Development of 7 T Superconducting Solenoid Magnet for Electron Beam Ion Source

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Background

Electron beam and proton accelerators have been used by many users in a wide range of fields. Development of an Electron Beam Ion Source (EBIS) capable of short pulse operation of less than 1 μs is needed to improve the utilization efficiency of users and to widen application field. For efficient operation of the EBIS, a smaller electron beam is required as possible as it can be. Additionally, 7 T is required below 1 mm in the center to focus the electron beam. Therefore, The 7 T superconducting solenoid magnet for EBIS was designed for electron beam focusing.

Objectives

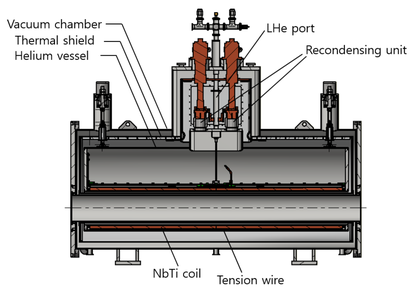
- The superconducting magnet should be designed to be large and horizontal to develop the uniform B-field distribution along the direction of the electron beam.
- The required uniformity of magnetic field is less than 0.3 % for focusing the electron beam.
- To prevent the quench and variation of magnetic field and uniformity, the magnetic field distribution should be recalculated after structural analysis.

Conclusion

- The 7 T superconducting solenoid magnet for EBIS was designed to be horizontally long for electron beam focusing.
- The optimized magnetic field had a uniformity of 0.17 %, which satisfied the uniformity condition of EBIS.
- We confirmed that it was structurally stable, because the total stress and deformation were up to 249 MPa and 2.51 mm, respectively.
- We confirmed that the magnetic field distribution satisfies the uniformity condition with deformed structure by using structural-magnetic coupled numerical analysis.
- the designed 7 T superconducting magnet was expected to be well applied to electron beam focusing in the EBIS system.

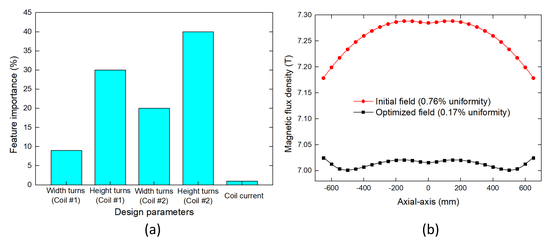
Design of 7 T Magnet

Superconducting System for EBIS



Structure of superconducting system with 7 T superconducting magnet for EBIS and cryostat.

Optimization of Magnetic Field Uniformity

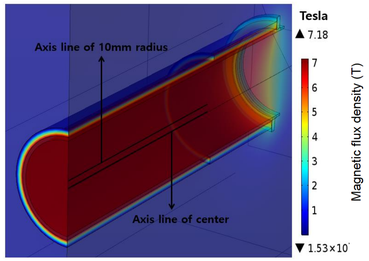


Optimization results using genetic algorithm: (a) feature importance of design parameters, (b) magnetic flux densities and uniformities in the initial and optimized models in the axial line.

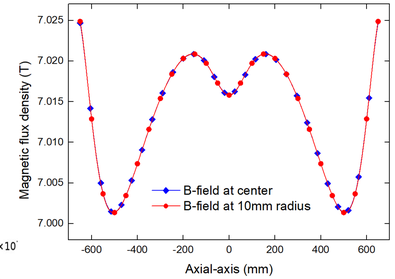
- The initially designed model does not satisfy the uniformity condition.
- it is necessary to derive the optimal design parameters satisfying this condition.
- The design parameters are specified by the coil turns of coil #1 and #2 thickness and length, and current.
- Genetic algorithm (GA) is a suitable method for optimizing the objective function derived from the design parameters nonlinearly.
- The number of initial populations was 100 and the optimal solution was obtained after 11 iterations.

Optimized Results

7 T Magnetic field and uniformity



Magnetic field distribution in the optimized solenoid of ¼ model.

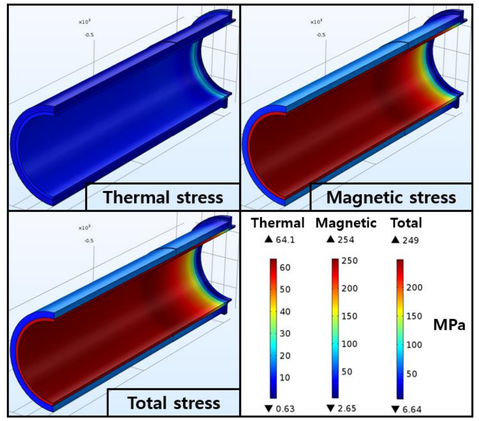


Magnetic field at center and 10 mm radius according to axial line.

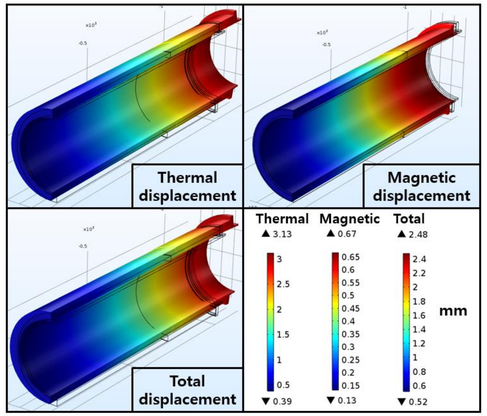
- The uniformity of the magnetic field in the beam tube is very important to improve the efficiency of EBIS.
- The magnetic field uniformity was 0.17 % according to 1300 mm in the axial direction 10 mm away from the center and the center of solenoid.
- It satisfy the uniformity condition of 0.3 %.

Coupled Analysis Results

Magnetic- and Thermal-Structural Analysis



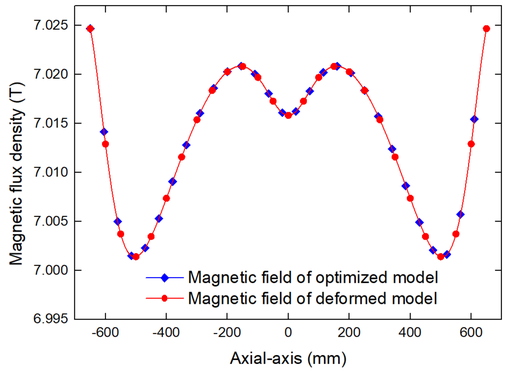
Thermal, magnetic, and total stresses for ¼ model.



The thermal, magnetic, and total displacements for ¼ model.

- The calculated thermal stress was the largest at the edge of the bobbin and was up to 64.1 MPa.
- The magnetic stress in radial direction, and the maximum was 254 MPa.
- The calculated total stress was up to 249 MPa, which was lower than the yield strength of the medium.
- The total deformation is more affected by the thermal than magnetic deformation, was up to 2.48 mm.
- To confirm the structural stability of the designed superconducting magnet, the magnetic field distribution should be recalculated due to the structural deformation.
- Thus, the magnetic-structural coupled numerical analysis should be carried out.

Coupled Analysis Result



Comparison of the magnetic flux densities for optimized and deformed superconducting magnet.

Final design specification of 7 T superconducting solenoid magnet.

Parameters		Values
Magnetic field		7 T
Uniformity of magnetic field		0.17 %
Inner diameter of coil		280 mm
Height of coil		2000 mm
Turn number of coil	Coil #1	19344 × 2
	Coil #2	10248 × 2
	Total	59184
Current		196 A
Length of NbTi wire		55.9 km
Total magnetic energy		2.728 MJ
Inductance		142 H
Operating temperature		4.2 K

Presented at the 25th International Conference on Magnet Technology, 2017 Aug. 27 – Sep. 1, Amsterdam, Netherlands; Session: Cryogenics for Magnet Cooling; Program I.D. number: Thu-Af-Po4.01-10 [10]