§ 32. Basic Research on the Conduction-cooled Oxide Superconducting Magnet Wound with Parallel Conductors

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1. Introduction

In order to develop conduction-cooled oxide super-conducting magnets with parallel conductors, it is necessary to grasp the basic electromagnetic properties of super-conducting 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 of a strand. We derived the theoretical expressions and verified the validity by experiment. 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. When the shielding current is less than the critical current of a strand, magnetic flux penetrates into the loop only due to the decay of the shielding current. The average magnetic flux density of the loop, B_i, can be calculated by the following equation,

$$\left(\frac{2\Delta l}{L}\right)B_e - \tilde{B}_i = \tau\frac{d\tilde{B}_i}{dt}$$

$$\tau = \mu_0 k\frac{d_s L}{2R}$$

where B_e is an external magnetic field, τ is the decay time constant of the loop, d_s is the distance between the centerlines of strands, R is the contact resistance at the both ends, k is the constant which is related with the demagnetization effect. When the external magnetic field is given by $B_e=B_m \sin \omega t$, B_i and the shielding current, I, is expressed as

$$\tilde{B}_i = -\left(\frac{2\Delta l}{L}\right)\frac{B_m}{\sqrt{1+(\omega\tau)^2}}\cos(\omega t+\phi)$$

$$I = -\frac{1}{k}\left(\frac{2\Delta l}{L}\right)\frac{\omega\tau}{\sqrt{1+(\omega\tau)^2}}\frac{B_m}{\mu_0}\sin(\omega t+\phi)$$

The additional ac loss is given by

$$W = \frac{1}{k}\frac{\pi\omega\tau}{1+(\omega\tau)^2}\frac{B_m^2}{\mu_0}\left(\frac{2\Delta l}{L}\right)^2\frac{d_s}{2uw} \quad \text{for } B_m < B_s$$

where B_m is the amplitude of external magnetic field, w and u are the width and thickness of the strand respectively.

3. Experiment

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 Figs.2 (a) and (b) in comparison with the theoretical ones. They show the case of $2\Delta l/L$=0.6. The experimental results are well explained by the theoretical prediction.

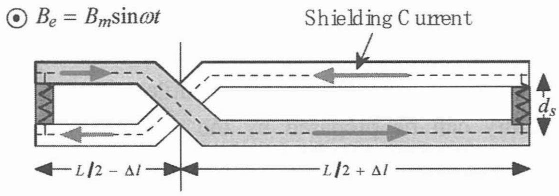
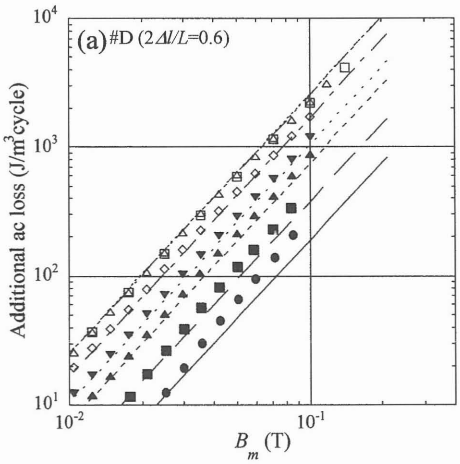


Fig.1 Projected figure of a 2-strand transposed parallel conductor in the direction of applied magnetic field.



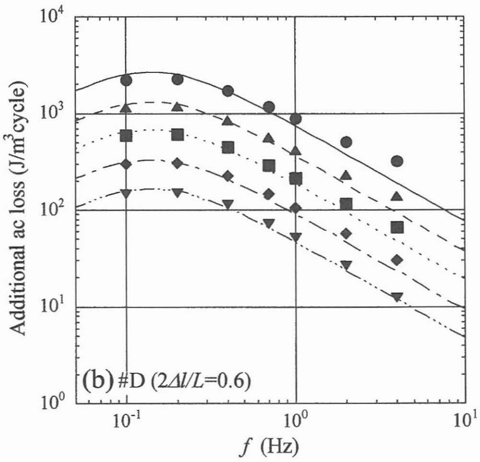


Fig.2 The additional ac losses in a 2-strand transposed parallel conductor vs (a)B_m and (b)f. The lines and symbols represent the theoretical and observed results.