

Survey of Core Loss Test Methods

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Core loss testing: difficult and important



- Nonlinear behavior requires:
 - Large-signal testing
 - Testing with bias
 - Understanding or testing the influence of the waveform shape.
- High Q (low-loss) measurements are difficult.
 - Especially at high frequency.

Types of core loss measurements



- Calorimetric measurements
 - Can be slow
 - Difficult, but possible, to do accurately
 - Sometimes retain accuracy where electrical measurements lose accuracy
 - Independent check on electrical measurements
- Electrical measurements
 - Conventional four-wire
 - Resonant methods

Calorimetric methods

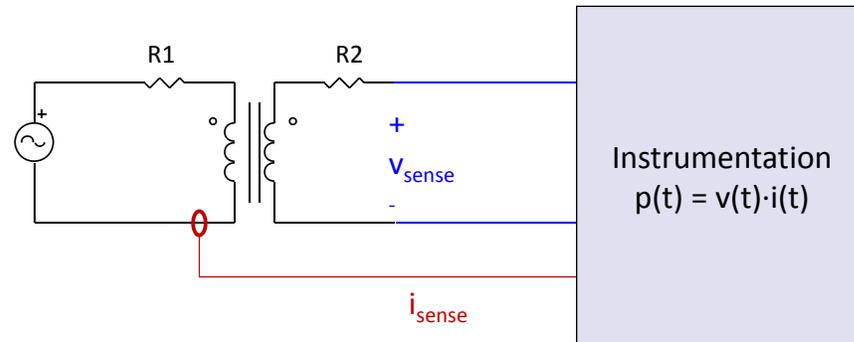


- Methods:
 - Steady-state temperature rise
 - dT/dt
 - Heat flux sensor: ΔT across a thermal resistor: equivalent of a current sense resistor.
 - Liquid coolant: flow and temperature rise
- Issues:
 - Dissipation in winding is included
 - Isolation: insulation and/or guarding
 - Lead wires

Electrical measurements



- Conventional two-winding measurement

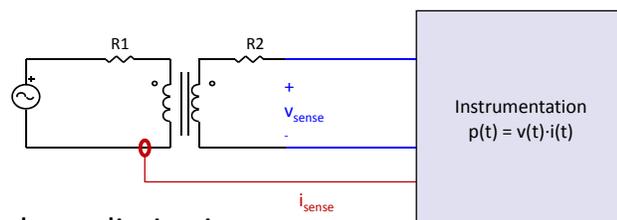


- Theory:
 - Voltage drop on R1 doesn't appear in measurement.
 - No current, and so no voltage drop, on R2.

Electrical measurements: Source options



- Sinusoidal oscillator with amplifier.
- Square-wave or other oscillator with amplifier.
 - Rise time and output impedance limitations.
- Power converter, e.g. full bridge.
 - Fast edges.
 - Stiff voltage source.
 - Example: Dartmouth PSMA core loss studies:
 - Programmable pulse generator.
 - Digital control of power supply bus voltage.
 - Automatic sequence of waveforms.



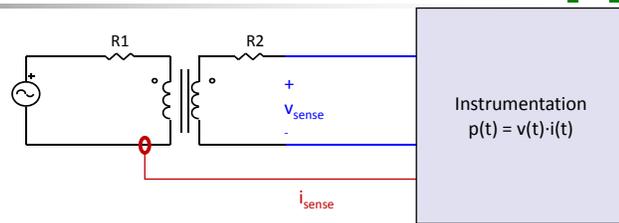
Electrical measurements: Instrumentation options



■ Current sensing:

■ Options:

- Shunt
- Current transformer
- Rogowski coil
- Wideband DC current probe.



■ Critical for any of these: bandwidth and delay (phase shift)

■ Power instrumentation: phase shift also critical

- Power meter
- Oscilloscope
 - On board power calculation.
 - Data acquisition; loss calculation off line.

Effect of phase error and delay



■ Fractional error in loss = $Q \Delta\phi$

where Q is quality factor of the core and $\Delta\phi$ is the phase error in radians.

- Example: $Q = 25$, 1° phase error \rightarrow 44% error!

■ Uncompensated delay translates to phase error.

- 1 ns delay is 0.36° at 1 MHz; 3.6° at 10 MHz;

■ Double jeopardy at HF (3~30 MHz frequencies):

- Small delay becomes intolerable phase shift.
- Low-permeability materials \rightarrow high Q .



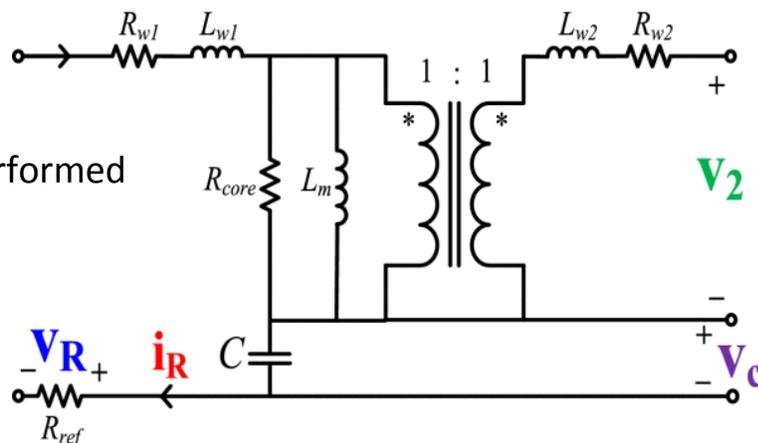
Resonant methods

- Virginia Tech resonant-corrected two-winding measurements.
 - Reduces sensitivity to phase errors by cancelling reactive impedance and reducing effective Q .
- MIT/Dartmouth direct Q measurement.
 - Eliminates sensitivity to phase errors—measure only voltage amplitudes, ignoring phase information.
- Papers provide detailed error analysis for each.

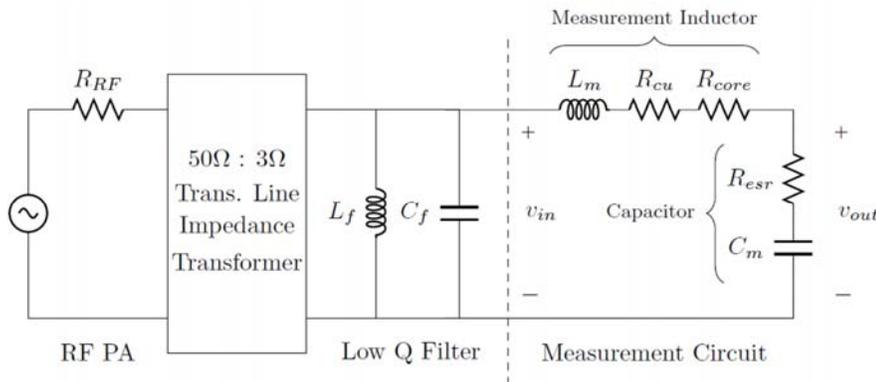


Virginia Tech Resonant Methods

- V_C is used to cancel reactive component of V_2
- This version (T. Pow. Elr. April 2017):
 - Doesn't require tuning cap value.
 - Cancellation performed off line.
 - Inductive version for non-sinusoidal waveforms.



MIT resonant method



- Must be tuned to resonant peak for each measurement frequency.
- Need only amplitudes: $Q = |V_{out}|/|V_{in}|$
- Measurement include winding loss: model it and subtract.

Other issues in electrical measurements



- Winding capacitance
 - Current in winding capacitance is not creating H field.
- Mutual resistance
 - High-frequency winding loss includes mutual resistance terms (discussed in Modelling this afternoon).
 - Mutual resistance appears as part of measured core loss.
 - Windings can be designed for low mutual resistance.
- Temperature control: test temperature + rise during testing.
 - Pulse tests, mineral-oil bath, forced convection.

Types of core loss measurements



- Calorimetric measurements
- Electrical measurements
 - Conventional four-wire
 - Instrumentation options
 - Source options
 - Resonant methods
 - MIT
 - Virginia Tech

References

For additional references see reference lists in each of these.

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