Optimal design of injection mold for plastic bonded magnet

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OPTIMAL DESIGN OF INJECTION MOLD FOR PLASTIC BONDED MAGNET

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Abstract — The optimal design of an injection mold to produce a stronger multi-pole magnet is carried out using the finite element method and the direct search method. It is shown that the maximum flux density in the cavity obtained by the optimal design is about 2.6 times higher than that of the initial shape determined empirically.

3-D analysis of the nonlinear magnetic field in the injection mold with complicated structure is also carried out. The calculated flux distribution on the cavity surface is in good agreement with the measured one.

I. INTRODUCTION

Recently the plastic bonded magnet (P.B.M.) has been widely used in electric and electronic instruments, due to the flexibility of the shape. In order to produce a stronger multi-pole magnet[1], the development of an optimal design method of an injection mold for the magnet is significant. Various kinds of optimal design methods[2] for determining the sizes of iron or magnet parts using the derivative-free minimization technique[3,4], the sensitivity analysis[5,6] and the nonlinear formulation technique[7~12] have already been reported. These methods, however, cannot be always applied to a practical use, because many iterations are necessary or the calculation of the derivative is time consuming.

In this paper, the optimal design of the injection mold for the P.B.M. is carried out by using the finite element method and Rosenbrock's method[13], in order to reduce the number of iterations and to apply it to any kinds of models. The effectiveness of the method is examined by comparing the flux distributions on the cavity surface between the initial and optimal shapes.

The 3-D nonlinear magnetic field in the mold with a complicated structure is analyzed to obtain an accurate flux distribution. The calculated and measured flux distributions on the cavity surface are compared.

II. 2-D OPTIMAL DESIGN OF INJECTION MOLD

A. Analyzed Model

Fig.1 shows the cross section of a permanent magnet type injection mold. Only 1/4 of the entire region is illustrated. The flux, which is generated by the permanent magnets installed radially around the cavity, penetrates into the cavity through yokes and forms the magnetic field for 24-pole polar orientation of magnetic particles. The yoke is made of steel and the permanent magnet is made of $SmCo_5$ ($Br=1.06T$, $Hc=7.84\times10^5 A/m$). The region to be analyzed can be decreased to 1/48 (enclosed by the dashed line shown in Fig.1) of the entire region as shown in Fig.2.

In order to produce a stronger polar oriented magnet, the radial component Br of the flux density on the outer surface of the cavity should be high. The optimal width W and length L of the magnet and the size T of the pole tip of the steel yoke which produce the maximum value of Br at the point P ($r=10mm$, $\theta=0°$) are determined by using the optimal design method. The right-hand side of the magnet is fixed on the line e-f. Due to the structural constraint, the following constraint is imposed:

$$W < 21mm \tag{1}$$

B. Optimal Design Method

2-D optimal design for the model shown in Fig.2 is carried out by using the finite element method and Rosenbrock's method, which is a direct search method[13].

The optimal dimensions of W, L and T can be obtained by minimizing the objective function[13] Z :

$$Z = (Br - Bo)^2 \tag{2}$$

where Bo is the specified value of Br. In order to determine values of W, L and T which produce the maximum value of Br, Bo is chosen to be high.

Rosenbrock's method is an iterative method for searching out the optimal values of dimensions (W, L and T) so that the objective function Z is minimized. The method can easily be combined with the finite element method, because the gradient of the objective function Z is not necessary[13]. In executing the method, the optimal dimensions which minimize Z are searched by changing W, L and T with different step lengths λ_1, λ_2 and λ_3 respectively. The initial values $\lambda_j^{(0)}$ ($j=1,2,3$) of respective step lengths are chosen as 1/10 of the respective dimensions of the initial shape. When the search succeeds (Z becomes smaller), the (k+1)th length $\lambda_j^{(k+1)}$ is changed as follows:

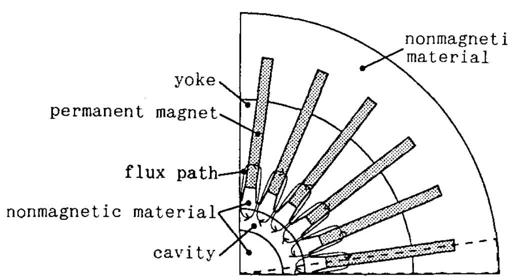

Fig.1 Analyzed model (permanent magnet type).

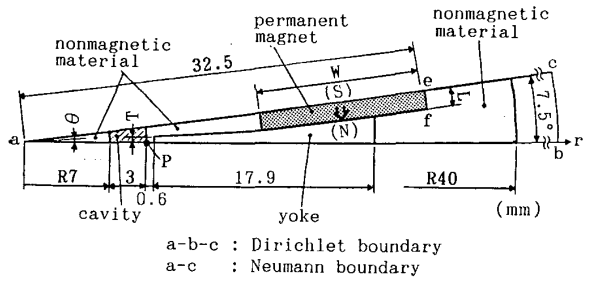

Fig.2 Region to be analyzed.

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$$\lambda_j^{(k+1)} = \alpha \lambda_j^{(k)} \quad (3)$$

When the search is not successful (Z becomes larger), $\lambda_j^{(k+1)}$ is changed as follows:

$$\lambda_j^{(k+1)} = -\beta \lambda_j^{(k)} \quad (4)$$

where α and β are the coefficients for the adjustment of λ_j and are chosen as 2 and 0.5 respectively. If λ_j becomes smaller than 0.01mm, the search is terminated, yielding the optimal shape.

C. Results

The flux distributions for the initial and optimal shapes are shown in Figs.3 and 4. The flux density Br on the outer surface of the cavity for the optimal shape is 2.6 times higher than that for the initial shape as shown in Fig.5, whereas the area which is occupied by the magnet of the optimal shape is smaller than that of the initial one by 21%. Fig.5 shows the flux distribution along the surface of the cavity.

The number of iterations for Rosenbrock's method is 69 and the CPU time is 86 sec. The computer used is NEC ACOS-2010 (maximum speed : 47MIPS).

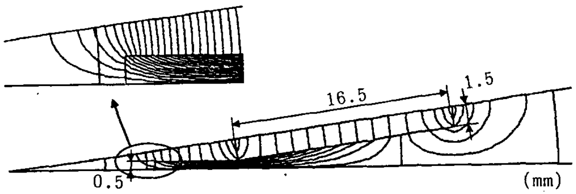


Fig.3 Flux distribution for initial shape.

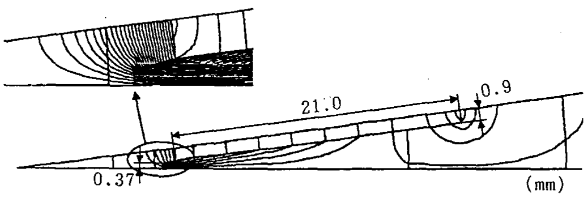


Fig.4 Flux distribution for optimal shape.

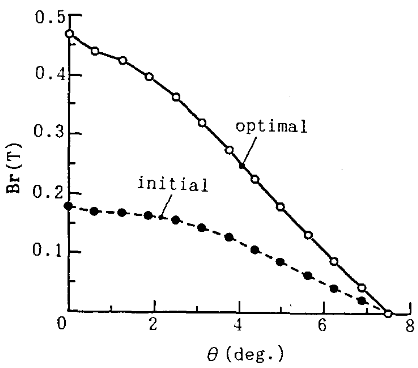


Fig.5 Comparison between initial and optimal flux densities Br in radial direction.

III. 3-D ANALYSIS OF INJECTION MOLD

A. Analyzed Model

Fig.6 shows a 3-D model of the winding type injection mold. Platens, tie rods, cores and yokes are made of steel. The windings are excited by a dc current of 5100AT.

Fig.7 shows an enlarged view near the cavity. The solid line indicates the flux path. The directions of magnetic field in the cavity for the 8-pole polar orientation are distributed as shown in Fig.8.

B. Method of Analysis

In order to obtain the optimal shape for the 3-D model shown in Fig.6, the 3-D nonlinear magnetic field is analyzed by using the $\mathbb{T}$-Ω method[14]. Fig.9 shows the region to be analyzed which can be decreased to 1/8 of the whole region by introducing the periodic boundary condition[15] of Ω.

C. Results

Fig.10 shows the flux density distribution in the yokes.

Fig.11 shows the calculated and measured radial components Br of the flux densities on the outer surface of the cavity. θ is defined as an angle from the x-axis as shown in Fig.8. The calculated result is in good agreement with the measured one, and the magnetic field for polar orientation can be obtained by this molding unit.

On an NEC supercomputer SX-1E (maximum speed: 285MFLOPS), the number of iterations for the Newton-Raphson method is 56 and the total CPU time is 1152 sec.

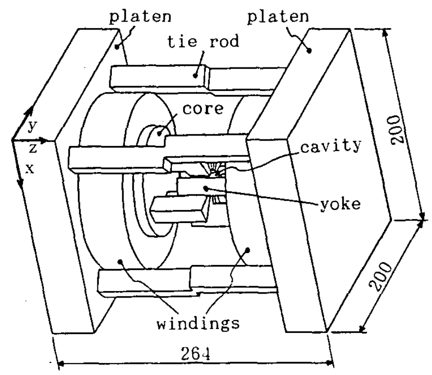


Fig.6 Analyzed model (winding type).

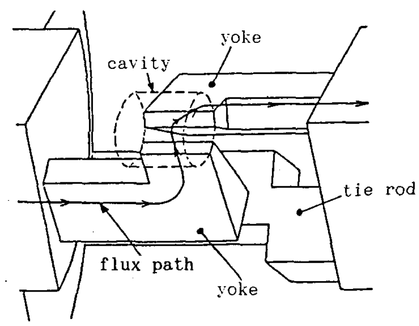


Fig.7 Enlarged view near cavity.

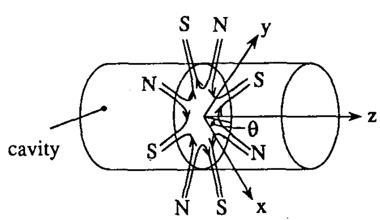
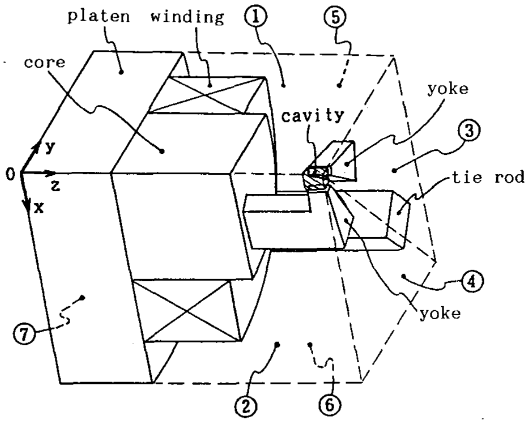


Fig.8 magnetic field in cavity.



①~④: periodic boundaries
⑤~⑦: Neumann boundaries

Fig.9 Region to be analyzed.

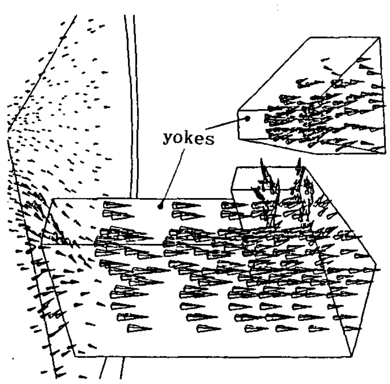


Fig.10 Flux density distribution.

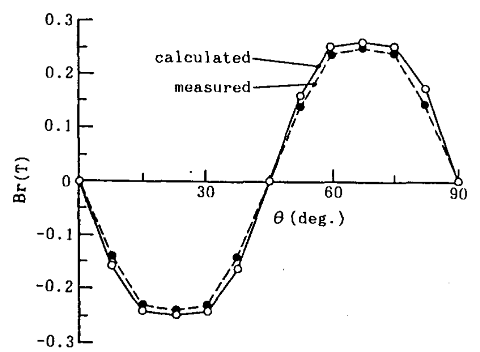


Fig.11 Comparison between calculated and measured flux densities Br in radial direction.

IV. CONCLUSIONS

The results obtained can be summarized as follows:

1) The optimal design of the dc nonlinear magnetic circuit for injection mold is possible within the allowable accuracy and CPU time by combining the finite element method and Rosenbrock's method. The number of iterations can be considerably decreased compared with the conventional optimal design technique[3] using the direct search method.

2) It is possible to analyze the 3-D dc nonlinear magnetic field in the injection mold with a complicated structure by introducing a periodic boundary condition. The validity of the periodic condition and the accuracy of the analysis are confirmed by comparing the calculated flux distribution with the measured one.

It is necessary to develop a more efficient optimal design method having a shorter CPU time, in which the optimal shape etc. can be successfully determined in every case. If such an efficient optimal design method is developed, and the CPU time for 3-D analysis is decreased, the optimal design of 3-D injection mold will become possible.

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