§1. 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.

In order to estimate the time constants $\tau = L/R$ of the long LCM loops, we measured the cross contact resistance between the two strands of the SMES and LHD in LHe. The test results showed that the cross contacting resistances were about 50 $\mu\Omega$ for both conductors. The results suggest that the time constants are around 0.1 s for SMES and 0.3 s for LHD, which are shorter than the measured time constants of 5 to 100 s. This stems from the fact that the cross contact area, which is estimated about 10 μm in the elastic limit, is very small compared with the line contact area, which is the order of cm.[1]

It is important to investigate the contact conditions in more detail. We used pressure-sensitive papers, which are comprised of two types of papers; the one paper has dye capsules and the other has color developer. The paper color changes according to experienced pressure due to a chemical reaction between the two papers. We wound the pressure-sensitive papers on the strand surfaces of all sub-cable stages, as shown in Fig.1, and fabricated a third-order cable (3×3×3) with 2 m in length, then squeezed the cable through a die to form 38 % void fraction in the cable.[2]

It is found that the averaged contact lengths between strands in 1-st, 2-nd and 3-rd sub-cable stages before the squeezing process are 13.0, 28.2 and 3.9 mm, respectively. This result comes from that the tension acting on the strand is not enough large in fabrication of the cable.

It is also found the averaged contact lengths between strands in 1-st, 2-nd and 3-rd sub-cable stages after the squeezing process are 79.0, 58.9 and 16.4 mm, respectively. The squeeze process elongates the contact lengths between strands 2 to 5 times larger than those before the squeeze.

This allows us to conclude the squeeze process plays an important role to form the long contact length between strands and suggests a mechanism of generating the long time constants of more than 100s.
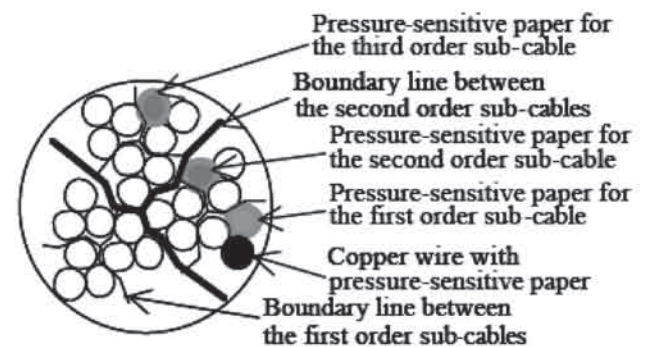

Fig. 1. Locations of pressure-sensitive papers on strand surfaces of all sub-cable stages.
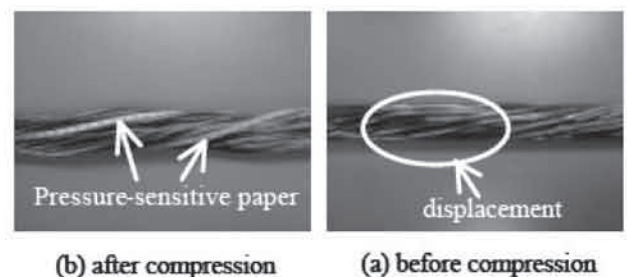

(b) after compression   (a) before compression

Fig. 2. Relative position between strands before and after compression.

References
1) Hamajima, T., et al., IEEE Trans. on Appl. Supercond. **13**, (2003) 2384
2) Tsuda, M., et al., IEEE Trans. on Appl. Supercond. **15**, (2005) 1533