§12. Degradation of Nb_3Sn Superconducting Cable Due to Mechanical Stress

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A new test method to evaluate the superconducting properties of multi-strand cable in high magnetic field under transverse compressive loading was developed. It is a kind of coil-test in high magnetic field with compressive load which simulated an electro-magnetic force in cable-in-conduit. When we look at the further fusion reactor, higher magnetic field will be required and larger electro-magnetic force will be generated. To develop new conductors for such an application, degradation because of the transverse compressive electro-magnetic force [1, 2] must be overcome.

A new test process was considered based on electro-magnetic induction by a back-up superconducting magnet [3], and the performance of the Nb_3Sn cable was investigated [4]. By using the induction current, the test process can be made simple and safe. At the same time, joint performance and mechanical deformation behaviour are also able to be characterized. This report will present principle of our methods and test results of a multi-strand Nb_3Sn cable.

Conceptual equivalent circuit is illustrated in Figure 1. The circuit is closed and circuit current, I, is induced by magnetic flux change, $d\phi/dt$. In eq. (1), the voltage of $d\phi/dt$ is constant during the change rate in magnetic field is constant, and is balanced with sum of induction voltage of closed circuit, $L(dI/dt)$, joint voltage, $R_J I$, and superconducting cable voltage, $R_{SC}I$.

$$\frac{d\phi}{dt} = L\frac{dI}{dt} + R_J I + R_{SC}(I,B,T,\varepsilon)I \qquad (1)$$

R_J is electric resistance of the soldered joint and supposed to be constant even in high magnetic field. R_{SC} is electric resistance of the superconducting cable. Since R_{SC} is given by V-I property of the superconducting cable, it is a function of current, I, magnetic field, B, temperature, T, and strain, ε. I is regulated by both R_J and R_{SC}, basically. However, at high field, $R_{SC}\ I$ is dominant because that $R_J I$ decreases with magnetic field. Consequently, we obtain regulated current by R_{SC} with this experimental principle. In our method, flux flow voltage, $R_{SC}\ I$ gradually changes during magnetic field change. In general, specific flux flow voltage is determined as a criterion to identify a critical current. Therefore, we call this regulated current in our study, quasi-critical current.

A sample fabricated with 18 + 9-Cu multi-strand Nb_3Sn cable is shown in Figure 2. The bias magnetic field was applied in the horizontal direction in Figure 2 and compressive portion located at the centre of the bias magnetic field. The closed circuit of the cable was made on a round shape stainless mandrel and both

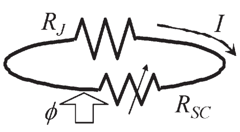

Fig. 1 Equivalent circuit of the sample

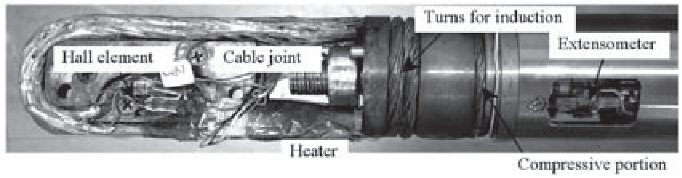

Fig. 2 Photograph of the sample. The Nb_3Sn cable wound with 3 turns are jointed in both ends.

ends were soldered. Near the joint, a hall element was attached to measure the circuit current, and a heater was installed to break the persistent current. Three extensometers were installed to measure the relative displacement between upper plate, which was fixed to the supporting pipe, and lower plate, which is connecting to the main pull-rod running thorough the supporting pipe.

The quasi-critical current measurement was carried out using 15 T superconducting magnet at Tohoku Univ. The ramp rate of the bias field was changed to 0.58 T/min. The load was applied by a motor and gear system. The compressive load was applied up to 5 kN, 10 kN, 15 kN and 20 kN. Here, 20 kN corresponds to averaged stress of 29.3 MPa on the compressive plane. After the load reached the related compressive load, the gear was stopped and the bias magnetic field was ramped up and down. Results of the quasi-critical current measurement are shown in Figure 3. As described above, the quasi-critical current decreases as the magnetic field increases. This degradation becomes larger as an increase of the load, e.g. less than 50 % of virgin state in the case of 20 kN. Load-displacement curves were also obtained by three extensometers successfully.

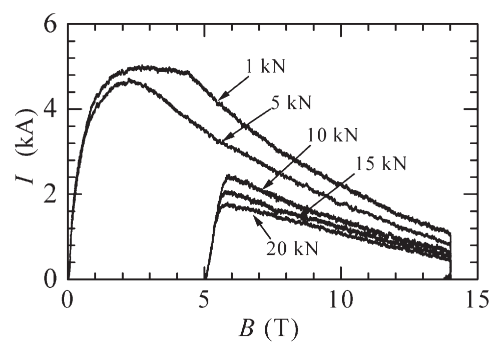

Fig. 3 Results of quasi-critical current measurement with compressive loading.

The degradation of quasi-critical current was observed by the new test procedure. With average stress of 29.3 MPa, the performance of the cable degraded less than half of virgin state.

Reference

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4) Seo, K. et al., to be published on Fusion Engineering and Design (2006).