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3-D MAGNETIC FIELD CALCULATIONS FOR WIGGLERS USING MAGNUS-3D

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ABSTRACT

The recent but steady trend towards increased magnetic and geometric complexity in the design of wigglers and undulators, of which tapered wigglers, hybrid structures, laced electromagnetic wigglers, magnetic cladding, twisters and magic structures are examples, has caused a need for reliable 3-D computer models and a better understanding of the behavior of magnetic systems in three dimensions. The capabilities of the MAGNUS-3D Group of Programs are ideally suited to solve this class of problems and provide insight into 3-D effects. MAGNUS-3D can solve any problem of Magnetostatics involving permanent magnets, linear or nonlinear ferromagnetic materials and electric conductors of any shape in space. The magnetic properties of permanent magnets are described by the complete nonlinear demagnetization curve as provided by the manufacturer, or, at the user's choice, by a simpler approximation involving the coercive force, the residual induction and the direction of magnetization. The ferromagnetic materials are described by a magnetization table and an accurate interpolation relation. An internal library with properties of common industrial steels is available. The conductors are independent of the mesh and are described in terms of conductor elements from an internal library. MAGNUS-3D uses the finite element method and the two-scalar-potentials formulation of Maxwell's equations to obtain the solution, which can then be interactively used to obtain all kinds of tables and plots and to calculate quantities needed in Magnetic Engineering. This includes tables of values of the field components at specified points or lines, plots of field lines in 3-D or of the

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included in MAGNUS-3D along with the normal Dirichlet and Neumann conditions. In MAGNUS-3D, each period is obtained from the preceding one by a general rigid motion, not just by a displacement. This includes combinations of rotations and translations, making MAGNUS-3D the ideal tool for the analysis of helical wigglers. Tapered wigglers can be studied by including a few periods in the model, which will then show the local effects of the variation of the parameters.

A permanent magnet is represented by a nonlinear demagnetization curve and the direction of its magnetization. Ferromagnetic materials are represented by the nonlinear B-H curve. Nonlinearity is fully taken into account by MAGNUS-3D, and wigglers with saturated iron or permanent magnets that behave nonlinearly can be studied. The restrictive condition on magnetic structures to be linear so they can be understood in terms of simple analytical models is, therefore, finally removed.

Output from MAGNUS-3D provides all kinds of plots and tables, and calculation of quantities such as force, torque, energy flux, and field harmonic coefficients. Graphs representing one or several field components plotted along a line in space, such as the transverse field along the beam line in a wiggler, are automatically generated by the program. Another useful feature of MAGNUS-3D is its ability to calculate line integrals of field components along any given line in space. Steering effects can be studied in this way.

MAGNUS-3D is fully documented, with manuals in English that include solved examples and a primer.

MATHEMATICAL FORMULATION

A general problem of magnetostatics is formulated in a domain that contains nonlinear ferromagnetic materials, nonlinear permanent magnets and electric conductors. The solution to the problem consists of two continuous functions, the two magnetic scalar coefficients. It is these quantities and the tables and plots, rather than the solution itself, what the magnetic engineer needs in the course of his work.

The following example of wiggler calculation is presented in order to illustrate the practical use of MAGNUS-3D and some of the available facilities. The problem is a helical wiggler consisting of infinitely many slabs, a "twister" [5]. Each slab consists of two permanent magnets with a constant magnetization of 8000 Oe and two rectangular poles of 1008 low carbon steel, as shown in Figure 1. Each slab is rotated 30° with respect to the preceding one, thus producing an approximately helical transverse field at the axis. Only one slab is modeled, and periodicity conditions are applied at the two boundary planes normal to the axis. If z is taken as the axis, the rigid motion that maps one period onto the next is a rigid translation along z by the thickness of the slab, followed by a rigid rotation of 30° around z. In terms of boundary conditions, this means that the first boundary plane must strictly map onto the second boundary plane if the same translation and rotation are applied to it, where "strictly" means that every mesh point or mesh line existing on the first plane must map onto a corresponding mesh point or mesh line on the second plane. Yet, the mesh must be such that the necessary rectangular bodies, rather than helical, could be represented.

It is not obvious how to construct a finite element mesh with such requirements, but the following standard technique and the mesh generator KUBIK do the job. Consider any $z = constant$ plane, such as any of the two boundary planes or an intermediate plane normal to z. The cross-section of the mesh by any such plane must be the same, in order to allow for the representation of bodies with flat sides parallel to z, such as the magnets or the poles. In Fig. 2, we have overlaid the cross-sections of three consecutive slabs, each rotated 30° with respect to the preceding one. We have also divided the air, both inside

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FIGURE CAPTIONS

Figure 1. One slab of the helical wiggler discussed in the example. The wiggler is assumed to consist of an infinite number of identical slabs, each rotated by 30° with respect to the preceding one. Only one slab was modeled, with periodicity conditions imposed on the boundaries. All dimensions are in cm.

Figure 2. Drawing obtained by overlaying the cross-sections of three consecutive slabs, each rotated 30° with respect to the preceding one, and dividing the air inside and around the magnets and iron into regions. This drawing has the property that it maps onto itself if rotated by 30°. The mesh based on this drawing is independent of z, thus allowing rectangular objects to be represented.

Figure 3. Plot of the transverse field components B_x and B_y, and of the total field $|B|$, along the beam axis z of the helical wiggler considered in the example. The plot covers two complete rotations, or 720°, and was obtained by mapping 24 calculated periods of 30° each. The sinus waves are remarkably smooth, and the total field stays constant within the accuracy of the calculation, indicating that the assumed geometry is capable of producing the desired helical field.

DISCLAIMER

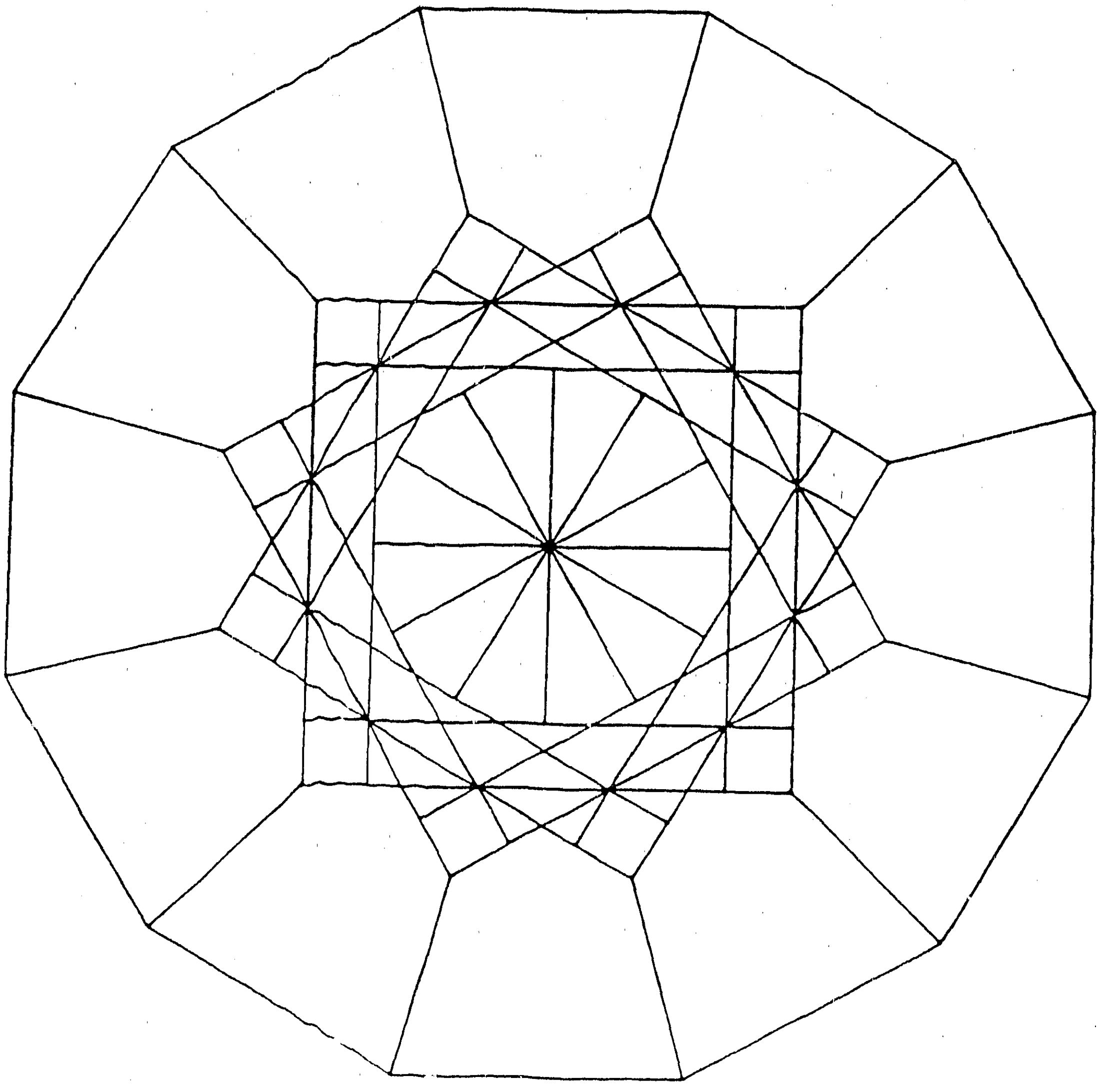

FIGURE 2

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