APPLICATION NOTE No 11, Issue F, 2015

D-SERIES MOTOR VACUUM PERFORMANCE

Experimental determination.

The motor was suspended in a 400 litre sec^{-1} (nominal) ion-pumped UHV system equipped with a Hiden (HAL1000) RGA and AML Bayard-Alpert (AIG17G + NGC2D) ionisation gauges and controllers. The motor was driven by an AML SMD210 drive. The system was pumped down and baked at 200°C for 24 hours. During the period in which the system cooled close to ambient temperature the motor was run at 1 Amp phase current using the SMD210 'Bake' program. This program controls the motor winding temperature with a setpoint of 175° C, and a hysteresis of around 20°, using drive current to self-heat both windings. The motor was then switched off to allow the system to attain its base pressure of 4 x 10^{-10} millibar.

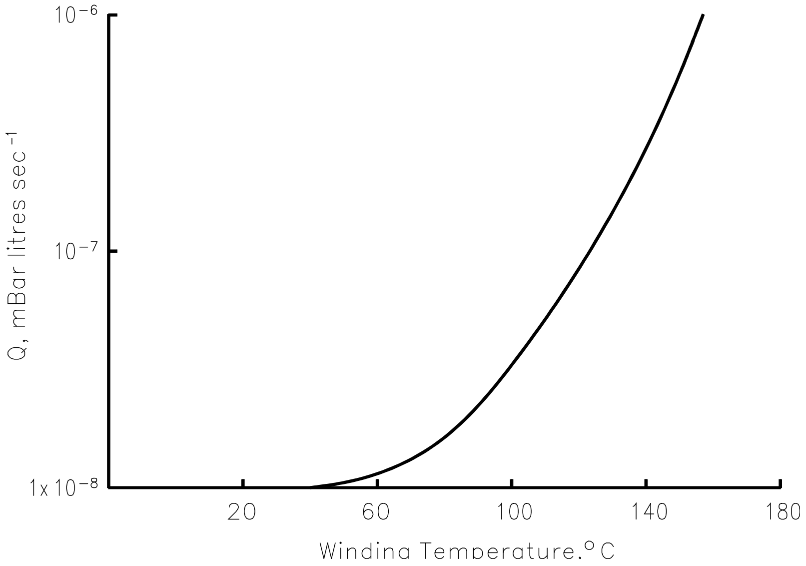
In order to ensure that the motor was adequately degassed the SMD210 'Bake' program was run again. After an initial rapid rise in temperature this produced a temperature oscillation with an initial period of about 40 seconds, with a synchronous oscillation in the system pressure as the drive power was switched on and off. The excursions in pressure and the steady pressure on which they were superposed reduced to a steady minimum over a few hours, showing that the motor was substantially outgassed.

The motor was then run continuously for long periods at various smaller phase currents, in order to allow its temperature to stabilise at a number of points in the range between 50 and 175°C. The total and partial pressures were then measured.

Results.

The only significant outgassing products were Hydrogen (90%) and Carbon Monoxide (10%). All other peaks in the spectrum were below 1% of the Hydrogen peak height and were characteristic of the system and independent of the motor temperature.

The derived outgassing rates for the D42.1 motor with respect to temperature are shown in the graph below. The outgassing rates of the three sizes of motors were found to be very similar, with a 2:1 spread. Since this variation is well within the measurement errors and the variation from unit-to-unit, the curve may be used for all types.



From the outgassing rate curve it can readily be seen that operation of a motor at the lowest possible temperature will be beneficial in reducing the gas load it produces. For example, operation at 100°C will produce about 10% of the gas compared to operation at 140°C. Selection of the largest possible motor for a given power requirement will result in the lowest temperature rise.

Estimating the gas load and pump capacity.

A simple application of the rate data will give a very conservative estimate of either the required pumping rate, **S**, or the ultimate pressure, $\mathbf{P_u}$, for a given pump.

1. Select the minimum motor phase current which will provide the required motor torque and speed.

2. Use the winding temperature graph on the last page of this note to predict the approximate temperature rise.

3. Use the outgassing rate curve to estimate the gas load, **Q**.

4. Derive the result required from **Q = S. Pu**

Improving the vacuum performance.

In practical situations the temperature rise is somewhat smaller than predicted, giving a substantially smaller gas load. An appreciation of the factors affecting temperature rise allows users to tailor their applications for minimum outgassing. The relative importance of these factors depends on the type of application: those which require continuous operation of the motor being the most challenging.

Since the curves of motor temperature were derived with no heat-sinking, they are conservative in predicting temperature rise in real applications. It is very easy to reduce equilibrium temperatures of 100°C and over by 30 to 40° by relatively simple means, such as mounting the motor on a plate or mechanism. Additional heat-sinking has little effect on the curves before some tens of minutes heating, because the transient thermal impedance of the motor is not reduced.

The temperature curves were obtained with both motor phases being driven with a steady direct current, which is only representative of low-frequency stepping. Since the motor windings are inductive, it takes a finite time to establish a current in them and this delay begins to become significant at stepping rates of a few hundred Hertz. The effect is that the average winding current is progressively less than the set current at increasing speeds. This means that a motor running at faster than a few hundred steps per second reaches a lower final temperature than predicted. Beyond about 2kHz the reduction is dramatic, however, the available torque is much reduced.

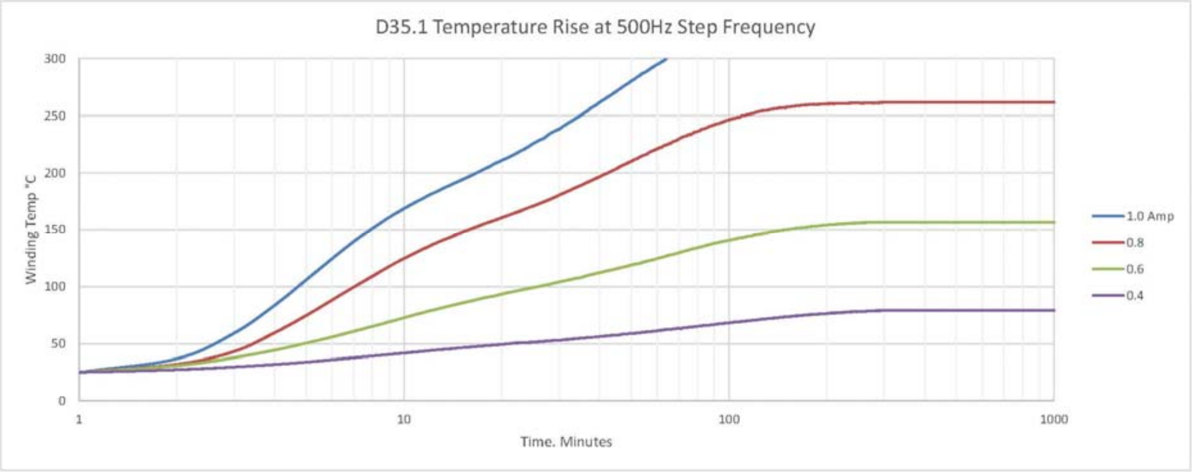
Wherever possible applications should be designed so that the load may be held in position by the detent torque of the motor, so that power may be removed between periods of motion.

The power output of the motor is proportional to the product of the output torque and the step frequency. At low step frequencies each step is taken in a few milliseconds, after which no useful work is done, although power continues to be dissipated. The effect of this is that the electromechanical efficiency of the motor increases with speed until other factors reduce it, reaching a peak between about 500Hz to 1kHz. Operation in this range of speeds will, therefore, minimise the temperature rise for a given power output. Where gearing is involved, as in most mechanisms, this is in any case the optimum range of speeds for mechanical reasons.

For slow speed applications the SMD210 drive allows the phase current to be reduced after each step. This increases the efficiency at low speeds.

For many applications motion is intermittent, with relatively short periods of motion and long periods of rest (low duty-cycle). Provided the temperature rise during each cycle is small it is valid to multiply the phase current by the duty-cycle to estimate an effective phase current. If interpolation between the curves is required, it should be remembered that the heat dissipated in the motor is proportional to the square of the phase current.

D35.1 Motor



D42.1 Motor