**Precision Motors for Motion Control**

**Application Note # 101**

The operating nature of Nanomotion’s motors provides the ability to meet a wide range of demanding motion control applications. The standing wave, inverse piezoelectric effect makes Nanomotion’s motors ideal for applications requiring slow speed constant velocity to high speed move and settle. The motor technology provides a bridge between high speed operation and exceptionally high resolution, in a very small footprint with unlimited travel.

Nanomotion’s motors are most often controlled as a closed loop servo motor, quite synonymous to a brushless dc motor. While standard motors can drive either linear or rotary motion, feedback from a linear or rotary encoder should be provided to control position. The purpose of this Application Guide is to provide technical support in:

- Motor Sizing
- Vertical VS Horizontal Applications
- Differences between the HR and LS Series
- Motor Mounting

Nanomotion’s motors are well suited to motion requirements of:

- **Constant velocity** (from 1µ/sec to 250mm/sec)
- **Move and settle** (within milliseconds)
- **Position stability** (with no servo dither)
- **High resolution** (to 1 nanometer)
- **Inherent braking** (self holding without power)

**Industries & Applications**

Nanomotion Motors are well suited to a diverse application base within the following industries:

- Semiconductor
- Photonics
- Bio-Medical / Pharmaceutical
- Metrology
- General Automation
- Automotive
- Aerospace

Motors are presently being used in broad based applications, such as:

- Wafer Metrology
- Mask Aligners & Photolithography (Photo, X-Ray, E-Beam)
- E-Beam Writing/Inspection
- Hard Disk Certification
- DNA Analysis
- High Throughput Screening

- Optical Cell Analysis
- Fiber Optic Component Assembly
- Laser Diode Manufacturing
- Fiber Alignment
- Gauging Actuation
- Optical Inspection
- And many more.......
The Sizing of Nanomotion Motors

When sizing a motor for vertical operation, the following guidelines should be observed:

To factor in the effects of frictional force, you would multiply the mass times the Cof of the bearing structure and recalculate the max acceleration force as the acceleration force + frictional force. As the coefficient of friction is typically very low, this additional component has little effect on the total mass and is often omitted from the calculation. It should be noted that in vacuum environments the friction from the bearing structure must be factored in, as a few Newtons could have significant impact.

**Vertical Mounting Orientation**

While the intrinsic friction of Nanomotion's motors create a significant holding/braking advantage in a vertical orientation, the force of gravity on the mass must be taken into account.

If used without a counterbalance, it is necessary to include the force of gravity in the upward direction. Consideration must also be given to the inertial force for stopping in the downward direction and different tuning parameters will likely be required in each direction.

If used with a counterbalance, it is necessary to account for the opposing spring force, when moving in the downward direction.

When sizing a motor for vertical operation, the following guidelines should be observed:

**Supporting a Vertical Load**

The nominal static holding force is:
- HR Series: 3.5 Newtons per motor element (finger tip)
- LS Series: 1 Newton per motor element (finger tip)

**Maximum Recommended Moving Mass**

(for vertical operations)

<table>
<thead>
<tr>
<th>Motor</th>
<th>Mass (g)</th>
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<tbody>
<tr>
<td>HR1</td>
<td>150</td>
</tr>
<tr>
<td>HR2</td>
<td>300</td>
</tr>
<tr>
<td>HR4</td>
<td>600</td>
</tr>
<tr>
<td>HR8</td>
<td>1200</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Motor</th>
<th>Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS2</td>
<td>75</td>
</tr>
<tr>
<td>LS4</td>
<td>150</td>
</tr>
<tr>
<td>LS8</td>
<td>300</td>
</tr>
</tbody>
</table>
HR Series VS LS Series

The only noticeable difference between the HR and the LS is the color of the fingertips, which are white on the HR Motors and silver (metallic looking) on the LS motors. The LS motors will also have a wiper assembly included with each shipment, that mounts to the top of the motor.

Operationally, the HR motors function with all fingers synchronized (doing the same thing at the same time) while the LS motors has half the fingers 180° out of phase, or alternating. The different fingertip material and the staggered operation, result in a lower force and speed capability for the LS Series. The LS also has half the preload pressure against the bearing structure as the HR series.

From an application perspective, the primary distinction should be made based on speed requirements and the smallest move. While the LS motor has a significantly lower speed capability, it is designed for low speed constant velocity and small stepping applications. However, similar to the HR, the LS can have multiple motors on an axis to increase force.

Small Stepping Applications

The difference between HR and LS comes from the ability to make small incremental moves. The LS motor is designed to make repetitive steps, below 20nm in size, whereas the HR is limited to step sizes of .1µ. The LS motor is capable of making over a billion steps with sub-micron resolution.

Estimated Life and Envelope of Performance (EOP)

Nanomotion motors have a linear speed / force curve, with a rating for duty cycle and maximum continuous operating time. This is quantified as the Envelope of Performance (EOP). Based on the percentage of maximum speed or maximum force used in a motion profile, duty cycle capability will be defined, and rated motor life will be estimated.

At its peak performance, operating at maximum speed or maximum force, within the EOP, Nanomotion motors are rated for 20,000 hours of operating time. As the operation of the motor moves within the EOP, at the 50% of maximum speed or force, life estimates increase to 50,000 hours of operating time. In many applications, where the EOP is lower than 50% of the force/velocity curve, life in excess of 80,000 can be achieved.

As most brushless dc motors are sized based on the thermal resistance, resulting in temperature rise during acceleration or constant velocity, Nanomotion's motors have thermal limits as well. The thermal resistance of Nanomotion's motors is a mechanical resistance of the Piezo elements and the limits are based on the ability to dissipate heat. Some of the heat generated at the Piezo element is dissipated through the front finger, some from convection and radiation, these two are ultimately dissipated through the motor mounting (see next section). Operating within the thermal limits and EOP, the ultimate limits of motor life will be a function of wear and tear on the ceramic strip and fingertip. As different motion profiles will have different effects on the ceramic, it is difficult to specify exact life times.

1. Operational life is an estimate and varies based on operating environment, mechanical structures, and motion profiles.
Motor Mounting

The key to extending the life of Nanomotion’s motor is the ability to dissipate heat. It is expected that at a 10 volt command from a servo controller, the power consumption is 5 watts per element. Based on the motor design it is expected that:

- 0.5 Watts Will Be Dissipated Through The Front Fingertip
- 1.3 Watts/Element Will Be Dissipated Through Convection (in non-vacuum versions)
- Up to 0.7 Watts/Element By Radiation.

In vacuum environments, heat dissipation is limited to a heat path through the fingertip and radiation via the motor mounting.

The design of a motor mounting bracket should be configured to dissipate between 1 and 1.5 watts/element, minimizing the temperature rise of the motor. Based on the size of the motor, the bracket thickness/surface area should be designed appropriately to maximize the heat dissipation.