§16. Increase of AC Losses for the Asymmetrically Transposed Superconducting Cable Due to the Non-uniform Current Distribution between the Strands

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Excitation experiments on a CICC coil for the Large Helical Device (LHD) were carried out to confirm its performance[1]. During these experiments, increases of AC losses were observed at low frequency region[2]. These increases of the AC losses are considered to be due to the non-uniform current distribution in the conductor caused by the asymmetrically transposed superconducting cable.

Twisted two NbTi/Cu strand cable have been used to study the effects of the non-uniform current distribution between strands on its AC losses. The specifications of the prepared samples are listed in Table I. Asymmetrically twisted cable of sample 1 is illustrated in Fig. 1. Sample 2 is normally twisted with a twist pitch of 30 mm by hand. Sample 3 is twisted with a twist pitch of 30 mm by a machine. A schematic of the experimental sample set-up is shown in Fig. 2.

AC losses have been measured electrically with the alternating external magnetic field and transport current simultaneously. The waveform of the AC transport current and the applied AC magnetic field were fixed to sine waves in these experiments.

To investigate the effect of non-uniform current distribution due to the asymmetry of the cable twist pattern on its AC losses, the normalized AC loss Q^* is estimated. In the case of an external magnetic field changing with a sine wave with a frequency f, Q^* is expressed as

$$Q^* = \pi \cdot \frac{\omega \tau_s}{1+(\omega \tau_s)^2} \qquad (1)$$

where τ_s is the time constant and $\omega = 2\pi f$.

Fig. 3 shows the frequency dependence of the normalized AC losses. An additional peak with a coupling time constant of about several seconds was expected for sample 1 corresponding to its asymmetric configuration. However, there was no clear difference as we expected that the AC loss of sample 1 is larger than that of sample 2 at the low frequency region. The reason of these similarities can be explained that twisting cable by hand strongly affects AC loss. Sample 2 was not entirely symmetric since the cable was twisted by hand. On the contrary, the frequency dependence of normalized AC losses of the two-strand cable twisted by hand are different from those of the cable twisted by a machine at low frequency region. The losses of sample 2 are greater than those of sample 3 at low frequency region. The profile of the frequency dependence of AC losses of sample 3 agrees with Debye curve, which is a theoretical curve expressed by Eq. (1). The slope of sample 2 is broader than that of sample 3 at low frequency region below 10 Hz. These AC losses include the hysteresis losses. However, the hysteresis losses of our samples are calculated and are confirmed to be negligible in the present study.

We also discussed the influences of the local loop current in asymmetrical twisted cable on its AC losses and pointed out the possibility of increase AC loss due to the inter-strand coupling loss of the asymmetric part in the cable.

TABLE I. Specifications of the prepared samples.

	Sample 1	Sample 2	Sample 3
Cabling Twist pitch	30 mm	30 mm	30 mm
The way of twisting	By hand Asymmetric (see Fig.1)	By hand symmetric	By machine symmetric
Strand diameter	0.76 mm	0.76 mm	0.89 mm
Cu/SC ratio	3.5	3.5	4.4
Filament diameter	12 μm	12 μm	14 μm
Filament twist pitch	7.8 mm	7.8 mm	9 mm
Number of Filament	864	864	750
Strand surface	Bare	Bare	Bare

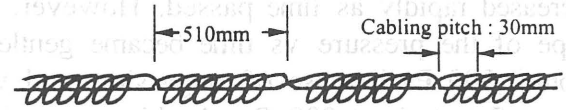

Fig. 1. Schematic of the asymmetric twisted strands.

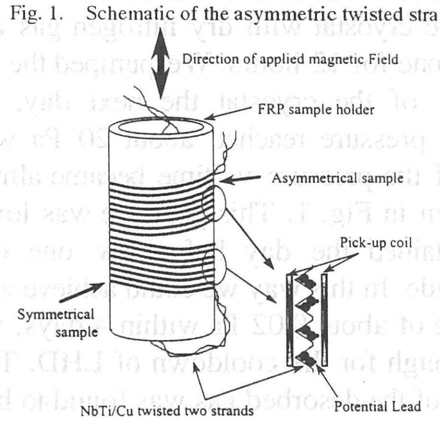

Fig. 2. Schematic of the experimental set-up.

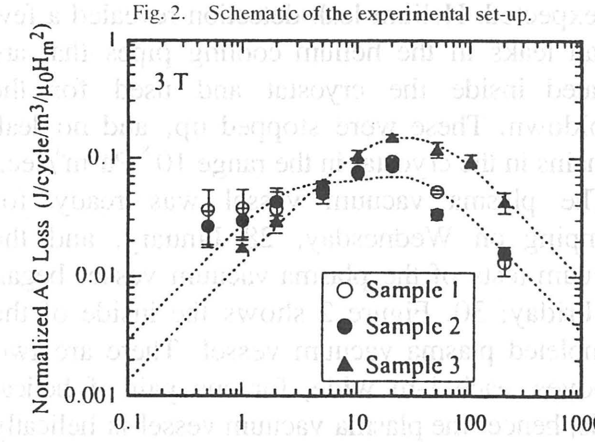

Fig. 3. Frequency dependence of normalized AC losses of the two-strand cable at the DC bias field of 3 T.

Reference
1) Takahata, K. et al.: IEEE Trans. Appl. Supercond. 7(2) (1997)477.
2) Mito, T. et al.: IEEE Trans. Appl. Supercond.7(1997)330.