
MOUNTING LTS INCHWORM MOTORS TO STAGES

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C. ELECTRICAL CONNECTIONS

LTO and LTS Series Inchworm motors are designed for use with Burleigh 6000, 7000 and 7010 Series Controllers. Refer to Section 8 for information on using them with Burleigh CE-1000 or CE-2000 Controllers.

Before connecting an Inchworm Motor to a Controller be sure that the Controller power is turned off. Plug the LTO or LTS Cable Connector directly into the High Voltage Driver Output which is located on the rear of the Controller. If the Inchworm motor must be located beyond its standard six foot cable length from the Controller Burleigh Model 7011 Extension Cables must be used. These are available in 10, 25, and 50 foot long versions. Extension cables can be connected in series but must not exceed 50 feet in total length.

The novel piezoelectric construction of the Inchworm Motor results in unique operating characteristics. As the motor moves a buzzing can be heard at high speeds changing to clicking at low speeds. This is due to the opening and closing of the clamp elements and is normal. When the Inchworm Motor is stopped one clamp firmly holds the shaft so the shaft is very stable and does not exhibit any vibration. In addition since piezoelectric materials do not draw current when held at constant voltage Inchworm Motors do not dissipate heat when stopped. The fast response of piezoelectric materials gives them very high acceleration and deceleration.

Refer to the Controller manual for more information on using the Inchworm Motor.

5. SERVICE

Clearance Compensation is a bias level that sets the unclamped voltage for the clamp elements and determines the clearance between the clamp elements and the shaft. Burleigh sets this operating level at the factory. In normal use no adjustment should be necessary. Under certain conditions the clearance between the shaft and clamps will change slightly leading to a loss of push force unless the clearance compensation is reduced. These conditions include:

- high ambient temperature
- large load combined with high duty cycle, and
- motor wear over a long period of time.

Refer to your Controller Manual for instructions on adjusting the Clearance Compensation.

CAUTION: Excessive wear and damage to the Inchworm Motor can result if the Clearance Compensation is set too low.

There is no other user service or maintenance that can be done for LTO and LTS Series Inchworm Motors. If any problems or questions arise please call the Burleigh Customer Service Department at:

Burleigh Instruments, Inc.
Burleigh Park
Fishers, New York 14453
Tel. (716) 924-9355
Tlx. 97-8379
Fax. (716)924-9072

Or contact your local representative.

CAUTION: Do not open an Inchworm Motor or remove any housing parts. Opening can expose high voltages and will void the warranty.

CAUTION: Do not remove an LTS Inchworm Motor from a stage without first replacing the shipping bar.

6. SPECIFICATIONS

Travel (inches)	Product Number
0.25	LTO-025-X
1.0	LTO-100-X
2.0	LTO-200-X
4.0	LTO-400-X
6.0	LTO-600-X
8.0	LTO-800-X
4.00	LTS-400-X
6.00	LTS-600-X
8.00	LTS-800-X

Load (maximum)	1.5Kg along direction of motion 0.1Kg perpendicular to direction of motion
Speed (minimum)	.004 micron/sec
(maximum)	>2mm/sec
Mechanical resolution	4nm (typical)
Discontinuity at clamp change	<0.05 microns at no load <0.2 microns at 1.5 Kg. load (Typical)
Temperature Range Operation	+10 to +50 degrees C.

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Temperature Range Storage
0 to +70 degrees C.

Force to move shaft
1.0 to 1.5Kg Controller off
0.0 to 0.7Kg Controller on, clamps open (Typical)

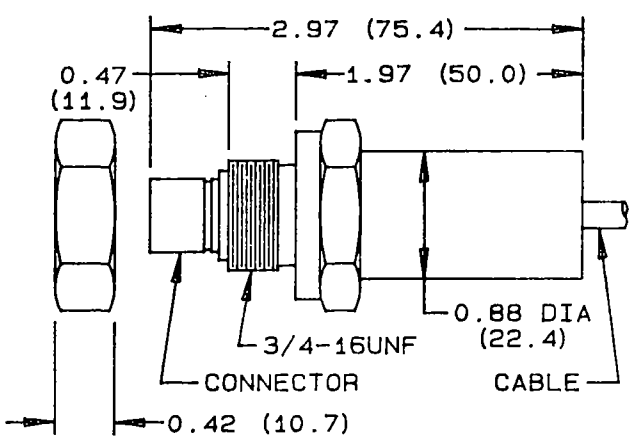
Refer to Figure 4 for LTO and LTS Inchworm Motor dimensions.

7. OPTIONS

A. VACUUM OPERATION

LTO and LTS Series Inchworm motors can be manufactured for vacuum operation. These are routinely used inside vacuums in the range of 10^{-6} to 10^{-7} Torr. Important features are:

- Teflon motor cables
- Bulkhead mount O-ring vacuum feedthroughs supplied for motor cable. See Figure 6.
- Special cleaning to remove residual contaminants.
- All cavities vented to prevent trapping air.



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FIGURE 6
VACUUM FEEDTHROUGH

NOTE: The 6-32 mounting holes on the LTO body, and on the shaft ends are not vented. Vented screws must be used.

There is a limitation on the product of duty cycle and speed due to excess heat generation by the Inchworm Motor when operated in vacuum. For vacuum use the recommended maximum is .25 X 100% duty cycle X 2mm/sec. This can be achieved by limiting duty cycle or speed. Regardless of duty cycle and speed the actual Inchworm Motor temperature must be kept at or below 60C during operation.

When the Inchworm motor is first run self heating may cause some excess degassing which will result in a higher initial outgassing rate. It will soon return to the outgassing rates listed below. The ultimate pressure obtainable depends on the pumping rate and background outgassing rate of the user's vacuum system.

CAUTION: The controller must be turned OFF when pumping through the corona region (.001 to 100 Torr). Failure to turn off the controller will result in permanent damage to the Inchworm motor, cabling, and controller. Inchworm motor replacement will likely be required. It is Burleigh's strongest recommendation that vacuum/power interlocks be installed to help prevent this type of damage.

TYPICAL PERFORMANCE:

With the exception of the maximum product of duty cycle and speed as described above all positioning specifications are identical for the vacuum and non-vacuum Inchworm Motors.

vacuum range - 10^{-6} to 10^{-7} Torr

bakeout temperature - 70 C (maximum)

outgassing rate - 1 - 3 ($X10^{-6}$ T-L/s) LTO
- 3 - 6 ($X10^{-6}$ T-L/s) LTS
(T-L/s = Torr-Liters/sec)

CAUTION: Vacuum LTS Inchworm motors are normally shipped without the painted cover. Upon request the cover will be included. See Figure 4.

B. NON-MAGNETIC LTO MOTOR

The standard LTO Series Inchworm motor uses a ferromagnetic shaft. For applications requiring non-magnetic construction a ceramic shaft can be used. Contact the Burleigh Sales Department or your local representative for further details.

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C. ACCESSORIES

LT SERIES TRANSLATION STAGES

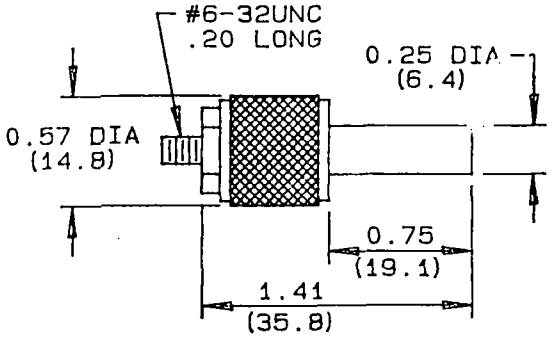
The LT Series Translation Stages feature 4.00", 6.00" and 8.00" travel and are directly compatible with the LTS Series Inchworm Motors. These can be purchased separately or as a system with the LTS Inchworm Motor and ENL Series optical encoder (see below) already mounted. Contact the Burleigh Sales Department or your local representative for further details.

ENL SERIES ENCODERS

These 1μm resolution optical encoders in 4.00", 6.00" and 8.00" travel versions are directly compatible with Burleigh Controllers and LT Series Translation Stages. Contact the Burleigh Sales Department or your local representative for further details.

LTO-H HARDWARE KIT

Burleigh's LTO-H Hardware Kit provides spring coupling directly to the spindle and provides a 0.25 inch diameter shaft for connection to the load. Each Kit has two spring loaded couplings. For vacuum applications a vented screw must be requested. See Figure 7.



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FIGURE 7
LTO-H

CE-7 CABLE

Adapter Cable for CE-1000 & CE-2000 Controllers only. See section 8.

8. OPERATION WITH CE-1000 AND CE-2000 CONTROLLERS

RESTRICTIONS:

i. A CE-7 Cable must be used (see below).

ii. Mechanical resolution is .01μm (typical).

As part of a design to improve noise immunity Inchworm motors designed for use with the 6000, 7000, and 7010 Controllers use a different ground and shield pin configuration than those designed for use with the CE-1000 or CE-2000 Controllers. For this reason the LTO and LTS Series are not directly compatible with Burleigh Model CE-1000 or CE-2000 Controllers. A CE-7 Adapter Cable must be used between the Controller and the Inchworm motor cable. When extension cables are used first connect the CE-7 cable to the Controller then connect the extension cable.

CAUTION: An electrical shock hazard exists if a CE-1000 or CE-2000 Controller is used without a CE-7 cable. If you have any questions please contact the Burleigh Customer Service Department or your local representative.

9. GLOSSARY

Accuracy - The degree to which an instrument can determine the true value of a quantity measured.

Backlash - An error in gear trains and lead screw systems arising from mechanical tolerances. It is the "dead band" of no motion observed when the direction of travel is reversed.

Closed loop control - Operation of a positioning system with position feedback. Positioning accuracy depends only on encoder.

Encoder - A measuring device which outputs a signal corresponding to a position or change in position. A rotary or shaft encoder measures angular position, a linear encoder measures position along a straight line.

Feedback - In closed loop positioning systems this refers to the signal used by the controller to measure and maintain position.

Lateral motion - The rapid sideways net motion of the spindle which occurs during a clamp change.

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Open loop control - Operation of a positioning system without position feedback. Positioning accuracy depends on drive system, stage and load.

Piezoelectric - A term used to describe a class of materials which expand or contract upon application of an electric field.

Repeatability - The degree to which a positioning system moves to the same actual position when commanded to move to a given measured position. Note that a system can be inaccurate, but very repeatable.

Resolution: Mechanical - The smallest mechanical motion that an actuator can achieve.

Resolution: Measurement - The smallest increment of motion that the encoder or sensor can resolve. In a closed-loop system this is also the smallest position step that can be taken under feedback control.

10. WARRANTY

Burleigh Inchworm Motors when operated by Burleigh Control Electronics are warranted against defects in material and workmanship for a period of one year after date of delivery. Burleigh's warranty card must be returned within 30 days after date of delivery. During the warranty period Burleigh will repair or at its option replace parts which prove to be defective when the Inchworm motor is returned prepaid to Burleigh Instruments, Inc. The warranty will not apply if the Inchworm motor has been damaged by accident, misuse, or as a result of modification by persons other than Burleigh personnel.

It is important to call Burleigh or your local representative for a Return Authorization Number (RA#) before returning any product. This will insure the prompt handling of the repair.

The liability of Burleigh (except as to title) arising out of supplying of said product, or its use, whether under the foregoing warranty, a claim of negligence, or otherwise, shall not in any case exceed the cost of correcting defects in the product as herein provided. Upon expiration of the warranty period specified herein, all liability shall terminate. The foregoing shall constitute the sole remedy of the buyer. In no event shall the seller be liable for consequential or special damages.

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burleigh

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