

APPENDIX

Stepper Motor Specifications

Type
NEMA Standards

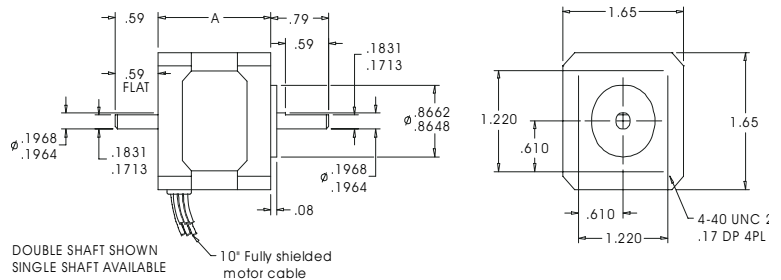
Models
17, 23, and 34 Sizes

The National Equipment Manufacturers' Association (NEMA) has developed standard motor case sizes which have been adopted by the world's major manufacturers of stepping motors. Three common case sizes for use in precision stage applications are the 17, 23, and 34. These size numbers refer to the approximate size in square inches of the square flange on the face of the motor.

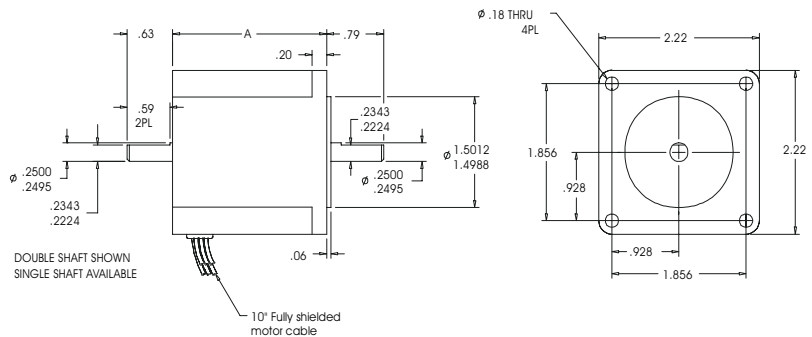
Rotor inertia values, shown in table on the following page, should be used when calculating system motor torques requirements.

JMAR Precision Systems will assist in selecting motors for your applications.

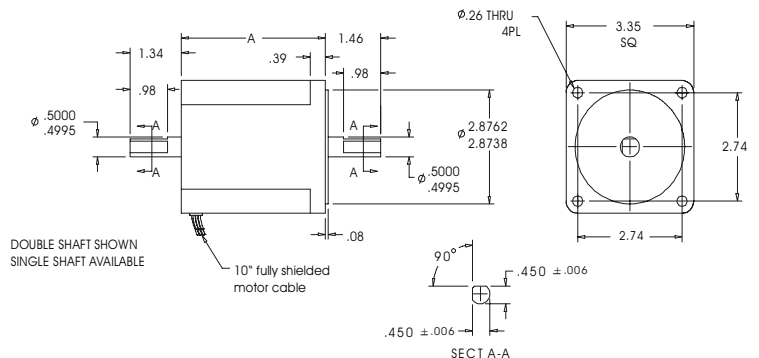
NEMA Size 17 Frame Motor Dimensions



NEMA Size 23 Frame Motor Dimensions



NEMA Size 34 Frame Motor Dimensions



NEMA Size 17 Frame Motor

Part #	Stacks	Current	Holding Torque	Inductor	# of Leads
#	#	A/phase	Oz-In	mH/phase	#
MTR-17SS-R	1	0.95	22	2.5	6
MTR-17DS-R	2	1.2	36	3.2	6
MTR-17TS-R	3	1.2	44	2.8	6

Part #	Length	Weight	Shaft Dia	Rotor Inertia	Step Angle
#	Inch	lbs	Inch	Oz-In ²	Degree
MTR-17SS-R	1.30"	0.48	0.1965	0.19	1.8
MTR-17DS-R	1.54"	0.6	0.1965	0.3	1.8
MTR-17TS-R	1.85	0.77	0.1965	0.37	1.8

NEMA Size 23 Frame Motor

Part #	Stacks	Current	Holding Torque	Inductor	# of Leads
#	#	A/phase	Oz-In	mH/phase	#
MTR-23SS-R	1	3	54	0.6	6
MTR-23DS-R	2	3	125	1.1	6
MTR-23TS-R	3	3	187	2.6	6

Part #	Length	Weight	Shaft Dia	Rotor Inertia	Step Angle
#	Inch	lbs	Inch	Oz-In ²	Degree
MTR-23SS-R	1.54"	0.99	0.25	0.66	1.8
MTR-23DS-R	2.13"	1.54	0.25	1.64	1.8
MTR-23TS-R	2.99"	2.2	0.25	2.62	1.8

NEMA Size 34 Frame Motor

Part #	Stacks	Current	Holding Torque	Inductor	# of Leads
#	#	A/phase	Oz-In	mH/phase	#
MTR-34SS-R	1	4.5	305	1.5	6
MTR-34DS-R	2	4.5	611	2.5	6
MTR-34TS-R	3	4.0	916	4.2	6

Part #	Length	Weight	Shaft Dia	Rotor Inertia	Step Angle
#	Inch	lbs	Inch	Oz-In ²	Degree
MTR-34SS-R	2.60"	3.75	.5	0.66	1.8
MTR-34DS-R	3.78"	6.17	.5	1.64	1.8
MTR-34TS-R	4.96"	8.38	.5	2.62	1.8

Errors in X-Y Stage Applications

All stages have six degrees of freedom: three linear and three rotary (see Figure 1 and 2). All stage manufacturers face the same challenge: tightly constrain all of the rotational and linear degrees of freedom. The higher the stage grade, the more the degrees of freedom are controlled.

A stage error budget is generally built around these errors:

1. Yaw, Pitch and Roll
2. X to Y Orthogonality
3. Abbé Error
4. Linear Accuracy
5. Repeatability

Yaw and Pitch (respectively) are the rotations about the vertical and horizontal axes perpendicular to an axis of travel.

Straightness of travel is the sum of the horizontal deviations in the straightline motion caused by yaw and roll. Flatness of travel is the sum of the vertical deviations in straightline travel caused by pitch and roll.

Other deviations must be controlled in order to make a suitable stage. A discussion of these errors follows, with the knowledge that a proper understanding of their natures can also lead to the minimizing of their effects. For instance, placing a map of the sum of these errors within a computer which controls a motorized and encoded stage allows compensation for system errors. The computer uses the error map to compensate for positional discrepancies, thereby achieving a new and higher synthesized system accuracy.

Linear Degrees of Freedom

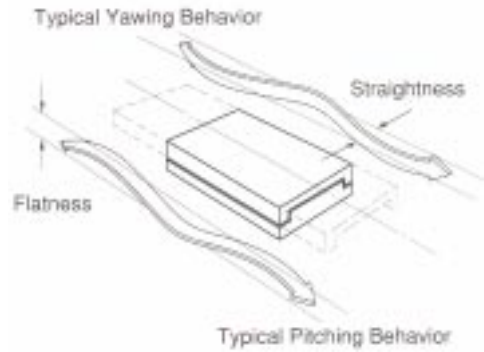


Figure 1

Rotational Degrees of Freedom

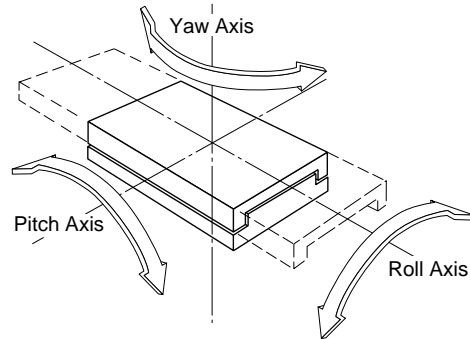


Figure 2

Error	Minimized By	Measurement Device
1. Yaw (Straightness) Pitch (Flatness) Roll (Axial Rotation)	Precision machining Adequate bearing length Load centered on stage Bearing preload	Auto Collimator Electronic Indicator Laser Interferometer
2. Orthogonality (X to Y squareness)	Precision machining Theodolite-alignment Square gaging	Theodolite Laser Interferometer Square Gage
3. Abbé Error	Mounting of Encoder close to area of measurement Precision encoder alignment	Auto Collimator Laser Interferometer
4. Linear Accuracy	Precision machining Accurate leadscrew Bearing preload	Rotary Encoder Linear Encoder Laser Interferometer
5. Repeatability	High Integrity Slideways Low Backlash Leadscrew Low Hysteresis Encoder	Rotary Encoder Linear Encoder Laser Interferometer

Abbé Error Discussion

In practice, every stage is oriented so that its guideways (that lie within the horizontal plane) will exhibit some pitch error, as they travel along the arc of a circle instead of a flat plane. This is due to the flatness error of the bearing guideway system, mounting plates and stage mounting surface. These deflections make the stage appear to follow a very gentle arc instead of a perfectly straight line. A much exaggerated view appears in Figure 3. The angle, theta, is constructed by drawing a line perpendicular to the top of the stage at either end of travel.

Therefore, instead of the workpiece and measurement axes being straight, horizontal, and parallel, they describe concentric arcs of two circles. The center of these circles is the intersection of the two construction lines. The difference between the two circle radii is labeled H , the Abbé Offset. The Abbé Error is equal to the angle θ , measured in radians, times the Abbé Offset.

In precision measurement applications, the largest source of uncorrected error next to stage orthogonality is Abbé Error. Named after the optical pioneer, Ernst Abbé, this error is present when the axis of measurement is not coincident with the plane of the workpiece and the workpiece and measurement axis are not parallel.

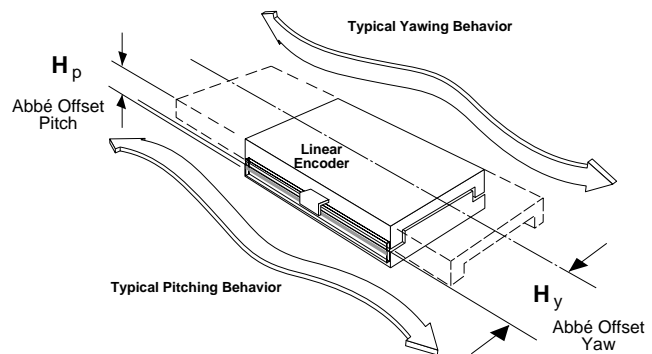


Figure 1

Abbé Error Diagrams

Design steps which may be taken to avoid Abbé Errors are:

1. Minimize the Abbé Offset in the design of stages and tooling.
2. Minimize pitch and yaw errors by choosing a precision stage with non deforming bearing elements. Center the load on the stage to minimize cantilevering.
3. Use a very precise reference grid to characterize the errors in your stage. Develop error offset tables in your motion control system to servo out these errors using the stage's inherent repeatability.
4. Eliminate the Abbé Offset by using a laser interferometer with the measurement beams coincident with the top surface of the workpiece.

In the most accurate and precise applications, the designer needs to consider using a laser interferometer instead of linear encoders. The Abbé Offset Error is eliminated by mounting the mirrors of the laser interferometer at the same level as the top surface of the workpiece.

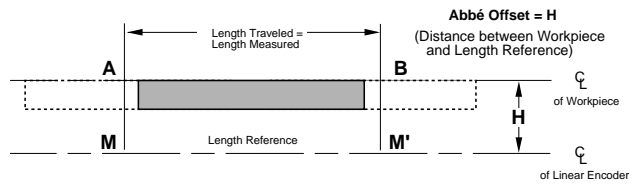


Figure 2 - Ideal Case
(No Pitch at Either End of Travel)

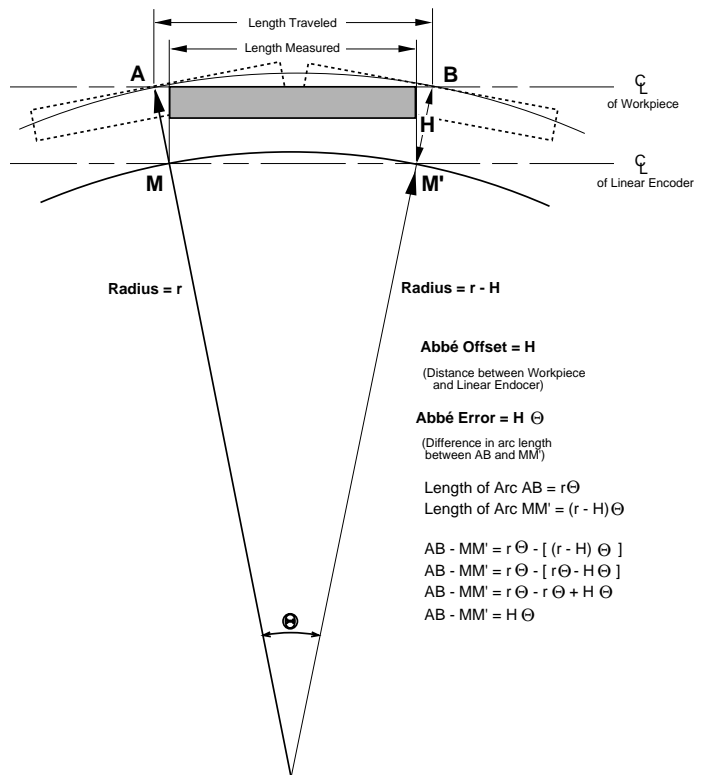


Figure 3 - Practical Case
(Pitch Errors Exaggerated at Both Ends of Travel for Clarity)

Orthogonality Error Discussion

Orthogonal X-Y stage travel is a matter of process to mechanically align and assemble independent stage axes at right angles. In practice this is a painstaking process requiring the oversight of a qualified technician! Even then, accuracy of the alignment is limited by the orthogonality of the tools and standards used to perform the operation.

Mechanical reference squares typically offer a range of orthogonalities from a few arc-seconds to ± 30 arc seconds. More precise optical reference squares are usually specified at ± 1 arc-second, or if carefully lapped, ± 0.1 arc-second can be achieved.

Example: An X-Y stage with 6-inch travels has a specified orthogonality of ± 10 arc-seconds. System error can be calculated as follows

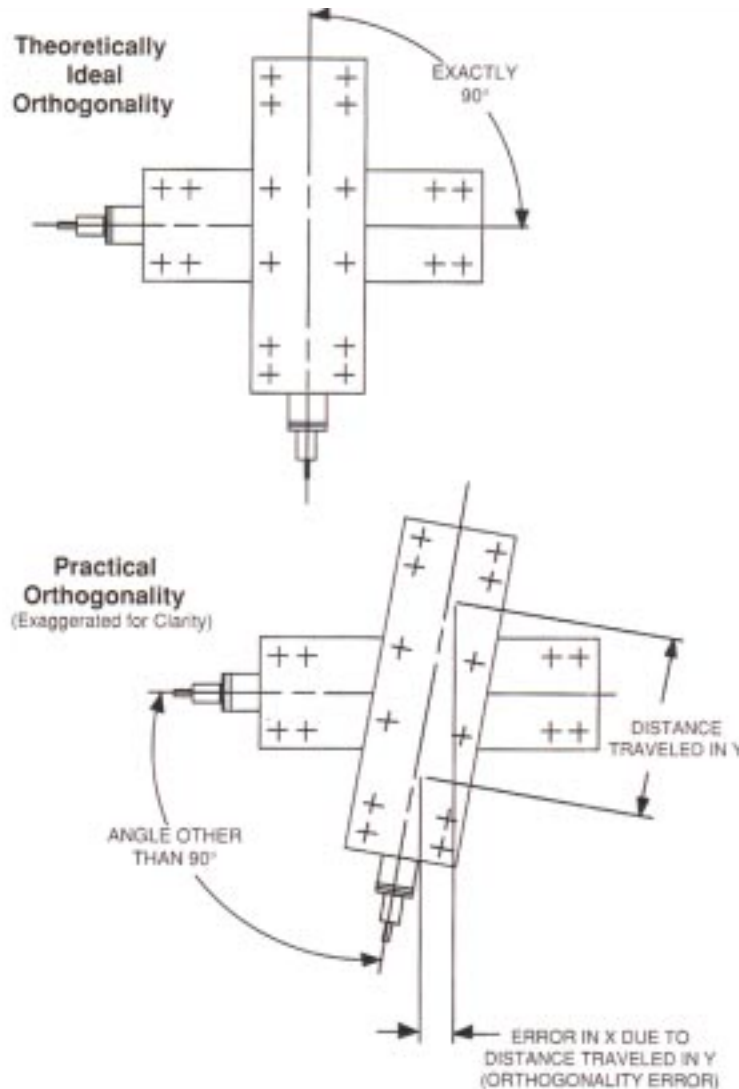
Recall that 1 arc-second is
 $(1 / 360^\circ \times 60 \times 60) \times 2\pi$
 $= (2 \times 3.14) / 1,296,000$
 $= 4.85 \times 10^{-6}$ radians.

The displacement error in the X direction caused by 6" travel in Y is given by:

$$\begin{aligned} dX &= 6'' \text{ tangent } (10 \text{ arc-sec}) \\ &= 6'' \text{ tangent } (4.85 \times 10^{-5} \text{ rad.}) \\ &= 6'' \times (4.85 \times 10^{-5}) \\ &= 291 \times 10^{-6} \text{ inches} \\ &= 291 \text{ m inches} \end{aligned}$$

Remember this is the error contributed by orthogonality only and does not include straightness of travel error, Abbé error, etc.

In multi-axis stage application, it is assumed that stages travel at exact right angles. It is safe to say that stages never travel precisely at right angles. Insidiously, even minute deviations in orthogonality produce significant system accuracy errors.



Glossary

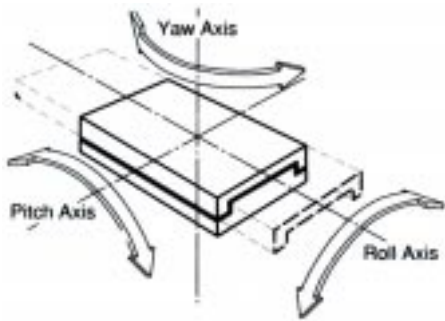


Figure 1
Roll, Pitch, and Yaw

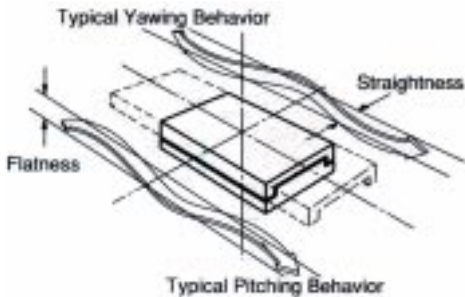


Figure 2
Flatness and Straightness

Accuracy - the deviation from the exact value of the desired position or velocity (see Figure 3).

Backlash - the amount of free play or clearance between two interactive components in a drive train or leadscrew, often referred to as a "dead-band" when the motion direction is reversed.

Closed-loop positioning - a positioning system that employs an external feedback element to measure stage position. Typically, a linear encoder mounted to the axis will eliminate hysteresis, backlash, and leadscrew errors.

Concentricity - the difference between a rotating member's centerline and the actual true centerline of rotation.

Error - the difference between the actual and the desired condition.

Flatness of travel - the vertical deviation of a single point moving horizontally along a straight line. Flatness errors are caused by a combination of roll and pitch errors (See Figure 2).

Home reference mark - the location on a linear scale which provides an independent electrical output to locate the home or zero reference position.

Holding torque - the amount of torque available from a stepping motor when the windings are energized but the rotor is stopped.

Hysteresis - lost movement in the absolute position of an object when motion is reversed. It is caused by accumulated forces in elastic materials.

Lead - the distance traveled by the leadscrew nut for each revolution of the leadscrew.

Leadscrew pitch - the number of revolutions required to advance the leadscrew nut one inch.

Linear positioning accuracy - the error between the desired move and the actual position achieved by a linear positioning component or stage system.

Open loop - a positioning system which does not employ feedback information.

Orthogonality - the error from true 90-degree perpendicularity of two axes.

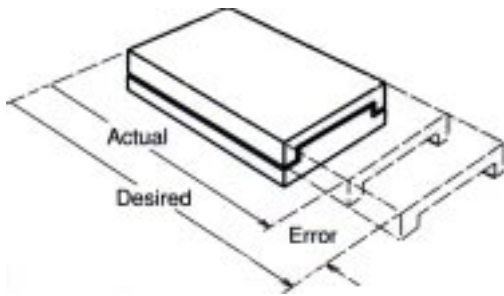


Figure 3
Linear Positioning Accuracy

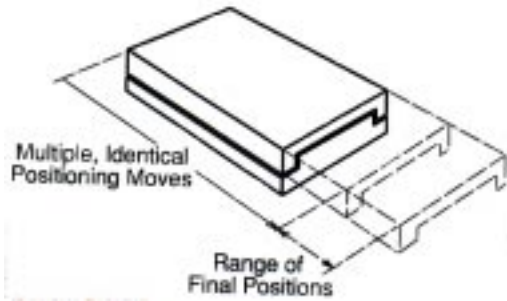


Figure 4
Repeatability

Pitch - rotation about the horizontal axis perpendicular to the axis of travel (See Figure 1).

Repeatability - (See Figure 4).

a. Uni-directional repeatability - the ability of a system to repeat to a desired location approaching that location from the same direction each time.

b. Bi-directional repeatability - the ability of a system to repeat to a desired location approaching that location from both plus and minus directions.

Resolution - the smallest incremental positioning move that a system can achieve or display.

Roll - rotation about the axis of movement while translating along that axis (See Figure 1).

Step - in a stepping motor drive, the minimum rotational movement allowed by the system.

Straightness of travel - the horizontal deviation of a single point moving horizontally along a straight line. Straightness errors are caused by yaw and roll errors (See Figure 2).

Velocity - the rate of change of position with time.

Yaw - rotation about the vertical axis which is perpendicular to the axis of travel (See Figure 1).

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