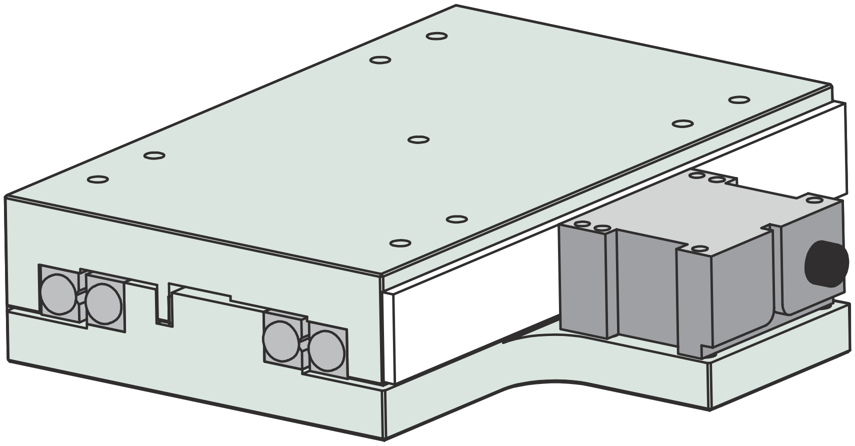
Technical Guidelines for Using Nanomotion Motors

Nanomotion motors provide direct drive performance for linear or rotary motion. Motion is transmitted through the contact of a finger pushing on a drive strip. The ‘friction pair’ is specifically selected to yield optimum performance with minimal wear, currently achieving 40,000 hours of operation and working in environments up to Class 10 clean rooms.

To yield the maximum performance benefits of Nanomotion’s ceramic servo motors, it is important to understand the operating characteristics of the piezo ceramic elements and the impact that they have on the mechanical structure.

As a direct drive, the Nanomotion motor is sized by the basic principles of F = MA (plus the resistance of the bearing structure & the force of gravity if on an incline or vertical). While this is a basic sizing method, one must calculate the maximum speed and force necessary to meet the application performance requirements and size the motor properly, operating within the defined EOP (Envelope of Performance).

NOTE: When operating a direct drive motor vertically, it is recommended that the motor force be 3 times greater than the total vertical load, to facilitate good servo performance.



Managing Normal Force and Stage Stiffness

In addition to the motor sizing, Nanomotion's motor exerts a normal force into the bearing structure in the direction that the motor is mounted and preloaded. This normal force is 5 times the driving force of the motor. Because of this force, it is optimum if the motor can be mounted on the centerline of the bearing structure. Nanomotion motors are in successful operation with:

- Crossed roller linear and rotary bearings
- Recirculating linear guides & shaft bearings.
- Linear and rotary air bearings.
- Angular contact & radial rotary bearings

A key design criteria is the bearing stiffness and preload, to assure successful operation of the motor. A good target value is 40N/micron of bearing stiffness. For less precise applications that do not require 20,000 hours of life, a lower stiffness number is acceptable. For more precise applications, operating in production environments, a minimum stiffness of 50N/micron should be targeted. These stiffness values are easily achieved with conventional bearings on the market today.

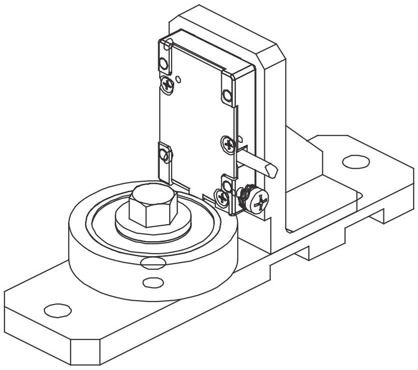
For example, an HR1 motor provides 1 lb (4.4N) of thrust, and will create 5 lbs (22N) force into the bearing structure, perpendicular to motion. In addition to the normal force, there is the potential for higher acceleration forces that are placed in the same direction, impacting the bearing. Acceleration forces can be 2 to 3 times greater than the normal force.

The most common linear bearings used in precision motion are crossed rollers and linear recirculating guides. While ball bushings and air bearings are acceptable technologies, they are in the minority.

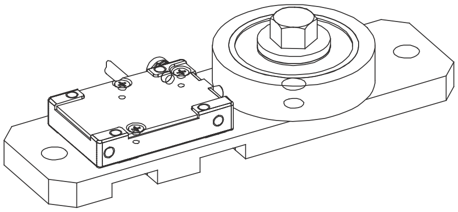
Rotary applications with Nanomotion motors are quite common as the direct drive motor can eliminate worm gears, belts and other rotary transmissions. In rotary applications there is design flexibility to apply the motor axially, driving on the flat surface of a disk, or radially, driving on the circumference of a ring.

Rotary Bearings

Typical Axial Mounting



Typical Radial Mounting



As with linear bearings, the bearing stiffness is critical to the performance of the Nanomotion motor. Moreover, a single motor applied axially will induce a moment load on the bearing whereas a single motor applied radially will induce a side load on the bearing structure. In many rotary applications it is appropriate to consider the use of two smaller motors, mounted 180º apart to maintain a balanced load on the bearing. Mounting two motors that are not 180º apart, with a slightly different angle, can also help to maintain a preload on the bearing and have a positive impact.

In evaluating rotary bearings, there are 3 common types that are utilized in rotary stages:

- Rotary crossed roller
- Angular contact
- Deep groove radial

While the same stiffness criteria apply to rotary applications, 50N/µm, each bearing offers different operating characteristics. The selected bearing should be fully evaluated for its specific load rating and stiffness in the appropriate directions.

Mechanical Mounting Tolerance

The Nanomotion motor is constructed with a spring behind each motor element. This spring is designed to provide a preload (normal force) as well as allow for mounting inaccuracies. The spring can compensate for 'out of parallel' conditions up to 50µm (.002").

All of the bearing types discussed provide linear accuracies well within these tolerances, but the machined mounting surfaces will contribute to linear accuracy. It should, however, be achievable to control linear straightness to 50µm in a precision motion system.

For systems that require ultrahigh resolution (below 100nm) and smooth constant velocity, it is important to maintain tighter tolerances on the straightness of motion, to optimize the servo performance.

Mechanical Assembly Procedures and Safeguards

**WARNING: NEVER OPERATE THE MOTOR UN-LOADED,
WITHOUT PRELOAD AGAINST A NANOMOTION DRIVE STRIP.**

Proper mounting procedures are described in each motor manual, with preload being set by a shim (provided with ST, HR1 & HR2 motors), or a cam (internal to the HR4 & HR8 motors). The motor should be mounted perpendicular to travel, with the arrows on the motor label indicating the direction of travel.

In applications utilizing the HR4 & HR8 motors, it is important to avoid compressing the motor against the ceramic strip, prior to engaging the cams. This additional force will result in a higher that expected preload. If there is a concern about controlling the force during mounting it is acceptable to use a shim, when the finger tips are in a retracted position, up to 15μm thickness. This will assure that the motor elements are not 'over compressed' against the drive strip.

Always make sure the mechanical travel does not permit the motor fingers to become disengaged from the ceramic drive strip. The finger tips should remain in a compressed state at all times.

Most Nanomotion provided drive strips have a 3M acrylic tape bonded to them. Nanomotion can provide the specification on the tape for those customers who require it. When applying the ceramic with the tape, make sure there are no air bubbles and the ceramic strip is applied to a clean surface. After adhering the drive strip, secure it with two drops of epoxy, per the instructions in the manual, to prevent any motion in sheer.

Sizing Example

Requirements:

Total moving mass (moving part of stage plus payload), $M = 1$Kg

Travel, $X = 0.01$ m (horizontal orientation)

Total move time, $T = 0.1$ sec (not including settling time)

Motion profile: trapezoidal, accelerate for 1/3 of the total time, move a constant velocity for 1/3 of the total time, decelerate for 1/3 of the total time

Calculate:

Acceleration / deceleration, $A = 4.5 * X / T^2 = 1 * 0.01 / 0.1^2 = 4.5$ m/sec^2

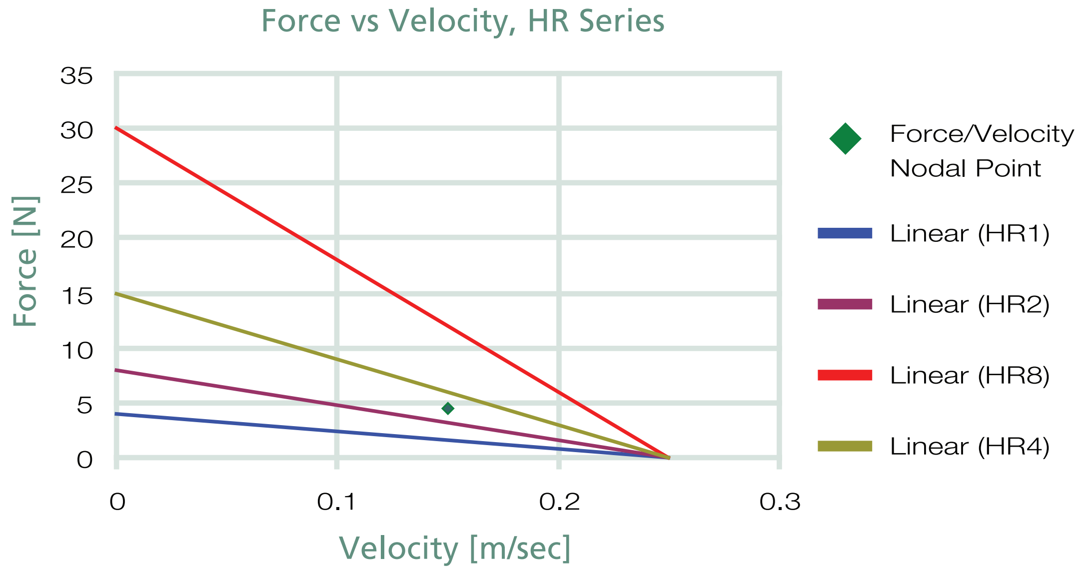
Maximum velocity, $V = 1.5 * X / T = 1.5 * 0.01 / 0.1 = 0.15$ m/sec

Acceleration force, $Fa = M * A = 1 * 4.5 = 4.5$ N

Add additional forces (bearing friction, load force, gravity/inclination, etc.) to obtain total force Ft.

Plot the point {Ft,V} on the Force/Velocity curves. See figure below.

Select the motor whose curve is above the {Ft,V} point. In this case it would be an HR4.



Settling Time

The achievable settling time is mainly dictated by the damping of the motor and the natural frequency of the system. A typical number of three cycles is required for the motor damping to damp the system vibration along the motion axis, so the settling time will be roughly according to the following formula:

$$Ts = 3/Fr$$

Where Fr is the natural frequency of the system, and is calculated according to the following formula:

$$Fr = 1/2\pi \quad \sqrt{K/m}$$

Where:

K - stiffness of the motor in Newton/meter

m - mass of the moving part in Kg

If the desired natural frequency is higher than the one calculated for a given configuration, adding another motor in parallel or in tandem will increase the system's natural frequency due to the increased stiffness. The combined stiffness of several motors is the algebraic sum of the stiffness of the individual motors. One should recalculate the natural frequency using the combined stiffness of the motors. It is worthwhile to note that the effective motor stiffness increases under close loop operation.

Driving vertically with a motor that actuates based on friction requires specific consideration to the static load, separate from the dynamic force. As a rule of thumb, each 4.4N element can drive 120 grams vertically. Beyond this a counter balance should be considered. This can be in the form of a spring, a continuous force gas spring, or opposing weight.

Electrical Interface

Nanomotion's motors run at resonant frequency and are sensitive to the capacitance of the electrical circuit. Changing cable lengths will affect the total capacitance. There are guidelines provided in Nanomotion's catalog and manuals as to the acceptable cable lengths.

In addition to the cable length from the motor to the amplifier, caution should be used if third party cable is used. Nanomotion provides motors with specific low capacitance cable at:

Standard motors:	64pF/foot
Vacuum motors:	13pF/foot

If the capacitance of the electrical circuit is too high, the full performance of the motor will not be realized. Nanomotion can provide guidelines for testing capacitance.

Quick Reference– Getting Started

Verify proper stage mechanics with preloaded bearings and appropriate stiffness.

Follow Nanomotion's motor mounting guidelines for preloading and motor orientation with respect to travel & verify that ceramic strip has two drops of epoxy.

Connect the ground wire from the motor to the amplifier.

Verify the connection (jumper) between power supply return and the controller's analog ground.

Condition the motor before tuning, per Motor Installation Manual (Always recondition the motor each time it is disengaged from the ceramic strip).

After conditioning, wipe the ceramic with a clean cloth and IP alcohol without disengaging the motor.

Use "Abort on Position Error" (or other safety mechanism) and appropriate torque limit during initial integration and conditioning. Do not exceed 5v and 50% duty cycle.

Avoid prolonged operation in an unstable condition (excessive vibration) during tuning process.

Consult with Nanomotion with any questions during the set up process.

- Do not operate the motor in an un-loaded (un-mounted) condition
- Do not exceed the duty cycle limits when operating the motor (see Motor Installation Manual)
- Do not allow the motor tips to leave contact with the ceramic strip during operation (Use mechanical hard stops)
- Do not remove the cover of the motor (High Voltage Inside)
- Do not immerse the motor in any liquids