§ 30. Optimization of Stress Distribution in Helical Coils

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Recently, we had developed a tokamak with force-balanced coils (FBCs) [1] which are multi-pole helical hybrid coils combining TF coils and a CS coil. The combination reduces the net electromagnetic force in the direction of major radius [2] by canceling the centering force due to the TF coil current and the hoop force due to the CS coil current. Moreover, the optimal condition of the FBC can achieve minimum structure requirements (virial limit)[3]. This type of the FBC equalizes the working stresses in all directions. We can easily achieve these conditions by selecting the optimal number of poloidal turns [3].

In order to demonstrate the validity of the FBC concept, we designed and fabricated a small experimental device which is composed of inner and outer helical coils mutualy wound in opposite toroidal directions using NbTi superconductors. Figure 1 shows a schematic illustration of the experimental device. Since a helical coil has both toroidal and poloidal current components, the distribution of the working stresses in this device can be changed by selecting the optimal current ratios between the inner coil current I_{in} and the outer coil current I_{out}. The whole number of poloidal turns of this device N is given by

$$N = \frac{N_{\text{device}}\,(I_{\text{in}} + I_{\text{out}})}{I_{\text{in}} - I_{\text{out}}}, \tag{1}$$

where N_{device} is the number of poloidal turns of each helical coil. From Eq. (1), this device can continuously vary the effective number of poloidal turns from zero to infinity by selecting the optimal current ratios. The winding of each helical coil is 6 poloidal turns with an aspect ratio (major radius / minor radius) of 4 which achieves the condition of the minimum structure requirement.

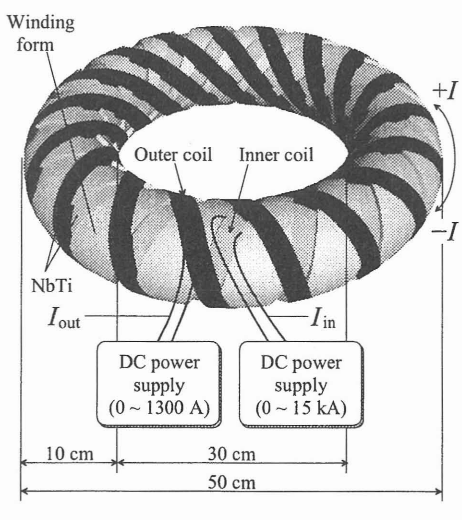

Figure 1: Schematic illustration of experimental device.

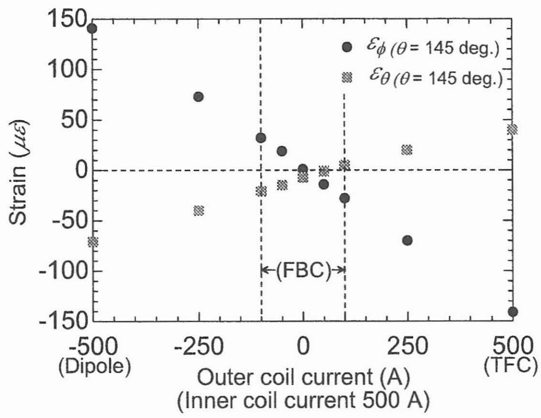

Figure 2: Monotonic variations of strains with the outer coil current at a poloidal angle θ of 145°. The range of the FBC conditions is from an outer current of -100 A to that of 100 A.

We measured the strains of the winding form in the toroidal direction ϵ_ϕ and that in the poloidal direction ϵ_θ with strain gauges at poloidal angles θ of 0°, 45°, 90°, 145° and 180°, respectively. Figure 2 shows the relationship between the combinations of the operated currents and the strains at a poloidal angle of 145°. The inner coil current was constantly set at 500 A. We can find that the distribution of the strains both in toroidal and poloidal directions continuously varies with the difference in the coil conditions.

From these results, the distributions of the maximum tensile stress and the maximum compressive stress change with the difference of the coil conditions. It means that we can control the distribution of the working stress by selecting the optimal number of poloidal turns. Compared with TFC and dipole conditions, the FBC conditions can reduce the maximum working stresses for the same magnetic energy. In particular, the FBC condition with the current ratio of 0.1 ($N = 7$) can minimize the working stress. Therefore the validty of the stress-minimized Force-Balanced Coil concept was demonstrated.

References

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