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Measurement of AC loss characteristics of HTS sample coils under the conditions assumed for use in power electronics devices

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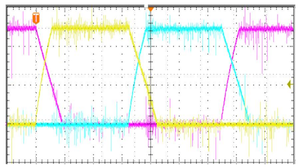
Background

From the viewpoint of expanding application areas of superconducting technology, it is important to examine the applicability of superconducting technology to fields of industrial applications such as linear conveyor, transfer, and transport systems.

Since inverters are used in the drive circuit of power electronics devices in a linear transfer system and so on, the drive current contains harmonic components, and then it is expected that AC losses increase. So, it is necessary to investigate the effect of harmonic components on the AC loss characteristics.



Typical current waveform of LSRM

objectives

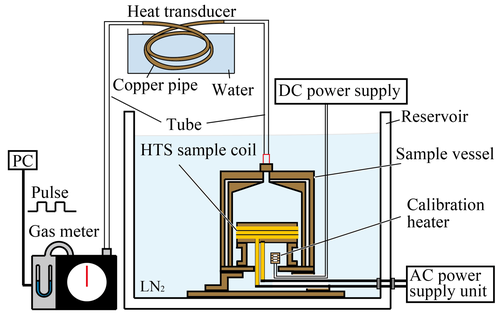
The purpose of this study is to elucidate the AC loss characteristics of HTS coils under conditions assumed for use in power electronics devices.

In this study, we measured AC loss characteristics of the HTS sample coil by the nitrogen boil-off method under various conditions in which the amplitude and frequency of the harmonic current were changed.

Experimental Setup

AC Loss Measurement

Liquid Nitrogen boil-off method

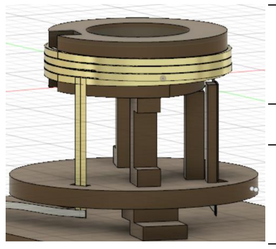


Convert gas flow rate to heat value

$$Q = 2.42 \times 10^2 M \frac{273}{T_M}$$

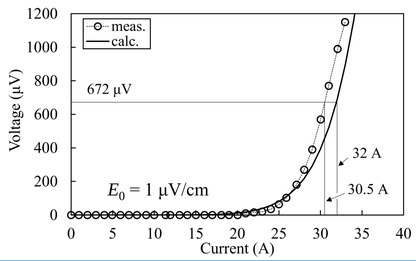
Q [W] : calorific value
M [ℓ/s] : gas flow rate
T_M [K] : gas temperature

HTS sample coil

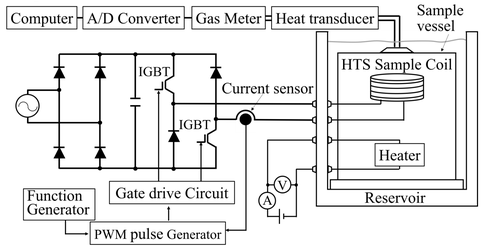


Bi-2223 Tape	
I_c@77 K,s.f.	56 A
Width	2.9 mm
Thickness	0.36 mm
HTS Sample coil	
Inner dia.	40 mm
Turns	3
Layer	30

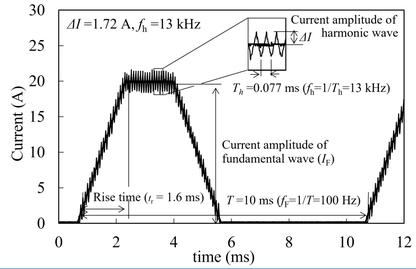
HTS Sample coil *I-V* characteristics



Experimental circuit

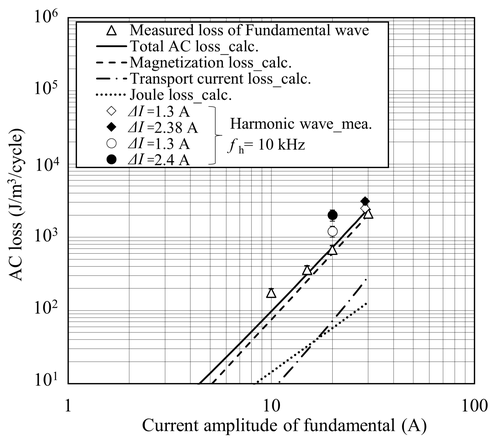


Waveform of transport current



Experimental Results

Measured AC loss and calculation of total AC loss of fundamental wave



Calculation of total AC loss

Total AC loss is the sum of these

Magnetization loss (W_m)

$$W_m = \mu_0 {H_0}^2 \frac{{C_1}{h_m}^3}{\left(\frac{C_1}{C_2}\right){h_m}^2 + 1} T'$$

$$T' = \frac{1}{2} \times \frac{2t_r}{T}$$

T' is the coefficient of the one-swing trapezoidal wave
C_1 , C_2 : coefficients
$H_0 : j_c(ab)^{-1/2}$
a :major axis, b :minor axis
$h_m : H_m / H_0$

Transport current loss (W_t)

$$W_t = \frac{\mu_0 {I_c}^2}{\pi S}\left[(1-i_m)\ln(1-i_m) + \frac{(2-i_m)i_m}{2}\right] T'$$

I_c : critical current
i_m : transport current
S : Cross-sectional area (Bi-2223 tape)

Joule loss (W_j)

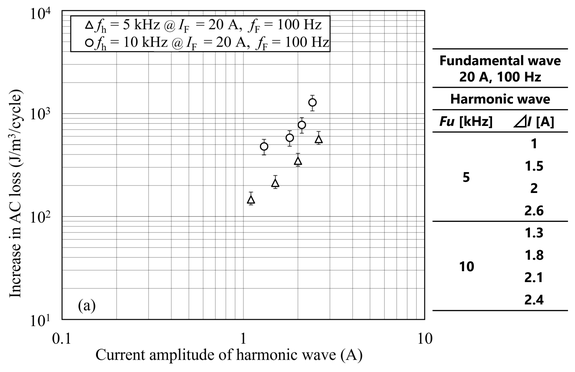
$$W_j = R {I_m}^2$$

R : connection resistance 83.9 μΩ@ 77 K

Experimental Results & Discussion

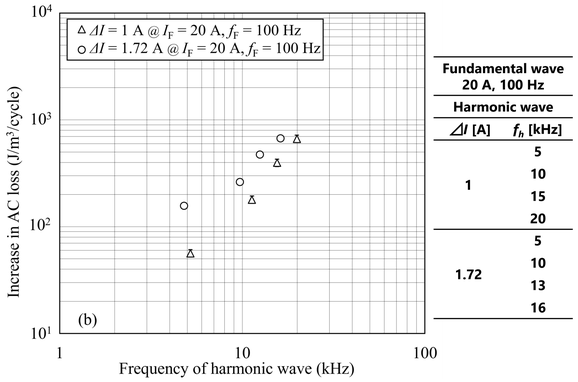
Extraction of only the increase in AC loss due to harmonic components

Harmonic current amplitude dependence of AC losses



Fundamental wave 20 A, 100 Hz	
Harmonic wave	
***Fu* [kHz]**	**ΔI [A]**
5	1
	1.5
	2
	2.6
10	1.3
	1.8
	2.1
	2.4

Harmonic frequency dependence of AC losses

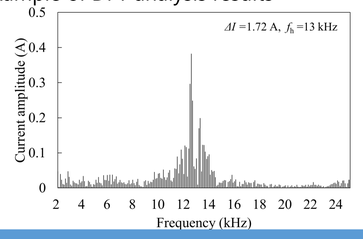


Fundamental wave 20 A, 100 Hz	
Harmonic wave	
ΔI [A]	**f_h [kHz]**
1	5
	10
	15
	20
1.72	5
	10
	13
	16

※[J/m³/cycle] : Fundamental wave 1 cycle, per unit volume

DFT analysis of current waveform

An example of DFT analysis results



Using these results, eddy current loss was calculatec

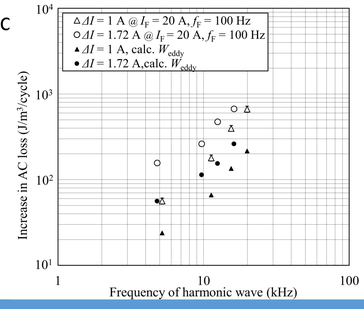
Eddy current loss (W_{eddy})

$$W_{eddy} = 2\pi \frac{r_2^2}{r_2^2 - r_1^2}\left(\frac{f_h}{f_e'}\right)^{-\frac{1}{2}} \mu_0 H_m^2 f_h S' l \qquad f_e' < f_h \le f_{h\_5th}$$

to sum

f_e' : cutoff frequency, r_1,r_2 : coefficients, H_m: experienced magnetic field
S' : Cross-sectional area (silver sheath), l: Wire length

The slope is nearly equal to the measured value.
But the value was smaller.



Conclusion

- To elucidate AC loss characteristics of HTS coils under conditions assumed for use in power electronics devices, we measured AC losses of the Bi-2223 sample coil under various conditions by a nitrogen boil-off method.
- Since measured results and the calculated results of AC losses at fundamental wave were in good agreement, our measurement system found that the AC loss can be measured with sufficient accuracy.
- By measuring using power electronic circuits, we found that AC losses increased in proportion to the square of the harmonic current amplitude and increased in proportion to the square of the harmonic frequency.