## §20. Study on Effects of Bending Strain to Critical Current Characteristics of $Nb_3Al$ CIC Conductors

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The $Nb_3Al$ is one of the attractive superconducting materials for future fusion devices like DEMO because of its higher critical current density ($J_c$) than $Nb_3Sn$ at around 16 T. In cable-in-conduit (CIC) conductor like the ITER conductor, strands suffer thermal and bending strain. The $J_c$ of $Nb_3Al$ strand is generally decreased by longitudinal strain. However, in previous work, no degradation of $J_c$ by bending strain of 0.4% was observed for a $Nb_3Al$ D-shaped coil made by react-and-wind (R&W) method in the R&D campaign for the JT-60 superconducting modification. The same tendency was also observed in the $Nb_3Al$-insert coil manufactured through ITER R&D. These observations suggest that some cabling effect causes the relaxation of the bending strain in the strands. In this work, bending strain dependence of critical current ($I_c$) of a CIC conductor wound like a torsion coil spring was measured. The new experimental apparatus which can bend samples in the cryostat was developed.

The CIC conductor for sample consisted of 54 $Nb_3Al$ strands and 27 copper (Cu) wires. The diameter of $Nb_3Al$ strands and Cu wires was 0.74 mm. The strand manufactured by the jelly roll process had Cu/non-Cu ratio of 4.0 and twist pitch of 50 mm. The non-copper critical current density was 1945 A/mm$^2$ at 4.2 K, 7.4 T. The thickness of chromium coating on $Nb_3Al$ strands and Cu wires were 2.3 μm. The final twist pitch and the void fraction of the CIC conductor were 270 mm and about 36%, respectively. The inner and outer diameter of the conduit made of JIS SUS304 were 8.4 mm and 12.4 mm, respectively. The CIC conductor of 2.3 m in length was wound into 4.5 turns of torsion coil spring as shown in Fig. 1. The diameter and winding pitch were 150 mm and 18.4 mm, respectively. This sample was heat-treated for 50 hours at 750°C and was soldered in the groove of upper and lower flanges to install the apparatus.

The test apparatus [1] for the measurement of the $I_c$ in various range of bending strain at 4.2 K in the presence of the external magnetic field consists of double shafts referred as the inner shaft and outer shaft. The external gear rotation generates bending strain in the CIC conductor sample from outside of the cryostat. The external magnetic field was generated by a 240 mm bore-13 T superconducting coil. The backfield magnet and the sample were cooled by pool boiling liquid helium.

The $I_c$ of the CIC conductor sample versus bending strain was measured at 4.2 K in the range of perpendicular external magnetic field of 9.2, 10.2 and 11.3 T as shown in Fig. 2. Measured $I_c$ was normalized by $I_c$ without bending. The $I_c$ was not decreased up to 0.4% and be slightly decreased when bending strain exceeds 0.4%. The $I_c$ at maximum bending strain of 0.55% was 96% of $I_c$ without bending. The only 5% of $I_c$ decrease by 0.6% of bending strain is expected.

The compressive strain dependence of the $Nb_3Al$ strand at 11T measured in the previous work [1] is also shown in Fig. 2. In order to compare the strand data with the CIC conductor data, the $I_c$ of compressive strain of 0.7% converted to the $I_c$ of 0%, since all strands in the CIC conductor sample suffer -0.7% in thermal strain. The degradation tendency of the CIC conductor is clearly different from that of strand. The difference suggests the cabling effect. Because strands in the cable are twisted, the strand placing at the inside of the cable moves to the outside of the cable with the twisting pitch of 135 mm. Thus, one strand in the cable suffers both compressive force and tensile force longitudinally. If strands slip each other by bending, compressive and tensile strain in one strand can cancel out each other. Another sample which has smaller void fraction is planed to be fabricated in future. Strands in new sample are hard to slip compared to the sample of this work. Thus, it will be clarified whether the reason of smaller degradation of $I_c$ of CIC conductor relates to the strand movement.

Reference

1) Kizu, K., IEEE Transactions on Applied Superconductivity, Vol. 16, No. 2, JUNE 2006, pp. 872-875.

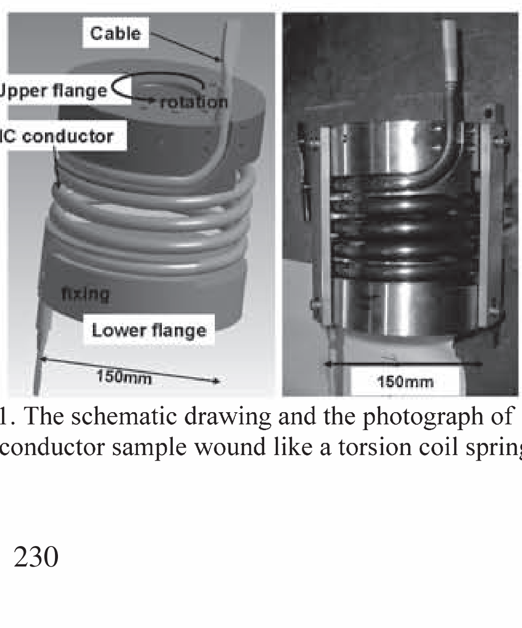


Fig. 1. The schematic drawing and the photograph of CIC conductor sample wound like a torsion coil spring.

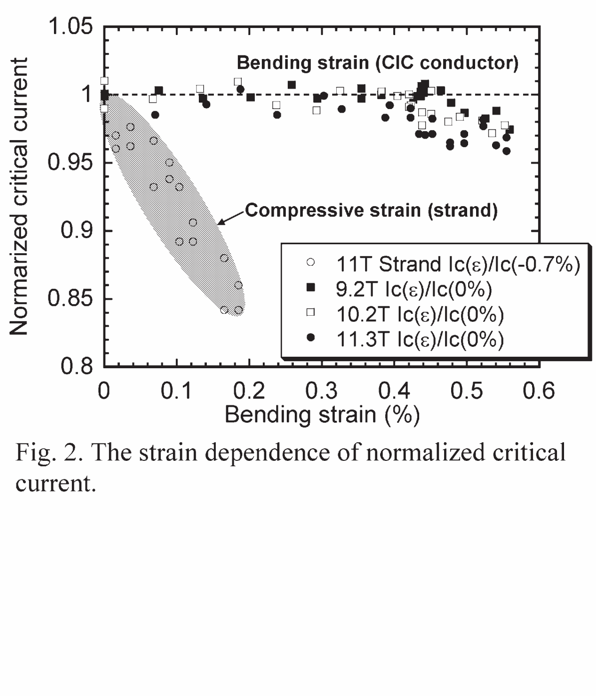


Fig. 2. The strain dependence of normalized critical current.