§31. Non-Uniform Current Distributions and Large Time Constant Inter-Strand Coupling Losses in Cable-In-Conduit Conductors

Seo, K., Takahata, K., Mito, T. (NIFS)
Nishijima, S. (Osaka Univ.)

Circulation current through parallel strands in a multi-strand cable results in large AC loss, which is called large time constant (τ) inter-strand coupling loss. The Joule heating at the contact point between strands attributes to the loss. This kind of AC loss had been observed in the poloidal field coil of LHD and other large magnets wound with cable in conduit conductors (CICC). Basically, in the CICC, the strands are transposed perfectly by means of multiple-stage twisting. This design philosophy is aiming at balancing induced voltages along the parallel strands and current distribution is expected to be uniform. When the circulation current is superposed on the transport current, non-uniform current appears among strands. In spite of the transposition, the large τ losses have been observed. We suspected that the mechanism of this kind of loss is based on the irregularity of the trucks of the strands and have performed some numerical simulations [1],[2].

Fig. 1 shows the numerical models. The conductor in the LHD poloidal field coil (Fig. 1 a) is made into the numerical models: b) - d). Size of the conduit is 20.5mm x 24.8mm. Number of strands is 486. The combination of twist pitches is 1st: 70 mm, 2nd: 120 mm, 3rd: 150 mm, 4th: 270 mm and 5th: 400 mm. b) is the modified numerical model concerning the trucks of 54 sub-cables. c) shows the conventional numerical model, which is composed of sinusoidally waving strand-trucks. d) is the modified numerical model with 486 strands; however, it is difficult to solve this kind of complicated network circuit. To calculate the inter-strand coupling loss, electrical contact between parallel strands must be considered. In this study, we assumed the conductance between two neighboring sub-cables as 10^7 S/m.

Fig. 2 presents the frequency dependent of normalized one cycle AC loss under alternative transverse magnetic field. Basically, the loss in the multi-strand cable is governed by the twist pitch of the final twist stage. The time constant τ_c in Fig. 2 corresponds to that of the final stage. The model shown in Fig. 1 b) and the similar 54 sub-cable model with rational twist pitch combination are compared. Here, rational means the combination of twist pitches is 3rd-100 mm, 4th-200 mm and 5th-400 mm, respectively. The rational combination and the large model length result in large τ loss (thick solid line). Here, the time constant τ_{CL} is 200 s and the fraction *f* is 0.003. This phenomenon is caused by the unbalance of induced voltages along parallel sub-cables and this unbalance is significant for rational combination model.

In the actual conductor, we should consider the circulation current in the lower stage sub-cables shown in Fig. 1 d). The unbalance of induced voltage was analyzed to be larger between strands than sub-cables.

The large τ loss was simulated with proposed numerical model. We are planning to discuss about the lower sub-cables to reveal the mechanism of large τ loss.

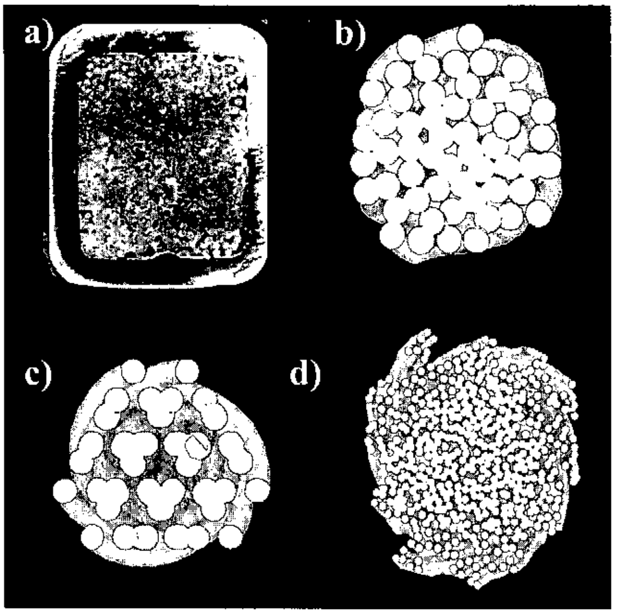

Fig. 1. Schematic illustrations of the modified numerical models. a) actual conductor, b) modified numerical model with 54 sub-cables, c) conventional numerical model and d) modified numerical model with 486 strands

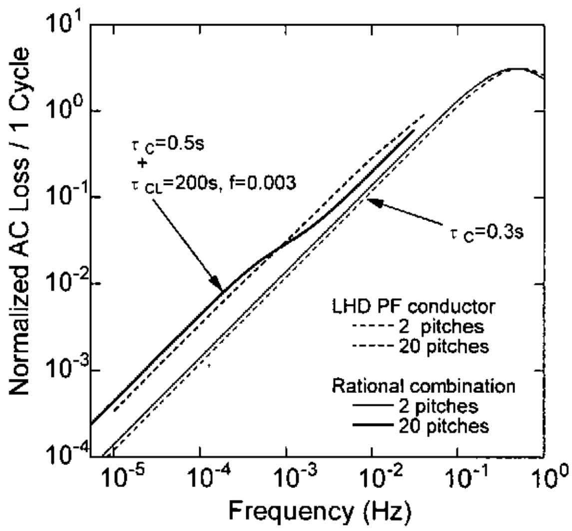

Fig. 2. Frequency dependent of normalized one cycle AC loss for the model shown in Fig. 1b). Parameters are length of the cable and the combination of twist pitches.

Reference
1) Seo, K., Hasegawa, M., Morita, M., Yoshimura, H., Physica -C, **310** (1998) 358-366
2) Seo, K., Takahata, K., Mito, T. and Nishijima, S., presented at MT-18 (2003)