§61. AC Losses in Superconducting Conductors Carrying Transport Currents for the Poloidal Field Coil

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Increase in ac losses was observed during the experiments on the poloidal field coil for the Large Helical Device.[1] This indicates that an additional long time-constant of inter-strand coupling currents exists besides the ordinary one which is given from measurements on short sample conductors, and that as the result large coupling losses are produced at actual condition of sweep rate. The purpose of the present study is to clarify quantitatively the mechanism of this phenomenon. In order to do so, we calculate here inter-strand coupling properties of the two-strand cable with irregular twisting as a most simple case.[2]

We think the mechanism is as follows: When a two-strand cable is exposed to transverse magnetic fields, shielding voltages are induced in every half twist-pitch of the cable. In case of regular twist cable, coupling currents with the ordinary coupling time-constant being not so long flow in the whole cable. In case of irregular twist cables, however, the additional coupling currents with longer time-constant are induced by the special shielding voltage at the point of irregular twisting. In order to calculate these coupling currents, we use equivalent distributed circuit model as shown in Figs. 1 and 2, where R is the contact resistance among two strands, L the inductance of a half twist pitch loop, and e the voltage source corresponding to shielding voltage. Figures 1 and 2 show the circuit model corresponding to the regular and irregular two-strand cable, respectively.

In the case that irregular half twist-pitches k times as long as regular ones exist at every m-pitches, inter-strand coupling losses per cycle per length W is given by

$$W = 2W_{1p}\frac{\omega\tau}{1+\omega^2\tau^2} + 2W_{2p}\frac{\omega\,\tau_{eff}}{1+\omega^2\tau_{eff}^2} \quad . \qquad (1)$$

In eq. (1), the first term is the inter-strand coupling loss characterized by the ordinary coupling time-constant τ, and the second term is the other one by the time-constant τ_{eff}, and W_{1p} and W_{2p} are peak values of loss components corresponding to these two terms. These quantities are written as

$$\tau = \frac{L}{4R} \quad , \qquad (2)$$

$$\tau_{eff} = 2\sqrt{\frac{2}{3}}\, m^2\tau \quad , \qquad (3)$$

$$\frac{W_{2p}}{W_{1p}} = (k-1)^2\frac{\tau}{\tau_{eff}} \quad . \qquad (4)$$

Figure 3 shows the frequency dependence of W, where peak frequencies f_c and f_c' are given by $f_c=1/(2\pi\tau)$ and $f_c'=1/(2\pi\tau_{eff})$, respectively. From the above theoretical result the existence of the additional inter-strand coupling time-constant τ_{eff} and resultant increase in coupling losses are confirmed.

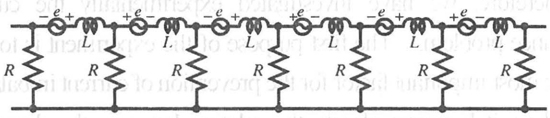

Fig. 1 Circuit model of two-strand cables with regular twisting

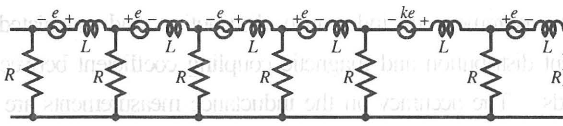

Fig. 2 Circuit model of two-strand cables with irregular twisting

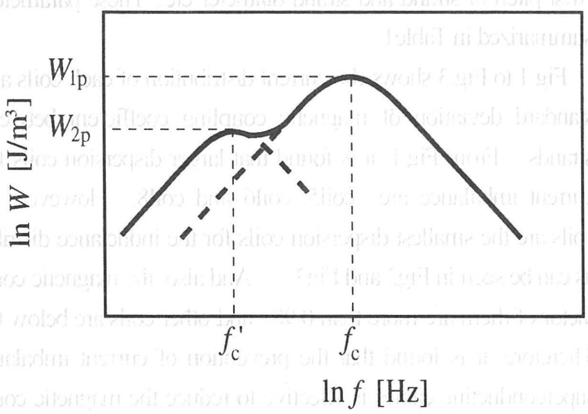

Fig. 3 Frequency dependence of inter-strand coupling losses in two-strand cables with irregular twisting

References

1) Mito, T. et al. : IEEE Trans. Appl. Supercond. 7(1997)330.
2) Kawagoe, A. et al. : Proc. of the 57th Meeting on Cryogenics and Superconductivity (Takamatsu, 1997) p.230