

**DUAL STEPPER MOTOR DRIVE MODEL SMD2**

**USER MANUAL ISSUE 3.43**

For use with Program Version 1.75 onward  
and instruments with serial numbers from D025 001.



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## 2. INSTALLATION

### 2:1 CHECKS ON RECEIPT OF THE INSTRUMENT.

On receipt of the instrument remove all packing material and check that all items on the delivery note have been received. Report any damage or shortages to the Company or the Distributor who supplied the instrument. The packing material has been specially designed to protect the instrument and should be retained for possible future use.

### 2:2 INSTRUMENT INSTALLATION.

#### ◆ **Mounting.**

The instrument is suitable for mounting in a standard 19" rack and occupies 1U ( 1.75", 44.5mm) of the rack. The mounting holes in the front panel are intended for retaining the instrument in the rack and will not support its weight. Additional support is required toward the rear and various arrangements are provided by rack manufacturers for this purpose. Support brackets may be mounted on the tapped M3 fixing holes on the sides near the rear. If these or other arrangements are attached to these holes, ensure that the screws used are steel and penetrate the case between 6 and 8 millimetres.

#### ◆ **Ventilation.**

The instrument is ventilated by a fan mounted on the rear panel and through grilles on the right hand side of the case. The instrument is tolerant of operation at elevated ambient temperatures up to 40° Celsius, although long-term reliability will be enhanced by operation at the lowest possible temperature. If there are other instruments in the rack which generate significant amounts of waste heat, try to ensure that this is deflected away from this instrument.

#### ◆ **Connection to the mains supply and earthing.**

The mains is connected via an IEC CEE22 pattern connector.

**THE INSTRUMENT MUST ALSO BE CONNECTED TO EARTH BY THE STUD PROVIDED. FAILURE TO PROVIDE THIS CONNECTION MAY RESULT IN A SHOCK HAZARD FOR THE OPERATOR IF EXTERNAL SOURCES OF HIGH VOLTAGES ARE INADVERTENTLY CONNECTED TO THE OTHER LEADS WHEN THE MAINS LEAD IS DISCONNECTED. SUCH MIS-CONNECTIONS ARE COMMON IN VACUUM SYSTEMS.**

### 2:3 FUSING.

The rating of the mains fuse is printed on the rear panel next to the fuseholder. It must be replaced with a 20mm x 5mm anti-surge fuse of the same type and rating. Such fuses are marked with a "T" next to the current rating: ceramic fuses are generally unsuitable, even if so marked. There is provision to house a spare fuse in the fuse drawer, which is integral to the mains connector. The inner fuse in the drawer is the one connected to the circuit. It is necessary to disconnect the mains supply when replacing fuses.

## 2:4 WIRING OF THE MOTORS TO THE VACUUM FEEDTHROUGH.

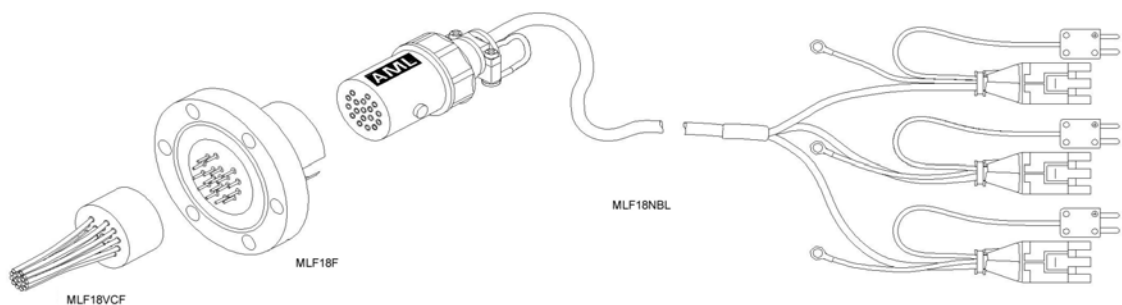
### ◆ Feedthrough requirements.

Each motor requires six vacuum feedthrough pins. It is not necessary to use a thermocouple vacuum feedthrough, as the error introduced by incompatible feedthrough material is usually less than 5 degrees.

AML feedthrough MLF18F is recommended, since it mates directly with the 1.5mm crimp socket terminals fitted to motor leads and simplifies installation.

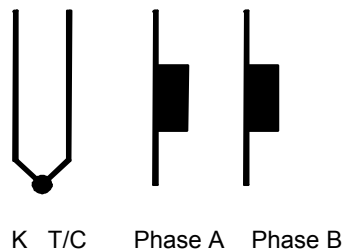
MLF18F has 18 1.5 mm gold-plated feedthrough pins and is suitable for one to three motors. An internal bakeable connector, MLF18VCF, is available into which the crimp terminals on the motor leads are inserted. This significantly reduces the risk of short-circuits and makes the installation more convenient. Motors may be ordered with connectors fitted.

AML supply an 18-way, screened external lead, MLF18NBL for direct connection to SMD2 drives. The use of this lead ensures compliance with the EU EMC Directive 89/336/EEC. Air-side connectors, MLF18AC are available for users wishing to make their own cables.



### ● Lead identification and interconnection

It is very easy to identify and connect the leads. An ohmmeter with resolution down to about 1 ohm is required to identify the two phase windings: most inexpensive multimeters are suitable.



The leadout wires are self-coloured polyimide film-wrapped silver-plated OFHC copper wires and each is fitted with a 1.5mm crimp socket terminal.

The phase leadout wires are much thicker than the thermocouple leadouts. Radiation-hard motors have multi-strand leads. Identify the two motor phases by their resistance, which will be in the range of 3 to 15 ohms, depending on the motor type. There is no electrical connection between the two phases or to the thermocouple or the case of the motor. Most of the resistance is in the windings of the motor and is virtually unaffected by shortening of the leads. Connect each phase to the appropriate drive terminals. The resistance of the wires from the feedthrough to the drive must be less than a few ohms.

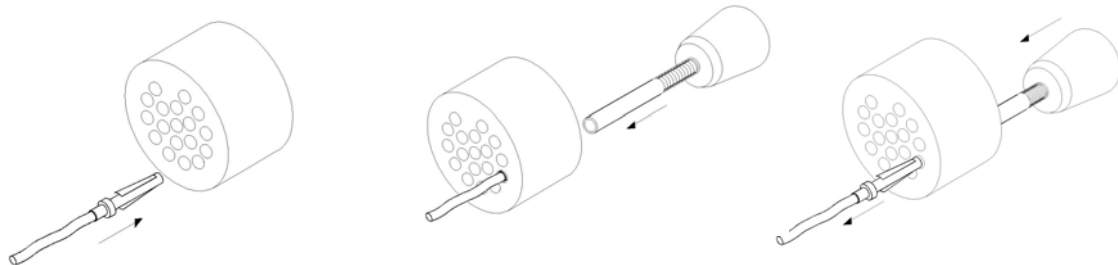
The thermocouple wires are much thinner than the phase leads. The thermocouple is insulated from the rest of the motor. The resistance of the thermocouple is 50 to 60 ohms, as supplied, and is proportional to the length, if shortened. The Alumel wire may be identified with the magnet supplied, since it is weakly magnetic. At the controller the Alumel lead should be connected to the terminal marked Alumel, N, -, or coloured blue, and the Chromel lead should be connected to the terminal marked Chromel, P, + or coloured brown.

The temperature measurement is not required to be very precise, so it is not necessary to use thermocouple-compatible feedthroughs or extension wires. If compatible materials are used then they must be connected the correct way round.

◆ **Connection to MLF18VCF or MLF18F**

If you are connecting crimp terminals directly to the feedthrough (i.e. not using MLF18VCF) do not forget to thread the wires through the copper gasket before connecting to the feedthrough! To avoid short-circuits insulate the crimp terminals with PTFE sleeving.

If you are using MLF18VCF it will be useful to have a socket extractor tool. RS Components stock number 466-876 is suitable and inexpensive.



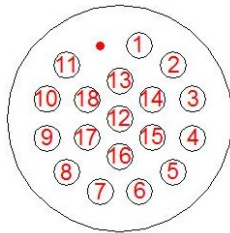
**Pin / Socket insertion**

1

**Pin / Socket extraction**

2

Make connections according to the following conventions. This will ensure compatibility with MLF18NBL leads. The diagram shows the rear of the connector or the vacuum side of the feedthrough.



	Motor 1	Motor 2	Motor 3
Phase A+	1	7	13
Phase A-	3	9	15
Phase B+	2	8	14
Phase B-	4	10	16
Thermocouple +	5	11	17
Thermocouple -	6	12	18

◆ **Preparation of motor lead-out wires for use with other feedthroughs**

It will be necessary to cut off the crimp terminals fitted to the leads and re-strip them. Standard motors are fitted with Polyimide film-wrapped leads: radiation-hard motors are fitted with Polyimide lacquer-coated leads.

Polyimide is strong, flexible and abrasion-resistant and therefore difficult to strip. The simplest method of stripping polyimide film is to cut a ring with a sharp knife and withdraw the cylinder of insulation over the end of the wire. Be careful not to mark the conductor surface with the knife. Strip lacquer-coated radiation-hard leads by scraping with a sharp knife. Either type of lead may be stripped with a suitable high-speed rotary stripper. Do not use a thermal stripper.

**Do not forget to thread the wires through a copper gasket before connecting to the feedthrough**

◆ **Reversal of rotation**

Since the phases are not identified there is a 50% probability that the direction of rotation will be reversed from the desired or conventional sense. To reverse the direction, exchange the connections to **one** of the phases.

Check that the drive, wiring and motor combination work properly before closing the vacuum system!

## **2:5 WIRING BETWEEN THE VACUUM FEEDTHROUGH AND THE DRIVE.**

### **◆ Using AML cables.**

Users of the MLF18 kit need only to connect the bakeable connector to the air side of the feedthrough and the other connectors to the SMD2. Ensure that each thermocouple connector is inserted in the same-numbered socket connector as the motor power. MLF18 cables are screened.

### **◆ Using custom-made cables.**

The thermocouples should be connected to the instrument with K-type extension cable using the connector in the accessory kit. Thermocouple extension cable is readily available, inexpensive and normally suitable for use in bakeout zones and should be used wherever possible. Take care to ensure consistent polarity throughout and connect the blue Alumel wire to the connector pin marked "-". Signal voltages from thermocouples are very small so some precautions against induced interference are desirable. Insulated thermocouple wires or extension cables should be twisted together to avoid magnetic induction and routed away from power cables.

Since the current and voltage on the drive are small the phase wiring can be of relatively small cross-section, and 16/0.2mm ( 0.5mm<sup>2</sup> or AWG20 ) wire is recommended. Twisting the pairs of wires for each phase together throughout their length will reduce radiated interference. An overall screen is recommended.

Pin connections on the 'Trident' motor connectors are shown related to the two arbitrarily-designated windings:

<b>Connector</b>	<b>Wire</b>
1	$\Phi_A$
2	$\Phi_A$
3	$\Phi_B$
4	$\Phi_B$

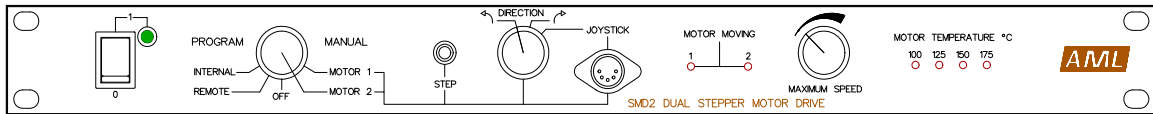
### **◆ Checking the motor-to-drive connections.**

It is essential that the drive, wiring and motor combination work properly before closing the vacuum system. The simplest check is to measure the resistances between pins on the motor and thermocouple connectors before they are connected to the SMD2 drive. Between pins 1 and 2 of the motor connector you should measure approximately the phase resistance of the motor. If the cables are several metres long the measurement may be increased by a few ohms. A similar resistance should be measured between pins 3 and 4. Between pins 1 and 3 there should be an open circuit. Check that there is an open-circuit between both phases and the vacuum chamber ground. The resistance between the pins of the thermocouple should be a few tens of ohms and there should be an open circuit to the motor connector. Reconnect the drive and exercise the motor using the joystick or 'Step' and 'Direction' switches.

### **◆ Reversal of motor rotation.**

Since the phases are not identified there is a 50% probability that the direction of rotation will be reversed from the desired or conventional sense. To reverse the direction exchange the connections to only one of the phases.

### 3. OPERATION.



#### 3:1 FRONT PANEL INDICATION AND CONTROLS.

##### ◆ Mains power indicator.

A green LED indicator is provided next to the mains switch. It is illuminated when the instrument is connected to the power supply and switched on.

##### ◆ Motor Moving Indicator.

A green "Motor Moving" LED is illuminated whenever a motor is being driven. The LED is illuminated for each step for 50 milliseconds and will therefore flash at low stepping rates. Both LEDs are flashed briefly five times immediately after the instrument is switched on.

##### ◆ Motor Temperature Indicator.

A row of four LEDs indicates "Motor Temperature". Each shows that the currently selected motor has exceeded the temperature marked adjacent. When the motor temperature is less than 100°C no LED is illuminated. When the motor temperature exceeds 175°C the red LED is illuminated, program execution is terminated (except in the case of the "motor bakeout" program) and the motor power is removed.

##### ◆ Program / Manual Switch.

This rotary switch specifies how the drive is controlled. The three sources of control are:

A program stored in the instrument	(Internal Program Control)
A remote computer	(Remote Program Control)
The front panel switches or joystick	(Manual Control)

Moving the switch to the "Internal" position when the instrument is switched on will cause the stored program to be executed once. If the instrument is switched on when the switch is in the "Internal" position the program will not be executed.

When the switch is in the "Remote" position the instrument will respond to commands received on the serial interface.

When the switch is in either of the "Manual" positions labelled "Motor 1" and "Motor 2" the selected motor may be controlled with either the "Step" or "Direction" switches on the front panel or joystick.

Moving the switch to the "Off" position removes motor power immediately if the motor is under program control. If the motor is being controlled manually power is removed as soon as either "step" switch is released.

##### ◆ Step Switch.

This pushbutton switch is used to move the selected motor in manual control. Pressing the "Step" button results in a single step, followed after a delay of 0.5 second by acceleration to the defined maximum speed. If any other switch which affects motion (e.g. "Direction" or "Program/Manual") is changed while the motor is moving the change is ignored until the motor stops. Repeatedly pressing briefly on the "Step" button results in a single step for each press.

Each single step is executed as eight mini-steps, and the power is held for 50 milliseconds after completion of each step. If the hold time parameter stored in the instrument has been changed via the serial interface since the instrument was last switched on then the power is held according to those parameters: this is described in section 5, below.

◆ **Direction / Joystick Switch.**

This is a three-position rotary switch which is used to control the direction in which the manually-selected motor rotates. The direction arrows show the direction of rotation of the motor shaft when viewing the flanged end of the motor. The "Joystick" position allows the direction of rotation to be controlled from the plug-in joystick. If the "Direction" switch is changed while the motor is moving the change is ignored until the motor stops.

◆ **Joystick Connector.**

Connecting the AML model SMDJ joystick to this connector allows direction and step control to be performed on the joystick when the "Direction/Joystick" control is in the "Joystick" position. The front-panel "Step" switch is still operational when the joystick is used.

◆ **Maximum Speed Switch.**

This control sets the motor slewing rate under manual control. The positions of the switch correspond to:

5, 10, 20, 50, 100, 200, 500, 1000, 2000, 5000 steps per second.

The speed can be varied dynamically, by rotating the switch while the motor is moving. At speeds above 100 steps per second a fixed acceleration/retardation profile is used. Because the motor is retarded when the switch is released some travel beyond the point of release will occur. Depending on the motor type and the load conditions the motor may not run at the higher speed settings on the switch.

Mini-stepping is used at speeds below 1000 steps per second in order to smooth the motion.

The speeds, accelerations and mini-stepping transition speeds available cannot be changed in manual control.

**3:2 INTERNAL CONTROLS (Links).**

Instruments are shipped with the baud rate set to 9600, checksum disabled and motor phase current set to 1.0 ampere. To check or change these settings use the following procedure.

Disconnect the power connector and remove the smaller screws at the sides of the instrument. Note that the ventilation slots are at the right side, when viewed from the front. Remove the cover in an upward direction.

◆ **Setting the Baud rate.**

Locate links BR0, BR1 and BR2 at the right side of the right hand circuit board. Fit or remove links according to the following, where L represents the presence of a jumper on the link:

BAUD RATE	BR0	BR1	BR2
19200	L	L	L
9600		L	L
4800	L		L
2400			L
1200	L	L	
600		L	
300	L		
110			

#### ◆ **Enabling the checksum.**

The checksum should only be enabled if the user's application program requires. Checksum should remain disabled for use with the AML demonstration program SMD2.EXE or a terminal.

Locate the CHK link at the right side of the right hand PCB. Remove the link jumper from the right hand pair of pins adjacent the CHK legend and transfer it to the left pair.

#### ◆ **Setting the motor phase current.**

Instruments are shipped with the phase current set to 1 amp. The recommended initial phase current for motors is 1 amp (all links fitted). It is probable that the motor can be run at lower phase currents in most applications and this will decrease the gas load.

Locate the two links LK2 and LK3 on the left hand printed circuit board, about 5 cm back from the front panel. On each set of links fit jumpers to the pairs of pins marked 100 200, 200 and 500mA as desired. Each fitted link adds the current marked adjacent into the total phase current. This arrangement allows current reduction in decrements of 100mA. **BOTH SETS OF LINKS MUST BE SET TO THE SAME CURRENT.** Spare links should be stored on "LKPARK" next to the relay.

Ensure that there are no loose links or foreign material inside the instrument. Replace the cover and screws in the correct locations. Do not use screws longer than those supplied.

### **3:3 MANUAL CONTROL USING THE JOYSTICK AND PANEL CONTROLS.**

Operation of vacuum stepper motors using the controls described in section 3:1 is straightforward.

#### ◆ **Limitations to manual control.**

The number of speeds available is limited and the acceleration and mini-step transition speeds are fixed. These are compromise values chosen to suit the majority of applications, however, large motors and heavily loaded motors will not run at higher speeds and motors driving large inertia loads may not be able to follow the acceleration profile. The flexibility afforded to the user by operation or programming through the serial interface is much greater and this is the major mode of operation intended for the SMD2, with local operation only being used to set up the initial position of a mechanism before running a program.

#### ◆ **Establishing a holding torque for unbalanced loads.**

In the case of unbalanced loads which may cause the motor to rotate when phase current is removed, permanent holding torque may be established for manual operation, by modifying the hold torque parameter via the serial interface or by running a stored program which modifies it. The default hold parameters are restored when power is removed from the instrument.

#### ◆ **Interaction between remote and manual operation.**

On returning from remote operation all of the default values for the acceleration and mini-step are reset. The hold parameters are, however, maintained as set by the program.

### **3:4 PROGRAMMING OR CONTROL BY HOST COMPUTER.**

Generally, the SMD2 drive will be programmed for 'stand alone' operation or controlled by a host computer via the RS232C-compatible interface. The connections to the RS232C "Remote" connector are described in Appendix A. A full listing of the available commands and protocol is included in Appendix B.

The Host Computer must be set to send and receive data with 1 start bit, odd parity, 7 data bits and 2 stop bits at the same Baud rate as set in the instrument. Instruments are shipped with the Baud rate set to 9600.

For 'stand alone' operation with a downloaded program the SMD2 Demonstration Program offers adequate facilities for developing and debugging application programs.

It is recommended that users requiring host computer control should use the SMD2 Demonstration Program to familiarise themselves with the commands before developing application programs.

### 3.5 ACCELERATION PROFILES.

Under program control, an exponential acceleration/retardation table is generated whenever the acceleration command ( X ) is executed. This command defines the start/stop speed the slewing speed and the number of steps in the acceleration/retardation profile. The first frequency in the table is the Start/Stop Speed,  $f_0$ , subsequent step frequencies,  $f_n$ , are calculated by the formula:

$$f_n = f_{n-1} + \frac{f_s - f_{n-1}}{N * 0.13 + 0.6}$$

Where:-

- $f_n$  = step frequencies
- $f_{n-1}$  = frequency of previous step ( $f_n$ ) or start speed if first step
- $f_s$  = slewing speed
- N = number of steps in the ramp.

The total time taken to accelerate to the Slewing Speed may be calculated iteratively.

Example:

(X) command parameters = Start speed 100, Slew speed = 1000, Number of steps in ramp = 50

STEP 1  $f_n = 100$

STEP 2  $f_n = 100 + \frac{1000 - 100}{50 * 0.13 + 0.6}$   
 $= 226.76$

STEP 3  $f_n = 226.76 + \frac{1000 - 226.76}{50 * 0.13 + 0.6}$   
 $= 335.67$

Step number	1	2	3	4-49	50
Frequency of step (Hz)	100.00	226.76	335.67	----	999.47
Period of step (Sec)	0.01	4.410x10 <sup>-3</sup>	2.979x10 <sup>-3</sup>	----	1.001x10 <sup>-3</sup>
Ramp time (Sec)	0.01	1.441x10 <sup>-2</sup>	1.739x10 <sup>-2</sup>	----	7.066x10 <sup>-2</sup>

Total ramp time = 0.07066 seconds.

The SMD2's processor may take several seconds to calculate this table. For this reason the acceleration command ( X ) should preferably be used only at the beginning of a program. In order to change the slewing speed within a program the slew command ( T ) may be used. This causes the acceleration to terminate at a lower speed without needing to recalculate the table. The acceleration parameters are restored to their default values when the instrument is switched off or to manual control.

The current parameters may be examined with the V5 command. The parameters returned are those of the last X command **executed** ( which might not be the last command sent to the SMD2 ), or the default parameters.

### 3.6 STEPPING RATE RESOLUTION

The stepping rate is derived from a crystal-controlled clock frequency of 1.8432 MHz. The period of any given step is generated by dividing the clock frequency by an integer value. From this it follows that the resolution of stepping rates is better at lower speeds. The average error in the range 100 - 6000 is 0.08% and does not exceed 0.3%

Slow speeds below 10Hz are normally programmed as a single step command and a delay command within a program loop which is executed once per step. The period of execution of a single step is the reciprocal of the starting speed as defined in the acceleration command ( X ). To this must be added the time parameter defined in the hold command ( h ) and the programmed delay to obtain the total period of the step. The SMD2's internal execution delays are insignificant and the overall frequency accuracy obtained is close to that of the crystal.

### 3.7 STEP DIVISION (Mini-stepping)

To control the motor at low frequencies, steps are divided into several smaller steps. The only reason for using step division with vacuum compatible motors is the control of low-frequency resonances and reduction of vibration. These application matters are discussed in section 4, below.

The table below gives the default settings.

Step Rate (sec <sup>-1</sup> )	Subdivisions
≥ 500	1
200 - 499	2
100 - 199	4
5 - 99	8

The Mini-step command, M, can be used to change the transition frequencies. The default values are restored every time the instrument is switched 'on' or is switched to manual control.

The current parameters may be examined with the V5 command. The parameters returned are those of the last M command executed ( which is not necessarily the last command sent to the SMD2), or the default parameters.

The SMD2 cannot maintain a motor in an intermediate position between complete step positions.

### **3:8 USE OF THE USER INPUTS AND LIMIT SWITCHES.**

Connection of these signals to the SMD2 is via the Limits and User Connectors, described in appendix A.

All of the User and End of Travel inputs have bias resistors which define a "high" state when no external connection is made to them. A contact closure between them and the "logic ground" connection on the "User" or "Limit" connector to define the "low" state. The open-circuit voltage on these inputs is around +3.5 volts, the short-circuit current is less than 1 milliamp, and less than 0.1 volt should appear across the switch when closed. Good-quality gold-plated switches or NPN transistors with good saturation are required to achieve this. No voltages outside the range 0 to +5v should be connected to these inputs, and there are none on the SMD2 Limits and User Connectors.

Switch "de-bouncing" is performed by the instrument, which results in a delay of 30 milliseconds between the switch closing and the program taking notice. Several steps may have occurred between these events, even at moderate speeds. If the switch can resolve a single step and this is desired then it should be approached at less than 20 steps per second.

#### **◆ End-of-Travel.**

The End-of-Travel inputs, EOT+ and EOT- are intended to prevent mechanisms being driven to their mechanical limits. EOT+ specifically means a location near the end of travel which will be reached by clockwise rotation and EOT- will be reached by anticlockwise rotation. The sensing devices (commonly micro switches operated by cams or ramps) that perform this function should be connected so that an approach close to the limit which they protect causes the EOT input to go "low", i.e. with a switch which closes for motion beyond the EOT location. It is not necessary to use the EOT to protect AML motors, which will not be damaged by running against a mechanical stop.

If EOT is reached during operation from the joystick or front panel switches, the motor will be retarded to a stop through the acceleration profile and drive current will then be removed. Only motion in a direction back toward the allowed range of travel will be allowed while an EOT input is 'low'.

If EOT is reached during execution of an instruction or program, execution will be terminated (except in the case of the Home command). The motor will be retarded to a stop through the acceleration profile and drive current will then be removed. The error code, E7+ or E7-, will be reported via RS232. Only motion away from the limit will be allowed while an EOT input is 'low'.

#### **◆ Home Command.**

The H+ command will cause the motor to rotate clockwise toward EOT+, retarding to a stop using the acceleration parameters when the EOT+ input goes low. The EOT location is overshoot by an amount which is dependent on the slew speed and the acceleration parameters. Rotation then reverses until a position exactly eight steps after the EOT+ signal goes 'high'. The EOT location is traversed at less than 30 steps per second, so that the switch 'de-bouncing' action will operate within a single step period. The H- command causes a similar sequence of motions to find the EOT- location. Usually, the 'H' command will be followed by the 'f' command, to preset the position counter.

#### **◆ Function and Location of the EOT switches.**

The EOT switch must remain closed whenever the mechanism is beyond the EOT limit. The positions of the switches must be such that there is sufficient space for the mechanism to be retarded from maximum speed without any mechanical restraint being reached. Allowance for the distance travelled during the 30 millisecond 'de-bouncing' of the EOT switch should be made. If these conditions are met then the content of the position counter will be preserved while the mechanism is beyond the EOT limit and the rest position after execution of a Home command will be as repeatable as the switch allows.

UHV-compatible micro switches are available for limit switching, but currently available types are bulky. Other types of in-vacuum switch and precision displacement transducers are available, but at a much higher price.

#### **◆ User inputs.**

The user inputs may be related to the position of the mechanism, or alternatively used to start, stop or synchronise operation of parts of the program with other events or processes. The user outputs of one SMD2 can be used to drive the inputs of another via suitably driven relay buffers. Programs using this type of synchronisation should be constructed carefully so that inputs are examined when interaction is expected and with delays to enable the de-bouncing to be completed before removal of the driving output.

### **3:9 USER OUTPUTS.**

The user outputs may be used to switch other devices or to indicate progress of the program.

The user outputs switch between about +0.4 volts in the "clear" state and about +3.5 volts in the "set" state. The source resistance is approximately 100 ohms. Direct drive of external 5 volt CMOS logic (e.g. 74HC devices) or small-signal NPN transistors with a series base resistance of >1kohm is the intended use of these outputs. The drive is insufficient for relays. No voltages should be connected to these outputs.

User outputs will drive low-current LED indicators connected with a series 2k2 ohm resistor connected to logic ground. This will reduce the "set" state voltage.

User outputs should not be connected directly to user inputs.

## 4. OPERATION OF VACUUM-COMPATIBLE STEPPER MOTORS (VCSM)

It is assumed that the reader is familiar with the production of UHV and the handling of UHV components.

The successful application of vacuum stepper motors requires an appreciation of their thermal as well as their mechanical properties. Compared to motors operated in air the available cooling means for motors in vacuum are much less effective, and until development of the B-series motors continuous operation was difficult to achieve.

Apart from extending the run time, operation at low temperature improves the outgassing performance of motors. For this reason minimum running times and motor currents should always be pursued. Selection of the largest motor possible for the application will result in longer running times, lower motor temperature and lowest outgassing.

Design mechanisms with balanced loads whenever possible, or arrange that either the static friction in the system or the motor detent torque will hold position without the necessity of maintaining phase currents to produce a holding torque. The 'h' command may be used to reduce the phase currents and produce a holding torque which is intermediate between the pullout torque and the detent torque. Refer to section 4:6 for a full description of power-reduction techniques.

Many applications that appear to require continuous running, for example substrate rotation for ensuring uniformity of deposition or implantation, can be equally well performed by intermittent short periods of stepping at low duty cycle.

Stepper motors should not be disassembled as this partially demagnetises the permanent magnet in the rotor and permanently reduces the torque.

It is recommended that motors and mechanisms are operated in air during early commissioning. This has the advantage that more cooling is available and that stepping can be seen and heard.

### **4:1 OPERATING TEMPERATURE AND RUN TIMES.**

The maximum recommended running temperature of AML motors is 175° Celsius, as measured by the embedded type K thermocouple.

Current B-series motors have published temperature and time graphs for typical operating conditions with the motor mounted by its flange. Improved B-series motors have increased surface radiation due to the increased emissivity of diamond-like coatings over etched surfaces, lower internal thermal impedances, increased winding masses and reduced winding resistances. Continuous running can readily be achieved with care at medium phase currents. Run times at higher currents can be increased by additional heatsinking at the other end of the motor. AML produce several OFHC copper accessories for this purpose.

AML motors are guaranteed suitable for operation at 77°K and they are believed to be suitable for use at lower temperatures. Because the resistance of the windings at low temperatures is small the efficiency of the motor is much greater than at normal temperatures. A resistance of a few ohms should be connected in series with each winding, in order to present a normal load to the SMD2. The leads of the motor will be very brittle at low temperatures and should not be allowed to flex. The normal mechanical and electrical properties of all materials are recovered on return to room temperature.

### **4:2 OUTGASSING AND BAKEOUT.**

Newly-installed motors will outgas, mainly due to water-vapour retention in polyimide. As this material is microporous the water is released rapidly and the rate will subside after a few hours. The rate may be accelerated by running the motor to self-heat it.

Baking at up to 200° Celsius is permissible, and a 24-hour bake at this temperature will normally reduce the outgassing to its minimum.

Motors are typically operated at some distance from the chamber walls where the bakeout temperature is most often controlled. If the temperature indicated by the motor thermocouple during bakeout is not high enough when the bakeout period is well advanced it may be increased to 175° by applying drive power. The preferred method of doing this is by using the "b" command described in Appendix B, since this energises both phases and keeps the motor stationary in a half-step position. Keeping the motor hot by this means while the rest of the vacuum system cools is recommended as this will prevent condensation on the motor. Where internal infra-red heaters are used for bakeout it is advisable to shield the motor from direct radiation and to achieve the desired temperature during bakeout by running the motor.

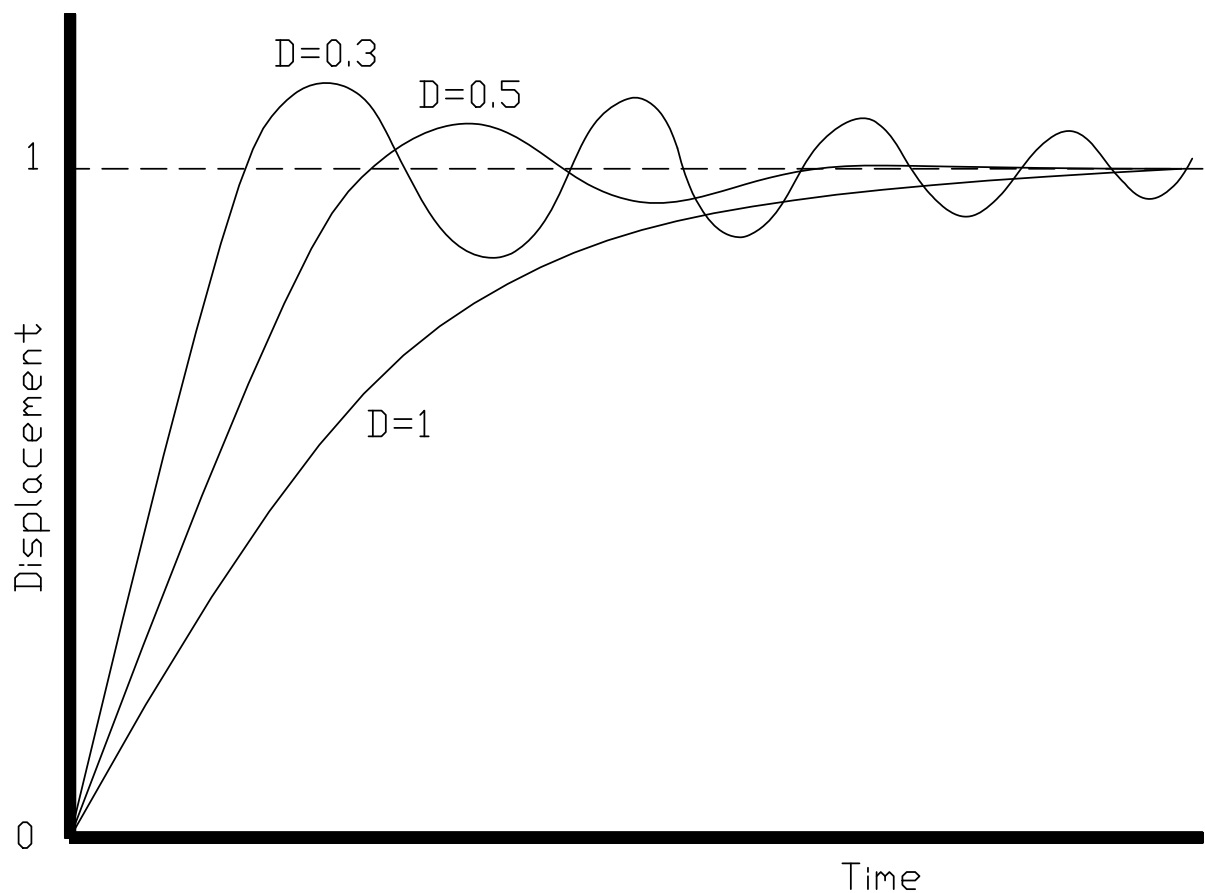
Irreversible deterioration of the winding insulation will begin to occur above 230° and the motor may subsequently produce larger amounts of gas, even at lower temperatures.

#### 4:3 RESONANCES.

Stepper motors are classic second-order systems and have one or more natural resonant frequencies. These are normally in the 50 - 100Hz region for unloaded motors. Operation at step rates around these frequencies will excite the resonances, resulting in very low output torques and erratic stepping. Another set of resonances can occur in the 1 - 2kHz region, but these do not normally present any practical problems.

##### ◆ The effects of load inertia, friction and drive characteristics.

The primary (lower) resonant frequency cannot be stated with any precision, since it is modified by the friction and inertia of the load, the temperature of the motor and by the characteristics of the drive. Coupling a load inertia reduces the resonant frequency and decreases the damping factor. Load friction increases damping. Because the drive circuits of the SMD2 produce a controlled phase current this produces heavy damping. Drives which are voltage sources and which rely on the motor winding and other resistance to define the current have a lower damping factor. The effect of changing the damping on the single step response of the motor is shown in the diagram below.



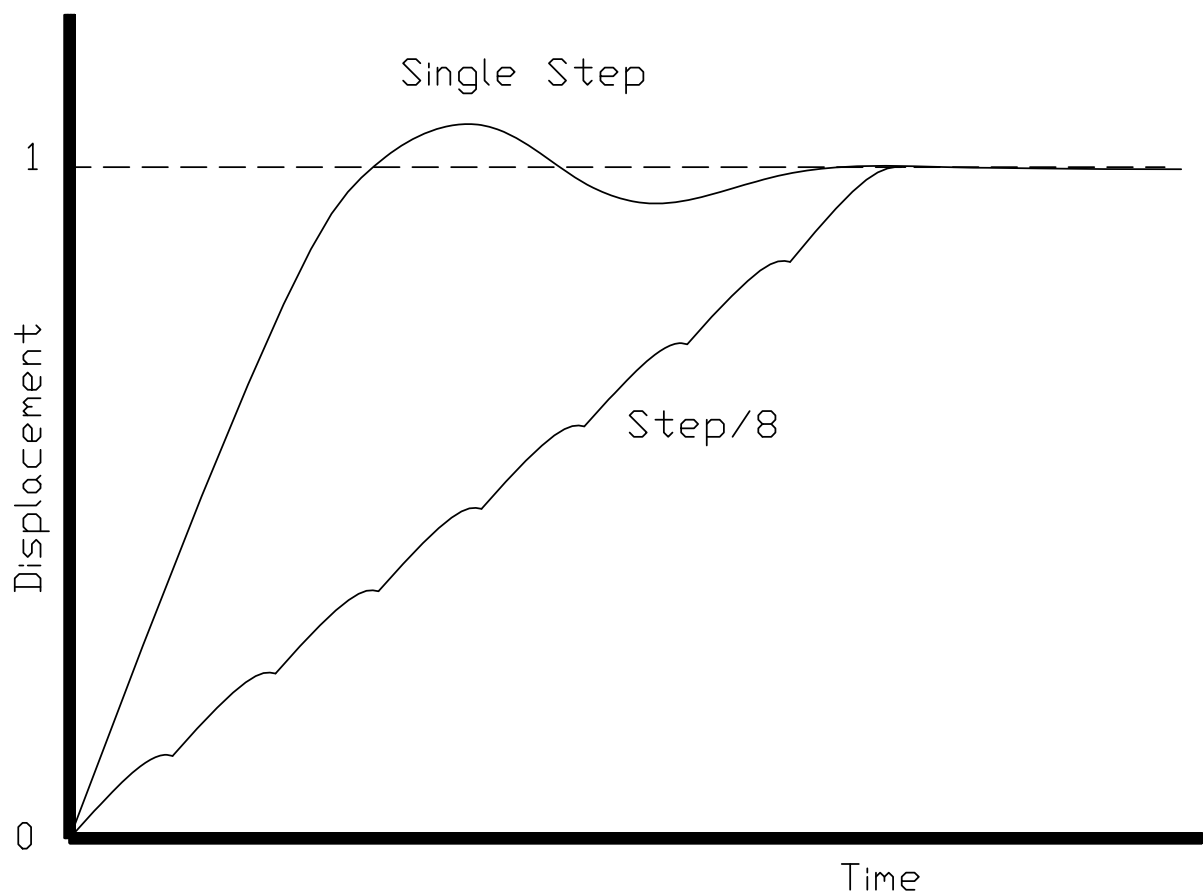
◆ **Control of Resonance.**

The simplest method of controlling resonances is to avoid operation of the motor close to the resonant frequencies. It is usually possible to start a motor at rates in excess of 300Hz if the load inertia is small, thereby completely avoiding the primary resonance. Resonances are not usually a problem when the motor speed is accelerating or retarding through the resonance frequency region.

If it is necessary to operate at slow speeds or with large load inertia the step division feature of the SMD2 (mini-step) helps. It effectively increases the stepping rate by the step division factor and reduces the amplitude of the step transients that excite the resonances. This is shown in the diagram below. Because both phases are energised in mini-stepping there are some other processes of interchange of energy between the windings which do not occur in the single step mode and these increase the damping factor.

In particularly difficult cases modifying the step frequencies at which transitions of the step divisions (mini-step modes) occur can be useful.

A typical motor response to a single step and to a single step subdivided into eight mini-steps is shown in the diagram below.



#### **4:4 MECHANISMS FOR USE WITH VCSMs.**

The following section is an introduction to this topic and is intended to indicate the major mechanical and vacuum considerations for various types of mechanisms. A working knowledge of mechanics and vacuum construction techniques is assumed. AML supply a range of standard mechanisms which can be customised and also design special mechanisms and components.

##### **◆ Rotation ( Position Control ).**

The load inertia coupled to the motor shaft should ideally be small compared to the rotor inertia of the motor. Load inertia up to two or three times that of the motor can be driven, without significant difference to the maximum start speed and acceleration which is achieved by the unloaded motor. Load inertia of around ten times that of the motor can be driven with absolute synchronism, provided care is taken over specifying the mini-step and acceleration parameters. Larger inertia loads should be driven through reduction gearing.

Significant loads should have their centre of gravity on their axis of rotation, unless they are rotating in a horizontal plane.

Angular resolution at the motor shaft is limited to a single step of  $1.8^\circ$ . The actual rest position within the step is determined mainly by the load friction and any torque imposed by the load on the motor at rest. If the rotor position is displaced  $\Theta^\circ$  from the nominal step position the restoring torque increases approximately in proportion to  $\sin(100 \times \Theta)^\circ$ . The maximum torque at the half step position is either the detent torque or the holding torque, depending on whether the motor is powered at rest. If the static friction and any torque due to an unbalanced load are known, this allows the rest position error to be estimated using the above approximation. The friction within the motor bearings is very low, so that a completely unloaded B23.1 motor will normally settle within  $0.2^\circ$  of the desired position if brought suddenly to rest from full stepping at 300Hz.

Angular resolution may be improved by reduction gearing: this is discussed below.

##### **◆ Rotation ( Speed Control ).**

In some applications the precise position of a rotating load is not important or can be deduced by other means but the speed of rotation may need to be controlled very precisely. Beam choppers and sample rotators for control of deposition uniformity are applications of this type. An increased load inertia may be desirable to smooth out the stepping action of the motor. Loads of up to about 1000 times the inertia of the motor can be controlled by using long acceleration ramps. Some steps may be lost during acceleration and retardation of such loads, but precise synchronism at constant stepping frequency is easily achieved and recognised.

Significant rotating loads should be balanced, at least to the extent that the torque presented to the motor shaft is less than the detent torque of the motor. The motor torque requirement will then be dominated by that required to accelerate the load.

A typical example of a large inertia load was a 1.5kg disk of uniform section, 20 cm in diameter. This was directly coupled to a B23.1 motor and rotated continuously in vacuum at 30 RPM.

##### **◆ Translation.**

Translation may be produced by a leadscrew and nut, wire-and-drum or rack-and-pinion mechanisms. The choice depends on the precision, length of travel, force and speed required.

Leadscrew-based translators are capable of exerting forces of kilograms with resolutions of a few microns per step. Accurate leadscrews are practical up to 300 mm long. With anti-backlash gearing between the motor and leadscrew resolution of one micron is practical. Anti-backlash nuts are not normally necessary for vertical motions. If a conventional nut is used with the leadscrew the load will be dominated by friction, especially if there is a reduction gear between the lead screw and the motor shaft which reduces the reflected load inertia. Because of the lubrication restrictions and the slow speeds of UHV mechanisms the static friction is usually much more significant than dynamic friction. The optimum material for nuts is phosphor bronze and for lead screws is stainless steel with a diamond-like coating (DLC). DLC has a very low coefficient of friction in vacuum. Burnishing or sputtering a layer of pure Molybdenum Disulphide on the leadscrew may be useful in reducing friction and wear. The typical coefficient of friction between these materials is 0.1 and typical efficiencies are 40% with ground trapezoidal threads. The gas load generated by frictional heating of the leadscrew is usually somewhat less than that of the motor. This may be reduced by changing to either a Molybdenum Disilicide or Tungsten Disilicide leadscrew coating, although this is an unusual and expensive process.

Recirculating ball nuts for vacuum use have recently become available. These offer much higher efficiencies but at very high cost. They produce a very low gas load due to their low friction and can be used to exert forces of tens of kilograms. They can be loaded with selected balls to reduce backlash to an extremely low level. The form of the associated lead screw is special and longer lengths are available.

The frictional losses in drum or rack drives are lower than in conventional leadscrew drives and considerations of inertia usually dominate. Rack and pinion drives are suitable for travel up to a few hundred millimetres and wire-and-drum mechanisms may be made several metres long. Another alternative for heavy loads is a studded stainless-steel band and matching pulleys. The repeatability and backlash of all these alternative translation drives are much worse than with screw-driven schemes.

#### ◆ **Linear guides.**

Low-cost translation mechanisms can use simple bushes running on ground stainless-steel rods. A variety of new carbon-reinforced polymer materials, such as PEEK, are suitable for the bushes. AML LCT-series translators are of this type.

'V' groove rollers and tracks and crossed-roller guides are suitable for more accurate translators. The former have the advantage of being practical to 1 metre and have minimal overall length for a given travel. Crossed-roller slides are more rigid and can support larger loads, but at higher cost. Both types have preload adjustments. 'V' rollers have smaller load-bearing surfaces and only have a rolling contact at a single point and are consequently liable to greater wear if heavily loaded. AML products of the LST and LSC series are small-dimension examples of these types of mechanisms.

#### ◆ **Reduction Gearing.**

The inertia of loads coupled by reduction gearing is reduced at the motor in proportion to the square of the reduction ratio. Where reduction gearing is used for load matching, the spur gear meshing with the motor pinion will normally dominate the load inertia and it is important to keep its diameter small. Anti-backlash gears and standard pinions should be used in the gear train to damp any resonances in the mechanism. Gears for use in UHV should be designed for low friction without lubrication and with dissimilar materials in contact to avoid cold-welding. Nitrogen ion-implantation of the rolling surfaces or complete Titanium Nitride coating of gears are effective means of achieving this and other desirable properties in all-stainless-steel gear trains.

#### ◆ **Bearings.**

Bearings for use in UHV should be unshielded and have a stainless steel cage and race. The balls should be either stainless steel coated with some other material or solid ceramic. As an alternative, all-stainless bearings having a PTFE composite component in the race (which is designed to transfer to the balls) are also suitable.

#### ◆ **Availability of components**

UHV bearings are not readily available in small quantities. AML will supply stock bearings and some other components to customers constructing their own mechanisms incorporating AML motors.

### **4:5 MAGNETIC FIELDS NEAR THE MOTOR.**

Motors should not be operated in fields of greater than 50 millitesla (500 gauss), as this will affect the performance while the field is present. Fields significantly greater than this may cause partial demagnetisation of the rotor, reducing the torque. Demagnetised motors can be restored by AML.

The leakage field of a motor is of the order of 1 millitesla (10 gauss) at 1 cm from the cylindrical surface of the motor in an axial direction and is present when the motor is not powered. Under drive an alternating component is added at the step frequency and its harmonics up to a few kHz. The field is easy to screen with Mumetal or similar high-permeability foil to below a few milligauss at the sides of the motor, but is more difficult around the projection of the shaft. Early consideration of the interaction of stray fields on nearby equipment is recommended.

## 4:6 LOW - POWER TECHNIQUES.

In the design of small mechanisms there are several factors that are not accurately known, or that have poor tolerances, for which generous allowances have to be made. The result should be a conservative design where the available torque is in excess of the requirement. Some of this excess can be exchanged for increased running time or decreased outgassing in vacuum by various techniques. Used in combination the improvement can be very significant.

Most of the 'tuning' procedures below require the motor or mechanism to be run on the bench under realistic representative operating conditions while adjusting a parameter to the point where normal stepping operation fails. Erratic stepping is easy to see; a cable tie on the motor shaft makes a useful pointer. Familiarity with remote operation and the command structure of the SMD2 is assumed.

The following techniques can be used in all applications to reduce motor power:

1. Run the motor at stepping rates between 500Hz and 2kHz, where its electromechanical efficiency is greatest, if possible.
2. Reduce the acceleration for inertia-dominated loads.
3. Reduce the phase current progressively to about 20% more than the minimum for consistent stepping. Some adjustment of the acceleration parameters may be needed.
4. Improve the heatsinking arrangements. A reduction in motor temperature decreases the winding resistance and increases its efficiency.

For applications where operation below few hundred steps per second is satisfactory, use the following technique beyond those above. The desired effect is to complete each step as quickly as possible and remove or reduce the power to the minimum as soon as possible. Each step is completed in a few milliseconds, so that the power saving is progressively greater at lower speeds. Read and ensure that you understand the complete procedure before starting.

5. Set the slew speed equal to the start speed and steadily increase them both to determine the highest speed at which the motor will start. Take care when increasing the speed through the expected resonance range because the motor may not start in that range, although it may start reliably at higher speeds.

Move the motor in single steps at the highest reliable starting speed with '+1' or '-1', followed by a delay of a few milliseconds or more. Under single step conditions the phase current is reduced after each step action is completed, in accordance with the 'h' command. This has the consequence of reducing the damping factor at the time the power is reduced, so some experimentation with the parameters is required to ensure an adequate margin of stability is obtained.

The following program segment will help to optimise the 'h' parameters. It causes the motor shaft to rotate by one complete turn slowly, so that individual steps can be observed.

B	1	Motor 1
X	s,s,1	Acceleration parameters (set as above)
h	xx,y	Set hold time and torque parameters
L	0	Loop start
+	1	One step
D	100	Delay 0.1 second
L	200	Loop 200 times (one shaft rotation)

If the load is unbalanced set the hold torque parameter to the smallest number which would hold the load stationary in any position, otherwise set it to 0. Set the hold time parameter to its maximum of 99 milliseconds. If stepping is erratic then increase the torque parameter. Reduce the hold time progressively to find the point of instability, increase the hold time parameter about 20% and then try reducing the torque parameter.

On an LST100 slide fitted with A13.2 motor reliable stepping occurred with a full-step start/stop speed of 400Hz, 2 milliseconds hold time with 0.4 amp phase current. The motor was powered for 4.5 milliseconds per step, as opposed to 52.5 milliseconds with the program default settings.

#### **4:7 POSSIBLE CAUSES OF DAMAGE TO VCSMs.**

Vacuum motors must be de-magnetised before dis-assembly and re-magnetised and cleaned after repair. For these reasons most will need to be returned to AML for repair. The notes below offer guidance on the avoidance of the most common problems and diagnostic advice.

##### **◆ Bearing damage.**

The ceramic balls in the bearings are very strong but more brittle than steel balls. Dropping the motor on its end will probably break some balls. The damage is occasionally visible and any roughness felt when rotating the shaft manually will indicate that this has happened.

##### **◆ Debris inside the motor.**

Foreign material can enter the motor via the pumping holes and gaps in the bearings. Particles of magnetic materials are particularly likely to be attracted through the pumping holes and they eventually migrate into the gap between the rotor and stator. They usually cause the rotor to stick at one or more points per revolution and can often only be felt when rotating in a specific direction. Fortunately, the larger motors have enough torque to grind them into a dust.

The main cause of this type of problem has been users modifying shafts. This can be avoided by sealing the motor inside a cleaned polyethylene bag and supervising the machining closely. Clean the projecting shaft and remove magnetic particles with a magnet before opening the bag. Remove the motor or similarly seal it if any filing or drilling of nearby components is done.

##### **◆ Overheating**

Motors which have been heated to 230°C will produce a much greater gas load thereafter, although their electromechanical performance may not be affected. Rewinding is practical provided the windings are not discoloured and the vacuum performance will be subsequently improved. If the windings are darker than a golden-brown colour the motor will not be repairable. In extreme cases the insulating material will ablate and deposit itself as a yellow powder inside the motor case and on any cool surfaces in line with the pumping holes.

Motors can overheat extremely quickly in vacuum. This is very unlikely to happen with a properly-connected SMD2 drive. Never use a drive capable of providing more than 1 amp of phase current and ensure that the drive current is removed as soon as the indicated temperature exceeds 175°C.

## 5. PROGRAMMING THE SMD2

### 5:1 THE SMD2 DEMONSTRATION PROGRAM.

The computer should be connected to the SMD2 with a cable between COM1 or COM2 and the SMD2 Remote connector. A 9 way D-Type male-to-female cable with 'straight through' connections is required and is supplied as part of the accessory kit. The SMD2 must be set to disable the checksum. All SMD2 baud rates are supported by the program but operation above 1200 is recommended. SMD2 instruments are shipped with 9600 baud set and the checksum disabled.

#### ◆ Starting the demonstration program

Switch on the SMD2 and observe the 'Motor Moving' LEDs flash five times. Rotate the Program / Manual switch to the 'Remote' position.

Run the program.

From the Options menu select COM port. Select the appropriate baud rate and COM port. Click OK

From the SMD2 menu select Command Window. Type F<sub>4</sub>

The SMD2 should respond with 'YES' or some error message. In either case you have successfully established communication with the SMD2.

Close the Command Window

#### ◆ Program Editing Screen & Command Window.

The Command Window is used mainly for executing commands directly, one at a time. The Program Editing screen is used for writing and editing programs which may then be sent down to the SMD2 and executed either by using the 'E' command from the Command Window or by selecting 'Internal' on the SMD2 Program/Manual switch.

#### ◆ Use of the Program Editing Screen.

New users should familiarise themselves with the commands by using the Program Editing Screen. The precise syntax of each command is handled by the demonstration program. Highlight the next program line number and press return to bring up a list of available commands. Select a command and the pop-up window advises on the range of permissible arguments to commands. Comments may be inserted in programs. Programs edited in this window may be downloaded to the SMD2 or saved to file.

Jump instructions contain destination line numbers. When editing programs with jump instructions these addresses may be changed by the insertion or deletion of instruction lines. The addresses affected will be changed automatically.

#### ◆ Use of the Command Window.

The principal commands used in the 'Command Window' are the 'E' and 'K' commands ( execute & terminate the program resident in SMD2 ), simple movements with '±' and the 'V' command which reports the status of the SMD2. Only directly executable commands denoted by a 'D' in the Command Summary table in Appendix B of this manual are executable from this window, for example jumps are not allowed. The syntax of each command is checked by the SMD2 after the return key is pressed and each command is responded to by a message such as 'YES', 'BUSY', or some defined response or error message.

The programming mode may be entered and terminated by using the 'P' command. Each command entered after declaring this mode is placed in the SMD2's memory and is not executed, neither is there any response from the SMD2 to each command entry. After exit of the programming mode the response is 'YES' or some error message. Only the first error found is reported. Use of this mode is not recommended until users are thoroughly familiar with the syntax and construction of SMD2 motor control programs.

## **5:2 GENERAL NOTES ON SMD2 APPLICATION PROGRAMS.**

Familiarity with the commands and the operation of stepper motors is assumed.

### **◆ SMD2 resident programs.**

Only one program may be resident in the SMD2 memory at any one time. Each downloaded program erases the previously resident program. Any resident acceleration, mini-step or hold parameters which are not overwritten by the downloaded program will remain in effect. These parameters are overwritten by the default set if the SMD2 is switched off or put into the manual mode. The current list of parameters may be interrogated by the V5 command.

The limitation of a single resident program can be overcome by the use of conditional jumps and user inputs to select different sections of a program.

### **◆ Use of the Acceleration command.**

Ensure that the acceleration parameters ( X ) are declared near the beginning of the program before any motions are commanded; otherwise a delay will occur during execution of the program, while the acceleration ramp is calculated.

If the calculation delay is not acceptable at the beginning of the program then declare the acceleration in a separate program and download and execute it immediately before the application program. This command should specify the highest slew speed which is to be used within a program since the slew rate may be changed to any smaller speed as often as required without causing the ramp to be recalculated.

### **◆ Use of the Mini-step command.**

Ensure that the mini-step parameters ( M ) are declared near the beginning of the program before any motions are commanded; otherwise a delay will occur during execution of the program, while the acceleration ramp is calculated.

If the calculation delay is not acceptable at the beginning of the program then declare the transition speeds in a separate program and download and execute it immediately before the application program.

Mini-stepping does not affect the execution time of commands resulting in motion.

Ensure that the mini-step rates are realistic. The mini-step frequency is the product of the step frequency and the step division parameter. For example, a motor moving at 100 steps per second while  $\frac{1}{4}$  - stepping moves at 400 mini-steps per second. Do not specify any mini-step frequency for an unloaded C14.1 motor of greater than about 500Hz. For this motor half-stepping should be used at less than 250Hz,  $\frac{1}{4}$ -stepping should be at less than 125Hz, etc.. Frequencies higher than these are not effective and will result in reduction of torque. The mini-step transition frequencies may need to be lower for larger motors or motors with high inertia loads.

Be aware of the interaction of the start speed and the mini-step transition speeds. If the start speed (specified in the X command) is greater than a mini-step transition speed then the mini-stepping specified for speeds below that transition will never occur.

### **◆ The Slew Rate command.**

The slew rate causes the acceleration ramp to be truncated at the speed declared in the T command. The ramp does not need to be recalculated when a new slew speed is declared, so execution is not delayed. Execution of a mini-step or acceleration command may cause the current slew speed to be altered, depending on the arguments of those commands.

#### ◆ Slow stepping and the Hold Command.

The hold command ( h ) function is intended for power reduction while taking single steps and operates after the final step of any command resulting in motion. The hold time is added to the execution time of the command.

Single steps are therefore completed in a time equal to the reciprocal of the start speed plus the hold time. By constructing a program loop with a single step and a delay the hold command may be made effective after every step for rates up to the start speed. Since the minimum multi-step slewing speed ( X ) is 10Hz this is also a method of extending the multi-stepping frequency range down to about  $15 \times 10^{-3}$ Hz with a maximum delay of 65.535 seconds. For lower step frequencies delay commands can be cascaded or placed within loops e.g.

X100,1000,20	Start at 100Hz, slew at 1kHz. Acceleration 20 steps
M200,200,200	
h0,2	Hold time 0, reduced current until next step
L0	Loop start
+1	Move 1 step clockwise
D990	Delay 990 milliseconds
L100	Loop 100 times

In this case a single step is executed in 10 milliseconds and the program executes 100 steps with a one second period.

#### ◆ Control of Two Motors.

Permanent holding torque is not possible if two motors are driven.

Each motor has its own position counter. Only the counter of the currently driven motor can be interrogated or altered by any command.

When drive is changed from one motor to another there is a delay of 100 milliseconds to allow the energy stored in the first motor to be removed. It may, therefore, be desirable to minimise the number of times the drive switches between motors.

It is good programming practice to select the motor to be driven before any motion commands are executed.

There are limitations on the differences of drive conditions of two motors driven from a single SMD2. They must be operated with the same current, since it is link-selected. There is only one set of acceleration and mini-step parameters so these must either be the same for each motor or be re-declared, with a calculation delay, every time the drive is switched to the other motor. There is also only one set of 'hold' parameters, although there is no delay when these are changed.

#### ◆ Multiple-SMD2 systems.

The most straightforward method of control is by a host computer with a serial interface to each SMD2 in the system sending individual commands in sequence. Use status commands (Vx) for determining when the SMD2s have completed commands which take significant or indeterminate times to complete.

For stand-alone applications one SMD2 can control others by connecting its user outputs to the slave SMD2 user inputs via buffers. Because the user inputs are de-bounced the outputs of the master controller should be cleared for at least 50 milliseconds to initiate an action in the slave. Incorporate a short delay in the slave program if subsequent interaction via the same input can occur within a few tens of milliseconds. Since the user outputs of an SMD2 appear to be in the 'clear' state when the instrument is switched off take care to ensure that the sequence of switching instruments on and off does not cause undesirable actions. 'Handshaking' on this type of interface is not recommended.

#### ◆ Program debugging.

Embedding Status commands (Vx) within programs can be a very useful tracing tool if there are multiple paths through the program. Alternatively, high-efficiency LEDs with a 2k2 ohm series connected to 0V may be driven from the user outputs. The LED should be buffered if the logical outputs are required for other purposes.

◆ **Emergency stops.**

The fastest way to stop a motor while executing a program is to move the Program/Manual switch to the 'OFF' position. Alternatively, send the Kill command. In either case the motor may overshoot by several steps so that the position counter content may have a small error. Switching the instrument off will not stop the motor until the energy stored in the power supply filters is depleted.

◆ **Over-temperature.**

If the motor temperature exceeds 175°C a status message is sent by the SMD2. This will appear in the left window if the SMD2 Demonstration Program is in use. Program execution is halted and drive is removed immediately. The motor may overshoot by several steps so that the position counter content may have a small error.

◆ **End of Travel.**

If an End of Travel input in the direction of travel goes low program execution is terminated, unless the H command is being executed. A status message is sent by the SMD2. This will appear in the left window if the SMD2 Demonstration Program is in use. Provided no physical end-stop is reached the position counter content remains correct.

## 6. TROUBLESHOOTING.

### ◆ **Motor does not rotate.**

Check that the motor is wired to the connector corresponding to the motor selected on the Program/Manual switch. Ensure that the "Maximum Speed" control is rotated to approximately the mid-range position.

Check that the temperature indication is less than 175°.

Press "Step" and observe the Motor Moving LED. If it flashes check the motor wiring. If it does not flash, switch the instrument off for a few seconds and then on again, observing that both "Motor Moving" LEDs flash briefly several times, then press "Step" again.

### ◆ **Temperature indication > 175°.**

Check that the thermocouple is connected to the correct socket for the motor in use.

If this error occurs as soon as a program is run ensure that the program defines which motor is in use early and before any motion is commanded.

The thermocouple circuits in the instrument are arranged to give a high temperature indication (>175°C) when the thermocouple is open-circuit. Check the continuity of the thermocouple at the connector pins. Thermocouple wire has a relatively high resistance, so some tens or hundreds of ohms may be expected. Check that the 'Motor Temperature' LEDs are extinguished if the thermocouple socket is shorted with a wire.

Normally the motor temperature will not exceed 100°C when operated in air at room temperature. Correct use of the motor thermocouple is essential to the protection of the motor in vacuum.

### ◆ **Motor buzzes but does not rotate or rotates intermittently.**

Check all motor connections, and that the electrical resistance between the pins on the motor connector is consistent with that expected for the motor in use. Motors will sometimes move even if they are wired incorrectly.

If using program control ensure that the specified start/stop speed and number of steps in the acceleration ramp are reasonable. If using manual control check that the "Maximum Speed" control is not set too high.

### ◆ **Motor stops and buzzes at some speeds or locations.**

Check all motor connections, and that the electrical resistance between the pins on the motor connector is consistent with that expected for the motor in use. Motors will sometimes move even if they are wired incorrectly.

If the motor is wired correctly this may be due to resonances, refer to section 4:3 for general advice.

### ◆ **Motor stops and buzzes at high speeds.**

The maximum speeds AML motors are capable of are less than the maximum that the SMD2 can drive. The maximum speed of a motor will be reduced by any loading. The maximum speed which can be achieved will be increased by increasing the number of steps in the acceleration ramp.

### ◆ **Motor direction reverses at some speeds.**

Check all motor connections, and that the electrical resistance between the pins on the motor connector is consistent with that expected for the motor in use. Motors will sometimes move even if they are wired incorrectly.

If the motor is wired correctly this may be due to resonances, refer to section 4:3 for general advice.

### ◆ **Motor rotation reversed.**

Correctly wired motors and drives should cause the motor to rotate in the direction specified when viewed from the flange end (B23) or the mounting stud end (B14.1). The direction of rotation may be reversed by exchanging the connections to **one** phase.

◆ **No communication with host computer.**

Check that the "Program/Manual" switch is set to the Remote position.

Ensure that the "Motor Moving" LEDs flash five times after the SMD2 is switched on.

If any program other than the AML demonstration program SMD2W.EXE is in use then load SMD2W.EXE and try again.

Check that the correct communications port is being used.

Check the Remote cable. This is a 9-way 'D' type with male and female connectors, and 'straight through' connections.

Check that the Baud rate, parity and number of start and stop bits are consistent in the computer and SMD2.

◆ **Program execution has delays not programmed.**

Before execution of a downloaded program SMD2 has to calculate the duration of individual steps in the acceleration ramp, which can take up to a second. If other ramps or mini-step transition speeds are specified part-way through a program then execution is delayed while they are calculated. This is not recommended.

Sequences of motions execute acceleration and retardation ramps. The motor may stop briefly between contiguous motions, depending on the start speed defined. If a non-zero hold time is defined then the motor will stop for the hold period.

◆ **Home command never finishes.**

Ensure that the EOT signal for the motor in use falls then rises during execution.

◆ **Problems in programs with loops and jumps.**

Check for jumps into or out of loops.

If using User Inputs check the wiring and switching.

◆ **Single stepping is erratic.**

The start speed may be too high. The hold time may be too low. The hold current may be too low.

## **APPENDIX A**

### **CONNECTORS**

IN THE SECTIONS BELOW THE MATING CONNECTORS ON THE CABLES ARE DESCRIBED.

ALL THE CONNECTORS REQUIRED ARE INCLUDED IN THE ACCESSORY KIT SUPPLIED WITH THE INSTRUMENT.

#### **◆ A.1 Mains connector.**

This is a female IEC CEE22 type and is normally supplied with the instrument in the accessory pack as a moulded lead with integral 13 Amp. British domestic-style plug. Continental or North-American pattern connectors may be supplied as alternatives in appropriate cases.

If you need to change from the British to an alternative style of connector take care to make the connections correctly to ensure operator safety. The wires are colour-coded as follows:-

Brown	Line
Blue	Neutral
Green and yellow	Earth

#### **◆ A.2 Motor Connectors.**

These are supplied with the instrument in the accessory pack, as two kits of parts. Each is a 4 pin ITT "Trident" rectangular male type, available from Farnell.

Cable mounting plug	TST04PA00
Hood	TST04AH00
Crimp pin (4 required)	T2P16MCILZ

Pin connections are:

Connector pin	Motor Phase
1	A
2	A
3	B
4	B

#### **◆ A.3 Remote connector.**

This is a 9 way "D" type female connector. The pin numbering has been chosen so that a 9-way 'straight through' male-to-female cable will be satisfactory for use with a PC and The SMD2 Demonstration Program and a suitable cable is provided with the instrument for this purpose.

Used pin connections and signal names are:

2	Received data
3	Transmitted data
5	Signal ground

The Received data line is connected to the Transmitted data from the computer and the Transmitted data is connected to the received data line at the computer. If users write their own application programs using BIOS routines it will be necessary to link pins 4 to 6 at one end of the cable.

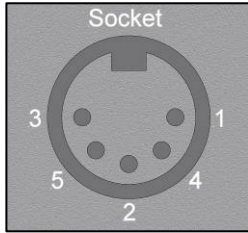
#### **◆ A.4 Thermocouple connector.**

This is a miniature flat pin K type connector, for example Labfacility type FMTC-K-M.

◆ **A.5 Limits connector.**

This is a 5-pin DIN audio connector, types with or without latches are suitable. The use of these inputs is explained in section 3:8

Pin connections as viewed on the rear panel are:

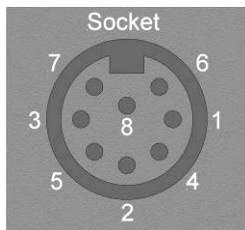


Pin 2	EOT +1 (motor 1)
4	EOT - 1 (motor 1)
1	EOT +2 (motor 2)
3	EOT - 2 (motor 2)
5	Logic ground

◆ **A.6 User connector**

This is an 8-pin DIN audio connector, types with or without latches are suitable. The use of these inputs and outputs is explained in section 3:8

Pin connections as viewed on the rear panel are:



Pin 1	User output 3
2	User output 2
3	User output 1
4	User input 3
5	User input 2
6	User input 1
7	Logic ground
8	Not used



### ◆ B.3 Direct and Programming commands.

An SMD2 program is a list of commands that will be executed either by turning the front panel control to 'INTERNAL' or by sending the **Execute** command. A program can contain up to 1000 bytes, and by using commands such as **Loop**, **Jump**, **Wait** and **Until** can perform repetitive tasks and respond to external inputs. While a program is being executed, the only commands that will be accepted from the remote computer are **K** and **Z**, which terminate the program execution. Any other command will receive a **Busy** response. Where possible, commands have been implemented both under direct control and program control. However, certain commands are applicable to one operating mode only. In the following command summary, the command type is shown by **D**, **P** or both.

A program in the SMD2 memory is retained after powering-down the machine, as is the position information for each motor.

### ◆ B.4 SMD2 positional information.

The SMD2 maintains a step position counter for each motor that may have a value between -8,388,608 and +8,388,607. These values are contiguous, i.e. on reaching +8,388,607 the counter value will next become -8,388,608, -8,388,607 etc. A positive increment in the counter corresponds to travel in the clockwise direction.

### ◆ B.5 Command Summary.

Command and Arguments		Type	Description
±	xxxxxx	DP	Move in specified direction x steps (1 - 999999) e.g. <b>+2400</b> ↵
A	x	DP	Set user output (1, 2 or 3) e.g. <b>A3</b> ↵
B	x	DP	Select motor (1 or 2) e.g. <b>B1</b> ↵ Always use this command near the beginning of a program, and at other times, as required.
b		D	Bake the selected motor. Both phases are driven when the indicated temperature <175°C. The motor moves to approximately the half-step position when driven and back when not. Terminate with <b>K</b> .
C	x	DP	Clear user output (1, 2 or 3) e.g. <b>C1</b> ↵
D	xxxxx	DP	Delay xxxxx milliseconds (1 - 65535) e.g. <b>D100</b> ↵
E		D	Execute the program in RAM
F		D	Feedback status Response: <b>Y</b> or <b>B</b> or <b>Ex</b> . ( <b>Yes</b> or <b>Busy</b> or <b>Error message</b> )
f	±xxxxxxx	DP	Preset position counter e.g. <b>f2000828</b> ↵
G	±xxxxxxx	DP	Go to specified position e.g. <b>G-9600</b> ↵
g	±	D	Move indefinitely in specified direction e.g. <b>g+</b> ↵
g	±x↕	DP	Move in specified direction until user input (x = 1, 2 or 3) is low (L) or high (H).

			e.g. <b>g-3H</b> ↵
H	±	DP	Find Home. The motor is moved until the EOT input goes low. The motor is retarded to a stop and the direction of travel is reversed. When a position close to the location where the EOT transition occurred is reached the motor is stepped at <30 steps per second until EOT goes high and then for a further eight steps. The position counter would normally be set to zero after executing this command. e.g. <b>H</b> ↵
h	xx,y	DP	Set hold time and torque parameters. The phase current is reduced xx milliseconds (0 to 99) after the final step of any movement has been completed. The hold torque parameter, y (0 to 7) specifies the reduction of the phase current after that period. The reduced phase current is $\sin(y/7 \times 90)^\circ$ x the current set by the links, approximately. The default parameters are 50,0. The default values are restored only when the instrument is switched off. The current settings of all dynamic parameters may be interrogated by the <b>V5</b> command. e.g. <b>h10,2</b> ↵ N.B. The hold current is maintained permanently (but may be zero).
l	x	DP	Initialise both position counters to zero (x = 1), clear all user outputs (x = 2) or both (x = 3). e.g. <b>l3</b> ↵
J	xxx,y↕	P	Jump to instruction number xxx (1 to N) if user input y (1, 2 or 3) is high (H) or low (L). e.g. <b>J1,24H</b> ↵
j	xxx	P	Jump to instruction number xxx (1 to N). e.g. <b>j102</b> ↵
K		DP	Kill program executing. This command can be sent by the host computer to terminate the program, or be embedded in the program. If a motor is moving when the command is received via the serial interface the motor is stopped immediately and not retarded, so that the content position counter may have an error.
L	0	P	Loop Start. This command must be followed by a Lxxx command defining the number of times the commands between them are to be executed. e.g. <b>L0</b> ↵ <b>+100</b> ↵ <b>D5</b> ↵ <b>L5</b> ↵
L	xxx	P	Execute program from the preceding 'L0' command xxx times (1 to 255). Loops may be nested up to 10 levels. Jumping (j or J) into or out of loops is not recommended.
M	b4,b2,b1	DP	Set the minimum step rate for the specified step divisions. e.g. <b>M50,100,200</b> ↵ means that the motor executes 1/8 steps below 50Hz, 1/4 steps at or over 50Hz, 1/2 steps over 100Hz and full steps over 200Hz stepping rates. The default transition speeds are 100, 200, 500 and are restored when the instrument is switched on or switched to manual control. The SMD2 program calculates a new acceleration table when this command is executed: this may take several seconds. The current settings of all dynamic parameters may be interrogated by the <b>V5</b> command. See sections <b>3:7</b> and <b>4:3</b> for an explanation of mini-stepping.
P		D	Enter / terminate programming mode. The commands that follow a P command are not executed, but are placed in the SMD2 RAM. Programming is terminated by another 'P' command. Execute the program with the 'E' command or by switching to 'Internal' on the Program / Manual switch.
Q		D	List program in RAM. The program is 'echoed' back in the downloaded format.

			The list is terminated by 'Y' or 'E3,xxx' if an error was found in the program. Only the first error found is reported.
T	xxxx	DP	Set the current slew speed in steps per second (10 - 6000). The allowed range is restricted to that specified in the most recently declared 'X' command. This command does not cause the acceleration ramp to be recalculated. The current slew speed may be changed by a subsequent 'X' or 'M' command. e.g. <b>T3000</b> . The current settings of all dynamic parameters may be interrogated by the <b>V5</b> command.
U	x⇄	P	Repeat program from start until user input x (1 to 3) is high (H) or low (L). e.g. <b>U2L</b> .
V	1	DP	Send position counter. Response: <b>V±xxxxxxx</b>
V	2	DP	Send user I/O status. Response: <b>Vxx</b> Where the first digit indicates the binary status of the inputs and the second digit the outputs. The status is the sum of the values assigned to each input or output line. I/O 3 = 4 when set, I/O 2 = 2 and I/O 1 = 1. All I/O = 0 when cleared.
V	3	DP	Send temperature status. Response: <b>V&lt;100C or V100C or V125C or V150C or V175C</b> As indicated on the SMD2 front panel.
V	4	DP	Send software version number. Typical Response: <b>V1.72</b>
V	5	DP	Send dynamic parameters. Response: <b>X: 100,200,100</b> <b>T: 2000</b> <b>M: 100,200,500</b> <b>h: 50,0</b> <b>N.B.</b> The stored values of these parameters are modified when X, T, M and h commands are <b>executed</b> , and not when programs containing them are downloaded.
W	x⇄	P	Wait until user input x (1, 2 or 3) is low (L) or high (H). e.g. <b>W3</b> .
X	ssss, tttt, rrrr	DP	Acceleration / retardation parameters command. Sets the start / stop speed s ( 10 to 6000 ) the slew speed t ( 10 to 6000 ) and the number of steps in the ramp r ( 1-1599 ). t must be greater than s. The SMD2 program calculates a new acceleration table when this command is executed: this may take several seconds. The default parameters are 100, 2000, 100 and are restored when the instrument is switched on. The current settings of all dynamic parameters may be interrogated by the <b>V5</b> command.  Refer to sections <b>3:5</b> , <b>4:3</b> and <b>5:2</b> for more explanation and typical uses of this command.
Z		D	Smooth stop through retardation ramp

#### **◆ B.6 Error Codes**

E1	Parity or checksum error
E2	Command argument out of limit or not requested
E3,xxx	Error in downloaded program (xxx = line number)
E4	Command not executable
E5	Temperature exceeded 175°C
E7	End of travel input at 'low'
E8	Loop nesting too deep
E9	Program too large

**END.**