# UNDERSTANDING TEMPERATURE-DEPENDENT DEMAGNETIZATION

## Using both fluid and electromagnetic simulation can better determine temperature-based demagnetization for permanent magnets used in electric vehicles.

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Permanent magnets are widely used in various high-performance electric machines, including hybrid electric/electric vehicle motors and generators. When an electric machine is overloaded or after a short circuit, irreversible demagnetization may occur due to a strong demagnetizing field and/or temperature increases — the two dominant reasons for demagnetization. Demagnetization can significantly reduce the magnet's ability to create flux, which, in turn, decreases the electric machine's overall efficiency. Electrical machine designers need to know what is actually happening to the magnet so that they can choose a permanent magnet with appropriate properties and properly designed cooling systems to withstand demagnetization. A combination of ANSYS Maxwell and ANSYS Fluent allows designers to accurately evaluate the demagnetization that occurs due to overloading and temperature changes. Overloading and increased temperatures can happen independently or simultaneously during a fault or during normal operation.

**Electrical machine designers need to know what is actually happening to the magnet.**

ANSYS Maxwell software provides a temperature-dependent permanent magnet model that can capture demagnetization due to increased temperature and/or overloading. In this model, the temperature of the magnet can be assigned as a uniform constant temperature. For increased accuracy, the temperature can also be calculated in ANSYS Fluent computational fluid dynamics (CFD) software based on losses mapped from Maxwell. CFD is widely used in industry and academia for electric machine thermal management design.

Magnets consist of many magnetic domains, and each domain has a magnetic moment vector. The orientation of these magnetic moment vectors from different domains could be quite dissimilar. The magnetization, $M$, is obtained by integrating the magnetic moment vectors over the entire magnet volume, and $M$ always has the same unit of magnetic strength $H$. The permanent material is, therefore, described as:

$$B = u0(M+H)$$

in which $u0M$ is the intrinsic flux density Bi, $B$ is the measurable flux density also known as normal $B$, and $u0H$ is the air flux. Therefore, Bi = $B - u0H$, and if either $B$ or Bi is given, the other is also known, and the magnet can be completely characterized at a particular temperature. This is the approach Maxwell currently uses. Since the BiH curve applies to one particular temperature, the magnet is only well defined at this temperature. To fully characterize the magnet in a temperature-dependent manner, the magnet remanence ($Br$) and coercivity ($Hci$) also need to be defined as a function of temperature:

$$B_r(T) = B_r(T_0)\cdot[1+\alpha(T-T_0)]$$
$$H_{ci}(T) = H_{ci}(T_0)\cdot[1+\beta(T-T_0)]$$

The parameters $\alpha$ and $\beta$ of the temperature functions are usually provided by the manufacturer, but Maxwell can extract these parameters from the given family of intrinsic BiH curves. An example of a temperature-dependent magnet model is shown in Figure 1. The input to this model is a single BiH curve at a particular temperature and the

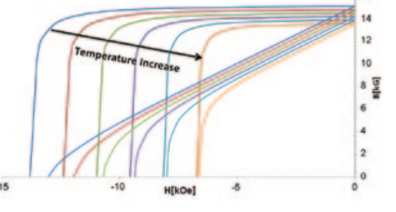


**Figure 1. The intrinsic and normal BH curves for rare earth material at different temperatures in ANSYS Maxwell**

temperature-dependent function. The curves at other temperatures are automatically generated by Maxwell.

Temperature gradients in the magnet often cause different parts of the magnet to demagnetize nonuniformly. To capture this demagnetization phenomenon, a spatial temperature distribution for the permanent magnet is required. Fluent can be used in this case.

As an example, an interior permanent magnet motor can be modeled entirely within the ANSYS Workbench environment using Maxwell and Fluent. First, define the temperature-dependent model in Maxwell, and set up the motor to run at one of its normal operating conditions. To capture eddy current and core loss phenomena, use the Maxwell transient solver to calculate the time-averaged loss distribution — such as winding copper loss, core loss and eddy current losses — at an initial temperature. The loss distribution obtained in this way is shown in Figure 2. This data is used as a heat source in Fluent for the thermal calculation.

In Fluent, generate a thermal model based on the same motor geometry. Using the losses calculated in Maxwell as the heat source, calculate the temperature distribution of the motor.

Calculate the temperature distribution of the motor using the steady-state solver in Fluent based on the heat source from Maxwell. Using the steady-state solver is valid because the electrical time scale is much smaller than the thermal time scale. Temperature distribution is then automatically mapped back to Maxwell, in which the magnet is defined as temperature-dependent. Because of this mapping, the magnetic properties of the magnets will change based on the spatial temperature distribution. Run Maxwell again to take into account the distributive temperature effects that change the overall performance of the motor. This is an iterative solution, and after four to five iterations, the solution usually converges. The temperature effects on the performance of the motor at this particular operating condition can then be studied. Figure 4 shows the torque of the motor with and without the temperature effects. Higher temperatures inhibit torque production. This insight is not possible without understanding the magnet's temperature dependency and the actual temperature distribution.

Permanent magnets in high-performance electric machines can suffer from severe demagnetization due to overloading and/or overheating. Demagnetization can significantly impair the electric machine's performance. Knowledge of demagnetization is critical for machine designers to properly select magnet materials and cooling methods. ANSYS Maxwell and ANSYS Fluent provide a temperature-dependent magnet model and temperature distribution capabilities that enable designers to gain real insight into what is physically happening. This coupled simulation is performed entirely within the ANSYS Workbench environment; it is a complete solution for studying demagnetization phenomena due to overloading and temperature effects.

**Figure 2. Electromagnetic losses calculated in Maxwell can be automatically mapped to Fluent as the heat source to calculate the motor's temperature distribution. The losses include copper loss in the copper winding, eddy current loss in the permanent magnet, and core loss in the stator and rotor cores.**

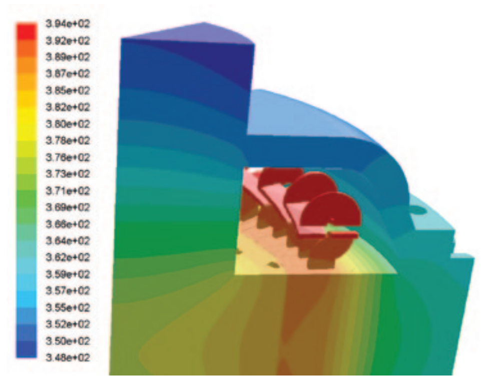

**Figure 3. Temperature distribution of motor calculated in Fluent. The temperature distribution is automatically mapped back to Maxwell, which then changes the conductivity of the copper winding and the magnetic property of the permanent magnet.**

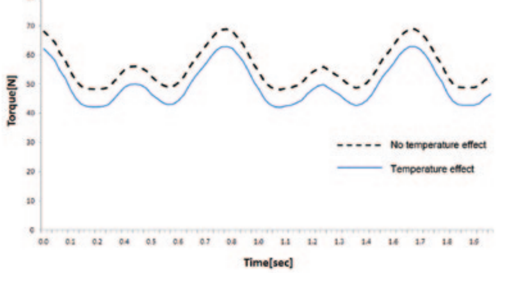


**Figure 4. The motor produces lower torque when the temperature effect on the permanent magnet is considered.**

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