ACCURACY AND COMPENSATION ISSUES FOR AC POWER LOSS MEASUREMENTS
Stefan Ehrlich, Tobias Stolzke, Thomas Heckel, Stefan Ditze, Christopher Joffe
OUTLINE

Motivation

Measurement Setups and Reference Coils

Phase Measurements using Reference Coils

Loss Measurement Accuracy

Measurement Accuracy: Triangular Currents

Summary and Outlook
OUTLINE

Motivation

Measurement Setups and Reference Coils

Phase Measurements using Reference Coils

Loss Measurement Accuracy

Measurement Accuracy: Triangular Currents

Summary and Outlook
Motivation

- Loss measurement for ferrites using toroidal cores (according to standard) → material characterization
- Reproducibility of the measurement was determined
- Measurement accuracy is examined in this presentation
  - For sinusoidal waveforms
  - For high frequencies
- Good data accuracy is essential
  - Comparability between materials and manufacturers
  - Good predictions in simulation
- Challenge: Compensation of the time delay in the signal paths → high loss measurement accuracy
Motivation

Device Under Test (Toroidal Core):

→ Physical phase between $V_{Ph}$ and $I_{Ph}$ leads to time delay: $\Delta t_{Ph} \rightarrow \Delta \phi_{Ph} = 2 \cdot \pi \cdot f \cdot \Delta t_{Ph}$

- Shift $\Delta t$ between voltage and current due to time delay in the signal paths → turns as: $\Delta \phi = 2 \cdot \pi \cdot f \cdot \Delta t \rightarrow$ high sensitivity of loss measurement
- Measured phase of the impedance: $\phi_{err} = \Delta \phi_{Ph} + \Delta \phi$
Motivation

Device Under Test (Toroidal Core):

- Physical phase between $V_{Ph}$ and $I_{Ph}$ leads to time delay: $\Delta t_{Ph} \rightarrow \Delta \phi_{Ph} = 2 \cdot \pi \cdot f \cdot \Delta t_{Ph}$

- Shift $\Delta t$ between voltage and current due to time delay in the signal paths $\rightarrow$ turns as: $\Delta \phi = 2 \cdot \pi \cdot f \cdot \Delta t \rightarrow$ high sensitivity of loss measurement

- Measured phase of the impedance: $\phi_{err} = \Delta \phi_{Ph} + \Delta \phi$

Physical: $R_{Ph} = |Z| \cdot \cos(\Delta \phi_{Ph})$

Screen: $R_{Sc} = |Z| \cdot \cos(\Delta \phi_{Ph} + \Delta \phi)$
OUTLINE

Motivation

Measurement Setups and Reference Coils

Phase Measurements using Reference Coils

Loss Measurement Accuracy

Measurement Accuracy: Triangular Currents

Summary and Outlook
Measurement Setups

- **Setup 1:** Current sensing → active current probe
  Voltage sensing → active voltage probe

- **Setup 2:** Current sensing → pearson current monitor
  Voltage sensing → passive voltage probe [1-2]

- **Setup 3:** Current sensing → Shunt [3]; Voltage sensing → passive voltage probe

DUT: Air Coil

Current and Voltage are measured electrically isolated \( \downarrow \)
### Reference Air Coils

<table>
<thead>
<tr>
<th>Air Coil 1</th>
<th>Air Coil 2</th>
<th>Air Coil 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inductance</strong></td>
<td>3 [μH]</td>
<td>3 [μH]</td>
</tr>
<tr>
<td><strong>Δφₚₑ</strong></td>
<td>&gt; 87.5 °</td>
<td>&gt; 87 °</td>
</tr>
<tr>
<td><strong>Current</strong></td>
<td>1 App</td>
<td>1 App</td>
</tr>
<tr>
<td><strong>Frequency range</strong></td>
<td>100 kHz-1MHz</td>
<td>100 kHz-1MHz</td>
</tr>
</tbody>
</table>
Setup 1: Active Voltage Probe and Active Current Probe

- Determining the time delay $\Delta t$ by using a compensation kit.
- We assume the delay between current and voltage to be 0 ns $\rightarrow$ best match of voltage and current signals.
Setup 1: Active Voltage Probe and Active Current Probe

- Small signal measurement with the impedance analyzer as a reference
- Small and large signal measurement for the black coil match very well
- Measurements deviate strongly for the other coils especially at small frequencies
- Although the signal delay was compensated using a compensation kit, there are still large deviations within the measurement.
Time Delay of Voltage Probes and Oscilloscope

- Measurement of a sinusoidal signal using two 10:1 voltage probes and an oscilloscope
  - Measurement includes the time delay between channel 1 and 2 as well as between the 10:1 voltage probes
  - Time delay is much smaller than 1 ns within the examined frequency range
  - The dependency on the voltage magnitude is proved to be small
Setup 2: Passive Voltage Probes and Pearson Current Monitor

- Time delay of voltage probes and oscilloscope is compensated for high frequencies
- Time delay of the current monitor is fitted that curve characteristics match; delay is the same for both coils
- Small and large signal measurement for the black coil match very well
- Measured curve characteristics for the yellow coil are similar
Setup 3: Passive Voltage Probes and Shunt 1

- Time delay of voltage probes and oscilloscope is compensated for high frequencies
- Time delay due to the Shunt inductance (≈120 pH) is compensated
- Small and large signal measurement for the black and yellow coil match very well
- Measurements for the red coil deviate strongly → as expected: measuring voltage in the range of the input white noise of the scope

\[ R_{\text{Shunt}} = 100 \text{ mΩ} \]
Setup 3: Passive Voltage Probes and Shunt 2

- To improve sensitivity a wired shunt was built up
- Shunt inductance, which causes a delay in the current sensing, can’t be measured exactly
- Choosing the same shunt inductance ($\approx 2.4$ nH) for all measurements $\rightarrow$ time delay is compensated
- Even for the red coil measurement accuracy is improved
Setup 3: Passive Voltage Probes and Shunt 3


- Simulations and measurements suggest that shunt inductance is <300 pH

- Small and large signal measurement for the black coil match very well

- Using this shunt, the highest measurement accuracy for the red coil was achieved
OUTLINE

Motivation

Measurement Setups and Reference Coils

Phase Measurements using Reference Coils

Loss Measurement Accuracy

Measurement Accuracy: Triangular Currents

Summary and Outlook
Loss Measurement Accuracy: Setup 1

- Small signal measurement of phase: $\phi_{sm}$
- Phase deviation between small signal and large signal measurement: $\Delta \phi$
- Using setup 1, the uncertainty in loss measurement for the yellow coil is up to 25%

Uncertainty is defined as:

$$\left| \frac{\cos(\phi_{sm} + \Delta \phi) - \cos(\phi_{sm})}{\cos(\phi_{sm})} \right| \cdot 100 \%$$
→ Uncertainty of loss measurement: within 5 % for the black coil and 10 % for the yellow coil
Loss Measurement Accuracy: Conclusion

- Setup 1: Active Voltage Probe and Active Current Probe
  - Uncertainty for the black coil within 15 %
  - Uncertainty for the yellow coil within 25 %

- Setup 2: Passive Voltage Probes and Pearson Current Monitor
  - Uncertainty for the black coil within 5 %
  - Uncertainty for the yellow coil within 10 %

- Setup 3: Passive Voltage Probes and Shunt
  - Uncertainty for the black coil within 5 %
  - Uncertainty for the yellow coil within 10 %
  - Highest accuracy for the red coil
OUTLINE

Motivation

Measurement Setups and Reference Coils

Phase Measurements using Reference Coils

Loss Measurement Accuracy

Measurement Accuracy: Triangular Currents

Summary and Outlook
Measurement Accuracy: Triangular Currents

- Measurement of core or coil losses with triangular, trapezoidal currents
- Time delay in the signal paths must be constant in a wide frequency range
  - Using a shunt → there’s no delay in the current sensing
  - Using a current monitor → Examination of time delay depending on excitation
OUTLINE

Motivation

Measurement Setups and Reference Coils

Phase Measurements using Reference Coils

Loss Measurement Accuracy

Measurement Accuracy: Triangular Currents

Summary and Outlook
Summary and Outlook

- Three different measurement setups were tested referring loss measurement accuracy
- Using a Pearson current monitor or a shunt, measurement uncertainty for the examined coils is similar
- To cover the whole current range, different shunts and current monitors are necessary
- Excitation with triangular currents: time delay in the signal paths must be constant in a wide frequency range
- Verification of the measurement accuracy with triangular currents
Any Questions
References


Setup 2: Passive Voltage Probes and Pearson Current Monitor