

§16. Design of a 7-T Force-Balanced Helical Coil

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A strong electromagnetic force caused by high magnetic fields and coil current is a serious problem in magnetically confined fusion devices and Superconducting Magnetic Energy Storage (SMES) systems. To cope with this problem, the concept of Force-Balanced Coil (FBC) has been developed. The FBC is a helically wound hybrid coil of toroidal field coils (TFCs) and a solenoid [1]. The FBC can minimize working stresses by selecting an optimal number of poloidal turns [2]. In order to demonstrate the feasibility of the FBC concept for high field superconducting magnets, a 7-T Force-Balanced Coil (7-T FBC) was designed.

Fig. 1 shows a schematic illustration of the 7-T Force-Balanced Coil (7-T FBC). The darker hatch indicates one complete helical winding. The outer diameter of this coil is 530 mm. This size was decided by the size of the available cryostat in the case of an experiment with pool boiling liquid helium cooling. The design parameters of the 7-T FBC are summarized in Table 1. The winding of the FBC is 6 poloidal turns with an aspect ratio of 4. This coil is a hand-made coil using NbTi superconductor with a diameter of 1.17 mm. The critical current of the NbTi strand is 570 A at 7 T and 4.2 K. The rated coil current of the 7-T FBC is 535 A with 6% margin of the critical current. This FBC will have 270-kJ stored magnetic energy at maximum magnetic field of 7.0 T.

The winding form is made of aluminum alloy and slots are cut on its surface with the shape of the helical winding with a numerically controlled (NC) lathe. The dimension of the slots is 30 mm × 30 mm as shown in

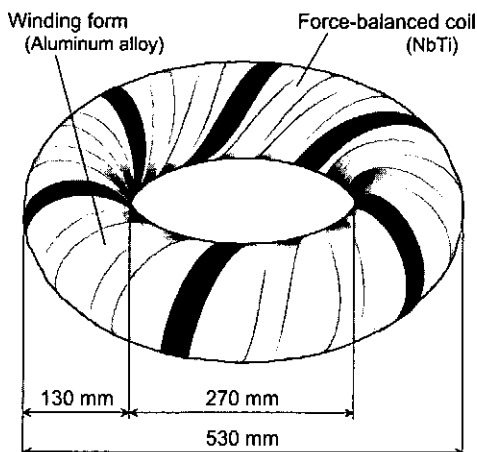


Figure 1: Schematic illustration of the 7-T force-balanced coil.

Table 1: Design Parameters of the 7-T Force-Balanced Coil.

Major radius R_0 (mm)	200
Minor radius a_0 (mm)	50
Aspect ratio α	4
Helical windings	6 poloidal turns × 3 coils
Total number of poloidal turns	10800
Maximum magnetic field (T)	7.0
Coil current (A)	535
Self inductance (H)	1.9
Stored magnetic energy (kJ)	270

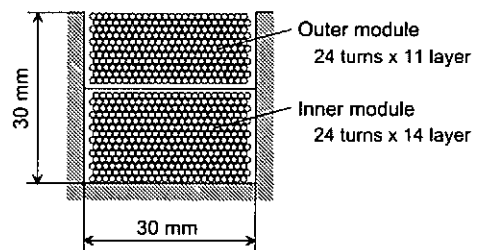


Figure 2: Schematic cross section of the 7-T force-balanced coil winding.

Fig. 2. The winding is composed of two winding modules with 24 turns per layer. The inner winding module with 14 layers and the outer winding module with 11 layers are connected in series.

The 7-T FBC is designed within an allowable coil dimension of which maximum working stress within an allowable stress of the stabilizer of the NbTi strand. Although this size of the coil can't be realized with toroidal field coils and a solenoid due to the induced electromagnetic forces, the 7-T FBC can be excited up to the rated magnetic field without reinforcing materials for the NbTi strand. Then the winding of the 7-T FBC will be carried out without reinforcing materials for the NbTi strand.

The experiments will be conducted with pool boiling liquid helium cooling in order to measure the quench properties of the 7-T FBC and evaluate the working stresses in the helical windings.

References

- [1] Y. Miura, M. Sakota, R. Shimada: Force-Free Coil Principle Applied to Helical Winding, *IEEE Trans. Magn.* **30**(4) (1994) 2573-2576.
- [2] H. Tsutsui, S. Nomura, R. Shimada: Optimization of SMES Coil by Using Virial Theorem, *IEEE Trans. Appl. Superconduct.* **12**(1) (2002) 800-803.