Journal of the Korea Institute of Applied Superconductivity and Cryogenics
Vol.7, No.4, (2005), pp.10~13

Total AC Loss by simultaneously applied AC transport current and AC external magnetic field in BSCCO Tape

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Abstract-- **Transport current and magnetic field which is generated by transport current make AC current - AC magnetic field condition(AC-AC condition) in AC power application system using HTS tape. Therefore, characteristics of AC loss under the AC-AC condition are necessary to estimate AC loss of power device with accuracy such as HTS transformer.**

In this paper, we researched transport current loss, magnetization loss by perpendicular magnetic field and total loss which is represented as summation of both losses under the AC-AC condition in single HTS tape.

As a result, magnetization loss showed increasing behavior under 65mT and decreasing behavior upper 65mT by influence of transport current. Transport current loss was increased continuously through out whole measurement ranges in the AC-AC condition. Total loss in HTS tape was dominated entirely by magnetization loss.

1. INTRODUCTION

AC loss is one of the main research area in AC power applications using high temperature superconductor(HTS) and has been researched actively because it is related to efficiency, economic efficiency and design of HTS power device[1]-[3]. AC losses in HTS tape are mainly classified self-field loss by transport current and magnetization loss by external magnetic field. Both losses are hysteresis loss due to demagnetization characteristic of superconductor. When transport current is applied to HTS coil, magnetic field which is in-phase with transport current is generated around HTS coil. This magnetic field acts as an external magnetic field which is applying to HTS coil with various incident angles. In view of large scale, HTS coil has more complex situation than the case of only transport current or the case of only external magnetic field. Therefore, a research for AC loss by influence of transport current and influence of external magnetic field is necessary to estimate more accuracy AC loss of AC power device such as HTS transformer under AC-AC condition.

In this paper, we applied AC transport current and in-phase perpendicular external magnetic field to a single BSCCO short sample at the same time and measured transport current loss by influence of external magnetic field, magnetization loss by influence of transport current and total loss which is represented summation of both losses.

2. MEASUREMENT AND RESULTS OF AC LOSS

2.1. Measurement

The cross-section of HTS tape for measurement of AC loss is 4.1 x 0.21mm^2. Total length of short sample is 14cm and the length of voltage tap to measure transport current loss and critical current is 10cm. Measured critical current of HTS tape is 130A. Table.1 shows detail specifications of measurement.

TABLE I
SPECIFICATIONS OF MEASURMENT

HTS Tape	Length of Tape Length of voltage tap Critical current	14cm 10cm 130A(at 77K, 0T)
Sample holder	Length Diameter	20cm 17mm
Spiral loop	Length of cylinder Inner diameter Number of turn	10cm 17mm 2 turns
Transport current	Range	0~94A_{rms}
Magnetic field	Range	0~0.125T (perpendicular)

Fig.1 shows a configuration set-up to measure total loss of HTS short sample. The configuration set-up of Fig.1 is consisted of combination of transport current loss measurement set-up and magnetization loss measurement set-up. Transport current loss was measured with spiral loop tap and Linked Pick-up Coil(LPC) proposed by Z. Jiang and N. Amemiya was used for measurement of magnetization loss[4].

In this work, AC power supply for carrying current to a magnet to generate external magnetic field was controlled by a 2ch function generator as Fig.1. Reference signal of Lock-In-Amp is obtained from current which is flowing to the magnet for generating external magnetic field. An output signal from Lock-In-Amp has in-phase signal with magnet current and can flow in-phase current to the short sample as transport current. All of output signals are passed through isolation amps to avoid phase shift of output signals. A 4ch oscilloscope was also used to receive all voltage and current signals from LPC, spiral loop

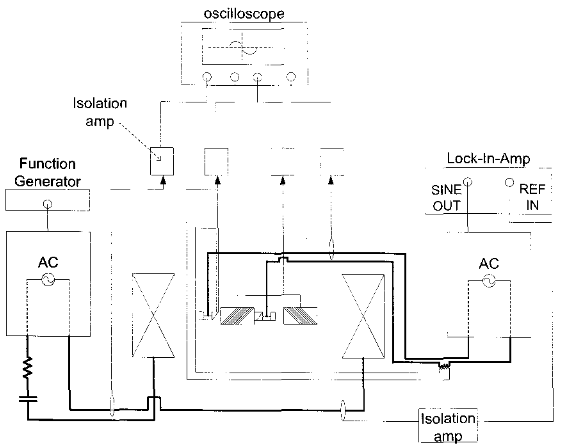

Fig. 1. Measurement configuration set-up for AC loss.

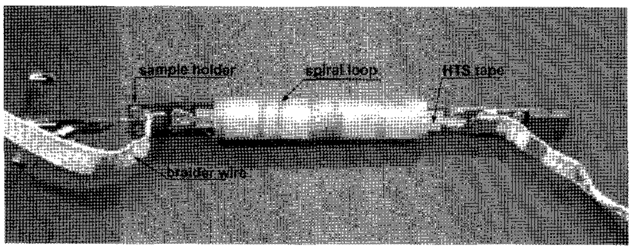

Fig. 2. Set-up of sample holder, HTS tape and spiral loop.

tap and current probes without error of time delay.

Fig.2 shows set-up of sample holder, short sample and spiral loop. A braider wire(22 x 2mm^2, 115A) to carry transport current was connected to current terminal which is placed both ends of sample holder. The braider wire is very flexible than other stranded wires and can keep flexibility under LN_2 temperature. The length of spiral loop holder and inner diameter are 10cm and 17mm, respectively. The number of turn of spiral loop is 2.

2.2. Results

Total loss of HTS tape is represented as a summation of transport current by influence of in-phase external magnetic field and magnetization loss by influence of transport current. Therefore view points of AC loss can be divided as a function of external magnetic field for various transport currents and as a function of transport current for various external magnetic fields.

2.2.1. The influence by transport current

Fig.3 represents magnetization loss as a function of external magnetic field for several transport currents. The measured data at 0A were compared with analytical results calculated by elliptical model equation which is proposed by B. Haken and showed well agreement with calculated result[5]. Magnetization loss showed decreasing tendency as increasing transport current. This decreasing tendency was begun to be seen about 65mT. This 65mT is full penettration field of single HTS tape at 0A. On the basis of 65mT, magnetization loss was increased as increasing transport current under 65mT and decreased as increasing transport current upper 65mT. We think that the tendency of Fig.3 is due to decreasing of screening current within HTS tape as increasing transport current.

Fig.4 shows transport current loss as function of external magnetic field for various transport currents. Transport current loss under external magnetic field was increased continuously as increasing external magnetic field. This tendency can be found from I_c-B_{dc} relation curve by perpendicular DC external magnetic field because increasing of DC external magnetic field causes degradation of critical current of HTS tape[6]. Generally, in case of same operating current, it also shows that transport current loss of HTS tape which has the lowest critical current is bigger than others. Therefore, we think that the tendency of Fig.4 represents same influence under AC external

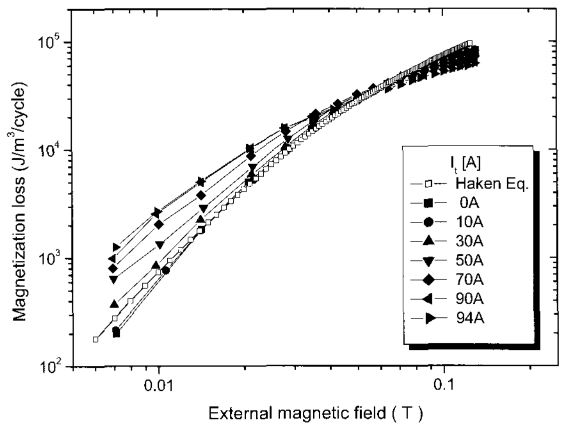

Fig. 3. Magnetization loss as a function of B_{ex} for various I_t.

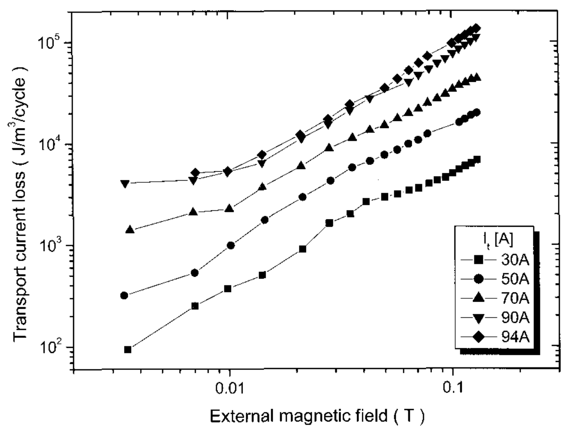

Fig. 4. Transport current loss as a function of B_{ex} for various I_t.

mag- netic field too. A flat region is showed under 10mT in Fig.4. Losses of this flat region have same amplitude with transport current loss without external magnetic field. It shows that when transport current is high close to critical current, the influence of loss by low ac external magnetic field is quiet small.

Fig.5 represents total AC loss by influences of transport

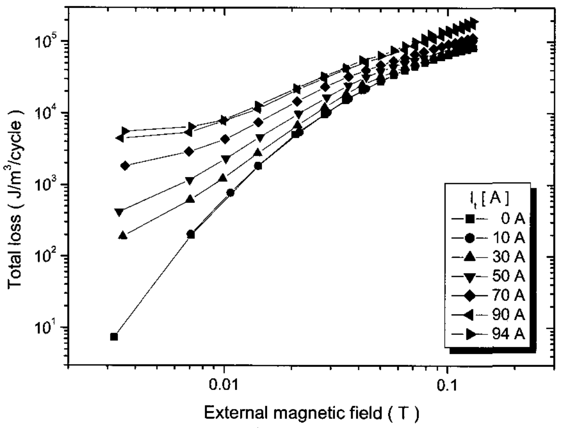

Fig. 5. Total loss as a function of B_{ex} for various I_t.

current and external magnetic field. Total AC loss in Fig.5 showed both tendencies of Fig.3 and 4 at the same time. Total AC loss didn't show decreasing behavior about 65mT as compared with Fig.3. This tendency is because that transport current loss in low external magnetic field region is smaller than magnetization loss but transport current loss in high field region has an unnegligible quantity compared with quantity of magnetization loss. Besides, when the peak value of applied transport current is reached to critical current, transport current loss has a big scale rather than that of magnetization loss. Therefore, the trend of total AC loss is to be similar to the trend of transport current loss as increasing transport current.

2.2.2. The influence by external magnetic field

Fig. 6 shows magnetization loss as a function of transport current for various external magnetic fields. Transport current loss had not influence upon mag- netization loss under 30A. Even though transport current was more increased, magnetization loss was increased slightly under 10mT but decreased upper 10mT. When both transport current and external magnetic field are increased, magnetization loss by the influence of transport current showed decreasing behavior in Fig. 6.

Fig. 7 represents transport current loss as a function of transport current for various external magnetic fields. Measurement result of transport current loss without external magnetic field showed well agreement with result of Norris's equation for elliptical model of HTS tape[7]. Overall, transport current loss by influence of external magnetic field was increased continuously for whole measurement range. Consequently, that means that transport current loss is dominated by the influence of external magnetic field.

Fig.8 represents total AC loss as a function of transport current by influence of transport current and external magnetic field. In general, total AC loss in Fig.8 showed similar tendency to that of Fig.5.

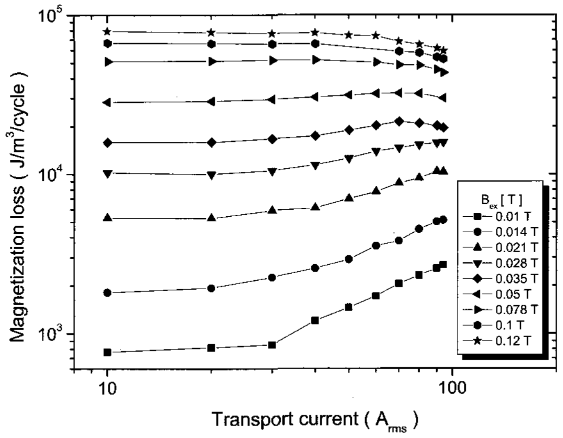

Fig. 6. Magnetization loss as a function of I_t for various B_{ex}.

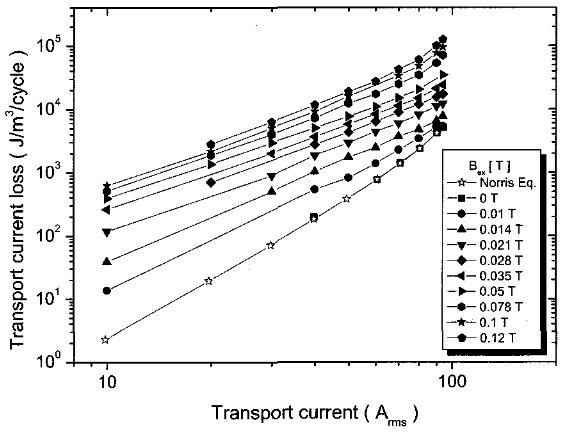

Fig. 7. Transport current loss as a function of I_t for various B_{ex}.

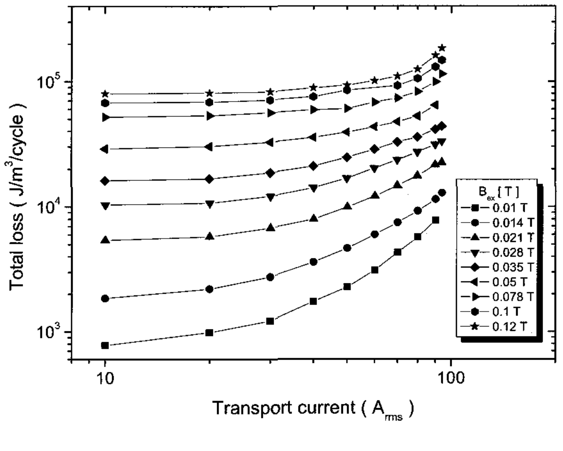

Fig. 8. Total loss as a function of I_t for various B_{ex}.

3. CONCLUSION

In this paper, we researched transport current loss, magnetization loss and total AC loss when transport current and In-phase perpendicular external magnetic field are applied to HTS tape at the same time. In view of total AC loss of HTS tape without considering degradation of I_c by external magnetic field, it seems that we can't neglect transport current loss in total AC loss because it showed bigger than magnetization loss in high external magnetic field and transport current region. But if we consider degradation of I_c by external magnetic field, AC loss of HTS tape is mainly dominated by magnetization loss. Those results can be used as background data to estimate AC loss more accurately in various coil systems.

ACKNOWLEDGMENT

This research was supported by a grant from Centre for Applied Superconductivity Technology of the 21st Century Frontier R&D Program founded by the Ministry of Science and Technology, Republic of Korea.

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