Linear Motors

Properties, Applications and Selection Guide

Power Transmission Engineering is collaborating with the Bearing Specialists Association (BSA) on a special section within the magazine. *Bearing Briefs* will present updated reports on bearing topics for each issue in 2016. Complimentary access to all BSA Bearing and Industry Briefs is available on the BSA website at *www.bsahome.org/tools*.

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When the need arises for linear motion or positioning, there are many choices. One can use an Acme screw, ball screw, rack & pinion, or belts. The cost of a linear motor solution is generally greater than a mechanical linear product, but when one needs highly accurate, repeatable, high-speed motion, then the answer may be a linear motor.

Linear motors have found applications in just about all industries and markets where any of the following combination of attributes is required: long strokes, high speed, accuracy or repeatability. Mechanically driven linear products may have some of these attributes but only linear motors can have all of the attributes.

Linear motors are available in the same types as rotary motors. This is because a linear motor can be considered a rotary motor that has been slit open and rolled out flat. The major difference between linear motors and rotary motors is the part that moves. In a rotary motor, the motor windings are stationary while the motor core rotates. In a linear motor this is generally reversed: the motor windings or forcer moves while the core or rack base is stationary. This results in the base being very long compared to the forcer. For all linear motors to work, some kind of bearing support is required. This is usually provided by linear guides or bearings.

Some of the common linear motors are stepper, DC brush, synchronous, hybrid, induction, voice coil and force tube. All linear motors generate force rather than torque. Different characteristics of this force include the force speed characteristics, smoothness, stiffness and continuous and peak force ratings.

Voice Coil: The voice coil motor is the simplest type of linear motor. A permanent magnet is placed inside a coil of wire. As current is sent through the coil, the permanent magnet moves away from the coil. These motors can generate a lot of force but are limited in travel to an inch or so.

Force Tube: This type of linear motor places a stack of disk-shaped permanent magnets inside a hollow, non-magnetic tube. This tube is placed inside an assembly of coils. By selectively applying current to the coils, the tube moves through the coils or the coils move down the length of the tube. This type of linear motor can generate a lot of force but does not have the travel limits of voice coil motors.

Stepper: This linear motor works just like a rotary step motor and has all of the same advantages and disadvantages. They are most often operated open loop and move in discrete steps. Linear stepper motors are simple to commutate but have poor speed-force characteristics, are inefficient, and have low stiffness because they are operated open loop. Their main advantage is that the rack base of the motor is passive. The rack is basically a slab of iron with slots milled into it. Since the magnets and motor coils are located in the forcer, the rack base does not attract and capture ferrous materials.

Hybrid: The hybrid linear motor's construction is almost identical to the linear stepper motor. The motor's magnets and coils are just configured differently. The main difference is in its performance. It is operated closed loop so it hashigher stiffness and is more efficient.

Brush DC: The brush DC linear motor was one of the first linear motors. The rack base contains all of the motor winding while the forcer has the permanent magnets and the brushes. The motor is self-commutating, so in some applications no controller is needed. The rack base is complex, and the motor has all of the disadvantages of all brush type motors, including brush wear and arcing.

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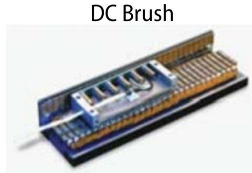
Induction: The induction linear motor is the only linear motor that does not use permanent magnets. The rack base consists of rods that are encapsulated such that all of the ends of the rods on each side are shorted together. The windings in the forcer induce currents in these rods to create a magnetic field. It is best suited for applications that have low duty cycle and long travels.

Synchronous: This is the most common type of linear motor. It is also known as a DC brushless linear motor or AC linear motor. They come in two styles - iron core and ironless core. The forcer of the iron core motor consists of a section of laminated iron with embedded motor windings. The rack base has permanent magnets affixed along its entire length.

The ironless core linear motor uses a U-shaped rack base that has permanent magnets affixed to both inside legs of the U-shaped channel. The forcer windings are embedded in a nonmagnetic core material that slides inside of the U-shaped channel. There is no iron used in the forcer. The iron core type linear motors dissipate heat better that the ironless core motors. To overcome the heat build-up in ironless core motors, they are available with cooling tubes built into the core through which air or a fluid is pumped to remove the heat.

There is one application for which linear motors are not generally suitable – vertical lifting. They can be used to lift objects but they need to be oversized to allow for a large continuous force to fight gravity or some type of counter balance needs to be designed into the system. Also some type of brake may be needed to hold the motor in position when power is lost. **PTE**

Quick Selection Guide	
Application	**Linear Motor Type**
Short Stroke, Light Load, High Frequency	Voice Coil
Short Stroke Moderate Load	Force Tube
Low Mass, Open Loop	Stepper
Long Travel and Low Duty Cycle	Induction
Low Cost and Low Duty Cycle	Brush DC
Smooth Motion	Ironless Core PM Synchronous
Machine Tool	Ironless Core PM Synchronous with liquid cooling.
General Automation	Iron Core PM Synchronous or Hybrid

Linear Motor Properties	
Motor Type	**Properties**
Voice Coil 	Speed: Very high Force: 35 lbf (160 N) Accuracy: Encoder dependent Cost: Low Limitations: Short travel.
Force Tube	Speed: 160 in/sec (4 meters/sec) Force: 1100 lbf (4800 N) Accuracy: Encoder dependent Cost: High Limitations: High profile.
Stepper 	Speed: 1 to 100 ips (25 to 2,500 min/sec.) Force: 2 to 50 lbf (9 to 220 N) Accuracy: 2 to 250 um. Cost: Low Limitations: Open loop, low stiffness, not efficient.
Hybrid 	Speed: 60 in/sec (1.5 meters/sec) Force: 180 lbf (800 N) Accuracy: Encoder dependent Cost: High Limitations: Speed force characteristics.
DC Brush 	Speed: 75 in/sec (3.8 meters/sec) Force: 171 lbf (1070 N) Accuracy: Encoder dependent. Cost: Moderate Limitations: Contamination from brush wear, brush wear, arcing of brushes.
AC Induction 	Speed: 270 in/sec (6.85 meters/sec) Force: 500 lbf (2,225 N) Accuracy: Encoder dependent. Cost: Moderate Limitations: Low Duty Cycle.
Iron Core AC Synchronous 	Speed: 400 ips (10 meters/sec) Force: 2,500 lbf (11,000N) Accuracy: Encoder dependent. Cost: High Limitations: Exposed magnets can attract and hold ferrous objects.
Ironless Core AC Synchronous 	Speed: 400 ips (10 meters/sec) Force: 450 lbf (2000 N) Accuracy: Encoder dependent. Cost: High Limitations: Exposed magnets can attract and hold ferrous objects. Needs liquid cooling for high force duty cycle.