§3. The Method to Reduce AC Losses in Stable Superconducting Pulse Coils

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It is difficult to control the inter-strand contact resistances between strands in fabrication of low temperature superconducting (LTS) conductors composed of non-insulated strands. The properties of these conductors, therefore, cannot be theoretically estimated. And there is the dilemma that low ac loss and high stability cannot be simultaneously attained. In this study, a new winding method to reduce ac losses in stable LTS coils is proposed. This winding method reduces the irregular arrangements of strands in the conductors, and hence, it is easy to control the electrical properties between the strands. As a result, low losses and high stability can be simultaneously attained. The validity of our winding method has been theoretically shown. In this work we investigate the possibility that a conduction cooled LTS pulse coil can be developed.

In our winding method, we use a conductor that has anisotropic loss properties under changing transverse magnetic fields, for example, Rutherford cables, as winding conductors. In the winding process, the twist angles around the axis of the conductor is continuously controlled to adjust the direction of edge-on orientation of the cables to direction of local magnetic fields applied to the cable in the winding area. Superconducting conductors have been developed for conduction cooled pulse coils using our winding method. This conductor consists of a Rutherford cable surrounded by aluminum. The Rutherford cable is composed of 8 copper stabilized NbTi strands, each of 0.823 mm in diameter. The cable was designed to minimize the coupling losses under transverse magnetic fields with edge-on orientation. For the purpose, the strand twist direction is the same as the cable twist direction, and adjustment of strands twist pitches were carried out. The outer aluminum of the conductor has roles not only to support the conductor but also to maintain the high thermal conductivity and high specific heat which are required for conduction cooling, In order to reduce the eddy-current losses in the aluminum under the changing transverse magnetic fields, the RRR of the aluminum is just 9.85. The time-constants of the conductor, $n\tau$, under the operating condition of the real coil are 10msec for EO fields despite being 82msec for FO fields.

The parameters of the designed coil are as follows: The inner and outer diameters are 305mm and 509mm, respectively. The height is 402mm. The number of turns is 938. The inductance of the coil is 0.2H, and the stored energy of the coil is 100kJ at operating currents of 1kA. The operating pattern is as follows: Firstly, the stored energy of the coil is charged up to 100kJ, at 1kA, slowly to neglect ac losses generated during charge. Secondly, the stored energy is discharged down to 50kJ for 1sec. In this operation, the generated ac losses in this coil including hysteresis losses during discharge of 1sec are evaluated and the temperature rise of the coil due to the ac losses are calculated under adiabatic conditions. The results are shown by 2 solid lines in Fig. 1. For comparison, ac losses in the coil without the twist winding are calculated. The coil with twist winding is named "New coil" and the coil without twist winding is named "Old coil". The bold and gray lines represent the New coil and Old coil, respectively. We found that ac losses are much reduced by twist winding method. Total ac losses in each coil and the maximum temperature are shown in Table 1. The maximum temperature in the Old coil without the twist winding is 8.2K, which is the current sharing temperature. In contrast, the maximum temperature in the New coil with the twist winding is 6.7K. From this result, it is found that the New coil with the twist winding has an adequate temperature margin for stable operation.

The possibility that a conduction cooled LTS pulse coil can be developed by using our new winding method was shown.

Reference

1) A. Kawagoe, et al., IEEE Trans. Appl. Supercond., Vol.13, No.2, pp.2404-2407

2) A. Kawagoe, et al., IEEE Trans. Appl. Supercond., Vol. 14, No. 2 (in press)

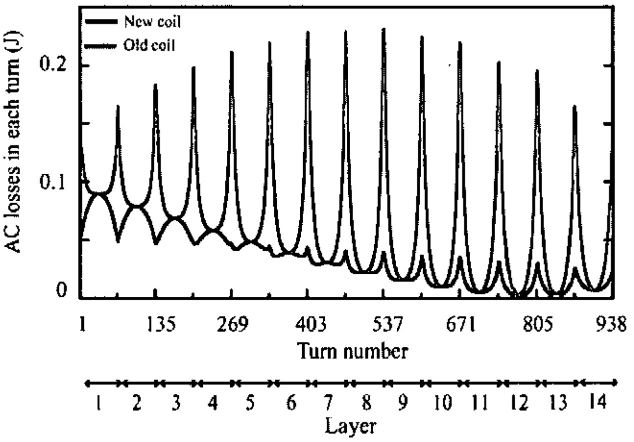

Fig. 1. AC losses in each turn of coils.

Table 1 Total ac losses and the maximum temperature in coils under pulse operation

	New coil	Old coil
Total ac losses in coils	32 J	61 J
Current sharing temperature	8.2K	
Maximum achieved temperature	6.7K	8.2K