# Basics of Voice Coil Actuators

**Bill Black, Mike Lopez** and **Anthony Morcos**,
BEI Motion Systems Company, Kimco Magnetics Division, San Marcos, California

*Originally used in radio loud speakers, voice coil actuators are gaining popularity in applications where proportional or tight servo control is a necessity.*

Voice coil actuators are direct drive, limited motion devices that use a permanent magnet field and a coil winding (conductor) to produce a force proportional to the current applied to the coil. These non-commutated electromagnetic devices are used in linear and rotary motion applications requiring linear force or torque output, and high acceleration, or high frequency actuation.

The electromechanical conversion mechanism of a voice coil actuator is governed by the Lorentz Force Principle. This law of physics states that if a current-carrying conductor is placed in a magnetic field, a force will act upon it. The magnitude of this force is determined by:

$$F=kBLIN \qquad (1)$$

where:

F = Force

k = Constant

B = Magnetic flux density

I = Current

L = Length of a conductor

N = Number of conductors

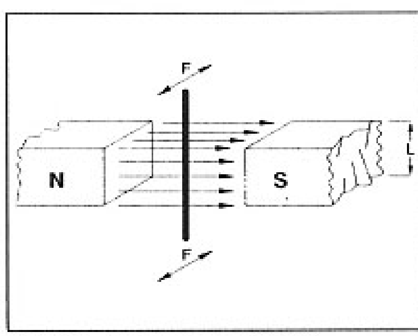


**Figure 1.** *Lorentz Force Principle.*

*Figure 1* is a simplified illustration of this law of physics. Here, the direction of the force generated is a function of the direction of current and magnetic field vectors. Specifically, it is the cross-product of the two vectors. If current flow is reversed, the direction of the force on the conductor will also reverse. If the magnetic field and the conductor length are constant, as they are in a voice coil actuator, then the generated force is directly proportional to the input current.

*Figure 1* also illustrates that a conductor moving through a magnetic field will have a voltage induced across the conductor. The magnitude of the voltage, E, is dependent on:

$$E = kBLvN \qquad (2)$$

where:

k = Constant

v = Velocity of the conductor

Equations (1) and (2) can be restated as follows: a device that contains a permanent magnet field and a coil winding moving in the field will produce a force proportional to current [carried in the coil] and a voltage proportional to velocity [of the coil].

In its simplest form, a linear voice coil actuator is a tubular coil of wire situated within a radially oriented magnetic field, as shown in *Figure 2*. The field is produced by permanent magnets embedded on the inside diameter of a ferromagnetic cylinder, arranged so that the magnets "facing" the coil are all of the same polarity. An inner core of ferromagnetic material set along the axial centerline of the coil, joined at one end to the permanent magnet assembly, is used to complete the magnetic circuit. The force generated axially upon the coil when current flows through the coil will produce relative motion between the field assembly and the coil, provided the force is large enough to overcome friction, inertia, and any other forces from loads attached to the coil.

Based upon the required operating stroke of the actuator, the axial lengths of the coil and the magnet assemblies can be chosen so that the force vs stroke curve is extremely flat: the degradation of force at the two travel extremes with respect to the mid-stroke force can often be kept below 5%. This is possible, because the working air gap of the permanent magnet circuit remains constant over the rated stroke.

If you "flatten" the linear voice coil actuator from a round tube to a flat tube, then bend the two ends to form a planar arc, such as a sector of an annulus, you would have a rotary voice coil actuator. This device can also be referred to as a limited angle torquer or a sector torquer. Its principle of operation and force generation is analogous to that of the linear counterpart; however, ratings are in units of torque, instead of force, because force is generated along the circumference of an arc (i.e., Torque = Force x Radius). *Figure 3* shows a typical rotary voice coil actuator.

The voice coil actuator is a single phase device. Application of a voltage across the two coil leads generates a current in the coil, causing the coil to move axially along the air gap. The direction of movement is determined by the direction of current flow in the wire.

The single phase linear voice coil actuator allows direct, cog-free linear motion that is free from the backlash, irregularity, and energy loss that results from converting rotary to linear motion. Rotary versions of voice coils provide such smooth motion that they are becoming the preferred device in applications requiring quick response, limited angle actuation, such as gimbal assemblies.

## Design Configurations

In one common configuration, the actuator consists of a cylindrical coil that is free to move axially in an air gap, as shown in *Figure 2*. The air gap is formed between a cylindrical center pole and a permanent magnet that surrounds it. A soft iron shell houses both the magnet and the pole (*Figure 4*).

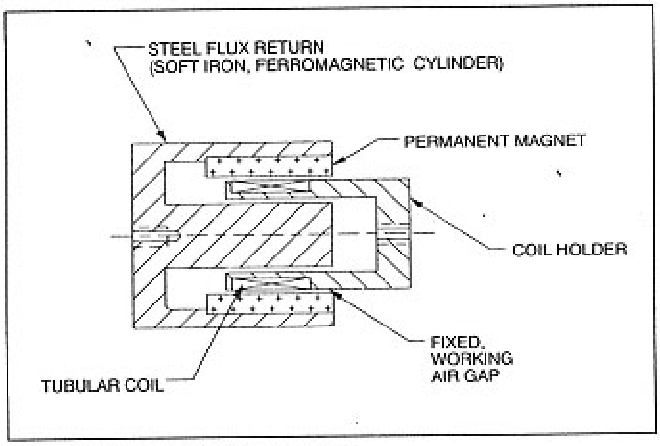


**Figure 2.** *Linear Voice Coil Actuator.*

In some cases the axial length of the coil exceeds that of the magnet by the amount of coil travel. In other cases the magnet is longer than the coil by the travel length. Compared to the short-coil configuration, the long-coil configuration provides a superior force-to-power ratio and dissipates heat better. The short-coil, however, has a lower electrical time constant, smaller mass, and produces less armature reaction. Neither arrangement provides a perfectly linear force-vs-travel characteristic. An armature reaction results from current in the coil and alters the level of flux in the air gap. Current through the coil in one direction decreases air gap flux, and current in the opposite direction increases it. Applications calling for a more linear force-vs-position characteristic may use two actuators working in concert. Here, one actuator pulls when the other pushes, and vice versa.

Motion control applications sometimes need more force than conventional moving coil actuators can provide. Referring to Equation (1), actuator force is proportional to the coil current as well as the flux density in the air gap. Thus, for a given coil winding and current, the flux density level determines the force magnitude.

Flux density in the air gap of conventional actuators is typically less than 50% of the residual value for the magnets in the device. For example, consider an actuator containing a rare-earth magnet. The magnet may have a residual flux density on the order of 11 kG, but the actuator will only have an air gap density of around 5 kG. Actuator magnets typically operate with load lines having a value of 1.0 - 1.5, which accounts for the relatively low air gap flux density. Magnetic flux leakage also reduces the useful magnetic field.

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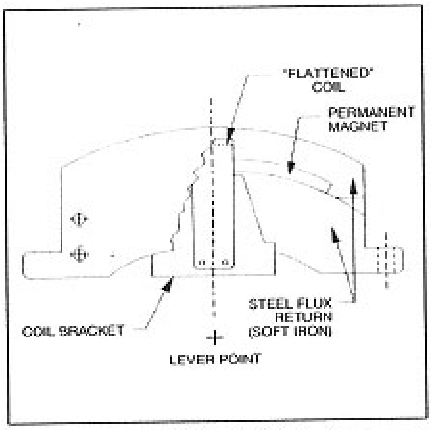


**Figure 3.** *Rotary Voice Coil Actuator.*

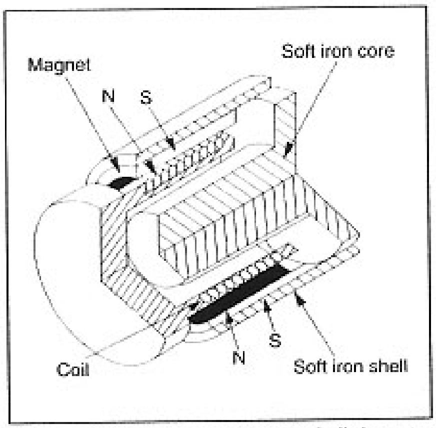


**Figure 4.** *Conventional Voice Coil Actuator Configuration.*

## Voice Coil Actuators

A flux-focus technique enables the design of actuators with air gap flux densities equal to or greater than the magnet residual value. Actuators based on this technique contain a magnet in the form of a hollow cylinder with one end closed, as illustrated in *Figure 5.* The cylinder interior (including the closed end) forms a north pole. The outside of the cylinder forms a south pole. The magnet is surrounded by a tight-fitting, cylindrical shell of soft iron that also has one end closed. The open end of the soft shell extends beyond the open end of the magnet. A cylindrical core, generally fabricated of soft iron, fits tightly inside the magnet and extends beyond its open end. An annular space between the inside face of the shell and the outside face of the core forms an air gap in which the cylindrically shaped coil is free to move axially.

The configuration shown in *Figure 5* allows the surface area of the magnet to be much larger than the cross-section area of the air gap. This design is magnetically very efficient, incurring few leakage paths. Nearly all flux emanating from the surface of the magnets passes through the air gap. Air gap flux densities on the order of 11 kG or greater are attainable for actuators that contain the 11 kG residual flux density rare-earth magnets.

Actuators using flux focus techniques are smaller and lighter than conventional types having equal force ratings. Flux focus actuators exhibit lower electrical time constants, higher force-to-mass ratios, and less armature reaction.

For applications requiring the highest force output in the smallest diameter possible, the company applies its patented interleaved magnetic circuit technology. For comparable performance characteristics, this design tends to be longer axially, but smaller in diameter than the conventional and flux-focus designs. The interleaved design also contains a considerably less massive magnet assembly. The coil assembly tends to be heavier because of the increased copper volume attainable in a given diameter. A significant advantage of the interleaved magnetic circuit voice coil is the lower coil inductance. This characteristic results in an actuator with a very low electrical time constant ($t_e = L/R$).

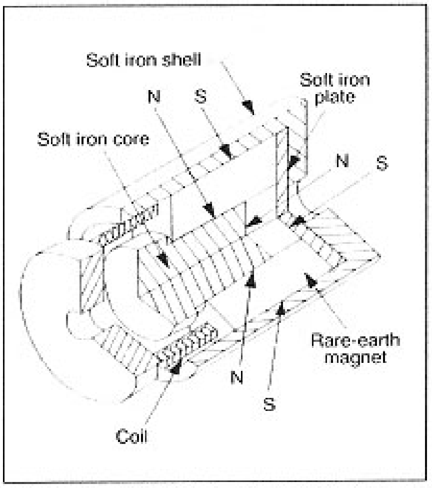


***Figure 5.** Flux-Focus Voice Coil Actuator Configuration.*

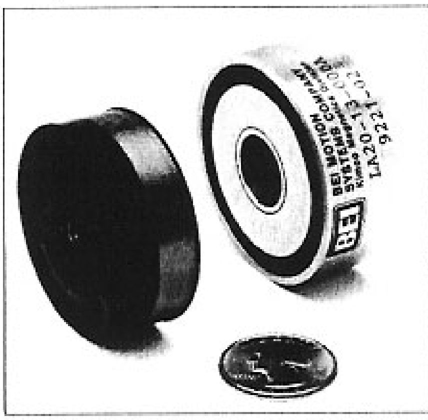

***Figure 6.** This Compact Unit Features Up to 0.16" of Hysteresis-Free and Cog-Free Linear Travel as Well as the Infinite Position Sensitivity Common to All Voice Coil Actuator Designs.*

### References


1. "Voice Coil Actuators, An Applications Guide," BEI Motion Systems Company, Kimco Magnetics Division, 1992.


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