§8. Development of a New Type Superconducting Conductor with High Stability and Low Losses

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Large inter-strand coupling losses are produced in superconducting conductor under changing transverse magnetic fields. Increasing contact resistance between strands is effective in reduction of losses. However, the high crossover resistance tends to result in low stability because transport current shearing is also suppressed. Recently an attractive new design has been proposed; it was expected that the dilemma of low losses and high stability would be solved by adopting short circuits among strands with every length of cable twist pitches. According to our numerical analysis using three-dimensional finite element method (FEM), however, this design is not valid because significant reduction of losses cannot be achieved. The purpose of the present study is to propose an alternative new design of Rutherford cable with both low losses and high stability. In order to confirm the validity of the design, two-dimensional FEM (2D FEM) calculation is carried out.

The new Rutherford cable has following structures: (1) The strand twist is the same direction as the cable one. (2) The strand twist pitch is relatively longer than the cable twist pitch (3) The cable have good crossover contacts between strand pairs located near each edge of the cable cross-section. By adopting this new cable structure, potential differences between crossover strand pairs become small and therefore induced inter-strand coupling losses are reduced. As a result, total coupling losses in the cable can be reduced in spite of increase in intra-strand coupling losses. Characteristic features of the new design compared with the existing one are as follows: (I) Composite cores inserted in cables have the same shape and resistive pattern of thin cross-sections along the cable axis. (II) Low resistive paths enabling transfer of transport currents from one strand to another are laid at every half-length of cable twist pitches.

Four cases of Rutherford cables as shown in Fig. 1 are taken for the 2D FEM analysis. A number ratio of the strand pairs with low resistive contact to total strand pairs, ξ vary from 0.87 for Case I to 0.13 for Case IV. Parameters of cables and strands used are listed in Table 1. In Fig. 2 the obtained results are plotted under ac transverse magnetic fields with amplitude H_m, a frequency of 0.01 Hz and face-on orientation, where the vertical and the horizontal axes are the coupling loss per cycle per unit volume normalized by $\mu_0 H_m^2$, W, and the twist pitch of strands L_s, respectively. In the region of small L_s, the coupling loss tends to decrease with decreasing ξ, however there exists clear difference between Cases II and III in spite of the same value of ξ. With increase in L_s, inter-strand coupling losses shown by broken lines in Fig. 2 gradually decrease and then increase again after reaching a minimum value, where the inter-strand coupling loss is given by subtracting coupling loss for Case V from that for Cases I-IV. Since the intra-strand coupling loss is proportional to L_s^2, the characteristic curve of total coupling losses vs. L_s^2 is much deformed from that of inter-strand coupling losses at a large L_s region. The 'achievement factor of low losses and high stability', ζ/ξ is shown in Table 2, where ζ is the number ratio of optimized coupling loss of each cable to the non-cored practical cable. The obtained value of ζ/ξ becomes smaller than 1 for Cases I-IV, and the smallest value of ζ/ξ is given as 0.14 for Case IV. This shows validity of the present design. This cable design could be useful in avoiding the deterioration of properties of multi-stranded cable caused by uncontrolled inter-strand contact resistance or the asymmetry in cable twisting.

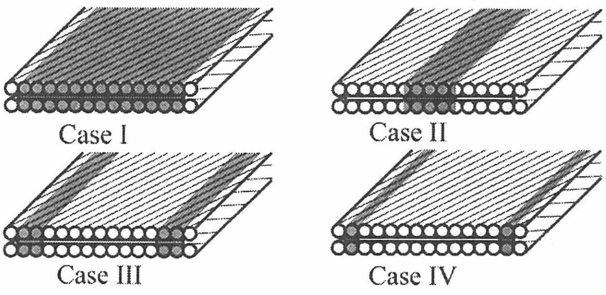

Fig. 1 Four types of Rutherford cables. Shaded area shows different low resistive section.

Table 1. Parameters of cables and strands used in 2D FEM analysis.

Cables	
Number of strands	30
Twist pitches of cables, L_c	87mm
Strands	
Matrix	Bronze/Cu
Twist pitches of strands, L_s	10mm～2000mm

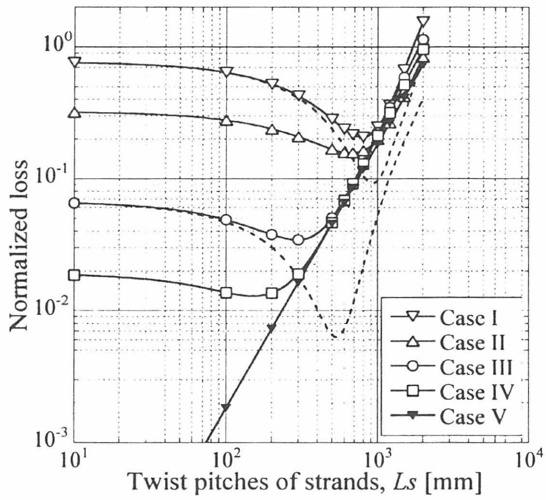

Fig. 2 Dependence of total coupling losses on twist pitches of strands, where dotted lines represent inter-strand coupling losses.

Table 2. 2D FEM results of coupling losses

	Practical design (no core)	Practical design (cored)	Case I	Case II	Case III	Case IV
ξ	100%	～0%	87%	27%	27%	13%
ζ	1	2.41×10^{-5}	2.72×10^{-1}	2.06×10^{-1}	4.50×10^{-2}	1.79×10^{-2}
ζ/ξ	1	–	0.32	0.76	0.17	0.14

Reference
1) Gohda, T. et al., Proc. of ISS '99, 775-777 (1999).