Temperature-Dependent Permanent Magnets

The demagnetization characteristic of permanent magnets is temperature dependent. Therefore, the performance of any device working with permanents magnets varies with temperature. In situations in which these devices are subject to large temperature variations, analysis must be acrried out at different temperatures to predict possible performance deterioration. Temperature-dependent permanent magnet models in ANSYS Maxwell can be applied to simulate the electromechanical performance of various devices.

Keywords

Permanent magnets, temperature dependence, moving-coil loudspeaker, permanent magnet synchronous motor, voice-coil actuator, Hall-effect sensor, magnetic field, finite element analysis

Products Used

ANSYS® Maxwell® 16.0, ANSYS Optimetrics™

Description

The temperature dependence of permanent magnets falls into three categories. The first is associated with reversible losses. These losses are recovered when the magnet returns to its original temperature. Reversible losses are described by the reversible temperature coefficients of remanence (residual magnetic flux density) and intrinsic coercive magnetic field. These coefficients are expressed as percents per degree Centigrade and vary for specific grades of each material. The demagnetization curve of a permanent magnet develops a knee at elevated temperatures because the temperature coefficients of remanence and coercive field are significantly different.

The second category defines the losses as irreversible but recoverable, which results from partial demagnetization of the magnet due to exposure to high or low temperatures. These losses are recoverable only by remagnetization; they are not regained automatically when the magnet's temperature returns to normal. Such losses occur when the operating point of the magnet falls below the knee of the demagnetization curve.

The third category includes irreversible and unrecoverable losses. Metallurgical changes occur in magnets exposed to very high temperatures that are not recoverable by remagnetization. When the temperature of a magnet reaches the Curie temperature, the elementary magnetic moments are randomized and the material is demagnetized.

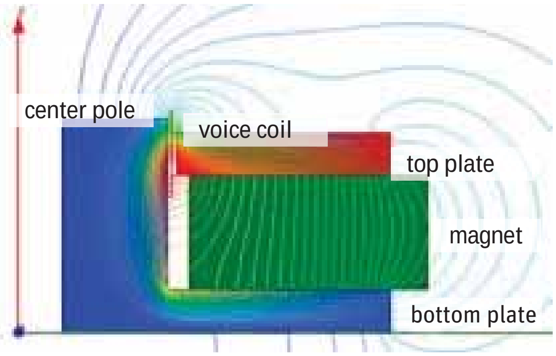

Figure 1. Typical axisymmetrical geometry of loudspeaker magnet assembly with flux lines plot in ANSYS Maxwell

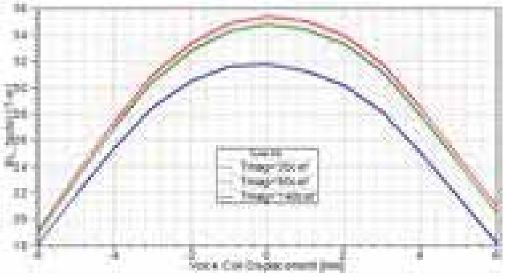

Figure 2. BL-factor of a loudspeaker as function of voice coil displacement for various magnet temperatures

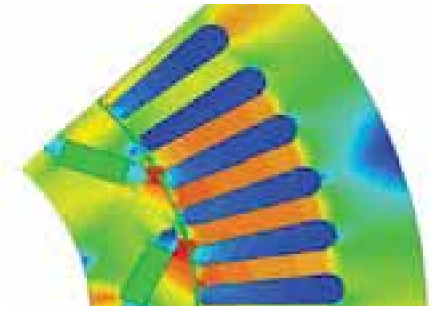

Figure 3. Flux density vector plot on curved surface in center of magnet assembly of HDD voice coil motor model in ANSYS Maxwell

Another important parameter of magnets is maximum service temperature, which is defined as the maximum practical operating temperature. This temperature is dependent on the operating point of the magnet in the circuit. An efficient permanent magnet design should have a magnetic circuit in which the magnet operating point is located above the knee of the demagnetization curve at the expected elevated temperatures. This prevents variations in performance at elevated temperatures.

To model temperature dependence of permanent magnets with a finite element tool, reversible temperature coefficients needs to be known along with the demagnetization characteristic. ANSYS Maxwell allows convenient entry of such data, for which the intrinsic demagnetization curve at nominal temperature is first specified. This is followed by designating the particular permanent magnet material as temperature dependent by entering temperature coefficients. As a result, the demagnetization curve at any given temperature is uniquely defined and modeled.

The main task is to determine some key parameters or the performance of a device at a given operating temperature of the magnet. Several examples are shown here, in which temperature-dependent magnet models have been applied in ANSYS Maxwell. The applications include a loudspeaker (Figure 1), permanent magnet synchronous motor (Figure 3), voice coil actuator (Figure 5) and Hall-effect sensor in an anti-lock braking system (ABS, Figure 7).

Analyses at various temperatures can be automatically performed using the ANSYS Optimetrics automation module. In all these applications, the temperature is assumed to be uniformly distributed in the magnet volume. If desired, the temperature in the magnet can be determined by ANSYS fluid dynamics or mechanical tools and mapped into Maxwell. This way, the actual temperature distribution in the magnet can be considered, which result in different magnet areas having different demagnetization characteristics, reflecting temperature distribution.

A loudspeaker magnet assembly typically exhibits rotational symmetry and consists of magnetic circuit shaping parts (top plate, bottom plate and center pole) and a voice coil located in the air gap (Figure 1). An important design parameter of a loudspeaker is the BL-factor, which describes the coupling between mechanical and electrical sides of a loudspeaker. This factor is defined as the integral value of the flux density B over voice coil length L and is a function of the magnetic circuit, voice coil displacement and voice coil current. Figure 2 depicts the variation of the BL-factor of the modeled loudspeaker as a function of voice coil displacement at various magnet temperatures. This graph clearly shows how the BL-factor deteriorates at elevated temperatures.

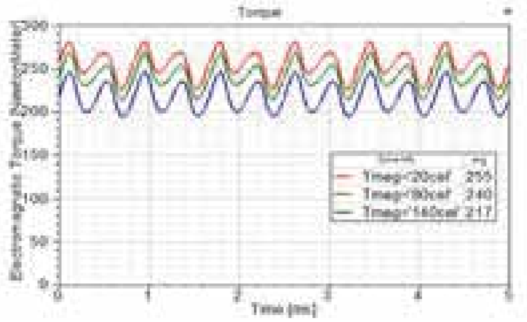

Figure 4. Electromagnetic torque time variation of modeled loaded permanent magnet synchronous motor rotating at 3,000 RPM for various magnet temperatures

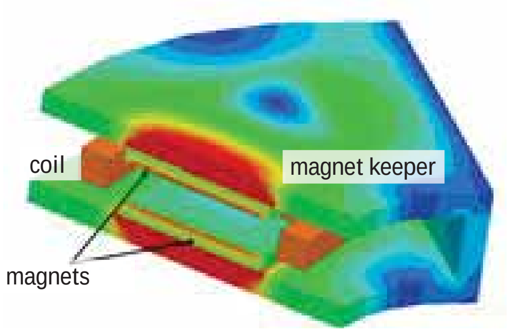

Figure 5. Flux density magnitude plot on cut-out view of typical voice coil motor model for hard disk drive application in ANSYS Maxwell

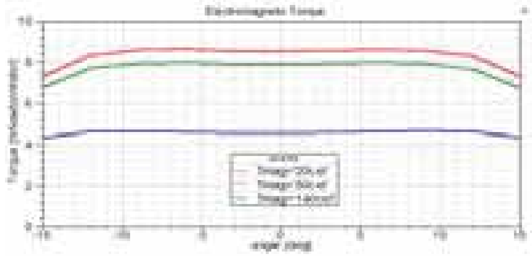

Figure 6. Torque exerted on coil of hard disk drive as function of coil angular position for various magnet temperatures

Figure 3 presents a typical geometry of a permanent magnet synchronous motor. The flux density distribution represents a loaded motor operation with the motor rotating at 3,000 RPM. The developed electromagnetic torque was studied for three different magnet temperatures, and its time variation is shown in Figure 4. The average developed torque is shown in the graph next to each temperature, clearly indicating a drop of about 15 percent for the highest studied temperature.

A cut-out view of a typical voice coil motor model in a hard disk drive application is shown in Figure 5, along with the flux density magnitude plot. The model consists of permanent magnets, nickel-plated iron magnet keeper and coil, which moves in a rotary fashion in the air gap between magnets. When designing a voice coil motor, the electromagnetic torque as a function of the coil position is an important performance indicator. Ideally, the magnetic circuit should be designed so that torque is constant as the coil moves in the air gap. For this example model, the requirement of torque flatness is satisfied for the most part, as can be seen in Figure 6, in which the variation of the torque is shown as a function of the coil angular position for various magnet temperatures. Although the flatness of the torque remains more or less the same at elevated temperatures, torque magnitude can be substantially reduced, which is very important information for a voice coil motor designer.

Figure 7 shows a possible application of a Hall-effect sensor in an ABS system. The sensor consists of a permanent magnet that is biasing the Hall element and a toothed wheel, which could be an internal disk brake hub. Maxwell computes the magnetic fields for this configuration and determines the normal flux density that is sensed by the Hall element. The variation of the normal component of the flux density at the Hall element as a function of the toothed wheel rotational position for several magnet temperatures is shown in Figure 8. The drop of the available trigger flux density is clearly noticeable at elevated temperatures, allowing correct positioning and dimensioning of the Hall sensor.

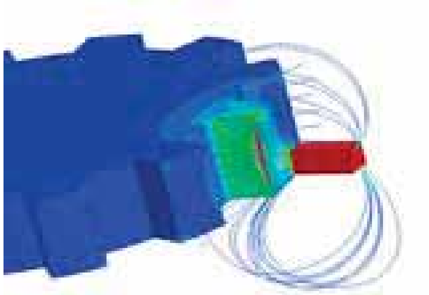

Figure 7. Magnetic flux density and flux lines plot on toothed wheel, magnet (red) and Hall element (located on magnet facing wheel) in ABS application model in ANSYS Maxwell

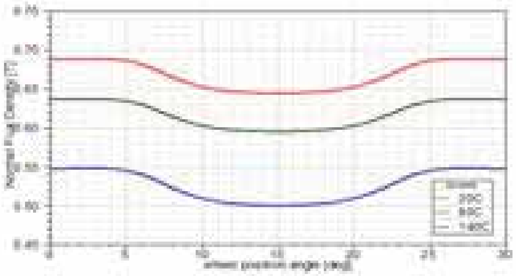

Figure 8. Variation of normal flux density at Hall element as function of toothed wheel position for various magnet temperatures

Summary

For devices in which the operation is based on permanents magnets, it is absolutely crucial to account for possible temperature variations, which may significantly influence performance. The temperature of a magnet can change because of both ambient temperature changes and losses generated in a device or magnet itself.

Four different scenarios have been discussed, showing temperature-dependent permanent magnet models available in ANSYS Maxwell. These are applied to determine various device performance characteristics as functions of temperature. This initial step in the analysis, in which uniform magnet temperature is assumed, can be followed by simulations using ANSYS fluid dynamics or mechanical tools, which would determine the actual nonuniform distribution of magnet temperature. This temperature could, in turn, be mapped back into ANSYS Maxwell, whereby different magnet areas would have different demagnetization characteristics, based on the mapped temperature distribution. Ultimately, the analysis can continue with the entire circuit and systems-level performance evaluation using ANSYS Simplorer, which offers a powerful system level design platform.

Author

Julius Saitz, julius.saitz@ansys.com

ANSYS, Inc.
Southpointe
275 Technology Drive
Canonsburg, PA 15317
U.S.A.
724.746.3304
ansysinfo@ansys.com

Toll Free U.S.A./Canada:
1.866.267.9724
Toll Free Mexico:
001.866.267.9724
Europe:
44.870.010.4456
eu.sales@ansys.com