§13. Development of Superconducting Conductors for Pulse Coils with High Stability and Low Losses

Sumiyoshi, F., Kawabata, S., Kawagoe, A. (Kagoshima Univ.), Kawashima T. (Fukuoka Jo Gakuin Univ.), Mito, T.

Large superconducting pulse coils for fusion and SMES are required to have both low losses and high stability. The purpose of this paper is to propose a new winding method for superconducting pulse coils with high stability and low losses, and to develop the suitable conductors for this winding method[1].

Conductors for this winding method are multi-layer type conductors composed of stacked Rutherford cables with anisotropic loss properties under changing transverse magnetic fields, and low resistive contact between strands. In this winding method, the twist angle around the axis of the conductor is 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 (Fig. 1). Inter-strand coupling losses in this coil are expected to be small in spite of low resistive contact between strands, because magnetic flux linkage between strands is small.

Firstly, a conductor was designed to test our new winding method for coils. An aluminum stabilized conductor was adopted, and a Rutherford cable composed of 8 Cu/NbTi strands was used as the sub cable of this conductor. For the sake of easy winding, the outer shape of the conductor is cylindrical (Fig. 1). Parameters of this conductor are listed in Table 1. To on sure contact between strands in a cable with low resistivity, the strand surfaces are cleaned before Rutherford cable is fabricated. When edge-on oriented transverse magnetic fields were applied to the Rutherford cable, the inter-strand coupling losses in the conductor were smallest. Two dimensional finite element method (2D-FEM) analyses was carried out on loss properties of this conductor.

In case1, ideal contacts between strands were assumed and in case2, very large contact resistances between strands were assumed. In each case, we assumed ideal contact between strand and aluminum. The results of calculations are shown in Table 2. $n\tau_s$, $n\tau_{c\_FO}$, $n\tau_{c\_EO}$ and $n\tau_{eddy\_Al}$, are loss time-constants per strand volume, and represented intra-strand coupling losses, inter-strand coupling losses for FO fields, inter-strand coupling losses for EO fields and eddy current losses in aluminum, respectively. $n\tau_{FO}$, $n\tau_{EO}$ are total loss time-constants when transverse magnetic fields in each direction were applied to the conductors. The ratios of $n\tau_{EO}$ to $n\tau_{FO}$ were 7% and 45% for case1 and case2, respectively.

Secondary, ac losses in test coils wound with this conductor were calculated. Two solenoid coils with the same dimensions were arranged coaxially and connected in series. The distance separating coils was 101mm. The dimensions of each coil were as follows; outer diameter was 507mm, inner diameter was 332mm, height was 203mm, and number of turns was 433. One coil was wound using the new method (new coil) and one coil was wound using the old method (old coil). The total inductance of the two coils was 171mH. Operating patterns were as follows; stored energy was 80kJ at stand by, then discharge was 40kJ for 1 second. Ac losses in coils including hysteresis losses during discharge were calculated (Table 3). AC losses in new coil were reduced by 71% and 16% in case1 and case2, respectively. Test coils are planned for fabrication and testing.

Reference

1) Kawagoe, A., et. al., The Papers of Joint Technical Meeting on Application of Superconductivity and Linear Drives, IEE Japan, pp. 31-35 (2002).

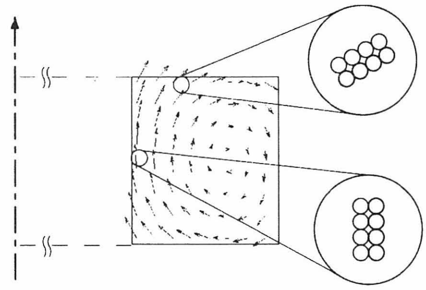

Fig. 1 Induced magnetic field of coils and optimum twist angles of conductors

Table 1 Parameter of conductors

Strand	
diameter (mm)	0.825
twist pitch (mm)	10
filament diameter (μm)	6
Cu/NbTi	1.95
twist direction	Z
Cable	
number of strand	8
twist pitch (mm)	35
twist direction	Z
Aluminum	
RRR	10
diameter (mm)	5.8

Table 2 Coupling losses and eddy current losses in the test conductor

		Case1	Case2
$n\tau_s$	(msec)	11	11
$n\tau_{c\_FO}$	(msec)	457	50
$n\tau_{c\_EO}$	(msec)	25	18
$n\tau_{eddy\_Al}$	(msec)	8	8
$n\tau_{FO}$	(msec)	465	58
$n\tau_{EO}$	(msec)	33	26

Table 3 AC losses in test coils

	Case1	Case2
losses in the old coil	20.2W	6.2W
losses in the new coil	5.8W	5.3W
loss reduction percentage	71%	16%