

## §16. Research and Development of Oxide Super-conducting Cables with a Large Current Capacity

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The currently developed high- $T_c$  superconducting wires are rolled into thin tapes for the sake of good alignment of crystallized grains in superconducting filaments. We proposed that the configuration of parallel conductors is most suitable to form a large-current-capacity conductor with such high- $T_c$  superconducting wires. We adopted this type of conductor to fabricate a 800kVA class superconducting transformer operating at a LN<sub>2</sub> temperature successfully. In this study, we are investigating the applicability of parallel conductors to superconducting magnets for a fusion reactor.

In parallel conductors, the constituent strands need to be insulated and transposed during the winding process to realize uniform current distribution and also to reduce ac losses. If all the strands are evenly transposed, the transport current flows uniformly and the additional ac loss due to composing a parallel conductor is not induced. However the transposition points might deviate from the optimum ones naturally and/or inevitably during the fabrication process. In this manuscript, we report the additional ac loss properties in parallel conductors exposed to ac magnetic field.

We derived the theoretical expressions of the additional ac losses in 2- and 3-strand parallel conductors due to the deviations of the transposition points from the optimum ones. In the case of a 3-strand parallel conductor with a length of  $L$  in which both transposition points deviate from optimum ones by  $\Delta\ell$  as shown in Fig.1, the additional ac loss density per one cycle is given by

$$W = \frac{1}{K'} \frac{\mu_0 d}{2d_w w} \frac{\pi\omega\tau_3}{1 + \omega^2\tau_3^2} \frac{B_m^2}{\mu_0} \left(\frac{6\Delta\ell}{L}\right)^2, \quad (1)$$

$$\tau_3 = K' \mu_0 \frac{Ld}{3Rw} = \left[ k_1' \left(1 - \frac{d_w}{2d}\right) \left(1 - 3\frac{\Delta\ell}{L}\right) + k_2' \left(1 - \frac{d_w}{4d}\right) \left(1 + 3\frac{2\Delta\ell}{L}\right) \right] \mu_0 \frac{Ld}{3Rw}, \quad (2)$$

where where  $k_1'$  and  $k_2'$  are the coefficient determined by the geometrical configuration,  $d$  is a distance between the center lines of strands,  $d_w$  is a thickness of strand,  $w$  is a width of

strand, and  $R$  is a contact resistance between strands at the terminals. In the case that the induced shielding current reaches to the critical current, assuming that the external field amplitude is much larger than the effective penetration field,  $B_{pe}$ , the ac loss densities are approximately given by

$$W \cong 4 \left| M_{\max} \right| \frac{B_m}{\mu_0}, \quad (3)$$

$$M_{\max} \cong -k' \frac{6\Delta\ell}{L} \frac{\mu_0 d I_c}{3wt}, \quad B_{pe} \cong \mu_0 \frac{I_c L}{6\Delta\ell w}, \quad (4)$$

where  $M_{\max}$  is magnetization by the saturated shielding current equal to the critical current.

These theoretical results were supported by the experiments as shown in Figs. 2 and 3, where rectangular cross-sectional NbTi wires were used for convenience sake.

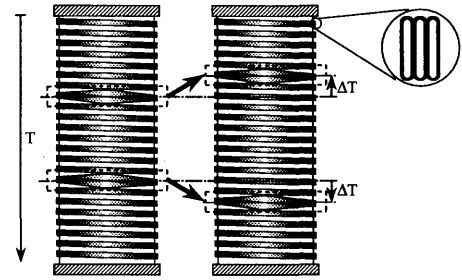


Fig.1 NbTi sample coil for ac loss measurement.

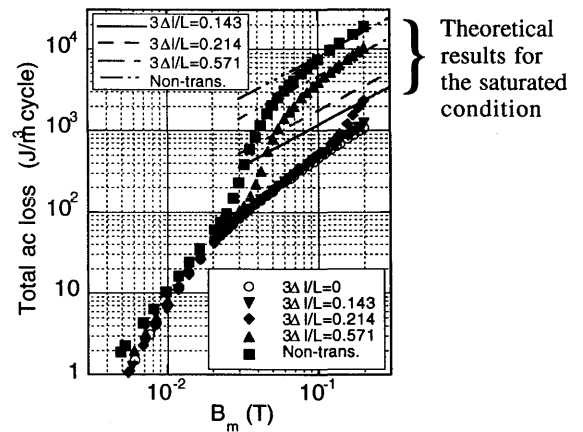


Fig.2 Total ac losses in 3-strand parallel conductors.

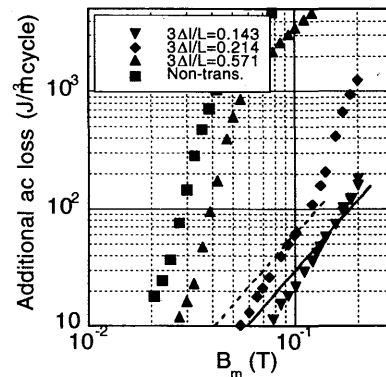


Fig.3 Additional ac losses in 3-strand parallel conductors.