Linear Motor Requirements

Engineering Information

Linear Motor

Calculating Requirements

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

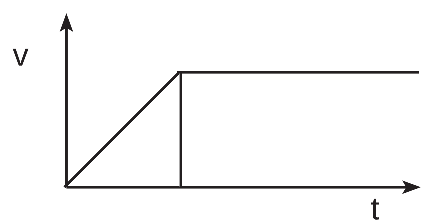
EQUATIONS OF MOTION

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
$a = \dfrac{2x}{386\ t^2}$	$a = \dfrac{2x}{9.81\ t^2}$

When velocity and stroke are known:

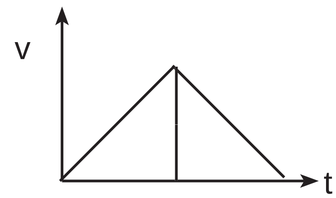
$$a = \frac{v}{386\ t} \qquad a = \frac{v}{9.81\ t}$$

$$a = \frac{v^2}{386\ (2x)} \qquad a = \frac{v^2}{9.81\ (2x)}$$

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

English	Metric
$a = \dfrac{20}{386 x 0.050}$	$a = \dfrac{0.508}{9.81 x 0.050}$
a = 1.04 g's	a = 1.04 g's

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
$a = \dfrac{4x}{386\ t^2}$	$a = \dfrac{4x}{9.81\ t^2}$

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

English	SI
$a = \dfrac{4 \text{ x } 1}{386 \text{x} (0.050)^2}$	$a = \dfrac{4 \text{ x } 0.0254}{9.81 \text{x} (0.050)^2}$
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

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%.

$$\text{Duty Cycle} = \frac{\text{time on}}{\text{time on} + \text{time off}} \times 100\%$$

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?

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

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

F_{30} = 197 D.C. = 30%

$$F_C = \frac{197}{\sqrt{\frac{100}{30}}} = 108 \text{ Lbs}$$

Metric

F_{30}= 877 D.C. = 30

$$F_C = \frac{877}{\sqrt{\frac{100}{30}}} = 480 \text{ N.}$$

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

$$a = \frac{4 \times}{386\ t^2}$$

$$a = \frac{4 \times 60}{386 \times (0.90)^2}$$

a = 0.77 g's

Metric

$$a = \frac{4 \times}{9.81 t^2}$$

$$a = \frac{4 \times 1.52}{9.81 \times (0.90)^2}$$

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:

	English	Metric
	$F = ma$	$F = mag$
so,	$F = 40 \times 0.77$	$F = 18.1 \times 0.77 \times 9.81$
	$F = 30.8$ 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.

English

$$F_{DC} = F_C\sqrt{\frac{100}{DC}}$$

$$F_{30} = 33\sqrt{\frac{100}{50}}$$

$F_{30} = 60.2$ Lbs

$m = 40$ Lbs

$F_{30} - ma_{30}$

$$a_{30} = \frac{F_{30}}{m} = \frac{60.2}{40}$$

$a_{30} = 1.5$ g's

Metric

$$F_{DC} = F_C\sqrt{\frac{100}{DC}}$$

$$F_{30} = 147\sqrt{\frac{100}{50}}$$

$F_{30} = 267.9$ N

$m = 18.1$ kg $g = 9.81\frac{m}{S^2}$

$F_{30} - ma_{30}g$

$$a_{30} = \frac{F_{30}}{mg} = \frac{267.9}{18.1 \times 9.81}$$

$a_{30} = 1.5$ g's

EFFECTS OF LOWER DUTY CYCLES

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

$F_{30} = 60.2$ Lbs

$m = 0.77$ Lbs

$F_{30} - m_{30}a$

$$a_{30} = \frac{F_{30}}{a} = \frac{60.2}{0.77}$$

$m_{30} = 78.2$ Lbs

Metric

$F_{30} = 267.9$ N

$m = 0.77$ g's $g = 9.81\frac{m}{S^2}$

$F_{30} - m_{30}ag$

$$a_{30} = \frac{F_{30}}{ag} = \frac{267.9}{0.77 \times 9.81}$$

$m_{30} = 35.5$ 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,	$F = 40 \times 0.9$	$F = 18.1 \times 0.9 \times 9.81$
	$F = 36$ 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

$$F_c = \frac{36}{\sqrt{\frac{100}{30}}}$$

$F_c = 19.7$ Lbs

Metric

$$F_c = \frac{160}{\sqrt{\frac{100}{30}}}$$

$F_c = 87.6N$

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)

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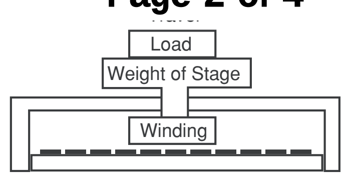
____

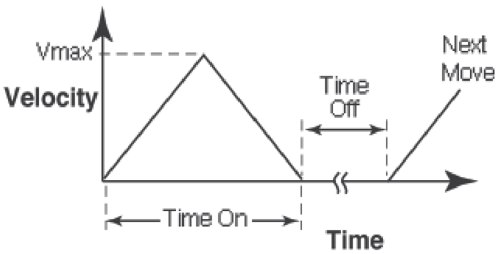
Linear Motor Sizing Worksheet



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



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)

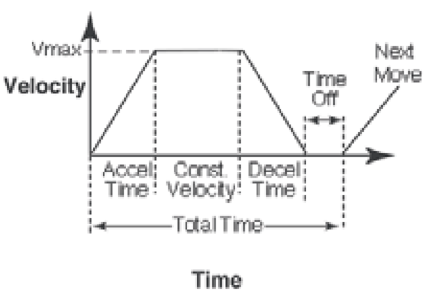
$$\text{Acceleration} = \frac{4 \times (\text{Stroke in in [m]})}{g \times (\text{Time in seconds})^2}$$

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

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

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

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

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

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)

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

NOTE:
1) When the Motor is Run more than 30 Seconds, it is at 100% Duty (motor type dependent)

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