Tue-Af-Po2. 10-08 [176], Tuesday, August 29, 2017, 13:30 – 15:00

Optimal Design of the LTS Magnet employing Genetic Algorithm for EMPS

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✓ Introduction

- The Korea Basic Science Institute (KBSI) embarked a project whose goal is to develop a 9 T 155-mm winding bore (50-mm sample space) NbTi magnet for an Electro-Magnetic Property measurement System (EMPS) in 2017.
- Prior to completion of the 9 T EMPS magnet, , a 5 T 155-mm winding bore NbTi magnet will be fabricated as a proto-type magnet.
- As the sample space is twice larger than that of conventional Physical Property Measurement System (PPMS, 25-mm), it will be possible to measure the electro-magnetic properties of several samples at a time, therefore measurement time and cost will be reduced.
- Optimal design and quench analysis were carried out to determine the specifications of the magnet.
- Hybrid genetic algorithm was used to design the 5 T magnet,. First Linear Programming Method (LPM) restricted the magnet area. After that, adoptive Genetic Algorithm (GA) was carried out to determine the detail specifications of the magnet.
- Quench analysis on the designed magnet was also performed to verify the maximum temperature of the magnet.

✓ Introduction of the 5 T EMPS magnet

◆ System structure of the EMPS

◆ Design constraints for the 5 T EMPS magnet

Parameters	Constraints
Center field	> 5 T
Field homogeneity	< 1 % @ 50 mm DSV
Operating current	< 70 % of critical current @ 4.2 K
Max. hoop stress	< 130 MPa
Height	< 300 mm
Outer radius	< 150 mm

✓ Design of the 5 T EMPS magnet

◆ Design Process

Set up the design specifications

↓

Linear Programming Method (LPM)

1) Center field > 5 T
2) Field homogeneity < 1.0 % @ 50 mm DSV

↓

Estimate the structure and region of the 5 T EMPS coils from the LPM results

↓

Set up the design variables (x)

↓

Genetic Algorithm (GA)
(Bounds are based on the LPM results)

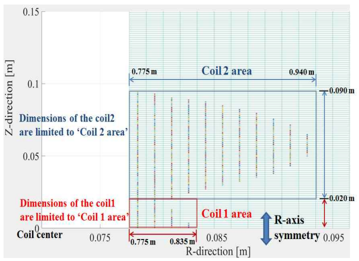
1. Objective function : wire length

2. Constraints
1) Center field > 5 T
2) Field homogeneity < 1.0 % @ 50 mm DSV
3) $I_{op} < I_c*0.7$
4) Max. hoop stress < 350 Mpa
5) Coil height < 300 mm
6) Outer radius < 150 mm

↓

Determine the optimized solution (x)

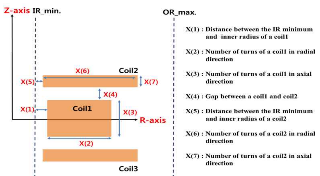
◆ Step 1 – Linear Programming (LPM)



[Global optimal current distributions from the LPM]

- The LPM is employed to obtain a global optimal current distribution in a feasible space of a magnet. The linear constraints related with magnetic field restrict the distribution of the magnet.
- The grid with points means the optimized magnet space and these points restrict the magnet region.
- The optimized magnet is composed of three coils. The limit of the R-direction and Z-direction are about 94 mm and 90 mm, respectively

◆ Step 2 – Genetic Algorithm (GA)



[The design variables for the GA, calculated from the LPM]

Parameters	Dimensions
Coil 1 inner radius	79.4 mm
Coil 1 outer radius	83.7 mm
Coil 2 inner radius	77.6 mm
Coil 2 outer radius	91.5 mm
Height	186.5 mm
Total length	11.2 Km
Parameters	**Performance**
Inductance	44 H
Center field	5.0036 T
Field homogeneity	0.999 % @ 50 mm DSV
Magnetic hoop stress	67.94 MPa
Min. critical current	79.3 A @ 4.2 K

[The design results of the GA]

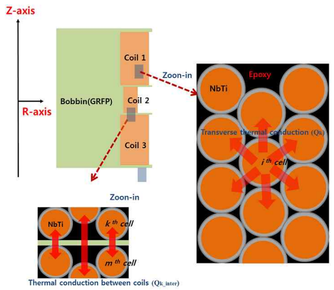
✓ Quench Analysis of the magnet

- To verify the thermal stability during a quench, maximum temperature calculation of the designed 5 T magnet was carried out.
- The magnet composed of multi-coils (3 coils) are divided into small unit cells in three dimensional space. The governing equation of the unit cell is as follows.

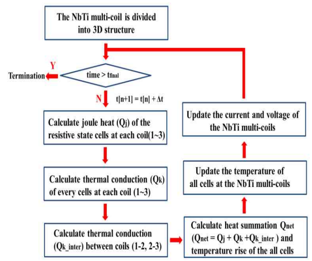
$$\underbrace{C(T)\frac{\partial T}{\partial t}}_{(1)} = \underbrace{\nabla \cdot [k_{cd}(T)\nabla T]}_{(2)} + \underbrace{\rho_{cd}(T)J_{cd}{}^{2}(t)}_{(3)}$$

(1) The rate of change of thermal energy density at each unit cell.
(2) Thermal conduction at each unit cell.
(3) Joule heat at each unit cell.

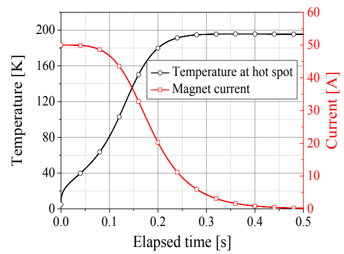
◆ The thermal conduction in coils



◆ The quench analysis process



◆ Maximum temperature calculation



✓ Conclusion

- In this presentation, optimal design and quench analysis of the 5 T EMPS magnet were provided.
- The two step design methods calculate optimized magnet specifications for the 5 T EMPS.
- The proposed quench analysis method calculated the maximum temperature of the 5 T magnet : the maximum temperature of the magnet < 195 K

This work was supported by KBSI grant (D37614) funded by Korea Basic Science Institute (KBSI).