Voice Coil Actuators

A voice coil actuator (VCA) is a limited-range motion device that uses magnetic field generated by permanent magnets in connection with a coil of wire to produce a force proportional to the applied current in the coil. These direct-drive systems with linear control characteristic are also referred to as voice coil motors (VCM). The name derives from the device's original use in audio loudspeakers. VCAs take two forms: linear and rotary (swing arm); they typically are used in applications requiring high acceleration, high frequency actuation and flat force output. The example used is a VCM in a typical hard disk drive implementation.

Keywords

Voice coil actuator, voice coil motor, hard disk drive, magnetic field, finite element analysis

Products Used

ANSYS® Maxwell® 3-D 15.0, ANSYS Optimetrics™

Background

Voice coil actuators work on the Lorentz force principle, which involves a force exerted on a current-carrying conductor in a magnetic field; this force is proportional to field strength and current. Changing current direction alters the direction of the force, so voice coil actuators are bidirectional actuators with similar behavior in both directions. These devices are single phase, offering advantages such as cogging-free operation, high dynamic response due to small moving mass, and very small hysteresis — which make them ideally suited for applications requiring well-controllable movement in both directions. Also, requirements regarding audible noise, small overshoot or very good controllability on force can be easily fulfilled with voice coils. The devices can be supplied as pure actuators without needing integrated sensors in which feedback for the control is derived from other variables in the application, such as pressure in medical or valve applications.

Fully integrated VCAs also are available. These include a bearing and encoder as position feedback so that, together with a servo-controller, these devices can be used directly as system components in a positioning system. Because of their speed and precise control characteristics, rotary voice coil motors are well suited to position the heads of computer hard disk drives (HDDs), which is a major application.

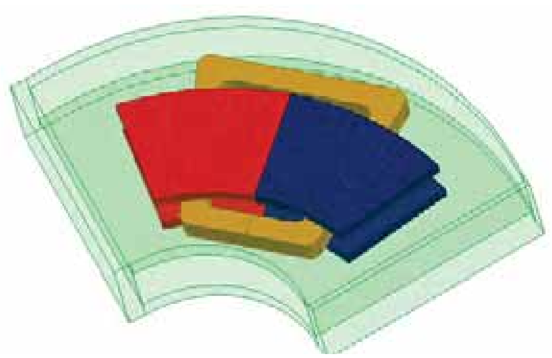

Figure 1. Voice coil motor geometry in HDD application. Blue and red segments are permanent magnets; green structure is magnet keeper, which completes magnet assembly. The voice coil (orange) moves in a rotary fashion in the air gap between magnets.

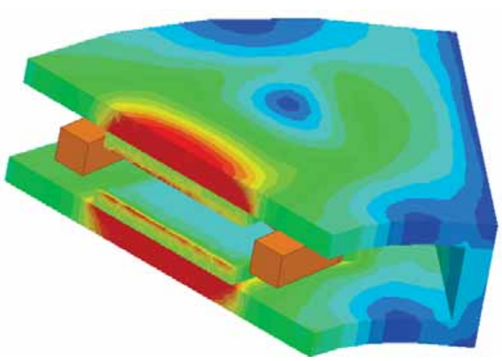

Figure 2. Magnetic flux density magnitude distribution on magnet assembly of HDD voice coil motor model in ANSYS Maxwell

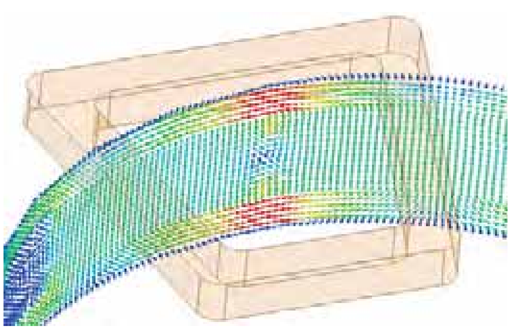

Figure 3. Flux density vector plot on curved surface in center of magnet assembly of HDD voice coil motor model in ANSYS Maxwell

Description

ANSYS Maxwell can model various design aspects of VCAs. The software's magnetostatic solver determines magnetic flux density generated by the specified DC current in the coil everywhere in the solution domain. This enables the user to study saturation of the magnetic circuit considering all the fringing flux and nonlinearity of magnetic materials. This solver also computes the force (torque) exerted on the coil as well as coil inductance for any given coil position and current level.

Maxwell's transient solver determines a VCA's dynamic behavior by performing its analysis in the time domain. This includes computation of the transient response to arbitrary time-dependent current (voltage) inputs in connection with the mechanical equation of motion, which allows important device characteristics to be determined, such as acceleration-related seek time. Utilizing Maxwell in connection with ANSYS Optimetrics allows a user to study various possible scenarios automatically, including variations of geometry, coil position, coil current and material properties. It also allows generation of an equivalent circuit model of the voice coil, which can be included in a systems-level simulation model of ANSYS Simplorer. The performance of the whole system can thus be modeled and assessed, making sure that the entire system meets defined design requirements.

For the VCM in a hard disk drive application presented here, Figure 1 shows a typical configuration. The blue and red objects are north- and south-oriented permanent magnets, respectively. Typically, these magnets are made from neodymium and coated with nickel. The green structure is a nickel-plated iron that serves as the magnet keeper; it guides the flux around the back of the magnets to complete the magnetic circuit and helps to keep the flux lines in the air gap parallel and minimizes flux leakage from the structure. The voice coil (orange) moves in a rotary fashion in the air gap between magnets. The coil is attached to the disk head through the pivot arm and together they move around the actuator axis.

Figure 2 shows the distribution of the magnitude of flux density on the magnet assembly for the given position and current level. Figure 3 plots flux density vectors on a curved surface in the center of the magnet assembly. The plot shows the direction of flow of the magnetic flux, any possible leakage and its uniformity in the air gap.

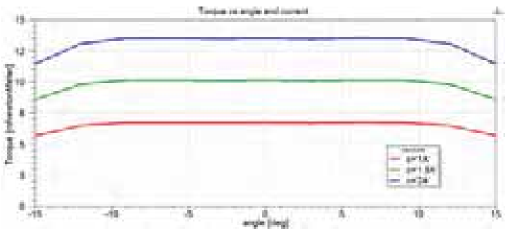

Figure 4. Torque exerted on coil as function of coil angular position for various currents applied to coil

A typical task related to VCM design for an HDD application is to determine the torque as a function of coil position and applied current. Parametric analysis in Optimetrics automatically changes the position angle of the coil along with the level of applied current and computes the fields and torque for every desired variation. The variation of the torque as a function of the coil position is shown in Figure 4 for three specified current values. The flatness of the torque can be observed for the position of the coil spanning 20 degrees between angles -10 and +10 degrees. Beyond 10 degrees in both directions, torque starts to decline. This is very important information for a VCM designer.

Summary

ANSYS Maxwell provides design engineers with an easy-to-use 3-D FEM modeling environment that is very well suited to evaluate performance of voice coil actuators. The analysis typically starts by computing the static magnetic fields and determining important design indicators, such as saturation, inductance and torque. The analysis continues by performing time domain analysis and studying the dynamic response, including motion-induced effects, back electromotive force (EMF) and losses. If needed, the analysis continues with entire circuit- and systems-level performance evaluations using ANSYS Simplorer, which offers a powerful systems-level design platform.

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