

§20. Study on Effects of Bending Strain to Critical Current Characteristics of Nb₃Al CIC Conductors

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Nb₃Al is one of attractive materials for the strand of superconducting coil. The critical current (I_c) of Nb₃Al strand is decreased by strain. In cable-in-conduit conductor (CICC), strands suffer thermal and bending strain. However, no decrease of I_c by bending strain of 0.4% was observed for a Nb₃Al D-shaped coil made by react-and-wind (R&W) method in the R&D campaign for the National Centralized Tokamak. The same tendency was also observed in the Nb₃Al-insert coil manufactured for ITER. Those observations indicate that some relaxation of bending strain in strands can be expected due to cabling effect. In order to evaluate such an effect in CICC, the effect of tensile and compressive strains on a strand and the relaxation effect of strain on strands in the CICC were investigated. It is of also great importance to clarify the maximum attainable bending strain in R&W method for the manufacturing of advanced large helical coils.

Nb₃Al strand manufactured by jerryroll process was 0.74 mm in diameter with a Cu/non-Cu ratio of 4.05. In order to investigate the behaviour of I_c by the tensile/compressive strain and the bending strain, three types of the test sample are planned. For the dependence on tensile/compressive strain, two samples are produced this year. One is Nb₃Al strand wound around the spring-shape holder (strand sample). The other is two Nb₃Al strands and one Cu wire inserted into a stainless steel conduit wound around the spring-shape holder (triplex CIC sample). For the dependence on bending stress, 54 Nb₃Al strands and 27 Cu wires contained in a stainless-steel conduit and formed in a spring-shape (CIC conductor sample) will be prepared next year.

Figure 1 illustrates the schematic setup of the test apparatus produced this year, for the measurement of I_c -characteristics against the various range of stress at 4.2 K in the presence of the external magnetic field. Stress is loaded through the shaft, by which an external twist force is converted to tensile/compressive stress in the strand sample and the triplex CIC sample, and to bending stress in the CIC conductor sample. The spring-shape holder with a diameter of 82 mm consists of 4.5 turns spiral winding, made of

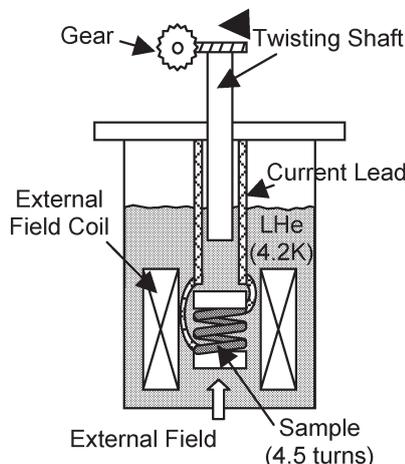


Fig.1 Schematic setup of the test apparatus.

beryllium-copper alloy not to yield against the strain of about 1%. FEM structural analysis is performed to estimate the stress loaded on the holder and the samples. In the holder the strain at the inner surface of the spiral is 20% larger than that at the outer surface. The longitudinal stress profile is almost the same between turns although there appears the difference within 5% in each turn. The torsion strength of the holder is experimentally investigated by the tension test on the test sample after the heat treatment. Based on the test results, summarised in Table 1, the maximum available tensile strain estimated by $\sigma_{0.2}/E$ is 0.92% at the inner surface and 0.76% at the outer surface.

Table 1 Mechanical characteristics of the test sample

	RT	4.2K
Young's modulus E (GPa)	134	144
0.2% proof stress $\sigma_{0.2}$ (MPa)	1120	1320
Tensile strength σ_u (MPa)	1269	1534

The I_c of the strand sample against the strain is measured at 4.2 K in the range of magnetic field from 6 to 11 T. The I_c is defined as the current measured when the voltage of 0.1 μ V/cm is detected between each divided segment of central one turn (4 segments here). Figure 2 shows the dependence of I_c on the strain for each segment. The I_c shows almost the same tendency against the strain, and the maximum I_c is observed at 0.12% strain, at which the net strain would be cancelled out. It is considered that the Nb₃Al filament suffers the compressive strain due to the difference in thermal contraction between the holder or stabilising Cu and the Nb₃Al filament. Therefore, it corresponds to the real strain range from -0.86% to +0.18%. Based on the measured I_c of strand sample, relation of the I_c and the strain in the CIC conductor sample will be precisely analysed next year.

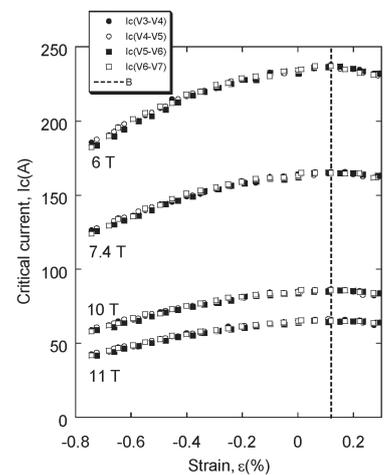


Fig.2 Dependence of I_c on the strain in each segment of the turn.

Reference

- 1) Kizu, K., 20th IAEA Fusion Energy Conference (Nov. 2004, Vilamoura, Portugal) IAEA-CN-116/FT/P1-6.
- 2) Kizu, K., to be presented at 19th International Conference on Magnet Technology (Sep. 2005, Genova, Italy).