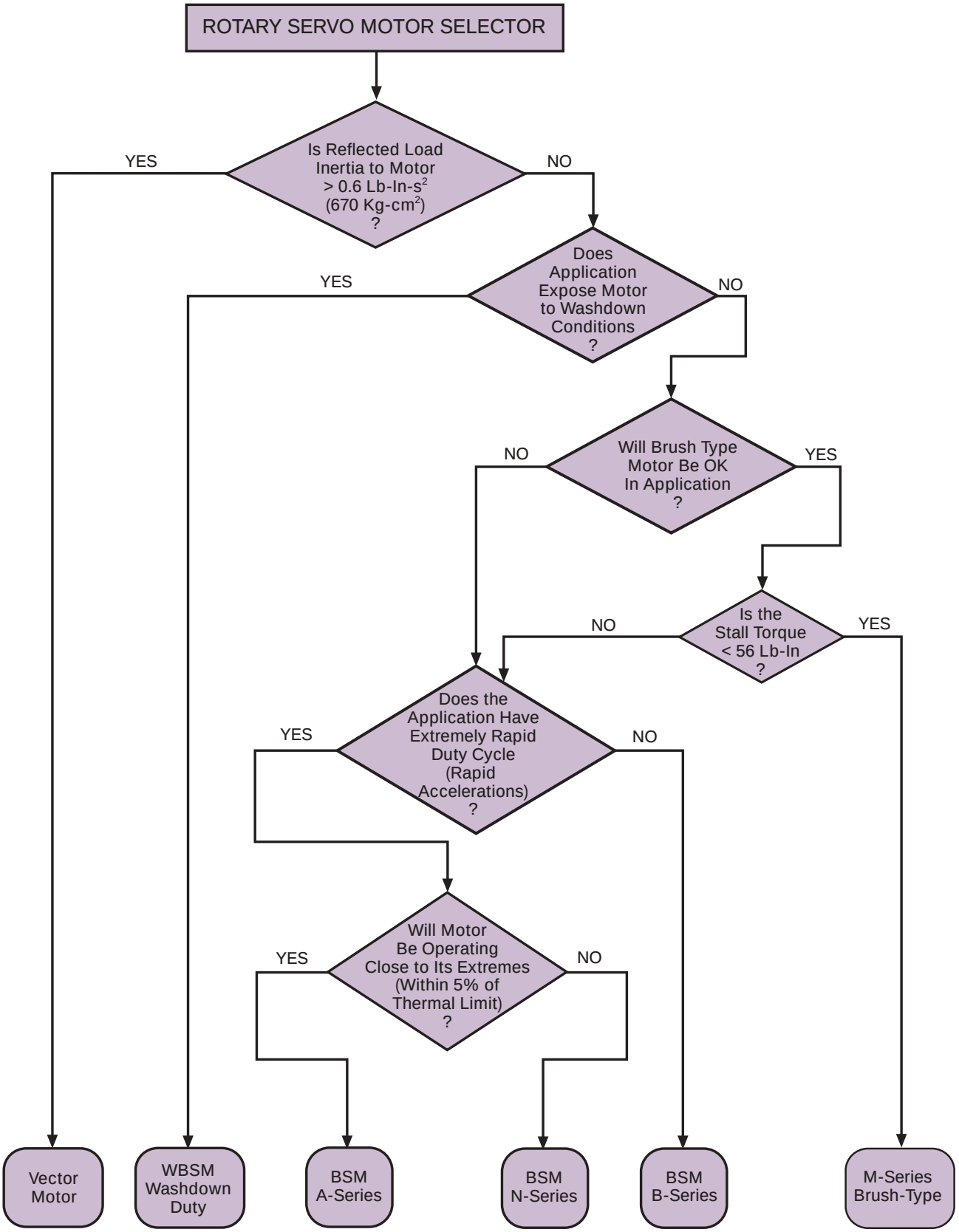
Engineering Information

- Servo Motor Selector
- Calculating Servo Motor Requirements
- Servo Motor Requirement Sheet
- How to Read Speed-Torque Curves
- How to Read Motor Information
- Linear Motor Selector
- Calculating Linear Motor Requirements
- Linear Motor Requirement Sheet
- Linear Motor Sizing Worksheet
- Linear Motor Block Diagrams
- Linear Motor Hall Effect Truth Table
- Linear Motor Thermal Considerations
- Frequently Asked Linear Motor Questions
- Glossary
- Conversion Tables


ROTARY SERVO MOTOR SELECTOR
Is Reflected Load Inertia to Motor > 0.6 Lb-In-s² (670 Kg-cm²) ?
YES
NO
Does Application Expose Motor to Washdown Conditions ?
YES
NO
Will Brush Type Motor Be OK In Application ?
NO
YES
Is the Stall Torque < 56 Lb-In ?
NO
YES
Does the Application Have Extremely Rapid Duty Cycle (Rapid Accelerations) ?
YES
NO
Will Motor Be Operating Close to Its Extremes (Within 5% of Thermal Limit) ?
YES
NO
Vector Motor
WBSM Washdown Duty
BSM A-Series
BSM N-Series
BSM B-Series
M-Series Brush-Type

Calculating Servo Motor Requirements

In selecting a motion control package, one of the areas requiring identification is the mechanics of the load which will be moved. Once this physical data is obtained, the proper matching of motor and control can easily begin.

The mechanics of the load involve both friction (which is easy to understand) and inertia (which is an unknown, since we have difficulty in recalling the physics we had in school).

The first part of the equation, determining friction of the load, can be accomplished by either estimating, or measuring by simply using a torque wrench.

The second part is determining the inertia. Inertia is the resistance of an object to be accelerated, or decelerated. In motion control, inertia is an important parameter since it defines the torque required to accelerate the load and get it into position.

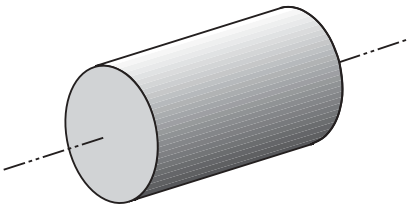
If no one has told you what the inertia is, then to answer this question, you will have to do a calculation. However, once sufficient information is obtained, the task is relatively simple.

To determine the inertia, the mechanical linkage system which will be moved will be analyzed. These mechanical systems can be divided into four basic categories: direct drive, gear drive, tangential drive, and leadscrew drive.

In the following, each of these mechanical linkage categories and relevant formulas for calculating the load parameters will be presented. In all instances, the formulas reflect the load parameters as “seen” by the motor. Reflecting all these parameters back to the motor shaft make the calculation easier for selecting the motor and control for your motion control application.

Inertia of a Cylinder (Figure 1)

Solid Cylinder:



where
J = inertia (lb-in-s^2)
W = weight (lb)
R = radius (inch)
g = gravitational constant (386 in/s^2)
L = length (inch)
p = density (lb/in^3)

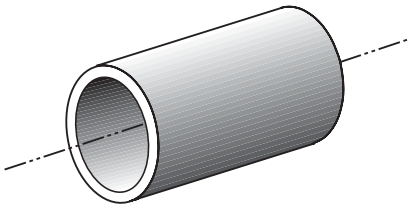
For a known weight and radius:

$$J = \frac{1}{2}\frac{W R^2}{g}$$

For a known density, radius, and length:

$$J = \frac{1}{2}\frac{\pi L p R4}{g}$$

Hollow Cylinder:



where
J = inertia (lb-in-s^2)
W = weight (lb)
Ro = outer radius (inch)
Ri = inner radius (inch)
g = gravitational constant (386 in/s^2)
L = length (inch)
p = density (lb/in^3)

For a known weight and radius:

$$J = \frac{1}{2}\frac{W}{g}\ (Ro2 + Ri2)$$

For a known density, radius, and length:

$$J = \frac{1}{2}\frac{\pi L p}{g}\ (Ro4 - Ri4)$$

Material	Density (lb/in^3)
aluminum	.096
copper	.322
plastic	.040
steel	.280
wood	.029

First, the formulas for calculating the inertia of a cylinder. The inertia of a cylinder can be calculated if either the weight and radius are known; or the density, radius, and length are known. Figure 1 presents the equations.

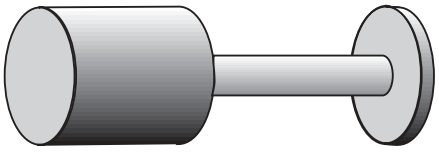
As an example, if the cylinder were a lead screw with a radius of .312 inches and a length of 22 inches, then the inertia would be:

$$J = \frac{1}{2}\frac{\pi L p R^4}{g} = \frac{1}{2}\frac{\pi (22)(.28)(.312)^4}{386} = 0.000237 \text{ lb-in-s}^2$$

These equations are important since the inertia of mechanical components (i.e. shafts, gears, drive rollers, leadscrews, etc.) can be calculated by using them. Once the inertia is determined, it becomes just a task of reflecting that load inertia and friction through the mechanical linkages to what the motor will “see”.

Direct Drive (Figure 2)

Direct Drive



where
S_m = motor speed (rpm)
S_1 = load speed (rpm)
T_m = motor torque (lb-in)
T_1 = load torque (lb-in)
J_t = total inertia (lb-in-s^2)
J_1 = load inertia (lb-in-s^2)
J_m = motor inertia (lb-in-s^2)

speed (motor) = speed (load)
$S_m = S_1$

torque at motor = torque at load
$T_m = T_1$

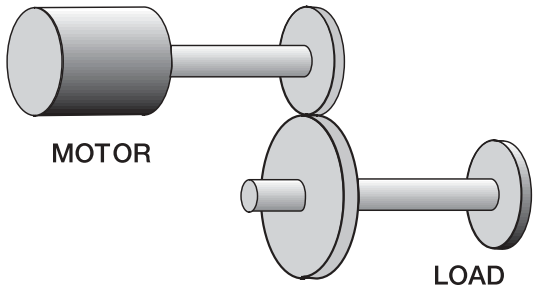
total inertia = inertia (load) + inertia (motor)
$J_t = J_1 + J_m$

The simplest of packages is the first basic category, the direct drive. This would not require the load parameters to be reflected back, since there are no mechanical linkages involved.

The equations for the direct drive are presented in Figure 2. The speed of the load is the same as the motor, the friction of the load is the friction which the motor must overcome, and the load inertia is directly what the motor would “see”.

Gear Drive (Figure 3)

Gear Drive:



where
S_m = motor speed (rpm)
S_1 = load speed (rpm)
N = gear ratio
N_1 = number of load gear teeth
N_m = number of motor gear teeth
T_m = motor torque (lb-in)
T_1 = load torque (lb-in)
e = efficiency
J_t = total inertia (lb-in-s^2)
J_1 = load inertia (lb-in-s^2)
J_m = motor inertia (lb-in-s^2)

speed (motor) = speed (load) x gear ratio

$$S_m = S_1 \times N$$

$$\text{or } S_m = S_1 \times N_1 \div N_m$$

torque at motor = torque at load ÷ gear ratio

$$T_m = \frac{T_1}{Ne}$$

total inertia = inertia (load) ÷ (gear ratio^2) + inertia (motor)

$$J_t = \frac{J_1}{N^2} + J_m$$

In a gear application, since there are mechanical linkages between the load and motor, the load parameters must be reflected back to the motor shaft. Figure 3 presents the equations.

As an example, if a solid cylinder with a diameter of 4 inches and weighing 6 pounds is connected thru a 3:1 gear, the reflected inertia would be determined by the following:

First, calculating inertia for a solid cylinder:

$$J_{load} = \frac{1}{2}\frac{W R^2}{g} = \frac{1}{2}\frac{6\,(2)^2}{386} = .031 \text{ lb-in-s}^2$$

reflecting this inertia thru the gear ratio:

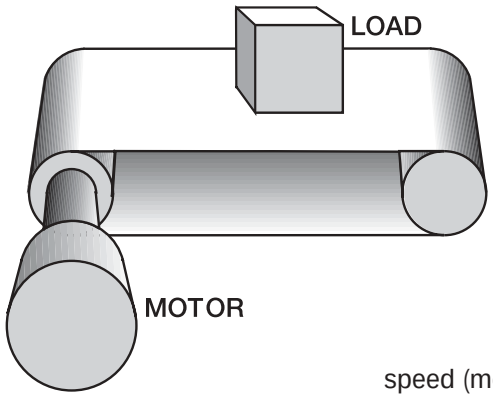
$$J_{ref} = \frac{J_{load}}{N^2} = \frac{.031}{(3)2} = .0034 \text{ lb-in-s}^2$$

The total reflected load inertia which the motor would “see” would be .0034 lb-in-s^2.

The inertia of the gears should be included in the determination of total load inertia to be really accurate (this can be obtained from literature or calculated using the formulas for the inertia of a cylinder). Efficiencies of the gearing should also be considered when calculating torques.

Tangential Drive (Figure 4)

Tangential Drive:



where S_m = motor speed (rpm)
V_1= load speed (in/min)
R= radius (inches)
T_1= torque reflected to motor (lb-in)
F1= load force (lb)
Tf= friction torque (lb-in)
Ff= friction force (lb)
Jt= total inertia (lb-in-s^2)
W= load weight + belt weight (lb)
Jp= pulley inertia (lb-in-s^2)
Jm= motor inertia (lb-in-s^2)
g= gravitational constant (386 in/s^2)

$$\text{speed (motor)} = \frac{1}{2\pi} \times \frac{\text{speed (load)}}{\text{radius}}$$

$$S_m = \frac{1}{2\pi} \times \frac{V_1}{R}$$

$$\text{load torque} = \text{load force} \times \text{radius}$$

$$T_f = F_f R$$

$$\text{friction torque} = \text{frictional force} \times \text{radius}$$

$$T_f = F_f R$$

$$\text{total inertia} = (\text{weight} \times \text{radius}^2)\ (\text{gravity}) + \text{inertia (pulley \#1)} + \text{inertia (pulley \#2)} + \text{inertia (motor)}$$

$$J_t = \frac{W\ R_2}{g} + J_{p1} + J_{p2} + J_m$$

For this type of drive, the load parameters have to be reflected back to the motor shaft. A tangential drive can be a timing belt and pulley, chain and sprocket, or rack and pinion. See Figure 4 for formulas.

As an example, a belt and pulley arrangement will be moving a weight of 10 lbs. The pulleys are hollow cylinders of 5 pounds each with an outer radius of 2.5 inches and an inner radius of 2.3 inches. The total inertia would be determined by:

calculating inertia for a hollow cylinder pulley:

$$J_p = \frac{1}{2}\frac{W}{g}(R_0^2 + R_i^2) = \frac{1}{2}\frac{5}{386}(2.5^2 + 2.3^2) = 0.0747 \text{ lb-in-s}^2$$

calculating load inertia:

$$J_1 = \frac{W\ R^2}{g} = \frac{10\ (2.5)^2}{386} = 0.1619 \text{lb-in-s}^2$$

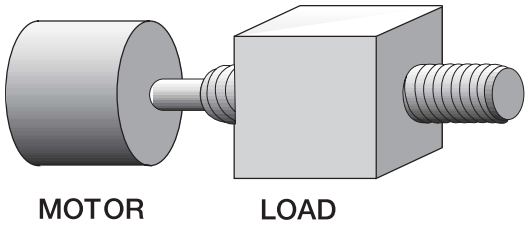
the total inertia reflected to the motor shaft would be the sum of the above:

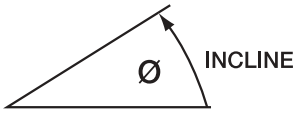
$$J = J_1 + J_{P1} + J_{P2} = 0.1619 + 0.0747 + 0.0747 = 0.3113 \text{ lb-in-s}^2$$

Don't forget to include the inertia of the pulleys, sprockets, or pinion gears in the determination of total inertia.

Leadscrew Drive (Figure 5)

Leadscrew Drive:





where
Sm = motor speed (rpm)
V1 = load speed (in/min)
P = pitch (rev/inch)
T1 = torque reflected to motor (lb-in)
F1 = load force (lb)
Fp1 = preload force (lb)
e = efficiency
Tf = friction torque (lb-in)
Ff = friction force (lb)
u = coefficient of friction
W = load weight (lb)
Jt = total inertia (lb-in-s2)
J1s = leadscrew inertia (lb-in-s2)
Jm = motor inertia (lb-in-s2)
g = gravitational constant (386 in/s2)

speed (motor) = speed (load) x pitch

$S_m = V_1 \times P$

load torque reflected to motor = $\frac{1}{2\pi}\frac{\text{load force}}{\text{pitch x eff}} + \frac{1}{2\pi}\frac{\text{preload force}}{\text{pitch}} \times 0.2$

$T_1 = \frac{1}{2\pi}\frac{F_1}{P\,e} + \frac{1}{2\pi}\frac{F_{p1}}{P} \times 0.2$

friction torque = $\frac{1}{2\pi}\frac{\text{frictional force}}{\text{pitch x eff}}$

$T_f = \frac{1}{2\pi}\frac{(\mu \times W\cos\phi + W\sin\phi)}{P\,e}$

total inertia = $\frac{\text{load}}{\text{gravity}}\left(\frac{1}{2\pi\ \text{pitch}}\right)^2 + \text{leadscrew inertia} + \text{motor inertia}$

$J^t = \frac{W}{g}\left(\frac{1}{2\pi P}\right)^2 + J_{1s} + J_m$

The load parameters have to be reflected back to the motor shaft for this type of drive as well. The inertias which have to be considered include the leadscrew as well as the load. If the leadscrew inertia is not readily available, the formula for a cylinder may be used. Figure 5 presents the formulas for determining reflected inertias.

As an example, a 200 lb load will be positioned via a leadscrew which is 0.5 inch in radius and 44 inches long. The pitch is 5 rev/inch. The total load and leadscrew inertia would be:

calculating reflected load inertia:

$$J_1 = \frac{W}{g}\frac{1}{2\pi P} = \frac{200}{386}\frac{1}{2\pi 5} = 0.00052 \text{ lb-in-s}^2$$

calculating leadscrew inertia:

$$J_{1s} = \frac{1}{2}\frac{\pi L \rho R^4}{g} = \frac{1}{2}\frac{\pi (44)(.28)(.5)^4}{386} = 0.00313 \text{ lb-in-s}^2$$

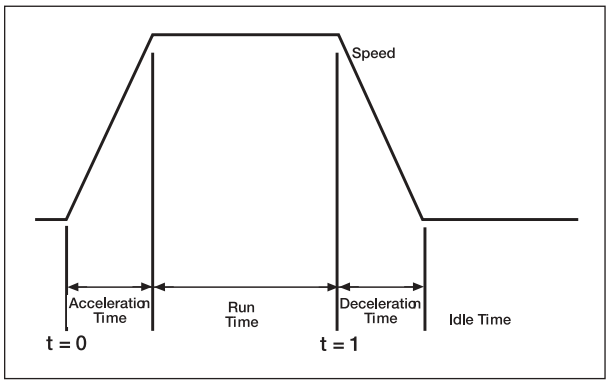
The total inertia which would be connected onto the motor shaft would be the sum of these:

$$J = J_1 + J_{1s} = 0.00052 + 0.00313 = 0.00365 \text{ lb-in-s}^2$$

For precision positioning applications, the leadscrew is sometimes preloaded to eliminate or reduce backlash. If preloading is used, the preload torque must be included since it can be significant. The leadscrew's efficiency must also be considered when finally determining torques.

The Move Profile

Typical Move Profile (Figure 6)

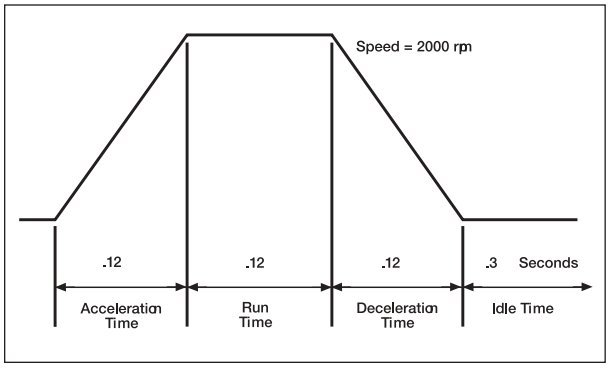


A move profile defines the desired acceleration rate, run time, speed and acceleration rate of the load. For example, suppose with a system at rest (time = 0 in Figure 6), the positioning controller issues a command to the motor to start motion. At t = 0, with full power applied, the motor has not yet started to move. At this instant, there is no feedback signal, but the error signal is large.

As friction and inertia torques are overcome, the motor and load begin to accelerate. As the motor reaches the commanded speed, the error signal is reduced, and in turn the voltage applied onto the motor is reduced. As the system stabilizes at running speed only nominal power (voltage and current) are required (to overcome friction). At time t = 1, the load approaches the desired position and begins to decelerate.

Applications with these move profiles result in most of the input energy dissipated as heat. Such packages are therefore limited by the maximum power dissipation capacity of the motor. In order to guarantee that maximum power handling capability of the motor is not exceeded, each application must be investigated individually. Basic motor dynamic equations must be solved and power calculated for each motor in order to determine whether the application will be handled successfully.

Example Move Profile (Figure 7)



The first step in the process is identifying the acceleration rate. For an example, let's assume that our application has a move profile as identified in Figure 7. The acceleration rate can be determined from the speed and the acceleration time, as follows:

$$\text{accel rate} = \text{speed} \div \text{accel time}$$

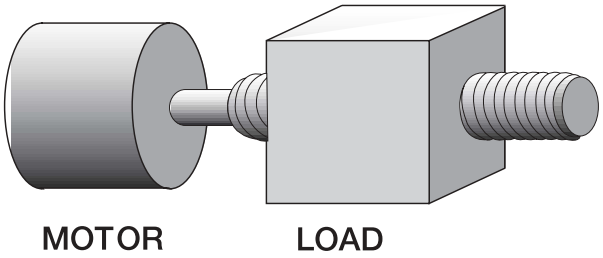
$$\text{accel rate (rad/sec}^2) = \frac{W_m(\text{rad/sec})}{t_{acc}(\text{sec})}$$

To convert from RPM to rad/sec divide by 9.55.

For our example the acceleration rate is:

$$\text{accel rate (rad/sec}^2) = \frac{209\ (\text{rad/sec})}{.12\ (\text{sec})} = 1741.6\ \text{rad/sec}^2$$

Parameters Used for Example



Baldor BSM Series
Motor Parameters
Inertia = .0037 lb-in-s^2
Continuous Stall Torque = 14.4 lb-in
Torque Constant = 4.8 lb-in/amp
Resistance = 4.5 ohms

Load Conditions
Load = 200 lbs
Ball Screw Inertia = .00313 lb-in-s^2
Friction Torque = .95 lb-in

Acceleration Torque

The torque required to start the load moving, termed acceleration torque (Tacc), is that torque which is needed to overcome the mechanical friction and inertia. Expressed mathematically, the equation is:

$$T_{acc} = (J_t)\ (\text{accel rate}) + T_f$$

where T_{acc} is acceleration torque (lb-in)
J_t is the total inertia (load and motor lb-in-s^2)
accel is rotary acceleration of the motor shaft (rad/sec^2)
T_f is the total friction torque of the package (lb-in)

As an example, the application calls for moving a 200 lb load thru a leadscrew (having an inertia of .00313 lb-in-s^2), at an acceleration rate of 1741.6 rad/sec^2. Typical motor parameters which will be used in this analysis are indicated in Figure 9.

$$T_{acc} = (J_t)\ (\text{accel rate}) + T_f$$
$$T_{acc} = (J_l + J_{ls} + J_m)\ (\text{accel rate}) + T_f$$
$$T_{acc} = (0.00052 + 0.00313 + 0.0037)\ (1741.6) + 0.95$$
$$= 12.8 + 0.95$$
$$= 13.75 \text{ lb-in}$$

The motor must be capable of providing torque to accelerate the entire mechanics of the load (friction plus inertia), as well as torque to move itself. In this example, the motor must be capable of supplying a total acceleration torque of 13.75 lb-in.

Torque Over the Duty Cycle

The motor must also be capable of providing a certain amount of torque continuously over the duty cycle, or move profile as was defined earlier. In order to determine this, we must look at the rest of the move profile and determine the torques associated with them.

During run time, the torque required is:

$$T_{run} = T_f$$
$$T_{run} = 0.95 \text{ lb-in}$$

During the stopping cycle, or deceleration, the torque required is:

$$T_{dec} = -(J_t)\ (\text{accel rate}) + T_f$$
$$T_{dec} = -(.00052 + .00313 + .0037)\ (1741.6) + .95$$
$$T_{dec} = -12.8 + .95$$
$$T_{dec} = -11.85 \text{ lb-in}$$

Now that these torques are identified, the amount of torque required over the move profile can be calculated. This is termed “determining the RMS torque”. It is calculated by simply inserting the figures from the previous page in to the following equation:

$$T^2_{RMS} = \frac{(T^2_{acc} \times t_{acc}) + (T^2_{run} \times t_{run}) + (T^2_{dec} \times t_{dec})}{t_{acc} + t_{run} + t_{dec} + t_{idle}}$$

$$T^2_{RMS} = \frac{(13.75)^2 \times 0.12 + (0.95)^2 \times 0.12 + (11.85)^2 \times 0.12}{0.12 + 0.12 + 0.12 + 0.3}$$

$$T^2_{RMS} = \frac{22.6 + 0.108 + 16.8}{0.66} = 59.86$$

$$T_{RMS} = 7.73 \text{ lb-in}$$

Thus, this application requires 7.73 lb-in of torque. The motor for this example has the capability of providing a continuous torque of 14 lb-in.

Control Section

The next step is to determine requirements for a suitable control (amplifier). The control must be able to supply sufficient acceleration current (for the application's acceleration requirements), as well as continuous current (or "RMS" current for the application's duty cycle requirements).

Acceleration current which must be supplied to the motor is calculated from:

$$\text{current (amps), acceleration} = \frac{\text{acceleration torque (lb-in)}}{\text{motor torque constant (lb-in/amp)}}$$

$$I_{acc} = \frac{T_{acc}}{K_t}$$

$$= \frac{13.75 \text{ (lb-in)}}{4.8 \text{ (lb-in/amp)}} = 2.86 \text{ amps}$$

RMS current over the duty cycle, which the control must be capable of supplying to the motor, is calculated from:

$$\text{current, RMS (amps)} = \frac{\text{RMS torque (lb-in)}}{\text{motor torque constant (lb-in/amp)}}$$

$$I_{RMS} = \frac{T_{RMS}}{K_t}$$

$$= \frac{7.73 \text{ (lb-in)}}{4.8 \text{ (lb-in/amp)}} = 1.61 \text{ amps}$$

Thus the servo control which would be selected must have the capability of supplying currents of 2.86 amps for acceleration and 1.16 amps continuously (RMS over the duty cycle).

Servo Motor Requirement Sheet

Company _____ Date _____

Contact _____ E-Mail _____

Title _____ Phone _____

Address _____ Fax _____

Address _____ Industry _____

City _____ Distributor _____

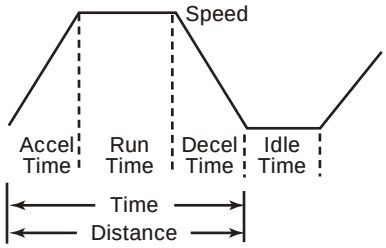
State, Zip _____ District Office _____

Describe the application and what you are trying to accomplish: Salesperson _____

_____

_____

Velocity Profile



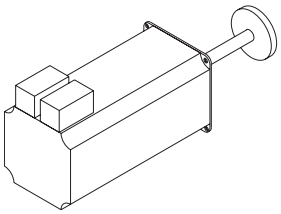
Specify

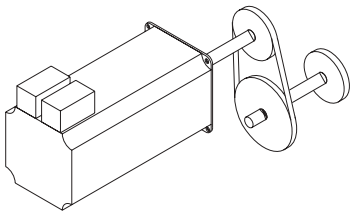
Speed	=	_____	RPM or in/sec or cm/sec
Accel time	=	_____	sec
Run time	=	_____	sec
Decel time	=	_____	sec
idle time	=	_____	sec

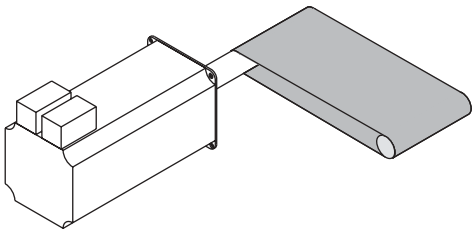
or:

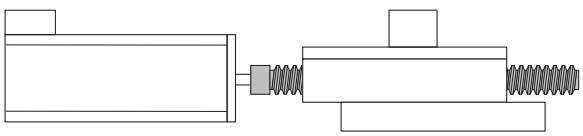
Distance	=	_____	radians, or _____in or cm
Time (total)	=	_____	sec
Idle time	=	_____	sec

Load Conditions









Direct Drive (Circle Units)

Load inertia	=	_____	lb-in-s² (kg-cm²)
Load friction	=	_____	lb-in (g-cm)

Reduction – belt or gearing (Circle Units)

Load inertia	=	_____	lb-in-s² (kg-cm²)
or diameter	=	_____	inch (mm)
and length	=	_____	inch (mm)
Load friction	=	_____	lb-in (g-cm)
Belt/gear ratio	=	_____	:1
Efficiency	=	_____	%

Linear – belt pulley or rack & pinion (Circle Units)

Load weight	=	_____	lbs (kg)
Belt/rack weight	=	_____	lbs (kg)
Pulley radius	=	_____	inch (mm)
Pulley inertias	=	_____	lb-in-s² (Kg-cm²)
Total friction	=	_____	lb-in (g-cm)
Gear ratio	=	_____	:1
Efficiency	=	_____	%

Linear – lead screw (Circle Units)

Load weight	=	_____	lbs (Kg)
load friction	=	_____	lb-in (g-cm)
Screw pitch	=	_____	rev/inch (mm/rev)
Screw inertia	=	_____	lb-in-s² (kg-cm²)
or Diameter	=	_____	inch (mm)
and Length	=	_____	inch (mm)
Efficiency	=	_____	%

How to Read Motor Speed-Torque Curves

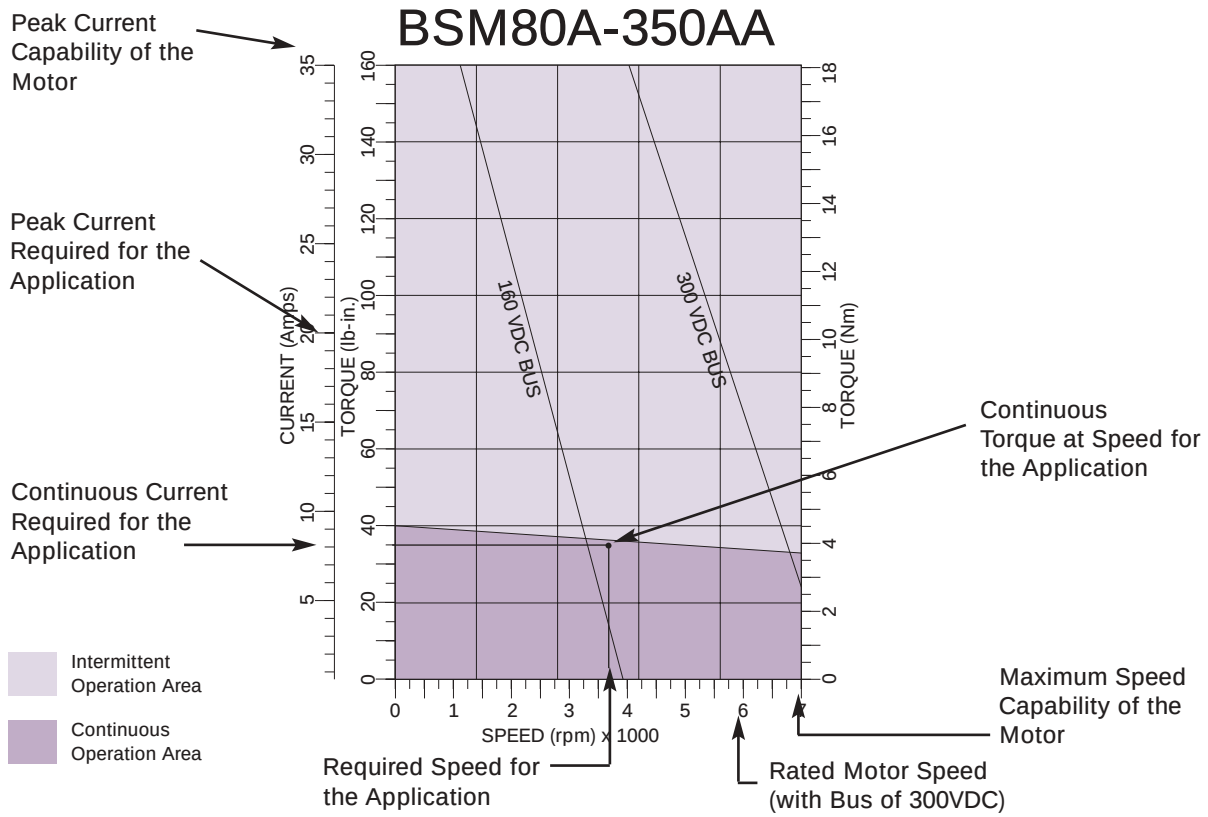
Baldor has provided the following curves in order to simplify the process of selecting both a motor and control for a specific application. The following paragraphs explain how the information in these curves should be interpreted.

In constant speed applications, motors are defined in terms of horsepower (which is torque at a base speed). Servo motors normally operate over a wide speed range. The curves show continuous torque (defined as torque which will not overheat the motor), and peak torque (defined as intermittent acceleration torque).

It is also necessary to know the current and voltage required for the motor to operate. The curves have a scale that shows current required for any torque, and voltage required for any speed.

As an example, an application requires a continuous torque of 35 lb-in at a speed of 3750 RPM. The peak torque required for acceleration is 80 lb-in.

This curve shows that the BSM80A-350AA will work in this application. The bus voltage required is 300VDC. The continuous and peak currents required is 8 and 18 amps. From this information, we select a 23H control (10 amps continuous, 20 amps peak) with a 230VAC input (300VDC Bus).



Contact Baldor for special windings, custom shafts/mountings, and custom specs. Precision balancing for high speed applications can be provided.

How to Read Motor Information

"RATED" VOLTAGE/SPEED

Adjustable speed drives, such as servos and vectors do not normally operate at one point. To determine the operating range, the motor's speed-torque curves are referenced.

"Rated" conditions refer to measurement points, and are selected as an easy and convenient "reference" or "measurement" point for the manufacturer. Manufacturers select a "rated voltage", operate with a "rated torque", to verify that "rated speed" is reached.

Note that any voltage may be applied. Thus, with the BSM series of brushless servo motors, either 160 VDC, 300 VDC, or 650 VDC may be applied. However the design limits must be observed. And those are:
1) maximum speed (rpm) limit, 2) demagnetization (max torque/current) limit, and 3) 650 VDC maximum.

MOTOR DATA

All Baldor BSM motors are 3-phase WYE connected. Connection is important because the motor/feedback is phase sensitive. All motor parameters are expressed as phase to phase (line-to-line) figures. This includes voltage constant, resistance and inductance.

The phase to phase voltage constant (back-emf) is a sinusoidal wave, which is measured while driving the motor (as a generator) at 1000 rpm, and measuring the output voltage. The peak of this measured output voltage is shown in the literature as Vpk/krpm; the RMS of the output voltage is Vrms/krpm.

Some data in the motor tables are expressed as "cold" figures (25°C), while others are "hot" (155°C) values. The cold figures are: voltage constant, torque constant, resistance, inductance. The hot figures are: continuous stall torque, current.

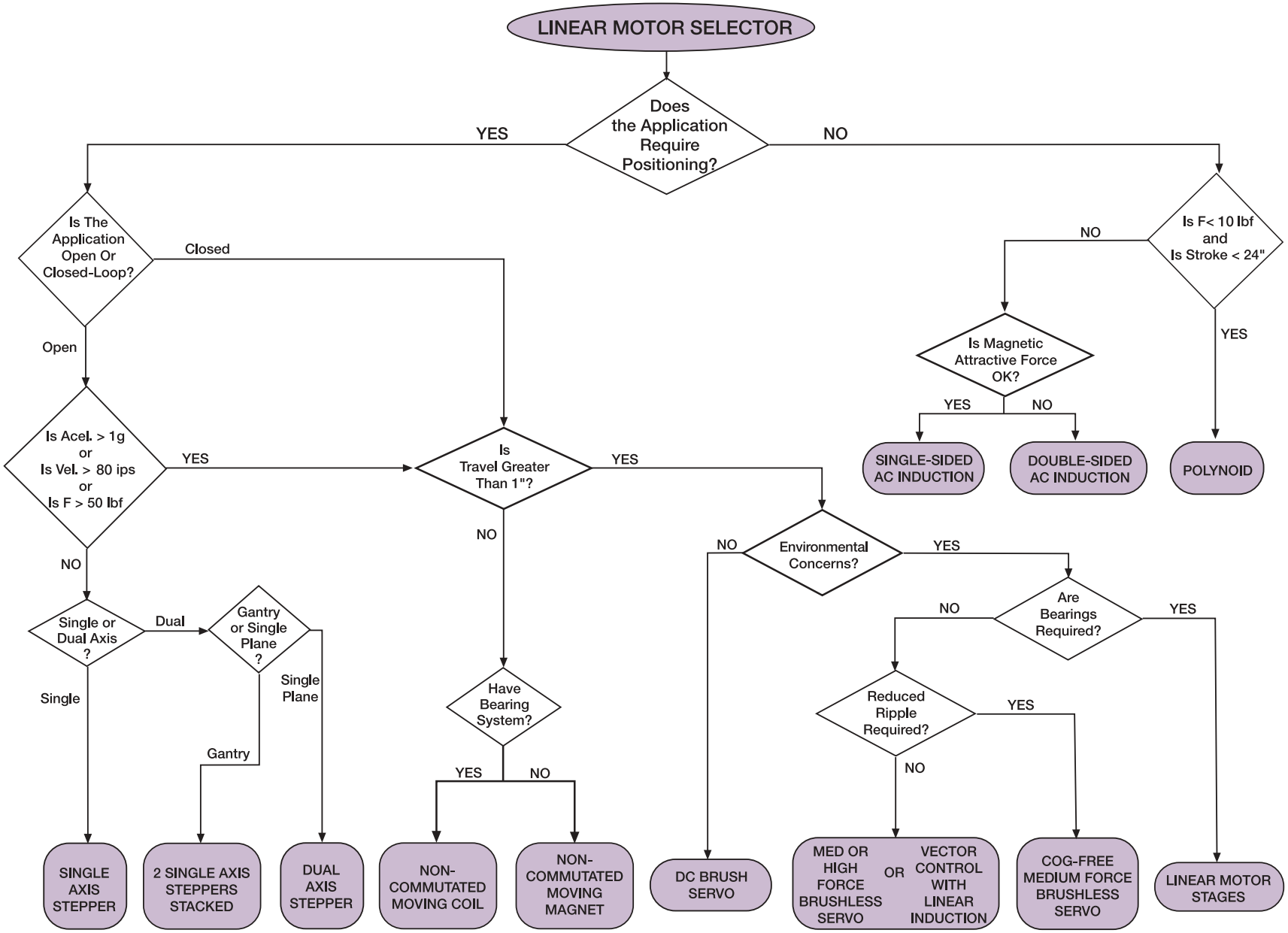
The temperature coefficient between cold and hot voltage constant (and torque constant) is 0.95 for BSM A series of motors, 0.90 for BSM N series, and 0.85 for BSM B series motors. Motor resistance changes by a factor of 1.5 from 25°C to 155°C.

MOTOR TEMPERATURE

The BSM series of servo motors are rated for a maximum continuous winding temperature of 155°C. This allows for a temperature rises of 130°C in a 25°C ambient.

The temperature rise of the motor windings depends upon the amount of torque which is being delivered to the load. In this brochure, the thermal limit line (line dividing dark and light shaded areas on the speed-torque curves) indicates the 155°C limit (130°C temperature rise).

The BSM motors include an internal thermal switch (bi-metallic) which is normally closed. It opens at 155°C ±5°. This switch may be connected to the input of a motion controller, programmable logic device, or other type of machine control. Any of these devices could then sense this switch and shut power down when the thermal switch opens.


LINEAR MOTOR SELECTOR
Does the Application Require Positioning?
YES
NO
Is The Application Open Or Closed-Loop?
Closed
Open
Is Acel. > 1g or Is Vel. > 80 ips or Is F > 50 lbf
YES
NO
Is Travel Greater Than 1"?
YES
NO
Is F< 10 lbf and Is Stroke < 24"
NO
YES
Is Magnetic Attractive Force OK?
YES
NO
SINGLE-SIDED AC INDUCTION
DOUBLE-SIDED AC INDUCTION
POLYNOID
Single or Dual Axis ?
Dual
Single
Gantry or Single Plane ?
Gantry
Single Plane
SINGLE AXIS STEPPER
2 SINGLE AXIS STEPPERS STACKED
DUAL AXIS STEPPER
Have Bearing System?
YES
NO
NON-COMMUTATED MOVING COIL
NON-COMMUTATED MOVING MAGNET
Environmental Concerns?
NO
YES
DC BRUSH SERVO
Are Bearings Required?
NO
YES
Reduced Ripple Required?
YES
NO
MED OR HIGH FORCE BRUSHLESS SERVO
OR
VECTOR CONTROL WITH LINEAR INDUCTION
COG-FREE MEDIUM FORCE BRUSHLESS SERVO
LINEAR MOTOR STAGES

Calculating Linear Motor Requirements

In order to determine the correct motor for a particular application it is necessary to be familiar with the following relations.

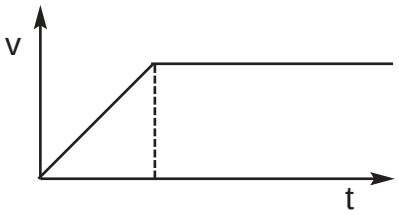
EQUATIONS OF MOTION

Basic kinematic equation: $x_o + v_o t = at^2/2$

a = acceleration (g's)
x = stroke (inch [m])
t = time (seconds)
v = velocity (in/sec [m/sec])
g = gravitational acceleration (in/sec^2[m/sec^2])

A trapezoidal velocity profile is common with linear motors and the basic kinematic equation can be manipulated to yield results based on what is known.

When time and stroke are known:



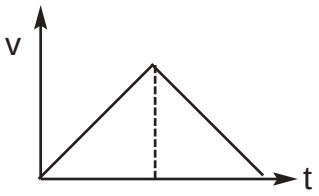
When time and velocity are known:

English	Metric
$a = \frac{2x}{386\ t^2}$	$a = \frac{2x}{9.81\ t^2}$

When velocity and stroke are known:

$a = \frac{v}{386\ t}$	$a = \frac{v}{9.81\ t}$

Another common velocity profile associated with linear motors is the triangular velocity profile. As before, the basic kinematic equation can be manipulated to solve for this case.



When time and stroke are known:

English	Metric
$a = \frac{4x}{386\ t^2}$	$a = \frac{4x}{9.81\ t^2}$

Example: Calculate the acceleration required to get to 200 in/sec [0.508 m/sec] in 0.050 sec.

English	Metric
$a = \frac{20}{386x0.050}$	$a = \frac{0.508}{9.81x0.050}$
a = 1.04 g's	a = 1.04 g's

Example: Calculate the acceleration required to get to move 1 in (0.0254 m) in 0.05 sec.

English	SI
$a = \frac{4 \times 1}{386x(0.050)^2}$	$a = \frac{4 \times 0.0254}{9.81x(0.050)^2}$
a = 4.14 g's	a = 4.14 g's

NEWTON'S SECOND LAW

Newton's Second Law provides a simple method of converting between forces, payloads, and accelerations. It states:

English	Metric
F = ma	F = mag

where,

F = Force	Lbs	N
m = payload	Lbs	kg
a = acceleration	g's	g's
g = gravitational accel	386in/sec	9.81 m/sec^2

Example: Calculate the force required to accelerate a 3.2 Lbs [1.45 kg] payload horizontally at 1.3 g's

English	Metric
F = 3.2Lbs x 1.3g	F = 1.45kg x 1.3g x 9.81m/sec^2
F = 4.16 Lbs	F = 18.5 N

Linear Motors

DUTY CYCLE

The duty cycle of a motor is defined as the time the motor receives power during a cycle divided by the total time of the cycle. When a linear motor receives power for more than thirty (30) seconds, it is operating at a duty cycle of 100%.

$$\text{Duty Cycle} = \frac{\text{time on}}{\text{time on + time off}} \text{ x100\%}$$

Example: During one cycle of operation a motor is on for 1 sec and off for 3 sec. What is the duty cycle of the motor for these conditions?

$$\text{Duty Cycle} = \frac{1}{1+3} \text{ x 100\%} = 25\%$$

Because duty cycles less than 100% allow time for the motor to cool, a lower duty cycle allows all linear motors, except steppers, to be run with more than three times their continuous current rating for a short period of time. Since force is proportional to current, motors operating at lower duty cycles can produce higher forces than when run continuously.

EFFECTIVE CONTINUOUS FORCE

The relation between the rated continuous force a motor can deliver and the effective continuous force it is capable of providing at a lower duty cycle is:

$$F_C = \frac{F_{D.C.}}{\sqrt{\frac{100}{D.C.}}}$$

Where	English	Metric
F_C = continuous force	Lbs	N
$F_{D.C.}$ = force at specified duty cycle	Lbs	N
$_{D.C.}$ = specified duty cycle	%	%

Example: Calculate the effective continuous force of a motor that provides 197 Lbs [877 N] of force at a 30% duty cycle.

English	Metric
F_{30} = 197 D.C. = 30%	F_{30}= 877 D.C. = 30
$F_C = \frac{197}{\sqrt{\frac{100}{30}}} = 108$ Lbs	$F_C = \frac{877}{\sqrt{\frac{100}{30}}} = 480$ N.

LINEAR MOTOR SELECTION PROCESS

Following is the selection process for an application that requires a cog-free brushless linear motor. The first section provides customer requirements. The second section provides the calculations that are necessary to make the motor selection. That last section demonstrates the effect of reducing duty cycle and acceleration on motor selection.

CUSTOMER REQUIREMENTS

Application	Optical inspection (moving a single-axis optics carriage assembly)
Stroke	60 in [1.52 m]
Duty Cycle	100%
Payload	40 Lbs. [18.1 kg]
Resolution	3 micron customer-supplied encoder
Load support	Customer-supplied bearings
Motion Profile	Low force ripple required. Payload must move full stroke in 0.90 sec.

English	Metric
$a = \frac{4 \text{ x}}{386\ t^2}$	$a = \frac{4 \text{ x}}{9.81 t^2}$
$a = \frac{4 \text{ x } 60}{386 \text{ x } (0.90)^2}$	$a = \frac{4 \text{ x } 1.52}{9.81 \text{ x } (0.90)^2}$
a = 0.77 g's	a = 0.77 g's

Linear Motors

CALCULATIONS

Acceleration and force must be calculated to select the appropriate linear motor. Acceleration is calculated with the following formula:

Force in calculated with the following formula:

	F = ma	F = mag
so,	F = 40 x 0.77	F = 18.1x 0.77x 9.81
F = 30.8 Lbs		F = 137N

MOTOR SELECTION

The linear motor that best meets the application requirements is the cog-free brushless linear motor model # LMCF08D. This motor's continuous force is 33 Lbs. [147N] and has a maximum acceleration at this 100% duty cycle of 0.77 g's.

EFFECTS OF LOWER DUTY CYCLES

	English	Metric
	$F_{DC} = F_C \sqrt{\frac{100}{DC}}$	$F_{DC} = F_C \sqrt{\frac{100}{DC}}$
	$F_{30} = 33 \sqrt{\frac{100}{50}}$	$F_{30} = 147 \sqrt{\frac{100}{50}}$
	$F_{30} = 60.2$ Lbs	$F_{30} = 267.9$ N
	m = 40 Lbs	m = 18.1 kg g = $9.81 \frac{m}{S^2}$
	$F_{30} - ma_{30}$	$F_{30} - ma_{30}g$
	$a_{30} = \frac{F_{30}}{m} = \frac{60.2}{40}$	$a_{30} = \frac{F_{30}}{mg} = \frac{267.9}{18.1 \times 9.81}$
	$a_{30} = 1.5$ g's	$a_{30} = 1.5$ g's

Using Newton's Second Law and leaving the payload unchanged, what acceleration is the LMCF08D motor capable of when operated at a 30% duty cycle?

Leaving the acceleration unchanged, what LMCF08D payload is the motor capable of moving when operated at 30% duty cycle?

	English	Metric
	$F_{30} = 60.2$ Lbs	$F_{30} = 267.9$ N
	m = 0.77 Lbs	m = 0.77 g's g = $9.81 \frac{m}{S^2}$
	$F_{30} - m_{30}a$	$F_{30} - m_{30}ag$
	$a_{30} = \frac{F_{30}}{a} = \frac{60.2}{0.77}$	$a_{30} = \frac{F_{30}}{ag} = \frac{267.9}{0.77 \times 9.81}$
	$m_{30} = 78.2$ Lbs	$m_{30} = 35.5$ kg

A reduction of duty cycle from 100% to 30% allows the LMCF08D motor to go from an acceleration of 0.77 g's to 1.5 g's and from a payload of 40 Lbs [18.1kg] to 78.2 Lbs [35.5 kg]. Both improvements cannot be realized simultaneously using the LMCF08D motor. Either a larger motor is needed or the requirements must be examined to determine which parameter takes precedence.

INITIAL REQUIREMENTS CHANGE

What motor best meets the following requirements?

	English	Metric
	F = ma	F = mag
so,	F = 40 x 0.9	F = 18.1 x 0.9 x 9.81
	F = 36 Lbs	F = 160N

Duty Cycle = 30%
Payload = 40 Lbs [18.1 kg]
Acceleration = 0.9 g's

$$F_c = \frac{F_{D.C.}}{\sqrt{\frac{100}{D.C.}}}$$

English	Metric
$F_c = \frac{36}{\sqrt{\frac{100}{30}}}$	$F_c = \frac{160}{\sqrt{\frac{100}{30}}}$
$F_c = 19.7$ Lbs	$F_c = 87.6$N

Since this is at a 30% duty cycle, the continuous force must be calculated.The

LMCF06D has a continuous force of 24.7 Lbs. [110N] and meets the acceleration and payload requirements of this application.

Linear Motor Requirement Sheet

Company _____ Date _____

Contact _____ E-Mail _____

Title _____ Phone _____

Address _____ Fax _____

Address _____ Industry _____

City _____ Distributor _____

State, Zip _____ District Office _____

Describe the application and what you are trying to accomplish: Salesperson _____

_____

_____

_____

Estimated quantity needed _____ Need: ☐ Immediate ☐ within 6 months ☐ within 12 months ☐ over 1 year

Please provide as complete as possible:

A) Motor Type Preferred

☐ Don't Know

Servo - Closed loop

☐ Brushless Cog-free, no magnetic attraction
☐ Brushless Iron-core
☐ Brush

Stepper - Open Loop

☐ Single Axis
☐ Dual Axis w/Air Bearing

Light Load, Short Stoke Applications

☐ Moving Coil - Customer Supplied Bearing
☐ Moving Magnet

AC Induction

☐ Linear Induction Open Closed Loop
☐ Polynoid - open loop, low duty cycle

B) Stage Type Preferred

☐ Don't Know

Single Bearing - open construction

☐ w/5 micron encoder standard
☐ w/1 micron encoder optional

Extruded - industrial

☐ w/5 micron encoder standard

Enclosed - precision

☐ w/5 micron encoder standard
☐ w/1 micron encoder optional

Cross-roller - high precision

☐ w/5 micron encoder standard
☐ w/1 micron encoder optional

Air Bearing on Granite

☐ highest precision

L Stage

☐ highest precision
☐ w/0.5 micron encoder standard
☐ w/0.1 micron encoder optional
☐ w/1 micron encoder optional

C) Voltage Available

☐ 115 VAC Single Phase
☐ 230 VAC Single Phase
☐ 230 VAC Three Phase
☐ 460 VAC Three Phase

Linear Induction Motors

NOTE: Higher speeds require higher voltage.

D) Environment

☐ _____ Degrees F
☐ _____ Degrees C
☐ Dusty
☐ Gritty
☐ _____
☐ _____

E) Mounting

☐ Horizontal - Table
☐ Horizontal - Wall
☐ Vertical with _____% Counterbalance
☐ Angled at _____ Degrees

F) Position Resolution

☐ None Required
☐ 10 Micron = 0.0004 inch
☐ 5 Micron = 0.002 inch
☐ 1 Micron = 0.00004 inch
☐ Other _____
☐ Stepper Repeatability of _____

G) Quote Additional

☐ Trap Amplifier - for point to point moves
☐ Sine Amplifier - for contouring moves
☐ Stepper Indexer Driver
☐ Motion Controller for _____# of axes
☐ Stand Alone PC-based
☐ Linear Encoder w/resolution from above
☐ Motor Power & Hall Cable Length _____

H) Cooling Available

☐ Convection - standard
☐ Forced Air
☐ Water

Additional Notes (reference letter from above)

_____

_____

_____

_____

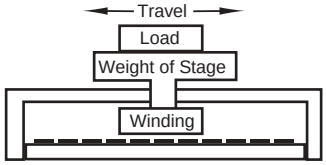
_____

_____

Linear Motor Sizing Worksheet

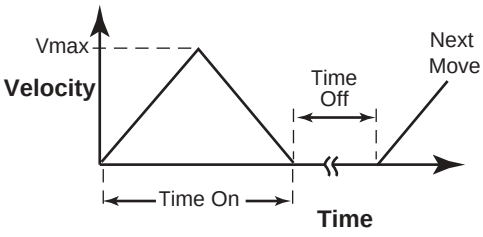
To Size a linear motor for a horizontal application you need to know:

A) Maximum weights of moving load
B) Length of move and overall travel
C) Time to complete move in seconds
D) Velocity Profile - Triangular (for smallest size motor) or Trapezoidal



Procedure - Start with Step 1a or Step 1b

Step 1a Establish Acceleration Rate with Triangular Move Profile (circle units)



Weight = _____Lbs (Kg)
Length of Stroke = _____in (m)
Move Time = _____seconds
Dwell Time = _____seconds
Max Overall Travel = _____in (m)
Velocity max = _____in/sec or (m/sec)

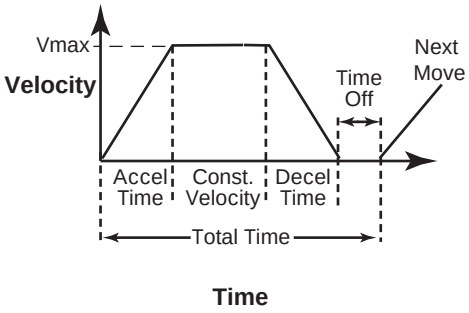
$$\text{Acceleration} = \frac{4 \times (\text{Stroke in in [m]})}{g \times (\text{Time in seconds})^2}$$

$$\text{Acceleration} = \frac{4 \times (\quad \text{in [m]})}{g \times (\quad \text{seconds})^2} = _____ g\text{'s}$$

For g use 386 for inches, 9.81 for metric.
Additional Acceleration Equations on Page 4 of this worksheet.

Acceleration Limits - If over 10g's not practical – need more time for move
Brushless < 10g's Induction < 1g Stepper < 1g

Step 1a Establish Acceleration Rate with Trapezoidal Move Profile (circle units)



Weight = _____Lbs (Kg)
Stroke During Accel = _____in (m)
Accel Time = _____seconds
Total Move Time = _____seconds
Dwell Time = _____seconds
Max Overall Travel = _____in (m)
Velocity max = _____in/sec or m/sec

$$\text{Acceleration} = \frac{2 \times (\text{Stroke During Accel in in [m]})}{g \times (\text{Time in seconds})^2}$$

$$\text{Acceleration} = \frac{2 \times (\quad \text{in [m]})}{g \times (\quad \text{seconds})^2} = _____ g\text{'s}$$

For g use 386 for inches, 9.81 for metric.
Additional Acceleration Equations on Page 4 of this worksheet.
Trap move may require RMS calculation.

Acceleration Limits - If over 10g's not practical - need more time for move
Brushless < 10g's Induction < 1g Stepper < 1g

Linear Motor Sizing Worksheet continued...

Step 2 Calculate Force Required to Accelerate the Load

English

F = mA Newton's Second Law

Force Required = Weight of Load x Acceleration (g's)

Force to Accel the Load = _____ lbs x _____g's

Force to Accel the Load = _____ lbs

Metric

F = mA Newton's Second Law

Force Required = Mass of Load x Acceleration (g's) x 9.81

Force Required = _____ kg x _____ g's x 9.81

Force Required = _____ N

Step 3 Calculate Force Required to Move the System

Add static friction (i.e. stiction which would include wiper friction, etc.)

English

Force = ([Weight of Load + Slide] x μ) + Stiction

Force = (_____ lbs. x _____ μ) + _____Lbs.

Force Required to Move the System = _____Lbs.

Metric

Force = ([Mass of Load + Slide] x μ x 9.81) + Stiction

Force = ([_____ kg x _____ μ] x 9.81) + _____ N

Force Required to Move the System = _____ N

NOTE: Typical Friction Coefficient μ
μ = 0.16 Steel Lubricated V-way
μ = 0.5 Steel on Steel
μ = 0.005 Recirculating Ball Linear Bearing
μ = 0.05 Nonfriction Sliding

Step 4 Calculate Force Required to Accelerate the System

Select motor with more force than the sum calculated in Step 2 & 3 (significantly larger if the acceleration is over 2 g's). Use the weight of the motor and the weight of the stage in your calculations below.

English

Force = (Weight of Motor + Slide) x Acceleration (g's)

Force = (_____lbs. + _____lbs) x _____g's

Force Required = _____lbs

Metric

Force = (Mass of Motor + Slide) x Acceleration (g's) x 9.81

Force = (_____ kg + _____kg) x _____g's x 9.81

Force Required = _____ N

NOTE: If the Force Required is Too Large for One Motor:
(1) Can multiple motors be used?
(2) Can time for the move be increased?
(3) Did you use the low weight Cog-free motor?

Step 5 Total the Force Required

Total the Force Required from Step 2, 3 and 4 and any additional force which a process may require (thrust). Verify the motor selected has a higher rating than calculated below.

Force Required English

from Step 2 _____ lbs

from Step 3 _____ lbs

from Step 4 _____ lbs

(may apply) _____ lbs of Additional Process Force

subtotal _____ lbs x 1.2 Saftey Factor

Force Required Metric

from Step 2 _____ N

from Step 3 _____ N

from Step 4 _____ N

(may apply) _____ N of Additional Process Force

subtotal _____ N x 1.2 Saftey Factor = _____ N

NOTE: If the total force required from Step 5 is:
(1) less than the continuous force of the stepper motor selected you can be finished
(2) for a brushless mtor, and the force is between continuous and 3x continuous go to Step 6
(3) for an induction motor, and the force is between continuous and 5x continuous go to Step 6

Linear Motor Sizing Worksheet continued...

Step 6 Verify Motor Sizing for Intermittent Motion

It may be possible to reduce the size of the motor if the duty cycle is less thatn 100%. When there is significant time between moves the motor cools.

Duty Cycle % = (Time On + Time Off)

Force Continuous = $\frac{\text{Force Required (step5)}}{\sqrt{\frac{100}{\text{Duty Cycle}}}} = \frac{\text{Force}}{\sqrt{\frac{100}{\text{_____\% Duty Cycle}}}} =$ _____ lbs or N (circle one)

NOTE:
1) When the Motor is Run more than 30 Seconds, it is at 100% Duty (motor type dependent)
2) Stepper Motors are rated at 100% duty (peak force = continuous force)
3) Linear induction motors are rated at 15% duty or continuous

Summary Fill in Summary if Known

_____ Total Moving Mass
_____ Peak Force Required
_____ Continuous Force Required
_____ Duty Cycle
_____ Velocity Maximum
_____ Velocity Minimum
_____ Typical Move Length
_____ Max Overall Travel
_____ Max Acceleration
_____ S-Curve Acceleration required – which significantly increases motor peak force

Additional Acceleration Formulas

Known Information		Triangular Profile English	Triangular Profile Metric	Trapezoidal Profile English	Trapezoidal Profile Metric
Time and Distance	accel =	$\frac{4X}{386\ t2}$	$\frac{4X}{9.81\ t2}$	$\frac{2Xa}{386ta2}$	$\frac{2Xa}{9.81ta2}$
Time and Velocity	accel =	$\frac{2V}{386\ t}$	$\frac{2V}{9.81\ t}$	$\frac{V}{386\ ta}$	$\frac{V}{9.81ta}$
Velocity and Distance	accel =	$\frac{V2}{386\ (2X)}$	$\frac{V2}{9.81\ (2X)}$	$\frac{V2}{386\ (1Xa)}$	$\frac{V2}{9.81\ (2Xa)}$

Where	English	Metric
Time	seconds	seconds
Distance	inches	meters
Velocity	in/sec	m/sec

Additional Information

☐ Holding Force required at End of Stroke
☐ One ☐ Both ☐ Amount_____
☐ Size or Space Limitations

☐ Special requirements pertaining to control, mounting, etc.

Complete Velocity Profile

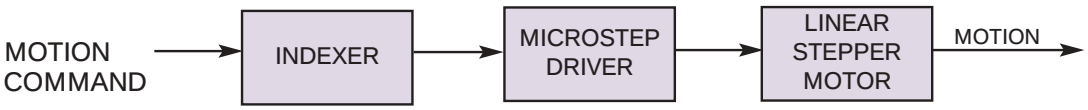
Attach any sketches or graphs.

Velocity Maximum _____ in/sec or m/s

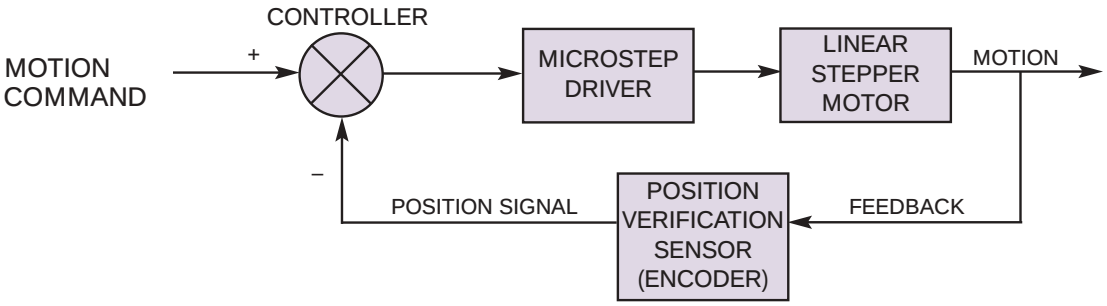
Velocity Minimum _____ in/sec or m/s

Linear Motor System Block Diagrams

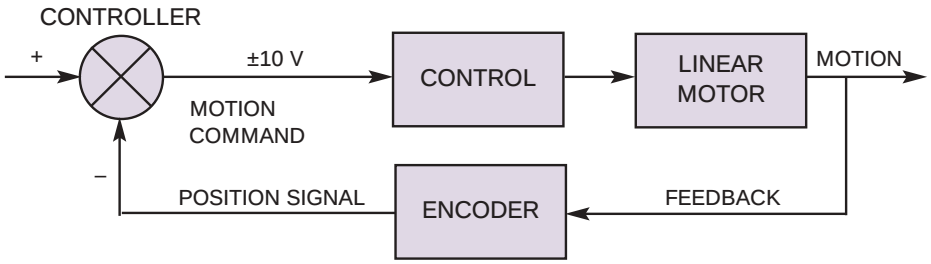
TYPICAL OPEN LOOP LINEAR STEPPER MOTOR



TYPICAL CLOSED LOOP LINEAR STEPPER MOTOR



TYPICAL CLOSED LOOP AC/DC LINEAR MOTOR

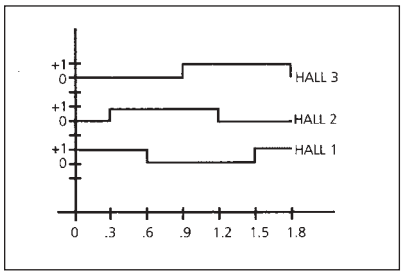


Linear Motor Hall Effect Sensor Commutation/Motor Winding Truth Table

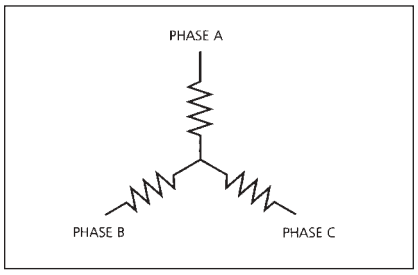
LMBL Motor Pitch: 0.9 in	LMCF Motor Pitch: 1.2 in	Hall Effect Sensor			Motor Winding		
		1 (White)	2 (Red)	3 (Black)	A (Black)	B (Red)	C (White)
0	**0**	**1**	**0**	**0**	**+**	**0**	**-**
0.3	0.4	1	1	0	0	+	-
0.6	0.8	0	1	0	-	+	0
0.9	1.2	0	1	1	-	0	+
1.2	1.6	0	0	1	0	-	+
1.5	2.0	1	0	1	+	-	0
1.8	2.4	1	0	0	+	0	-

0 = Low (0 volts out) 1 = High (+5 volts out) + = + Voltage - = Voltage 0 = 0 Voltage

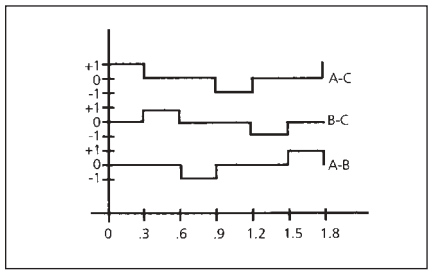
Digital Hall Effect Sensor Output



Motor Windings (Wye-Connected)



Motor Windings Input



Frequently Asked Questions about Linear Motors

Q. What happens if the system loses power or velocity feedback?

A. If a power loss occurs, the system loses all stiffness. So, if the payload is moving, it will continue to move until it hits a stop or until friction brings it to a stop. If the system is already stopped, it will not be affected. If the feedback loop is lost, it may lead to a runaway situation. This condition can be avoided with the use of soft and hard stops as well as braking systems.

Q. Do magnets ever lose their magnetism over time?

A. Baldor's linear motors use rare earth magnets, which maintain their strength over time. However, when operating at high temperatures (>150°C), rare earth magnets can lose strength.

Q. What is cogging?

A. Cogging is a tendency of some linear motors to move in discrete distances rather than infinitely variable distances. The effect is a result of varying magnetic forces along the length of motor travel.

Linear Motor Thermal Considerations

Linear motors can operate at temperatures of: –148°F to 392°F [–100°C to 200°C].

- The cooler the ambient temperature the better, as the larger thermal gradient allows more heat dissipation.
- The more heat that is dissipated, the more power that can be applied and the higher the motor's force.
- Heat dissipation of linear motors is improved with a heat sink, such as an aluminum mounting plate.

Thermal Dissipation W/in^2 $[W/cm^2]$	Cooling Type
1.0 [0.155]	None
2.0 [0.310]	Forced Air
3+ [0.465]	Water

Frequently Asked Questions about Linear Motors

Q. What is duty cycle?

A. Duty cycle is defined as (time on) / (time on + time off) per cycle. A lower duty cycle allows the motor to be run with as much as three times its continuous current rating for a short time period to produce higher forces than if the motor runs continuously.

Q. Do standard rotary motor electronics work with linear motors?

A. Baldor's linear motors are designed to operate with most off-the-shelf motor controls and drives. Basically, linear motors use the same electric circuit as rotary motors. This applies to stepper, brush, brushless, and AC linear motors alike.

Q. Can a linear motor be mounted vertically or upside-down?

A. Yes, a linear motor provides the same performance when mounted vertically, upside-down, or horizontally. However, a vertically-mounted linear motor must be counterbalanced.

Q. Can more than one stepper motor forcer be mounted on a stepper motor platen?

A. Yes, multiple forcers that move independently may be mounted on one platen, as long as they do not physically interfere with each other.

Q. Can more than one brushless linear motor moving coil (primary) assembly be used with a single magnet track (secondary)?

A. Yes, more than one coil assembly can be used in conjunction with a single magnet assembly as long as the coil assemblies do not physically interfere with each other.

Q. Does Baldor make specialty motors for waterproof, vacuum or clean room environments?

A. Yes, linear motors can be built for a variety of operating environments. To determine if a linear motor is suitable for a specific application, an applications engineer must review the specifications.

Q. What types of linear motors does Baldor make?

A. We offer one of the broadest lines of linear motors in the industry, so customers are assured they get the best linear motor solution for their application. Our product line includes single and dual-axis linear steppers, single and double sided linear brushless and brush motors, non-commutated DC motors, enclosed positioning stages, single and cross roller bearing positioning stages, AC linear induction motors, polynoid linear actuators and position verification sensors. Also, new concepts in linear motion technology are continuously being introduced.

Q. Does Baldor make solenoids?

A. Baldor makes a polynoid AC linear motor and a non-commutated DC linear motor, both of which are similar to solenoids. The polynoid provides long stroke with constant force in both directions. (With a solenoid, force is only applied in one direction). Travels are only limited by end stops on the support rod. The non-commutated DC linear motor provides short stroke, up to 5 inches, with constant force in both directions.

Q. What are the advantages of a moving magnet actuator over a solenoid?

A. A moving magnet actuator is a DC motor which can be operated as a servo. This allows the device to move with extreme accuracy to any position throughout its entire stroke. The moving magnet actuator is well-suited for short stroke applications.

Q. What are the advantages of a linear motor over a lead screw?

A. The advantages of linear motors include higher velocities [>80 in/sec (>2 m/s)], non-wear moving part, free movement when power is off, no backlash because there are no mechanical linkages.

Q. Does Baldor build stages?

A. Yes, Baldor offers Enclosed Positioning Stages, Single Bearing Positioning Stages, Cross Roller Bearing Positioning Stages, L-Stages, single-axis Stepper, and Dual-axis Stepper.

Q. What type of feedback devices are available?

A. Feedback devices are not included with standard motors. However, a position verification sensor is offered for single and dual-axis linear stepper motors and linear encoders are offered for closed-loop positioning systems.

Glossary

Abbe Error: The angular error that occurs when the measuring point of interest is displaced from the actual measuring scale location.

Acceleration: Rate of change of velocity in g's (Gravity constant) which is equal to 386 in/sec^2 = 9.81 m/sec^2.

Accuracy: Measure of discrepancy between the expected and the actual position. Accuracy is indicated as the maximum deviation from the target location.

Air Gap: Distance required between the linear motor stationary and moving members.

Back EMF: Electro-Magnetic Force generated as the coil windings move through the magnetic field of the secondary. The Back EMF constant is the ratio between the phase to phase Back EMF voltage and the motor speed.

Backlash: Deadband (lost motion) caused by clearances between mechanical motion components which may occur when starting or reversing direction.

Bandwidth: Frequency range in which a servo operates.

Closed Loop: Use of a feedback device to measure speed and/or position.

Cogging: The tendency of some linear motors to move unplanned discrete distances. This effect is a result of varying magnetic forces along the length of the motor and platen.

Commutation: The sequence at which the controller switches the drive voltage/current among the various motor windings to ensure smooth linear motion of the motor. Commutation can be achieved through the use of brushes, Hall Effect sensors, or with a sinusoidal current.

Duty Cycle: Percentage of time during a specified time interval that power is applied to the motor. If time on is greater than 30 seconds the duty cycle is 100%.

Efficiency: Ratio of output power to input power .

Electrical Time Constant: Time in seconds for a step current input to reach 63% of its final value.

Encoder: A position feedback device that outputs an analog or digital signal proportional to position.

Forcer: Linear stepper motor component that contains the coil assembly.

Force Ripple: The periodic force variation that occurs when the motor is in operation.

Full Step: Longest distance that a stepper motor moves during one pulse.

Hall Effect Sensor (HES): A semiconductor chip that senses magnetic flux changes when passing over magnets. Typically, a Hall Effect Sensor is used for commutation in brushless motors.

Home Position: Unique position used as the initialization location from which all other programmable locations are referenced. Also known as the reference marker.

Indexer: A programmable motion controller that sends step or step and direction signals to the linear stepper motor driver.

Laser Interferometer: Feedback device used to measure the distance between the incident and reflected light beam. Provides the highest degree of resolution and accuracy.

Linear Motor: Type of motor that converts electric current into direct linear motion without ball screws, gears, or other mechanical transmission systems.

Mapping: Method used to calibrate or compensate for repeatable system errors.

Glossary

Microstep:	A finer unit of displacement that is achieved by proportioning the current in each phase of the linear stepper motor. It provides smoother motion and higher resolution.
Orthogonality:	Measure of squareness (90 degree relationship) between motion axes. The value of error is typically expressed in arc-seconds.
Platen:	The long stationary component of the linear stepper motor.
Primary:	The linear motor component that contains the coil assembly.
Repeatability:	The discrepancy between two successive approaches of a motor to a target position. Approaching the target position from the same direction twice and determining the discrepancy between them provides unidirectional repeatability. Approaching the target position from two different directions and determining the discrepancy between them provides bidirectional repeatability.
Resolution:	The smallest displacement that a motor is able to move or the smallest displacement an encoder is able to detect.
Rotary Motor:	Type of motor that converts electric current into rotational motion.
Secondary:	Linear motor component that contains the steel and permanent magnets or aluminum plates.
Settling Time:	Time required for the system to settle within a finite error band of its final position after a commanded move.
Servo:	An electric motor used in feedback control of a mechanical device for closed loop systems.
Stepper Motor:	A motor that moves in predetermined steps. The stepper motor's position is determined by the number of step pulses that are supplied to the motor. Typically, this type of motor operates as an open loop system. Although a position verification sensor is available to provide closed loop operation.
Stiffness:	Ability of an object to resist displacement. A measure of deflection for a positioning axis under load. Expressed in pound per inch.
Velocity ripple:	Periodic velocity fluctuation that occurs when the motor is in operation.

Conversion Tables (To convert from A to B, multiply by value in table)

Rotary Inertia

A \ B	gm-cm²	oz-in²	gm-cm-s²	kg-cm²	lb-in²	oz-in-s²	lb-ft²	Kg-cm-s²	lb-in-s²	lb-ft-s² or slug-ft²
gm-cm²	1	$5.46x10^{-3}$	$1.01x10^{-3}$	10^{-3}	$3.417x10^{-4}$	$1.41x10^{-5}$	$2.37x10^{-6}$	$1.01x10^{-6}$	$8.85x10^{-7}$	$7.37x10^{-8}$
oz-in²	182.9	1	0.186	0.182	0.0625	$2.59x10^{-3}$	$4.34x10^{-4}$	$1.86x10^{-4}$	$1.61x10^{-4}$	$1.34x10^{-5}$
gm-cm-s²	980.6	5.36	1	0.9806	0.335	$1.38x10^{-2}$	$2.32x10^{-3}$	10^{-3}	$8.67x10^{-4}$	$7.23x10^{-5}$
Kg-cm²	1000	5.46	1.019	1	0.3417	$1.41x10^{-2}$	$2.37x10^{-3}$	$1.019x10^{-3}$	$8.85x10^{-4}$	$7.37x10^{-5}$
lb-in²	$2.92x10^{3}$	16	2.984	2.926	1	$4.14x10^{-2}$	$6.94x10^{-3}$	$2.98x10^{-3}$	$2.59x10^{-3}$	$2.15x10^{-4}$
oz-in-s²	$7.06x10^{4}$	386.08	72	70.615	24.13	1	0.1675	$7.20x10^{-2}$	$6.25x10^{-2}$	$5.20x10^{-3}$
lb-ft²	$4.21x10^{5}$	2304	429.71	421.40	144	5.967	1	0.4297	0.3729	$3.10x10^{-2}$
Kg-cm-s²	$9.8x10^{5}$	$5.36x10^{3}$	1000	980.66	335.1	13.887	2.327	1	0.8679	$7.23x10^{-2}$
lb-in-s²	$1.129x10^{6}$	$6.177x10^{3}$	$1.152x10^{3}$	$1.129x10^{3}$	386.08	16	2.681	1.152	1	$8.33x10^{-2}$
lb-ft-s² or slug-ft²	$1.355x10^{7}$	$7.41x10^{4}$	$1.38x10^{4}$	$1.35x10^{4}$	$4.63x10^{3}$	192	32.17	13.825	12	1

Torque

A \ B	dyne-cm	gm-cm	oz-in	kg-cm	lb-in	Newton-m	lb-ft	Kg-cm
dyne-cm	1	$1.019x10^{-3}$	$1.416x10^{-5}$	$1.0197x10^{-6}$	$8.850x10^{-7}$	10^{-7}	$7.375x10^{-8}$	$1.019x10^{-8}$
gm-cm	980.65	1	$1.388x10^{-2}$	10^{-3}	$8.679x10^{-4}$	$9.806x10^{-5}$	$7.233x10^{-5}$	10^{-5}
oz-in	$7.061x10^{4}$	72.007	1	$7.200x10^{-2}$	$6.25x10^{-2}$	$7.061x10^{-3}$	$5.208x10^{-3}$	$7.200x10^{-4}$
Kg-cm	$9.806X10^{5}$	1000	13.877	1	0.8679	$9.806X10^{-2}$	$7.233X10^{-2}$	10^{-2}
lb-in	$1.129x10^{6}$	$1.152x10^{3}$	16	1.152	1	0.112	$8.333x10^{-2}$	$1.152x10^{-2}$
Newton-m	10^{7}	$1.019x10^{4}$	141.612	10.197	8.850	1	0.737	0.101
lb-ft	$1.355x10^{7}$	$1.382x10^{4}$	192	13.825	12	1.355	1	0.138
Kg-m	$9.806x10^{7}$	10^{5}	$1.388x10^{3}$	100	86.796	9.806	7.233	1

Material Densities

	oz/in³	lb/in³	gm/cm³
Aluminum	1.57	0.098	2.72
Brass	4.96	0.31	8.6
Bronze	4.72	0.295	8.17
Copper	5.15	0.322	8.91
Plastic	0.64	0.04	1.11
Steel	4.48	0.28	7.75

Mechanism Efficiencies

Acme Screw (Bronze Nut)	0.4
Acme Screw (Plastic Nut)	0.5
Ball Screw	0.9
Helical Gear	0.7
Spur Gear	0.6
Timing Belt/Pulley	0.9

Friction Coefficients

(Sliding)	μ
Steel on Steel	0.58
Steel on Steel (Greased)	0.15
Aluminum on Steel	0.45
Copper on Steel	0.36
Brass on Steel	0.40
Plastic on Steel	0.20
Linear Bearings	0.001

Temperature

$^{o}F = (1.8x\ ^{o}C) + 32$

$^{o}C = .555\ (^{o}F - 32)$

Gravity

(Acceleration Constant)

$g = 386\ in/s^2 = 32.2\ ft/s^2 = 9.8\ m/s^2$

Conversion Tables

(To convert A to B, multiply by value in table)

Length

A \ B	Inch	Feet	Micro Inch	Micron	Millimeter	Centimeter	Meter
Inch	1	8.33×10^{-2}	1.0×10^{6}	2.54×10^{4}	25.4	2.54	2.54×10^{-2}
Feet	12	1	1.2×10^{7}	3.05×10^{5}	305	30.5	0.305
Micro-Inch	1.0×10^{-6}	1.2×10^{4}	1	2.54×10^{-2}	2.54×10^{-5}	2.54×10^{-6}	2.54×10^{-8}
Micron	3.937×10^{-5}	3.28×10^{-6}	39.37	1	0.001	1.0×10^{-4}	1.0×10^{-6}
Millimeter	3.937×10^{-2}	3.28×10^{-3}	3.937×10^{4}	1000	1	0.1	0.001
Centimeter	0.3937	3.28×10^{-2}	3.937×10^{5}	1×10^{4}	10	1	0.01
Meter	39.37	3.28	3.937×10^{7}	1×10^{6}	1000	100	1

Power

A \ B	Watts	Kilowatts	ft.lb/sec	in-lb/sec	Hp (Imperial)	Hp (SI)
Watts	1	1×10^{-3}	0.74	8.85	1.34×10^{-3}	1.33×10^{-3}
Kilowatts	1000	1	738	8850	1.34	1.33
ft-lb/sec	1.35	1.36×10^{-3}	1	12	1.82×10^{-3}	1.81×10^{-3}
in-lb/sec	0.113	1.13×10^{-4}	8.3×10^{-2}	1	1.52×10^{-4}	1.53×10^{-4}
Hp(Imperial)	746	0.746	550	6600	1	0.995
Hp (SI)	750	0.750	553	6636	1.005	1

Mass

A \ B	ozm	lbm	slug	gm	kg
oz-m	1	6.25×10^{-2}	1.94×10^{-3}	28.35	2.835×10^{-2}
Lb-m	16	1	3.11×10^{-2}	453.6	0.453
slug	514.72	32.2	1	14590	14.59
gm	3.53×10^{-2}	2.205×10^{-3}	6.85×10^{-5}	1	0.001
kg	35.274	2.205	6.85×10^{-2}	1000	1

Force

A \ B	ozf	lbf	Newtons	dyne	gmf	Kgf
oz-f	1	6.25×10^{-2}	0.278	2.78×10^{4}	28.35	2.835×10^{-2}
lb-f	16	1	4.448	4.448×10^{5}	453.6	0.4535
Newtons	3.596	0.225	1	1×10^{5}	101.9	0.1019
dyne	3.59×10^{-5}	2.248×10^{-6}	1.0×10^{-5}	1	1.02×10^{-3}	1.02×10^{-6}
gm-f	3.53×10^{-2}	2.205×10^{-3}	9.81×10^{-3}	981	1	0.001
kg-f	35.3	2.205	9.81	9.81×10^{5}	1000	1

Linear Velocity

A \ B	in/sec	feet/sec	mm/sec	cm/sec	meter/sec	inch/min	feet/min	meter/min	km/hour	miles/hour
in/sec	1	0.083	25.4	2.54	2.54×10^{-2}	60	5	1.524	0.091	5.7×10^{-2}
feet/sec	12	1	304.8	30.48	0.3048	720	60	18.29	1.09	0.682
mm/sec	3.937×10^{-2}	3.3×10^{-3}	1	0.1	0.001	2.36	0.197	0.059	3.6×10^{-3}	2.24×10^{-3}
cm/sec	0.3937	3.28×10^{-2}	10	1	0.01	23.62	1.97	0.59	3.6×10^{-2}	2.24×10^{-2}
meter/sec	39.37	3.281	1000	100	1	2362.2	197	60	3.6	2.24
inch/min	0.0167	1.39×10^{-3}	0.42	0.042	4.2×10^{-4}	1	8.33×10^{-2}	2.54×10^{-2}	1.52×10^{-3}	9.5×10^{-4}
feet/min	0.2	0.0167	5.08	0.508	5.08×10^{-3}	12	1	0.3048	1.8×10^{-2}	1.14×10^{-2}
meter/min	0.656	5.46×10^{-2}	16.667	1.67	1.67×10^{-2}	39.4	3.28	1	5.9×10^{-2}	0.37
km/hour	10.936	0.911	277.8	27.78	0.2778	656	54.67	16.67	1	0.62
miles/hour	17.59	1.47	447	44.7	0.447	1056	88	26.8	1.609	1