⚠ READ FULLY BEFORE INSTALLATION

UHV Compatible Stepper Motors User Instructions.
Issue 3.0

SUMMARY AND WARNINGS

The mounting screws are fitted with metered torque. **Do not disturb.** Do not drop, demagnetise, disassemble, modify, touch or overheat the motor or allow particles to enter the bearings or pumping ports.

The published performance was obtained using an SMD210 drive operating with standard settings for step division. SMD210 is a bipolar, switch-mode, current-regulating drive, optimised for use with vacuum stepper motors. Different drives will produce different speed/torque curves. Drives capable of producing a total phase current of more than 1A RSS (root sum of squares) may damage the insulation, even if the current is claimed to be adjustable

Design mechanisms with balanced rotating loads and/or friction to maintain position with reduced or zero phase current for minimum outgassing. Use step division only to smooth transitions: increase resolution by reduction gearing.

Ensure ice cannot form in the motor if testing at low temperature in air. Avoid thermal shocks e.g. plunging in liquid nitrogen.

Motors are supplied pre-baked at HV. They will adsorb water in storage and handling. A 24-hour self-bake by SMD210, with an adequate pump, will achieve UHV-compatibility.

INSTALLATION

Use the extended screws for mounting but do not attempt to remove them. Take normal vacuum precautions, avoid creating trapped volumes when mounting the motor and obstruct as few as possible of the pumping holes in the end faces. The location spigot projecting from the face of the motor is accurately concentric with the shaft and intended for precise location in a recess.

LOAD CONNECTION

The preferred method of coupling a load to the shaft is by a set-screw or collet fixing. AML do not recommend users modify shafts.

DRIVE REQUIREMENTS

These motors are specifically designed for use in conjunction with the AML SMD210 current-regulated switch-mode drive. If another drive is used it must be a bipolar 2-phase drive and capable of providing a selection of well-regulated currents of less than or equal to 1 Amp per phase. If the drive can provide simultaneous currents to both phases (for step division) then the root of the sum of the squares of the phase currents must never exceed 1 Amp.

The source voltage of alternative drives should be greater than 45V. Lower voltages will result in loss of torque at higher stepping rates. Voltages over 100V are not suitable for vacuum use. Switching frequencies should not exceed 22kHz and peak-to-peak switching ripple on the phase current should not exceed 15%.

The drive current should be reduced or removed when the motor is stopped. For this reason attempts to improve angular resolution by step division are not recommended,

Refer to the current motor data sheet for electrical, mechanical and thermal characteristics.

OVER-TEMPERATURE PROTECTION

All AML motors are provided with a K-type Thermocouple (Chromel/Alumel) embedded between adjacent windings, which must be used for over-temperature protection. The drive current must be removed when the indicated temperature of the windings reaches 175°C. The SMD210 drive provides this function. Simple on/off temperature controllers may be used but ensure that the adverse electrical noise environment within the motor under drive does not affect the temperature measurement.

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.

The 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.

AML supply an 18-way non-bakeable, screened external lead, MLF18NBL for direct connection to SMD210 drives. The use of this lead ensures compliance with the EU EMC Directive. Air-side connectors, MLF18AC are available for users wishing to make their own cables.

MLF18VCF   MLF18F

MLF18L
or
MLF18NBL
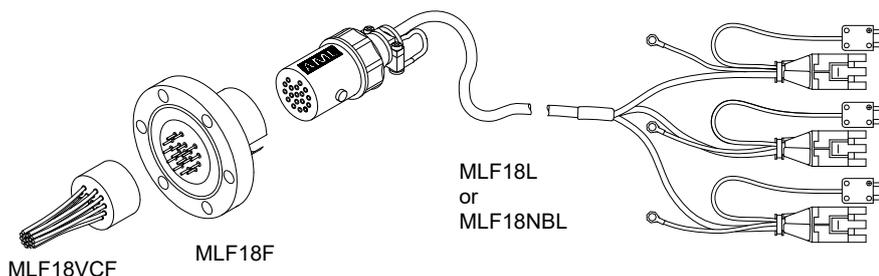
IDENTIFYING AND CONNECTING THE LEADS

The leadout wires are self-coloured polyimide film-wrapped, silver-plated OFHC copper and each is fitted with a 1.5mm crimp socket terminal. They are supplied fitted with UHV compatible coloured glass beads for identification. Leadout wires are supplied 1.5 metres long but can be shortened if required. For replacement crimp terminals use ITT Cannon part number 192990-0090.

Motor windings in series — K-Thermocouple
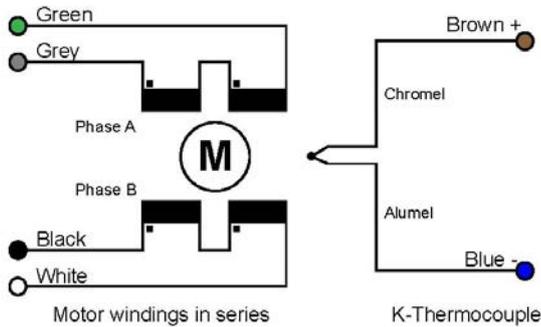
If the identification beads have been removed then use the following procedure. An ohmmeter with resolution down to about 1 ohm is required to identify the two phase windings: most inexpensive multimeters are suitable.

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 Alumel wire may be identified with a magnet, 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 though 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.

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.

	Colour	Motor 1	Motor 2	Motor 3
Phase A+	Green	1	7	13
Phase A-	Grey	3	9	15
Phase B+	Black	2	8	14
Phase B–	White	4	10	16
Thermocouple +	Brown	5	11	17
Thermocouple -	Blue	6	12	18

PREPARATION OF MOTOR LEADOUT 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.

REVERSAL OF ROTATION

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!

TROUBLESHOOTING

If the motor rotates at the wrong speed, frequently changes direction or has low torque this is probably due to one of the phase connections being open-circuit.

If the SMD210 indicates that the motor temperature exceeds 175° when the motor is not hot then a connection to the thermocouple is open-circuit.

GENERAL OPERATION CONSIDERATIONS FOR UHV-COMPATIBLE MOTORS

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 the operator can see and hear that the motor is stepping.

Temperature rise and run times

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

The motor should be run at the minimum phase current consistent with the requirements of the load. This will reduce the maximum temperature of the motor and outgassing from the motor. Resistive heating losses in the winding resistance, R, are given by I^2R. The winding resistance is approximately proportional to absolute temperature so even small reductions in phase current, I, produce worthwhile reductions in temperature rise and outgassing. For phase currents down to about 50% of maximum the output torque is reduced roughly in proportion to phase current.

The minimum practical phase current is determined by the load friction and inertia, and the required acceleration and maximum speed. It is best found by experiment. A reasonable margin of safety should be allowed for any expected increase in load friction, which might occur after bakeout.

Vacuum stepper motors achieve maximum efficiency at full-step rates between 500 and 2kHz.

The SMD210 allows the reduction of the phase current dynamically during each step at low step rates, with separate control of initial and final currents and transition times. Use of this technique can dramatically reduce the power dissipated in some applications. The provision of heatsinking will improve the performance.

Irreversible deterioration of the winding insulation will occur at 230°C and the motor will subsequently produce large amounts of gas, even at lower temperatures.

Outgassing and Bakeout

A newly-installed motor will outgas in vacuum, mainly due to water-vapour retention in the polyimide. As this material is micro-porous 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° C is required for operation at UHV. Motors are typically operated at some distance from the chamber walls where the bakeout temperature is most often controlled. The motors will not reach a high enough temperature in such cases, and it may be increased by using the windings as heating elements. The SMD210 includes a bake program, which automatically controls the motor temperature at 175°C by applying phase current. Maintain the motor temperature above that of the rest of the system during cooling, 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 controlled temperature during bakeout solely by self-heating.

The outgassing rate for well-baked motors installed on a typical mechanism and run below 120°C winding temperature is in the order of 10^{-8} millibar litres sec^{-1}. This represents high duty-cycle operation at rated phase current for size 14, 17, 35 & 42 motors. The gas species are H_2 (90%) and CO (10%) and originate mainly from the windings and laminations. As a rule of thumb, an additional 100 litres per second of pumping capacity per motor will be required for UHV. This gas load is insignificant at HV and higher pressures.

Rotation Mechanisms - Holding Torque

Design rotation mechanisms with balanced loads to reduce or eliminate the necessity for holding torque. If the torque imposed on the motor by any imbalance of the load is less than the detent torque then the motor will hold position without power. The gearing required to achieve the desired angular resolution or to match the load inertia will increase the effect of detent torque and also add friction.

Translation Mechanisms - Shaft end-float

The motor shaft has a compression spring, which pushes the shaft toward the mounting-face of the motor. The amount of end-float is 100 to 200µm for D35.1 and 200 to 400µm for D42 motors. The spring is fully exercised with an axial force of 3kg toward the rear of the motor. For linear mechanisms where the motor is directly coupled to a leadscrew use gravity and/or apply an opposite axial pre-load to avoid adding end-float to backlash.

There may be a significant static friction component added to the compression spring force, which may give the impression that the end-float is less or that the spring is stiffer than specified. This should not be relied on to reduce backlash, as repeatedly exercising the end-float will reduce the static friction and may also produce particles.

Resonances

Stepper motors are classic second-order systems and have one or more natural resonant frequencies. Operation at step rates around these frequencies will excite the resonances, resulting in very low output torques and erratic stepping. The resonant frequency is modified by the friction and inertia of the load, the temperature of the motor and by the characteristics of the drive and therefore cannot be stated with any precision. Fortunately, coupling a load normally reduces the resonant frequencies, which for unloaded AML motors occur below 300Hz. The drive circuits of the SMD210 are optimised to produce heavy damping of mechanical oscillations in the motors.

The simplest method of controlling resonances is to avoid operation of the motor close to the resonant frequencies. It is almost always possible to start a motor at rates in excess of 400Hz if the load inertia is matched as described in the next section. 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 slower speeds than this, the step division feature of the SMD210 (ministep) helps by effectively increasing the stepping rate by the step division factor and reducing the amplitude of the step transients which excite the resonances. In particularly difficult cases modifying the step frequencies at which transitions of the step divisions (ministep modes) occur can be useful.

Load inertia and reduction gearing

The load inertia coupled to the motor shaft should ideally be comparable to the rotor inertia of the motor where accurate position control is required. The load inertia can be very much larger for speed control applications where some slip of absolute position is unimportant. 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. Loosely-coupled loads may give rise to additional resonances at higher frequencies: these can usually be damped by substituting either anti-backlash or helical gears in the gear train or arranging additional friction in the train.

Magnetic fields near the motor

It is recommended that motors are not 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, permanently affecting the performance.

The leakage field of a motor is less than 100 microtesla (1 gauss) at 1 cm from the surface of the motor and in an axial direction. It is due to the permanent magnet in the rotor and is present when the motor is stationary and unpowered. Under drive an alternating component is added at the fundamental and harmonics of step frequency, up to a few kHz. This field is easy to screen at the sides and non-shaft end of the motor, but more difficult at the shaft end because of the projection of the shaft. Early consideration of the interaction of stray fields on nearby equipment is recommended.