Equipment Solutions
Voice Coil Stages and Actuators
Interfacing, Operation and Maintenance

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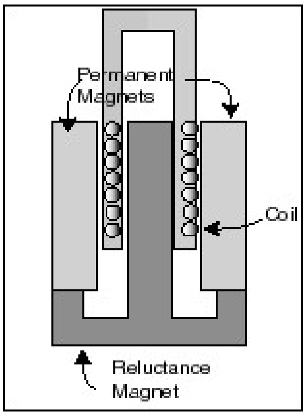
Voice Coil Motor Basics

Many of the Equipment Solutions stages incorporate voice coil motor technology to provide their impressive specifications. To understand this less known technology, the following brief presentation is offered.

The voice coil is a direct drive linear actuator. Stroke (length of travel) ranges from microns to several centimeters. It is ideal for applications that require positioning over a small to medium range, such as beam steering mirrors and pilot valve control.

Directly below is an image of the internal design.



As you can see the voice coil actuator is made up of essentially two components, a moving member and a fixed member. The core of the moving member is basically a group of coiled wires in a tubular form, represented by the circles. The stationary member is made up of a permanent magnet that surrounds the outer layer of the coil, and a ferromagnetic magnet of the inner structure that completes the magnetic field radiating through the coil of the moving member. Simple electromagnetics tells us that a force is exerted on a current carrying conductor when placed in a magnetic field. By applying a voltage across the leads of the coil, the magnetic field produces a force on the moving member, creating linear motion. Because the force is proportional to the current applied, good control can be achieved.

The voice coil itself is a non-commutated, two terminal limited motion device. It has linear control characteristics, zero hysteresis, and zero cogging and infinite position sensitivity. It has low electrical and mechanical time constants and a high output power to weight ratio. As such, it is nearly a perfect servomechanism.

A voice coil actuator can be operated in several modes including positioning mode with the assistance of some feedback device. To complete the servo loop, a variety of different feedback devices, commonly a linear potentiometer, are used depending on the requirements of the application.

Beam steering mirrors is one example of many that are appropriate and well suited for voice coil stages. The mirrors are used in optical scanning, pointing, aiming, tracking, and stabilization applications. Inherent features of a voice coil actuator are high force-to-mass ratio, linear constants, cog-free and hysteresis-free motion are ideal for design of high performance electro-optical assemblies.

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Motor Connector

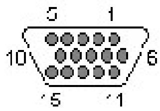

Figure 1:Motor Connector

The Motor Connector (P1) is used to interface the motor and it's sensors to a servo amplifier. The connector is a High-Density DB-15 style male connector. A mating high-density 22D type plug is available from several manufacturers including AMP under part number 748364-1 using crimp style pin part number 748333-4. Determining the correct polarity of both the motor and associated position sensor is often accomplished through a trial-and-error process. Usually only one of the two sources (motor or sensor) should be varied. That means that there are only two possibilities one correct and the other incorrect. When experimenting with these connections the precious motor loads (such as mirrors) should be considered.

Table 1: Motor with PSD Sensor Connector (P1)

Pin #	Signal	Color	Description
1			
2	SIG-	Black	Position or other sensor minus side feedback signal.
3	TEMP	Gray	Primarily provides a interface between a motor with an integrated temperature sensor and the controller. 10K @ 25º C with . Alternatively used as general-purpose analog (0-5V) input.
4			
5			
6	MTR+	Red	Plus Motor Supply Current. This is a 22 gauge wire.
7	MTR+	White	Plus Motor Supply Current. This is a 22 gauge wire.
8			
9	+5V	Red	Plus supply voltage to an analog position sensor or other device on or near the motor. Can provide up to 50 ma of current for this application.
10	+SIG	Yellow	PSD Sensor signal plus.

11	MTR-	Black	Minus Motor Supply Current. This is a 22 gauge wire.
12	MTR-	Green	Minus Motor Supply Current. This is a 22 gauge wire
13	GND	Motor Shield	Ground.
14	GND	Encoder Shield	Ground.
15	GND	Shield	Ground

Table 2: Motor with Digital Encoder Connector (P1)

Pin #	Signal	Color	Description
1	EncA-	Black	Digital Quadrature Output. Signal is a RS-422 compatible square wave. Pulses are 90º out of phase with EncB-.
2	EncA+	Brown	Digital Quadrature Output. Signal is a RS-422 compatible square wave. Pulses are 90º out of phase with EncB+.
3	EncB-	Yellow	Digital Quadrature Output. Signal is a RS-422 compatible square wave. Pulses are 90º out of phase with EncA-.
4	EncB+	Orange	Digital Quadrature Output. Signal is a RS-422 compatible square wave. Pulses are 90º out of phase with EncA+.
5	EncI-	Red	The Index Window defines one particular fringe on the grating.
6	Mtr+	Red	Plus Motor Supply Current. This is a 22 gauge wire.
7	Mtr+	White	Plus Motor Supply Current. This is a 22 gauge wire.
8	Therm	Gray	Primarily provides a interface between a motor with an integrated temperature sensor and the digital controller. Alternatively used as general-purpose analog (0-5V) input. 10K @ 25º C.
9	Enc+5	White	+5VDC Supply to Encoder. Be sure to account for voltage lass over distance and tolerance from nominal power supply voltage so that at least 4.75V DC is available to the encoder under all operating conditions. Do not exceed 5.25V DC.
10	EncI+	Blue	The Index Window defines one particular fringe on the grating.
11	Mtr-	Black	Minus Motor Supply Current. This is a 22 gauge wire.
12	Mtr-	Green	Minus Motor Supply Current. This is a 22 gauge wire.
13	MtrShd	Shield	Shield.
14	EncShd	Shield	Shield.
15	EncGnd	Green	Encoder Ground.

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Analog Position Feedback Sensor

In most cases Equipment Solutions Voice Coil Stages are configured with an analog position feedback element. A sensor such as this is directly compatible with the SCA family of Equipment Solutions Servo Controlled Amplifiers. The sensor will output a DC voltage between –4 VDC and +4 VDC that is directly proportional to actuator position. In order to perform this function the sensor module needs to be supplied with +5 VDC to +12 VDC.

The Analog Position Feedback signal is normally brought directly out to the Motor Connector. For more detailed information including pin assignment for this function please refer to Table 1: Motor with PSD Sensor Connector (P1).

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Digital Output Encoder

The motor can be optionally configured with a digital output encoder signal.

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Encoder Resolution

Typically the quadrature encoder is configured to have a one (1) micron resolution. Other resolutions including 5um, 2.5um and 0.50um are possible. Contact your Equipment Solutions sales representative for details regarding the non-standard resolutions.

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Encoder Linearity

Encoder linearity is the maximum peak-to-peak error over the specified movement when compared to a NIST traceable laser interferometer standard used at room temperature. The linearity of the digital encoder is typically better than ±3um.

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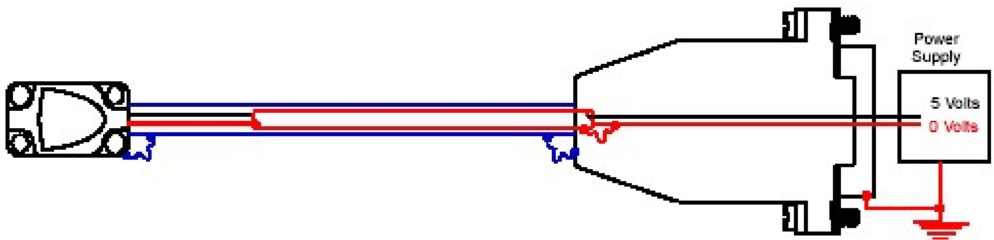
Encoder Grounding

For the encoder system to operate reliably, it is essential that the sensor and cable shield are grounded properly according to the following instructions. The diagram below shows how to make the connections when the encoder's connector is plugged into the customer's controller chassis. If a customer-supplied extension cable is used, it should be a double shielded cable with conductive connector shells and must provide complete shielding over the conductors contained within it over its entire length. Furthermore. The shields should be grounded at the connection to the controller chassis the same way as the encoder connector in the diagram below.

The encoder's connector shell must be in intimate, electrically conductive contact with the customer-supplied mating connector, which must be connected to the controller's ground. If a customer-supplied shielded cable connects the encoder to the controller, then the outer shield on the customer-supplied cable must be connected to the controller's ground. The controller must be grounded to earth at the point of installation.



Encoder Grounding Diagram

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Encoder Power

The encoder requires a minimum of 4.75 VDC continuously. When designing circuits and extension cables for the encoder be sure to account for voltage loss across distance and tolerance from the nominal supply voltage so that at least 4.75 VDC is available to the encoder under all operating conditions. Do not exceed 5.25 VDC.

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Customer Interface Cable Requirements

Customer cables that interface to the encoder must have the following characteristics:

- Twisted pair signal wiring.
- Characteristic impedance of 100 – 120 ohms.
- Sufficient wire gauge to meet the minimum voltage requirement at the encoder, for example 24 AWG gauge wire for a 24 meter length cable. Examples of acceptable cables with 24 AWG gauge wire and 4 twisted pairs are Belden 9831, 8104, and 9844 or other manufacturer's equivalents.
- Single shield cable with a minimum of 90% coverage. Note that a double-shielded cable may be required in high-noise applications.

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Signal Wiring

Each differential signal should be connected to a corresponding twisted par as follows:

Signal Wiring Chart

Signal	Twisted Pair
A+ A-	Pair 1
B+ B-	Pair 2
Index+ Index-	Pair 3
+5 VDC GND	Pair 4

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Shield Termination

The customer's cable shield should be in 360 contact with the connector shroud and the connector shell to provide complete shielding. The connector shell should be metal with conductive surfaces. Suggested metal connector shells for use with the encoder are: AMP 745172-3, -2, or –1 where the dash number is dependent on the customer's outside cable diameter. The double-shield should be terminated as illustrated in the following diagram. Note that dimensions shown are for illustration only.

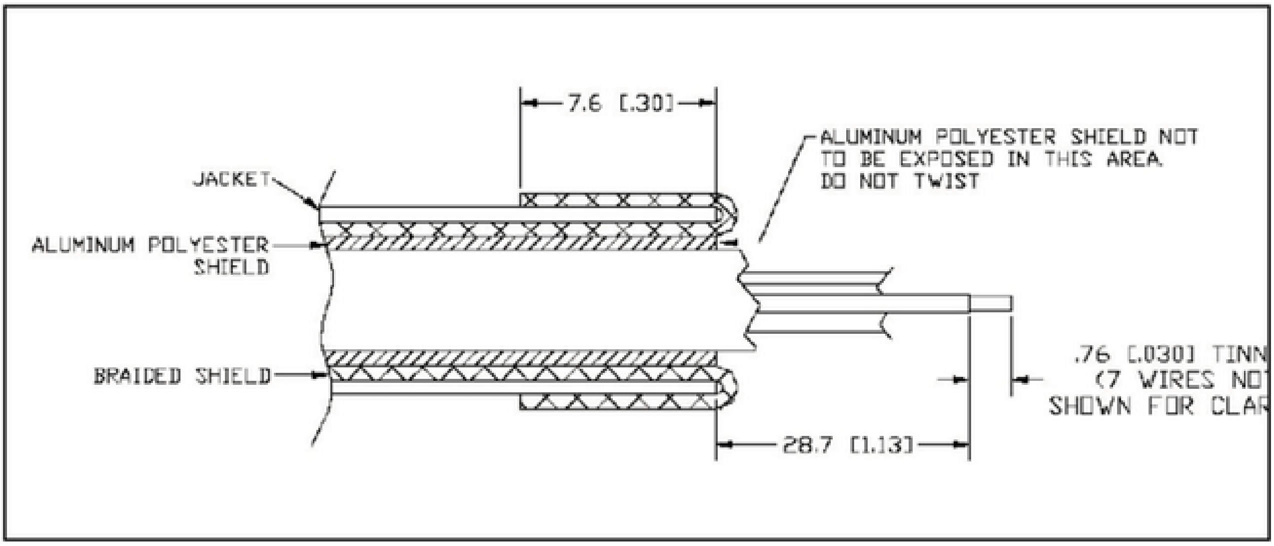

Figure 2: Encoder Cable Shield Termination

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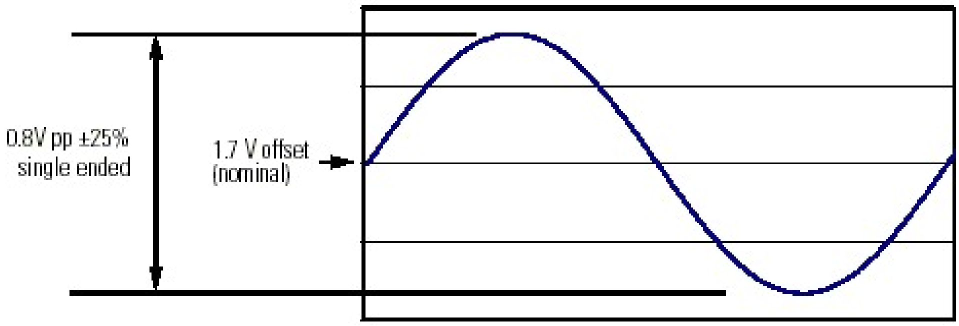
Encoder Analog Output Signals

Analog signal with nominal peak-to-peak amplitude of 0.8 V. The output signal has a source impedance of 1 K . This signal is only used to align the sensor using an oscilloscope and is not suitable for feedback in a control system.



Encoder Analog Output Signals

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Output Signals

Encoder Digital Output Signals

A+/A-	Digital Quadrature output. Signal is a RS-422 compatible square wave. Pulses are 90 out of phase with B+/B- outputs. Please see below.
B+/B-	Digital Quadrature output. Signal is a RS-422 compatible square wave. Pulses are 90 out of phase with A+/A- outputs. Please see below.
Index Window	The Index Window defines one particular fringe on the grating

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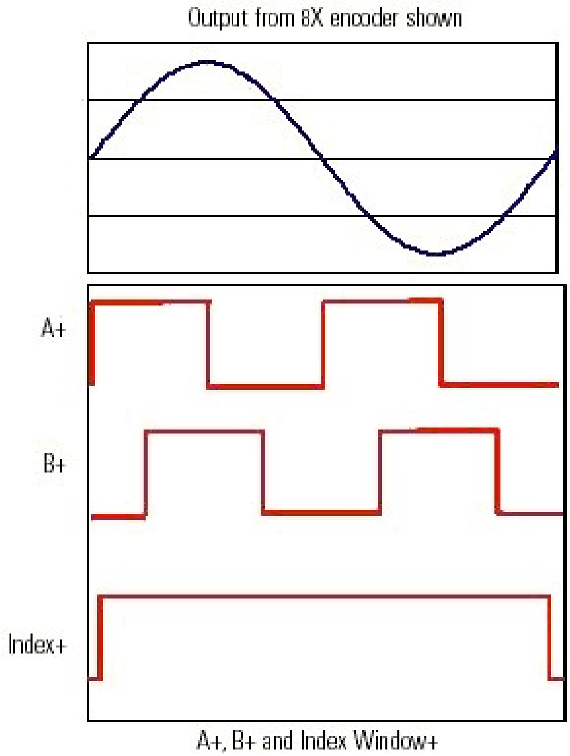

Figure 4: Encoder Digital Output Signals

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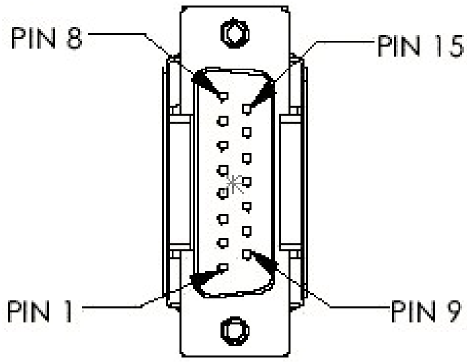
Encoder Connector



Encoder Connector

Encoder Connector Pin Definitions

PIN	FUNCTION
1	Reserved – Do not connect.
2	Reserved – Do not connect.
3	Reserved – Do not connect.
4	A- quadrature
5	A+ quadrature
6	Reserved – Do not connect.
7	Sine+
8	Cosine+[2]
9	B- quadrature
10	B+ quadrature
11	Reserved – Do not connect.
12	+5VDC ±5% @ 60mA
13	Ground
14	Index Window+

15	Index Window-

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Cleaning Scales and Head Assembly

General Particle Removal

General Particles on either the scale or head assembly can be removed by blowing off the contamination with nitrogen, clean dry air, or similar gas. It may be necessary to remove motor covers to enhance this process.

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Contamination Removal

The combination of a very small gap between the encoder and scale and the encoder size itself makes access and cleaning of the scale or encoder nearly impossible. If it is suspected that the encoder system has been contaminated the motor should be returned to the factory for servicing.

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Motors with Linear Ball and Roller Slides

Some Equipment Solutions stages use linear ball or roller slides as their primary means of guidance. This section describes the special issues related to those motors.

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Rated Life

The rated life "L" of a linear slide is the length of travel endured by the slide under a specified condition. Since in reality, life varies from one slide to another, industry normally uses the L10 life rating which is defined as the length of travel that 90% of apparently identical slides will complete before the first evidence of failure.

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Speed Factor

The effect of speed on the load rating of a slide can be accounted for by a speed factor:

$$fs = \sqrt[m]{\frac{30}{V}}$$

Where:

V = Speed of the slide movement in inches/min (when the speed varies during the cycle, the peak value should be used)

m = 3 for ball slides, or 10/3 for roller slides

Note: When the speed is less than 30 in/min, fs = 1

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Temperature Factor

When the temperature of the slide exceeds certain limits, it reduces the hardness of contacting elements and consequently affects the load rating of the slide. Therefore, its load rating shall be adjusted by a temperature factor "ft". The values of this factor are presented in Table 5: Bearing Temperature.

Table 5: Bearing Temperature

Temperature, Deg. F	Contacting Elements Temperature Factor, "ft"	
	Steel	Stainless Steel
220	1	1
300	0.9	1
400	0.75	0.9
500	not recommended	0.75

Note: When specifying slides for elevated temperature service, it should be kept in mind that the Delrin retainers found in many slides are not recommended for temperatures above 180 degrees Fahrenheit.

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Load Type Factor

In reality, the load endured by a slide can never be absolutely smooth, but rather is a sum of variable forces that include working load, inertial forces, vibrations, impacts, occasional loads, etc. In order to have their influence taken into account, the load rating of the slide shall be adjusted by a load type factor "fw". The values of "fw" per formula (2) and (3) are presented in Table 6: Load Factors.

Table 6: Load Factors

Condition of Load	Value of "fw"
Relatively smooth motion	1 to 1.5
Motion with impacts	2 to 3

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Life Formula for Ball and Roller Slides

Based on the above definitions and role of different factors, the life of linear slides can be obtained from the following formula:

$$L10 = \left(\frac{C \times fs \times ft}{Pc \times fw} \right)^m \times 10^7 \text{ inches}$$

Where:

L10 =	life of the slide at 90% or reliability as defined above (in inches)
C =	catalog "load capacity" of the slide in lbs. (which is a load that corresponds to an L10 life of 10 million inches, provided the factors fs, ft and fw are equal to 1
Pc =	calculated effective load slide is subjected to in lbs. (fs, ft and fw are factors as described above.)
m =	3 for ball slides, or 10/3 for roller slides.

When other than 90% reliability is required (for instance, "K"% reliability), the known value of L10 shall be multiplied by a reliability factor "fr" so that:

$$Ln = fr \times L1\ 0$$

Where:

Ln = rated life at the reliability of K% (n = 100-K).

The values of the factor "fr" are presented in Table 3.

Table 7: Bearing Life Reliability

RELIABILITY K%	"Ln" rated life	"fr" reliabilityfactor
50	L50	5.00
90	L10	1.00
95	L5	0.62
97	L3	0.44
99	L1	0.21

The general formula for the life of a linear slide is expressed as follows:

$$Ln = fr \times \left(\frac{C \times fs \times ft}{Pc \times fw}\right)^{m} \times 10^{7} \text{ inches}$$

Design considerations lead to the selection of a ball slide. Find the life at 95% reliability (L5 life) under the following conditions:

- Peak speed during the cycle: V= 150 in/mint
- Working temperature of slide = 150 deg.F
- Calculated effective load the slide is subjected to: Pc = 20 Ibs.
- Type of load: Moderate vibration, no impacts.

Solution:

1. With the formula (1) the speed factor "fs" is found as:

$$fs = \sqrt[3]{\frac{30}{150}} = 0.58$$

2. The value of the temperature factor '~' is found in Table 1 as: ft = 1.
3. Using Table 2, the value of the type of load factor can be estimated as: fw = 1.25.
4. The value of reliability factor "fr" is found in Table 3 as: fr= 0.62.
5. The value of the load capacity for the bearing is C= 60 Ibs.
6. The required life of the slide can then be calculated using formula (3):

$$L5 = 0.62 \times \left(\frac{60 \times 0.58 \times 1}{20 \times 1.25}\right)^3 \times 10^7 = 1.67 \times 10^7 \text{ inches}$$

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1.1 Moment Load Ratings

A =	Distance (inches) from slide centerline to line of acting force.
F =	Acting force (lbs.)
L =	Published load capacity (lbs.)
M_1, M_2, M_3 =	Moment load rating (lbs. - inch).
m1 - m2 - m3 =	Acting moment load (lbs. - inch).

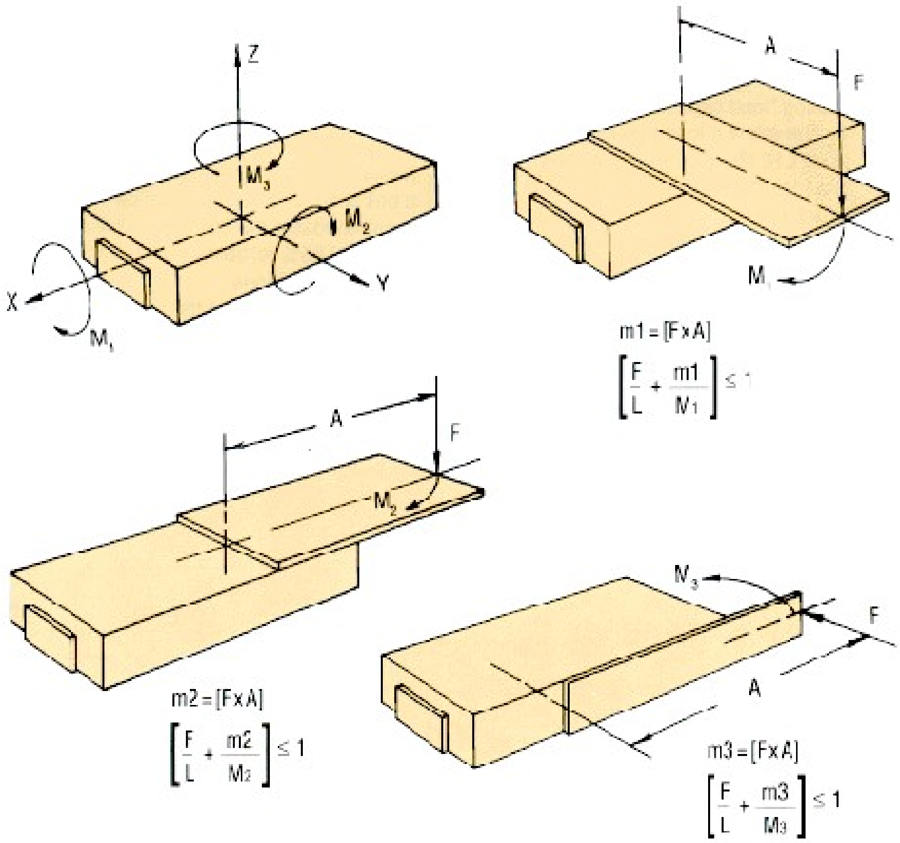

Figure 6: Stage Moments

Please contact the factory for detailed Moment Load Ratings (M1, M2 and M3) for your particular Equipment Solutions Stage

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Lubrication and Maintenance

The bearings and their surfaces are preconditioned with a thin layer of machine oil. Under normal operating conditions there should be no need for further lubrication. In situations where the stage temperature is elevated by either the ambient or through long periods of fast motions some lubrication may be needed. Use only approved lightweight machine tool oil. Avoid finger contact with the bearings and their surface. Always re-lubricate surfaces after cleaning with and solvent.

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Motors with Coil Temperature Sensor

Some versions of Equipment Solutions voice coil motors can be optionally configured with a coil temperature sensor. The sensor used for this purpose is a type Thermistor type element. Temperature rating is from –50 to 150 °C (-58 to 302 °F). The specified thermistor has an accuracy of ±1°C and has a dissipation constant of 1.4 mW/°C. Additionally the sensor has a time constant of 15 seconds and a temperature coefficient of -4.40 % / °C. In most cases this signal is routed to the main motor connector. Please refer to Table 1: Motor with PSD Sensor Connector (P1) for pin assignment information for this function. There is no polarity in regard to this function.

It is recommended that the temperature of the coil does not ever exceed 100° C (212° F). Should the temperature of the coil approach this limit some sort of enhanced convection cooling using a fan may be necessary.

Table 8: Coil Thermistor Characterization Data

Temp °C	Temp Accy. ± °C	R_T / $R_{25\ °C}$	Temp Coef % / °C
-50	2.5	69.27	-7.25
-45	2.4	48.55	-6.98
-40	2.3	34.47	-6.73
-35	2.2	24.78	-6.49
-30	2.1	18.01	-6.27
-25	2.0	13.24	-6.06
-20	1.9	9.832	-5.86
-15	1.8	7.372	-5.67
-10	1.7	5.579	-5.49
-5	1.6	4.258	-5.32
0	1.5	3.277	-5.14
5	1.4	2.546	-4.97
10	1.3	1.993	-4.82

15	1.2	1.573	-4.67
20	1.1	1.250	-4.53
25	1.0	1.000	-4.39
30	1.1	0.8055	-4.26
35	1.3	0.6528	-4.14
40	1.4	0.5323	-4.03
45	1.6	0.4365	-3.91
50	1.7	0.3599	-3.81
55	1.9	0.2983	-3.70
60	2.0	0.2486	-3.60
65	2.1	0.2082	-3.50
70	2.3	0.1753	-3.40
75	2.5	0.1482	-3.31
80	2.6	0.1258	-3.23
85	2.8	0.1073	-3.14
90	2.9	0.09189	-3.06
95	3.0	0.07899	-2.99
100	3.2	0.06816	-2.90
105	3.4	0.05906	-2.83
110	3.6	0.05134	-2.77
115	3.8	0.04479	-2.70
120	4.0	0.03920	-2.64
125	4.2	0.03441	-2.57
130	4.4	0.03030	-2.52
135	4.6	0.02676	-2.46
140	4.8	0.02369	-2.40
145	5.0	0.2104	-2.35
150	5.2	0.01873	-2.30

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