1. Introduction

2. Uncertainty in making (Rico Wachs)

3. Uncertainty of data for magnetics design (JC Sun)

4. Take home message
» Product-Industry Chain «

- Raw Material
- Powder Preparation
- Core
- winding
- Inductor, transformer
- Resistor
- Capacitor
- High power & high voltage segment & high precision sensor
- CT
- FI
- PFC
- Power choke
- Current choke
- Inverter transformer

μ, A_L, L
### Product-Industry Chain «

<table>
<thead>
<tr>
<th>Year</th>
<th>GO FeSi</th>
<th>FeSiB</th>
<th>FeSiBNbCu</th>
<th>Ferrite</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>750,000</td>
<td>20,000</td>
<td>~0</td>
<td>180,000</td>
</tr>
<tr>
<td>2005</td>
<td>1,500,000</td>
<td>60,000</td>
<td>2,000</td>
<td>250,000</td>
</tr>
<tr>
<td>2010</td>
<td>1,600,000</td>
<td>100,000</td>
<td>4,000</td>
<td>350,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>GO FeSi</th>
<th>FeSiB</th>
<th>FeSiBNbCu</th>
<th>Ferrite</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>1,7</td>
<td>2,5~50</td>
<td>&gt;200</td>
<td>20~60</td>
</tr>
<tr>
<td>2005</td>
<td>3,5</td>
<td>4,0~25</td>
<td>60~120</td>
<td>12~60</td>
</tr>
<tr>
<td>2010</td>
<td>3,8</td>
<td>4,1~12</td>
<td>40~120</td>
<td>8~80</td>
</tr>
</tbody>
</table>

**ICF**: International conference of ferrite 10/11  
**WSA**: world steel association  
**EERE**: Office of Energy Efficiency and Renewable Energy
2. About the manufacturing process and its uncertainties

Continuous monitoring and checking of the individual process steps by means of special laboratory and measuring technology.
Raw Materials – Iron Oxid from Regeneration Plants

- Milling increases spec. Surface and bulk density
- Quality grading acc. to SiO2-content
- Purified oxides (with WAPUR)
- Chemical precipitation ensures removal of Al, Cr, Ti, Nb, P and partly Cu
- Si is bonded adsorptive

Voestalpine
ONE STEP AHEAD.
» Weighing and Mixing «

- **Weighing Area (3. Floor)**
  - Weighing accuracy $\Delta 50g$

- **Mixing Area (2. Floor)**
  - Mixer capacity 150kg

- **Raw Material and Rolling Mill Area (1. Floor)**
  - Raw material is conveyed to the 3rd floor for weighing by means of tube chain conveyors

---

**Example of 4 tons batch**

- 27 mixtures a 150 kg with a weighing error of $\Delta 50g$ per main component
- Total weight error corresponds to $\Delta 10kg (= 2.5 \%m)$ per main raw material $\Rightarrow$ **99.5 % repeatability**
» Presintering «

- Throughput 120 - 150 kg/h (depending on material)
- Presintering at between 1000°C - 1050°C
- The presintering temperature is extremely important for the subsequent final geometry of the cores
  - The final shrinkage is set with it!

Red Flakes

Black Flakes

Heating Area 1000°C – 1050°C

Cooling Area from 1000°C to 40°C

16 m

5 m
Milling

- Milling process takes place in an emulsion of pre-ferrite particles and water
  - Emulsion calls Slurry
- 2 process steps: coarse and fine milling
  - **Coarse**: Ball Mill with ball-Ø 30 – 40mm
    - Adding of Dopants
  - **Fine**: Ball Mill with ball-Ø 3mm
- Particle distribution < 12 µm
  - Continue recirculation trough ball mill

**Typical Particle size distribution of ferrite-slurry after milling**

<table>
<thead>
<tr>
<th>Particle size [µm]</th>
<th>Percentage of Particles in Slurry [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.04</td>
<td>0</td>
</tr>
<tr>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>0.15</td>
<td>0</td>
</tr>
<tr>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>0.8</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>1.5</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
</tr>
</tbody>
</table>
• Addition of binders
• Solids content in slurry > 70%
• Heated to 300°C
• Dust < 40 µm is separated and fed to the previous production step
» Press Granulate «

- Particles Distribution (see Spray Drying)
- Bulk Density $1,36 \pm 0,04 \text{ g/cm}^3$
- Residual moisture $< 0,2\%_{\text{H}_2\text{O}}$
- Addition of lubricants to assist in the demolding of the cores
» Compacting «

• **Dry press automats / Eccentric press**
  - Work according to the coat removal method
  - This process was developed in Hermsdorf (Germany)

• **Press sizes between 6t – 200t**
  - Compaction of the cores with 2 - 2.5 t/cm²
  - max. pressing area = 200t / 2.5t/cm² = 80 cm²

• **Different pressing pressure for each pressing cycle**
  - Different density distribution in each core ⇒ Displacement of the press neutral or its position different each time
    - Typical pressing density between 2.85 – 3.1 g/cm³
  - Use of press controllers stabilizes the pressing process ⇒ Fluctuations are minimized ⇒ Consistency pressing process approx. 97 - 98 %
Sintering

- Top-hat furnaces
- Sintering temperatures between 1180 - 1350°C (depending on material) under oxygen-reduced atmosphere
- Typical sinter density between 4.8 – 4.9 g/cm³

Some Sintering Faults
DIN EN IEC 60401-1

- For MnZn ferrites it is important to monitor and control the oxygen partial pressure in the ppm-range ⇒ reduction process
⇒ otherwise decomposition into starting raw materials
» Grinding «

Some Grinding Faults
DIN EN IEC 60401-1

- Final grinding is used to remove the sintered skin on the core contact surfaces after the sintering process
- DIN EN IEC 60401-1 describes which faults are permissible and which are not
- Typical achievable surface roughness Rz 20 to Rz 40
- Cores without air gap and with air gap can be produced in one grinding process
  - Grinding tolerances depending on the depth of the air gap
    - Gap < 0,2 ± 0,02 mm
    - 0,2 < Gap < 0,5 ± 0,03 mm
    - 0,5 < Gap < 2,0 ± 0,05 mm
    - Gap > 2 ± 0,1 mm
  - Multi-air gap cores are possible
Only at the end of the entire process chain can you see if you did something wrong at the beginning!

- Ferrite cores are standardized
  - in shape and size
  - Magnetic properties

- A large number of indirect variables are required along the process chain, which have to be measured, monitored and controlled.
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 & Chicago Corp. 1/4/2022
**Sinus Magnetization AC**

- high excitation
- low excitation
- IEC 62044-3
- IEC 62044-2
- dB/dt
- loss, $\mu_a$ driven by B mode
- $B_{peak}$, loop driven by H mode
- DC superposition

**Pulse Magnetization**

- fast transit of magnetic state
- dB/dt
- IEC 60367-1 Annex G

**BsT-Pro**

- loss map $(f, B, T, H_{dc})$
- $\mu_{rev}$
- major, and biased minor loop

**BsT-Pulse**

- differential and amplitude L,
- energetic L, power loss i.e. Q factor
Pulse Magnetization

- Fast transit of magnetic state
- dB/dt

BsT-Pulse

Differential and amplitude \( L \)

Energetic \( L \), power loss

Square Wave

\[
V_L(t) = \begin{cases} 
V_0 & \text{for } 0 \leq t < \frac{T}{2} \\
-V_0 & \text{for } \frac{T}{2} \leq t < T 
\end{cases}
\]

\[
I_L(t) = \begin{cases} 
rac{V_0}{R} & \text{for } 0 \leq t < \frac{T}{2} \\
-rac{V_0}{R} & \text{for } \frac{T}{2} \leq t < T 
\end{cases}
\]

\[
dt = \frac{T}{2}
\]
Coil (Core+Material) is Nonlinear and shows Saturation

Piecewise linearization is only possible, as long as assignment of magnetization inductance and current is unique, i.e. (de)magnetization curve is uniquely given

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

**Differential L**

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

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

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

**Amplitude L**

\[
L_s(i) = \frac{1}{i} \int_{0}^{i} L_s(i') \, di'
\]

**Energetic L**

\[
L_e(i) = \frac{2}{i^2} \int_{0}^{i} i \cdot L_s(i') \, di'
\]
IEC standard 62044-2 description low excitation

- **IEC 62044-2**: “Magnetic properties at low excitation level”

9  **Inductance Measurement – Test Signal**

- LCR meters or impedance analysers are used to make inductance measurements.
- The upper limit for AC voltage for this type of equipment is typically between 1 Vrms and 20 Vrms.
- Measurements are made using the **series** mode unless the parallel mode is specified.
- The recommended peak flux density is \(0.25 \text{ mT}\) (for small toroids 1 mT)
- The recommended test frequencies are either 10 kHz or 100 kHz
IEC standard 62044-2 description (demo session afternoon)

### Table 1- Relationship of test turns to magnetic structure, test frequency and inductance factor $A_L$

<table>
<thead>
<tr>
<th>Turns</th>
<th>Frequency kHz</th>
<th>$A_L$ nH/N^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toroid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>&gt; 10 000</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>&gt; 1 000</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>&gt; 100</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>100</td>
<td>10</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>NA</td>
</tr>
<tr>
<td>Cores using bobbin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>NA</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>NA</td>
</tr>
<tr>
<td>100</td>
<td>10</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>Cores using Planar Winding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>10</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>NA</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>&gt; 100</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>&gt; 10</td>
</tr>
<tr>
<td>100</td>
<td>10</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>NA</td>
</tr>
</tbody>
</table>
6.3 Power loss

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

<table>
<thead>
<tr>
<th>Measuring method</th>
<th>Useable excitation waveform</th>
<th>Domain of acquisition</th>
<th>Domain of processing</th>
<th>Subclause of annex C</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-A-W meter</td>
<td>Sinusoidal</td>
<td>Time</td>
<td>Time</td>
<td>C.1.1</td>
</tr>
<tr>
<td>Impedance analyser</td>
<td>Sinusoidal</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>C.1.2</td>
</tr>
<tr>
<td>Digitizing</td>
<td>Arbitrary</td>
<td>Time</td>
<td>Time</td>
<td>C.1.3</td>
</tr>
<tr>
<td>Vector spectrum</td>
<td>Arbitrary</td>
<td>Frequency</td>
<td>Frequency</td>
<td>C.1.4</td>
</tr>
<tr>
<td>Cross-power</td>
<td>Arbitrary</td>
<td>Time</td>
<td>Frequency</td>
<td>C.1.5</td>
</tr>
</tbody>
</table>
Hardware 1 oscilloscope 2 channels C1.1
Hardware 2 power meter C1.3
Physic principle & device damped oscillation

IEEE 393 & IEC60076 JWG 11
magnetization vs. demagnetization
Correlation magnetic component, **core** and material

<table>
<thead>
<tr>
<th>$L$</th>
<th>core</th>
<th>$A_L$</th>
<th>material</th>
<th>$\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>component</td>
<td>[\Phi = \frac{\Psi}{W_s}]</td>
<td>[\Theta = \frac{i}{W_p}]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$N$</th>
<th>$Le [\text{mm}]$</th>
<th>$Ae [\text{mm}^2]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>53</td>
<td>242.7</td>
<td>704.4</td>
</tr>
</tbody>
</table>
Take home message

• Ferrite is artificial ceramic, demand long process steps, uncertainty in making reliable ferrite is composition and each process controls, but standard exists for ferrite quality!

• Uncertainty in designing components cored with ferrite needs accurate data, and needs standard which meeting contemporary energy conversion requirement

• Magnetostatic anisotropy includes the geometric parameter, more dominant than material impact for the most design

• Measuring is only way to provide limit value of magnetic component as specification
» Thank you for your attention «
Annex 1 measuring data for simulation

BsT-Pro 2016
BsT-SQ 2018
BsT-Pulse 2017

BsT-Pro
DC biased AC loss

BsT-SQ

BsT-Pulse
Annex 2 uncertainties of process parameter
Annex 3 datasheet of iron oxide, material, core and ...?
» Annex 4: History of TRIDELTA Weichferrite GmbH - from the beginning «

1890 Establishment of the „Kahla Porcelain Factory“, branch Hermsdorf-Klosterlausnitz

1922 Foundation of the HESCHO (Hermsdorf-Schomburg Isolator Society)

1945 Development of soft magnetic ferrite materials Manifer® and cores

1952 Development of hard magnetic ferrite materials Maniperm® and cores

1957 Establishment of the CWH (Ceramic Works Hermsdorf)

1990 Foundation of the TRIDELTA AG

2002 TRIDELTA GmbH can look back on over 50 years of ferrite history

2014 Spin off of the TRIDELTA Weichferrite GmbH from the TRIDELTA GmbH through change of ownership ⇒ Nukas VBB GmbH

2018 Relocation to the new company building on Robert-Friese-Straße in Hermsdorf
• 28 employees
• More than 1500 customers
• Export to 58 countries on 6 continents
• 15 different soft magnetic materials with continuous further development
• The product portfolio currently includes 550 different combinations of geometry and material as well as many customer-specific special designs
Annex 6: Products made from soft ferrite materials – standard shapes

- Ring cores
- E- and EF-cores
- ETD-cores
- Planar-cores
- ECL- and EVD-cores
- EC- and ER-cores
- U-, UI- and UR-cores
- PM-cores
- RM-cores
- Tube- and Cylinder-cores
- C-, Roll- and Mushroom-cores, Disc-cores
- Segment- and Profil-cores
Diversity

Material
- ferrite
- oxide ceramics
- non-oxide ceramics
- silicon (mono. / poly.)
- quartz glass
- hard-past porcelain

Machining
- abrasive cutting
- flat grinding
- cylindrical grinding, centerless
- drilling
- milling
- assembly
- put
- glue

» Annex 7: Customer-specific designs – more than 15 years of experience «
soft magnetic materials are characterized by easy magnetizability ⇒ small external magnetic fields $H$ influence the internal alignment of the elementary magnets

- Differentiation via the definition of the coercivity $H_C$
- Convention $H_{CBorder} = 1000 \text{ A/m}$

$< 1000 \text{ A/m} = \text{soft magnetic} \quad > 1000 \text{ A/m} = \text{hard magnetic}$

- typical values for Manifer®-materials $5 – 50 \text{ A/m}$
- typical values for iron powder $300 – 650 \text{ A/m}$
- typical values for Maniperm®-materials $300 – 355 \text{kA/m}$

New curve

$B_S = \text{Saturation flux density}$

$B_R = \text{Remanence flux density}$

$H_C = \text{Coercive field strength}$