AC core loss measurement on high phase angle material

Power Magnetics @ High Frequency – Eliminating the Smoke and Mirrors
Technology Demonstration Session
on 3rd March, 2018

Iwatsu Electric Company Limited
Ryu Nagahama
PRODUCTS OF IWATSU ELECTRIC

PRODUCTS (Test and Measurement Business)

- B-H Analyzer
- Digital Oscilloscope
- Curve Tracer
- Isolation System up to 500MHz BW
- Basic Measurement (DMM, Counter, Signal Generator)
- Isolation Probe
- Current and Voltage Probe
Think Important Issue for Power Loss Measurement

• Measuring method
  – Excitation method ?
    – Power Analyzer
    – B-H Analyzer
    – Digitizer

  – Condition
    – Temperature ?
    – Humidity ?
1. Power Loss Measurement by Power Analyzer
1.1 Issues in low power factor of the power measurement

When close to the power factor = 0, $P_c = I_{rms} \cdot V_{rms} \cdot \cos \theta$

Maximum of the power error at zero power factor.

Reference N4L Application
1.2 Power Analyzer Accuracy

![Power Analyzer Image]

### Summary report

Verify power measurement at different phase angles at 220V 5A

<table>
<thead>
<tr>
<th>frequency</th>
<th>applied</th>
<th>phase 1</th>
<th>phase 2</th>
<th>phase 3</th>
<th>deviation</th>
<th>spec</th>
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<tbody>
<tr>
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1.3 Reactor loss Measurement

![Graph showing power loss and phase angle versus current.](image)

**Power Loss (W)**

**Phase (deg)**

**Precision Power Analyzer**

**Power Analyzer**

- **PH1**: 14.431 W
- **PH2**: 1.254 kW
- **PH3**: 49.935 V
- **I**: 25.116 A
- **freq**: 11.00 kHz
- **V**: 100 V
- **W**: 2.20 Hz
1.4 Power Analyzer Accuracy for Reactor loss error

- Sin wave accuracy on the Voltage
  - 0.01% Rdg+0.038% Rng+(0.004% × kHz Rdg)+5mV
- Sin wave accuracy on the Current
  0.01% Rdg+0.038% Rng+(0.004% × kHz Rdg)+300μA
- Sin wave accuracy on the Power
  - 10mHz-2MHz [0.03%+0.03%/pf+(0.005% × kHz)/pf] Rdg+0.03%VA Rng
  - 40-850Hz [0.03%+0.03%/pf+(0.005% × kHz)/pf] Rdg+0.03%VA Rng

- Fourier series expansion for square
  \[ f(x) = \frac{4}{\pi} \left\{ \sin(x) + \frac{1}{3} \sin(3x) + \frac{1}{5} \sin(5x) + \frac{1}{7} \sin(7x) + \cdots \right\} \]
- Fourier series expansion for triangle
  \[ f(x) = \frac{8}{\pi} \left\{ \sin(x) + \frac{1}{9} \sin(3x) + \frac{1}{25} \sin(5x) + \frac{1}{49} \sin(7x) + \cdots \right\} \]

The deskew can not be highly accurate measurement.
In this case, it can be measured by high accuracy measurement.
Core loss $P_c$ when Current $I$ and Voltage $V$ are single sine waves;

$$P_c = I_{rms} \cdot V_{rms} \cdot \cos \theta$$

1.5 It is difficult to measure “Zero”. ~A problem in evaluating loss of low loss materials~

Relation between Phase error and loss measurement value error
2. Power Loss Measurement by B-H Analyzer
2.1 The principles of High-precision Core loss Measurement

- Standard: IEC 62044-3
- Japanese Industrial Standards (JIS)

SY-8218/19 adopts CROSS-POWER method that the Standards above employ.
2.2 What is the measurement principle of AC magnetic property?

Core loss per volume

\[ P_{cv} = \frac{1}{A_c L_c} \frac{N_1}{N_2} \cdot f \cdot \int_0^T i_1(t) \cdot V_2(t) dt \]

\[ = f \cdot \int_c H(t) \cdot \frac{dB(t)}{dt} dt \]

Magnetic field strength

\[ H(t) = \frac{N_1 \cdot i_1(t)}{L_c} = \frac{N_1 \cdot V_s(t)}{L_c \cdot R_s} \]

Lc; Effective length of magnetic path

Ac; Effective cross-section area

\[ B(t) = \frac{1}{N_2 \cdot A_c} \int V_2(t) dt \]
2.3 Comparison of Core loss measurement by presence or absence of phase correction

There are 20% error in Power Core loss between Digitizer and Cross-Power method when the frequency is around 500kHz. This is because the frequency property between current detection resistor and each detection circuit is not compensated at the frequency axis under the Digitizer method.

CROSS-POWER method realizes the high-precision measurement. CROSS-POWER method is adopted in IEC 62044-3.

Data by Metropolitan University
2.4 What is CROSS-POWER method?
2.5 Comparison between Digitizer method and CROSS-POWER method

1. Both Digitizer and CROSS-POWER methods capture excitation current waveforms and inductive voltage waveforms through time sampling as the time axis waveforms (sampling data). However, these two methods are distinguished by the way of dealing with the time axis waveforms.

2. Digitizer method executes the time integration calculation directly as the time axis waveforms.

3. CROSS-POWER method, on the other idea
   (1) converts the time axis waveforms into the frequency spectrum and executes integral calculation with no phase difference and compensates the amplitude and the phase error of current detection sensor.
   (2) executes the compensation of the amplitude and the phase property of the detection circuit on the frequency axis.
   (3) captures the time axis waveforms with little error by returning the frequency spectrum having the error compensation to the time axis waveforms.
2.6 B-H / Core loss measurement

- **B-H Analysis**

  - **Core Loss Feature**
    - **Excitation condition**
    - Change in Temperature
    - Evaluation under a condition equal to an actual use condition

  - **PC40 20T Pcv [Sample]**

  ![Graph showing B-H analysis and core loss measurement results.](image-url)
2.7 B-H / Core loss measurement

-30°C ~ 150°C
2.8 Constant Temperature Chamber Scanner System

- Control PC
- Power Amplifier IE-1125A (350VA, 140V, 5.2A)
- B-H Analyzer SY-8219 (10Hz ~ 1MHz)
- Constant Temperature Chamber Scanner System
  - Temperature: -30 to +150°C
  - Samples: Max. 41pcs
- Turn tables
  - SY-510: No. of samples Max. 20pcs
  - SY-511: No. of samples Max. 41pcs

Products to be shipped:

- Control PC
- Power Amplifier IE-1125A
- B-H Analyzer SY-8219
- Constant Temperature Chamber Scanner System
- Turn tables SY-510 and SY-511

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2.9 Is the target Magnetic field (Current) or Flux density (Voltage) ?

1. Hm designated method:
   Designate Hm (Max. Magnetic field)

2. Bm designated method:
   Designate Bm (Max. flux density)

3. Current designated method:
   Designate Excitation current

4. Voltage designated method:
   Designate Inductive voltage
2.10 Hm method

a. Keep measurement frequency constant and excite the sample slowly.

b. Capture the excitation current waveform and the inductive voltage waveform and calculate magnetic field waveform by the excitation current waveform.

c. Adjust the output voltage of power amplifier manually or automatically so that the maximum value is within the tolerance level of the targeted magnet field.

d. After the adjustment, calculate the saturation magnetic flux density $B_s$, etc. with B-H curve calculated from magnetic field waveform and magnetic flux density.

e. This method is suitable for the measurement of saturation property such as saturation magnetic flux density, residual magnetic flux and coercive force.
2.11 Bm method

a. Keep measurement frequency constant and excite the sample slowly.

b. Capture the excitation current waveform and the inductive voltage waveform, and calculate magnetic field waveform by time integration of inductive voltage waveform.

c. Adjust the output voltage of power amplifier manually or automatically so that the maximum value is within the targeted magnet flux density Bm.

d. After the adjustment, calculate time integration of multiplication of excitation current waveform by inductive voltage waveform, and then calculate core loss.

e. Calculate the phase angle by the ratio between Core loss and Appearance power, and the permeability at Max. magnetic field Hm via Max. magnetic field and Max. flux density, i.e. the amplitude ratio of permeability respectively.

f. This method is suitable for the measurement of property for the large amplitude such as core loss, amplitude ratio of permeability, phase angle, etc.
2.12 Outline of DC bias tester

- **Fully-automatic control** is available with SY-8219 and future B-H series.
- Continuously-variable current value is available.
- DC bias non-sine wave (chopper excitation) is also available.
- DC bias current of Max.30[A] is supported.
- Ripple current of Max.5[A] is supported.
- Measurement frequency: Max.3MHz (sine wave)
- Measurement frequency: Max.1MHz (Chopper excitation)

Main target is SMD power inductor!
Toroidal is supported, of course!
DC bias non-sine wave

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30 [A]
5 [Apk]
2.13 Measurement method when DC bias is overlapped with toroidal core

- $i_1(t)$: Number of primary winding
- $N_1$: Number of primary winding
- $N_2$: Number of secondary winding
- $N_3$: Number of tertiary winding
- $v_2(t)$
- $v_S(t)$
- $R_S$
- Sine wave oscillator
- The excitation frequency
- DC current generator
- Toroidal core
- DC

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2.14 Measurement method when DC bias is overlapped with a chip inductor

Mathematical equations:

\[ i_1(t) \]

Capacitor

\[ N_1: \text{Number of primary winding} \]

Sine wave oscillator

\[ f \]

The excitation frequency

\[ R_S \]

\[ v_S(t) \]

\[ v_2(t) \]

Chip inductor

Capacitor

DC generator

SY-931 DC current generator

2.14 Measurement method when DC bias is overlapped with a chip inductor

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2.15 An measurement example of DC bias tester on chip inductor measurement (Pulse excitation)
2.16 Chip Inductor
2.17 Toroidal Core Inductor
2.18 DC-Bias System

Pulse & Sinusoidal with DC biasing
Setting Measurement Conditions

Full automatic test

Winding a coil
Future Events and Contact us

Contact Us
IWATSU ELECTRIC CO., LTD.
Overseas Sales Sect. Sales Dept. No.2,
7-41, Kugayama 1-Chome, Suginami-ku, Tokyo, 168-8501 Japan
TEL : +81-3-5370-5483
FAX : +81-3-5370-5492