§9. Feasibility Study on SMES Systems Using Stress-Minimized Helical Coils

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A superconducting force-balanced coil (FBC) has been developed [1),2),3)]. The FBC is a helically wound coil of toroidal field coils and a solenoid. This coil can significantly reduce the required mass of the structure for the same magnetic energy compared with the conventional coil configurations, indicating that the FBC will be one of the feasible options for large-scale SMES.

Fig. 1 shows a photograph of the model coil based on the FBC design. The model FBC, with an outer diameter of 0.53 m, will have 270-kJ magnetic energy at the critical magnetic field of 7.1 T using NbTi strands. The hand-made winding of the model FBC was carried out without reinforcing materials such as stainless steel wires and finished with 10584 poloidal turns after four months.

Three excitation tests with liquid helium cooling were conducted at an interval of several months. Fig. 2 shows the quench properties of the model FBC. The model FBC was usually excited with a ramp rate of 1 A/sec. The first quench current was 293 A, which is 53% of the critical coil current. The training phenomena of the model FBC could be observed even after the coil was warmed up to room temperature. After successive excitations, it was successfully excited up to 6.1 T without reinforcing materials for the NbTi strand. This fact demonstrates a primary capability of the FBC concept as a SMES coil. At the 79th excitation, the quench current was suddenly decreased. However, the training history was instantly recovered and the model FBC could be excited over 6 T.

Fig. 3 shows an equivalent circuit of the model FBC windings and the number of quenches. The quenches mostly occurred in the inner winding blocks where the NbTi strands experienced higher magnetic fields. The winding of the model FBC was started with coil 2, next coil 3, and finished with coil 1. However, there seems to be no direct relationship between the quench properties and the familiarization of the hand-made winding techniques. Each quench was almost initiated in a random winding block, meaning that it can be considered that each helical coil was successfully wound without any significant defects.

1) Nomura, S., Tsutsui, H., Tsuji-Iio, S., Chikaraishi, H., Shimada, R. : Fusion Eng. Design **81** (2006) 2535–2539.
2) Nomura, S., Kasuya, K., Tanaka, N., Tsutsui, H., Tsuji-Iio, S., Shimada, R. : IEEE Trans. Appl. Supercond. **17** (2007) 1998–2001.
3) Nomura, S., Kasuya, K., Tanaka, N., Tsuboi, K., Tsutsui, H., Tsuji-Iio, S., Shimada, R. : IEEE Trans. Appl. Supercond. **18** (2008) 701–704.

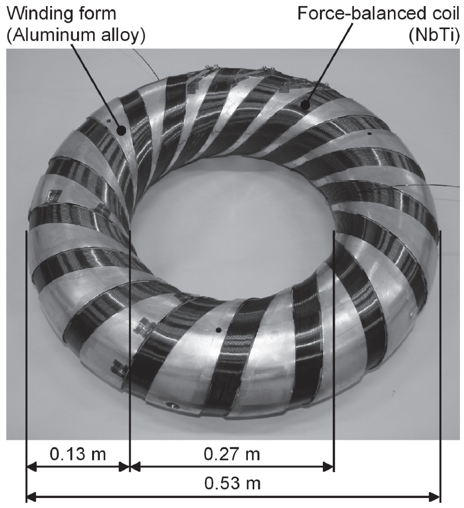

Figure 1: Photograph of the superconducting FBC.

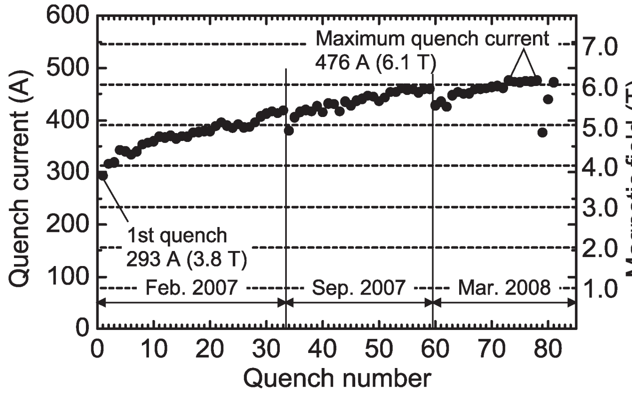

Figure 2: Quench properties of the model FBC. The critical coil current is 552 A. The magnetic fields are calculated from the quench current.

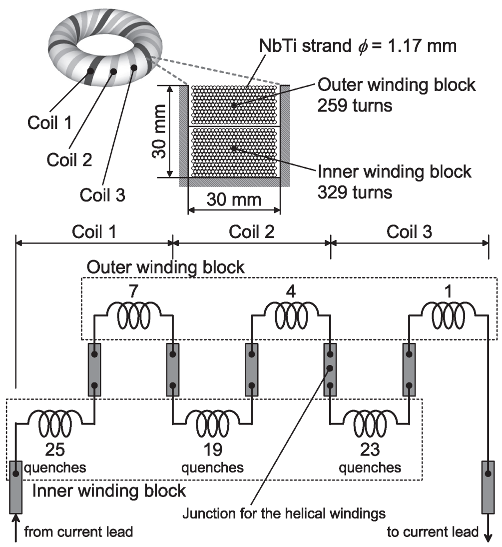

Figure 3: Equivalent circuit of the model FBC windings and the number of quenches. The helical winding that initiated a quench was evaluated based on the voltage waveforms. The voltage waveforms of the 7th and 12th quenches were not monitored.