§14. Experiments of Bending Strain on Reduced-Scale YBCO Conductors for Fusion Reactor Magnets

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The conceptual design studies on the heliotron-type fusion energy reactor FFHR are being conducted on both physics and engineering issues [1]. We propose, as a design option, that the helical coils of a continuous manner and a huge size (major radius: 17 m, stored magnetic energy: ~160 GJ) be constructed by prefabricating half-pitch segments using high-temperature superconductors (HTS); the segments are then jointed on site [2, 3]. We consider the YBCO coated-conductor be a good candidate according to the recent development of wire production technology. The present conductor design gives a nominal current of 100 kA at a maximum magnetic field of 13 T. We have successfully carried out a proof-of-principle experiment of HTS conductors with 15 kA critical current at 8 T and 20 K [2]. It was confirmed that the stability margin is about two orders of magnitude higher than that of low-temperature superconductors (LTS).

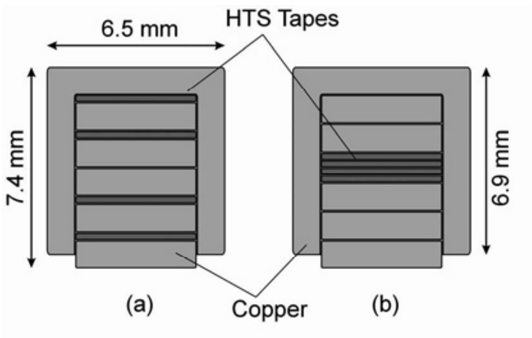

Fig. 1 Cross-sectional images of reduced-scale HTS conductors of (a) Type-A and (b) Type-B.

One of the crucial requirements of the winding conductors is to secure a sufficient margin for the bending strain applied in the winding process. In this respect, an idea of having rather thin layers of HTS wires within the cross-section of a conductor is proposed [2, 3]. With this configuration, the bending strain applied on the HTS tapes is minimized to be ~0.05%, which is an order of magnitude smaller than the allowable limit. In order to confirm this idea, we have carried out a proof-of-principle experiment by preparing reduced-scale samples shown in Fig. 1. Four YBCO tapes are used for both samples; in Type-A, the tapes are distributed in the whole cross-sectional area within the jacket, whereas in Type-B, the tapes are stacked together at the center [4]. The critical currents of these conductors were measured in liquid nitrogen (temperature: 77 K) and self-field after bending the samples using Bakelite formers. Voltage taps (length: 200 mm) were attached at the central part of the samples. The experimental results are summarized in Fig. 2. The degradation of the critical current of the Type-A sample is significant above the conductor bending strain of ~0.5% (defined by the ratio between the conductor thickness and bending diameter). On the other hand, the degradation of Type-B is much smaller, as it was expected.

These experimental results were then verified by carrying out another series of experiments using single tapes. The strain values expected at the locations of each tape inside the four tape conductors are calculated using the single-tape sample data. As is shown in Fig. 2, the results of four-tape samples have been well reconstructed. Thus, we consider that the conductor bending strain of 0.4% (expected value for the FFHR helical coils) should not create any degradation in the critical current, especially with the Type-B configuration.

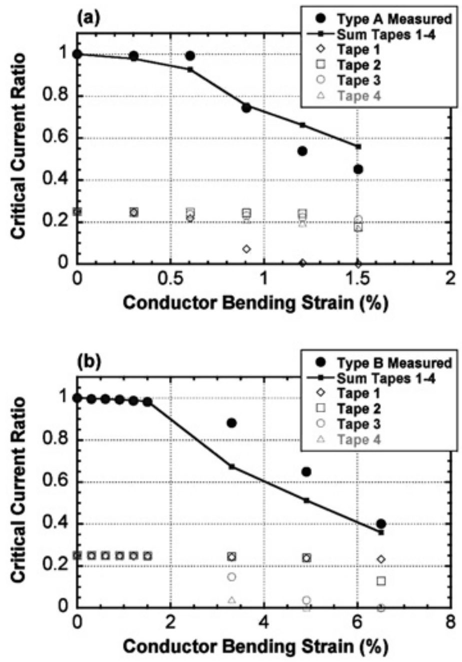

Fig. 2 Critical current ratio of (a) Type-A and (b) Type-B conductor samples as a function of bending strain. The measured data are compared with reconstructed data from single-tape measurements.

1) Sagara, A., et al., Fusion Eng. Des. 83 (2008) 1690.
2) Bansal, G. et al., Plasma Fusion Res. 3 (2008) S1049.
3) Yanagi, N. et al., Plasma Fusion Res. 5 (2010) S1026.
4) Champailler, R. et al., IEEE Trans. Appl. Supercond. 20 (2010) 1565.