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A New Active Field Uniformity Compensation Method with Pattern Search For Superconducting Magnets

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1. Introduction

➢ Given that the performance of many scientific instruments employing superconducting magnets, such as magnetic property measurement systems, magnetic resonance imaging (MRI), and nuclear magnetic resonance (NMR), is affected by the uniformity of the spatial field, it is very important to improve the degree of field uniformity before experiments involving these instruments.

➢ Especially for high-temperature superconducting (HTS) magnet-based instruments, it is more important to enhance the field uniformity repeatedly or periodically due to the screening-current-induced field (SCF).

➢ In this research, we present a new concept and methodology of uniformity improvement to control compensation coils currents by employing pattern search, an optimization theory.

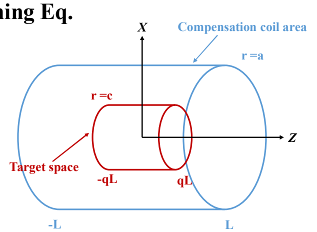
➢ To verify the feasibility of the method, we initially designed several zonal and tesseral field compensation coils with the target field method, The optimized geometry and detailed dimensions of six compensation coils were calculated and applied to a 5 T class NbTi magnet model

➢Unlike conventional uniformity improvement methods that require recursive field mapping and a compensation-coil current-adjustment process, the proposed approach has a shorter process time and does not require a time-consuming field mapping process.

➢These advantages can be helpful especially for HTS magnets, which require repetitive or periodic uniformity enhancement operation due to the temporal changes of the field distributions from the SCF

2. Field Uniformity Compensation Coils

1) The geometries of the target space and governing Eq.



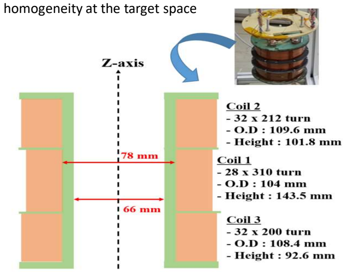
Target field

Current density of the compensation coils

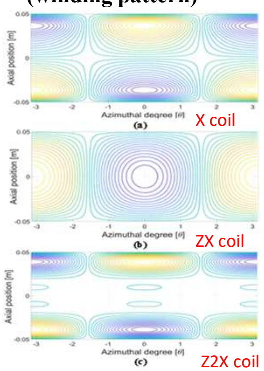
$$H_T(c;\theta,z) = -\frac{a}{2\pi}\int_0^{2\pi}\int_{-L}^{L}[c*\cos(\theta-\theta')-a]*j_\theta(\theta',z') \times [c^2+a^2-2ac*\cos(\theta-\theta')+(z-z')^2]^{-\frac{3}{2}}dz'd\theta',$$
$$-qL<z<qL$$

2) Target Superconducting magnet

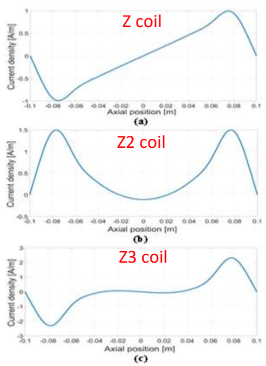
- 5 T NbTi magnet is composed of three coils connected in series.
- Each coil module was wound with NbTi wire with a radius of approximately 0.47 mm and operated at 67.5 A.
- There are several differences in the dimensions and number of turns between manufactured coils 2 and 3 that worsen the field homogeneity at the target space



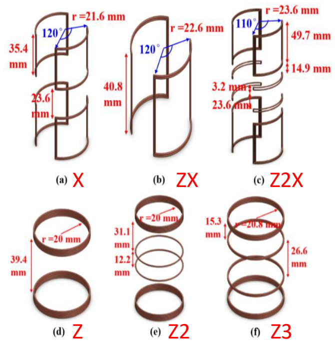
3) Calculated stream function of tesseral coils (winding pattern)



4) Calculated current density of zonal coils

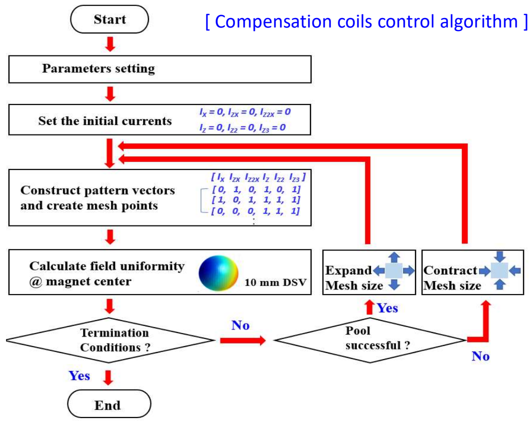


5) Design results of the 6 compensation coils



3. Active Field Uniformity Compensation Method employing Optimization

1) Concept of the proposed method



[Compensation coils control algorithm]

➢ The aim of the proposed method is to find the proper operating currents to apply to the six designed compensation coils (three zonal coils and three tesseral coils) to improve the uniformity.

➢ The method variables are the six applied coil currents, whose values are from – 5 A to 5 A, and the objective function is field uniformity at the magnet center.

➢ The algorithm finds a set of points around the current point, searching for one point where the objective function is lower than the current point.

➢ At each step, the method finds a set of points, called a mesh, around the current point. Subsequent mesh points are calculated by adding the current point to the product of the mesh size and a set of vectors called pattern vectors.

➢ After moving to the next mesh, the algorithm calculates the field uniformity and increases the mesh size if the newly calculated field uniformity is improved. If not, the mesh size is decreased.

➢ This process repeats until termination conditions are satisfied.

2) Test results

➢ We tested the proposed method by means of a MATLAB simulation to verify its feasibility.

➢ The main MATLAB code calculates the magnetic fields generated by the 5 T NbTi main coil and the six compensation coils to find an appropriate set of current values based on the pattern search algorithm.

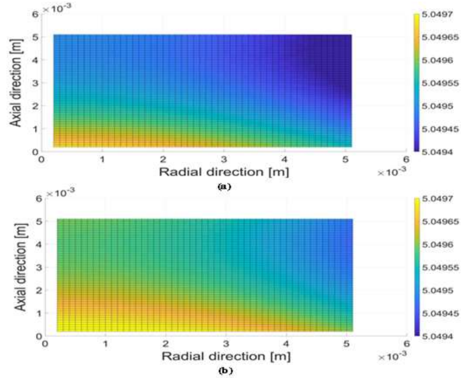
➢ The field uniformity (objective function of the algorithm) in a 10 mm DSV around the physical center was quickly calculated upon each iteration.

➢ The field uniformity improved from 24.8 ppm to 15. 7 ppm with the six compensation coils

➢If we apply a superconducting wire with a larger current capacity, we expect much greater improvements with the proposed method

Harmonics	Z1	Z2	Z3	X	ZX	Z2X
Current [A]	1	-2.021	-5	0	-4.672	5

[Calculated compensation coil currents]



[Magnetic field distributions around the center: (a) without and (b) with field uniformity compensation]

4. Conclusion

➢ The proposed method adopts the pattern search algorithm, an optimization theory, to find the proper channel currents to apply to active field compensation coils.

➢ We calculated the field distributions around the magnet center with and without the proposed method. The field uniformity of the 5 T NbTi coil improved from 24.8 ppm to 15. 7 ppm in a 10 mm DSV

➢ The approach can be beneficial for HTS magnets, which require repetitive or periodic uniformity enhancements due to temporal field fluctuations from the SCF.

➢ Field uniformity improvement experiments using an actual superconducting magnet, an active field uniformity compensation coil set, a multi-channel current amplifier and a real-time magnetic field uniformity measurement system will also be carried out to verify the performance of the method.