September, 11th - 13th 2018 Hall in Tirol, Austria

15th International Workshop on

Optimization and Inverse Problems in Electromagnetism

2018

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Poster Contributions List

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ECONOMICAL OPTIMIZATION METHOD OF REBCO SUPERCONDUCTING MAGNETS USING GAME THEORY

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Abstract. REBCO (REBa2Cu3O7-x, RE = Rare Earth) superconducting magnets have been applied to MRI, NMR, fusion devices, and accelerators. Nowadays REBCO coated conductors is still very expensive, hence it is required to optimally design a magnet shape to reduce the winding volume. When design REBCO magnets for MRI, NMR, or accelerators, the more accurate the generated field is, the larger the winding volume is needed. Hence it is necessary to obtain the reasonable REBCO magnet configuration using the Game theory considering the economical efficiency.

Keywords: Economical optimization, Game theory, Magnet design.

INTRODUCTION

Superconducting magnets wound with REBCO (REBa2Cu3O7-x, RE = Rare Earth) coated conductors have been applied to MRI, NMR, fusion devices, and accelerators. Their application strong need an accurate magnetic field identical to a designed field, such as a homogeneous field or an isochronous field, however it is impossible to generate an ideal magnetic field. Therefore, a shimming that an inaccurate field is compensated with pieces of iron and/or correction coils is done after manufacturing REBCO superconducting magnet. Hence, at the design stage, the rational magnet configuration is desired preventing the REBCO coated conductor cost from being expensive but generating an accurate field. The game theory is used as an economical optimization method.

ECONOMICAL DESIGN OPTMIZATION METHOD

REBCO Superconducting magnet

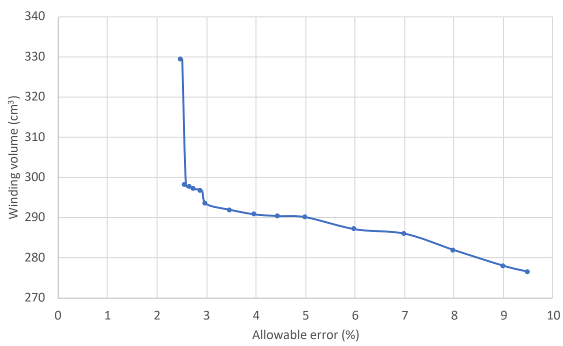
In this paper, the REBCO superconducting magnet for cyclotron accelerator [1] that generates isochronous field is designed. The center field is 1.45 T, the outer isochronous field is 30 cm, and the field error ε varies from 2.5% to 9.5%. The magnet configuration is optimized to reduce the winding volume using the simulated annealing method as an optimization method.

The design variables are the operating current, the inner radius and z-position of REBCO double pancake coils as continuous variables and the number of REBCO double pancake coils and the number of turns each REBCO double pancake coils as discrete variables. The objective function is the winding volume V identical to the length of REBCO coated tape. Actually the field error should also be the objective function as a multi-objective optimization, however the field error is considered as a constraint, because it is difficult to optimize the magnet configuration as a multi-objective problem from the viewpoint of the economy. In this paper, the REBCO magnet configuration is optimized fixing an arbitrary field error as a constraint.

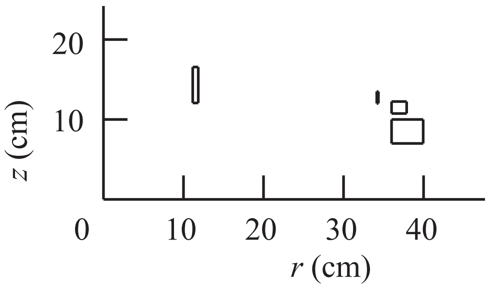
Table 1 and Fig. 1(a) show the optimized winding volume to the different allowable errors. Obviously, the designed magnet with 2.5% error is not acceptable due to the large winding volume. Of course, even though the winding volume is enough small, the field error is too large.

Table 1: Minimized winding volume depending on allowable error.

Field Error ε (%)	9.00	8.00	7.00	6.00	5.00	4.54	3.98	3.49
Winding volume V (cm^3)	277.9	281.8	285.9	287.0	290.0	290.3	290.7	291.8
Field Error ε (%)	2.99	2.90	2.76	2.68	2.58	2.53	2.50	2.49
Winding volume V (cm^3)	293.3	296.6	297.0	297.5	298.0	298.1	301.6	329.3



(a)



(b)

Figure 1: (a) Minimized winding volume to different field errors ε (%). (b) Magnet configuration optimized by Game theory.

Game theory

It is necessary to obtain the final solution among the optimized configuration shown in Table 1 as a rational solution. Based on the Game theory (non-zero-sum game) [2], the economical design must be selected as the following equation:

Maximize $$(\varepsilon - \varepsilon_{\min})(V - V_{\min})$$

where $\varepsilon_{\min}$, V, and $V_{\min}$ are the minimum permitted field error, the winding volume, and the minimum allowable winding volume, respectively. In this paper, $\varepsilon_{\min}$ and $V_{\min}$ are 5% and 300 cm^3, respectively. Finally, under the above conditions, the optimized magnet in the case of the allowable error 2.99% was selected as the economically rational solution. Fig. 1(b) shows the selected magnet configuration.

CONCLUSIONS

Since the REBCO coated conductors are expensive, it is strongly desired to reduce the winding volume of REBCO magnet applicable to NMR, MRI, and accelerators. However, it is impossible to generate an accurate magnetic field with small amount of the winding volume. It is difficult to obtain a rational solution with a balance of economy and magnet performance so far. Using the game theory, we can optimize the magnet configuration considering the economical efficiency.

REFERENCES

[1] H. Ueda, et al., Conceptual design of next generation HTS cyclotron. IEEE Transactions on Applied Superconductivity, vol. 23, no. 3, (2013) 4100205.

[2] T. Miyamoto, S. Noguchi, and H. Yamashita. Selection of an optimal solution for multiobjective electromagnetic apparatus design based on game theory. IEEE Transactions on Magnetics, vol. 44, no. 6, 2008, pp. 1026-1029.