

# Loss vs. E/U shaped cores

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19. March 2022 Houston(TX)  
Workshop PSMA HF Magnetics



## JC and his...

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- ❖ physicist & engineer
- ❖ make and design ferrite 3Cx and 3Fx
- ❖ sales amorphous metals 2605/2714/2705
- ❖ marketing nanocrystalline 500F components



*Metglas*<sup>®</sup>



- ❖ Bs & T Frankfurt am Main GmbH & Chicago Corp.



## Outline

- Introduction Bs&T
- magnetic vs. loss equivalent geometry
- Correction of cross section
- Consideration of eddy current loss (separately)
- Limit loss value setting toroid to E&U shaped core
- Take home message

# Bs & T Analyzer

## Sinus Magnetization AC

high excitation

*IEC 62044-3*

loss,  $\mu_a$  driven by B mode

$B_{peak}$  loop driven by H mode

DC superposition

BsT-Pro

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

$\mu_{rev}$

major, and biased minor loop



low excitation

*IEC 62044-2*

## 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

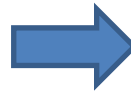
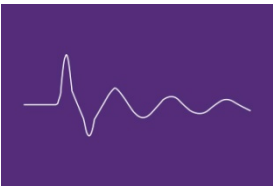
dB/dt

**Damped oscillation**

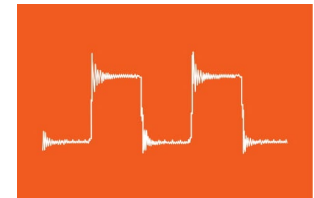
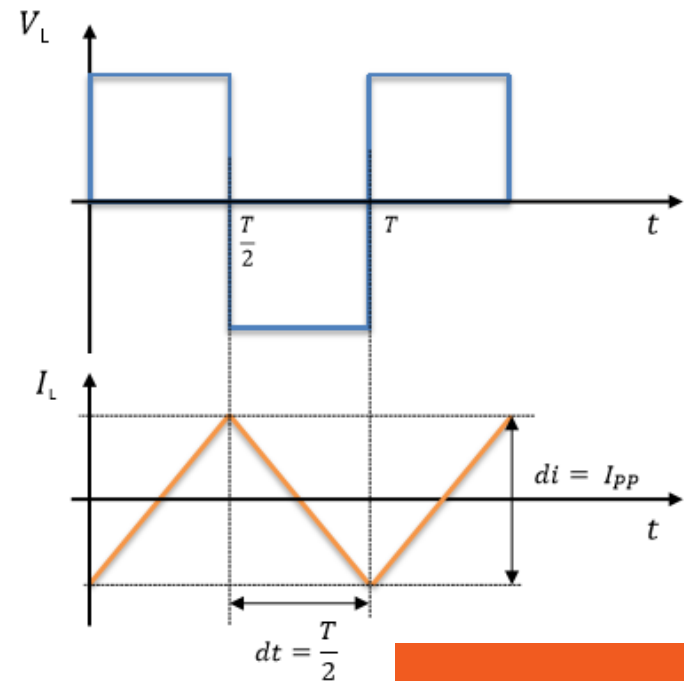
**BsT-Pulse**

differential and amplitude L

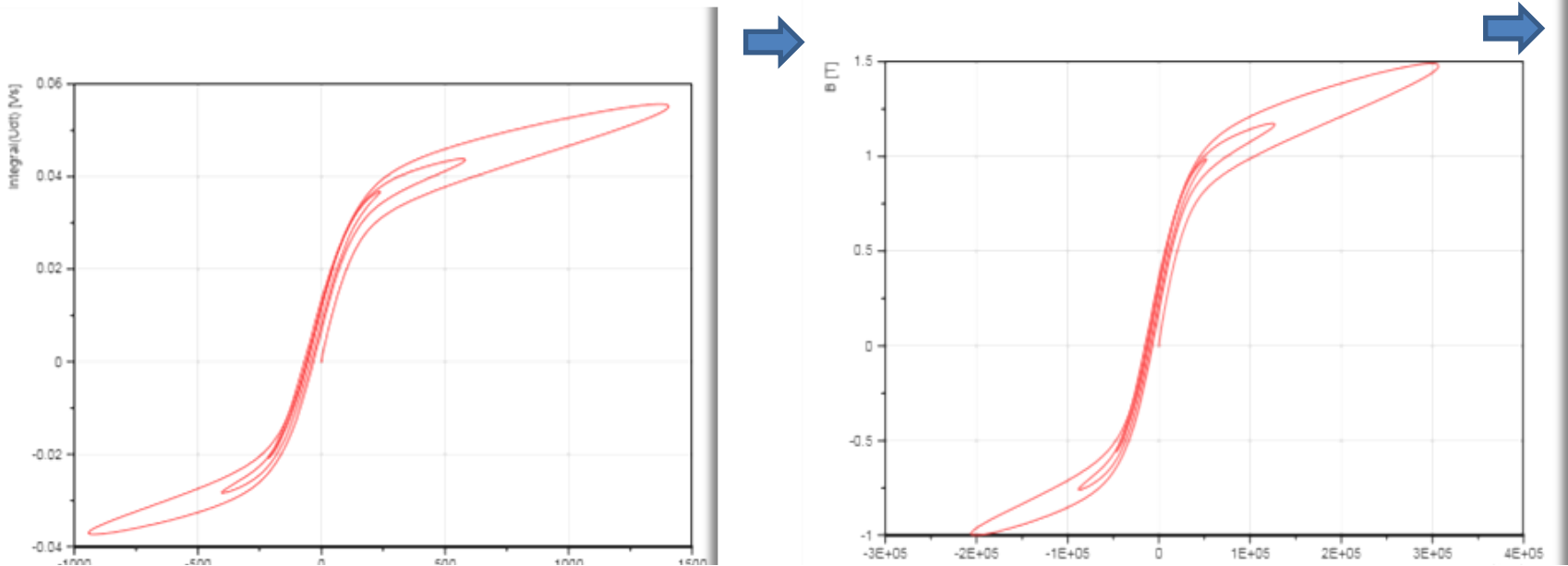
energetic L, power loss



## Square Wave



# Correlation magnetic component, CORE and material



- Material
- Geometrie
- Spulendaten

$$\Phi = \Psi / w_s$$

$$\Theta = i \cdot w_p$$

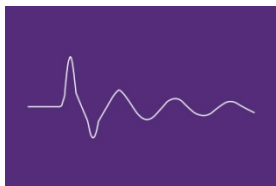
- Material
- Geometrie

$$B = \Phi / A$$

$$H = \Theta / L$$

- Material

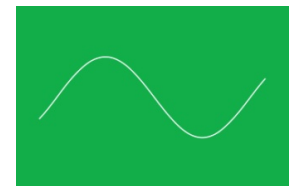
component



CORE

N	Le [mm]	Ae [mm <sup>2</sup> ]
53	242,7	704,4

material



## Calculation Basics

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- The magnetic parameters, such as  $A_e$ ,  $L_e$  and  $V_e$  are defined according to the standard **IEC 60205**, their physical principles will also be followed due to its intrinsic correctness.
- The simplification in the **IEC 60205** for the toroidal core has a fair precision, however, as the difference from outer to inner flux path of the shaped core increases, the error will also increase correspondingly  
 $C_1 \neq C_{1m}$ ;  $C_2 \neq C_{2m}$
- Calculus via **integral** vs. **arithmetic**

## Example Toroidal OD25ID15H10 [mm]

$$C_1 = 1,2294$$

$$C_2 = 0,02513$$

$$A_e = 48,93 \text{ mm}^2$$

$$l_e = 60,15 \text{ mm}$$

$$C_{1m} = 1,2560$$

$$C_{2m} = 0,02512$$

$$A_e = 50,00 \text{ mm}^2$$

$$l_e = 62,80 \text{ mm}$$

the standard IEC 60205 **only** describes the determination of the loss-equivalent effective quantities, but did not distinguish the reference data valid for the saturation **flux density** and the  $A_L$  value. The entire cross section of the toroidal core is available for the magnetic flux. It only has to be ensured that the magnetic field strength is sufficiently large to saturate homogeneously the cross section with the maximum magnetic path length. The flowed through magnetic flux is determined by the saturation flux density of the material and the smallest nominal cross section perpendicular to the magnetic path. In the aforementioned magnetic core, the physical cross section is a  $50 \text{ mm}^2$ . However, by using the loss-equivalent effective cross-section of  $48.93 \text{ mm}^2$  will bring an error of approx. **2%** when calculating the saturation flux density of the material from the corresponding voltage measurement (for a given current). Furthermore, the same error (i.e. 2% between  $50 / 62.8$  and  $48.95 / 60.15$ ) will all be induced when calculating the  $A_L$  value of any molded body with a uniformly circumferential cross-section.



## Continue

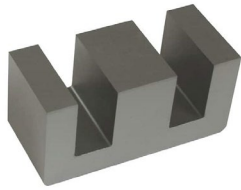
When determining the **loss-equivalent** reference values, proportional losses were assumed to derive the relationship for  $C_2$  to  $B^3$ . The dependence of the losses on the flux density is insignificant for the flux in a magnetic circuit. Rather, the attention must be taken that the magnetic flux is determined by the ratio  $I / A$  and the fact that the entire available cross-section is inhomogeneously flooded due to the dependency  $I / A$ . The prerequisite is that the inhomogeneity remains within the limits while the prerequisite that the permeability is a constant holds its validity. For magnet-equivalent reference quantities, the constant  $C_1$  is as with the loss-equivalent reference quantities

$$C_1 = \oint \frac{dl}{A} \quad \tilde{C}_{2m} = \oint A dl \quad \begin{array}{l} C_1 = 1,2294 \\ C_{2m} = 3140 \end{array} \quad \begin{array}{l} A_e = 50,54 \text{ mm}^2 \\ l_e = 62,13 \text{ mm} \end{array}$$

The ratio  $A_e / l_e$  is therefore the same for the loss-equivalent and the magnet-equivalent calculated reference values. It is therefore sufficient to determine the loss-equivalent quantities, because only the ratio  $(A_e / l_e)$  is used for the  $A_L$  value calculation.

## Example E 20/10/05 [mm]

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E-core has the following dimensions (in mm):

Length = 20.15

Width = 13.10

Depth = 5.10

Center pole thickness = 5.00

Height = 10.00

Chamfer depth = 6.50

**IEC 61246**

The aforementioned method only applies if the cross section of the core is perpendicular to the magnetic path, such as in a toroidal shaped core. In practice, however, there are cases with a non-constant cross-section. An example is the E20/ 10/ 05 core, where the center leg has a cross-section of  $25.5\text{mm}^2$ , the crossbeams of  $35.7\text{mm}^2$  and the outer legs is of  $35.96\text{mm}^2$ . In such cases, the  $A_e$  value calculated for a uniform cross-section must be corrected with weighting the volume fractions and the flux density dependence of the losses. Then the ratio  $A_e / l_e$  is “equivalent to loss” unequal to the  $A_e / l_e$  ratio “magnetically equivalent”.

## Continue

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From these dimensions, the cross-section of the central leg is calculated to be 25.5 mm<sup>2</sup> perpendicular to the magnetic flow direction and the area of the outer legs to be 35.96 mm<sup>2</sup> and the area of the crossbeams to be 35.70 mm<sup>2</sup>. Basically, it is important to determine the center of gravity line (also known as the "heart line") of the magnetic flux. In the case of E-cores with a rectangular cross-section, the width of the heart line of the body is given by  $\frac{1}{4}$  of the sum of the winding width and the central leg thickness plus  $\frac{1}{2}$  of the outer leg thickness. The height of the heart line is given by **doubling** the body depth of the E core plus its crossbeam height. The length of the heart line for example with E20/10/05 is calculated as 47.125 mm.

The maximum and minimum magnetic path length for an E-core with a rectangular cross-section result from the given dimensions. The error to correlate from toroid to square frame is about  $2\pi/8 \sim 0,78$ , In the case of different cross-sectional shapes, e.g. an E core with a round center pole, like ETD/ER, the cross-sections of the legs must be converted into equivalent rectangular cross-sections of the same area and arranged symmetrically to the determined center line. This procedure can be traced in detail with the formulas systematically.

## Correction of cross section

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the loss-equivalent reference quantity  $A_e$ , initially calculated for a uniformly circumferential cross-section, can then be corrected in the following way

the magnet-equivalent reference values are not corrected

$$A_{e,korr} = \sum_i \frac{A_e}{\left( \frac{A_i}{\langle A \rangle} \right)^{2.5} \cdot \frac{l_i}{\langle l \rangle}}$$

- $A_{e,korr} = 29,96 \text{ mm}^2$
- $A_{\min} = 25,5 \text{ mm}^2$
- $A_{e,m} = 32,62 \text{ mm}^2$
- $l_{e,m} = 46,55 \text{ mm}$

## calculation of the limit values for the losses of core set

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The losses of a pair of cores can be estimated based on the basic data of the material and the volume ( $V_e$ ) of the molded body. The basic data (in  $\text{mW} / \text{cm}^3$ ) always apply to a toroidal core in a certain size, e.g. with  $A_e = 58 \text{ mm}^2$  and  $l_e = 60 \text{ mm}$ . Since the eddy current losses are proportional to the frequency square and the cross-sectional area of the product, this contribution to the total losses must be taken into account, separately, when using the basic data, especially for large sized cores and at high frequency excitation.

## Continue

The basic data of the power losses in mW/ cm<sup>3</sup> (P<sub>v</sub>) at 100 ° C are:

\* Saturation flux density in mT (B<sub>s</sub>) at 100 ° C

Material	25kHz/200mT	100kHz/100mT	400kHz/50mT	25kHz/250A/m*
PW1	<88	<88	---	<330
PW2	---	<110	<190	<320

- Saturation flux density in mT (B<sub>s</sub>) at 100 ° C
- Material PWx according to IEC61332

**Table 1: P<sub>v</sub>-Basic data**

Material:	PW1	PW2
P <sub>v—eddy</sub> 100kHz, 100mT [mW/cm <sup>3</sup> ]	6,5	5
P <sub>v—eddy</sub> 400kHz, 50mT [mW/cm <sup>3</sup> ]	---	20

The addition due to eddy current losses (P<sub>v—eddy</sub>) per surface normal (= 58mm<sup>2</sup>) at a given frequency for the corresponding power materials can be found in the following table.

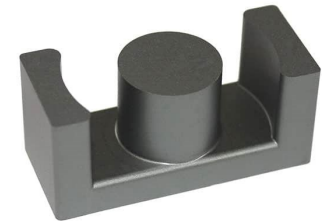
**Table 2: Eddy current modification for loss specification**

## Like E & U shaped core set:

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- E, ETD, ER-core (**IEC 61246/61185/61860**)

$$P_v^{\text{Spezifikation}} = \left( 2 / 3 \cdot \frac{A_e^{\text{Artikel}}}{58} - 1 \right) \cdot P_v^{\text{Wirbel}} + P_v^{\text{Basis-Spez., Artikel}}$$



- U, UR-core IEC

$$P_v^{\text{Spezifikation}} = \left( \frac{A_e^{\text{Artikel}}}{58} - 1 \right) \cdot P_v^{\text{Wirbel}} + P_v^{\text{Basis-Spez., Artikel}}$$



## Take home message

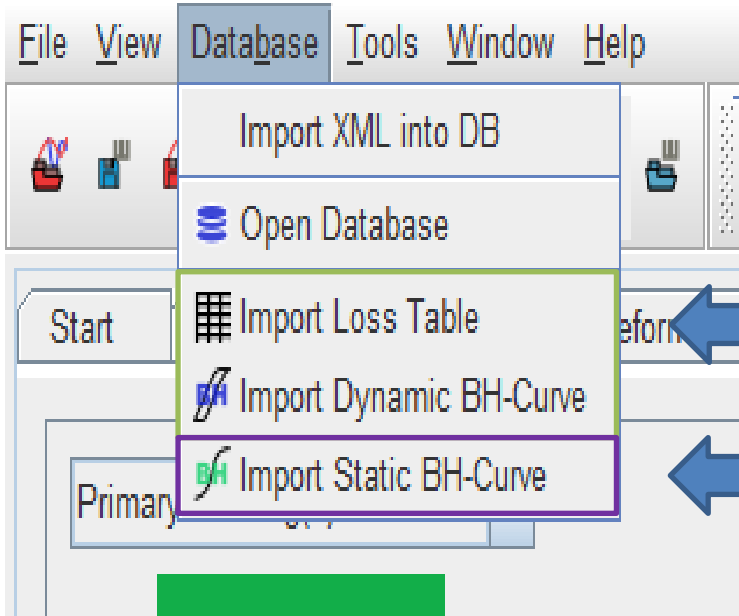
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- Loss mechanism of softmagnetic **material** is **not** well understood, there is no micromagnetic model to describe loss e.g. loss density
- Magnetostatic anisotropy includes the geometric parameter, more dominant than material impact for the most design
- Measuring is only way to provide limit value as specification
- Measuring compliant standard is only way to scale up the acceptance



# Annex 1 measuring data for simulation

GeckoMAGNETICS 1.5.1 beta test



BsT-Pro

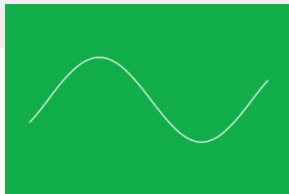
2016

BsT-SQ

2018

BsT-Pulse

2017



**BsT-Pro**

DC biased AC loss



**BsT-SQ**



**BsT-Pulse**

## Annex 2 Abbreviations and terms used

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$A_e$  = magnetically effective cross-section

$A_{min}$  = the minimum available magnetically effective cross-section (except for toroidal cores,  $A_{min} = A_e$  always applies).

$l_e$  = magnetically effective length

$V_e$  = magnetically effective volume

$C_1$  = (integral) magnetic form factor, equal to the line integral over the area along the closed circle:

$C_2$  = (integral) magnetic form factor, equal to the line integral along the square of the area of the closed circle:

$C_{1m}$  = (Discrete) magnetic form factor, equal to the sum over the surface sections of the closed circle:

$C_{2m}$  = (Discrete) magnetic form factor, equal to the sum over the surface segment squares of the closed circle:

= Magnetic equivalent form factor  $C_{2m}$  in integral form, equal to the line integral over the area segments along the closed circle:

$\mu_0$  = permeability in vacuum ( $=4\pi \cdot 10^{-7} \text{H/m}$ )

$A_L$  = inductance of a magnetic circuit normalized to the square of the turns [nH]

$G$  = magnetically effective residual air gap [mm]

$A_G$  = cross-sectional area of the remaining air gap

$\mu_i$  = initial permeability

$r_i$  = inner radius of a toroidal core

$r_a$  = outer radius of a toroidal core

$a_a$  = outer circumference of a rectangular frame

$a_i$  = inner circumference of a rectangular frame

$P_v$  = core loss [ $\text{mW} / \text{cm}^3$ ]

$B_s$  = saturation flux density [mT]

$P_{v\text{-eddy}}$  = power losses caused by eddy currents

## Annex 3 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 <sup>2</sup>
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

