§10. 3-dimensional Measurement of the Strand Trajectories in a Large CIC Conductor

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The superconducting coils wound with Cable-In-Conduit Conductors (CICCs) which are composed of several stages of sub-cable has been applied to large devices such as experimental fusion reactors and Superconducting Magnetic Energy Storage (SMES) devices because of its high mechanical and dielectric strength. In recent years there has been a growing interest in coupling loss with long time constants (from several second to several hundred seconds) which are not observed in test result using short sample conductor [1]. The loss is approximately proportional to both the time constant of the coupling current loop and flux linkage area of the changing magnetic field strength.

The time constant depends on both inter-strand contact resistance and inductance of the coupling current loop. The time constant is supposed to be long with large inductance of the loop and small contact resistance. The flux linkage area is determined by the projection area of a pair of strand trajectories.

In this work, we focus on the flux linkage areas which provide the driving force of the coupling current through the measured strand traces of 486-strand OV coil conductor of rectangular-shape conduit and 81-strands circular shape conductor, which are representative shape of the conductor for fusion apparatus.

The procedure of the measurement of 486 strands (about 200mm in length) is described in [2].

The rectangular-shape sample conductor for the strand-traces measurement is the OV coil conductor of 200mm in length which consists of 486 (3^4×6) strands and the circular-shape sample one consists of 81-strands (3^4). Two conductors have the same strand-material that is NbTi without any surface coatings.

The flux linkage area should be canceled when the strand traces are completely symmetrical. Unfortunately, when the twisted conductor is inserted into the conduit, the conductor is pressed and strongly deformed by the conduit in order to reduce the void fraction.

Figure 1 shows the schematic view of flux linkage area formed by a pair of strands. We have to notice that the difference between "loop area" and "flux linkage area". The former is proportional to the loop inductance and the cross section can be calculated by using the distance between two strands. On the other hand, the latter is the projection area and proportional to the coupling current driving force. According to Fig. 1, the flux linkage area of the loop should be smaller than the loop area. When the flux linkage area is well canceled, the ratio of the loop area and flux linkage area should be very small, but it is not, the ratio would be large.

Figure 2 shows the flux linkage area estimated by using the measured strand traces as a function of the loop area for different shape conductors. Fig. 2 (a) represents the case of circular-shape conductor and Fig. 2 (b) shows rectangular-shape one. It is clear that many flux linkage areas are approximately proportional to the loop area in the rectangular-shape conductor, which is unlikely in the circular-shape conductor. In our analysis of the strand traces, this remained area would be caused by the linear moving of strands along with the wall of rectangular conduit. In the circular-shape conductor, the linear trajectory of strands is not seen and then, the flux linkage area would be small. In present conclusion, for reduction of the inter-strand coupling losses, the circular-shape conductor would be better in terms of smaller flux linkage area which leads to smaller coupling current driving force.

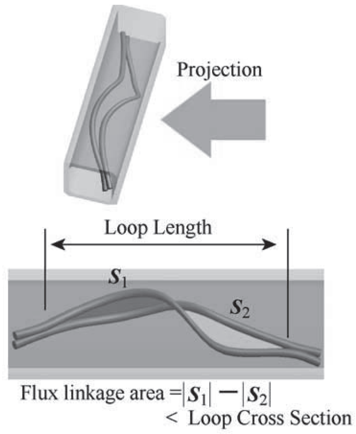

Fig. 1: Schematic view of flux linkage area.

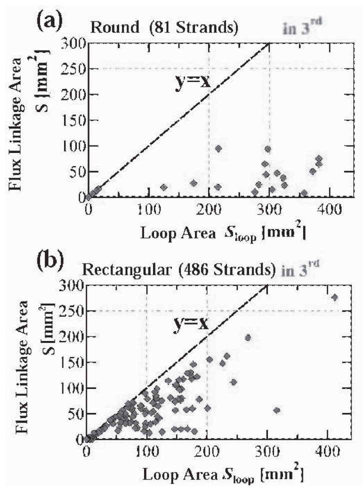

Fig. 2: The flux linkage area as a function of loop area in circular and rectangular-shape conductor.

1) Hamajima, T., et al.: Cryogenics, **39** (1999) 947.
2) Hamajima, T., et al.: Ann. Rep. NIFS (2006-2007)107.