A Program for Computation of Magnetic Field of an Electromagnet

著者	Shibuya S., Sugawara M., Fujioka M., Orihara H.
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Shibuya S., Sugawara M., Fujioka M.* and Orihara H.*
Department of Physics, Faculty of Science, Tohoku University
Cyclotron and Radioisotope Center, Tohoku University*

We made a computer code (MATICO[†]) to calculate the field distribution of a twodimensional ironcore electromagnet. The methods described in the program NUTCRACKER[1] were used with some simplifications for running on the MELCOM-COSMO 500 system of CYRIC. The present program is applicable to an electromagnet consisting of up to three kinds of magnetic materials. It requires 24 K words (1 word = 16 bits) of memory for 81 × 81 mesh points.

The vector potential $\mathbf{A}$ satisfies

$$\mathrm{rot}\ (\frac{1}{\mu}\ \mathrm{rot}\ \mathbf{A}) = \mathbf{i}, \tag{1}$$

where $\mathbf{i}$ is a current density. The permeability μ is a function of the flux density $\mathbf{B} = \mathrm{rot}\ \mathbf{A}$. For a two-dimensional probrem $\mathbf{A}$ and $\mathbf{i}$ have only one component, i.e., A_z and i_z in the cartesian coordinates or A_ψ and i_ψ in the cylindrical coordinates, and $\mathbf{A}$ and $\mathbf{i}$ are independent of z or ψ. From eq. (1) we have

$$\frac{\partial}{\partial x}\ (\frac{1}{\mu}\ \frac{\partial A_z}{\partial Y}) + \frac{\partial}{\partial y}\ (\frac{1}{\mu}\ \frac{\partial A_z}{\partial x}) = -i_z \tag{2}$$

or

$$\frac{\partial}{\partial r}\ [\frac{1}{\mu r}\ \frac{\partial}{\partial r}\ (rA_\psi)] + \frac{\partial}{\partial z}\ [\frac{1}{\mu r}\ \frac{\partial}{\partial z}\ (rA_\psi)] = -i_\psi\ . \tag{3}$$

The differential equation (2) or (3) is transformed into a five-point difference equation, and the latter is solved numerically by means of an iteration method with an overrelaxation for $\mathbf{A}$ and an underrelaxation for μ[2]. For the calculation of relative permeability μ_r two B-μ_r tables corresponding to pure iron and Fe-Co alloy (50% Fe, 50% Co) are incorporated in the program; if a third material is used in the magnet the corresponding B-μ_r table must be given as an input data. If wanted the so called scaling technique can be used; the vector potential after n iterations is multiplied by S_n calculated from

$$S_n = \iint \mathbf{i} \cdot d\mathbf{s} / \oint \mathbf{H}_n \cdot d\mathbf{l}. \tag{4}$$

The value of S_n can be used also as a measure of convergence of the solusion. Another measure of the convergence is C_n given by

$$C_n = [\sum^{N} \sqrt{(A_n - A_{n-1})^2 / A_n^2}\,]/N, \tag{5}$$

where the summation is taken over all the mesh points. The iteration terminates when C_n and S_n satisfy $C_n \leqq 5.0 \times 10^{-5}$ and $0.95 \leqq S_n \leqq 1.05$, respectively, or

† Program for MAgnetic field in Two-dimensional area including Iron COmponents.

when the number of iterations exceeds a prescribed value. A detailed description of input and output formats will be given elsewhere.

Fig. 2 shows an example of the use of this program applied to the PAD magnet in the in-beam course of CYRIC. In this case eq. (3) was solved, corresponding to the cylindrical symmetry of the poles and polepieces. Using 61 × 61 mesh points with 0.6 cm square meshes the calculation took approximately 90 minutes for one excitation current of the magnet.

The present program was also applied successfully to the problem of a permanent magnet circuit[3]. In this case the current density $\mathbf{i}$ in eq. (1) was replaced by the equivalent current density $\mathbf{i}_{eq}$ = rot $\mathbf{M}$, where $\mathbf{M}$ is the magnetization of the permanent magnet.

References

1) Burfine E. A. et al., Stanford Linear Accelerator Center Report SLAC-56 (1966).
2) Shibuya S., M. Thesis, Tohoku University (1978).
3) Fujioka M. et al., "A study of Magnetic Circuits Employing Permanent Magnets", this annual report.

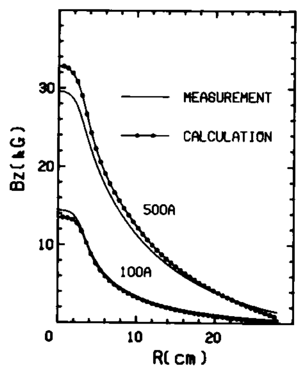

Fig. 1. Calculation of the magnetic field of the PAD magnet using the present program. Measured and calculated field distributions on the median plane are compared for two excitation currents, I = 100 A and 500 A. The disagreement around R = 0 is due to the relatively large mesh dimension (0.6 cm) compared with the gap length (3.0 cm) and, especially for I = 500 A, due to the B-μ_r curves extrapolated to B $\geqq$ 15 kG.