§14. Study on Irregular AC Losses in Large CIC Conductor

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In recent years there has been a growing interest in additional AC losses observed in large coils made of CIC conductor. The term "additional AC loss" is defined as irregular AC loss which cannot be measured from short conductor sample tests. While "regular AC loss" is estimated from the short sample test results, and thereby is proportional to the largest twist pitch squared.

The additional AC losses with long time constants were typically observed in a Japanese SMES model coil. The similar long time constant was observed in a poloidal superconducting coil of Large Helical Device in National Institute for Fusion Science in Japan. The long time constant was also observed in a dipole magnet for accelerator. Current loops, which were irregularly formed in the cable, decay with the long time constant, and hence enhance the AC loss. Consequently, the loops might induce an imbalanced current distribution in a conductor, and cause so called RRL (ramp rate limitation), which was observed in DPC coils.

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 must 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.

In order to establish the above mechanism, we carried out following experiments; measurement of strand positions in a real CIC conductor, numerical analysis of strand positions and comparison with measured ones in the CIC conductor, and estimation of contact resistance between strands.

First, we orderly labeled all strands in a real CIC conductor, disassembling carefully the cable after peeling the conduit. The orderly labeled strand positions on a cross section are shown in Fig. 1. It was found that the strands in a triplex were widely displaced from their original positions, and thereby their contacting lengths became longer than calculated ones. This fact makes the time constant of loop longer and hence can explain the observed long time constants.

Secondary, we analyzed all strand positions in the cable. Numerical results indicate that there are about 20,000 loops in the LCM cable length, which is extremely vast loop number. The most probable time constant is about 10 s, and the averaged time constant about 18 s. The maximum time constant is about 150 s, and thereby we can explain the various experimental time constants of about 4s to 110 s observed through Hall probe signals in the SMES coil tests.

Finally, we measured the contact resistance of strands with oxidation surface. The results are shown in Fig. 2. It is found that the resistance drastically decreases after threshold voltage of about 0.2 V. This means the time constant of loop becomes large after several charges.

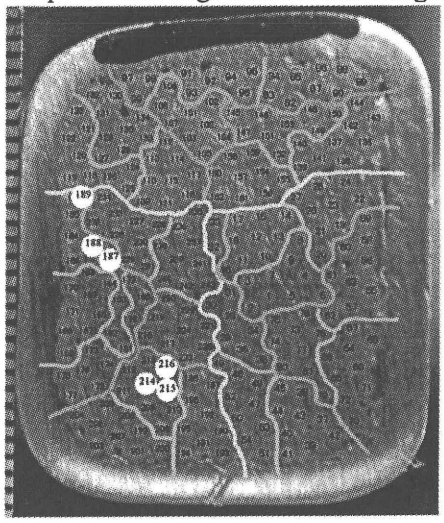

Fig.1. Labeled strands in a CIC conductor

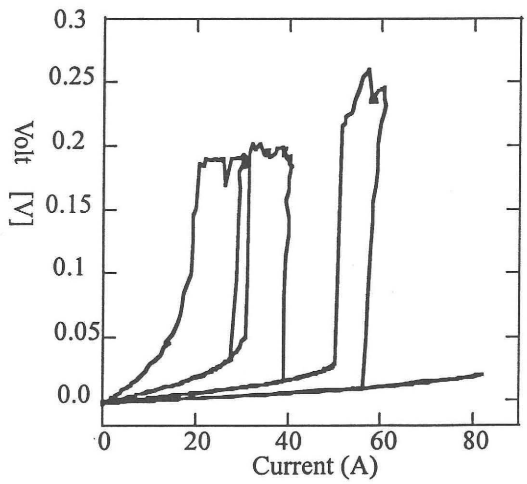

Fig. 2. V-I characteristics of strand contact.

Reference

1) Hamajima, T., et al., IEEE Trans. of Appl. Supercond. **11**, (2001) 1860