What is a Linear Motor?

Prepared by H2W Technologies, Inc.
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Linear motors should be thought of as rotary electric motors that have been cut along a radial plane and unrolled. The resultant motor is a linear electric motor that can produce linear motion without the need of pneumatic or hydraulic cylinders or translation of rotary motion with the use of belts, pulleys, or screws. This is desirable because the extra machine parts make the machine more complicated, and there are more parts that will wear out, and need replacement.

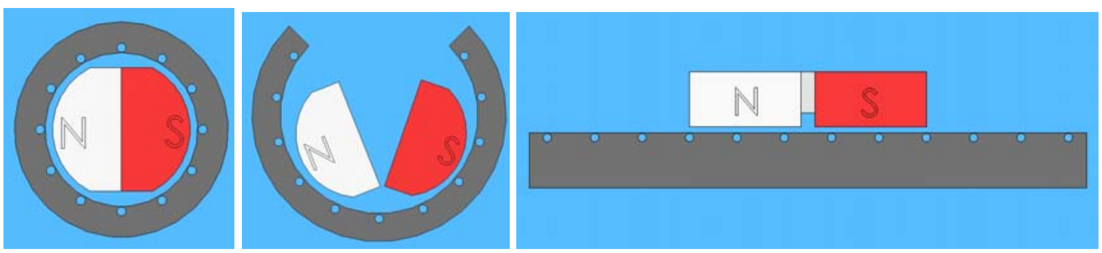

Figure 1. Illustrating the Imaginary Process of Unrolling a Rotary Motor.

However, because linear motors do not have the luxury of 360 degree contained rotation, they must either increase the length of the primary, coil assembly, and keep a short moving secondary, magnet assembly, or increase the length of the secondary, and keep a short moving primary. There is a diagram that can be found below illustrating the differences between these two options.

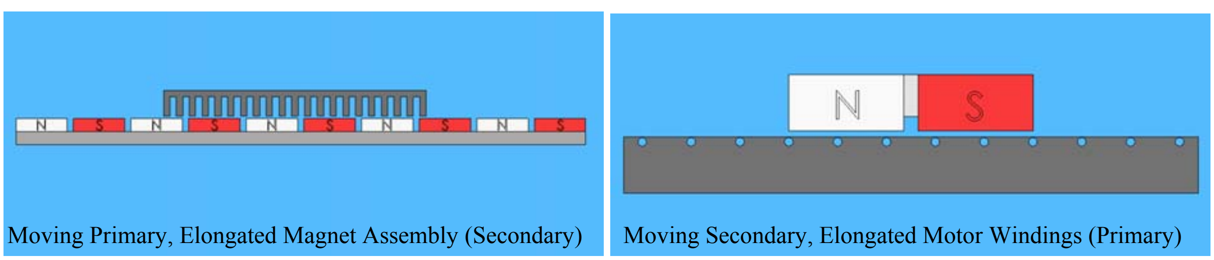

Figure 2. Illustrating the Differences between Moving Primary and Moving Secondary.

Although you notice there are obvious differences between the geometries of linear and rotary motors, they indeed exhibit the same performance characteristics. The basic motor theory for each type of motor applies equally to both linear and rotary motors. The types of linear motors available are Non-Commutated DC Linear Actuators, Linear Stepper Motors, DC Linear Brush Motors, Brushless Linear Servo Motors, and AC Linear Induction Motors.

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PRINCIPLES OF OPERATION

Linear motors operate on the principal of the **Lorentz Force Equation.** This states that the amount of force generated is equal to the cross product of the magnetic flux density and the amount of current flowing through a current carrying conductor.

$F = B \times I$ Where: B is the magnetic flux density
I is the amount of current

Simply stated, a current carrying conductor placed in a magnetic field will have a force exerted upon it. This force is proportional to the direction and magnitude of the current and the flux density field. Since the permanent magnet flux density field is fixed, the direction of the linear displacement depends on the polarity of input current.

Since all of the wires are perpendicular to the direction of the magnetic field and direction of force the result of this equation can be simplified to state the following:

$F = B * I * L$ Where: L is the length of wire in the magnetic field

In an electric circuit there is a voltage that is applied to a closed electrically conductive path with some resistance, which causes current to flow. These are related by Ohms Law, and illustrated by the diagram below.

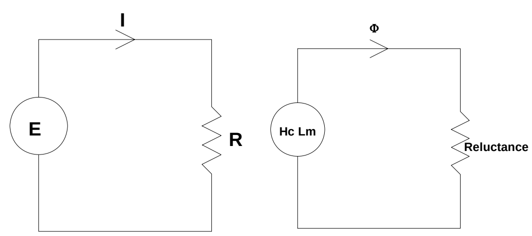

Figure 3. A Closed Magnetic Circuit is Analyzed Similar to a Closed Electric Circuit.

The magnetic circuit can be analyzed using similar techniques as the electric circuit where the magnetomotive force is analogous to voltage, the magnetic Flux is analogous to current, and reluctance, the measure of the relative opposition of a material to the passage of magnetic flux, is analogous to resistance.

These are analyzed to determine the magnetic flux density within the air gap of the magnetic circuit, which are used to calculate the amount of force generated by the linear motor.

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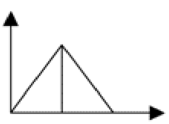
GENERAL RULES OF THUMB TO CONSIDER WHEN USING LINEAR MOTORS

To size a motor properly the force must be known. If force is not known it must be calculated from Newton's Second Law. The mass is the total mass of the customer payload plus the mass of the moving components of the stage.

Newton's Second law states: F = m * a where: F =Force (lbs or [N])
m=moving mass (lbs or [Kg])
a=acceleration (g's)

If the motor will be moving to a point at the fastest time possible it will move with a triangular motion profile, and the acceleration can be found using the equation below:

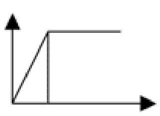
$$A = \frac{4 \times d}{t^2 \times G}$$



where: d = distance moved (in or [m])
t = time to complete move (sec)
G= gravitational constant (386 in/sec2 or [9.81 m/sec2])

If the motor will accelerate until it reaches a constant speed it will move with a trapezoidal motion profile, and the acceleration can be found using the equation below:

$$A = \frac{2 \times d}{t_a^2 \times G}$$



where: d = distance moved (in or [m])
t = time to complete move (sec)
G= gravitational constant (386 in/sec2 or [9.81 m/sec2])

Efficiency for linear motors is described as the amount of force output per square root of watt input. This is important and used to show the amount of force that a linear motor can generate without cooling, which is shown below.

$P_{dissipated} = k_h * A_s$, where k_h is an empirical value of 1.1 watts / sq. in., and A_s is the surface area of the coil. This is then plugged into $F_{continuous} = \sqrt{P_{dissipated}} * k_m$, where, k_m is the motor constant, or efficiency, of the linear motor.

$$\text{Duty Cycle (\%)} = \frac{t_{on}}{t_{on} + t_{off}} \times 100$$

$$F_{duty} = F_{continuous}\sqrt{\frac{1}{Duty(decimal)}}$$

Various forms of forced cooling will improve the amount of force you can get out of a given linear motor, some of the examples are below.

If Power dissipated with no forced cooling is = X watts
Forced Air: Power Dissipated = 1.41 X watts
Water Cooling: Power Dissipated = 1.73 X watts

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Heat Sinking: Power Dissipated = 1.25 X watts

Non-Commutated DC Linear Actuators (also known as Voice Coils)

Voice coils come in two types. Moving coil actuators, seen at the left, do not have an internal bearing system, and are designed to fit in a variety of applications where there is an existing bearing system. Moving magnet actuators, seen at the right, generally have an internal bearing system, and are designed to fit in a variety of applications where there is a need for an internal bearing system.

Linear Stepper Motors

Linear stepper motors are offered with air bearings or roller bearings. This is an ideal motor for applications which require high resolution, open-loop control. With a micro stepping driver, a resolution of 1-micron is possible. Multiple forcers can be added to a single platen, and a single homing switch can be added to initialize a startup routine.

Linear Brush Motors

The motor is commutated using brushes on the moving permanent magnet secondary in conjunction with a stationary commutator bar on the coil assembly. This results in only the coils directly beneath the secondary with current flowing in them. The short moving brush assembly is magnetically attracted to the long stationary laminated coil assembly. A bearing system is required to guide the moving secondary and to maintain a constant gap between the secondary and the coil assembly.

Brushless Linear Motors

Brushless Linear Motors come in two types. Ironless Core Double Sided Brushless Linear Motors, seen at the left, The short encapsulated moving coil assembly moves thru a gap in the long "U" shaped magnet assembly. A customer supplied bearing system is required to guide the moving coil assembly and to maintain a .025" [0.63 mm] clearance between the magnet and the coil assembly. Iron Core High Force Single Sided Brushless Linear Motors, seen at the right, The short laminated moving coil assembly moves over the top of a magnet assembly. A bearing system is required to guide the moving coil assembly and to maintain clearance between the coil and the magnet assembly.

Linear Induction Motors

A Linear Induction Motor (LIM) is a non-contacting, high speed, linear motor that operates on the same principal as a rotary, squirrel cage, induction motor. They are capable of speeds up to 1800 in/sec [45 m/s] and are typically used in applications where accurate positioning is not required. LIM's can also be operated at stall to produce static thrust. The amount of thrust produced by the LIM is proportional to the active surface area of the motor. The laminated coil assembly is used in conjunction with a customer supplied aluminum and steel reaction plate to produce a force. A customer supplied bearing system is required to maintain the .040" - .060" [1 - 1.5 mm] air gap between the coil assembly and the reaction plate. The length of the reaction plate is equal to the coil length plus the stroke.

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