§19. Basic Research on the Conduction-Cooled Oxide Superconducting Magnet Wound with Parallel Conductors

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1. Introduction

To develop conduction-cooled oxide superconducting magnets with parallel conductors, it is necessary to grasp the basic electromagnetic properties of superconducting parallel conductors in detail. We investigated the ac loss properties in the non-saturation case, where the induced shielding current is less than the critical current in the strand, last year. We derived the theoretical expressions and verified the validity by experiment. This year we investigated the ac loss properties in the saturation case. We report the results.

2. Theoretical expression

We studied the simple situation that a 2-strand parallel conductor with only one transposition is exposed to uniform external magnetic field as shown in Fig.1. In the case that the transposition point deviates from the center, which corresponds to the optimum point, by Δl, the interlinkage magnetic flux of the loop is not cancelled perfectly and the shielding current is induced. The shielding current reached the critical current of the strand, magnetic flux penetrates into the loop through the flux-flow. The induced shielding current is expressed as

$$I = -\frac{1}{k}\frac{\omega\tau}{\sqrt{1+(\omega\tau)^2}}\frac{B_m}{\mu_0}\left(\frac{2\Delta l}{L}\right)\sin(\omega\tau+\phi) + \left\{\frac{1}{k}\frac{(\omega\tau)^2}{\sqrt{1+(\omega\tau)^2}}\frac{B_m}{\mu_0}\left(\frac{2\Delta l}{L}\right) - I_c\right\}\exp\left(-\frac{t-\frac{\pi}{2\omega}}{\tau}\right) \quad \left(\frac{\pi}{2\omega}\le t < t_{sd}\right)$$

$$I = I_c \quad \left(t_{sd} \le t < \frac{3\pi}{2\omega}\right)$$

$$I = -\frac{1}{k}\frac{\omega\tau}{\sqrt{1+(\omega\tau)^2}}\frac{B_m}{\mu_0}\left(\frac{2\Delta l}{L}\right)\sin(\omega\tau+\phi) + \left\{I_c - \frac{1}{k}\frac{(\omega\tau)^2}{\sqrt{1+(\omega\tau)^2}}\frac{B_m}{\mu_0}\left(\frac{2\Delta l}{L}\right)\right\}\exp\left(-\frac{t-\frac{3\pi}{2\omega}}{\tau}\right) \quad \left(\frac{3\pi}{2\omega}\le t < t_{su}\right)$$

$$I = -I_c \quad \left(t_{su} \le t < \frac{5\pi}{2\omega}\right)$$

where B_m is the amplitude of extermal magnetic field, τ is the decay time constant, t_{sd}、 t_{su} are the time when the shielding current reaches the critical current at the decreasing- and increasing-field process respectively, k is a coefficient in rrelation to the demagnetization effect. The ac loss in this case is given by

$$W = \mu_0 \oint \frac{I d_s}{2uw}\left(\frac{2\Delta l}{L}\right) dH$$

where d_s is the distance between the centerlines of strands, w and u are the width and thickness of the strand respectively.

3. Experoment

We carried out the verification experiment using NbTi multifilamentary strands for convenience. The parallel conductors with a length of 2.6m were wound into one-layer solenoidal coils. The ac losses were measured with applying external magnetic field parallel with the coil axis. The observed results are shown in Fig.2 in comparison with the theoretical ones. It shows the case of $2\Delta l/L$=0.4. The experimental results are well explained by the theoretical prediction.

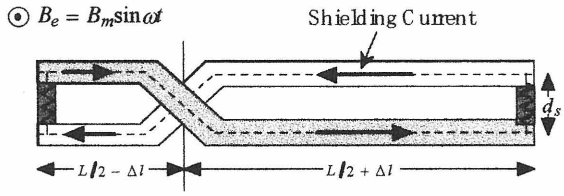

Fig.1 Projected figure of a 2-strand transposed parallel conductor in the direction of applied magnetic field.

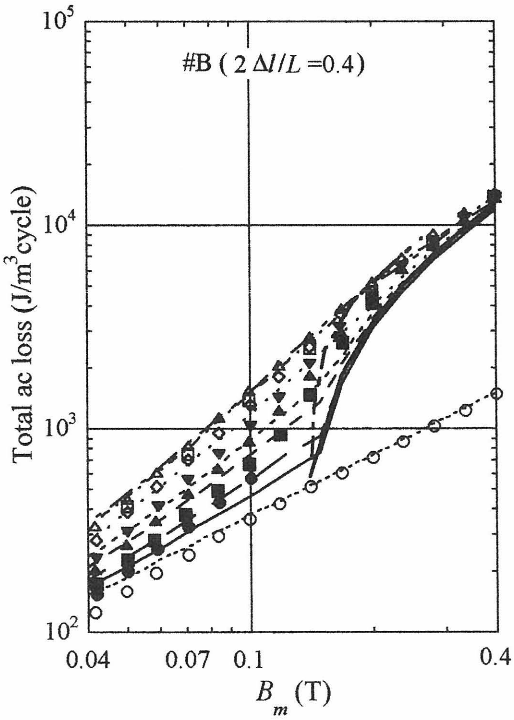

Fig.2 Total ac losses in a 2-strand transposed parallel conductor. The symbol, ○ represents the observed reluts in a strand. The other symbols represent the observed ones at 4, 2, 0.7, 0.4, and 0.1 Hz in order from below to upper on graph. The curves corresponds to the respective theoretical ones. The thick chained line shows the threshold amplitude of the saturation condition. The thick solid line is the asymptote of ac loss at high frequency. The right-hand side of the threshold amplitude corresponds to the present study.