TRIDELTA Weichferrite GmbH

» Uncertainties of Ferrite Parameters «

by R. Wachs and J.C. Sun

» Content «

TRIDELTA Weichferrite GmbH

» Product-Industry Chain «

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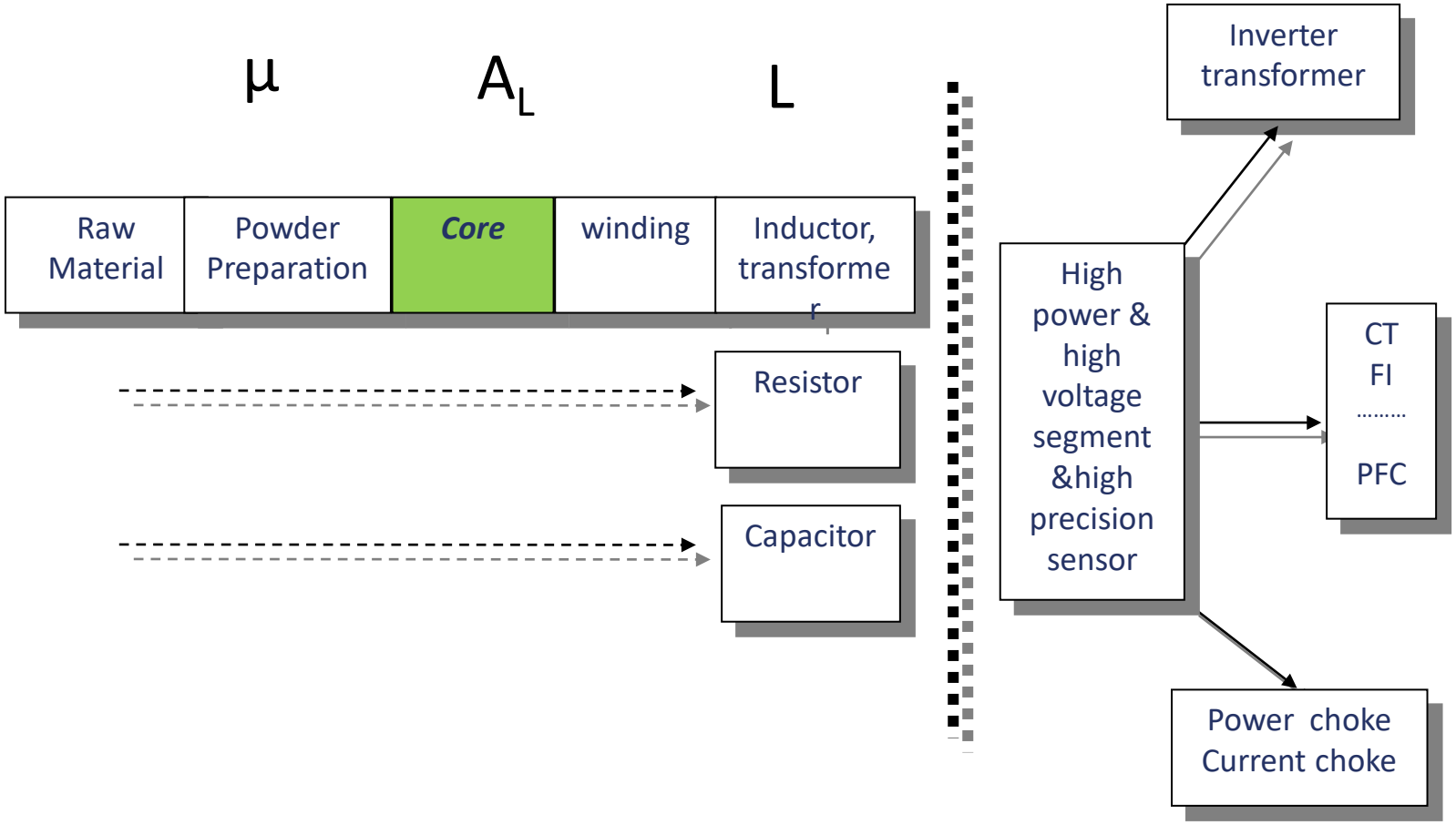

» Product-Industry Chain «

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mT/year	GO FeSi	FeSiB	FeSiBNbCu	Ferrite
1995	750,000	20,000	~0	180,000
2005	1,500,000	60,000	2,000	250,000
2010	1,600,000	100,000	4,000	350,000

$/kg	GO FeSi	FeSiB	FeSiBNbCu	Ferrite
1995	1,7	2,5~50	>200	20~60
2005	3,5	4,0~25	60~120	12~60
2010	3,8	4,1~12	40~120	8~80

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 «

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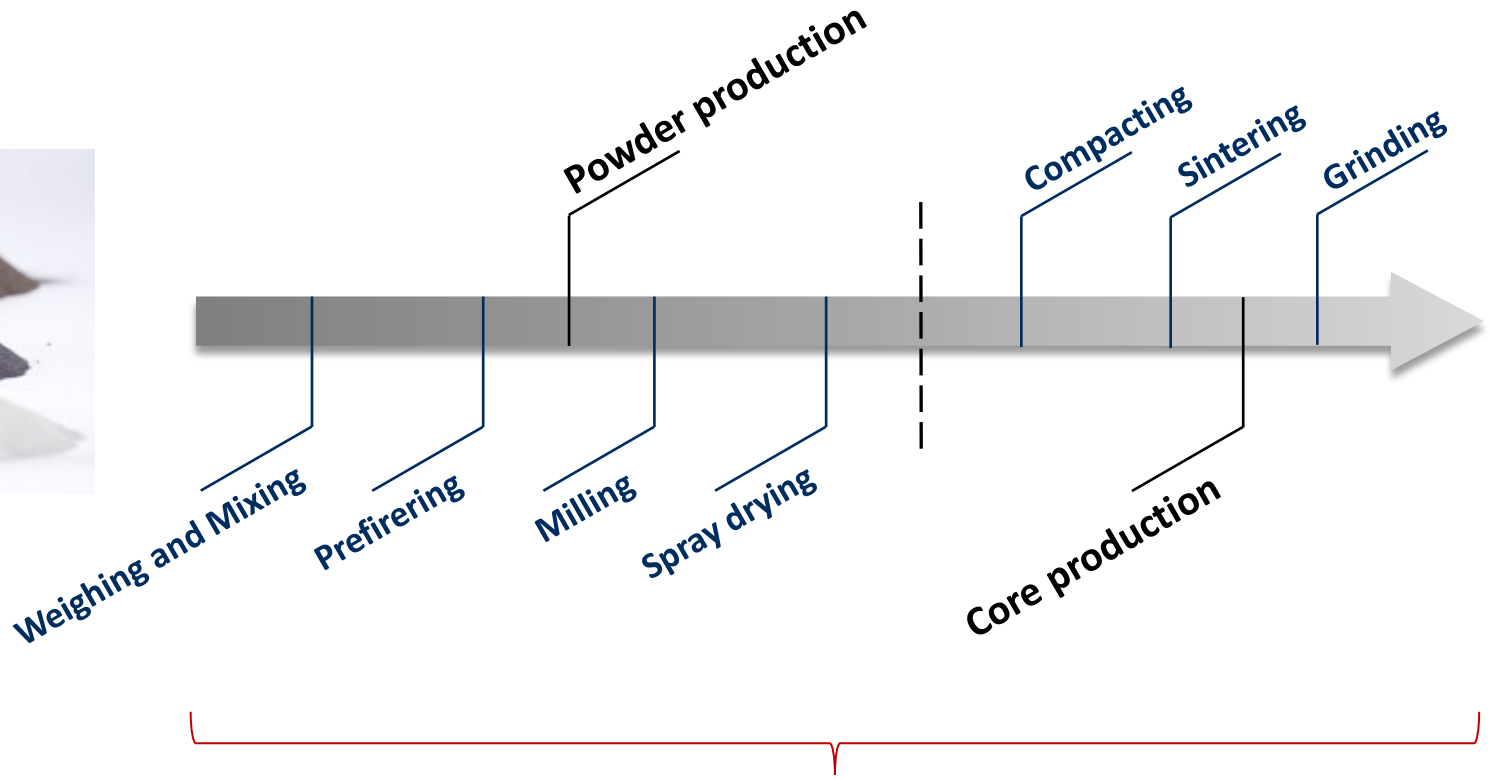
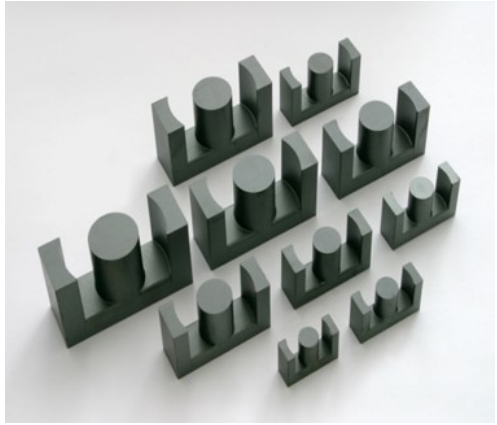
Raw materials





ETD-Core assortment

Continuous monitoring and checking of the individual process steps by means of special laboratory and measuring technology

» Raw Materials – Iron Oxid from Regeneration Plants «

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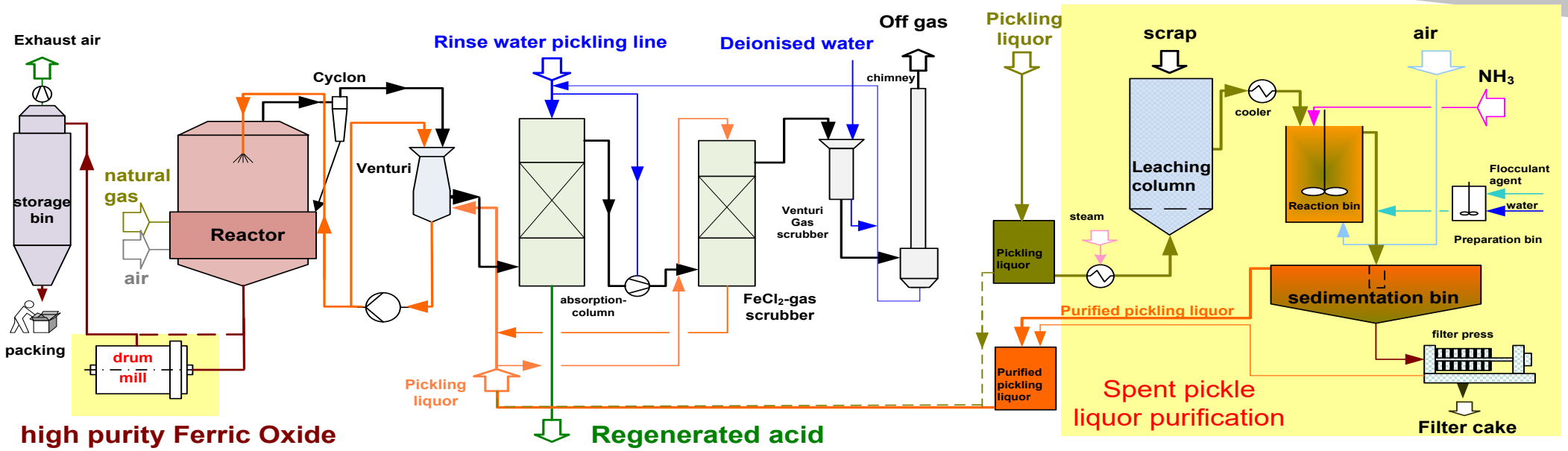

- Milling increases spec.

  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 «

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- **Weighing Area** (3. Floor)
  - Weighing accuracy Δ 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

Raw materials

In

Scale

Example of 4 tons batch

- 27 mixtures a 150 kg with a weighing error of Δ50g per main component
- Total weight error corresponds to Δ10kg (= 2.5 ‰m) per main raw material ⇒ **99,5 % repeatability**

Mixer

20 m

Rolling Mill

Out

Red Flakes

» Presintering «

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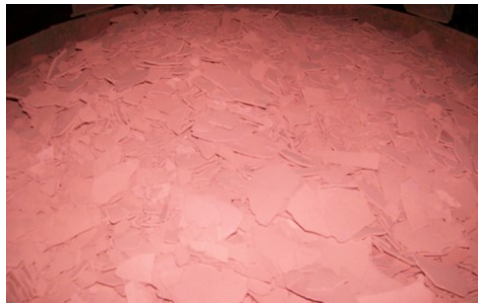
- Throughput 120 - 150 kg/h (depending on material)
- Presintering at between 1000°C - 1050°C
- The presintering temperature is extremely important for the subsequent final geometry of the cores
  - ➢ **The final shrinkage is set with it!**



Red Flakes

Black Flakes

» Milling «

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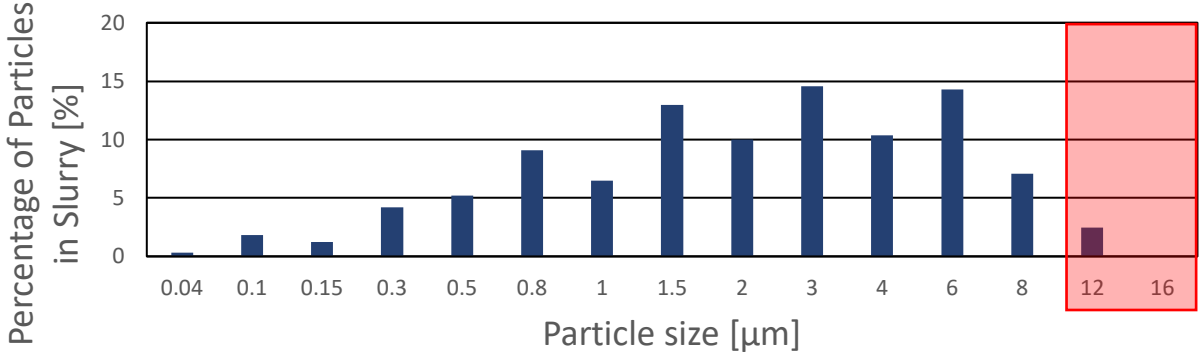
Multiple recirculation through ball mill

Fine Milling Process

Ball Mill

- 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-∅ 30 – 40mm
    - ➢ Adding of Dopants
  - Fine: Ball Mill with ball-∅ 3mm
- Particle distribution < 12 µm
  - ➢ Continue recirculation trough ball mill

Typical Particle size distribution of ferrite-slurry after milling



» Spray Drying «

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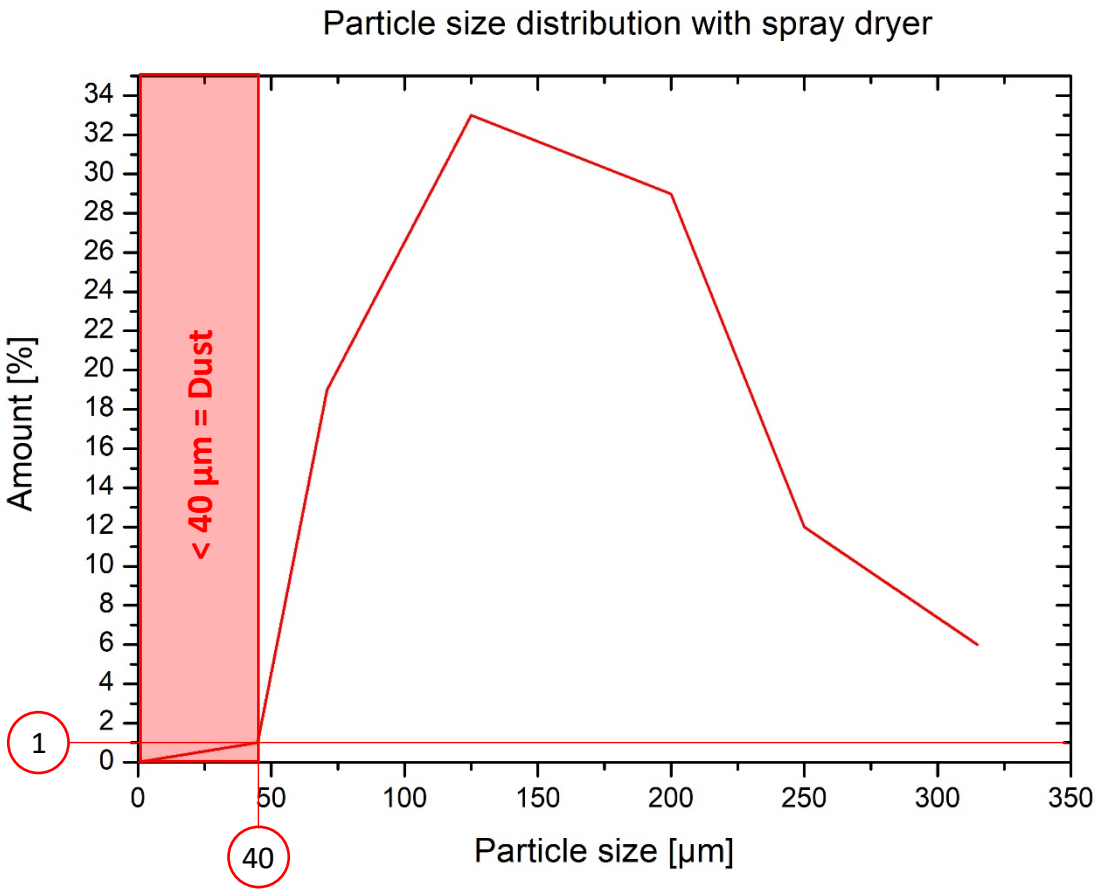
- Addition of binders
- Solids content in slurry > 70%
- Heated to 300°C
- Dust < 40 µm is separated and fed to the previous production step



Great Spray Dryer

» Press Granulate «

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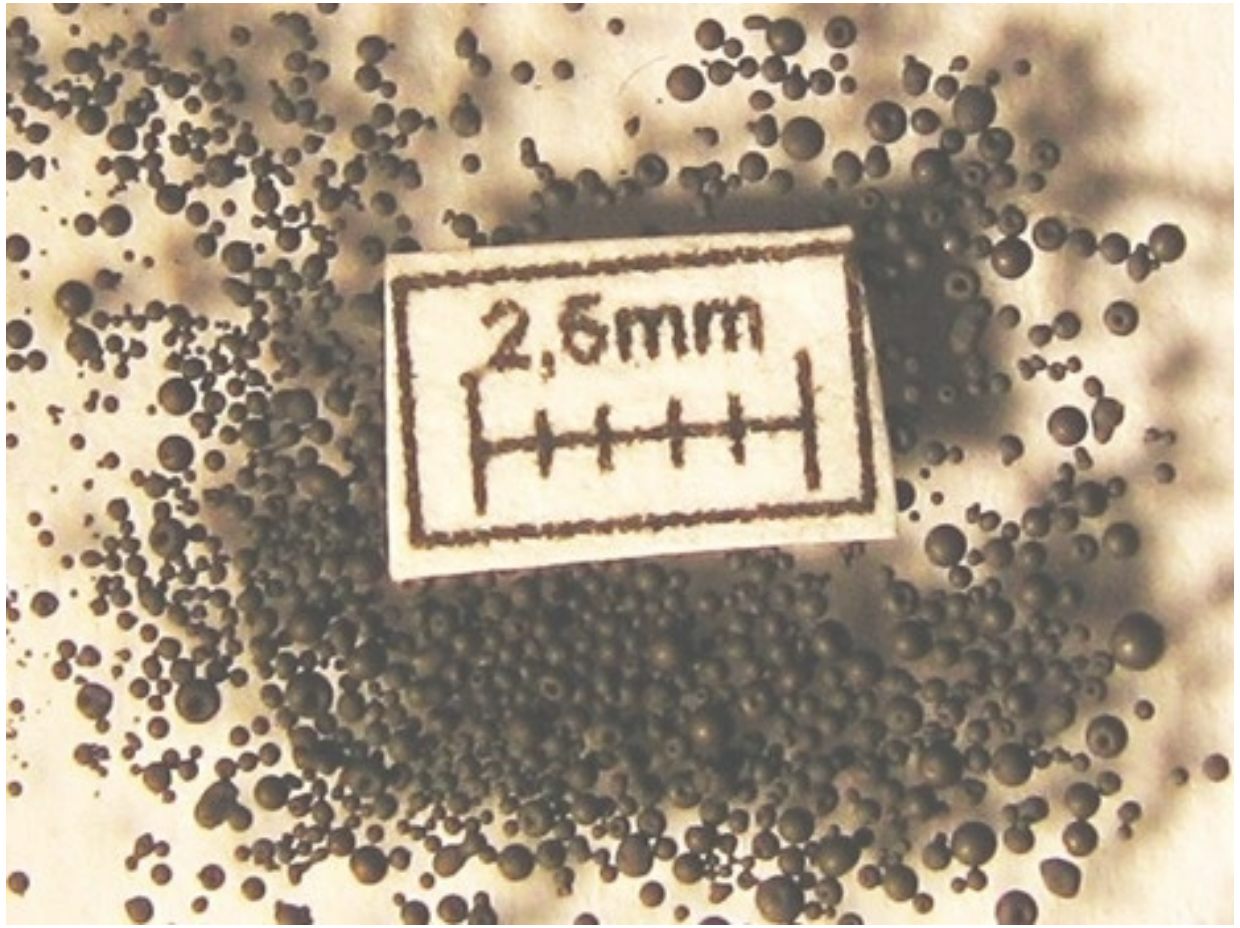
- Particles Distribution (see Spray Drying)
- Bulk Density 1,36 ± 0,04 g/cm³
- Residual moisture < 0,2 $\%_{H2O}$
- Addition of lubricants to assist in the demolding of the cores



Granulatprobe

» Compacting «

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Dorst-Press Street with handling systems (green)

- **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 it 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 «

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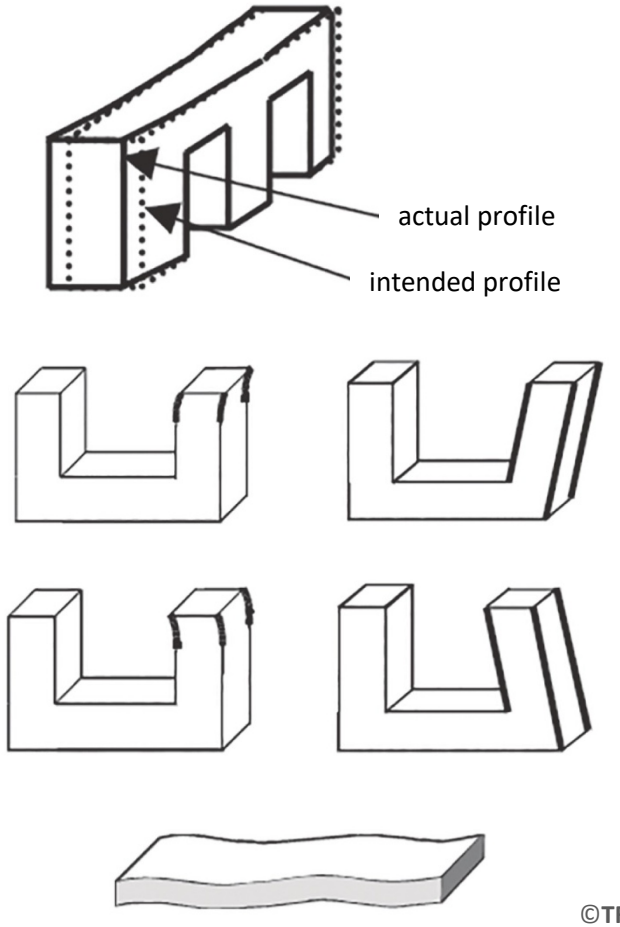
Sinter area

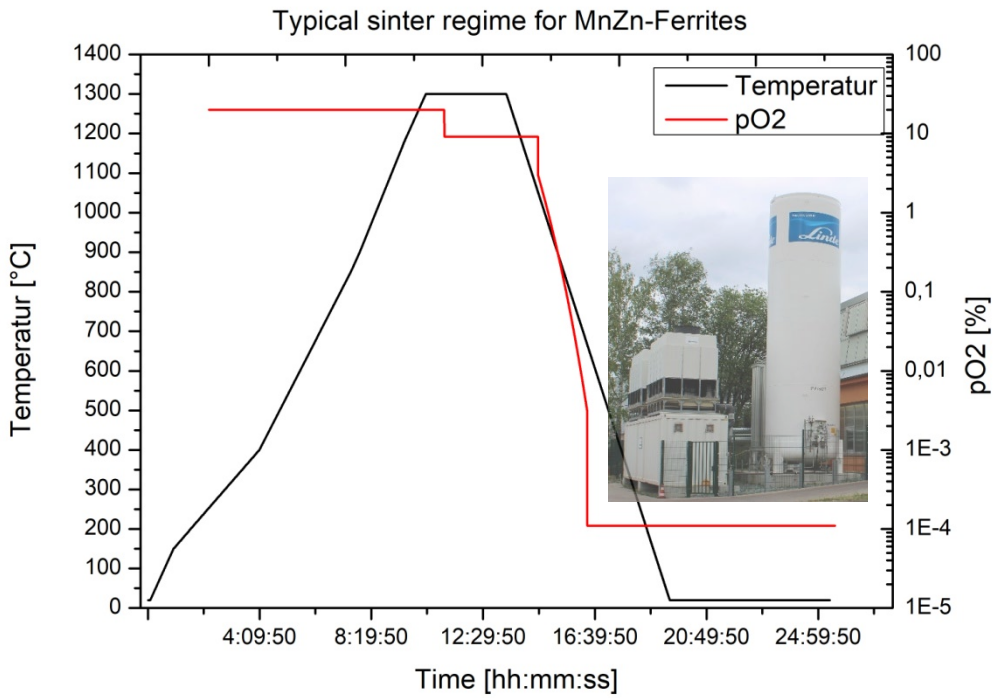
- Top-hat furnaces
- Sintering temperatures between 1180 - 1350°C (depending on material) under oxygen-reduced atmosphere
- Typical sinter density between 4.8 – 4.9 g/cm³

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 «

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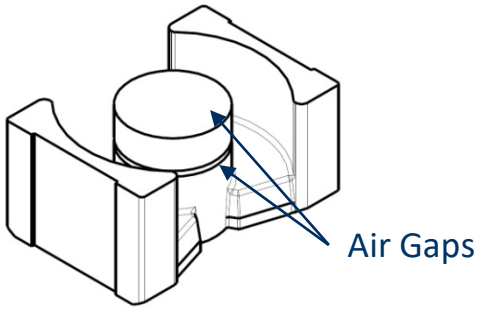
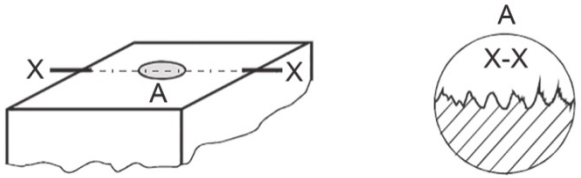
Grinding Area



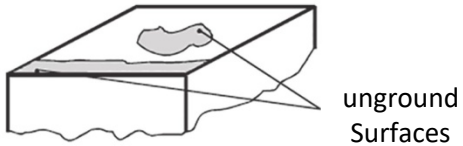
Multi Air Gap Core

Some Grindring Faults

DIN EN IEC 60401-1



Roughness



unground Surfaces

not parallel ground

not ground at right angles

- 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 ± 0,1mm
  - ➢ Multi-air gap cores are possible

» End Product - Measurement «

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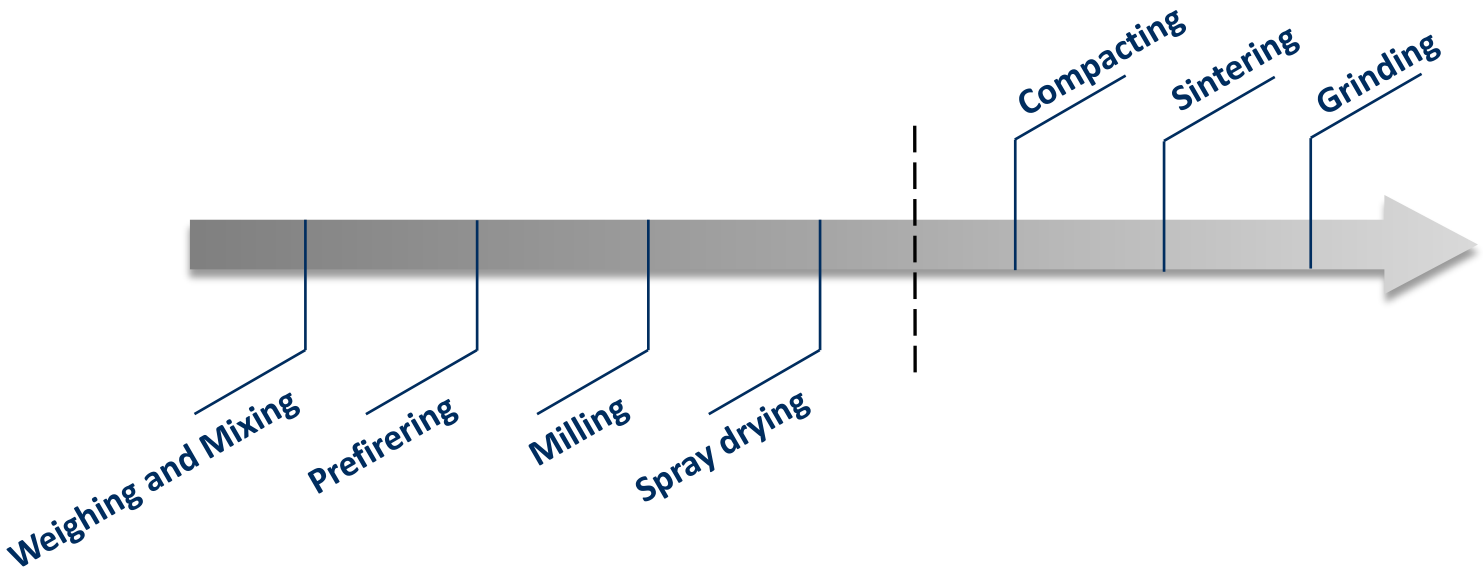
Only at the end of the entire process chain can you see if you did something wrong at the beginning!



- **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

FERROXCUBE
A YAGEO COMPANY

- sales amorphous metals 2605/2714/2705

Metglas®

- marketing nanocrystalline 500F components

VAC
VACUUMSCHMELZE

- Bs & T Frankfurt am Main GmbH & Chicago Corp.1/4/2022

Bs&T Analyzer

Bs & T Analyzer

Sinus Magnetization AC

high excitation

IEC 62044-3

loss, μ_a driven by B mode

B_{peak}, loop driven by H mode

low excitation

IEC 62044-2

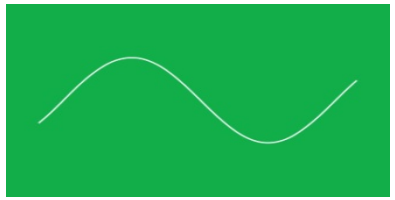
DC superposition

BsT-Pro

loss map (f, B, T, H_{DC})

major, and biased minor loop

μ_{rev}



Pulse Magnetization

fast transit of magnetic state

dB/dt

IEC 60367-1 Annex G

BsT-Pulse

differential and amplitude L,

energetic L, power loss i.e. Q factor

Bs & T Analyzer

Pulse Magnetization

fast transit of magnetic state

dB/dt

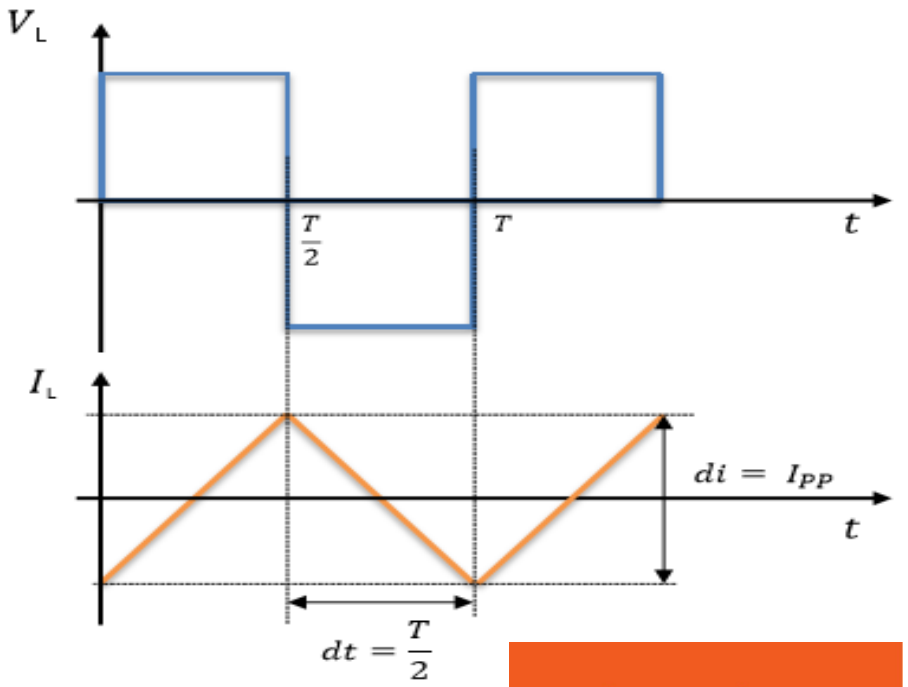
Damped oscillation

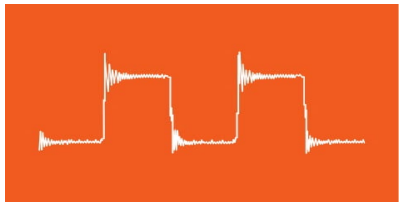
BsT-Pulse

differential and amplitude L

energetic L, power loss

Square Wave





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

$$\boxed{L_d(i) = \frac{\mathrm{d}(N \cdot \Phi)}{\mathrm{d}i} = \frac{\mathrm{d}\Psi}{\mathrm{d}i}}$$

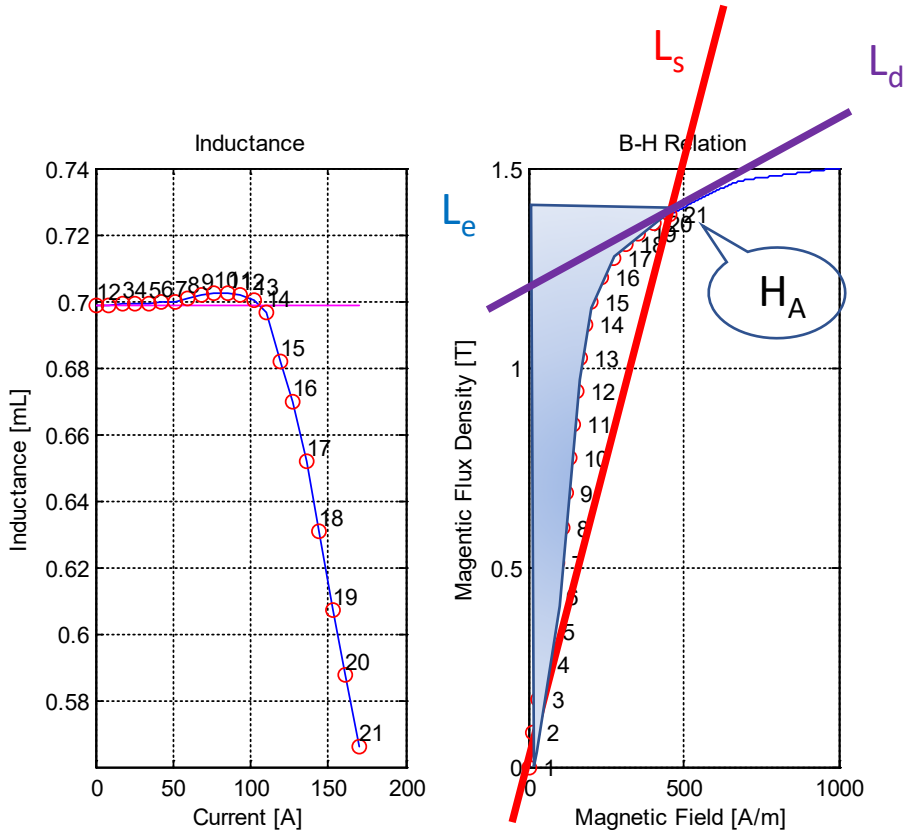
$$v(t) = L_d(i) \cdot \frac{\mathrm{d}i}{\mathrm{d}t} = \frac{\mathrm{d}\Psi}{\mathrm{d}i} \cdot \frac{\mathrm{d}i}{\mathrm{d}t} = \frac{\mathrm{d}\Psi}{\mathrm{d}t} =$$

$$\frac{\mathrm{d}\left[i \cdot L_s(i)\right]}{\mathrm{d}t} = L_s(i) \cdot \frac{\mathrm{d}i}{\mathrm{d}t} + i \cdot \frac{\mathrm{d}L_s(i)}{\mathrm{d}t}$$

Amplitude L $\rightarrow$ $\boxed{L_s(i) = \frac{1}{i} \int_0^i L_s(i')\, di'}$

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

Energetic L



Alex van den Bossche

IEC standard 62044-2 description low excitation

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

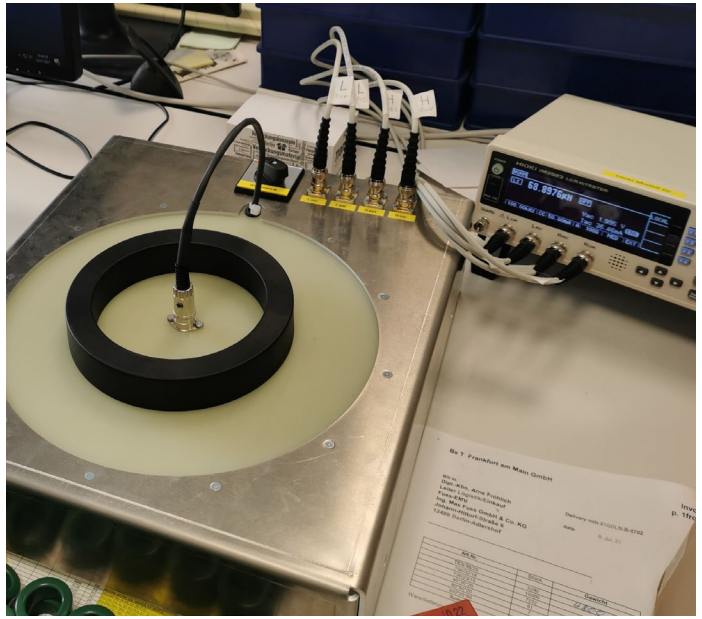
9 Inductance Measurement – Test Signal

- 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 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

	Turns	Frequency kHz	A_L nH/N^2
Toroid	1	10	> 10 000
		100	> 1 000
	10	10	> 100
		100	> 10
	100	10	NA
		100	NA
Cores using bobbin	1	10	NA
	10	10	NA
	100	10	> 10
Cores using Planar Winding	1	10	NA
		100	NA
	10	10	> 100
		100	> 10
	100	10	NA
		100	NA

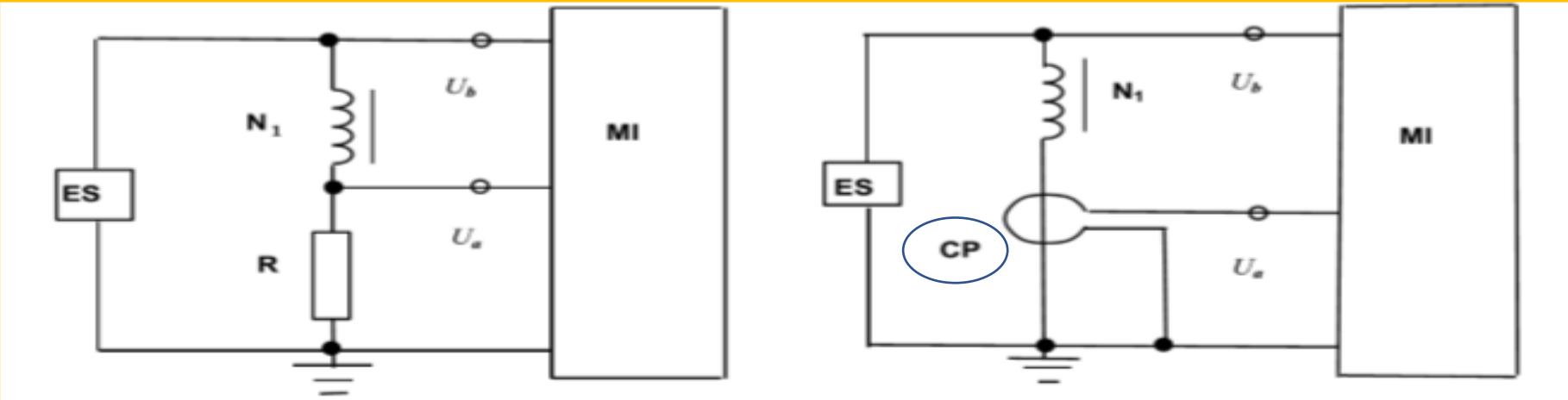


IEC standard 62044-3 description (high excitation)

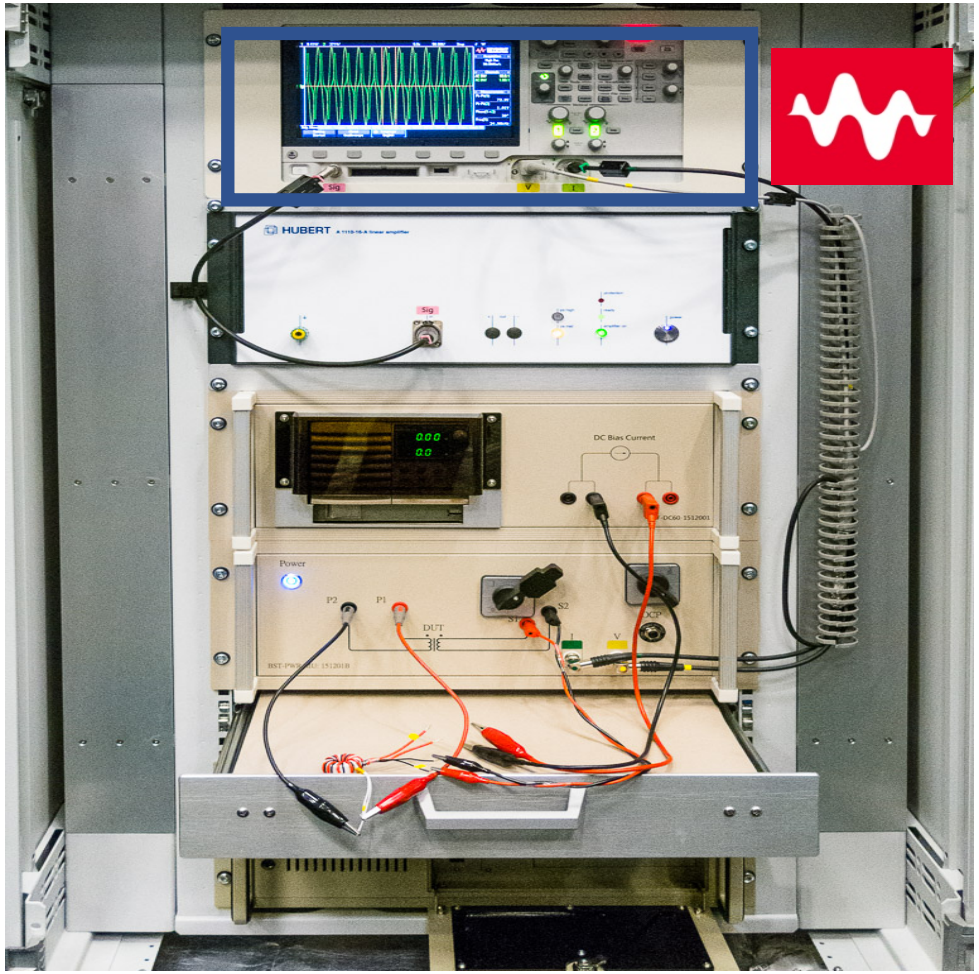
6. 3 Power loss

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.1.1
Impedance analyser	Sinusoidal	Not applicable	Not applicable	C.1.2
Digitizing	Arbitrary	Time	Time	C.1.3
Vector spectrum	Arbitrary	Frequency	Frequency	C.1.4
Cross-power	Arbitrary	Time	Frequency	C.1.5



Hardware 1 oscilloscope 2 channels C1.1



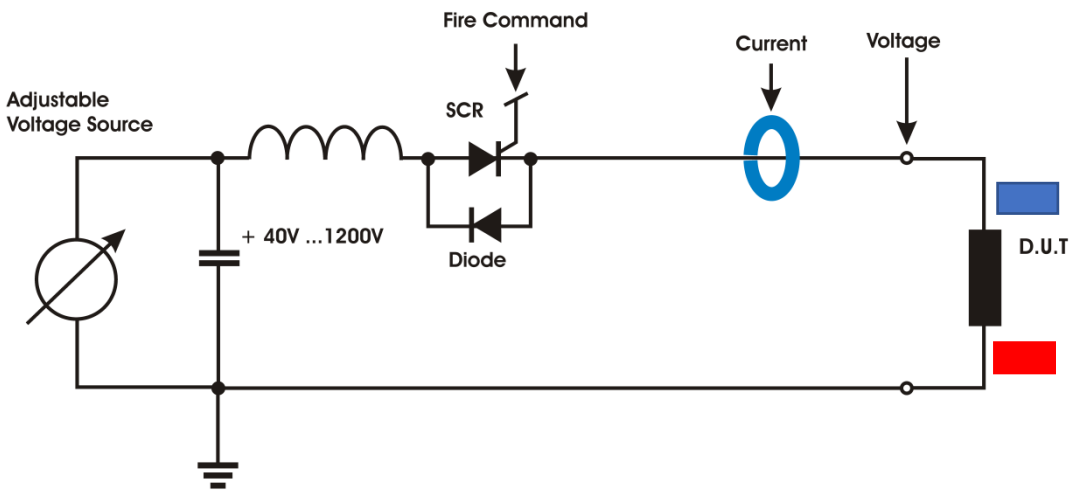
Tek

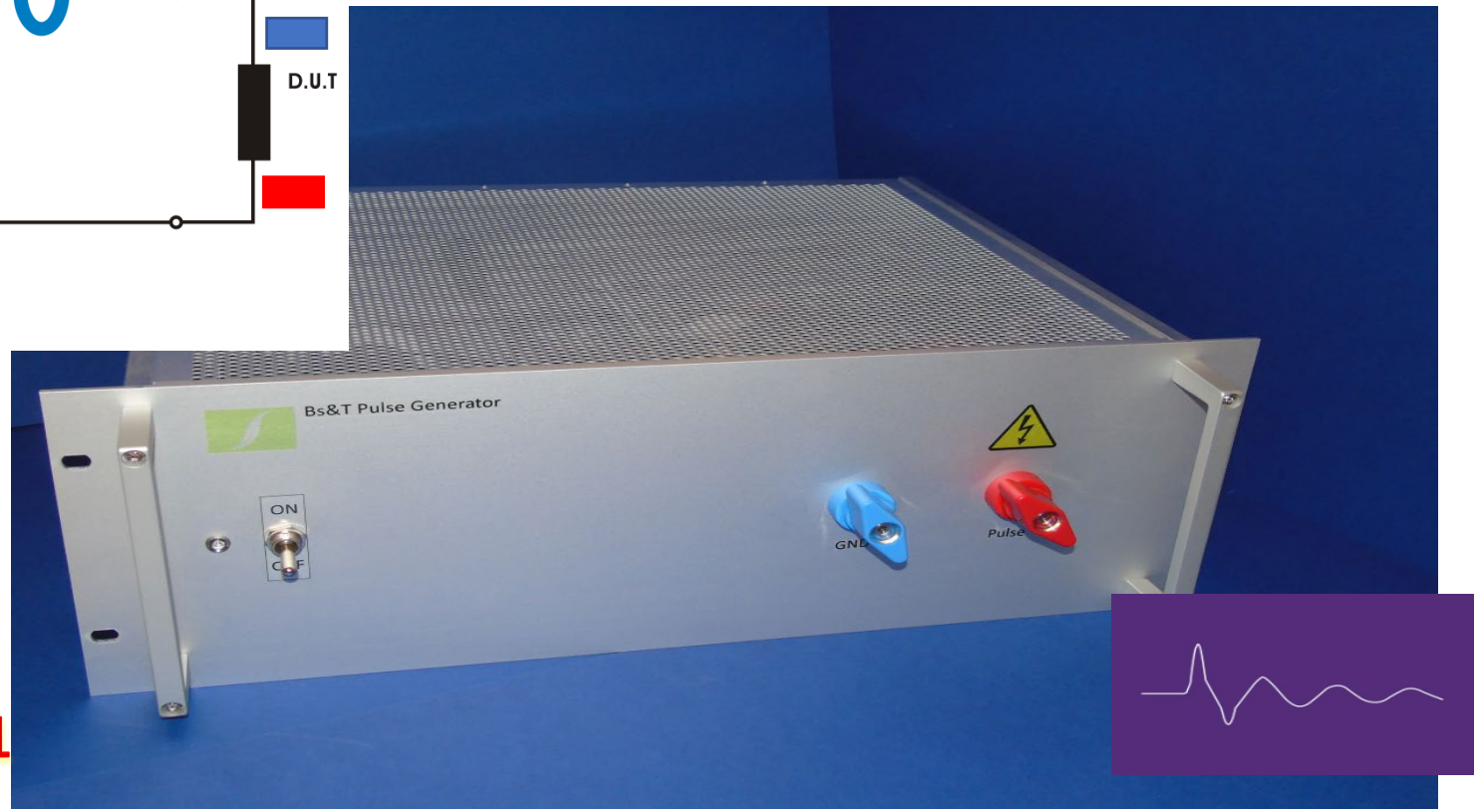
PicoScope®

DIGILENT®
A National Instruments Company

Hardware 2 power meter C1.3

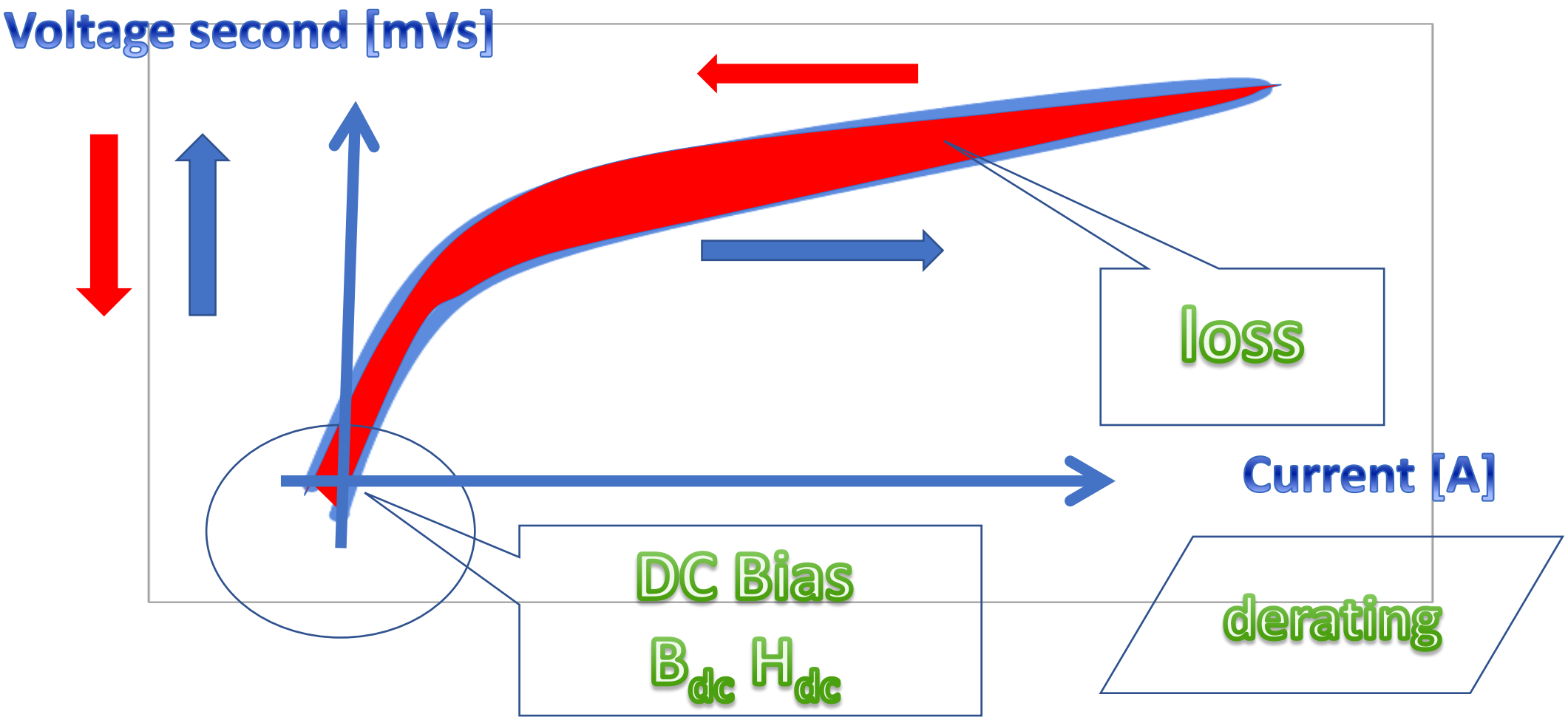
Physic principle & device damped oscillation



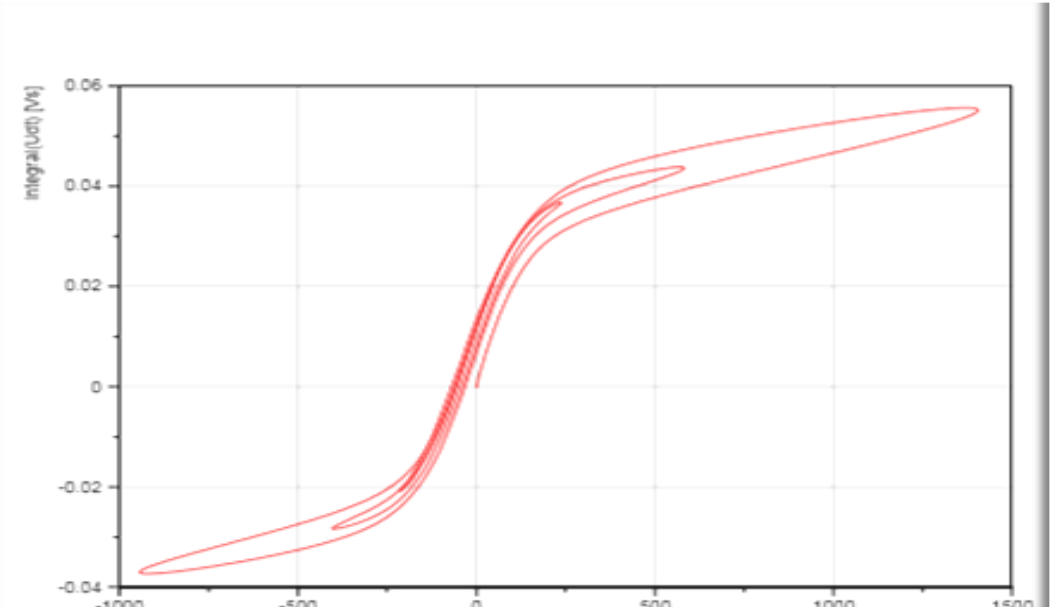


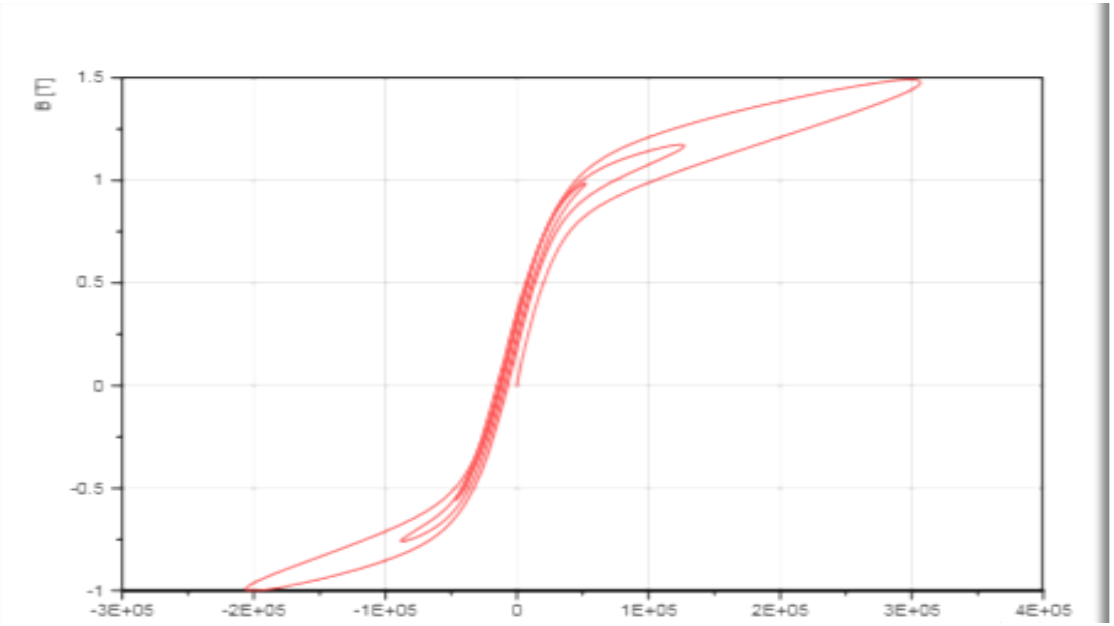
IEEE 393 & IEC60076 JWG 11

magnetization vs. demagnetization



Correlation magnetic component, core and material





- Material
- Geometrie
- Spulendaten

$\Phi = \Psi / w_s$
$\Theta = i \cdot w_p$

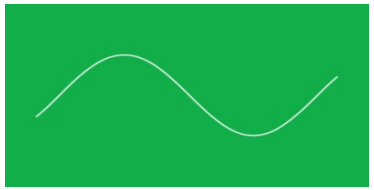
- Material
- Geometrie

$B = \Phi / A$
$H = \Theta / L$

- Material

component L core A_L material μ

N	Le [mm]	Ae [mm²]
53	242,7	704,4



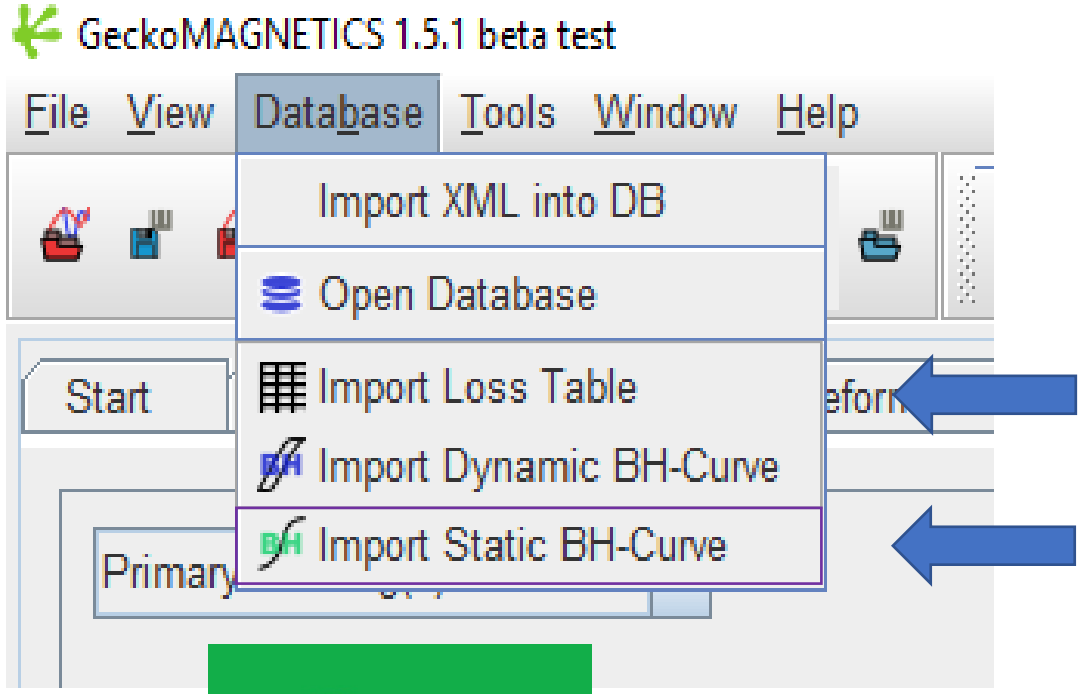
Take home message

- 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

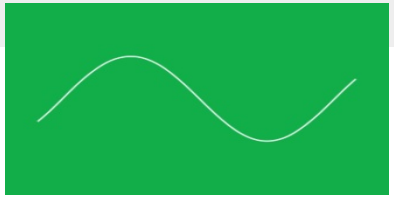
TRIDELTA Weichferrite GmbH

» Thank you for your attention «

Annex 1 measuring data for simulation



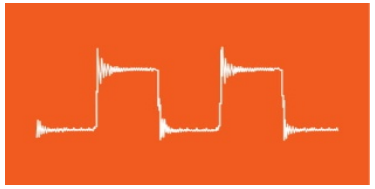
BsT-Pro	2016
BsT-SQ	**2018**
BsT-Pulse	2017



BsT-Pro

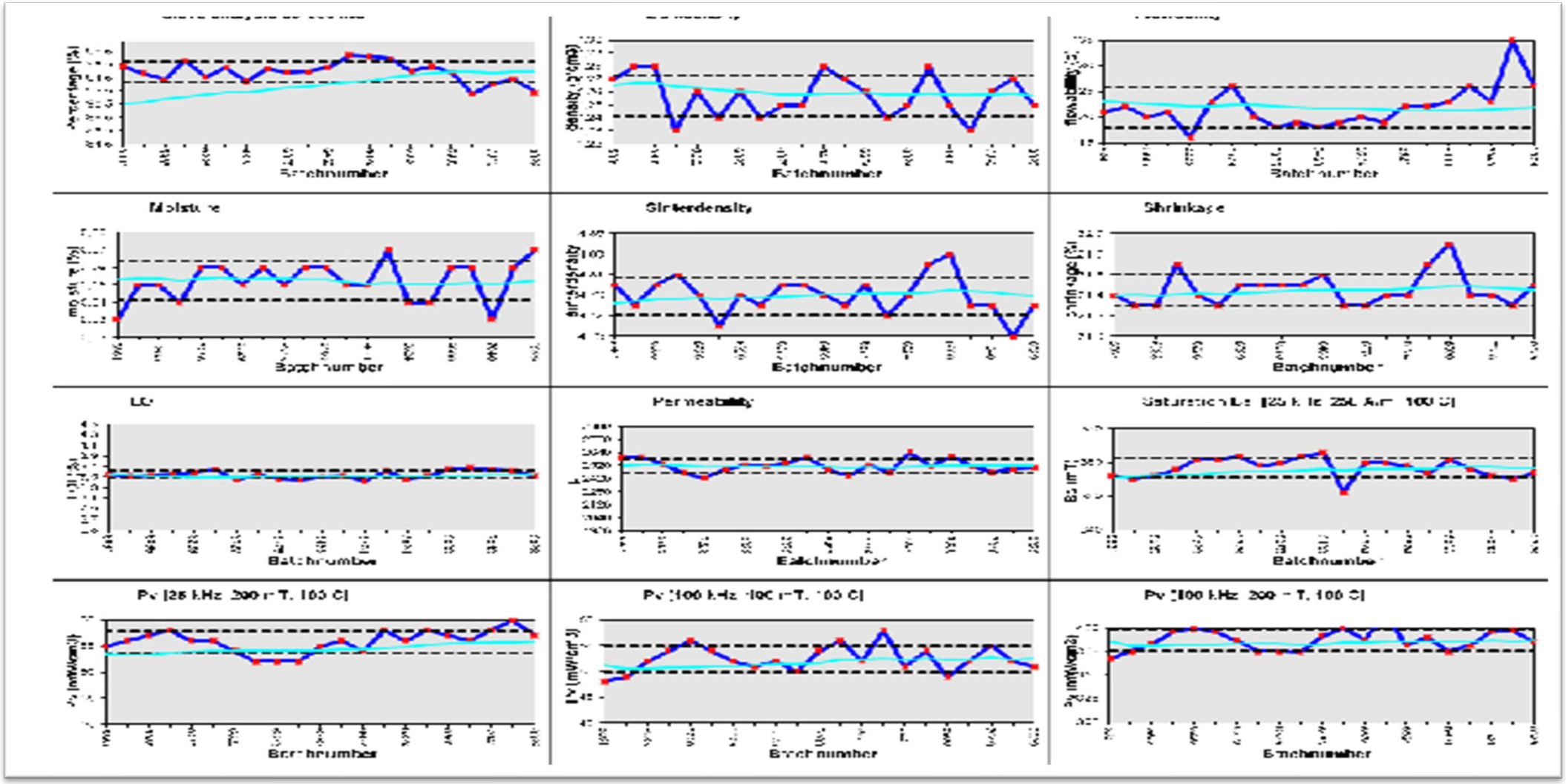
DC biased AC loss

BsT-SQ



BsT-Pulse

Annex 2 uncertainties of process parameter



Annex 3 datasheet of iron oxide, material, core and ...?

thyssenkru

Steel

Quality Certification

Hoesch Premium ®-Iron Oxide

Bs T Frankfurt am Main — Qingdao

Batch 2-3/2022

Fe_2O_3	%		99,6
Al_2O_3	%		0,003
SiO_2	%		0,009
CaO	%		0,007
Cr_2O_3	%		0,001
NiO	%		0,015
TiO_2	%	<	0,001
CuO	%		0,004
SO_3	%		0,002
P_2O_5	%		0,002
V_2O_5	%	<	0,001
PbO	%	<	0,001
SnO_2	%	<	0,001
ZnO	%		0,004
MgO	%		0,001
MnO	%		0,22
Na_2O	%		0,009
K_2O	%	<	0,001
Cl	%		0,09
anealing-loss	%		0,15
moisture	%		0,01
bulk-density	g/l		489
specific surface area	m^2/g		3,76
tap-density	g/cm^3		0,73

GRANULATE PROPERTIES

binder ≈ 0,8 wt.% (cocktail)

				specification	info	r.f.c.
sieve analysis	[%]	< 80 µm	0,70	≤ 5		
		80-315 µm	83,85	≥ 75		
		315-400 µm	13,65	rest to 100		
		> 400 µm	1,80	≤ 7		
bulk density	[g/cm³]		1,44	1,41 - 1,45		
flowability ∅ 6 mm	[s]		22,2	≤ 23,5		
moisture	[%]		0,06	0,04 - 0,10		

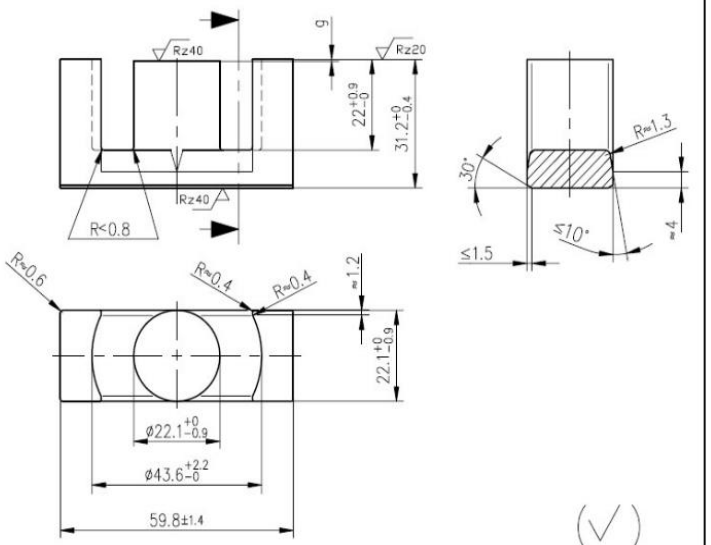
SINTER RESULTS

sinter program: FHO, 2506, 1325°C/3h, c_1=13385, c_2=9,115

			specification	info	r.f.c.
press density	[g/cm³]	**2,87**			
sinter density	[g/cm³]	4,74	4,80 ± 0,05		
ring compaction force	[kN]	44,8			
NSF nominal shrinkage factor	[%]	19,1	19,5 ± 0,5		
SBC spring-back coefficient	[%]	0,4	≈ 0,4		
loss on ignition	[%]	2,78	≈ 2,8		

ELECTRICAL RESULTS

			specification	info	r.f.c.
µi: initial permeability	[-]				
25°C, 10 kHz, 0,1mT		2487	2400 ± 20%		
Pv: power losses	[kW/m³]				
100°C, 25 kHz, 200 mT		57	≤ 60		
100°C, 100 kHz, 100 mT		49	≤ 60		
100°C, 100 kHz, 200mT		384	≤ 400		
100°C, 400 kHz, 50 mT		162			
B: flux density	[mT]				
25°C, 25 kHz, 250 A/m		442	≥ 430		
100°C, 25 kHz, 250 A/m		355	≥ 340		



C1	0.382	mm⁻¹
le	141	mm
Ae	368	mm²
Amin	366	mm²
Ve	51700	mm³

nach DIN EN 61185

AL-Wert (nH) 25°C	Verlustleistung P≤ (W/Satz) 100°C	25°C	$\hat{B}$ ≥ (mT) 100°C	Meßbedingung f	Aussteuerung
5200±25%				10 kHz	≤0,25 mT
			330	16 kHz	250 A/m
	3.6	7.2		25 kHz	200 mT
	5.2			100 kHz	100 mT
	23.3			100 kHz	200 mT

» Annex 4: History of TRIDELTA Weichferrite GmbH - from the beginning «

TRIDELTA Weichferrite GmbH

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

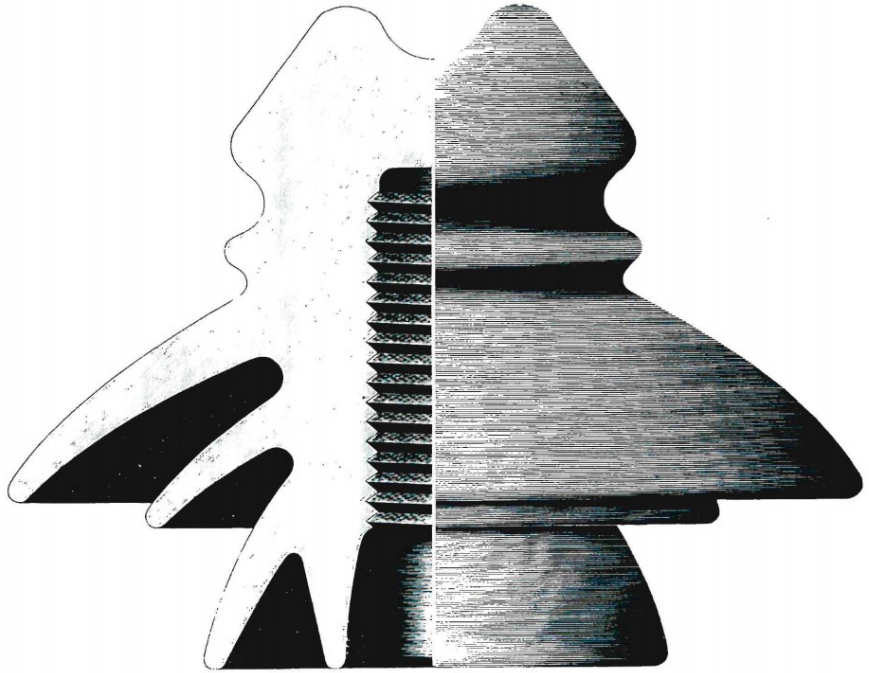
1957 Establishment of the CWH (Ceramic Works Hermsdorf)

1990 Foundation of the TRIDELTA AG

2002 TRDIELTA 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



Delta-Glocke von 1927

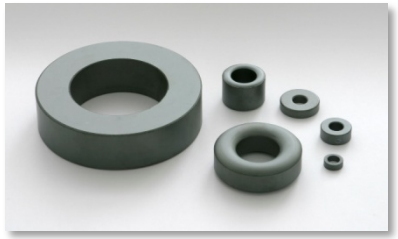
» Annex 5: History of TRIDELTA Weichferrite GmbH – until today «

TRIDELTA Weichferrite GmbH

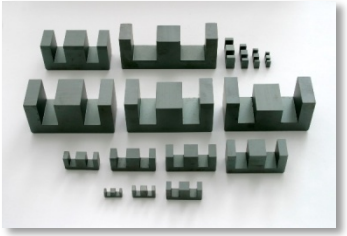
- 28 employees
- More than 1500 customers
- Export to 58 countries on 6 continents
- 15 different soft magnetic materials with continuous further development
- The product portfolio currently includes 550 different combinations of geometry and material as well as many customer-specific special designs

» Annex 6: Products made from soft ferrite materials – standard shapes «

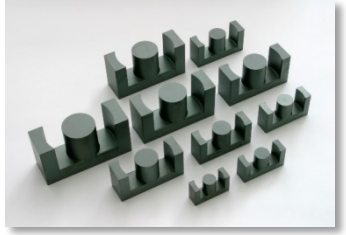
TRIDELTA Weichferrite GmbH



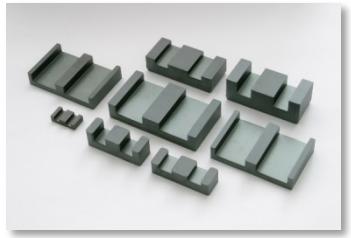
Ring cores



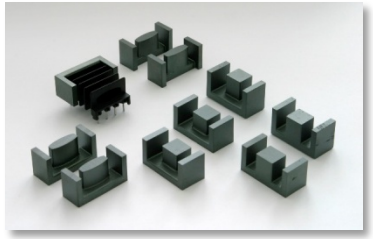
E- and EF-cores



ETD-cores



Planar-cores



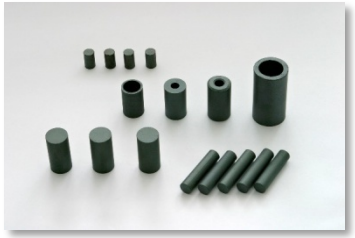
ECL- and EVD-cores

EC- and ER-cores

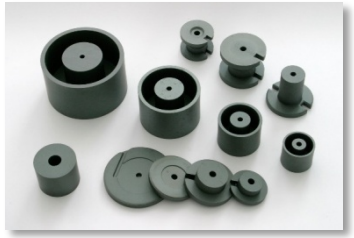
U-, UI- and UR-cores

PM-cores

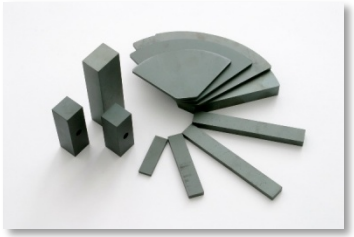
RM-cores



Tube- and Cylinder-cores



C-, Roll- and Mushroom-cores,
Disc-cores



Segment- and Profil-cores

» Annex 7: Customer-specific designs – more than 15 years of experience «

TRIDELTA Weichferrite GmbH

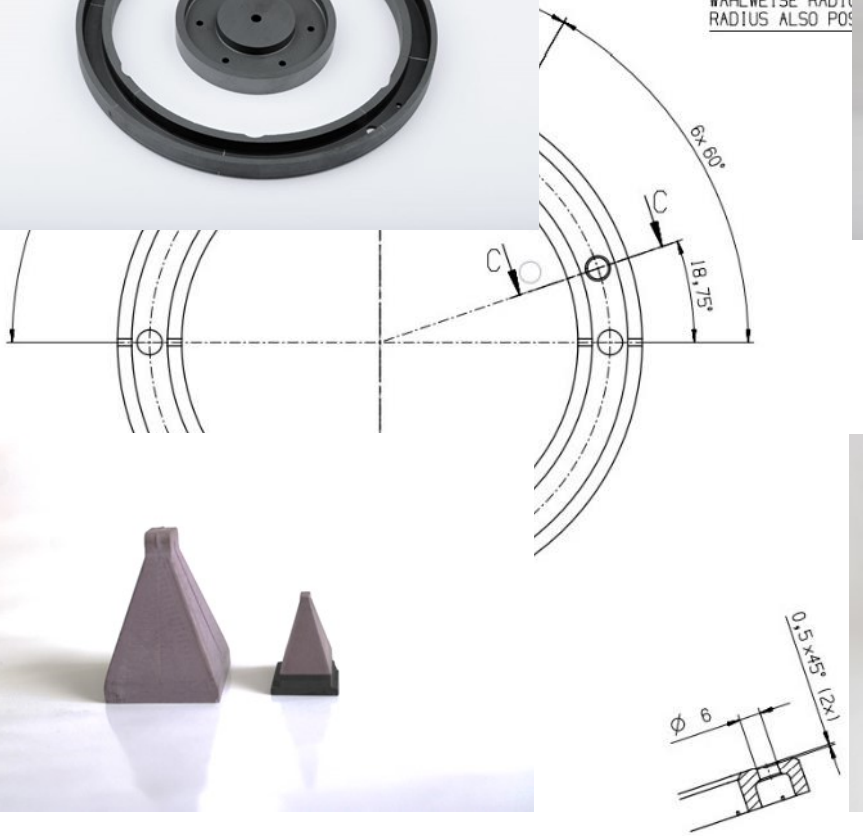
Diversity

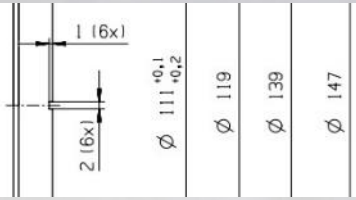
Material

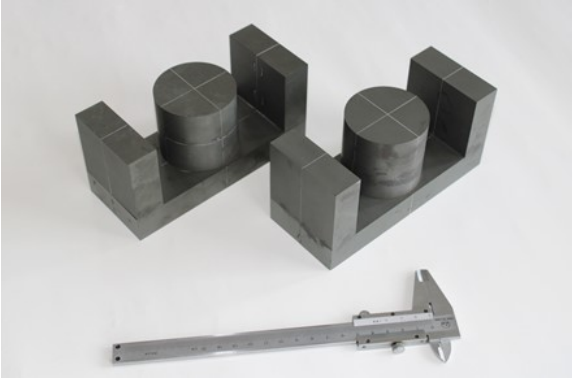
- ferrite
- oxide ceramics
- non-oxide ceramics
- silicon (mono. / poly.)
- quartz glass
- hard-past porcelain

Machining

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







» Annex8: soft magnatic vs. hard magnetic «

TRIDELTA Weichferrite GmbH

- 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 A/m

< 1000 A/m = **soft magnetic** > 1000 A/m = hard magnetic

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