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Voice Coil Actuators

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Voice Coil Actuators For Use in Motion Control Systems

By Anthony C. Morcos
Senior Magnetics Engineer
BEI Sensors & Systems Co.
Kimco Magnetics Division
San Marcos, CA

I. Introduction

Voice coil actuators are versatile direct drive, hysteresis-free, non-commuted limited motion servo motors with linear control characteristics. They are virtually ideal servo devices. They employ a permanent magnet field assembly in conjunction with a coil winding to produce a force proportional to the current applied to the coil. These two-terminal, non-commutated electromagnetic devices are used in linear and rotary motion applications requiring high acceleration, high frequency actuation, and flat force vs. displacement output. Voice coils provide cog-free,

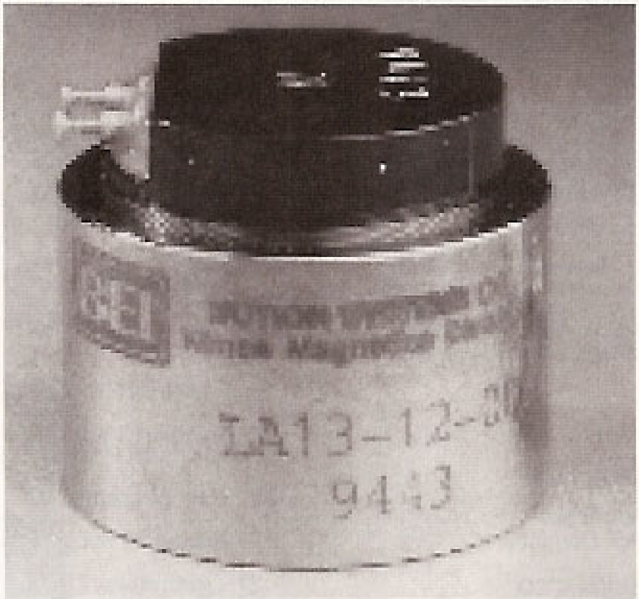

Figure 1 - Linear Voice Coil Actuator

hysteresis-free motion capable of infinite position sensitivity, limited only by the feedback sensor used to close the control loop. Originally used in audio loudspeakers, voice coil actuators have gained recognition and acceptance in applications where proportional or tight servo control is a necessity.

Typical applications for voice coils include mirror and lens positioning in optical systems; X, Y, and Z positioning stages for machine tools; coordinate measuring machines; semiconductor fabrication and packaging; head positioning in computer hard disk drives; precision valve control in medical and industrial devices; and linear drives for refrigerators, cryocoolers, and other pumps.

The following sections discuss the fundamentals of voice coil actuators: the magnetic circuit configurations, the electronic systems required to drive and control them, and the mechanical systems required for attaching to and moving the load. The goal is to provide readers with a better understanding of how voice coil actuators might be applied to their specific motion control, harmonic drive, or servo systems applications.

II. Magnetics

In its simplest form, a linear voice coil actuator is a tubular coil of wire situated within a radially-oriented DC magnetic field, as shown in Figure 1. This magnetic 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.

When current is applied to the circumferentially-wound coil, it interacts with the radial magnetic field of the permanent magnet assembly via the Lorentz Force Principle to create an axial force (i.e., mutually perpendicular to the vectors of the current flow and the magnetic field) between the coil and magnet assemblies. The polarity of the current-producing voltage applied to the two terminals of the coil dictates the direction of the force upon the coil.

Based upon the required operating stroke of the actuator, the axial lengths of the coil winding and the permanent magnet can be chosen so that the force versus stroke curve is extremely flat: the degradation of the force at the two travel extremes, with respect to the mid-stroke force, can often be kept below 5%. This is possible because the DC magnetic field within 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, you will have a rotary voice coil actuator. Such devices can also be used as limited angle torquers or sector torquers. Rotary voice coil actuators generate force in an identical manner to their linear counterparts. However, rotary voice coil 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 2 shows a cutaway schematic of a typical rotary voice coil actuator.

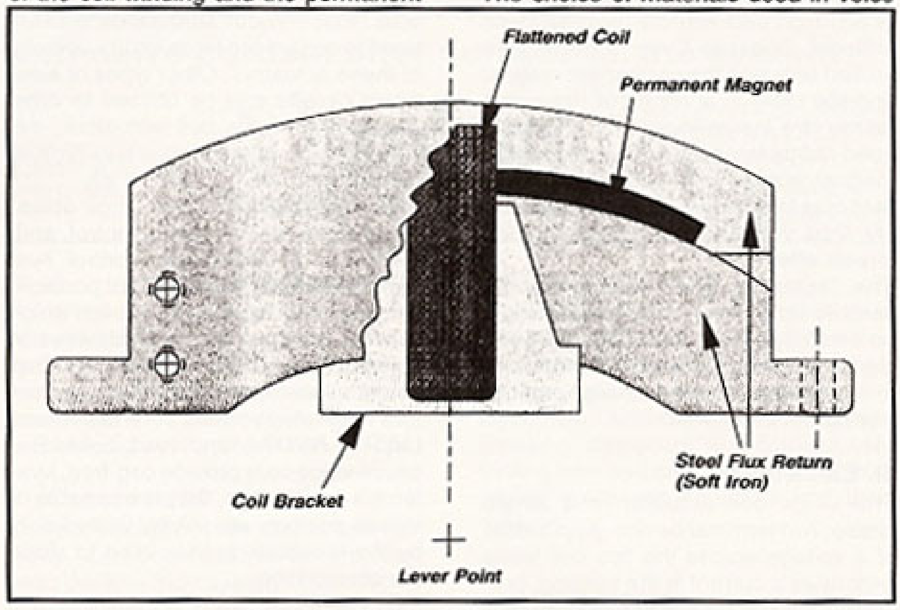

Figure 2 - Rotary Voice Coil Actuator

The choice of materials used in voice coil actuator design is dictated by factors such as required system performance, operating environment, manufacturing considerations, and cost. The coil is wound upon a non-ferromagnetic bobbin with copper or aluminum magnet wire coated with a thin polymer film for electrical insulation. Because the moving coil assembly is composed entirely of non-ferromagnetic materials, there are no cogging forces between the coil and magnet assemblies.

The most common permanent magnet materials are hard-magnetic ferrite, Neodymium Iron Boron, and Samarium Cobalt. The magnet assembly's working air gap must be large enough to accommodate the coil winding, which means that the magnet must operate at a fairly low load line; i.e., B/H = 1.0 - 2.0 typically. The magnet material should have a high coercive force and a fairly linear 2^{nd} quadrant demagnetization curve.

The "back-iron" steel can be composed of any high permeability ferromagnetic material. Because there is no relative motion between the permanent magnet and the steel in a voice coil, iron core losses are insignificant, and the steel need not be laminated. The permanent magnet applies a large DC magnetic field bias to the steel in the field assembly, thus virtually eliminating any hysteresis effects.

The fasteners and bonding agents used to hold everything in place must be carefully chosen to facilitate the efficient manufacture of the actuator and to survive the required storage and operating environments.

III. Electronics

The voice coil actuator is a single phase, two terminal device. Application of a voltage across the two coil leads generates a current in the winding, producing a force on the coil directly proportional to the current and 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. When the coil moves through the permanent magnet field, a voltage (i.e., the "back emf") proportional to the coil velocity, the magnetic field, and the length of the conductor is induced across the coil. The power supply used to drive a voice coil actuator must provide sufficient current to meet the application's force requirements. It must also provide sufficient voltage to overcome the back emf at maximum coil velocity and to allow for the resistive and inductive voltage drops across the winding.

The coil resistance (Ohms) and force sensitivity (Newtons/Ampere) of the voice coil actuator can be impedance matched to most DC power supplies, provided enough volt-amps are available to do the work required for the application. H-bridge amplifiers are commonly employed to drive voice coils. Pulse-Width Modulation is often used to control the force and/or velocity of these actuators. Other types of electronic circuits can be utilized to drive and control voice coil actuators, dependent upon the degree and type of control required.

Many applications of voice coil actuators require precise servo control, and, therefore, a closed-loop control system. There is a wide variety of position, velocity, and force transducers which can be used as feedback devices in voice-coil-based servo systems. Most common are optical encoders, contact and magneto-resistive potentiometers, LVDTs, RVDTs, and load cells. Because voice coils provide cog-free, hysteresis-free motion, they are capable of infinite position sensitivity, limited only by the feedback sensor used to close the control loop.

IV. Mechanical Systems

Voice coil actuators are usually sold as a parts set consisting of a magnet assembly and a coil assembly. A minimum air gap clearance, usually 0.010 - 0.015 inches but sometimes more if required by the application, is provided between the coil and field assemblies. The user must provide a guidance system to allow for the full range of desired motion while preventing the coil winding from rubbing against or crashing into the magnet assembly. In most cases, the load to be moved is connected to the coil assembly because it has a much lower mass (often by an order of magnitude) than the magnet assembly. In cases where the load is especially sensitive to applied heat, the load can be connected to the magnet assembly.

Linear voice coil actuators allow for direct, cog-free linear motion that is free from backlash, irregularity, and energy loss that results from converting rotary to linear motion. For such actuators, the preferred means of guidance are linear bearings or bushings combined with hardened steel shafts, though flexures are often used in short-stroke applications. Shaft/bushing combinations can be constructed as an integral part of most voice coil actuators by the manufacturer. It is important to keep the friction levels of the guidance system low so as not to negate the smooth response characteristics of these actuators.

Rotary voice coil actuators typically utilize shaft/ball bearing guidance systems identical to those used in conventional electric motors. Rotary versions of voice coils provide such smooth motion that they have become the preferred device in applications requiring quick response, limited angle actuation, such as gimbal assemblies.

V. Applications

Voice coil actuators are being employed in an increasingly-wide variety of applications. Their ease of control, fast actuation, smooth response, high reliability, and high efficiency in converting electrical to mechanical energy make them an ideal replacement for conventional electric motors and hydraulic and pneumatic actuators.

Because of their speed and their precise control characteristics, rotary voice coils are employed to position the heads of computer disk drives. Linear voice coils are used for speakers because of their flat response over a wide frequency range. Other voice coil applications requiring high frequency operation include linear cryocoolers, refrigerators, and various other pumps, where the actuators are operated in resonance against a gas spring to provide the necessary compression for the particular cooling cycle employed.

The smooth, precise, hysteresis-free, cog-free response of voice coil actuators make them ideal for the control of many types of valves. These actuators are increasingly used in medical devices to modulate the flow of air, oxygen, blood, and other fluids. Because there is no contact between moving parts (i.e., the coil and field assemblies), voice-coil controlled valves are more reliable than hydraulic or pneumatic valves. Voice coils are also free of the hysteresis inherent in other types of actuators, thus making them easier to control.

Voice coil actuators have become the preferred drivers for precision optical systems. The smooth, fast, cog-free motion provided by voice coils make them ideal for positioning mirrors and lenses in tightly-controlled servo loops.

VI. Conclusions

Voice coil actuators are simple, two-terminal, non-commutated electromagnetic devices increasingly employed in a wide variety of linear and rotary motion systems. Their fast, smooth, cog-free, hysteresis-free response characteristics make voice coils ideal for applications requiring high speed and acceleration, wide bandwidth, linear force or torque response and tight servo control. The electrical and mechanical simplicity of these actuators allow for high reliability and high energy conversion efficiency.

Current applications for voice coil actuators include mirror and lens positioning, beam steering, and auto-focusing in optical systems; head positioning in computer hard disk drives; servo valve control; microlithography; semiconductor fabrication; and linear drives for cryocoolers and other types of pumps. Systems designers are continuously finding new and creative ways to incorporate voice coil actuators into their devices.

About the Author

Mr. Anthony C. Morcos is a Senior Magnetics Engineer for BEI Sensors and Systems Company's Kimco Magnetics Division. He is responsible for the design of linear and rotary actuators, magnetic bearings, and specialty magnetic devices.

For More Information Circle 108