IEEE PELS
PELS Standards
Overview of
ETTC & IEC TC51 Standards
for Magnetic Core Loss Testing

2023 August 17

Energy Innovation Center, Pittsburgh, PA

IEEE POWER ELECTRONICS SOCIETY
Powering a Sustainable Future

IEEE
Advancing Technology for Humanity

Background Info on Working Groups
(ETTC Vs IEC TC51)

- Electronics Transformers Technical Committee (ETTC)
  - Low Power: $P_{OUT} \leq 10$ Kilo-watts
  - Wide Frequency: (F > 1 Hz)
  - Low Voltage: $V_{WORKING}$ <1 kV
- IEC TC51- Magnetic components, ferrite and magnetic powder material
  - Focus on higher frequencies: F ≥10 kHz
  - Lower currents: I ≤ 125A
  - Lower voltages: $V_{WORKING}$ <1 kV
  - To prepare standards relating to:
    - parts and components displaying magnetic properties and intended for electronics in a wide range of application areas, including telecommunications, computers, automotive, aircraft, audio-visual, digital camera, lighting, solar and wind power systems, welding, inductive heating, power conditioning (UPS), wireless charging, RFID and medical;
    - parts associated with such components;
    - measuring methods and tests, and specifications for transformers and inductors using such components;
    - ferrite and magnetic powder materials.

IEEE PELS ETTC / IEC TC51
(Active Standards Reference For Core Loss testing)

1. IEEE-393 Procedure for Testing Magnetic Cores
   A. Updated standard targeted for 2025Q1
2. IEC62024-3 ED1: High frequency inductive components – Electrical characteristics and measuring methods – Part 3: AC loss measured by sinusoidal wave of inductors for DC-to-DC converters
   A. Publication targeted for 2026Q1
3. IEC62044-3 ED2: Cores made of soft magnetic materials measuring methods – Part 3: Magnetic properties at high excitation levels
   A. ED2 to be published 2023Q3
4. IEC63300 Test methods for electrical and magnetic properties of magnetic cores
   A. To be published 2023Q3

Standards for Magnetic Characterization
(Material Vs Core Vs Component)

A. Material
   A. Comparisons Between Materials Not Structures
   B. Toroids of Fixed Physical Dimensions
   C. Sized to Avoid Impact of Physical Dimensions, etc.,
      i. For example, ratio of outside diameter to inside diameter
   D. Test Coils Turns and Conductor Size, Distribution of Winding
   E. Closed Magnetic Path
   F. Continuous Magnetic Path - No Discrete or Intrinsic Physical Air Gaps
B. Core
   A. Specific to Magnetic Material, Structure, Physical Dimensions, Gap
   B. Specific to Test Coils
      i. Agreed upon test coils
      ii. Fill factors
      iii. Leakage flux
   C. Impact of Discrete Physical Air Gaps, Intrinsic Air Gaps and Distributed Air Gaps

Standards for Magnetic Characterization
(Core Vs Component)

B. Core
   A. Specific to Magnetic Material, Structure, Physical Dimensions, Gap
   B. Specific to Test Coils
      i. Agreed upon test coils
      ii. Fill factors
      iii. Leakage flux
   C. Impact of Discrete Physical Air Gaps, Intrinsic Gaps and Distributed Air Gaps

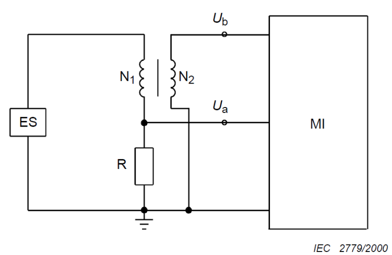
C. Component
   A. Total Power Loss
   B. Specific to Component Fabrication
      A. In most cases different from test coils used for measurements of core parameters
   C. Coil Contribution On Power Loss Measurements
      i. Fringing
      A. Leakage flux
   D. Impact of discrete physical air gaps

IEC 62044-3 ED1

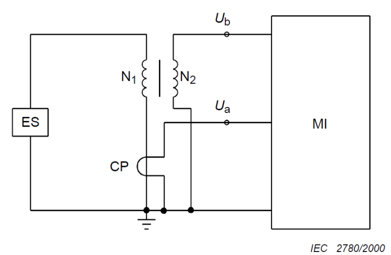
(Magnetic properties at high excitation level)

Table 1 – Some multiplying methods and related domains of excitation waveforms, acquisition, processing

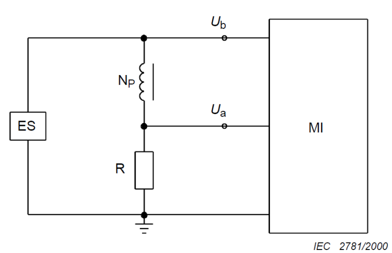
Measuring method	Domain of			Subclause of Annex C
	useable excitation waveform	acquisition	processing	
V-A-W meter	Sinusoidal	Time	Time	C.5
Impedance analyzer	Sinusoidal	Not applicable	Not applicable	C.6
Digitizing	Arbitrary	Time	Time	C.7
Vector spectrum	Arbitrary	Frequency	Frequency	C.8
Cross-power	Arbitrary	Time	Frequency	C.9



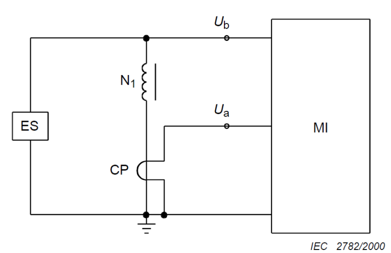
Circuit a)



Circuit b)



Circuit c)



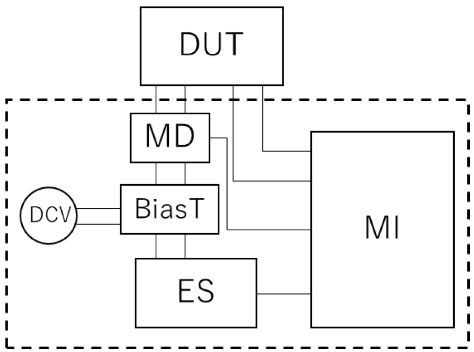
Circuit d)

IEC 62024-3 ED1

(AC loss measured by sinusoidal wave of inductors for DC-DC Converters)

Table 1 – AC loss measuring method

Measuring method	Connection method	Frequency range	Impedance range
BH analyzer method	-	10 kHz to 10 MHz	0,1 Ω to 10 kΩ
Vector network analyzer method	Shunt	100 kHz to 200 MHz	1 Ω to 100 Ω
	Series	100 kHz to 200 MHz	10 Ω to 10 kΩ



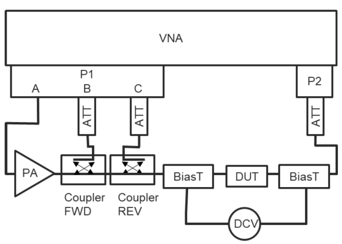
MI Measuring instruments

ES Excitation source

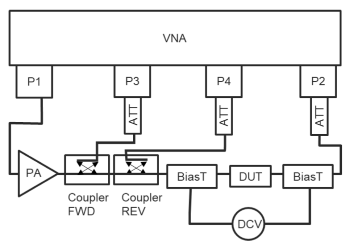
MD Measuring device

DCV DC bias current source

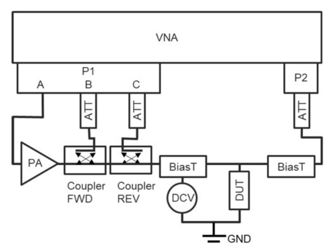
Bias T Bias T to connect DC bias current source



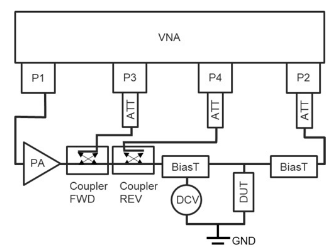
a) 2-way coupler/ 2-port VNA / Series



b) 2-way coupler/ multiport VNA / Series



e) 2-way coupler/ 2-port VNA / Shunt



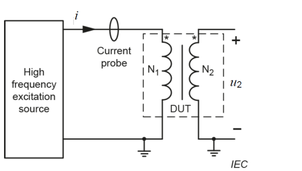
f) 2-way coupler/ multiport VNA / Shunt

IEC 63300 ED1

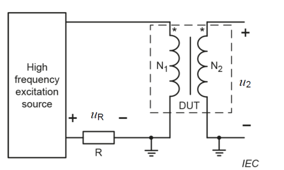
(Test methods for electrical and magnetic properties of magnetic powder cores)

Table 1 – Comparisons of measuring methods for power loss

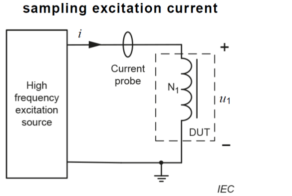
Measuring method	Excitation waveform	Source required	Separation of source losses	Separation of winding losses	Influence of impedance angle	Influence of frequency	Annex
AC power method	arbitrary	high frequency and high power capacity AC	no	yes (with dual windings)	yes	yes	Annex A
DC power method	square or PWM	constant voltage DC	yes	no	no	yes	Annex B
Calorimetric method	arbitrary	any	no	no	no	no	Annex C



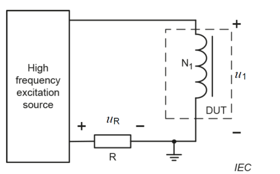
a) **Sample of dual winding and current probe for sampling excitation current**



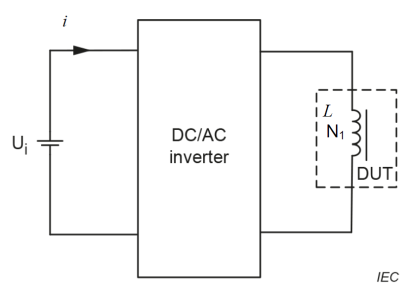
b) **Sample of dual winding and resistor for sampling excitation current**

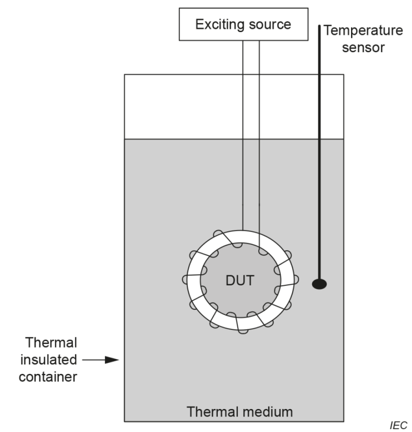


c) **Sample of single winding and current probe for sampling excitation current**



d) **Sample of single winding and resistor for sampling excitation current**





IEEE POWER ELECTRONICS SOCIETY
Powering a Sustainable Future

IEEE Advancing Technology for Humanity

IEC 63300 ED1
(Test considerations for current measuring resistor)

4.4.1 Sampling resistor

The error of the resistance of the sampling resistor shall be less than 0,1 % (including the temperature drift of resistance). The parasitic inductance of the sampling resistor shall meet both Formula (4) and Formula (5).

$$L \leq \frac{R}{2 \times \pi \times f} \sqrt{2 \times \delta_a} \tag{4}$$

$$L \leq \frac{R \times \tan(\delta_\varphi)}{2 \times \pi \times f} \tag{5}$$

where

L is the parasitic inductance of the sampling resistor, in henrys (H);

R is the resistance of the sampling resistor, in ohms (Ω);

δ_a is the allowable relative error of the voltage drop across the sampling resistor at the test frequency (no unit);

δ_φ is the phase difference of voltage and current on the sampling resistor at the test frequency, in radians (rad).

EXAMPLE

For δ_a = 0,1 %, δ_φ = 4,363 × 10^{-4} rad = 0,025°, R = 1 Ω, f = 500 kHz, then:

$$L \leq \frac{1}{2 \times \pi \times 500 \times 10^3} \sqrt{2 \times 0{,}001} = 14{,}2 \text{ nH} \tag{6}$$

$$L \leq \frac{1 \times \tan(0{,}025^\circ)}{2 \times \pi \times 500 \times 10^3} = 0{,}139 \text{ nH} \tag{7}$$

IEC 63300 ED1

(Test considerations for measurement equipment)

4.3 Measuring equipment

4.3.1 General provisions

Voltage meter or voltage-measuring equipment shall be of high internal impedance. In order to reduce measurement error, probes shall be of high input impedance. Additionally, the bandwidth of the voltage meter or voltage-measuring equipment shall cover the frequency of harmonics whose amplitude is 1 % of the amplitude of the fundamental wave.

4.3.2 Voltmeter

In order to measure the RMS, average value and peak value of the excitation voltage accurately, a voltmeter with accuracy of 0,2 % is recommended.

4.3.3 Data acquisition unit

In order to measure the RMS, average value and peak value of the excitation voltage accurately, the sampling rate of the data acquisition unit shall be not less than 256 points per cycle, and the resolution shall be not less than 12 bits.

IEEE 393

(Considerations for specific test methods)

Method Description	Measurement Parameters					Post Processing			Waveforms			Product Development Stage	Frequency Range
	V	I	T	Θ	F	P_{AVG}	$\int(P_{INST})$	FFT	Type	Drive	Measuring		
Wattmeter													
V-A-W Ballistic	X	X			S	X			Sine			Both?	≤ 1 kHz
V-A-W Analog	X	X		X	S	X			Sine/Rectangular			Quality Conformance	≤ 1 MHz
V-A-W Digital	X	X		X	S	X			Sine/Rectangular			Quality Conformance	≤ 10 MHz
Cross Power	X	X		X	M		X	X	Any			Quality Conformance	≤ 10 MHz
Impedance													
Impedance Analyser	X	X		X	S	X			Sine			Both?	≤ 100 MHz
Spectrum Analyser (VNA?)	X	X		X	M	X		X	Sine			Both?	≤ 1000 MHz
Reactive Power Compensation													
Resonant VV	X, X				S	X			Sine			Material Characterization	1 MHz - 100 MHz
Resonant VA	X	X			S	X			Sine			Material Characterization	1 MHz - 100 MHz
Capacitive Compensation													
Inductive Compensation													
Pulse Methods													
Single Pulse	X	X	X		N	X			Damped Sine			Material Characterization ?	NA
Triple Pulse	X	X	X		N	X			Damped Sine			Material Characterization ?	NA
Caloriometric									Any		Thermocouple	Material Characterization	≤ 1000 MHz
open type balance													
double jacket closed													
heat flux sensor													
vacuum													
two chamber compennsation													
Bridge measurments												Quality Conformance	< 1 kHz
Oscilloscope - tool - Not a method	X	X	X		S		X		Any			QC Sampling	≤ 25 MHz

1. Further categorize applicability of test for
   A. Research
   B. Design verification
   C. Product verification
   D. Reliability
   E. Manufacturing

IEEE POWER ELECTRONICS SOCIETY
Powering a Sustainable Future

IEEE Advancing Technology for Humanity

Curve Fits From Measurement Data Ranges

(Some Typical Guidelines)

$$P_{AC} = KB^{a} f^{b}$$

- Frequency
  - Target operating frequencies should be **within** range of measurement frequencies
    - Including major harmonics
  - If the raw measurements indicate deviation from linear on log-log plot
    - Frequency exponent will be encompassing multiple frequency range behaviors
- Flux Density – Volt Seconds – Peak to Peak Current
  - Target operating conditions should be within range of measurement frequencies
  - If the raw measurements indicate deviation from linear on ln-ln plot
    - Frequency exponent will be encompassing multiple frequency range behaviors
- Bias
  - Minor Loops in non-linear region of major BH loop have different power loss than minor loops in linear region of major BH loop
- Temperature
  - Maintain constant temperature via
    - Heat Sink – Verify that heat sink does not impact fringing effects
    - Forced Air

Core Data eXchange Format (CDX)
(Proposal in Process)

CDX – Core Data eXchange format

variables

- By file
  - Material
  - Core size
  - Core shape
  - Waveform
  - Frequency
  - Duty cycle
  - Flux density
  - Dc bias offset
  - Temperature
  - Error band
  - Test setup
  - Who, what, where, when

- Per file
  - Waveform points
    - Voltage(s)
    - Current
  - B-H loop
    - Flux density
    - Field intensity
  - Loss

metadata

- Test method used
- Test excitation parameters
- Waveform (sine or as data points)
- Equipment used
- Who done it
- Where was it done
- When was it done

- Test Coil Details
  - Turns
  - Wire Size
  - Winding technique

Magnetic Characterization In General
(Publicly Available Reference Information)

- PSMA Magnetics Committee Technical Forum
  - https://www.psma.com/technical-forums/magnetics
- Workshop Presentations
  - 2016 Magnetics Workshop
  - 2017 Magnetics Workshop
  - 2018 Magnetics Workshop
  - 2019 Magnetics Workshop
  - 2020 Magnetics Workshop
  - 2021 Magnetics Workshop
  - 2022 Magnetics Workshop
- Industry Session Presentations
  - https://www.psma.com/technical-forums/magnetics/presentations
- PSSMA Core Loss Studies
  - https://www.psma.com/coreloss

Summary

- Measurement details are different for material testing, magnetic core testing and magnetic component testing
- Magnetic core specifications must be specific to magnetic material, structure, physical dimensions and any intrinsic or introduced physical gap or distributed gap – must reference the test coil
- Standard test procedures tend to try to be agnostic relative magnetic materials, magnetic structure and component assembly
  - However, is circumstances warrant standards, recommended practices or guidelines can be developed for specific materials and structures
- Since we are actively updating standards for core loss measurements (cores) and ac power loss measurements (components) – we need your inputs to guide the next releases

ETTC/IEC TC51

(Reference Standards for Core Loss Testing)

Thank You