§2. Study on Long Loops with Long Time Constants in Cable-in-Conduit Superconductor

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In recent years there has been a growing interest in irregular AC losses that cannot be measured from short conductor sample tests. The irregular AC losses with long time constants were typically observed in a Japanese SMES model coil, and the similar long time constants were estimated in poloidal superconducting coil conductors of Large Helical Device in National Institute for Fusion Science in Japan. Current loops, which must be irregularly formed in the cable, decay with the long time constants, and hence enhance the AC losses. The loops can induce an imbalanced current distribution in a conductor, and lead to RRL (ramp rate limitation), which was observed in DPC coils at Japan Atomic Energy Research Institute.

In this research, we propose a mechanism forming the long loops. The CIC conductor is composed of several staged sub-cables. If one strand on the surface of a sub-cable contacts with the other strand on the surface of the adjacent sub-cable, the two strands should encounter each other again at LCM (Least Common Multiplier) distance of all staged cable pitches, and thereby result in forming a pair of a long loop. There are a number of such long loops in the CIC conductor. The time constants of these loops are fundamentally described as ratios of their inductances to their contact resistances. The inductance of the loop is estimated to be about 5 to 15 mH for SMES and LHD-IV conductors. We measured cross contact resistance between strands, and obtained the time constants of 0.1 to 0.3 s, which are shorter than the measured coupling loss time constants.

It is important to investigate the contact conditions and the contours of the loops. We orderly labeled all strands in a real CIC conductor, disassembling carefully the cable after peeling the conduit. It is found that the strands in a triplex are widely displaced from their original positions. The fraction of the triplets with largely displaced strands is computed for the SMES conductor and the LHD-IV, IS and OV conductors, as shown in Fig. 1. It is found that around 5 % of all triplets have largely displaced strands. However, it is confirmed from the data on both sides of the conductor about 1 m in length, that almost of all the triplets with displaced strands on one side become regular triplets without displaced strands on the other side.

This suggests that the largely displaced strands have longer line contact length than point contact one. The line contact length must be more than 10 mm, while the point contact radius is estimated to be about 10 μm from Hertz theory. This leads to contact length more than 3 order, and hence explains the observed long time constants.[1)]

It is important to reduce the AC losses, we studied current distributions between strands depending on location of high resistivity CuNi layer. The typical FEM results are shown in Fig. 2, where (a) and (b) shows the current distributions in the case of the CuNi layer located inside and on the surface of the strand, respectively. The results suggest that the CuNi layer on the surface is effective for reduction of the AC loss.[2)]

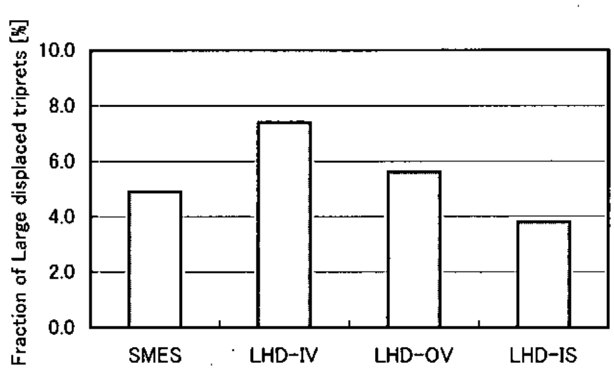
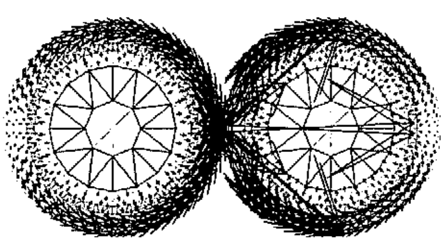
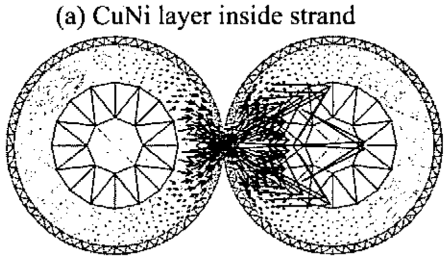


Fig. 1. Number of the large displaced triplets in CICCs.



(a) CuNi layer inside strand



(b) CuNi layer on surface

Fig. 2. Current distributions depending on the CuNi layer locations.

Reference

1) Hamajima, T., et al., IEEE Trans. on Appl. Supercond. **13**, (2003) 2384
2) M. Tsuda, et al., EUCAS2003, 2-17, (September, 2003) 15