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

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Large-scale superconducting pulse coils for fusion and SMES are required to have both low losses and high stability. In order to satisfy the requirement, the new winding method has been proposed. Suitable conductors for this winding method are multi-layer type conductors composed of stacked Rutherford type cables that have anisotropic loss properties under changing transverse magnetic fields and low resistive contact between strands. In the winding process, the twist angle around the axis of the conductor is continuously controlled to adjust the direction of edge-on orientation of stacked cables to direction of local magnetic fields applied to the conductor in winding areas.

The purpose of this paper is to clarify the effect of this winding method. A test conductor for test coils with the new winding method was fabricated and measurements of ac losses in short samples of the conductor were carried out. Moreover, ac losses in an example of test coils wound with the conductor are calculated.

An aluminum-stabilized conductor was adopted as the test conductor, and a Rutherford cable composed of 8 Cu/Nb-Ti strands was used as the core of this conductor. In order to reduce inter-strand coupling losses in the conductor to which the transverse magnetic fields is applied with edge-on orientation, the strand twist direction is the same as the cable twist direction. And in order to reduce eddy-current losses in the aluminum, the aluminum with a low degree of purity was used. The RRR of the aluminum is 9.85.

The coupling losses in the conductors were measured by our original ac loss measuring system. As a result, it was found that the coupling time-constants under operating conditions of the coil were 82msec and 10msec when face-on and edge-on oriented transverse magnetic fields were applied to the Rutherford cable, respectively. From these results, we found that inter-strand contact resistances per unit area in our conductors are about $10^{-12}[\Omega m^2]$. This value is less by one or two orders of magnitude than that of generally used superconducting conductors. Thus we succeeded in fabricating conductors with low losses and high stability when edge-on oriented transverse magnetic fields were applied to conductors.

In order to clarify the effect of a new winding method, the calculation of ac losses in an example of the coils wound with this conductor are carried out. In this calculation, two solenoid coils with the same dimensions are arranged coaxially (see Fig. 1). One coil is wound with the new method (new coil) and another coil is wound with the old method (old coil). In the operation of these coils, directions of transport currents are opposite. Induced magnetic fields at coil windings were calculated on this operation. Twist angles of a conductor were determined from this calculation. The ac losses in each coil including hysteresis losses during the operation are calculated, when transport current is changed from 966 A to 683 A for 1 second. Figure 2 shows the results of calculations. The vertical axis represents the generated ac losses in each turn, and the horizontal axis represents turn number. (The turn number starts from the turn which is shown by solid symbols in Fig. 2.) The ac losses in old coil and new coil are represented by fine line and bold line, respectively. We found that ac losses are much reduced by our new winding method; especially ac losses in the new coil are reduced by about 88% at the nearest position between each coil. The total loss in the new coil is reduced by 74%. Obtained results show that a much greater reduction of ac losses in the whole coil compared with the old winding method can be expected. And the effects of errors in twist angles of the winding on ac losses are also calculated. As a result, it is clear that the effects on ac losses are not considerable. We found that a great reduction of ac losses can be achieved in coils with our new winding method, even if high stability is maintained due to low contact resistances between strands.

Reference

1) Kawagoe A., et al. IEEE Trans. Appl. Supercond. (to be published)

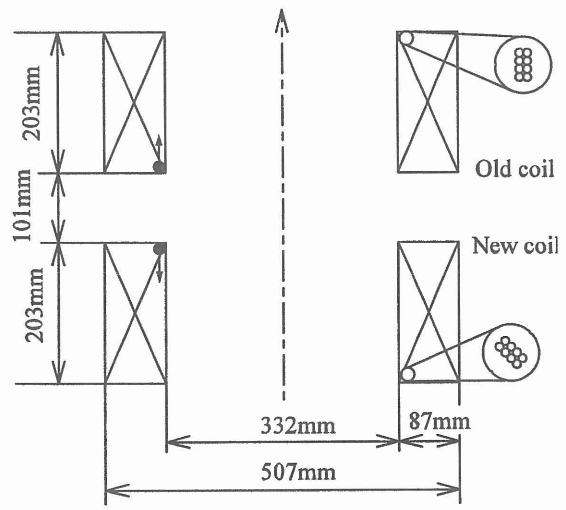

Fig. 1 . The model arrangement of coils, one coil with the new winding method and another coil with the old winding method.

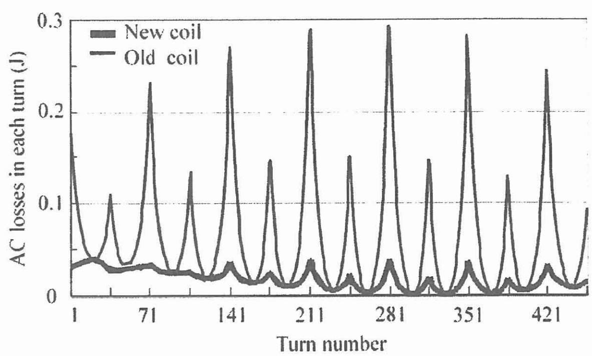

Fig. 2 Results of calculation of ac losses in each turn of coils.