§28-1 Study on Circulation Current Distribution in a Cable-in-conduit Conductor

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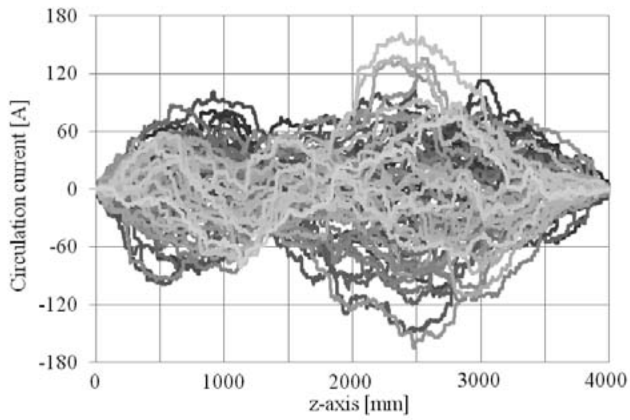
Superconducting coils used for a fusion reactor and a SMES are formed from Cable-in-Conduit-Conductors (CICCs). A CICC is made of many superconducting strands twisted in multiple steps and has superior characteristics such as large current capacity and high mechanical strength. However, in some experiments, it has been observed that the critical current of a CICC was lower than the expected. One of the reasons is unbalanced current caused by inhomogeneous circulation current distribution. Under variable magnetic field, the circulation current is induced at a loops between strands. In a large loop between strands, the circulation current is large. Therefore, a large number of the large loops can result in the inhomogeneous circulation current distribution. In this study, we investigated the relationship between the combination of twist pitches and the circulation current distribution using numerical calculation. Moreover, we examined the CICC configuration which had trouble inducing the inhomogeneous circulation current distribution in a CICC.

Table 1 shows the specifications of a CICC sample used for a large helical device (LHD) outer vertical (OV) coil. All strand paths in the CICC were calculated by using an equivalent area method that we proposed, and circulation currents among the all strands in the CICC induced by the external magnetic field were calculated. The CICC of a LHD OV coil is exposed to the magnetic field which is proportional to the transport current flowing through the CICC when the LHD OV coil is exited. In this study, we assumed that the excitation waveform was trapezoid wave. The maximum magnetic flux density was 5.0 T when the transport current was 31.3kA (60A per strand). The ramping rate of the exciting current was 200A/s, and amount of time during flat top was 10s. The circulation current distributions were calculated in two kinds of CICC models which have different combination of twist pitches. One was chosen similar to the CICC for a LHD OV coil. Its combination of twist pitches is 70/120/170/250/400mm (model I). The other was the CICC in which inhomogeneous circulation current distribution was inhibited by a suitable combination of twist pitches. Its combination of the twist pitches is 40/80/100/200/400mm (model II).

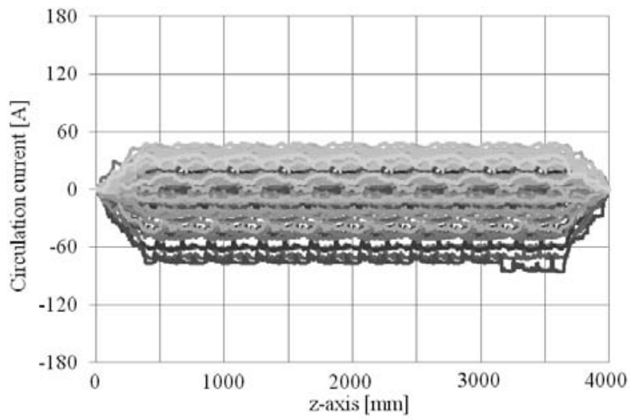
Fig 1 shows the calculated results of the circulation current distribution in a certain 4th sub-cable (81 strands) when the current through the coil is increased. As shown in Fig. 1 (a), in the model I, the circulation current distribution is inhomogeneous and changes a lot along the longitudinal direction of the CICC. In particular, in some parts of strands, larger currents than the transport current (60A) flow in the opposite direction of the direction of the transport current. On the other hand, as shown in Fig. 1 (b), in the model II, the inhomogeneity of the circulation current distribution is inhibited. These results presented in this work show that the combination of twist pitches of 1st-5th sub-cables affects the circulation current distribution. And the inhomogeneous circulation current distribution is improved when twist pitch of the n-th order sub-cable is a multiple of those of all the previous sub-cables. Furthermore, the least common multiples of the twist pitches of the model I and the model II are 714 m and 400mm, respectively. These numerical results denote that the inhomogeneous circulation current distribution could be reduced by decreasing the least common multiple of twist pitches.

Table 1 Specifications of a CICC sample used for a LHD OV coil.

CIC conductor	number of strands	486
	strand diameter [mm]	0.89
	cable length [mm]	4000.0
	cable shape [mm]	20.5×24.8



(a) CICC used for a LHD OV coil. Twist pitches of sub-cables in the CICC are 1st; 70 mm, 2nd; 120 mm, 3rd; 170 mm, 4th; 250 mm, and 5th; 400 mm.



(b) The improved CICC for suppressing inhomogeneous circulation current. Twist pitches of sub-cables in the CICC are 1st; 40 mm, 2nd; 80 mm, 3rd; 100 mm, 4th; 200 mm, and 5th; 400 mm.

Fig.1 Circulation current distribution in CICCs (numerical results).