Pulse Testing of Magnetic Cores and Inductors

JC Sun
Bs&T Frankfurt am Main GmbH
JC and his...

- physicist & engineer
- make and design ferrite 3Cx and 3Fx
- sales amorphous metals 2605/2714/2705
- marketing nanocrystalline 500F components
- Bs & T Frankfurt am Main GmbH

www.powerlosstester.de
• Introduction Bs&T
• Typical value and Limit value of inductor
• Demonstration of pulse testing
  example 1: temperature dependence of saturation current
  example 2: life demo 3 phase delta inductor D9B
• Take home message
Bs & T Analyzer

**Sinusoidal Magnetization**

- High excitation
- IEC 62044-3
- Loss, $\mu_a$ driven by B mode
- $B_{\text{peak}}$ loop driven by H mode
- DC superposition

**Pulse Magnetization**

- Low excitation
- IEC 62044-2
- Fast transit of magnetic state
- $\text{dB/dt}$
- IEC 60367-1 Annex G (393 IEEE)

**BsT-Pro**

- Loss map ($f$, $B$, $T$, $H_{DC}$)
- $\mu_{\text{rev}}$ ($f$, $B$, $T$, $H_{DC}$)
- Major, and biased minor loop

**BsT-Pulse**

- Differential $L$ and amplitude $L$,
- Energetic $L$, power loss i.e. $Q$ factor
BsT Pro

H_{DC} oven

Diagram showing the setup with:
- Function Generator
- Power Amplifier
- Transformer
- Current Sensor
- DC Power
- Oscilloscope
- Computer
- DUT

Equipment listed:
- Oscilloscope
- Power Amplifier
- DUT
- Function Generator
- Transformer
- Current Sensor
- DC Power
- Oscilloscope
- Computer
- DUT
BsT-Pulse

Pulse Magnetization

fast transit of magnetic state
dB/dt

differential and amplitude L
energetic L, power loss

pulse energy \( \sim 200 \text{ J} \) with discharge voltage till 1000 V \((>3000A_p)\)

bipolar pulse magnetization with full reversal current
**Coil (Core&Material) is Nonlinear and shows Saturation**

**Piecewise linearization** is only possible, as long as assignment of magnetization inductance and current is unique given

\[
L_s(i) = \frac{N \cdot \Phi}{i} = \frac{\Psi}{i}
\]

**IEC 60076-6**

**Differential L**

\[
L_d(i) = \frac{d(N \cdot \Phi)}{di} = \frac{d\Psi}{di}
\]

\[
v(t) = L_d(i) \cdot \frac{di}{dt} = \frac{d\Psi}{di} \cdot \frac{di}{dt} = \frac{d\Psi}{dt} = \frac{d[i \cdot L_s(i)]}{dt}
\]

\[
\frac{d[i \cdot L_s(i)]}{dt} = L_s(i) \cdot \frac{di}{dt} + i \cdot \frac{dL_s(i)}{dt}
\]

**Amplitude L**

\[
L_s(i) = \frac{1}{i} \int_0^i L_s(i') \, di'
\]

**Energetic L**

\[
L_e(i) = \frac{2}{i^2} \int_0^i i \cdot L_s(i') \, di'
\]

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Alex van den Bossche

Bs&T Frankfurt am Main GmbH
Inductance analysis to characterize saturation

![Graph showing inductance analysis]

![Graph showing B-H relation]

Bs&T Frankfurt am Main GmbH
## Typical value and Limit value

### Inductor

<table>
<thead>
<tr>
<th>Document classification</th>
<th>Typical value</th>
<th>Limit value</th>
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</thead>
<tbody>
<tr>
<td>Catalogue*</td>
<td>THD$_F$, Z, P$_V$</td>
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</tr>
<tr>
<td>Material table</td>
<td>all other properties than those</td>
<td></td>
</tr>
<tr>
<td></td>
<td>described in “Limit value”.</td>
<td></td>
</tr>
<tr>
<td>Material curve</td>
<td>all properties</td>
<td></td>
</tr>
<tr>
<td>(Shaped) Core table</td>
<td>A$_L$, THD$_F$, Z, P$_V$</td>
<td></td>
</tr>
</tbody>
</table>

### Problem:
1. no differentiation between $L_{\text{diff}}$, $L_{\text{amp}}$ and $L_{\text{energetic}}$
2. Instantaneous large current causes heat dissipation

### Solution: BsT-Pulse

- Non-linearity of inductance value and Q factor

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IEC 60076-6 & IEC 62024 NO CLEAR INSTRUCTION TO SPECIFY INDUCTANCE

IEC 60401
Measuring principle with example

2x HS1016

<table>
<thead>
<tr>
<th>N</th>
<th>Le [mm]</th>
<th>Ae [mm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>53</td>
<td>242,7</td>
<td>704,4</td>
</tr>
</tbody>
</table>

* This project received funding support from EU SME Horizon 2020
Damped oscillation with voltage and current decay

micro second ~ milli second  heat dissipation neglected
Correlation magnetic component, core and material

Material
Geometry data
Coil data

**Component**

**Core**

<table>
<thead>
<tr>
<th>N</th>
<th>Le [mm]</th>
<th>Ae [mm²]</th>
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<tbody>
<tr>
<td>53</td>
<td>242,7</td>
<td>704,4</td>
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</table>

**Material**
Demagnetization curve
Assignments of magnetization inductance vs. current
Example 1: Temperature dependence of saturation current

Demagnetization factor $\sim 0.38$

Open magnetic circuit

D9B vs. P4 (~N87)

incremental inductance ($\mu$H)

$I$ [A]

25°C

120°C
**Example 2:** Life demo: pulsation of 3 phase delta inductor

Ferrite material D9B™ 0.6 T escalating (like lego stone)

- 100, 110, 111
  - 1 short circuit
  - 0 open circuit
  - 1 limb to pulse
$L_{\text{diff}}$ vs. $U_{\text{dt}}$ $100 \sim 220 \, \mu\text{H}$
L measurement 100 LCR 182
$L_{\text{diff}} \text{ vs. } U_{\text{dt}} \sim 160 \, \mu\text{H}$
L measurement 110 LCR 157 µH
$L_{\text{diff}}$ vs. $U_{dt} \sim 80 \mu H$
L measurement 1 1 1 LCR 73 µH
Take home message

- **BsT-Pulse** enables precise, robust, reliable and quick inductance analysis, *no* self heating disturbance
- **BsT-Pulse** provides accurate power loss, *no* importance on phase angle error between voltage and current
- **BsT-Pulse** provides characterization of inductor quality factor with $\omega L_{\text{energetic}} / R$
- Linkage of reading material loss map *is over* $L_{\text{diff}} @ \mu_{\text{rev}}$

**BsT-Pulse** provides limit value for maker and user of magnetic component

*granted and supported by H2020, DIN, VDE*
Annex 1 measuring data for simulation

BsT-Pro

BsT-Pulse

BsT-Pro

BsT-Pulse

Bs&T Frankfurt am Main GmbH
## Annex 2 loss map reading with linkage over $\mu_{\text{rev}}$ and $L_{\text{diff}}$

### Example data log file

<table>
<thead>
<tr>
<th>Temp ($^\circ$C)</th>
<th>Freq (kHz)</th>
<th>TestB (mT)</th>
<th>I_Hdc (A)</th>
<th>$\mu_{\text{rev}}$</th>
<th>$L_{\text{diff}}$</th>
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### Table 1

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<th>Vpp_sp (V)</th>
<th>Vpp_Mv</th>
<th>Vrms_Mv</th>
<th>V_CF</th>
<th>V_DC</th>
<th>Ipp_Mv (A)</th>
<th>Irms_Mv</th>
<th>I_CF</th>
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### Table 2

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<th>$P_{\text{cal}}$ (mW)</th>
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<th>$P_{\text{final}}$</th>
<th>$P_{\text{rev}}$</th>
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### Loss Map

- $\mu_{\text{rev}}$: \[ f, B, T, H_{DC} \]
- $L_{\text{diff}}$