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.

1. ## Temperature Rise and Run Times

   The maximum recommended operating temperature of AML motors is 190 °C, 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 I2R. 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 Hz and 2 kHz.
   The SMD3 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.

2. **Outgassing and Bakeout**

A newly installed motor will outgas in vacuum, mainly due to water-vapour retention in the 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 °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 SMD3 includes a bake program, which automatically controls the motor temperature at 200 °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 35, 42 & 57 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.

3. **Rotating 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.

4. **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 200 µm for D35.1 and 200 to 400 µm for D42 motors. The spring is fully exercised with an axial force of 3 kg 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.

5. 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 300 Hz. The drive circuits of the SMD3 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 400 Hz 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 (micro-stepping) 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 to micro-stepping occurs can be useful.

6. 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.

7. ## 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