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MAC 2000 Configuration Manual

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MAC 2000 CONFIGURATION REFERENCE

Introduction:

Overview:

The MAC 2000 is a modular system for providing automation control. The system can be configured with different modules to suit different tasks. Several systems are defined as products using the MAC 2000 control unit. Motorized XY(Z) stages are the most common configuration for the MAC 2000. The MAC 2000 can be configured also as a photometer controller, filter/shutter controller, and an autofocus controller - to name a few. Any combination of the previous is also possible. The purpose of this manual is to explain the possible configuration options for each type of module in the MAC 2000.

Terminology:

Throughout this manual references are made to components of the system. The term *MAC 2000* is a generic description of the entire electronics console. A MAC 2000 describes nothing more than the style of the unit and the format of its components. A *module* is referred to as a single circuit board that plugs into the MAC 2000 frame. A MAC 2000 *frame* refers to an empty MAC 2000 control unit. The frame includes only the main power transformer, the passive motherboard, and the mechanical housing for mounting the modules. Most modules have an onboard CPU to communicate and perform the module's function; these are known as *intelligent* modules. Each intelligent module has an *address* on the control bus. The address range is from 1 to 255. No two modules can have the same address for the unit to operate properly.

Inserting and Removing modules:

The MAC 2000 system allows convenient removal and replacement of each module for service or configuration. To remove a module from the MAC 2000 frame the two locking screws located on the top bottom edge of the front panel of the module must be turned so the slot is horizontal (perpendicular to the long axis of the module front panel). The module can be removed by gripping the module handle tightly between the forefinger and the thumb and wiggling the module up and down with a firm pulling motion. Since the connectors can be quite tight, care should be taken so that when the module is freed, no injury to the module or person occurs.

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Configuration:

There are x standard configurations available in three different frame sizes. The standard configurations include the XY stage (most common), photometer, autofocus, and filter wheel combinations. Frame sizes are 4"(4 slots), 9"(9 slots), and 19" (19 slots).

The standard XY stepper motor stage controller configuration (990052) is shown in Figure 1, Figure 2. The system consists of two (2) each MCMSE and MDMSP modules, a power supply module, and RS-232 interface module. The XY joystick inputs are connected to the modules internally via the motherboard.

The standard stage controller can have one or more of the following: photometer controller, video autofocus, filter wheel controller, digital/analog I/O board.

Dedicated photometer control systems are also offered in standard configurations with digital readout control panel, and filter wheels as expansion options.

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MAC 2000 Interface and Communication:

Description:

The interface provides communication from an external computer to each of the modules in the MAC 2000 frame by either RS-232 or IEEE-488. Each type of communication provides for high-level ASCII or low-level binary protocol.

RS-232 Configuration:

The RS-232 serial communication parameters are configurable. In serial mode the switch positions 1-3 are used for setting the baud rate of the serial transmission and the communication mode:

Table I RS-232 Serial Parameter Settings

Baud Rate	Sw 1	Sw 2	Sw 3
19200	open	open	open
9600	open	open	closed
4800	closed	open	open
2400	closed	open	closed
1200	open	closed	open
600	open	closed	closed
300	closed	closed	open
150	closed	closed	closed

The serial parity bit is also switch selectable:

Parity	Sw 4	Sw 5
Odd	open	open
Even	closed	open
None	n/a	closed

Switches 6 and 7 program a delay between transmission of the serial data. When both switches are closed there is no delay, when both are open there is a 1.5 ms delay.

Switch 8 sets the default commuication mode:

Mode	Sw 8
Low Level	open
High Level	closed

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IEEE-488 Configuration:

In the IEEE-488 mode, switches 1-5 determine the address of the device on the IEEE-488 bus. The selection is binary from 0 to 31 with an open switch position representing a binary 1. For example, the IEEE-488 address 7 would have switches 1, 2, and 3 open and switches 4 and 5 closed. When the interface is in IEEE-488 mode, all data received or transmitted is echoed out the RS-232 port at a fixed 9600 baud, no parity and 2 stop bits.

Low Level Communication Protocol:

The LEP low-level communication protocol is an efficient binary communication protocol with access to all commands on all modules in the system. The low-level protocol forms a message in five (5) parts: address, command, length, data, and end of transmission. The protocol must be strictly adhered to in order to avoid unnecessary system hangups. The low-level communication mode can be initiated at any time by sending the byte sequence: 0xFF 0x42.

First the device address is sent (this is the module bus address, not the IEEE-488 bus address). The address is a single byte with a range from 1 to 254 (255 is reserved). Once the address byte is received the device is selected on the bus and the communication must be completed according to the protocol. If the communication is not completed, the system will hang.

After the device is selected with the address byte, the command is sent. The command byte is immediately sent to the device which then prepares to either execute the command, send data back to the host, or receive more data from the host. The command is a single byte from the known command list published with each device. If an unrecognized command is received by the device, the command is ignored, but this may cause problems if the command is interpreted as read command.

Following the device command, a data length byte is sent. The data length is sent so the interface knows how many bytes to send or receive from the device and how many bytes to send or receive from the host. If the number of bytes is incorrectly sent, the protocol will become confused and the system will probably hang. Each command has a command data length.
Some commands have no data associated with them, and a zero byte is sent after the command to indicate that there is no data.

After the address, the command, and the data length are sent, the data follows. If the data is to be read back from the MAC 2000, the host computer reads bytes from the interface until the programmed number of bytes is received. When data

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is to be transmitted to the MAC 2000, the interface will receive the specified number of bytes from the host. The interface will timeout after 10 seconds if the count is not satisfied.

To finish the message protocol, a single colon (ASCII 58 decimal) is sent. This closes the communication and resets the interface for the next communication message.

The above protocol covers all messages and commands with the exception of the test busy command. The test busy command is implemented in a slightly different fashion to allow for highest communication rate with minimal overhead for the target device. The test busy protocol is similar to the normal protocol except that no data length byte is sent and a single byte is read from the interface. The message still requires the device address, the command, and a colon to terminate the message.

Example (all values shown are hex representation):

Host computer sends:	0x01	/* address */
	0x6C	/* read position cmd for motor driver */
	0x03	/* number of data bytes */
	0x3A	/* colon for end of command */
MAC 2000 replies:	0x21	/* Least significant byte of position */
	0x48	
	0x62	/* Most significant byte of position */

High Level Communication Protocol:

The LEP high-level communication protocol provides a more 'human' mode of communication. The commands are formatted as strings containing English words that are parsed and interpreted by the interface and translated into commands to be sent to the modules on the bus. The high-level protocol can be set either by configuring the switch on the interface board or by sending the byte sequence: 0xFF 0x41.

Contrary to the low-level protocol, the high-level protocol is very flexible in its implementation. The command string can be of any length less than 80 characters terminated by a <CR>. Full error checking for command syntax and the module compatibility is performed prior to command execution to eliminate errors and system lock-ups. The format for a high level command is:

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command *module_id*[=value]<cr>

The interface always responds with either an acknowlege or Negative acknowledge. This is represented by either the character 'A' or 'N' respectively. After the acknowledgement, either the requested data or an error code is sent preceded by a colon (':') and terminated by the end of line sequence <CR><LF>.

For example, to read the current position of a motor drive for the X axis, the command string: "WHERE X<CR>" would be sent. The proper response from the interface would be ":A 12324<CR><LF>", assuming that the controller has a motor driver module set for the proper address. Commands can be stringed together. The commmand : "WHERE XYZ<CR>" will cause the controller to reply with ":A 12324 451345 390239<CR><LF>". If a command is issued not requiring a data reply, the response is ":A<CR><LF>".

When sending data to the MAC 2000, the data is sent to a module by using the '=' assignment. The command : "HERE X=12324<CR>" will set the current position of the X axis. Furthermore, the command "HERE X=12324 Y=54543 Z=32430<CR>" will set the positions of the X, Y and Z axes.

In the case of an command error, either a syntax error or a system error, the MAC 2000 will reply with an error code. For example, the command: "WHERE Q<CR>" will result in the reply: ":N -2<CR><LF>". The 'N' indicates that it is an error and the '-2' is the error code (-2 = illegal point type or module not installed). See MAC 2000 programming manual for error code listing.

The module ids refer to predefined default module and address convention. The following table describes the defaults:

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Table II Module high level ids and addresses

Modul-Id	Address	Label	Description
X	1	EMOT	stage X axis
Y	2	EMOT	stage Y axis
B	3	EMOT	aux axis
R	4	EMOT	aux axis
C	5	EMOT	aux axis
Z	6	EMOT	aux axis
T	7	EMOT	aux axis
I	9 & 8	EDAIO	digital in ports
O	9 & 8	EDAIO	digital out ports
F	11	EAFC	auto focus finder
P[1]	12	HPHCD	photometer No. 1
P2	13	HPHCD	photometer No. 2
P3	14	HPHCD	photometer No. 3
P4	15	HPHCD	photometer No. 4
P5	16	HPHCD	photometer No. 5
S[1]	17	EFILS	filter shutter No. 1
S2	18	EFILS	filter shutter No. 2
S3	19	EFILS	filter shutter No. 3
S4	20	EFILS	filter shutter No. 4
S5	21	EFILS	filter shutter No. 5

IEEE-488 Communication Interface

The MAC 2000 IEEE-488/RS-232 communication interface provides communication with MAC 2000 devices according to either the IEEE-488 bus or RS-232 serial standard. The communication protocol follows the standard LEP low-level (binary) communication protocol. The device is fully configurable in either mode. In serial mode the baud rate is switch selectable from 150 to 19200 baud. The IEEE-488 bus address is configurable from 0 to 31.

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Configuration:

The interface can operate in either RS-232 or IEEE-488 mode. The function of the IEEE-488/RS-232 interface is configured with the DIP switch located on the 73000401 interface circuit board. The interface is switched between serial and IEEE-488 mode by setting switch 8. When switch 8 is open, the interface is in RS-232 mode; and when switch 8 is closed, the interface is functioning in IEEE-488 mode.

Table III IEEE-488 Interface Switch Settings

Baud Rate	Sw 1	Sw 2	Sw 3
19200	open	open	open
9600	open	open	closed
4800	closed	open	open
2400	closed	open	closed
1200	open	closed	open
600	open	closed	closed
300	closed	closed	open
150	closed	closed	closed

The serial parity bit is also switch selectable:

Parity	Sw 4	Sw 5
Odd	open	open
Even	closed	open
None	n/a	closed

Switches 6 and 7 program a delay between transmission of the serial data. When both switches are closed there is no delay, when both are open there is a 1.5 ms delay.

Switch 8 selects IEEE-488 mode or serial mode. When switch 8 is closed the interface will communicate in IEEE-488 mode.

Switched 1 through 5 select the IEEE-488 device address when switch 8 is closed. The switch positions are decoded in binary fashion with an open switch representing a binary 1. For example:

IEEE-488 Address	Sw 1	Sw 2	Sw 3	Sw 4	Sw 5
1	Open	Closed	Closed	Closed	Closed
7	Open	Open	Open	Closed	Closed

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Message Protocol:

The communication protocol for either the RS-232 mode and the binary mode follows the LEP low-level protocol. The low-level protocol forms a message in five (5) parts: address, command, length, data, and end of transmission.
First, the device address is sent (this is the module device address, not the IEEE-488 bus address). The address is a single byte with a range from 1 to 255. Once the address byte is received, the device is selected on the bus, and the communication must be completed according to the protocol. If the communication is not completed the system will hang.

After the device is selected with the address byte, the command is sent. The command byte is immediately sent to the device which then prepares to either execute the command, send data back to the host, or receive more data from the host. Command is a single byte from the known command list published with each device. If an unrecognized command is received by the device, the command is ignored, but this may cause problems if the command is interpreted as a read command.

Following the device command, a data length byte is sent. The data length is sent so the interface knows how many bytes to send or receive from the device and how many bytes to send or receive from the host. If the number of bytes is incorrectly sent, the protocol will become confused and the system will probably hang. Each command has a command data length. Some commands have no data associated with them, and a zero byte is sent after the command to indicate that there is no data.

After the address, the command, and the data length are sent, the data follows. If the data is to be read back from the MAC 2000, the host computer reads bytes from the interface until the programmed number of bytes is received. When data is to be transmitted to the MAC 2000, the interface will receive the specified number of bytes from the host. The interface will timeout after 10 seconds if the count is not satisfied.

To finish the message protocol, a single colon (ASCII 58 decimal) is sent. This closes the communication and resets the interface for the next communication message.

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The above protocol covers all messages and commands with the exception of the test busy command. The test busy command is implemented in a slightly different fashion to allow for highest communication rate with minimal overhead for the target device. The test busy protocol is similar to the normal protocol except that no data length byte is sent and a single byte is read from the interface. The message still requires the device address, the command, and a colon to terminate the message.

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IEEE-488 Communication:

By default, the MAC2000 is configured as a Listener on the IEEE-488 bus. Parallel poll mode is not supported by the MAC 2000. The MAC 2000 utilizes the following IEEE-488 bus lines:

Handshake Lines:

DAV **Data Valid.** Asserted by the controller to show that a control byte has been placed on the data bus. Also asserted when a data byte is placed on the data bus.

NRFD **Not Ready For Data.** Asserted by the MAC 2000 to prevent any new data from being placed on the data bus until it is ready.

NDAC **Not Data Accepted.** This line is asserted by the MAC 2000 to indicate that the last data byte placed on the bus has not yet been accepted.

Control Lines:

ATN **ATteNtion.** Indicates to the MAC 2000 that the data bus contains a system command (IEEE-488 bus command) when asserted. When not asserted, indicates that data on the bus contains either status information of data.

IFC **InterFace Clear.** Clears the IEEE-488 bus; has the effect of resetting all devices on the bus (IEEE-488 reset only, not MAC 2000 reset).

SRQ **Service ReQuest.** This line is asserted by the MAC 2000 when it is selected and data is ready to be read by the host.

REN **Remote ENable.** Not supported by the MAC 2000.

EOI **End Or Identify.** Used to identify the end of multibyte data transfers to or from the MAC 2000. Also used in conjunction with the ATN line to indicate a parallel poll (not supported).

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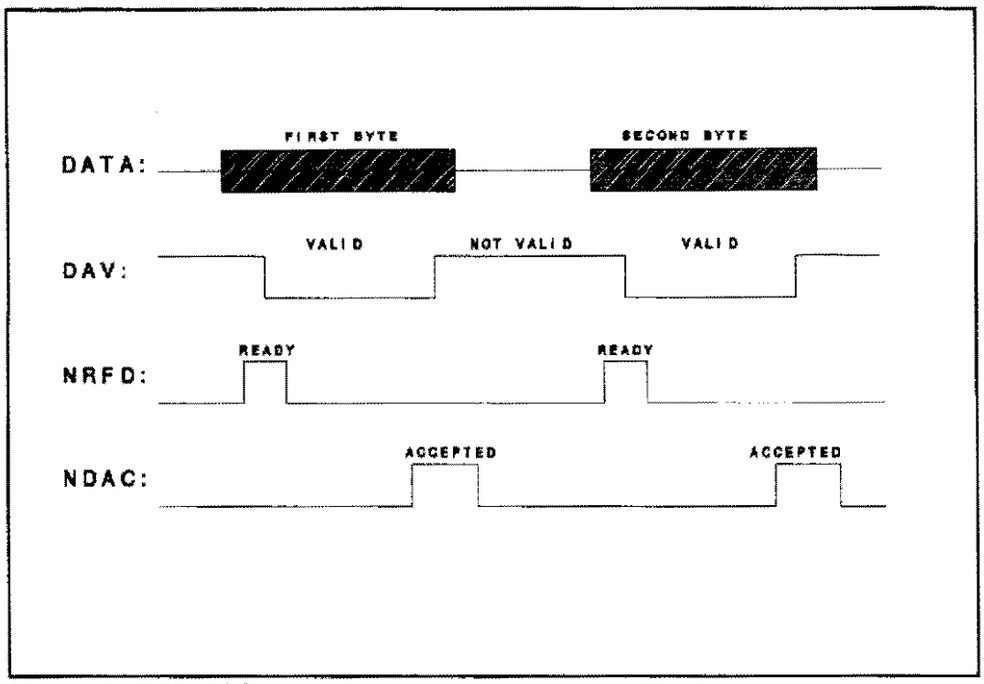


Figure 1 IEEE-488 handshake sequence (simplified)

IEEE-488 Commands Supported by the MAC 2000:

MTA *addr* My Talk Address. Configures device at *addr* to be a talker.

MLA *addr* My Listen Address. Configures device at *addr* to be a listener.

SPE Serial Poll Enable. Send to initiate serial poll sequence.

UNT UNTalk. All devices addressed as talkers are deconfigured.

UNL UNListen. All devices addressed as listeners are deconfigured.

DCL Device CLear. Clears all devices on the IEEE-488 bus.

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A typical IEEE-488 communication sequence with the MAC 2000 could be as follows: First, issue an UNT and an UNL command to clear any prior communication. Then a MLA is sent to put the MAC 2000 in listen mode. At this point the MAC 2000 is addressed to listen and will accept data on the bus. Send the MAC 2000 device address byte, the command byte, the data length byte, the data block (if data is to be sent) and the colon as a single data block. The data could also be sent bytewise (sequential single byte blocks) but it is less efficient. At this point the MAC 2000 has the command and will process it. The MAC 2000 expects EOI to indicate the end of communication.

When data is ready to be sent back to the controller, the MAC 2000 will assert the SRQ line. The host then performs a serial poll to determine which device is requesting service. This is done by sending an SPE to all devices on the bus. Then sequentially the controller addresses all devices on the bus to talk (MTA). The MAC 2000 will respond with a data byte indicating status. If data is ready to be sent, the bit 7 will be set. No other bits in this byte are used by the MAC 2000. After the serial poll for each device is complete, the controller issues a UNT to clear the addressed device.

Once it is determined that the MAC 2000 is ready to send data, an MTA is sent to the MAC 2000 IEEE-488 address to configure the MAC 2000 as a talker. The data is then transferred with the IEEE-488 handshake. The MAC 2000 asserts the EOI line to indicate an end of transfer.

Differences between IEEE-488 and RS-232:

The only significant difference between the RS-232 and the IEEE-488 communication lies in the host computer's handling of the data transmission. The two protocols are byte for byte compatible.

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XY Stepper Motor Stage:

Description:

The LEP motorized XY stages all consist of X and Y axis motor driven leadscrews. The connections to the motors are by DB-15 male connectors. The minimum step resolution and the maximum stage speed are calculated from mechanical and electrical parameters of the stage and motor drives.

All stages have electronic and mechanical limits on travel. Each axis has limit switches at each end of travel. The limit switches are an electronic protection to prevent the system from encountering the mechanical limits which would cause the stage to stall, lose position, and perhaps cause damage. The limit switches can be used for location of the home position of the stage provided the software does not allow the stage to strike the switches at a high rate of speed.

Configuration:

The motor rotational motion is translated to the linear stage axis motion be turning the leadscrew. The minimum stage axis resolution is calculated from two factors: the motor step resolution and the lead screw pitch. The motor resolution is determined from the setup and configuration of the motor drive electronics, typically the step resolution is 10,000 steps per revolution. The leadscrew pitch is a measurement of the distance the stage moves for a single turn of the lead screw shaft.

$$StageResolution = \frac{LeadscrewPitch}{MotorStepsperRevolution}$$

The speed of the stage is similarly calculated from the leadscrew pitch and the maximum motor speed. The maximum motor speed is not as clearly defined by the configuration of the motor drive. Theoretically, the motor can be driven to a maximum speed of 5mHz; however, the motor will never go this fast no matter what configuration is chosen. If the motor is configured for 10,000 steps per revolution, it is safe to say that it will operate at 300KHz (300,000 steps per second). Using this as a baseline, the motor can be run at 400KHz when set for 20,000 steps per revolution and 150KHz when the motor is configured for 5,000 steps per revolution. Please note that these values are typical and most systems should be able to run beyond this limit.

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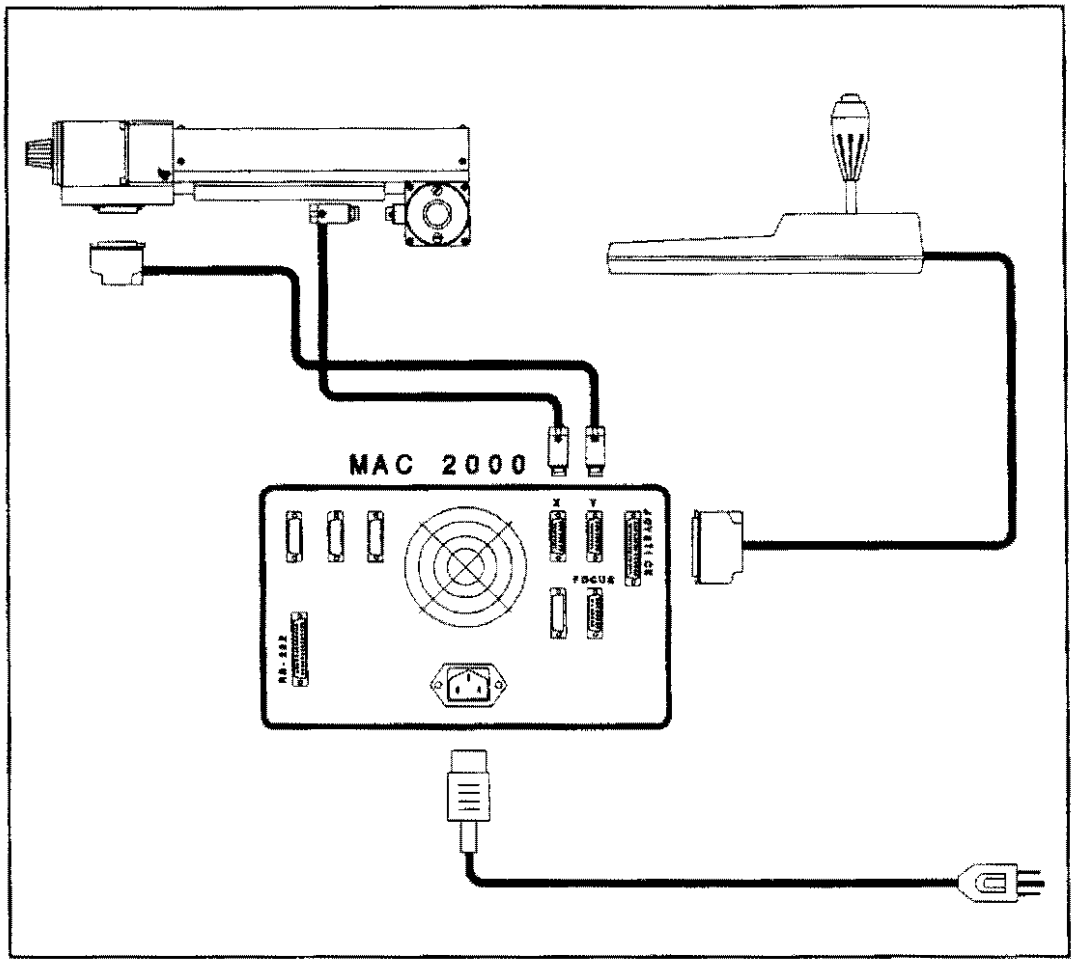


Figure 2 XY Stage Connection

The motor acceleration values also have a direct effect on the maximum speed of the axis. The motor control has default value of 20 which is adequate for a motor set for 10,000 steps per revolution. As the acceleration value decreases, the time to ramp from the starting speed to the maximum speed will be decreased. With a stepper motor, care should be taken not to program the acceleration so that the motor will not be able to keep up. When the drive electronics try to drive the motor beyond its physical capability, it will stall; and in an open loop system, it will lose position.

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When the motor begins turning, it does not begin a speed of zero. The starting speed is also programmed. The default speed is normally adequate and does not need to be changed. If the programmed motor speed is less than that of the motor starting speed, the motor will start at the programmed speed and acceleration will be instantaneous.

In summary, most stages are designed to provide good resolution and speed at the default motor drive settings. The maximum speeds will range between 25mm/sec. and 100 mm/sec. for 1mm and 4mm pitch leadscrews with motor drivers set with the factory defaults. Stage resolutions range from 0.1um to 0.4um for stages with 1mm and 4mm pitch lead screws respectively.

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Stepper Motor Drive:

Description:

The stepper motor driver consists of a two-module set: the MCMSE and the MDMSP. Because these modules are related to each other, they must occupy adjacent slots in the frame with the MDSMP immediatly to the right of the MCMSE module.

The first module is identified as the MCMSE module (Motor Controller Micro Stepping Encoder). The MCMSE is an intelligent motor control system comprised of a microprocessor, memory, and other electronics for digital control of the motor. The digital motor control signals are connected to the MDMSP module.

The second module, the MDMSP (Motor Driver Micro Step Power) module, controls the motor itself. The MDMSP module translates the digital output from the MCMSE module into the high-power stepper motor phase control signals necessary to operate the motor. This is done with a complex array of digital and analog circuits to provide stable linear motor phase control outputs to the motor. The MDMSP module allows for the programming of the microstep size and the maximum driving current for the motor.

Manual control of the motor is by external joystick or trackball input. The system senses on power-up if there is a joystick or trackball present. If a joystick is present, the system assumes that the current joystick position is the idle position; deflecting the joystick either direction will rotate the motor. The fast joystick button, located on the top of the joystick, will increase the slew rate of the motor. If no joystick is sensed, the system defaults to trackball mode, where it will respond to motion from the trackball input.

The motor connection is provided with a single DB-15 female connector on the rear panel of the controller. The connector is labelled according to the system configuration. The X-axis motor, for example, is labelled as such.

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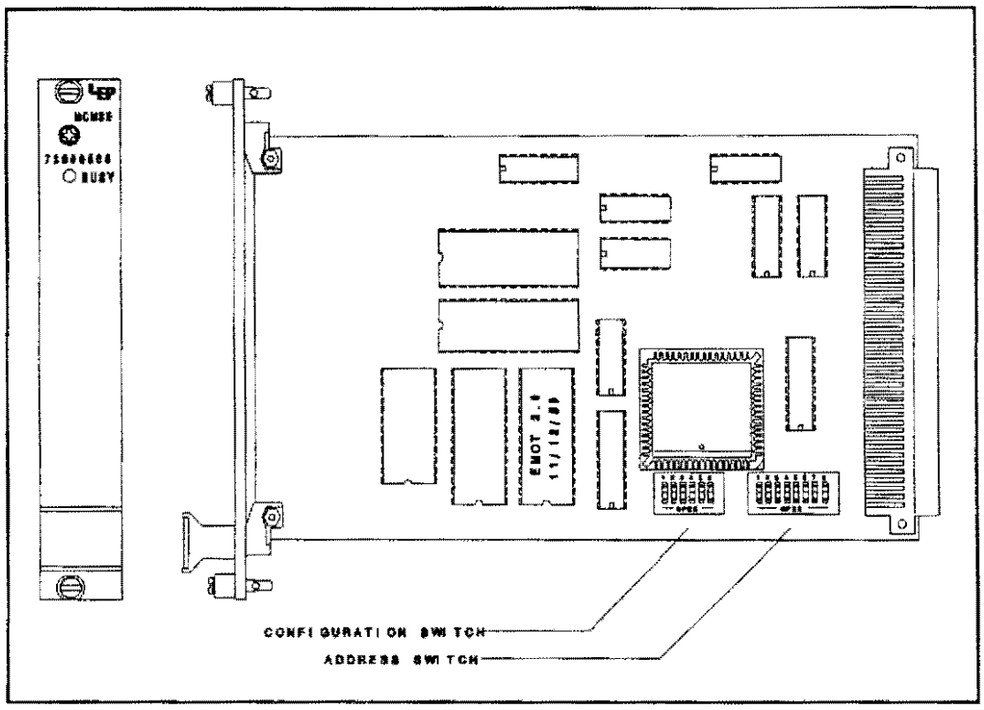


Figure 3 Motor Control Module

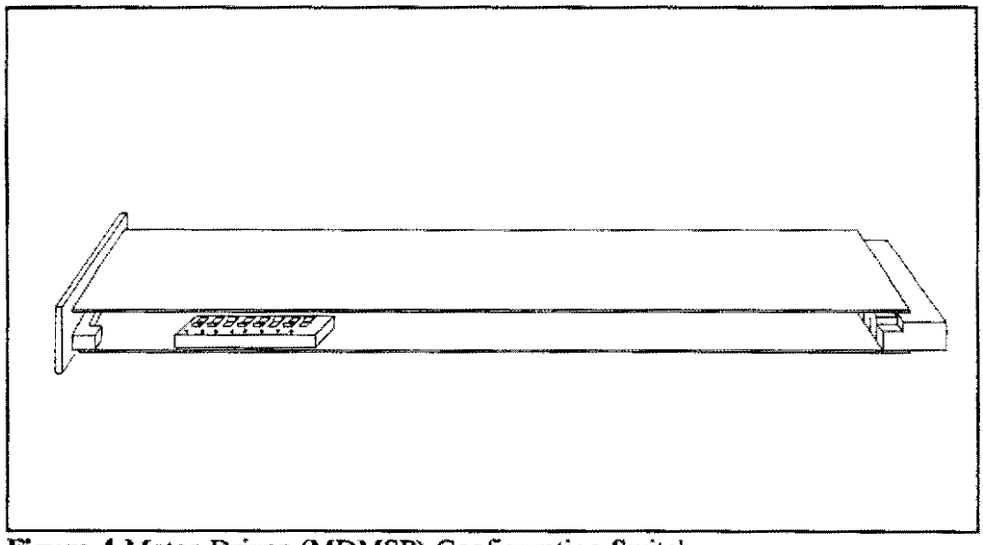


Figure 4 Motor Driver (MDMSP) Configuration Switch

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Specifications:

The combined operation of the MCMSE and the MDMSP modules can operate a standard 200 step-per-revolution motor at a maximum microstep rate of 300KHz. The microstep size is selectable from 1000, 5000, 10000, and 20000 microsteps per full motor revolution. Motor current is selectable form 300mA to 1.4 amps. All motion control parameters are fully software programmable (see accompanying software documentation).

Motor Control Switch Settings:

Since the MCMSE module controls the motor performance and position, the MCMSE is configurable for relative joystick direction, limit switch logic, relative motor direction, open/closed loop feedback, and the device address.

The joystick response is configurable to operate the motor in opposite directions. This accommodates different perceptions of motion and also optical image erection. The direction of the joystick action does not affect the motor's relative position.

Each MCMSE module has inputs for two end limit switches, two pre-limit switches, and a single reference-pulse input. The module is configurable to support either a positive or negative TTL level to trigger the end limit for the axis of travel. Normally, with a mechanical switch (in a standard LEP XY stage, for example), the low-level TTL will trigger the end limit, while a typical optical interrupter type switch will have the opposite logic.

The relative motor direction is controlled by the CPU on the MCMSE and can therefore be configured. The motor direction inverts the coordinates for a given axis. Regardless of the motor direction, the joystick direction remains the same unless it is also changed.

The motor controller module can accept feedback from either its own internal step counter or from an external quadrature encoder. When an encoder is connected to the controller, the actual speed, direction, and ramping of the motor is unaffected. The position resolution, however, depends entirely upon the encoder resolution. When the encoder mode is enabled, the controller can be programmed to hold the present position and, if necessary, correct its position.

Motor Driver Switch Settings:

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The configuration of the MDMSP for the proper microstep size is accomplished according to the diagram in Figure 5. The motor step size is configured with switches 1 and 2. The factory default setting is 10000 steps per revolution. The default setting is assumed in the determination of the default speeds and accelerations for the MCMSE module. If the step size is changed, then the supporting software should reset the other motor parameters accordingly.

The peak motor current is set with switch positions 3-8. Each switch adds approximately 180mA to a base current setting of 300mA. A closed switch position is active; that is, it provides the programmed current. Each switch is independent of the others, and no prescribed order needs to be followed when enabling. Normal motor current is set for 800-900mA with the execption of the LEP inverted microscope stage which is configured for 600mA.

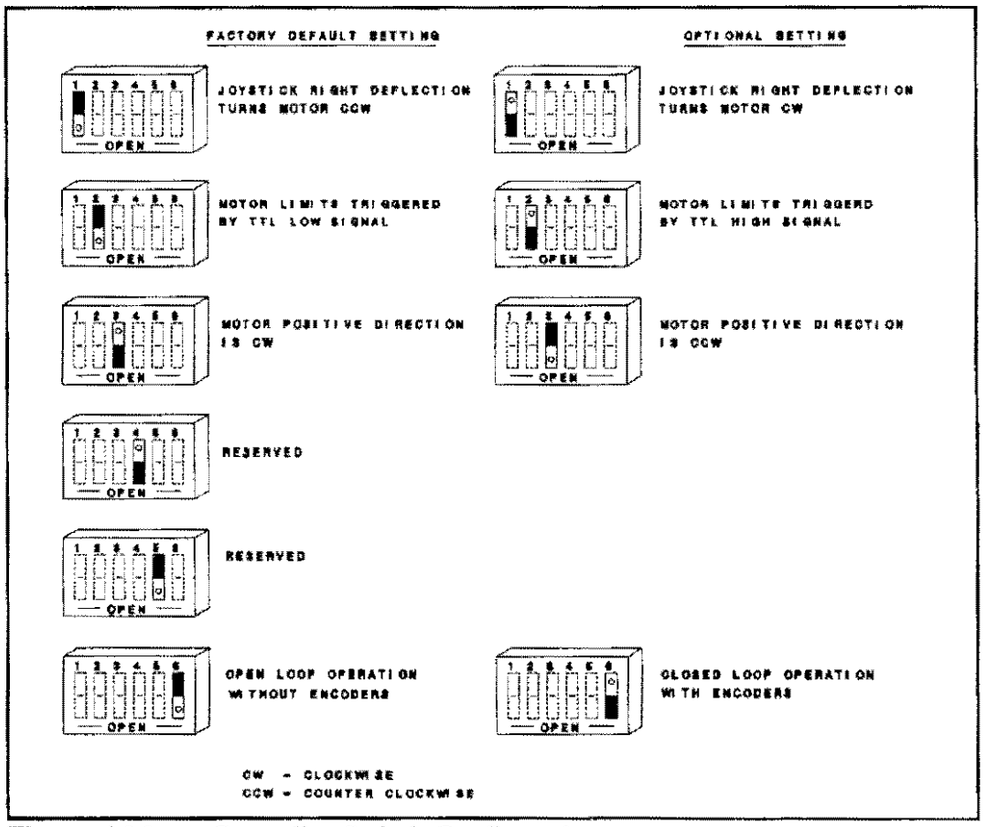


Figure 4 Motor Controller Switch Configuration

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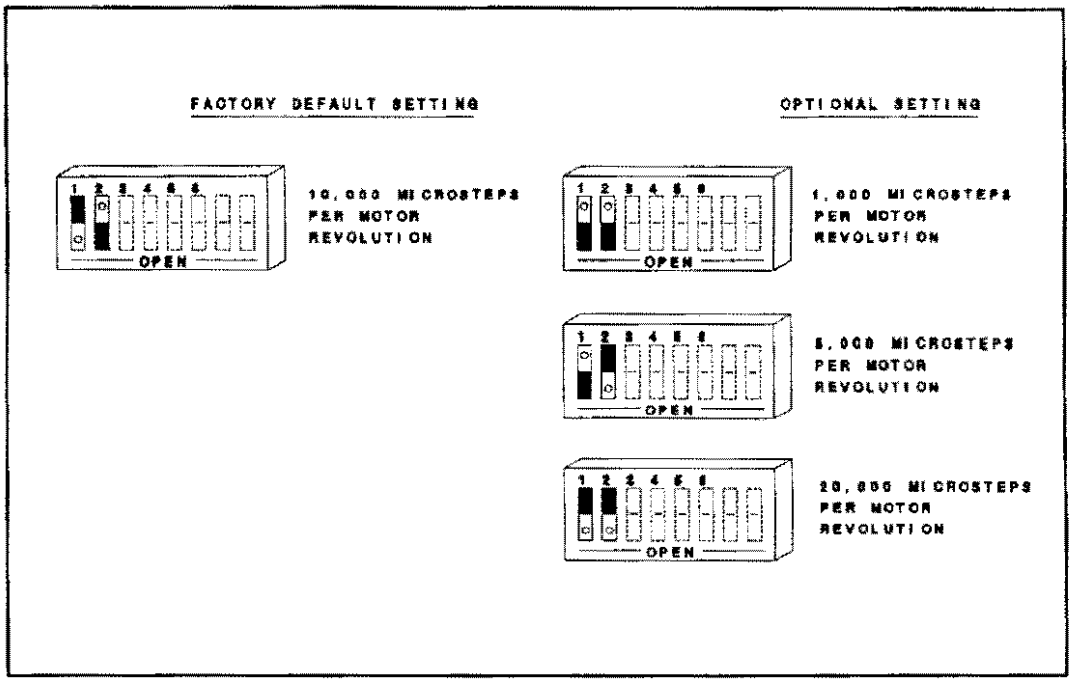


Figure 5 MDMSP Motor Step Size Configuration

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DC Servo Motor Drive:

Description:

The DC servo motor driver consists of a two-module set - the MCDCE and the MDDCP. Because these modules are related to each other, they must occupy adjacent slots in the frame with the MDDCP immediately to the right of the MCDCE module.

The first module is identified as the MCDCE module (Motor Controller DC Encoder). The MCDCE is an intelligent motor control system comprised of a microprocessor, memory, and other electronics to control and track the motor position. The digital motor control signals are connected to the MDDCP module.

The second module, the MDDCP (Motor Driver DC Power) module, controls the motor itself. The module constantly monitors the encoder outputs from the motor and corrects position based on either changes from the encoder or movement commands from the controller. The drive module has adjustments for controlling the gain and damping of the servo control loop.

Manual control of the motor is by external joystick or trackball input. The system senses on power-up if there is a joystick or trackball present. If a joystick is present, the system assumes that the current joystick position is the idle position. Deflecting the joystick either direction will rotate the motor. The fast joystick button, located on the top of the joystick, will increase the slew rate of the motor. If no joystick is sensed, the system defaults to trackball mode, where it will respond to motion from the trackball input.

The motor connection is provided with a single DB-15 female connector on the rear panel of the controller. The connector is labelled according to the system configuration. The X-axis motor, for example, is labelled accordingly.

Specifications:

The combined operation of the MCDCE and the MDDCP modules can operate a DC motor equipped with an incremental encoder to maximum speed of 150kHz encoder rate. The encoder pulses are internally mulitplied to increase the resolution by a factor of 4. The actual motor speed will depend upon the encoder resolution. All motion control parameters are fully software programmable (see accompanying software documentation).

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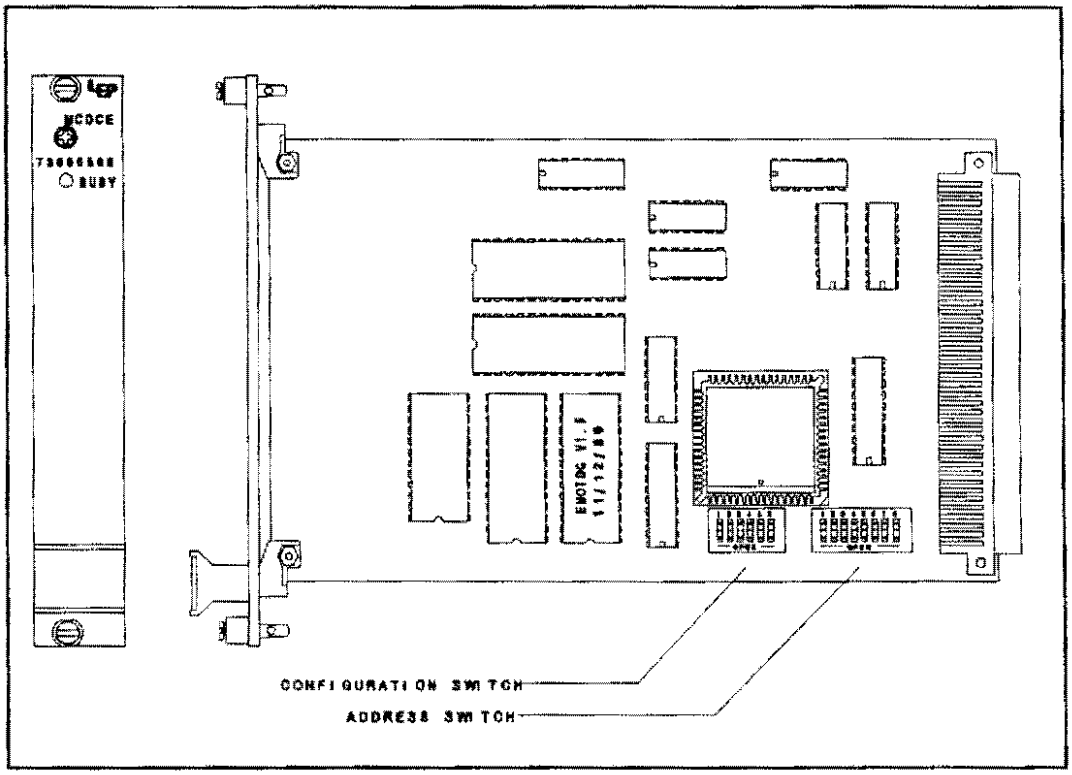


Figure 6 Motor Control Module

Motor Control Switch Settings:

Since the MCDCE module controls the motor performance and position, the MCDCE is configurable for relative joystick direction, limit switch logic, relative motor direction, open/closed loop feedback, and the device address. Refer to switch settings in Figure 4.

The joystick response is configurable to operate the motor in opposite directions. This accommodates different perceptions of motion and also optical image erection. The direction of the joystick action does not affect the motor's relative position.

Each MCDCE module has inputs for two end limit switches, two pre-limit switches, and a single reference-pulse input. The module is configurable to support either a positive or negative TTL level to trigger the end limit for the axis of travel. Normally with a mechanical switch (in a standard LEP XY stage, for example), the low level TTL will trigger the end limit, while a typical optical interrupter type switch will have the opposite logic.

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The relative motor direction is controlled by the CPU on the MCDCE and therefore can be configured. The motor direction inverts the coordinates for a given axis. Regardless of the motor direction, the joystick direction remains the same unless it is also changed.

A DC motor always has an encoder connected. The MCDCE therefore should always be configured to operate in encoder mode. With the encoder mode enabled, the motor can be 'servoed' to hold position and, if necessary, correct its position. Acceleration, speed, and position are always expressed in terms of encoder pulses.

DC Motor Driver Configuration and Adjustment:

The motor driver has adjustments for gain and damping. Normally, a controller configured for a specific application will not require adjustment. Before making adjustments, make sure that all the cables are fully connected and that the motor turns freely.

The gain is an adjustment of the 'stiffness' of the motor response. The damping adjustment provides a reaction delay in the movement of the motor. There is no general setting that is good for all applications. Different motors, encoders, and loads will require different settings. A step-by-step adjustment of the servo loop is as follows:

- Switch off power to the unit and disconnect the line cord.
- Remove top cover from the controller by removing the four screws located on the sides of the unit.
- Remove the DC motor driver module.
- Note the approximate orientation of the adjustment potentiometers and write it down on a piece of paper.
- The DC motor driver has an on-board step generator to provide a 2Hz pulsation of the motor. This pulsation will allow for simple adjustment of the gain and damping. This is activated by setting position 1 of the 2 position dip switch to closed.
- Turn both gain and damping control pots fully counter clockwise (CCW).
- Replace the motor driver module into the controller, reconnect the line cord, and switch it on.
- Slowly turn the gain clockwise (CW) until the motor begins to vibrate.
- Turn the damping control CW until the vibration stops.
- Remove the motor drive and return switch 1 to the open position.
- Replace module into the system.
- Repeat for other modules requiring adjustment.
- Replace the cover on the MAC 2000 controller.

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When the stage is moved with either the joystick or computer control, the stage should move smoothly without vibration and hum or excessive position overshoot. If, upon rapid reversal of direction by joystick, the stage begins to hum and vibrate, then the above tuning steps should be repeated. If it seems that the adjustment is not working, return the adjustments to the old settings and check for other problems.

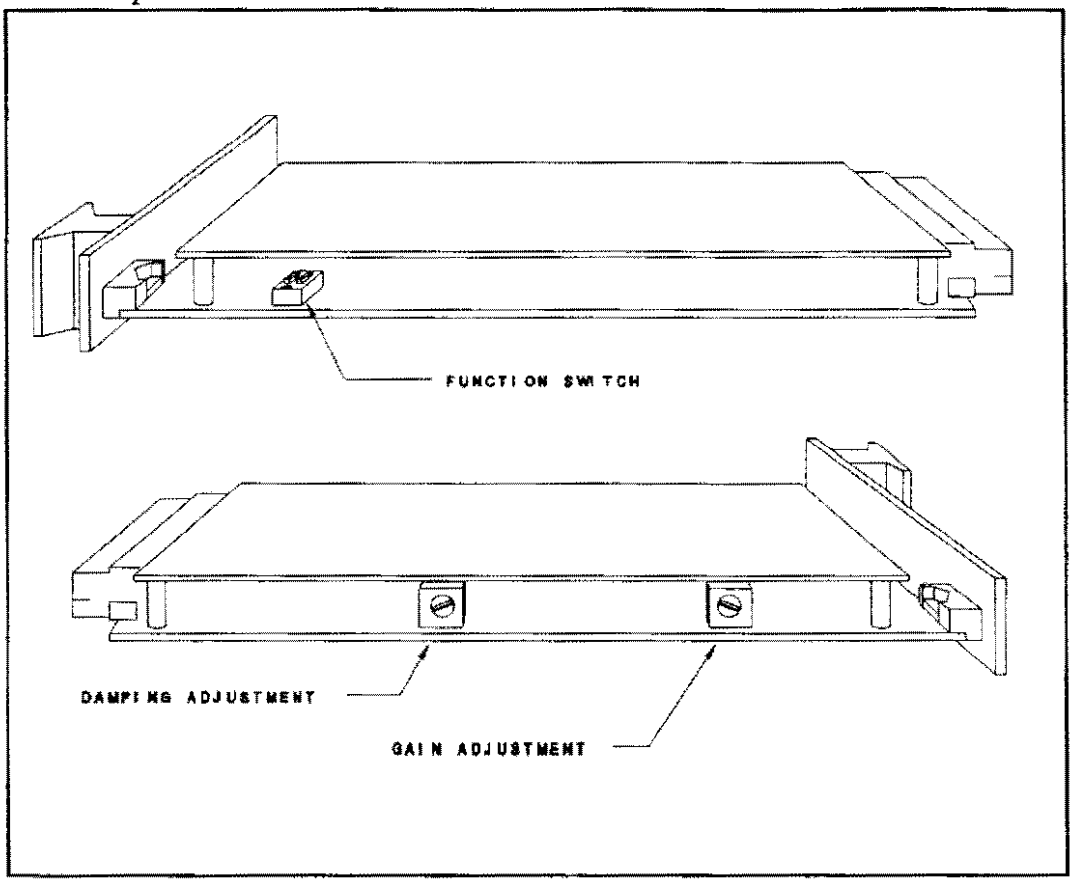


Figure 7 DC Motor Driver Adjustments

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Filter Wheel Control:

Description:

The filter wheel can accommodate up to six (6) filters with a diameter of 25 mm. The filter wheel is driven by a stepper motor via a timing belt. There is an integral home position sensor for fully automatic initialization. The maximum speed is 100 ms between adjacent filter positions. The operator has control of the filter position from the front panel with a toggle switch. The shutter also can be controlled from the front panel of the controller. The shutter housing is pre-drilled to accommodate mounting flanges for most microscopes including Leitz, Olympus, Nikon, and Zeiss.

The filter wheel module is identified on the front panel as FWSHC, which stands for Filter Wheel SHutter Controller. The FWSHC module is a single card module capable of controlling two (2) filter wheels and up to three (3) high-speed shutters. Front panel controls are provided for one (1) filter wheel and two (2) shutters.

The shutter control can operate up to three (3) shutters. The drive electronics utilizes a bi-level drive, supplying an initial high opening voltage for high-speed action followed by a lower holding voltage. The closure of the shutter is by a spring. Shutters can be held open indefinitely without damage. Owing to the simple design, the shutters have proven to be extremely durable under heavy usage.

The shutters are referenced as Nos. 1, 2, or 3. In the standard configuration Shutter No. 1 is mounted in filter wheel No. 1 housing.

The shutter status is indicated by LEDs on the front panel of the control module. Shutter Nos. 1 and 2 are controllable from the front panel while the third is controlled only by external host computer.

Configuration:

Connections are made from the rear panel of the MAC 2000 frame via a DB-15 female connector. Each filter wheel/shutter combination requires a separate connector. In the case of a dual filter wheel/shutter, two cables are required. Shutter No. 2 is connected to the filter wheel itself via a 4-pin round connector.

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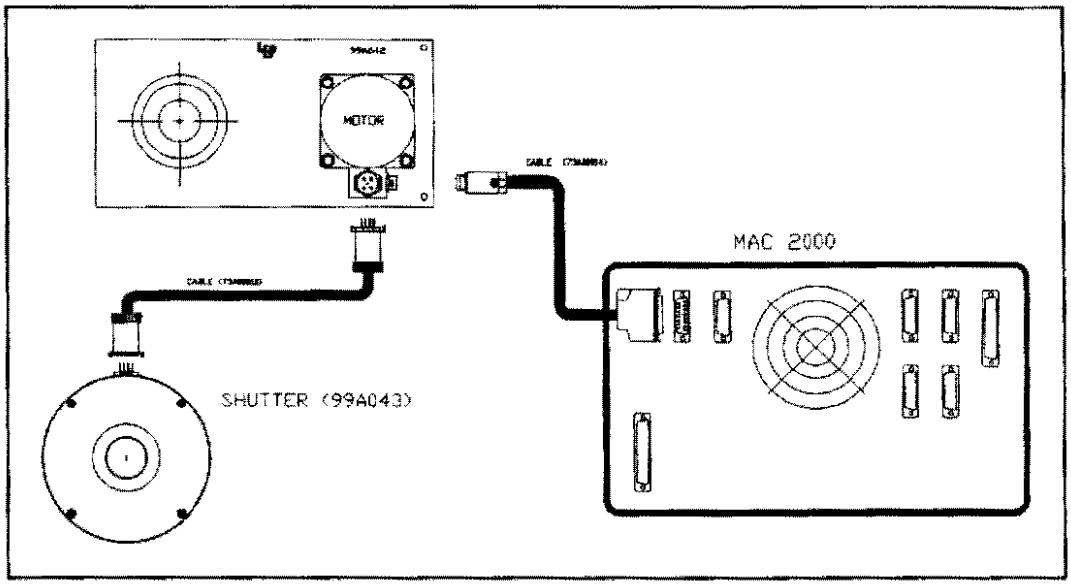


Figure 8 Filter Wheel/Shutter Connections

The filter wheel module is configurable by the six-position dip switch located on the module PC board. The first two positions set the filter wheel speed. The maximum speed is 100ms between adjacent filter positions; the minimum speed is 500ms. Switches 3 and 4 adjust the direction of rotation of the wheel. The remaining two switches set the interface mode.

Single Filter Wheel:

The single filter wheel can accommodate 25mm diameter filters in six positions. The housing also incorporates a high-speed shutter. The filter wheel has mounting holes to accommodate mounting flanges for Leitz, Nikon, Olympus, and Zeiss microscopes.

Filters can be easily inserted and removed from the filter wheel while the entire assembly is mounted on the microscope. By loosening the two thumbscrews, the filter wheel door can be hinged open to give access to the interior of the housing. The filter is held in place by a slit retaining ring which is spring loaded to hold the filter in place without tightly clamping it, allowing for thermal expansion. The retaining ring is pried from the filter aperture, and the filter is removed and replaced. The filter position should be noted when it is placed in the wheel so that in programming the system the proper filter is moved into place.

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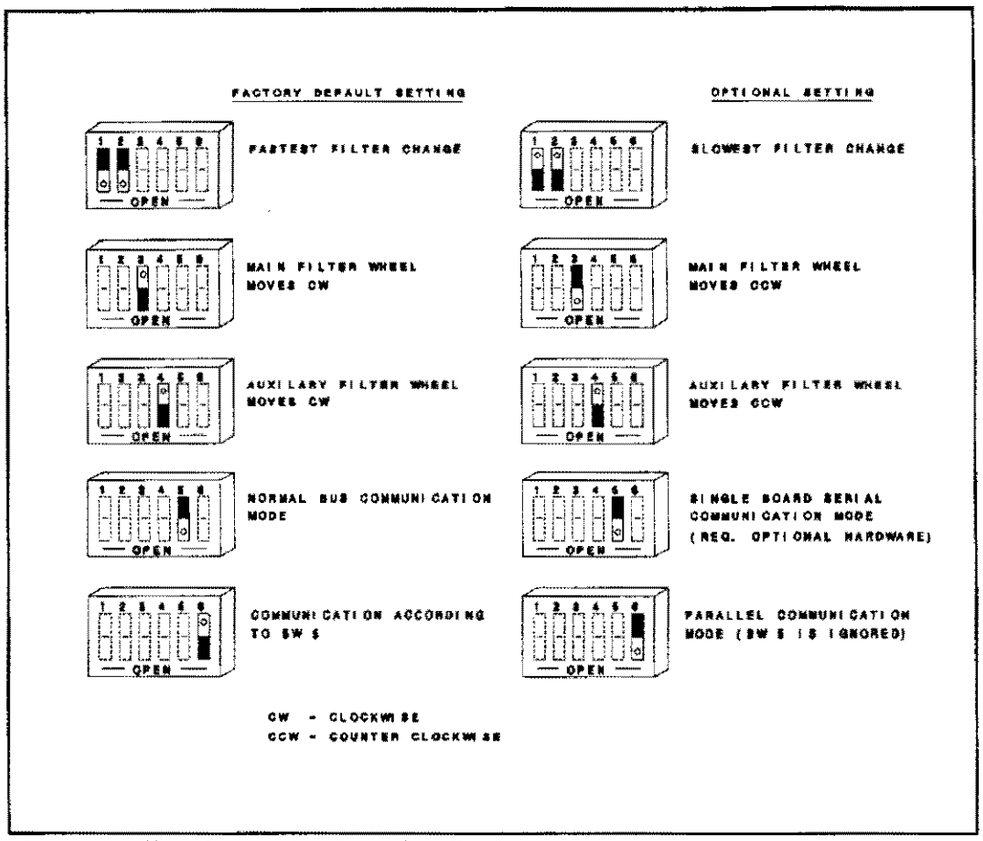


Figure 9 Filter Controller Function Settings

Dual Filter Wheel:

The dual filter wheel can be described as two-single filter wheels packaged in a single housing. The unit has two motors to drive the two six position wheels that can accommodate six 25mm filters. The unit also has a single high-speed shutter.

Exchanging filters in the main filter wheel is performed according to the procedure described for the single filter wheel. Changing filters in the second wheel is similar but slightly different. The filter apertures are accessed from the cutout in the microscope side of the housing. Depending upon the filter wheel direction, the filter position 3 or 5 is in position when the filter wheel is homed (position 1 is at the illumination aperture).

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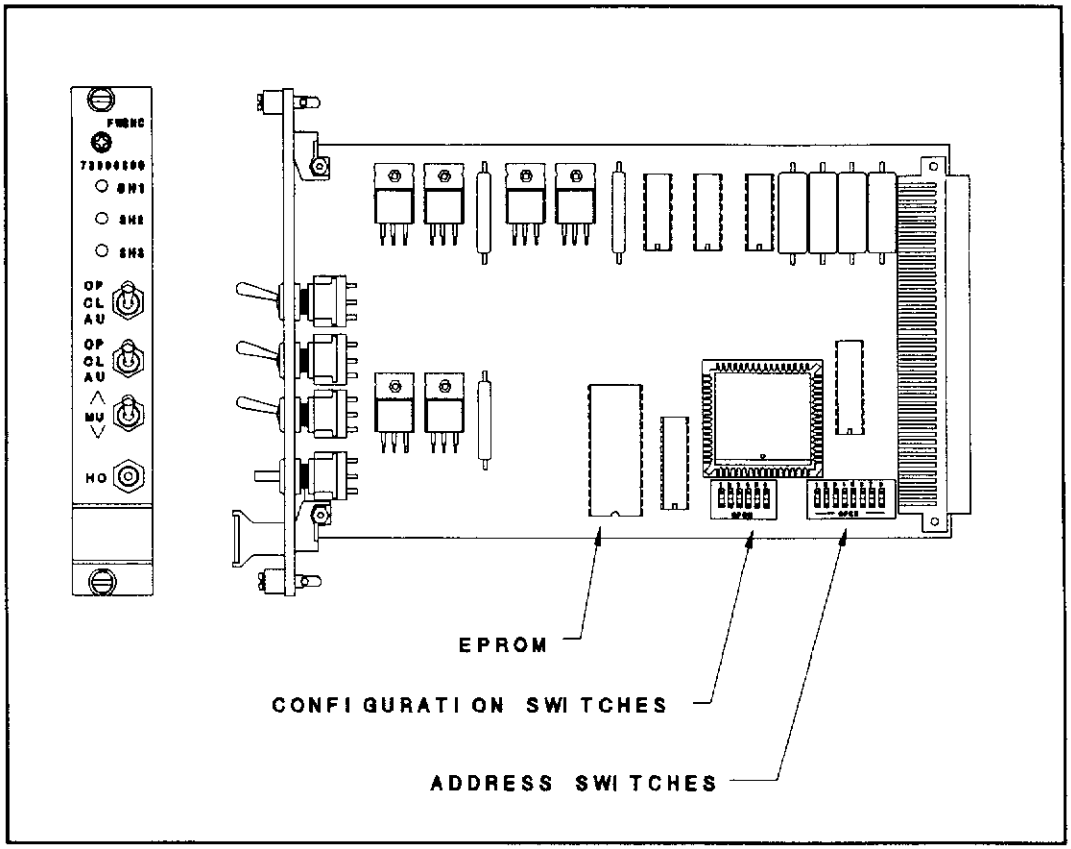


Figure 10 Filter/Shutter control card, FWSHC

Operation:

The shutter control switches have three positions, labelled OP, CL and AU. These are abbreviations for OPen, CLosed and AUtomatic. When the toggle switch is in the open position, the shutter will ALWAYS be open regardless of the host computer control; the LED will show the actual status. When the switch is in the closed position, the shutter will ALWAYS be closed regardless of the host computer instruction. When in automatic, the shutter will act only on computer instruction; the LED will still show the actual status of the shutter.

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The manual filter wheel control is activated with the momentary contact toggle switch labelled MV and the pushbutton switch labelled HO. To change filter position manually, the toggle switch is moved up or down to change the filter position. The filter will move only one position for each switch change. For example, to move two filter positions, the switch must be activated twice. When the system is first switched on, the filter wheel automatically homes to position 1.

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Video Autofocus:

Description:

The LEP Video Autofocus system is a high-speed, high-resolution contrast seeking autofocus. The system accepts RS-170, RS-330, NTSC, or PAL video (color or monochrome) and calculates focus based on the contrast within an area of the video image. The size and location of this focus area is user adjustable from the front panel of the MAC 2000 and is indicated by a superimposed box on the video image. The focus can be initiated from the front panel by means of a pushbutton with an additional control for the speed and search range. Under computer control an extensive command set is available for setting all focus parameters, i.e. image averaging, search speed, and delay between measurements. A full command set is also available for control of the motor drive. The focus parameters are set to defaults at power-up so that the system will operate with most video systems without extensive programming.

Overview:

The autofocus operates on video contrast. To determine the best focus, the microprocessor turns the focus drive and measures contrast over a programmed range of focus travel. Once the search is complete the motor is driven to the point at which the best contrast was measured. This is a simplified description of the process. There are many other parameters and variables that affect both the measurements and the focus motion. The system power up defaults are normally adequate for all focusing functions except the more critical such as those involving low light levels, unstable microscopes, and very low contrast images.

The video autofocus module is identified from the front panel by the legend "AFCMS". The autofocus requires a MDSMP module to drive a stepper motor in a similar manner to the motor control module MCMSE.

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Focus Window:

The autofocus uses only a portion of the video image to make the contrast measurements. The focus window is adjustable to include any or all areas of the video image. An outline image of this box is visible superimposed on the video output. The outline may be white, black, or an inbetween gray (depending upon adjustment). The window position is determined in horizontal and vertical directions by adjustments on the front panel labelled HP and VP, for Horizonal Position and Vertical Position respectively. By turning the small slotted screw inside the hole, the positions can be adjusted. Similarly, horizontal and vertical sizes can be adjusted with the trim pots labelled HS and VS respectively.

The focus window size adjustment is important for good repeatable and accurate focusing. A window that is too large with too much video contrast can overflow the measurements and cause inaccurate focusing. A window that is too small can provide too little signal and result in focusing that repeats poorly.

On the AFCMS module there are jumpers and adjustments to control the window outline on the output video. As shown in the Figure 12, the potentiometer on the upper edge of the module controls the intensity of the outline, from white to black. The jumper located toward the front of the module will completely disable the outline. When the jumper is on the left two pins the box is under computer control, when it is on the right two pins the box is always off, if the jumper is removed the box is always off.

Connection:

The video autofocus connections are relatively straightforward. The focus motor connects to the 'FOCUS' connector on the rear panel of the MAC 2000. The pinout of this connector is the same as the connector for the XY stage and Z-axis drive. The camera input connects to the BNC connector labelled as VIDEO IN on the rear panel. Standard configuration applies a 75ohm impedance load to this input. The output to the video monitor is connected to the VIDEO OUT BNC connector. When the proper motor and video connections are made, the focus will activate by pressing the FOCUS button on the front panel of the MAC 2000. Optional digipot or joystick control may be included for manual control of the focus motor.

Maximizing Performance:

The obtain maximum performance of the autofocus, there are several key issues that should be addressed. The most important factor is the video image itself. The video image should not be too bright to wash out the contrast. Conversely,

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it should not be too dim so there is noise and/or low contrast. The persistence of the video camera is also important. An ISIT camera, for example, has a very slow reaction time and will cause the autofocus to improperly focus because it measures very fast. The objective lens used is very important since it contributes to two factors that influence the focus. The depth of focus is determined by the objective and consequently affects the range where there is contrast. The objective also provides contrast based on the optical characteristics of the lens. At very high magnification, a high numerical aperture lens will provide a very shallow depth of focus which, depending upon the sample and optical quality, can produce washed-out low-contrast images. Finally, the image content is a determining factor in the focus performance. The autofocus will have difficulty focusing on a bare specimen with little or no contrast.

The performance of the autofocus with videos that have low contrast, high noise, slow response, or low levels can be improved by altering the focusing parameters. The parameters that affect the focus are: focus search range, number of focus measurements within the search range, number of frames to count before taking a measurement, and scan speed.

The search range is programmable for the coarse and fine searches for each high, medium, and low focus range. This is useful if your microscope focus mechanism provides too little or too much focus travel. This indirectly changes the resolution of the autofocus measurement since this range is divided by the number of measurements taken in the scan.

The number of measurements taken in a focus search defines the resolution of the autofocus. The autofocus will first search the coarse range, and then the fine range taking 'n' number of measurements for each range. The resolution is the programmed range divided by the number of measurements. The range and number of measurements should be set so that the coarse range will travel through the focus plane but not crash the objective lens into the specimen. The fine range should be set so that the resolution is less than the depth of focus for the particular lens.

The autofocus has the ability to delay before taking a focus measurement. This is programmable in terms of number of video frame periods. This parameter permits the programming of delays to allow time for mechanical settling and slow video response to catch up. For example, SIT or ISIT cameras have a very slow response time and require some delay.

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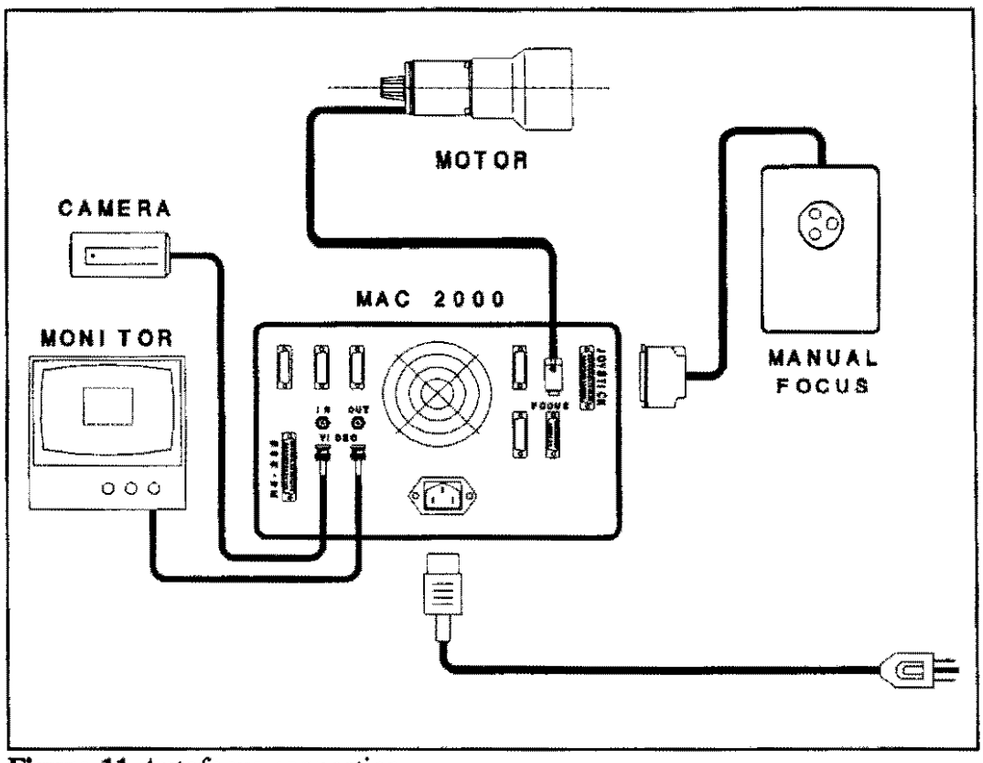


Figure 11 Autofocus connection

The focus scan speed is also progammable. The scan speed can be slowed to help compensate for unstable mechanical assemblies or fluid samples that must be moved slowly. The speed can also be used to reduce the time delays that may be required in some systems.

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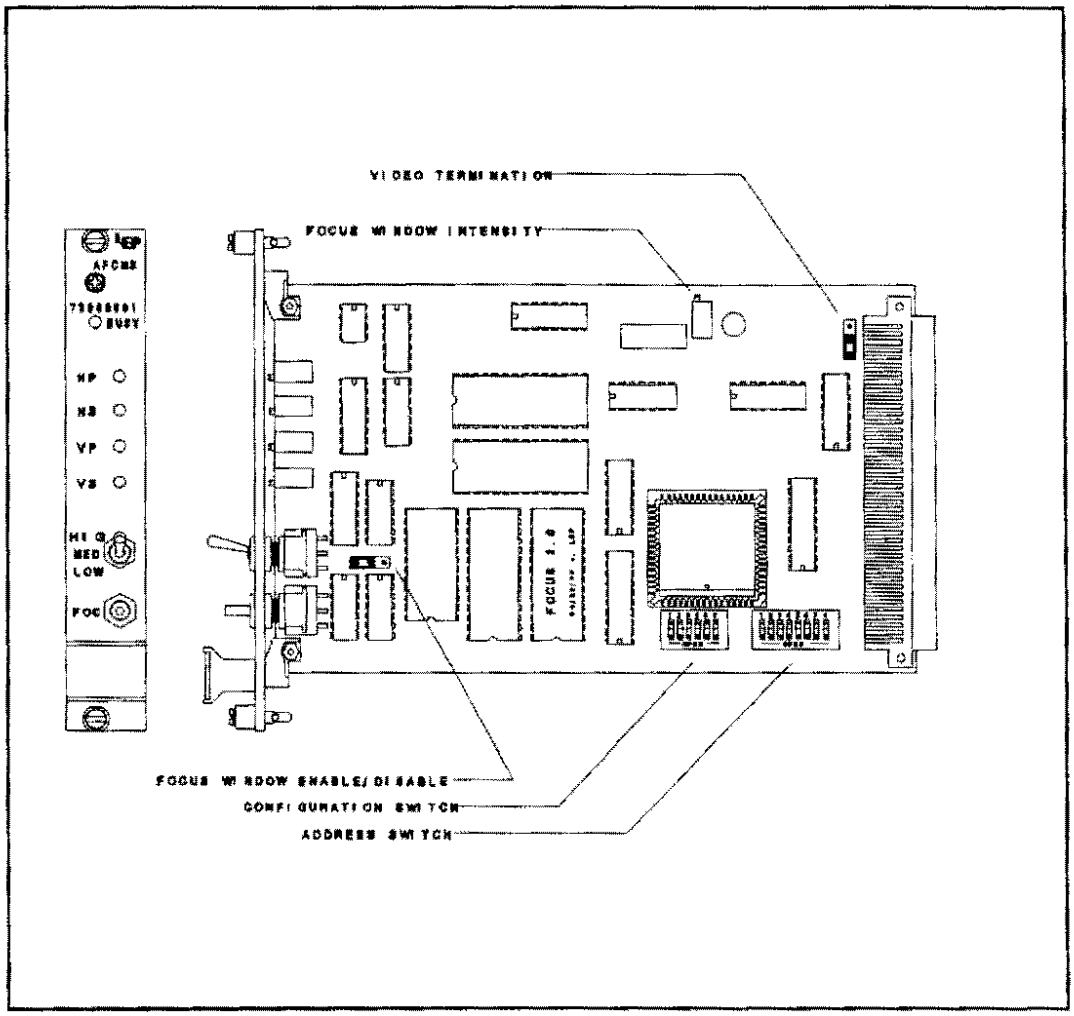


Figure 12 Autofocus Module

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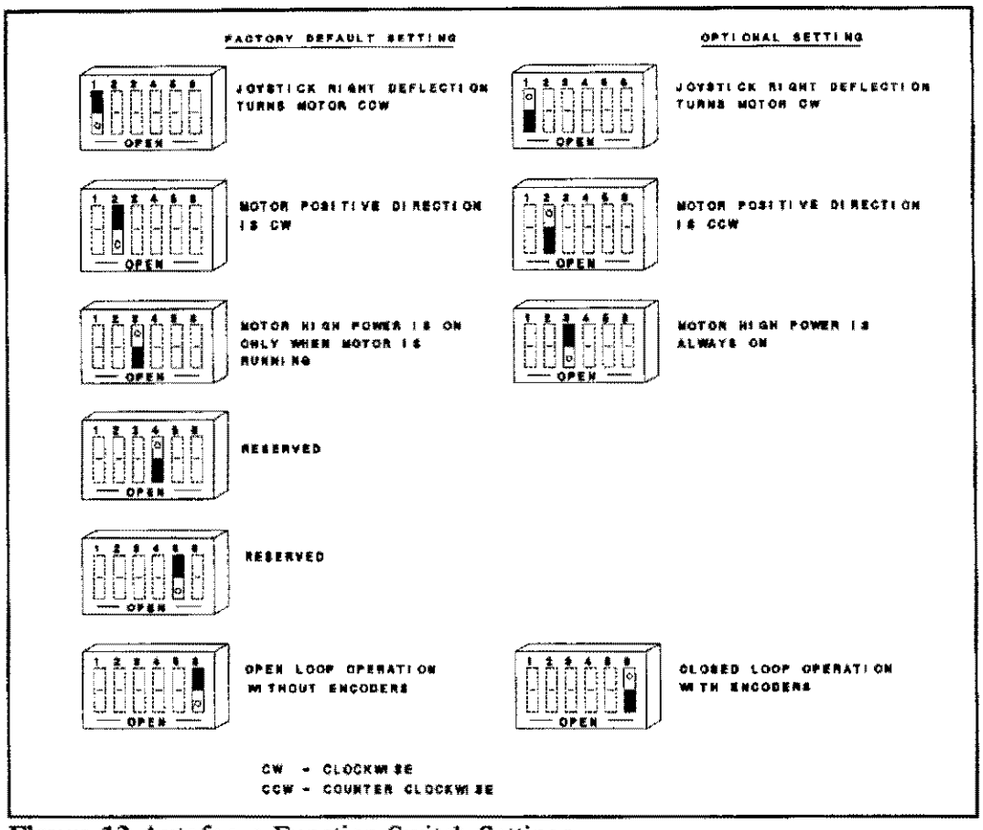


Figure 13 Autofocus Function Switch Settings

How Stepper Motors Work:

Stepper motors, as their name implies, are motors that move in steps. The design of a stepper motor essentially consists of several electromagnets arranged in a circular fashion around a magnetic armature. These electromagnets are known as *phase* windings. When a phase is switched on, it will cause a section of the magnetic armature to be attached; this causes motion. Most standard stepper motors are designed to provide 1.8 degree of motion when this occurs. To drive the motor, the phases are continuously switched on and off sequentially to make repeated 1.8 steps resulting in continuous motion. Since 1.8 degree steps will give a resolution of 200 steps-per-motor revolution (360 degrees), electronic techniques are used to multiply that resolution. *Microstepping* is one technique. Microstepping involves partially energizing adjacent phases under microprocessor control to move the armature a fraction of the distance between the full steps. High-speed microstepping requires complex electronic digital and analog circuits to achieve high microstep resolutions at high speeds.

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Checking Stage Performance:

After the stage system is installed, set up, and configured, the stage performance should be evaluated. With few simple checks, problems can be discovered early and corrected thereby saving valuable time. There are three checks that can be performed with the use of the microscope and software to drive the stage and readout position:

The *mechanical integrity* of the stage can be evaluated easily without power applied to the stage. By manually rotating the knob at the end of the motor, the stage should move with little resistance. The stepper motor provides some 'roughness' from the magnetic detent characteristics of the motor. The resistance should feel the same for the full range of travel of the stage. At the ends of the stage travel, the limit switches should be triggered with an audible click just before the mechanical stop is encountered. With the stage mounted on the microscope, the stage should be able to travel to the limits without any obstruction from the microscope stand or optics.

The *stage repeatability* can be checked by placing a specimen on the stage and using the application software. Using the joystick, align a unique feature to the center of the field of view using a total magnification of about 500x. A crosshair reticle is very necessary for this. This position should be stored or the stage coordinates should be recorded. Note also which direction the stage was moving in the final approach to the position for each axis. Again using the joystick move away from the point in the opposite direction about 5-10 millimeters. Now move back to the previous position, preferably with software control or joystick. Note how far the crosshair is from the alignment point; this error should be less than the specified repeatabilty for the stage. Repeat this several times from different directions at different locations on the stage. The errors should not exceed the stated values for repeatability in the specification sheet.

Absolute *stage accuracy* can be determined on the microscope using a known specimen as reference. A reference specimen can be a calibrated glass scale of sufficient length or other specimen with known dimension such as a semiconductor wafer or mask. The specimen should be placed on the stage so the graduated scale is parallel to the axis to be measured. The parallelism can be verified by moving the stage with the joystick for that axis only; there should be little or no runout from end to end of the scale with a high magnification lens. Once the reference is aligned on the stage, move the stage to the origin of the scale. Next, using application software, 'home' the stage so that the software readout displays 0,0. Now, using the joystick, move the stage along the scale and align a crosshair to graduations and note the position readout on the computer. Once all the data has been accumulated, the stage readout positions

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should show two things: First, a plot of measured (scale readout) position vs. stage position readout should be linear (i.e. a straight line). Second, the position readout (in motor steps) of the stage, using the leadscrew pitch, should calculate to exactly the scale position, within the published specification of the stage accuracy. This procedure is to be repeated for both the X and Y axes of the stage.

Once the X and Y accuracy are confirmed, the stage orthagonality can be checked with that same scale. This test involves placing the scale diagonally on the stage so that both the X and Y axes are used to measure the length. Place the scale on the stage at an angle. Position the stage at one end of the scale, and home the stage. Now, move the stage to the end of the scale with the joystick, and record the position. Using the Pythagorean theorem to calculate the distance based on the X and Y data:

$$C=\sqrt{(X^2+Y^2)}$$

The result should match closely the scale calibrated length. The error in distance can be used to calculate the actual orthagonality error.

EPROM Upgrade:

Occasionally, upgrades are made to the firmware on the MCMSE board. The circuit board has an EPROM on board that can be exchanged if necessary. The EPROM is located on the MCMSE module which can be easily removed from the frame (see above). Before removing the EPROM, note the location of the notch on the chip. The exchange EPROM needs to be replaced in the exact same orientation. The EPROM is carefully removed from the socket with either an IC removal tool or by prying with a thin screwdriver between the actual chip and the socket. When inserting the replacement EPROM, take extra care that all the pins are going into their respective sockets. Before replacing the module in the frame, check the update notes supplied for changes in configuration. Replace the module in the frame in the same slot from which it came.

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Troubleshooting:

IEEE-488 Interface:

Most problems with the IEEE-488 communication stem from the use of host device drivers configured for ASCII communication. HPIB drivers, in particular, are normally configured for ASCII communication and send an EOL (end of line) sequence. These types of drivers must be configured to not send any EOL sequence, or failing to do this the colon can be set up as the end-of-line character. Some manipulation may also be required to coerce the driver into sending certain non-ASCII characters with 8 bits.

Motor Drive:

The MCMSE is a completely digital system which ensures high reliability. If the motor is not running properly, generally it is due to a configuration problem. Table III (p. 21) will help to isolate problems that are common to configuration errors.

Filter Wheel:

The filter wheel, because of its simplicity, is relatively trouble free. It may be possible to cause the motor to stall if the wheel is loaded with six (6) very heavy filters. In this case, it can be remedied by either reducing the filter load or slowing the filter change time.

If there are apparent problems with the shutters under computer control, check the position of the shutter control switches. They should be in AUtomatic position.

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Table IV

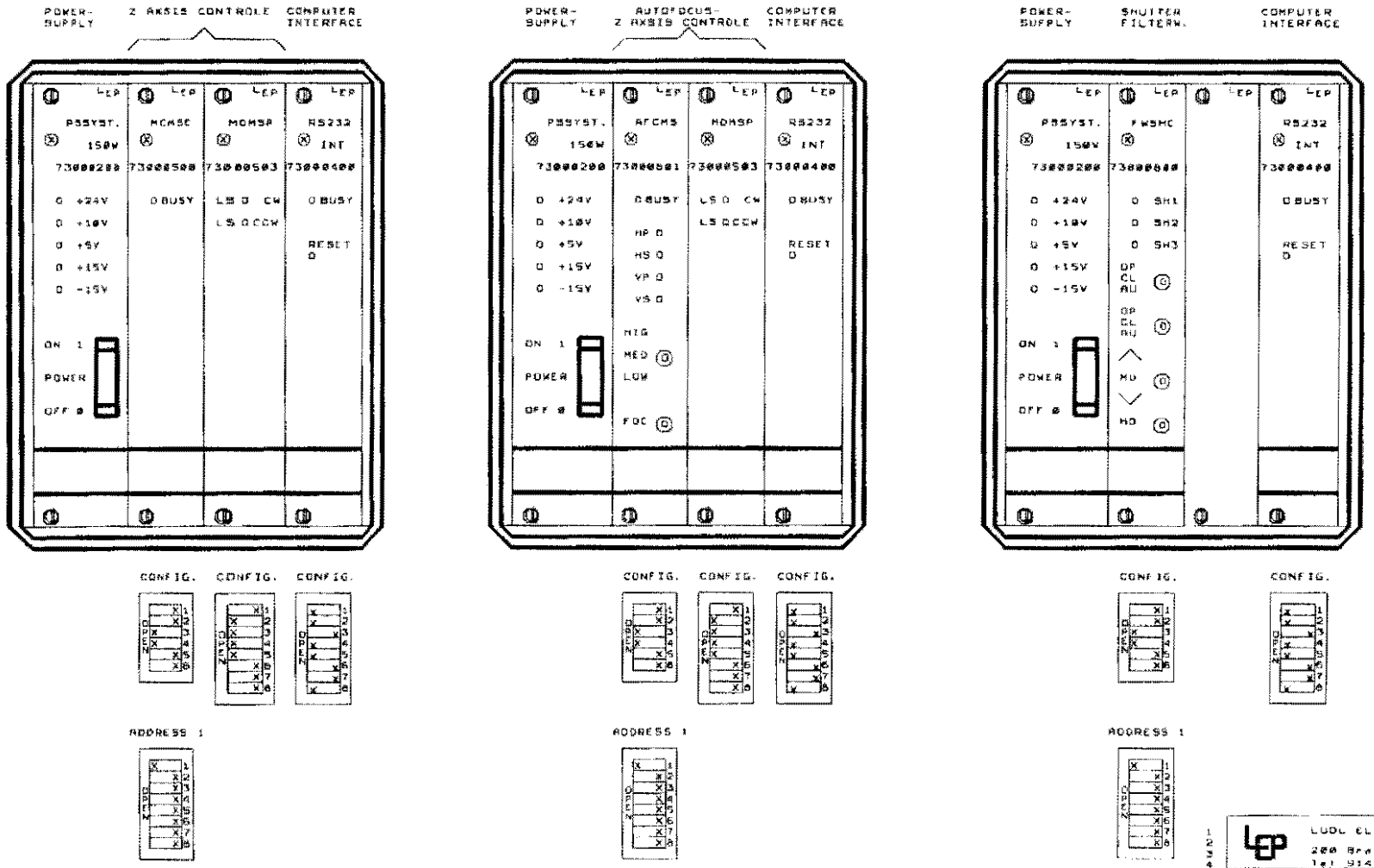
Motor Symptom	Possible Cause	Solution
Motor not running but is energized	Limit switch logic configuration error	Change configuration switch 2
Motor not running and not energized	Cables are connected improperly	Check all connections, including 117v line
		Modules replaced in the wrong slot in MAC2000 frame
		Check to make sure all modules were replaced properly after configuration
Joystick not functioning	Joystick not connected	Check joystick cable connection
	Joystick defective	Replace joystick
Motor runs continuously	System was powered up with joystick partially deflected	Power-down system, make sure joystick is in full upright position
Motor stalls too easily	Motor current set too low	Increase motor current on MDMSP module according to table
Motor ramps up, stops, the ramps up again repeatedly	MCMSE is configured for encoder feed back with no encoder attached	Configure MCMSE according to above table
Motor turns in wrong direction	Configuration error	Change the motor direction configuration switch on the MCMSE
Motor vibrates but does not rotate	Cable is not making full connection on all pins	Make certain both ends of the cables are fully inserted and the slide-lock is engaged

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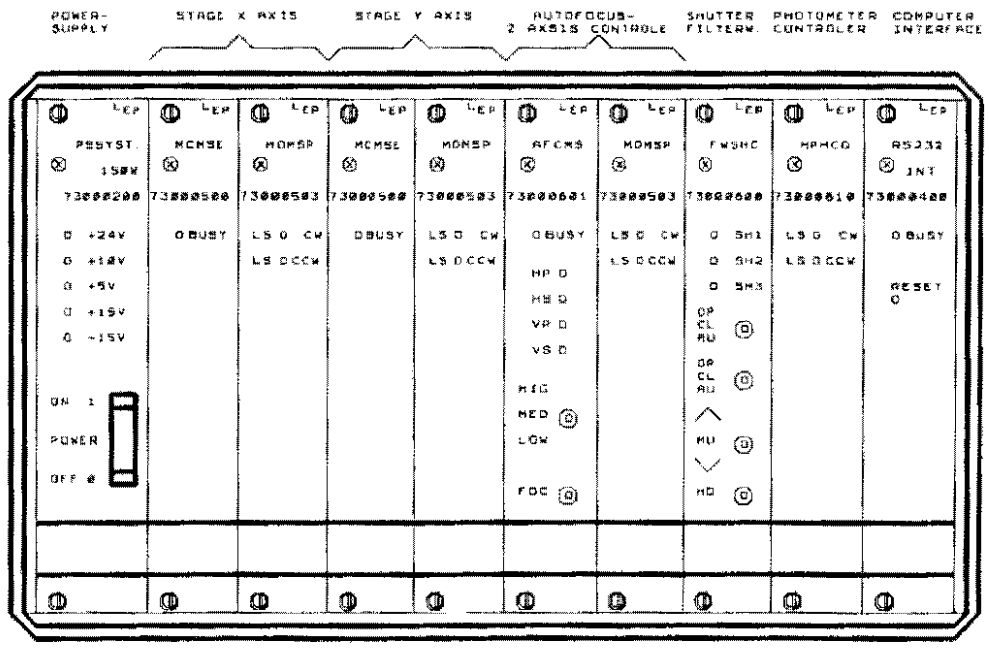
Last Minute Changes:

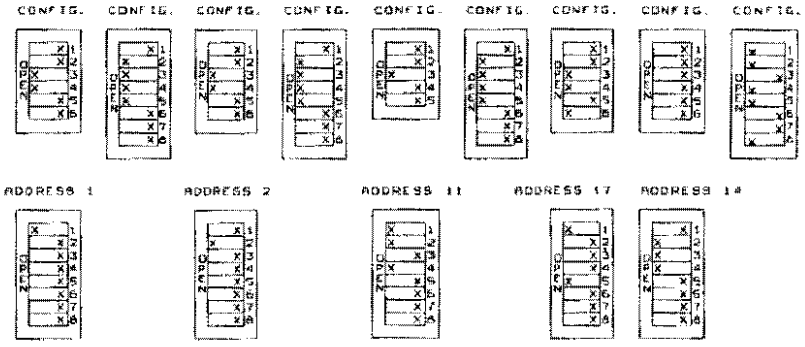
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X MEANS ROCKER PUSHED DOWN

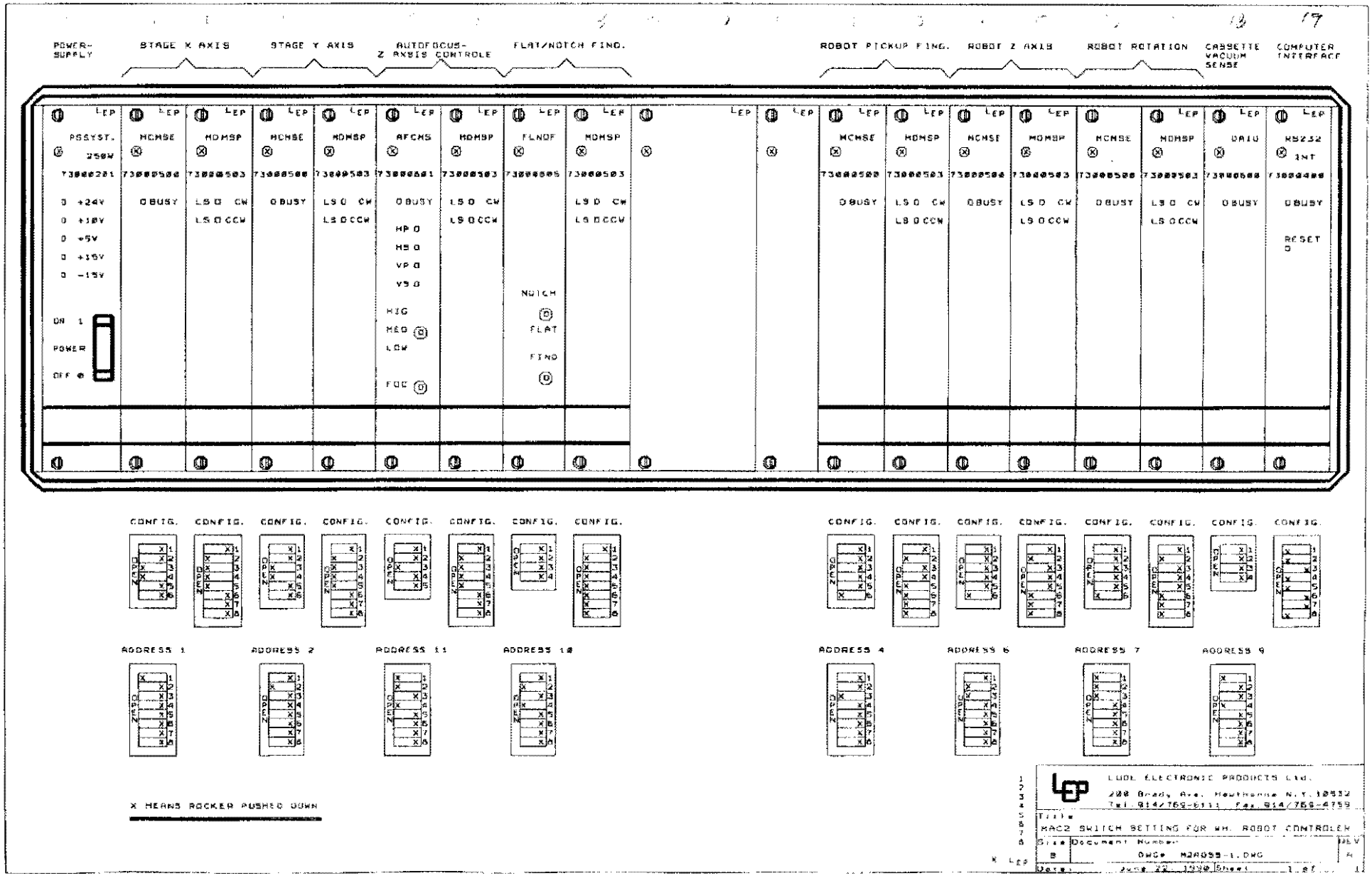
LEP	LUDL ELECTRONIC PRODUCTS Ltd. 288 Brady Ave. Hawthorne N.Y. 10532 Tel. 914/769-5111 Fax 914/769-4759	
Title: MAC2 SWITCH SETTING FOR XY STAGE CONTROLER		
Size: B	Document Number: DWG# M2XYSS-1.DWG	REV: A
Date: June 25, 1989	Sheet 1 of 1	

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25.16 counts

500 counts / mm

200,000 counts / 360°



X MEANS ROCKER PUSHED DOWN

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