Optimizing Magnetic Shielding

Continuous exposure to high electro-magnetic fields (EMF) generated by sources such as busbar connections to transformers, cabinets, high voltage overhead lines, etc. can impede normal function of electronic equipment. For example, high EMF can cause broken strips, communication problems and even hardware degradation. When re-arrangement of substation equipment is neither practical nor feasible, shielding in the immediate vicinity around EMF sources is implemented.

This article by Amandeep Bal of Integrated Engineering Software in Canada discusses such shielding in a magnetic resonance imaging (MRI) model. It also presents results of magnetic field analysis inside and outside of unshielded and shielded electromagnets in free space using a Boundary Element Method (BEM) solver.

Boundary Element Method

Material properties of thin layers and their environment differ greatly and can impact electromagnetic field distribution. Owing to geometric complexity and other issues, optimizing such configurations can only be accomplished by means of numerical methods. But, unfortunately, applying numerical methods to thin layers is often problematic.

One solution is to use fine discretization. However this implies a relatively large system of equations. Numerical errors can be significant and unacceptable. Thin layers therefore require special treatment, e.g. using air gap finite element or transforming the governing equations into more applicable forms. These issues can best be resolved by the Boundary Element Method (BEM), which is well suited to calculate fields for open region problems. Otherwise, artificial truncation has to be done and this requires time and reduces accuracy.

The basis of the BEM method is to transform the original partial differential equation (PDE), or system of PDEs that define a given physical problem, into an equivalent integral equation or system. This is accomplished either by means of the corresponding Green's representation formula (i.e. the direct method) or, alternatively, in terms of a continuous distribution of singular solutions over the boundaries of the problem (i.e. the indirect method). The unknowns in the integral formulation of the boundary value problem are the primitive variables on the boundary (direct formulation) or fictitious surface densities of the singular solutions (indirect formulation). As such, the integral equation obtained satisfies the governing field equation exactly, even though the goal is only to approximately meet the boundary conditions imposed.

The Finite Element Method (FEM) approach requires the design's entire domain, including free space, to be modeled with a finite element mesh. By contrast, the BEM approach requires modeling only the design's surface with boundary elements. This means the BEM model is an order of magnitude less complex. BEM also allows easy visualization of element distribution, especially for 3-D designs where FEM meshes are almost impossible to represent and comprehend.

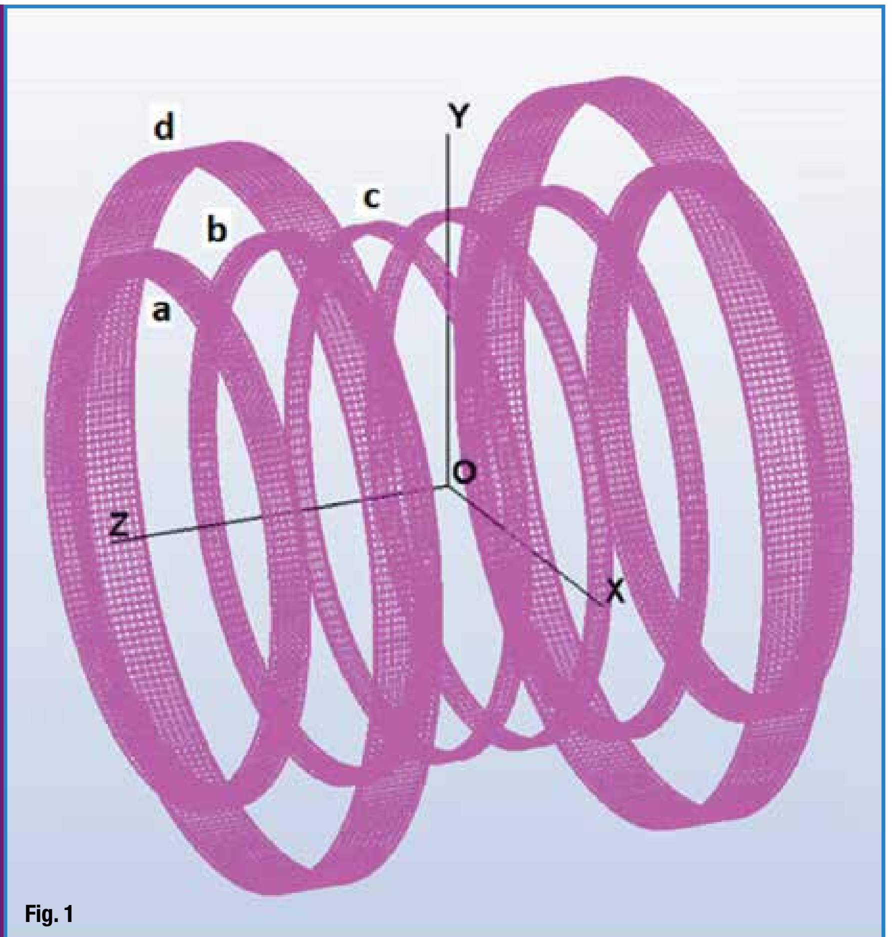

Fig. 1

Electromagnetic Geometry

Fig. 1 shows a full model of an electromagnet meshed with 3-D brick elements in the current-carrying coil volumes. This model was created by first completing a half portion and then developing the full model using the 'copy on' and 'mirror symmetry' features found in simulation software.

The current densities in the copper coils of the electromagnet are as follows:

- Coil a: 1.37727X10^6 Amp/m^2 (anti-clockwise);
- Coil b: 7.15188x10^{-5} Amp/m^2 (anti-clockwise);
- Coil c: 3.78390x10^5 Amp/m^2 (anti-clockwise); and
- Coil d: 1.315905x10^6 Amp/m^2 (clockwise).

The simulation software used to analyze this particular electromagnet offers the option of switching to either FEM or BEM field solvers, but the latter was adopted here. The space around the device was not meshed since, as discussed, the BEM approach requires only the design surface to be modeled. This relative simplicity is especially useful for this type of application.

Magnetic Field Analysis of Electromagnets by BEM

Figs. 2 and 3 present magnetic field results after solving the model with the BEM solver. A magnetic field of 1.5 Tesla is observed within a volume of 1 cm^3 around the origin inside the electromagnet (as shown in Fig. 2).

Fig. 3 provides the plot of variation of z component of magnetic field along the z-axis. It can be observed that value of B is 1.5 Tesla up to 34 cm; thereafter the value decreases to 30 Gauss at 240 cm and remains constant for 300 cm.

The contour plot of magnetic field magnitude on a circular surface constructed around origin with radius 300 cm is presented in Fig. 4. It shows a magnetic field of circa 8.721 Tesla (red) is present around the corners of the first and last coils.

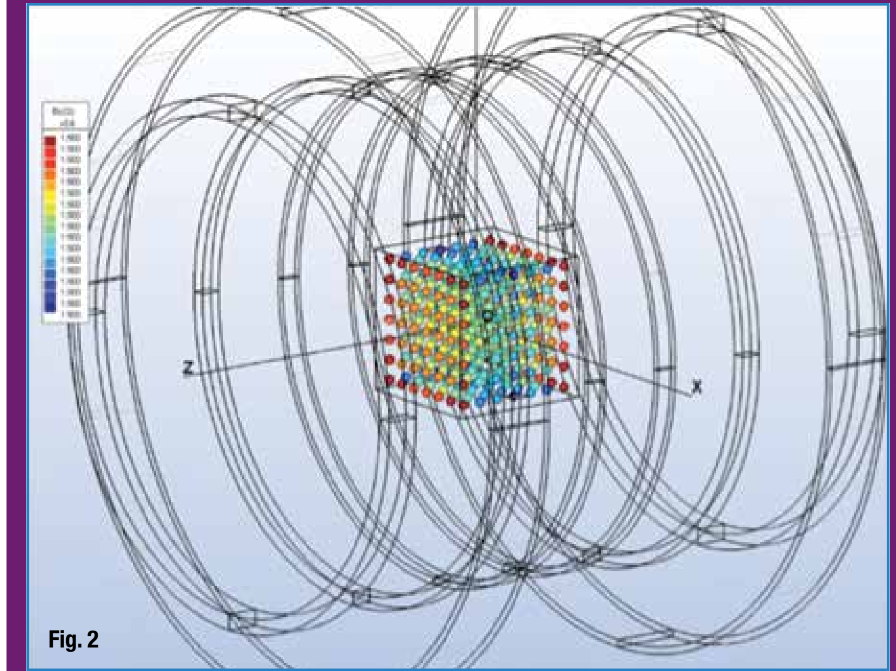
Fig. 2

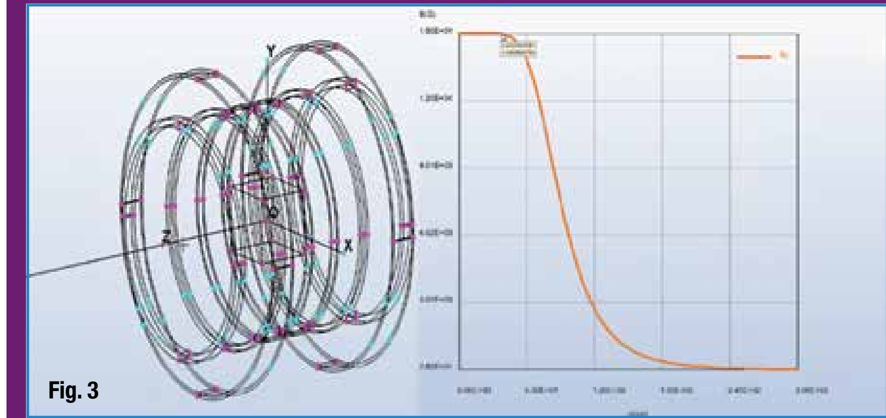
Fig. 3

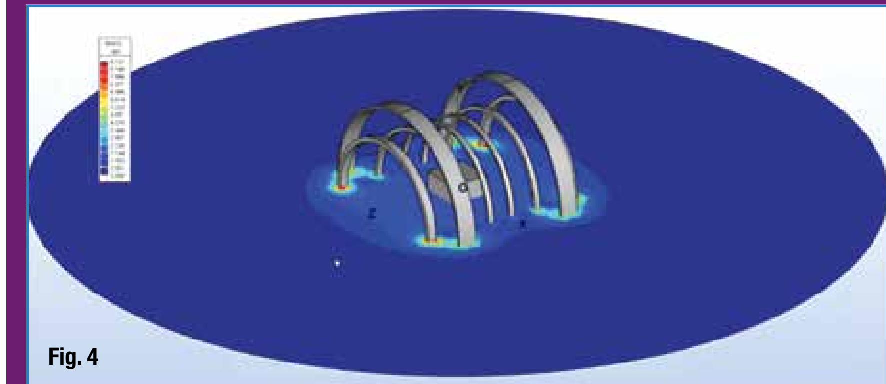
Fig. 4

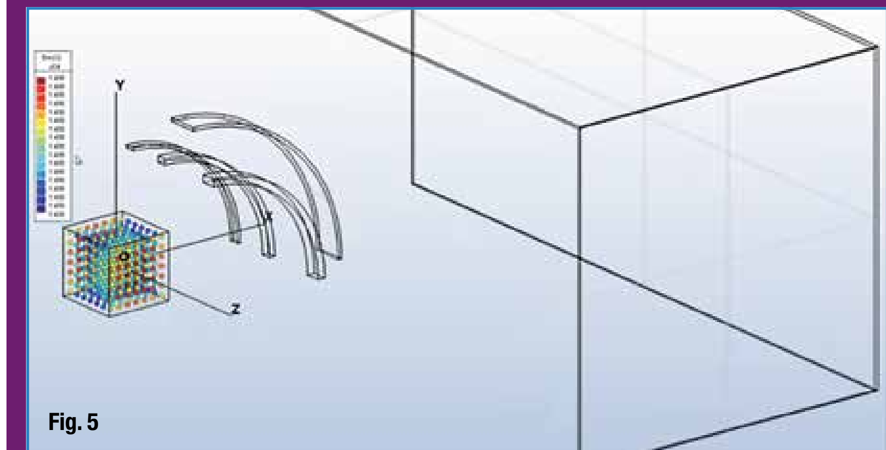
Fig. 5

Magnetic Field Analysis of Shielded Electromagnet

A 1 cm thick, 3 x 3 x 6 m^3 1010 steel shield was constructed around the electromagnet. Symmetry conditions were applied to reduce the size of the model to 1/8 of normal size. The symmetry features of the solver allow reducing model size while still providing results that apply for the full model. This reduces number of meshed elements and memory requirements. Here, 9000 elements were required to mesh 1/8 of model versus 72,000 for the full model. Moreover, only 7 GB of memory was required in contrast to 400 GB for a full model.

Fig. 5 shows the results after solving the model with the BEM solver. A reduction is observed in value of the B_z component to 1.498 T compared to 1.5 T for the unshielded magnet (see Fig. 3).

Fig. 6 shows the contour plot of the full model. It is evident that magnetic field has a considerably high value (red contour) near the walls of the shield. Fig. 7 graphs values of magnitude of magnetic field along the segment of circle of radius 350 cm. These values can be reduced by increasing wall thickness but this will make the shielding structure heavy. An alternative is placing the electromagnet in a double-layered shield with air gaps between the shields.

Fig. 8 shows a two-layered shield with a 1 cm separation around the electromagnet. Again, symmetry features were applied to reduce the model to 1/8 of its original size. The graph shows magnitude of magnetic field along the segment of circle with radius 350 cm. There is reduction in field values compared to those in Fig. 7, meaning the double wall shield has reduced the values of magnetic field in comparison to a single-walled shield.

Conclusions

BEM allows for easy visualization of the element distribution in magnetic shielding, especially for 3-D designs where FEM meshes are too complex. The BEM approach therefore provides designers with a valuable alternative approach to design magnetic shields. These types of CAE tools not only enhance engineering productivity but also increase competitive advantage. ☒

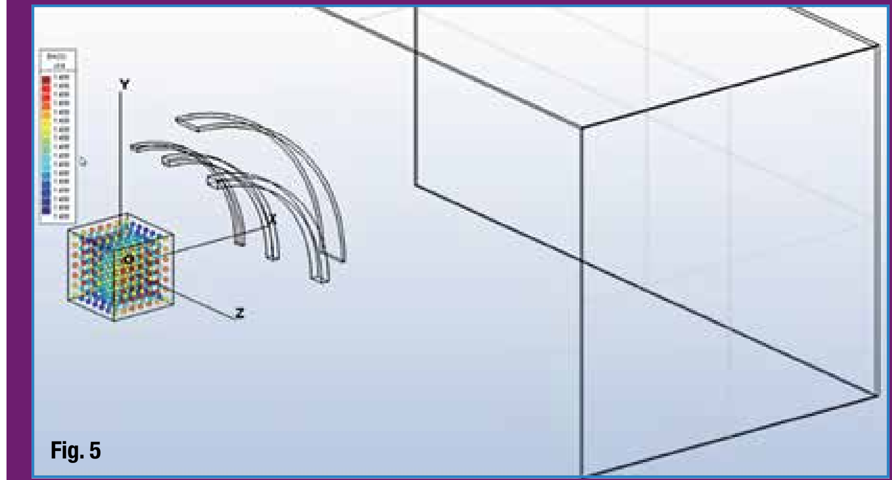

Fig. 5

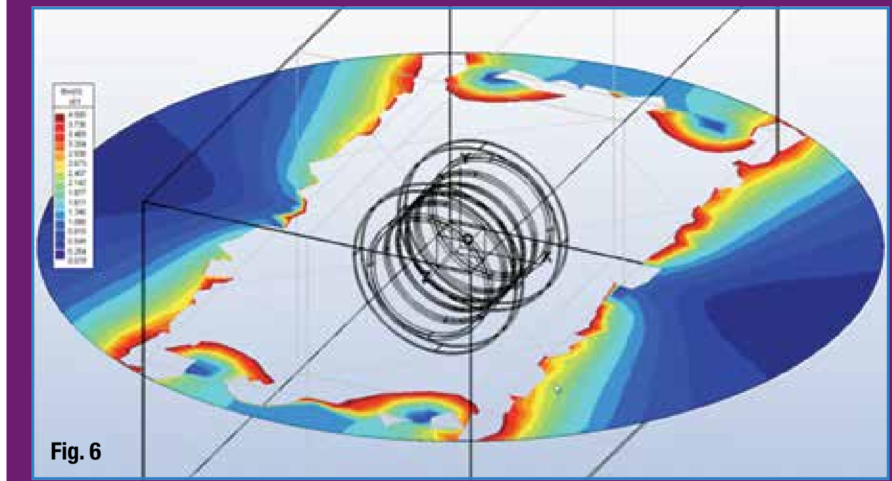

Fig. 6

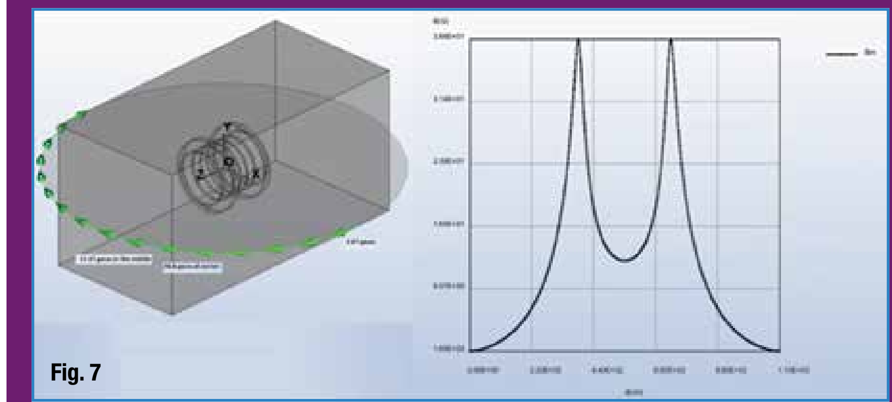

Fig. 7

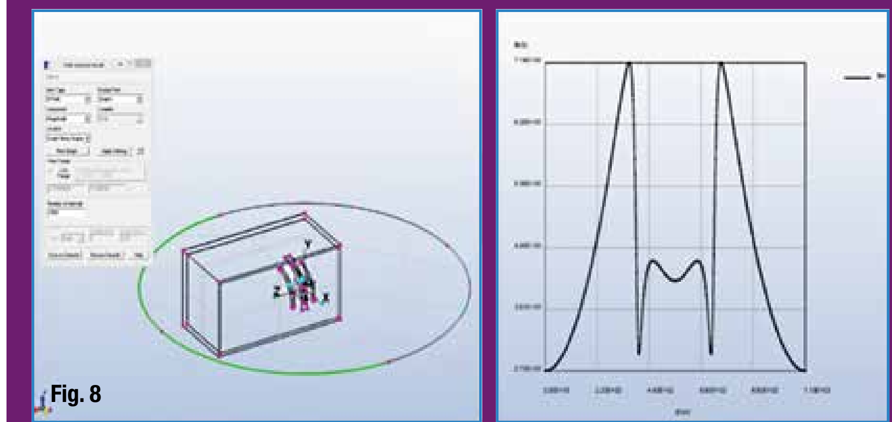

Fig. 8

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