§9. Increase of Inter-strand Coupling Losses in Large Superconducting Conductors

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Increases in coupling losses were observed during the excitation test on poloidal field coils for the Large Helical Device at operating condition of these coils. This indicates the generation of additional inter-strand coupling losses with another long time-constant beside the intrinsic one corresponding to the twist pitch of the final stage cabling process. This phenomenon can not be explained by the previously reported theories. The purpose of the present study is to clarify the mechanism of this phenomenon.

As a candidate of the cause, it is considered that the effect of non-uniform transverse magnetic fields applied to cables on loss properties. The calculation taking account of this effect for the inter-strand coupling properties in two-strand cables were carried out. The result of this calculation clarified that the additional inter-strand coupling losses with the long time-constant are produced in this case. In order to confirm this result, coupling losses in superconducting samples were measured, when samples were applied non-uniform ac transverse magnetic fields which generated by using magnets of 30mm in length wound by Cu wire. These Cu magnets were set over the sample as shown in Fig. 1. In this experiment, two intervals of Cu magnet arrays L_{Cu}, i.e., L_{Cu} = 40mm and 80mm. For the non-uniform field, we use here a new Poynting vector method to get values of losses by measuring energy flows from Cu magnets into samples. Here, we used multifilamentary wires themselves as a sample in stead of the two-strand cable by taking account that inter-filament coupling properties similar to inter-strand ones. Sample 1 is a Nb_3Sn cable-in-conduit conductor with a void fraction large enough for inter-strand coupling currents to be neglected regardless of non-insulated strand surfaces, i.e., it is able to be considered each Nb_3Sn wire is effectively insulated. (This property of the inter-strand coupling loss was confirmed by preliminary measurements.) Sample 2 is composed of insulated NbTi multifilamentary 56 wires. These samples are straight and 300mm in length.

The frequency dependencies of W/W_1 are shown in Fig. 2, where W/W_1 are ratios of measured losses in non-uniform fields W, to those in uniform fields W_1. As can be seen, we notice that W/W_1 increases with a decrease in frequency and saturates at low frequency regions. In Fig. 2, the theoretical results of W/W_1 are also shown by solid and dash lines, which agreed with experimental results qualitatively.

The characteristic length corresponding to the long time-constant which was observed during the excitation test on the large-scale superconducting magnet was about 9m, and

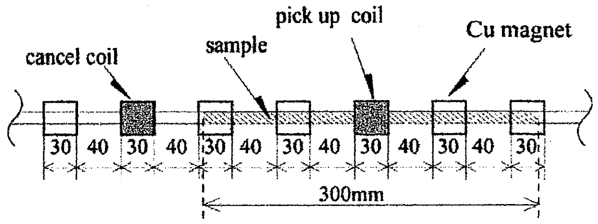
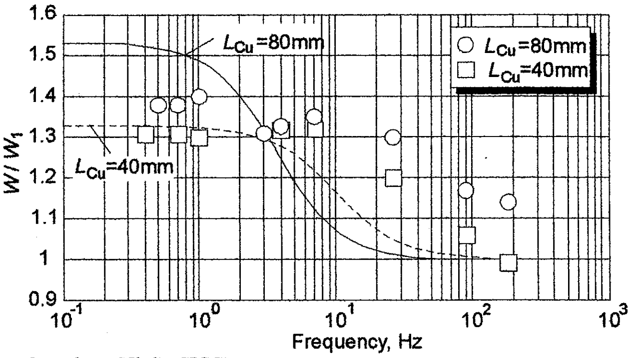
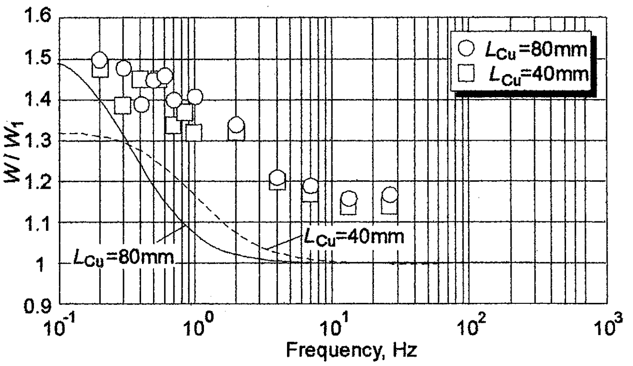


Fig. 1 Schematic of experimental set up



(a) Sample 1 (Nb_3Sn CICC)



(b) Sample 2 (The bundle of NbTi multifilamentary wires)

Fig. 2 The frequency dependencies of W/W_1.

was nearly 1-turn length of such magnet which was double pancake one. In the magnet, transverse fields applied to the cable are expected to change gradually every 1-turn length oriented to the long axis of the cable. Such distributions of applied transverse fields largely able to be divided into two components. The first one has a characteristic length of 1-coil (about 300m), and the second one has a characteristic length of 1-turn (about 10m). It is considered the effect of this second component as one of the cause of additional inter-strand coupling losses arising with the long time-constant.

Reference

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

2) Kawagoe, A. et al.: Proc. of the 59th Meeting on Cryogenics and Superconductivity (Yamaguchi, 1998) 203