By John Simkin, Technical Director, Vector Fields

Optimizing Permanent Magnet Designs

The simple fixtures that are used to permanently magnetize components, a process that often takes place during the production of the end equipment itself, can introduce imperfections. Great care also needs to be taken with the operating environment, to minimize subsequent demagnetization. This is even the case with an advanced magnetic materials such as neodymium iron boron, because it has a lower maximum operating temperature limit than conventional ferrites.

Design tools are rarely used in this area: a lot of permanent magnet users simply assume that their components have a uniform magnetization. This article outlines a new three-dimensional finite element simulator called DEMAG. The simulator is provided as part of the OPERA electromagnetic modeling suite, which allows users to accurately simulate the magnetization process, and then subsequent demagnetization effects that might be encountered, in their real-life application environments such as a motor or actuator.

By being able to accurately model the complete magnetization and demagnetization process, including within the real in-service environment, the tool presents opportunities to greatly improve the design and performance of permanent magnet based equipment.

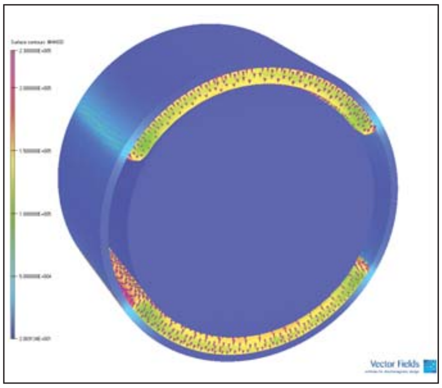

Figure 1a. Remanent field strength after magnetization

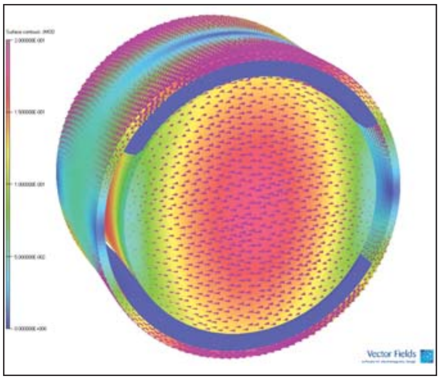

Figure 1b. Eddy current distribution at peak of magnetizing field

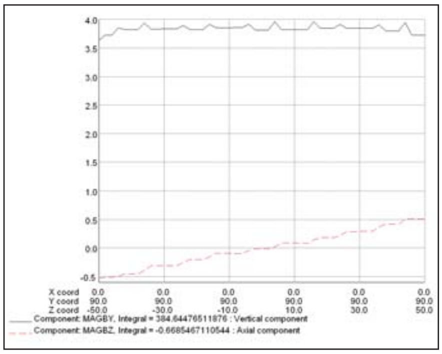

Figure 2. Graph of peak magnetizing flux density in magnet

More Flexible Simulation

DEMAG has introduced a more flexible method of modelling the permanent magnet material in this application by employing look-up tables, rather than analytic expressions, to represent the demagnetization characteristics. By interpolating from actual measured BH (magnetic induction, and applied field) characteristics, it can be configured to simulate any magnetic material. Rather than using a theoretical magnetization distribution, the true distribution is calculated from the properties of the magnetizing fixture. The performance of permanent magnets is therefore predicted with great accuracy.

The solver has been further enhanced to include a model for the recoil of the magnets during in-service operation. This in-service operation modelling can also include the effects of other coupled physical fields, such as temperature or stress, and the material models include dependencies on other physical parameters that are not within the electromagnetic analysis.

Example Application

Permanent magnets are usually magnetized in a fixture comprising an electromagnet driven by a capacitor discharge circuit, iron former and the un-magnetized specimen. DEMAG and other tools in OPERA can be used to model the whole magnetization process including the capacitor discharging into the electromagnet, eddy currents induced in the formers and magnets, and non-linear saturation of the materials. The calculated temperature dependent magnetization of the specimen can then be used, to determine the performance of the end product. This will be illustrated with the example of a permanent magnet direct current (PMDC) motor.

Figure 1a shows part of a magnetizing fixture designed for producing the ferrite magnets of a PMDC motor - the coils and frame have been removed so that the retaining ring, magnet and iron core are visible. The contours and vectors show the remanent field strength after a pulse magnetization with a uniform field of 30 kA/m. Figure 1b shows the same structure at the peak of the magnetization with the contours displaying the eddy currents induced in the solid members of the fixture. Induced eddy currents can significantly modify the distribution of magnetizing flux in the magnets. Although this fixture has been designed to give a radial flux density, it can be seen that there is also an axial component to the field near the ends of the magnet.

The imperfections in the magnetisation distribution (for example, an axial component) can be seen more easily by plotting a graph of the peak magnetizing flux density in each finite element of the magnet during the magnetizing process. Figure 2 shows the vertical (applied field direction) and axial components of the peak magnetizing flux density along an axial line at the centre of one of the two sections of magnet in the fixture. The dimensions of the retaining ring and core have been optimised to achieve a uniform vertical component of magnetization, with minimum axial component.

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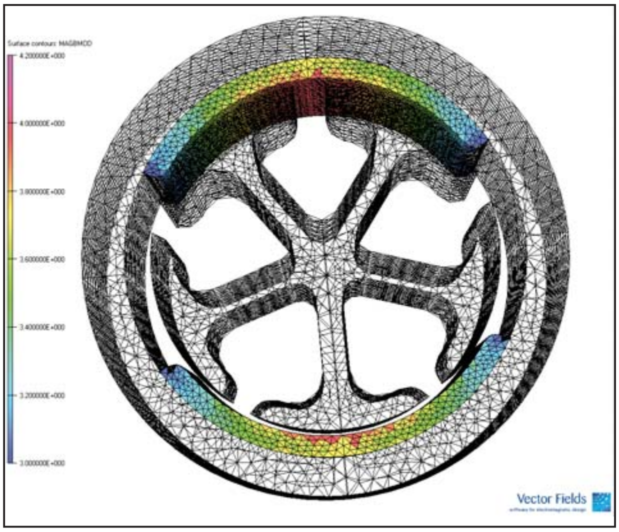

Figure 3. Peak magnetization flux density of magnets when imported into a PMDC model

Representation of In-Service Material Response

Once the calculated magnetization of the model is available, it can then be used in all other OPERA simulation modules, such as those for the design of rotating machines or linear actuators, to study and optimize the performance of the overall equipment itself.

The calculated magnetization distribution from the DEMAG simulator is imported into the application model, as illustrated in Figure 3 where a permanent magnet DC motor is shown using the magnets created in the fixture shown earlier. The figure shows that the peak magnetizing flux density varies considerably over the magnet from 3 Tesla to 4.2 Tesla. However, even the lowest flux density in this range is sufficient to ensure that the magnets are fully magnetized.

Designers can then study the effects of service factors such as fault currents and high operating temperatures, for example. In the case of a PMDC motor, the field created by armature currents (or similar) will further modify the operating point of the magnets.

The Opera modules maintain the history of maximum and minimum flux density that the permanent magnet materials experience during magnetisation and operation. Thus when the field from the armature current starts to re-magnetize the magnet a recoil material characteristic can be used; or when the armature current further demagnetizes the magnet its demagnetisation characteristic can be applied.

Multi-Physics Modelling

Supporting the DEMAG simulation module is a general purpose system for modelling non-linear material characteristics that are a function of many variables. This had immediate benefit in the design of permanent magnet machines because critical temperature dependent effects could be evaluated. Another good example is the simulation of catastrophic failure (quench) in superconducting magnets. Figure 4 shows the time evolution of a quench in a coil.

The Opera suite of programs is based on efficient, fast, high accuracy simulations for electromagnetic devices. Designing new products for today's markets means pushing technologies to the limit in order to achieve more at lower cost, multi-physics modelling, as exemplified by the DEMAG simulator, is the next phase of computer aided engineering.

After graduating from the University of Birmingham (Physics) John Simkin joined the Rutherford Laboratory to work on the design of superconducting magnets for particle accelerators and medical applications. His work at the laboratory lead to the development the first commercial 3D electromagnetic design system (Tosca). In 1985 he become the Managing Director of Vector Fields Ltd. and continues to lead the company's technical software development as well as being actively involved in collaborative projects. He is also an active consultant to customers in areas such as MRI systems, permanent magnet devices, particle detectors, liquid metal pumps and electron beams.

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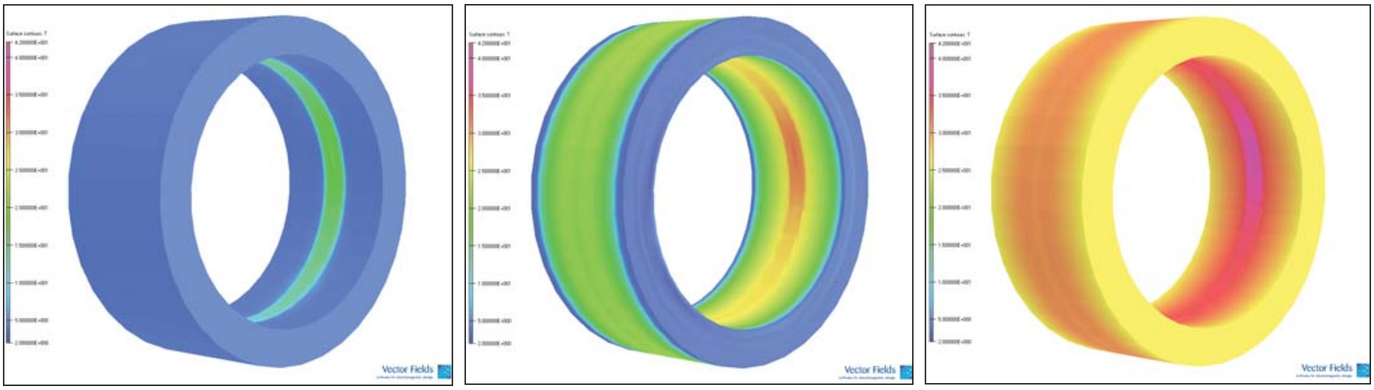

Figure 4. Left to right. Temperature 10 milliseconds after initiation of quench, then at 50 and 100 milliseconds

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