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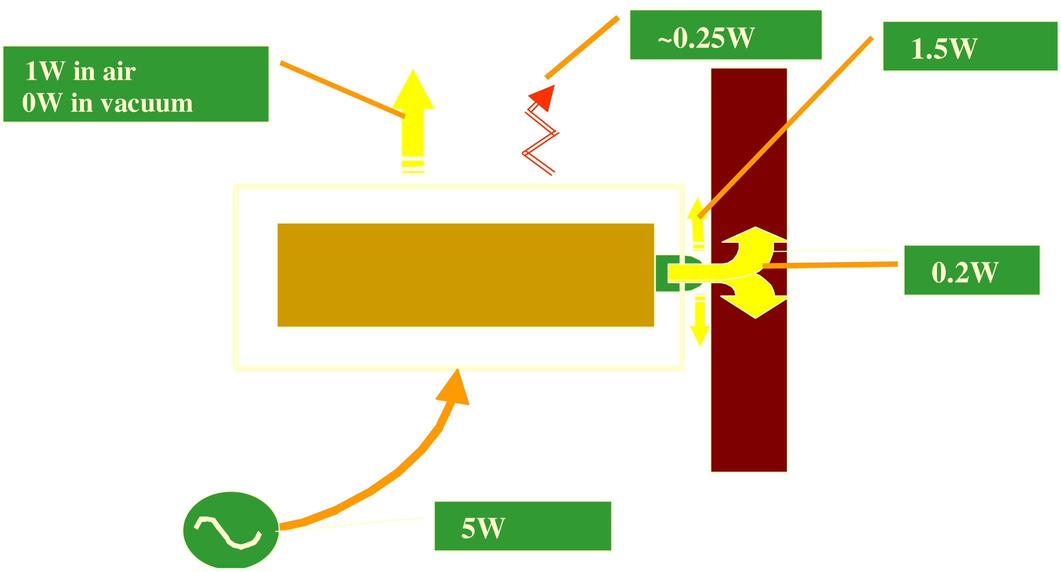
NM motors operation in a Vacuum Environment

Introduction

Nanomotion motors can facilitate high duty cycle and heavy-duty operation if the motor's Envelope Of performance (EOP) is adhered. The present document summarizes key issues related to the motor heat dissipation and the good practice for vacuum operation.

In an ambient environment, the motor is cooled mainly by the surrounding air (convection). In vacuum, there is no convection, and it is important to make sure that the motor does not overheat.

Nanomotion's high-resolution vacuum motors heat dissipation mechanisms are depicted in the following drawing:



The heat is dissipated via

- Radiation to the motor case (0.25 W).
- Conduction through the finger tip (0.2 + 1.5 w).

To assure effective dissipation, the motor base and the ceramic drive strip base must both be thermally designed to dissipate 2W each (per motor element), with a maximal temperature rise of 15°C.

The temperature of all parts in contact with the motor and with the ceramic drive strip should not exceed 40°C.

The following graph and table are designed to help the user determine the correct performance Envelope Of Performanc so as to not overheat and damage the motor. The curves are for HR-8 but could be scaled to other motors (refer to the specific motor manual).

The values given are absolute maximums. To work at these levels, one must ensure that:

- Heat dissipates effectively through the fingers (see *Example* 4:

In some cases the motors are exposed to a single job. In this case it is possible to fine-tune the EOP model to the specific job. An example is shown below,

However it is highly recommended to consult NM in cases where the conservative EOP is exceeded!!

The example is:

- Typical move: 25 mm
- Horizontal operation
- Max. Speed: 150 mm/s
- Accel: 1 m/s^2
- Moving mass: 5 Kg.
- Friction 6 N (including the x5 safety margin mentioned above)

Analysis

- The max force during acceleration is thus 11 N.
- During constant velocity the required force is 6 N.
- For the typical move of 25 mm, 0.15 sec will be the acceleration, which is about 47% of the step time.
- During deceleration velocity will gradually decrease to zero maintaining 6 N force, this is also 47% of the step time.
- 0.016 sec will be the travel @ 150 mm/sec.
- Total move time is 0.316 sec.

Going to the force-velocity curve, we can see that:

- During acceleration we are just below curve "f"
- During constant velocity just below curve "e"
- During deceleration we move from the previous one to curve "a" and below. We shall assume here curve "c" as an average.

The effective duty cycle for this typical move is:

Effective Duty Cycle = [150 DC ("f") + 16 DC ("e") + 150 DC ("c")]/316

Taking from the attached the DC:

DC ("f") = 9%
DC ("e") = 13%
DC ("c") = 26%

We get:

Effective Duty Cycle = 17%

Obviously adding a motor will relax the force requirement per motor and the operation will be on lower curves.

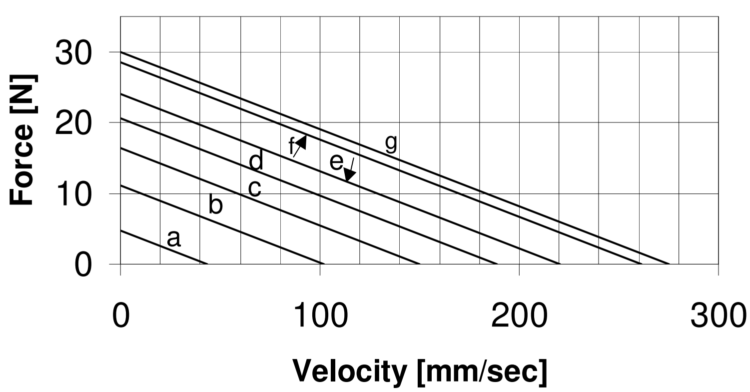
- Guidelines, *Mounting*

If the motor is not pressed firmly against the stage and the motor base, the heat dissipation capability will be reduced.

Mount the motor pressed firmly against the stage and the motor base assuring good thermal conduction (see *Appendix One: Mounting the Motor).*

- Run-In and
- Heat dissipates effectively through the base (see *Recommendations, Base*)
- Heat dissipates effectively through the stage and bearings (see *Recommendations, Stage* and *Bearings*)

Force Vs. Velocity at various work regimes



	25^0 C		50^0 C		Vacuum 25 C	
Curve	Duty Cycle	max.continuous operation time	Duty Cycle	max.continuous operation time	Duty Cycle	max.continuous operation time
a	100%	-	100%	-	100%	-
b	100%	-	100%	-	44%	184
c	100%	-	92%	137	26%	107
d	100%	-	62%	93	17%	72
e	78%	87 seconds	47%	70	13%	55
f	56%	62 seconds	33%	50	9%	39
g	50%	56 seconds	30%	45	8%	35

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How to select the operating curve?

The selection is in accordance to the dynamic requirements of the application. The application requires:

- Acceleration – a [m/sec^2]
- Maximum velocity – Vmax [m/sec]
- Inclination – α [deg.]
- Moving mass – m [kg]
- Friction – f [N] (note that the friction in vacuum is higher than in ambient environment hence take f as 5 times the value in ambient!!!)

The max force required is - Fmax:

$$F_{max} = m \cdot a + f + m \cdot g \cdot \mathrm{Sin}\,(\alpha)$$

The curve to be selected is the one ABOVE the crossing point of Fmax and Vmax in the graphs above.

Example 1:

Accelerate a body of 1.5 kg, up hill on a slope of 30 degrees to a max velocity of 100 [mm/sec] in an acceleration of 0.2g. The friction force in ambient was measured to be 1 [N]

We get:

$$F_{max} = 1.5 \cdot 2 + 5 \cdot 1 + 1.5 \cdot 10 \cdot \mathrm{Sin}(30) = 15.5 \text{ [N]}$$

and

$$V_{max} = 100 \text{ [mm/sec]}$$

The curve just above this maximal point is curve “f” and the values in the table above, for curve “f”, should not be exceeded.

Note – if the vacuum environment exceeds 25 degrees C, consult NM on the EOP.

Example 2:

Operate a motor in an XY set up where Y is on top of X.

X – See example 1.
Y - Move 2 curves up. For example 1, use curve “g”.

Example 3:

Same as example 1 on a non-metallic stage.

Move 2 curves up. For example 1, use curve “g”.

Example 4:
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However it is highly recommended to consult NM in cases where the conservative EOP is exceeded!!

The example is:

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We get:
Effective Duty Cycle = 17%

Obviously adding a motor will relax the force requirement per motor and the operation will be on lower curves.

Guidelines

The following guidelines are necessary conditions that must be adhered to avoid overheating and ensure trouble free functioning:

Mounting

If the motor is not pressed firmly against the stage and the motor base, the heat dissipation capability will be reduced.

Mount the motor pressed firmly against the stage and the motor base assuring good thermal conduction (see *Appendix One: Mounting the Motor).*

Run-In

Before run-in, the ceramic finger is in minimal contact with the stage. Run-in shapes the finger correctly, assuring good contact and thus allowing heat to dissipate from the motor.

1. **Before** placing the motor in the vacuum, perform a run-in for 4 hours (50% duty cycle; 50% command).
2. When the run-in is completed, carefully clean the ceramic strip with a vacuum and clean room compatible cloth soaked in IPA, **without dismounting or retracting the motor**.

When dismounting and remounting the motors in the future, steps 1 and 2 should be followed again, **before** replacing the motor in the vacuum.

Inherent Brake Feature

An advantage of the motor is that it precisely holds the stage in location when at rest and non-energized. Leaving the motor on consumes energy and creates heat, and does not create additional brake force.

Do not supply command voltage to the motor when at rest.

Recommendations

Base

Heat is conducted through the motor casing to the base.

Mount the motor on a conductive base.

Stage

Heat is conducted through the fingers to the stage.

Construct the stage with conductive materials (such as metals, rather than ceramics) where possible. In case of a ceramic stage, consult NM on the EOP.

Bearings

Heat is conducted through the bearings to the stage base. Maximizing the contact area of the bearings increases heat dissipation.

Use cross-roller bearings where possible.

> Note: The friction in the bearings increases under vacuum conditions. It may increase fivefolds temporarily and locally. It is recommended to assume friction, which is 5 times larger than measured in ambient environment.

Ambient Temperature

At higher temperatures (such as after baking), the EOP should be recalculated. Consult NM if the motors are to operate in vacuum above 25 degrees C.

Summary

The table below is a concise summary:

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#	Feature	Do	Do not do	Comment
1	Thermal conductance of the motor base			> 0.5 W per finger with a temperature rise of 15 degrees max
2	Thermal conductance of the moving stage			> 2 W per finger with a temperature rise of 15 degrees max
3	Conditioning in ambient	Do		4 hours 50% Duty Cycle 50% command
4	Clean setup before entering to vacuum	Do		Use IPA and a clean room compatible cloth
5	Dismantle or retract motor for cleaning		Do not do	
6	Operate in vacuum @ > 25 degrees C			Consult NM
7	Disable motor when standing still	Do		
8	Use NM control algorithm with Dzone max and Dzone min	Do		
9	Operation on a non metallic stage			Consult NM

Appendices

Appendix One: Mounting the Motor

1. Preload the motor: using a 3mm flat screwdriver, turn both of the two preload setting screws counter-clockwise until the turn is completed and the slot is in the position illustrated below.

NOTE: the motor is usually supplied with the preload screws already at the preloaded position. If so, please continue to step 2.

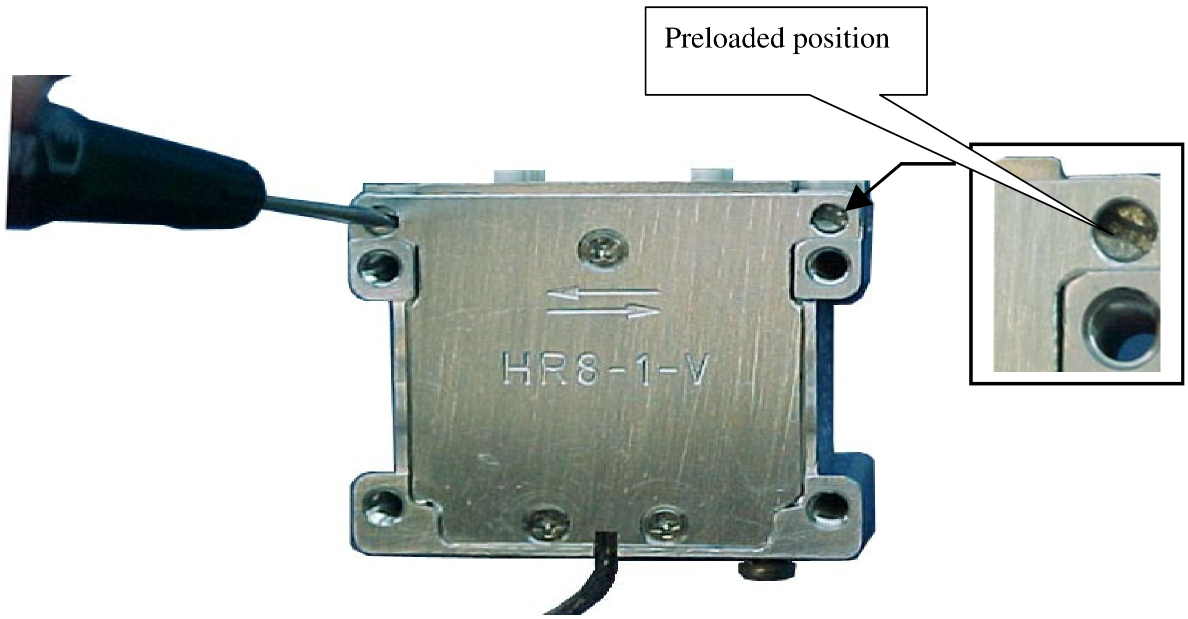

Figure 2-1: Non-preloaded Position

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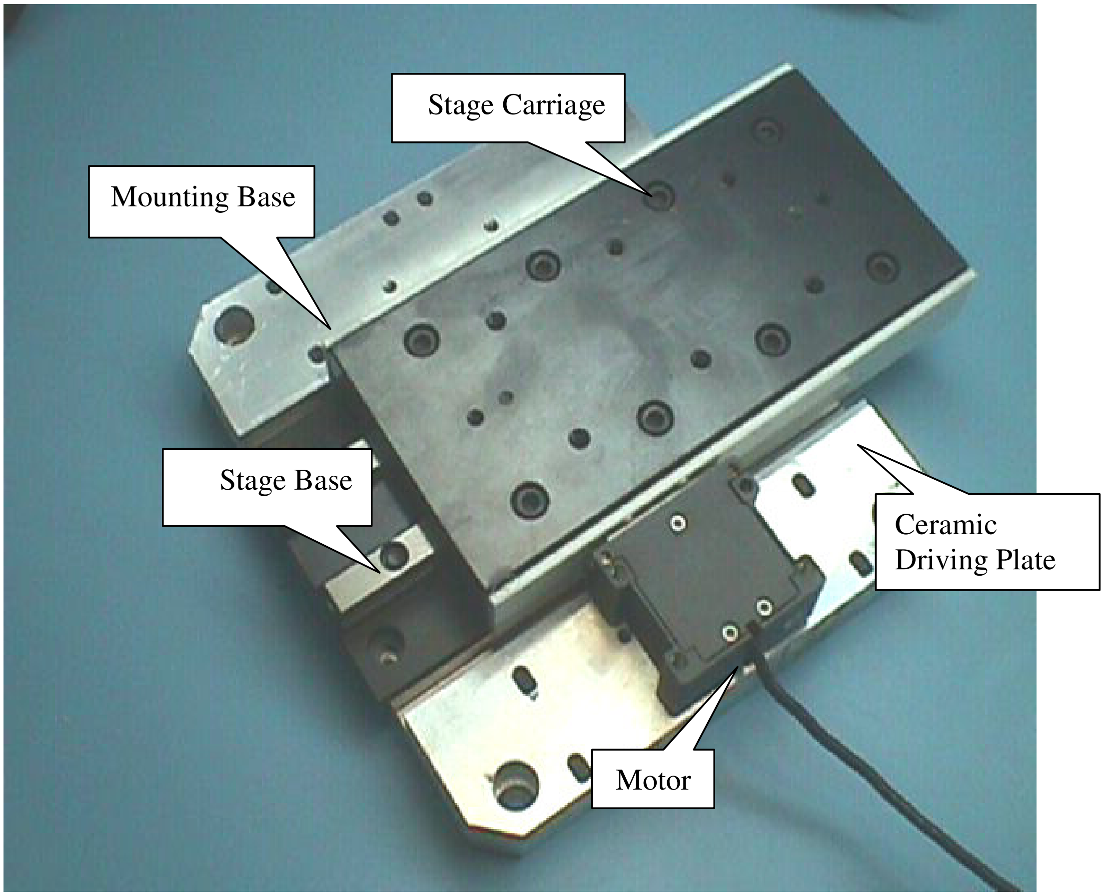

Figure 2-2: Mounting the Motor

2. While making sure not to exert any force on the fingers, place the motor on the mounting base and loosely secure it using four M4 screws and spring washers inserted from the underside of the mounting base. **Do not tighten yet.**
3. *Gently* press the motor against the ceramic driving plate, until it just contacts it and **tighten** the four screws of Step-2 at a torque of 0.5 - 0.7 Nm.
4. Release the preload setting screws: using again the 3mm flat screwdriver, turn both screws clockwise until the turn is completed and the slot is in the position illustrated below. The motor is now preloaded against the ceramic drive plate.

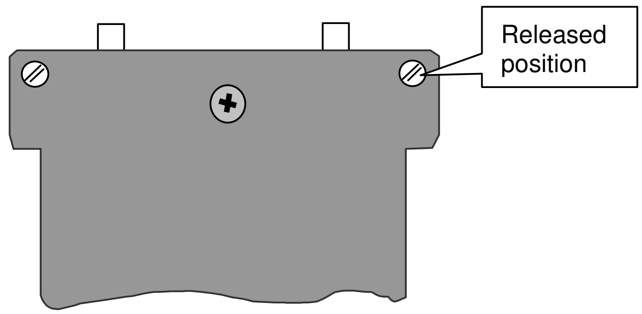

Figure 2-3: Released Position

Appendix Two: Mounting the Ceramic Driving Plate

1. Referring to the figure below, apply two drops of epoxy adhesive, on the center of the Ceramic driving plate *upper* surface, about 2cm apart. The Epoxy must bond between the plate and the stage.
2. Allow the required time period for curing, according to the Epoxy manufacturer specifications.

   NOTE: *Be sure the epoxy contacts the upper surfaces of the plate and the stage carriage but* does not flow over *the Ceramic plate front surface.*

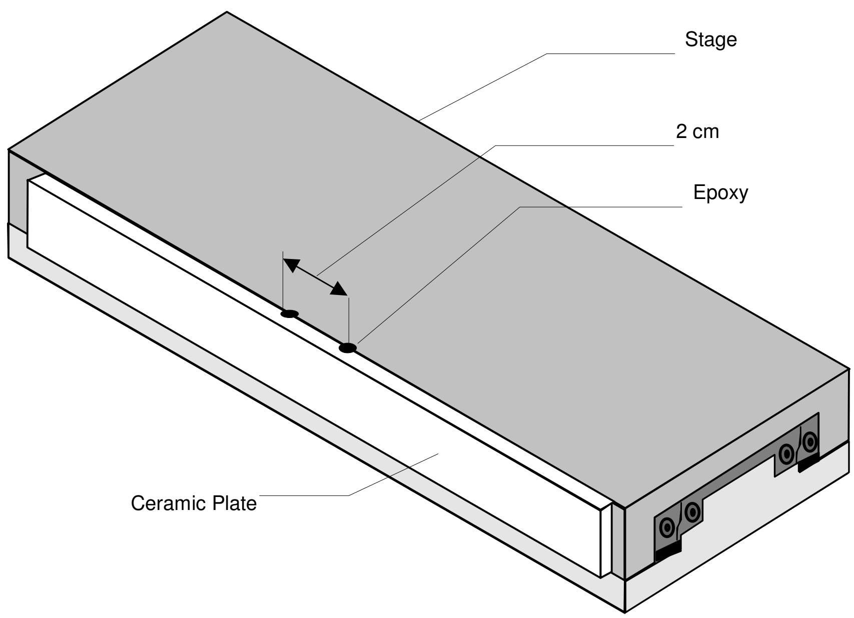

Figure 2-4: Securing the Ceramic Driving Plate to the Stage