Pulse Testing of Magnetic Cores and Inductors

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Bs&T Frankfurt am Main GmbH
16. March 2019 Anaheim (CA)
Workshop PSMA HF Magnetics

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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

Bs&T Analyzer

www.powerlosstester.de

Outline

- 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, μ_a driven by B mode

B_{peak}, loop driven by H mode

low excitation

IEC 62044-2

DC superposition

Pulse Magnetization

fast transit of magnetic state

dB/dt

IEC 60367-1 Annex G (393 IEEE)

BsT-Pro

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

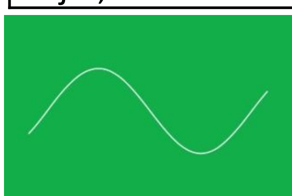
μ_{rev} (f, B, T, H_{DC})

major, and biased minor loop

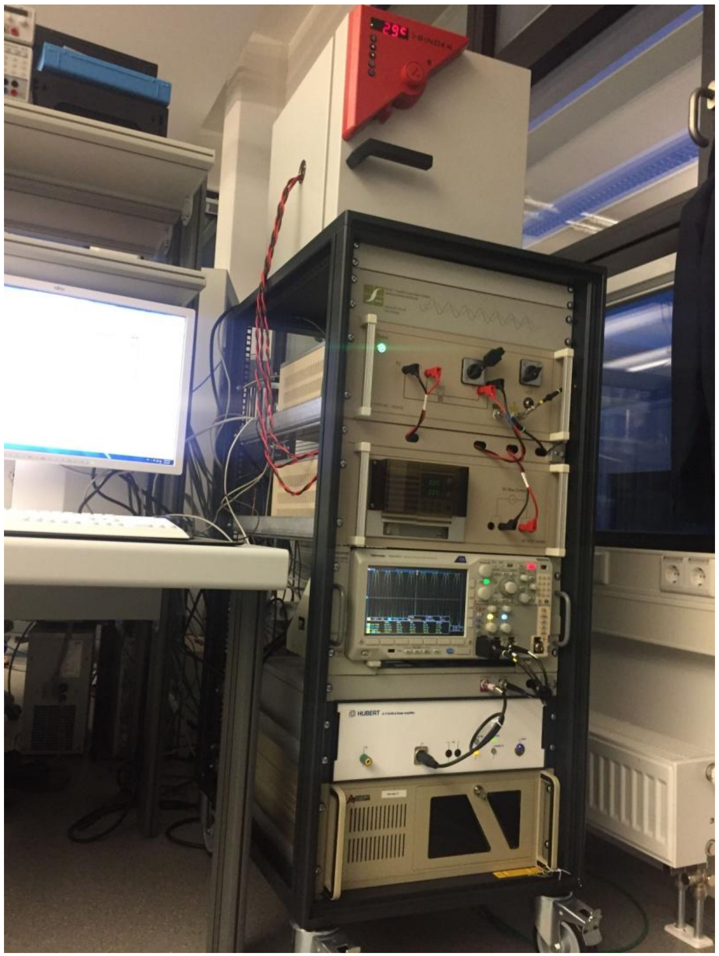
BsT-Pulse

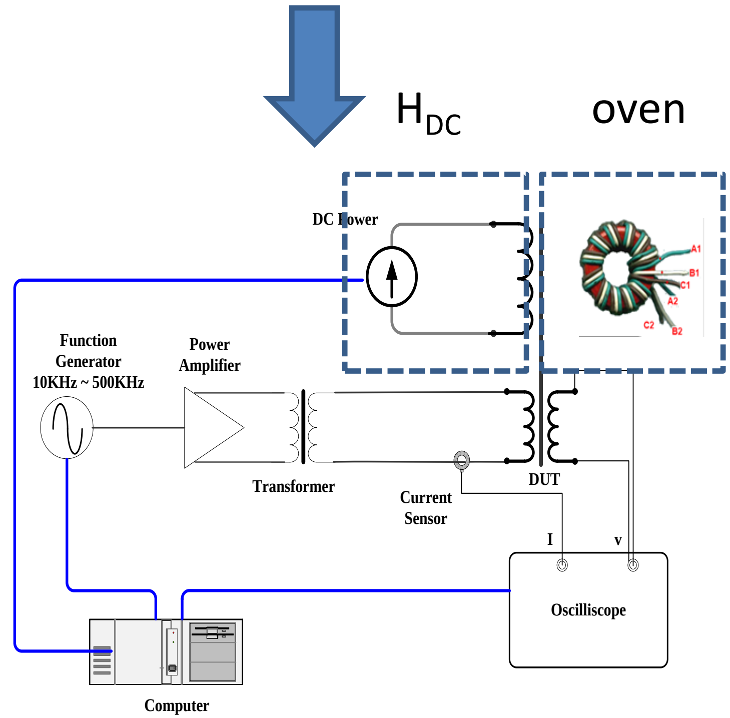
differential L and **amplitude L**,

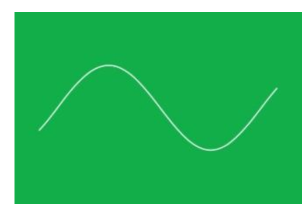
energetic L, power loss i.e. Q factor



BsT Pro




H_DC
oven
DC Power
Function
Generator
10KHz ~ 500KHz
Power
Amplifier
Transformer
Current
Sensor
DUT
I
v
Oscilliscope
Computer



BsT-Pulse

Pulse Magnetization

fast transit of magnetic state

dB/dt

Damped oscillation

BsT-Pulse

differential and amplitude L

energetic L, power loss

pulse energy ~ **200 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

IEC 60076-6

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

Differential L

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

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

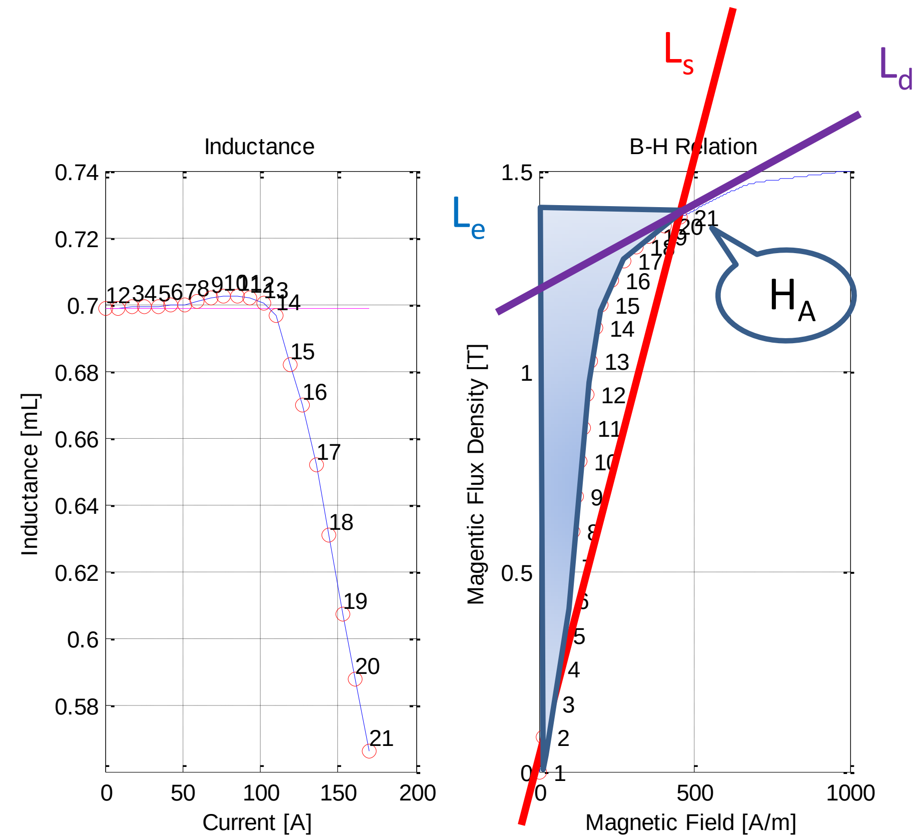
$$\frac{\mathrm{d}\left[i \cdot L_s(i)\right]}{\mathrm{d}t} = L_s(i) \cdot \frac{\mathrm{d}i}{\mathrm{d}t} + i \cdot \frac{\mathrm{d}L_s(i)}{\mathrm{d}t}$$

Amplitude L →

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

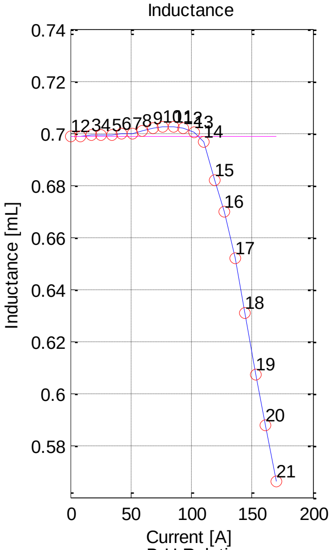
Energetic L

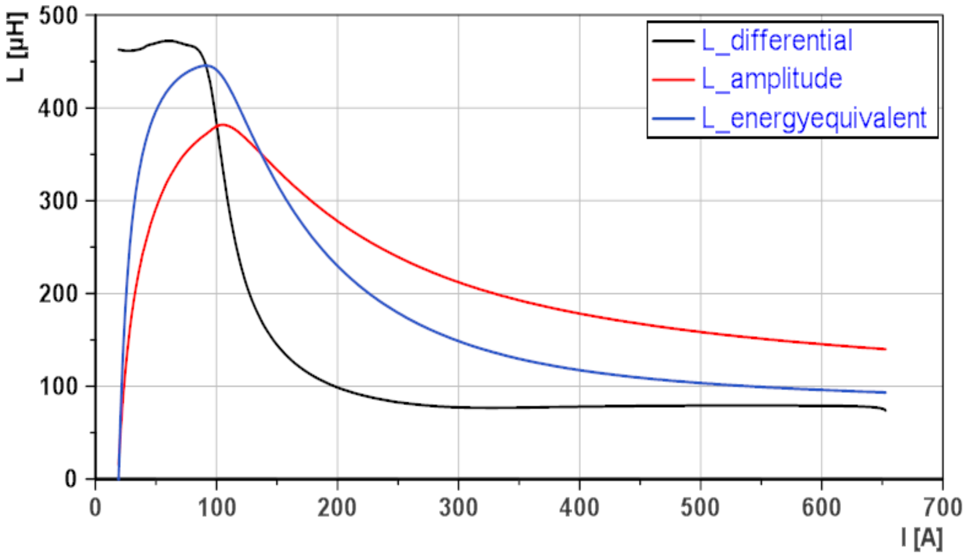
$$L_e(i) = \frac{2}{i^2} \int_0^i i \cdot L_s(i')\, di'$$

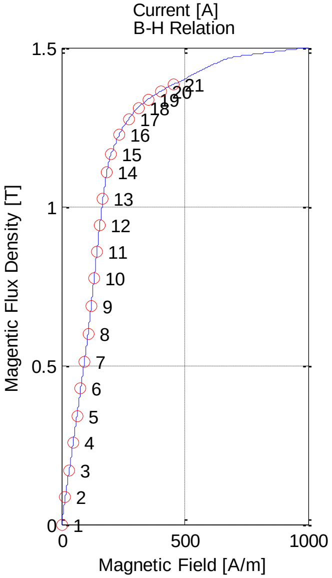


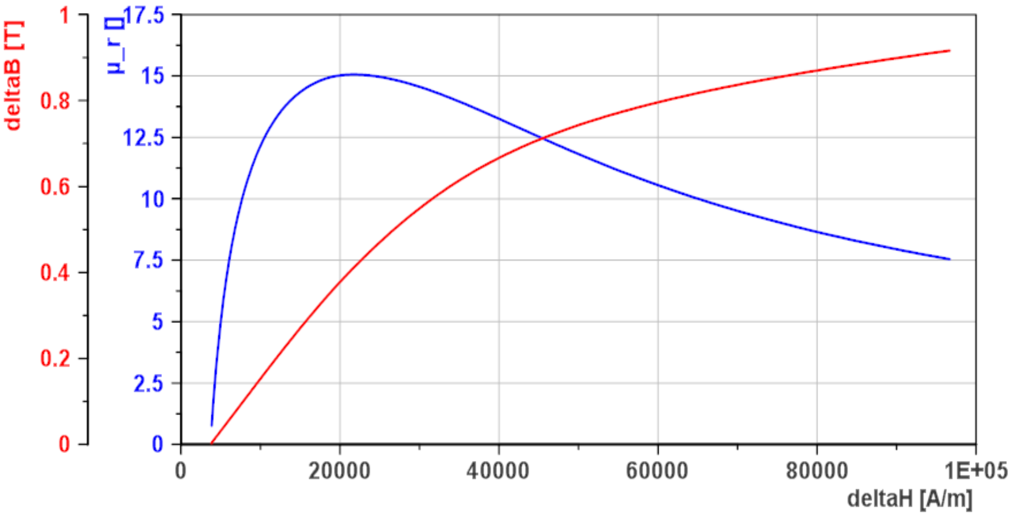
Alex van den Bossche

Inductance analysis to characterize saturation





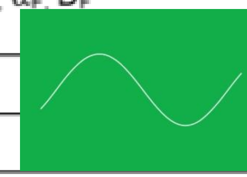




Typical value and Limit value

IEC 60401

Document classification	Typical value	Limit value
Catalogue[a]	THD_F, Z, P_V	
Material table	all other properties than those described in "Limit value".	μ_i, B_s, B_r, H_c, $\tan\delta/\mu_i$, η_B, T_c, α_F, D_F
Material curve	all properties	
(Shaped) Core table		A_L, THD_F, Z, P_V



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

Inductor rated current / saturation current, rated inductance, R_{DC}

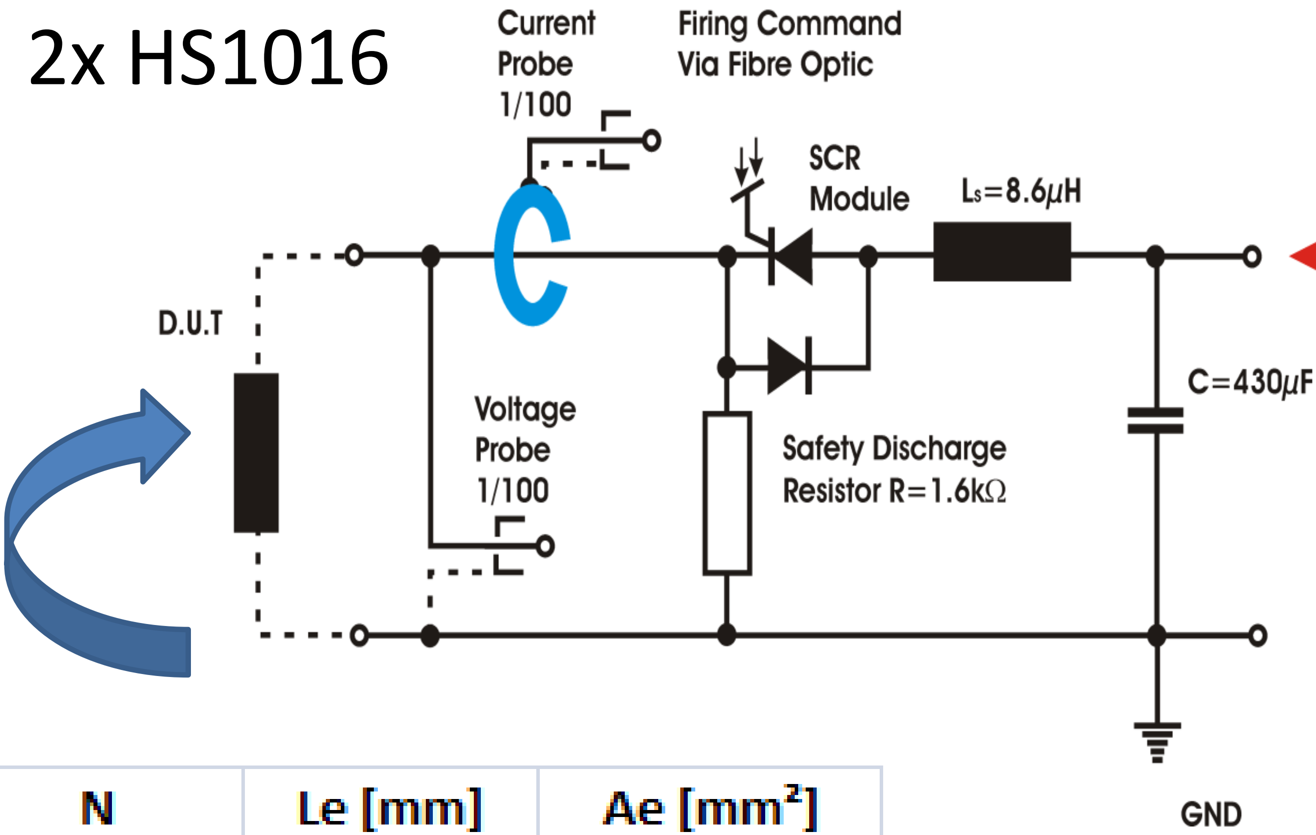
Problem:

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

Solution: **BsT-Pulse** non linearity of inductance value and Q factor

Measuring principle with example

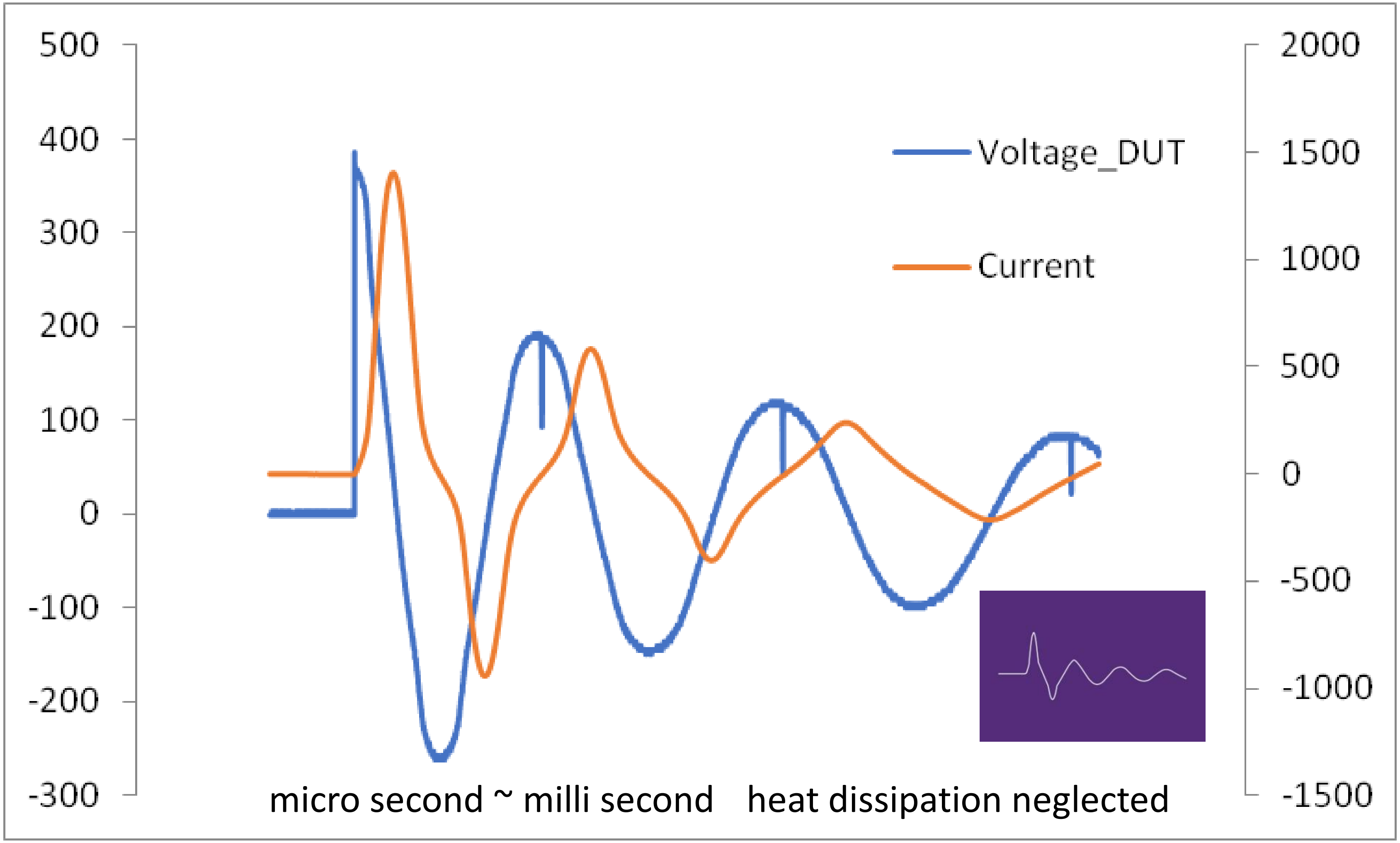
2x HS1016



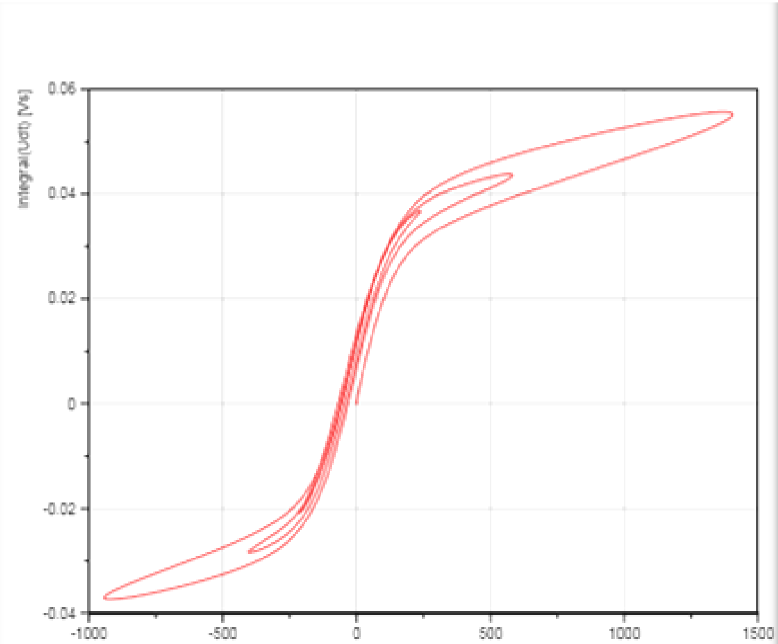
N	Le [mm]	Ae [mm²]
53	242,7	704,4

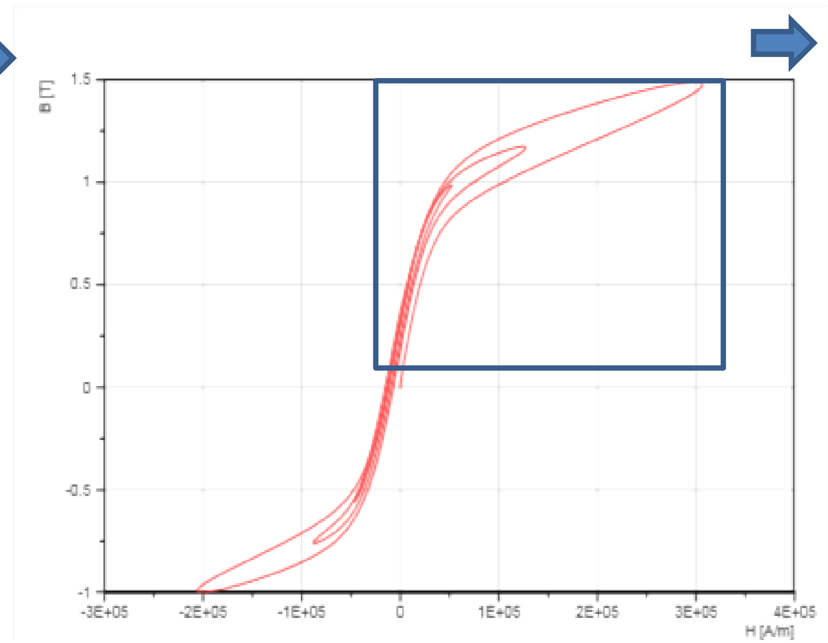
* This project received funding support from EU SME Horizon 2020

Damped oscillation with voltage and current decay



Correlation magnetic component, core and material





Material
Geometry data
Coil data

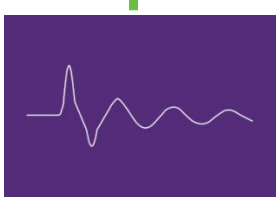
$\Phi = \Psi / w_s$
$\Theta = i \cdot w_p$

Material
Geometry data

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

Material

component **core** **material**



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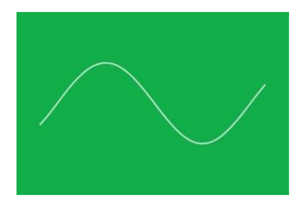
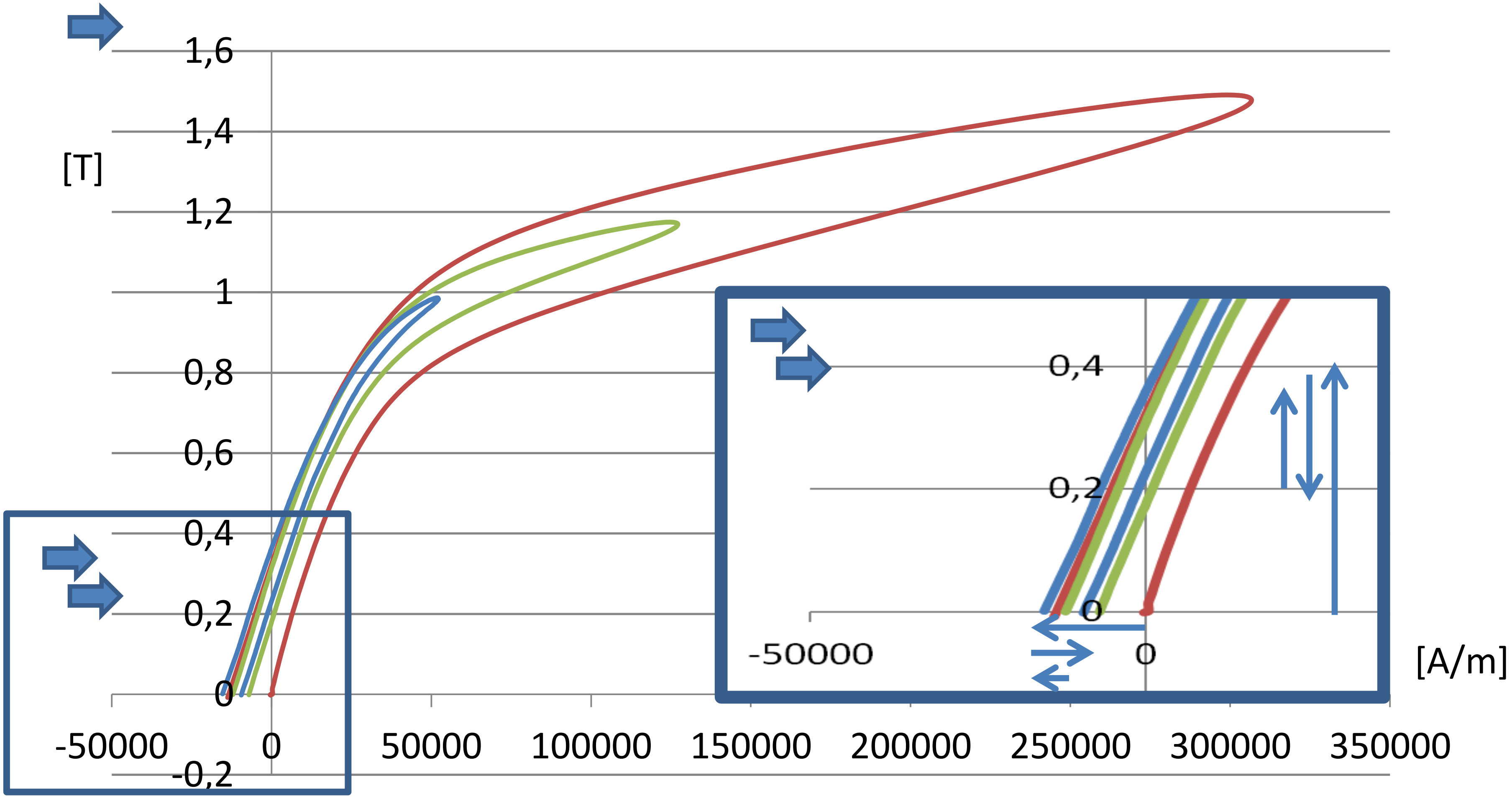
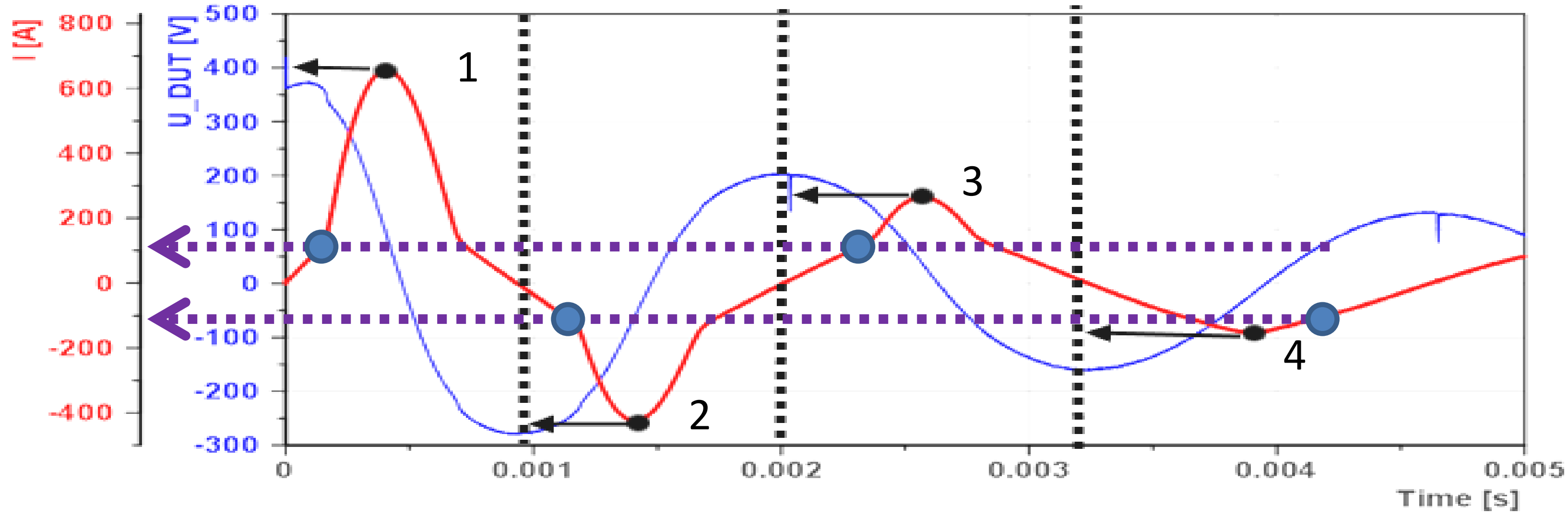
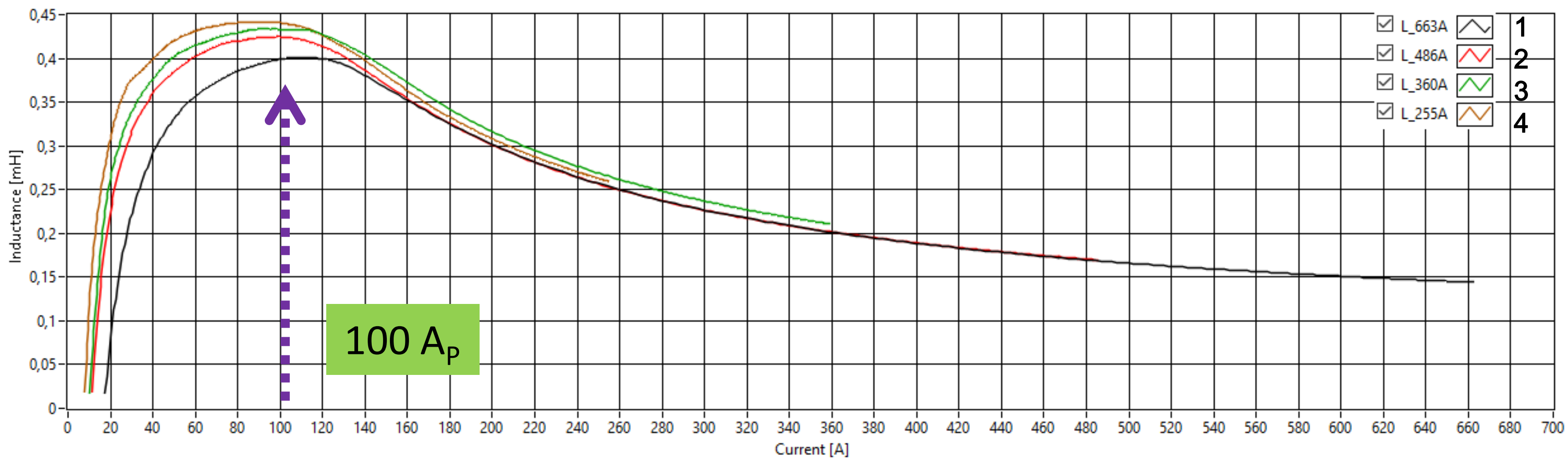


Demagnetization curve

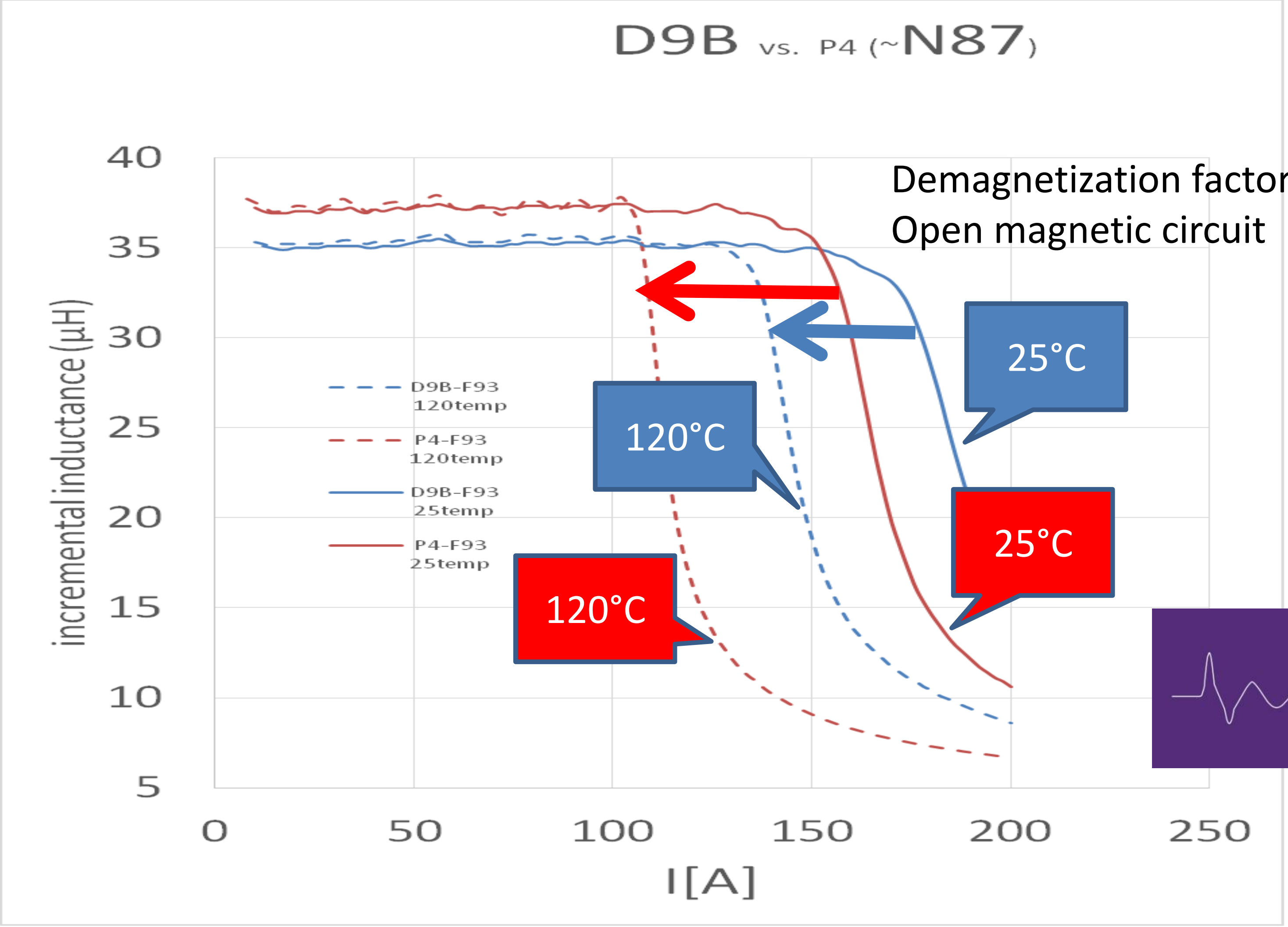


Assignments of magnetization inductance vs. current

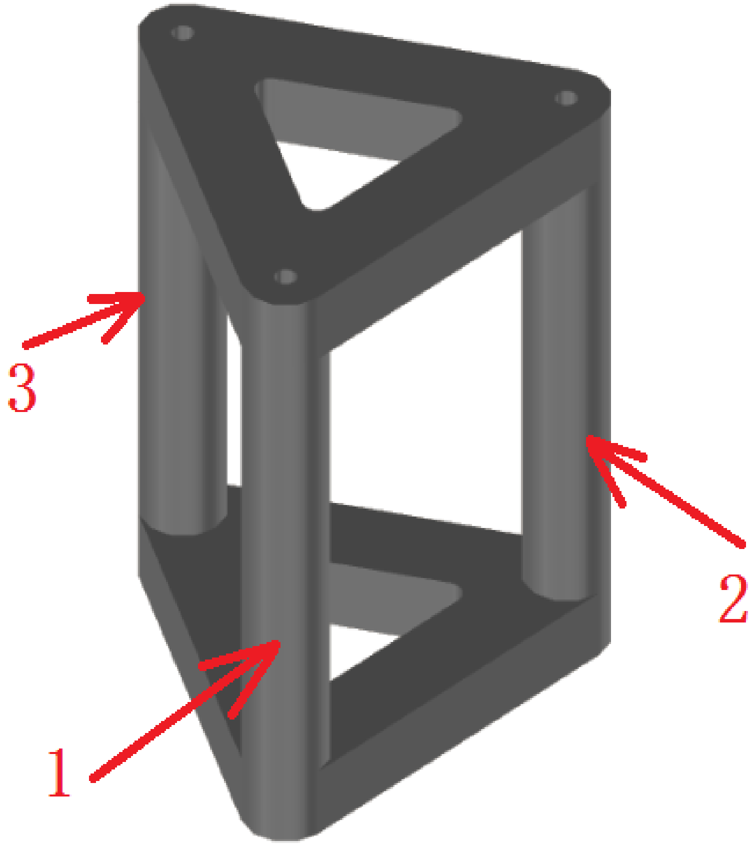




Example1:Temperature dependence of saturation current



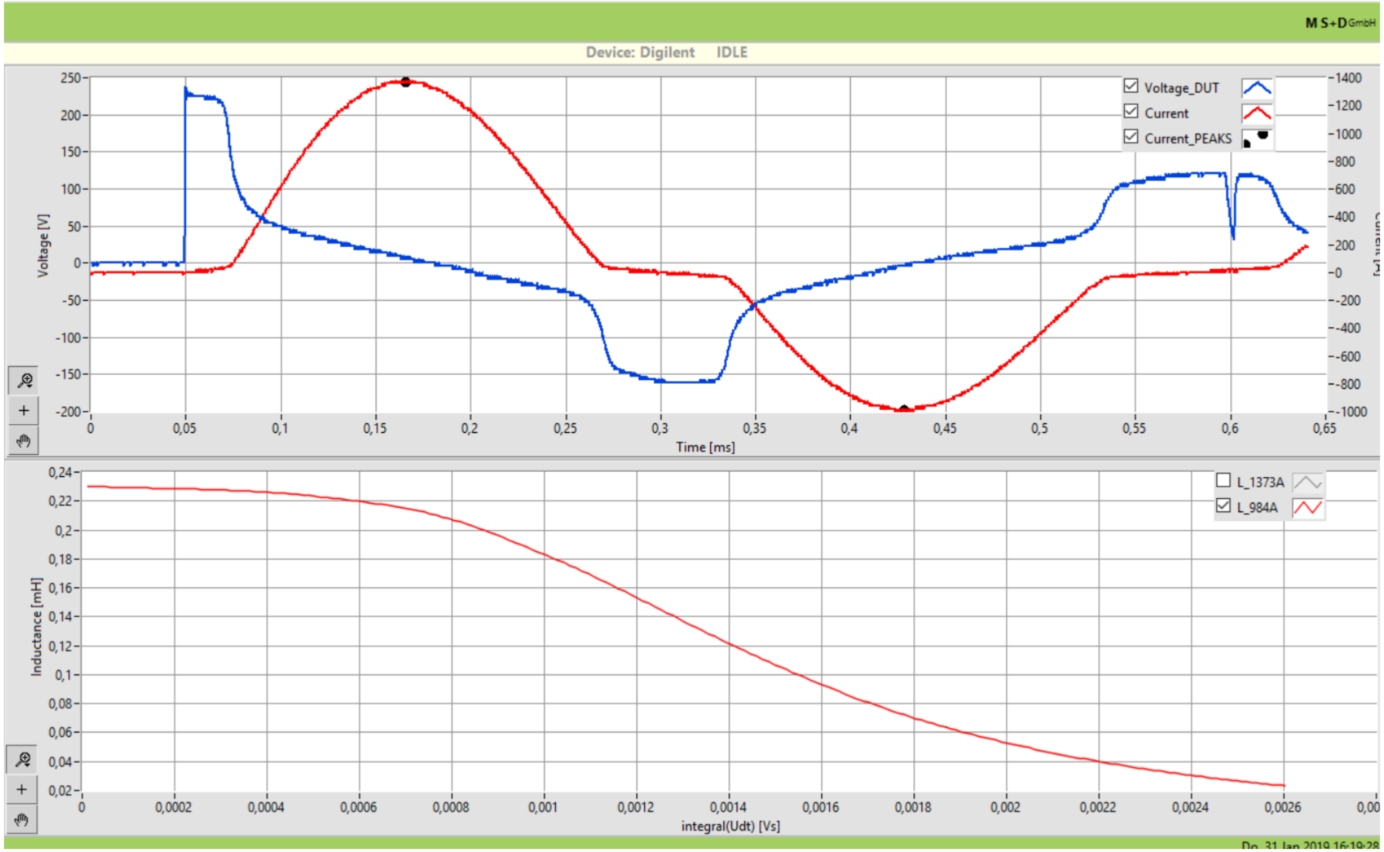
Example2:Life demo: pulsation of 3 phase delta inductor



Ferrite material D9B™ 0,6 T escalatable (like lego stone)

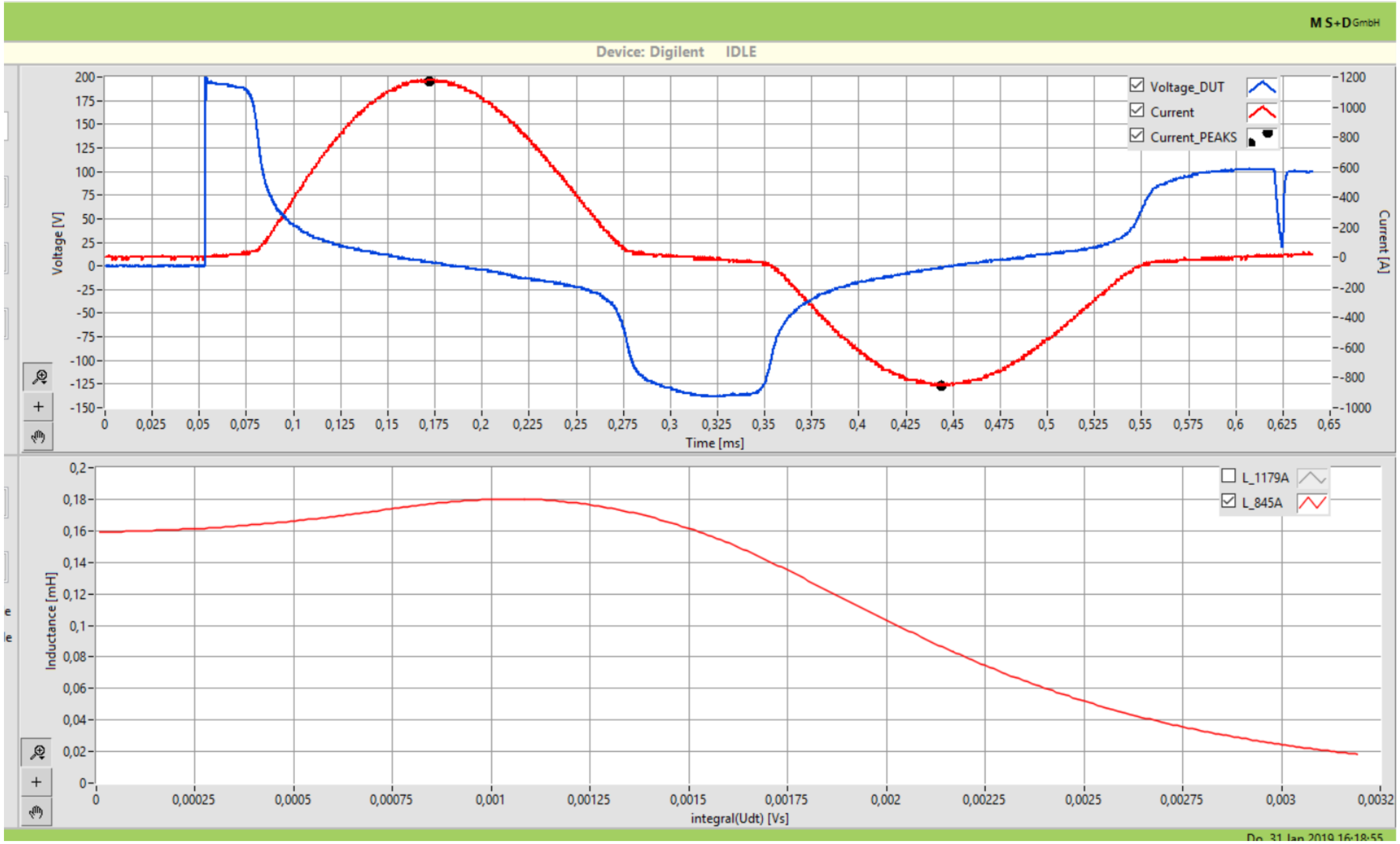
1 0 0 , 1 1 0 , 1 1 1
1 short circuit
0 open circuit
1 limb to pulse

L_{diff} vs. Udt 1 0 0 ~ 220 µH

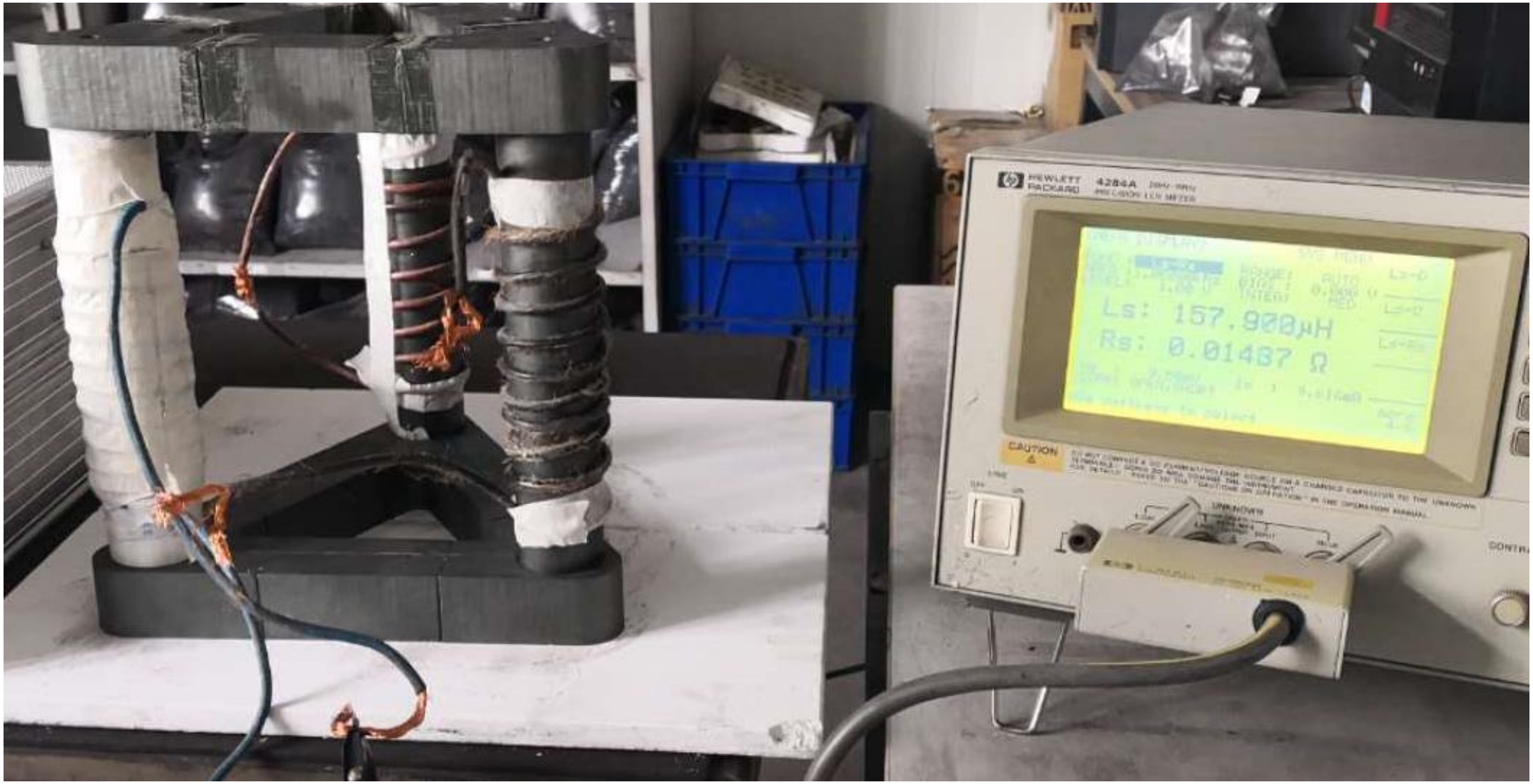


L measurment 1 0 0 LCR 182

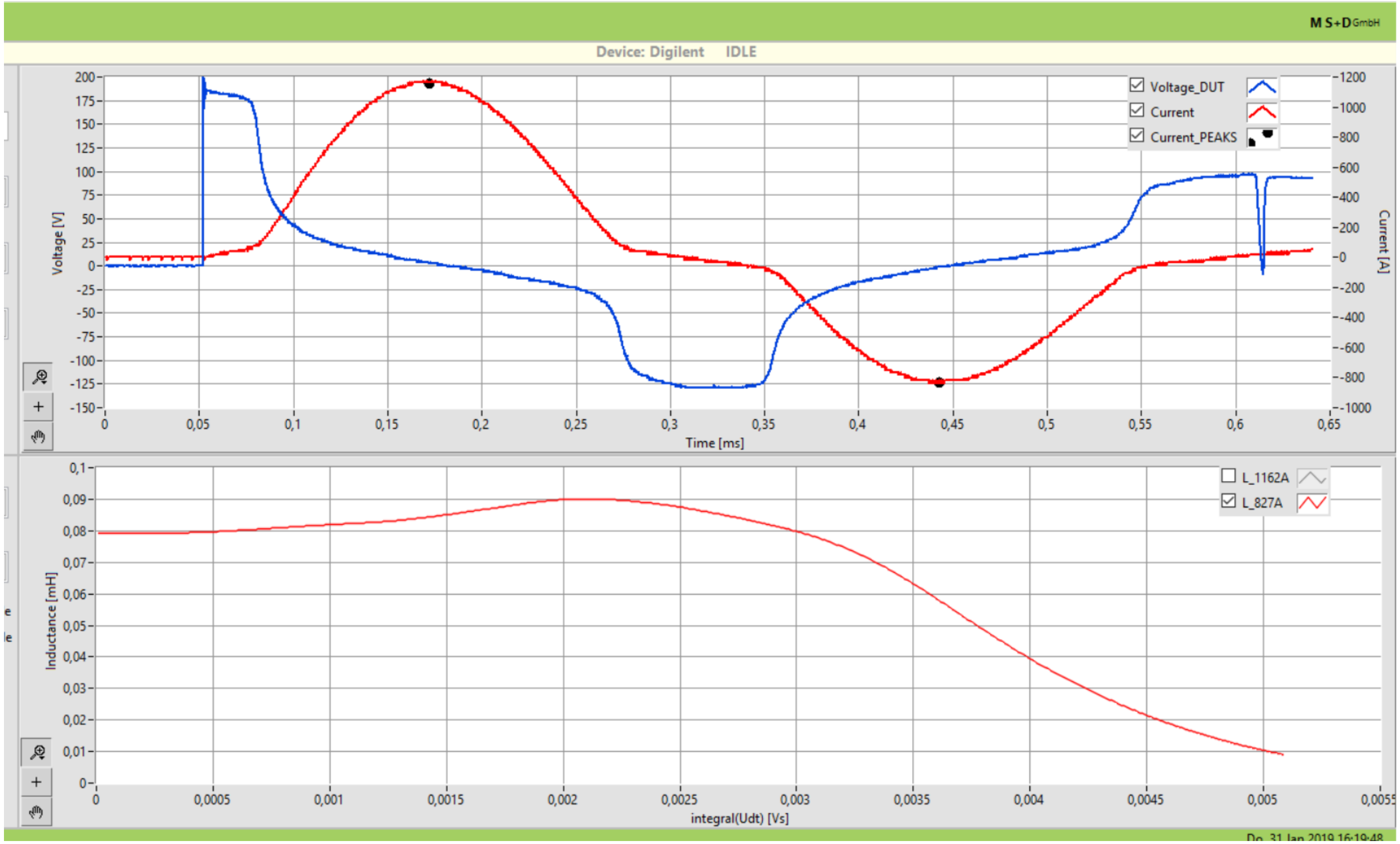
L_{diff} vs. Udt 1 1 0 ~ 160 µH



L measurment 1 1 0 LCR 157 μH



L_{diff} vs. Udt 1 1 1 ~ 80 µH



L measurment 1 1 1 LCR 73 µH

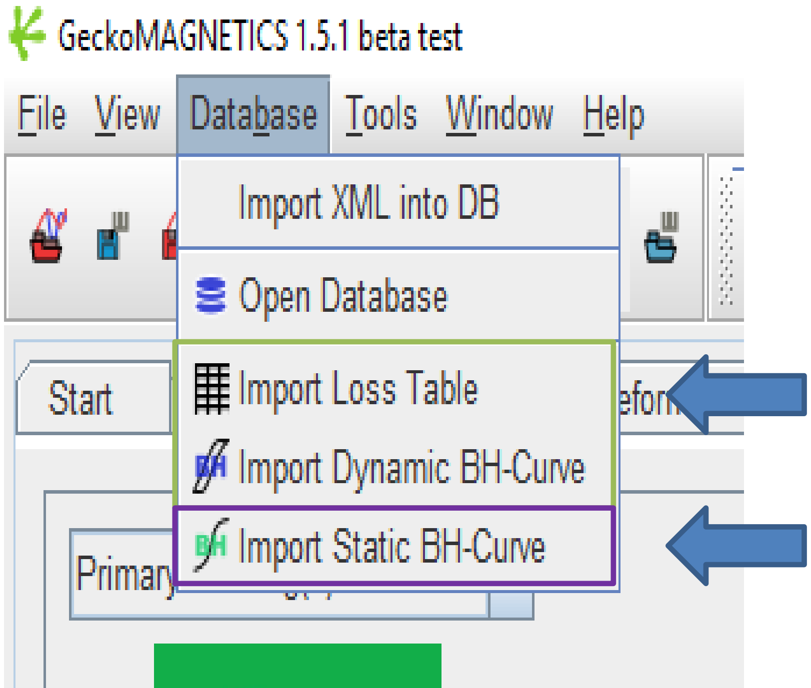
Take home message

- **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 $\omega L_{energetic}/R$
- Linkage of reading material loss map **is over** L_{diff} **@**μ_{rev}

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

*granted and supported by **H2020, DIN, VDE**)

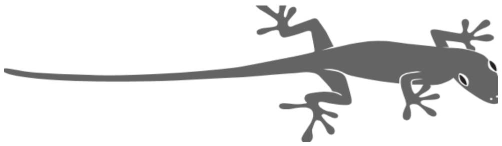
Annex 1 measuring data for simulation



BsT-Pro

BsT-Pulse

BsT-Pro



BsT-Pulse

Annex 2 loss map reading with linkage over μ_{rev} and L_{diff}

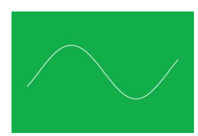
Temp(°C)	Freq(kHz)	TestB(mT)	I_Hdc(A)	Hdc(A/n	Z(ohm)	Z_DFT(ohm)	PhaseShift	Phi_Cal	Phi(DFT)	Phi_Corrected	CosQ
25	20	5,00	24,38	7958,	2,069	2,071	0,182	89,501	89,457	89,316	0,012
25	20	10,00	24,38	7958,	2,039	2,040	0,182	89,467	89,448	89,283	0,013
25	50	5,00	24,38	7958,	5,174	5,179	0,195	89,752	89,743	89,556	0,008
25	50	10,00	24,38	7958,	5,107	5,112	0,195	89,577	89,569	89,381	0,011
25	20	5,00	36,57	11937,	1,790	1,821	0,182	89,700	89,638	89,517	0,008
25	20	10,00	36,57	11937,	1,421	1,424	0,182	89,667	89,604	89,483	0,009
25	50	5,00	36,57	11937,	4,456	4,531	0,195	89,928	89,895	89,734	0,005
25	50	10,00	36,57	11937,	3,573	3,584	0,195	89,758	89,718	89,561	0,008

Vpp_Sp(V)	Vpp_Mv	Vrms_Mv	V_CF	V_DC	Ipp_Mv(A)	Irms_Mv	I_CF	I_DC
6,474	6,538	2,306	1,417	0,003	2,988	1,115	1,340	-0,010
12,948	12,975	4,577	1,418	-0,048	6,375	2,245	1,420	-0,036
16,185	16,213	5,715	1,419	-0,046	2,988	1,105	1,352	-0,010
32,371	32,479	11,451	1,418	-0,051	6,362	2,242	1,419	-0,039
6,474	6,503	2,292	1,419	0,004	2,988	1,280	1,167	-0,006
12,948	12,935	4,559	1,418	-0,044	8,211	3,209	1,279	-0,039
16,185	16,138	5,691	1,418	-0,050	2,988	1,277	1,170	-0,005
32,371	32,536	11,458	1,420	-0,048	8,171	3,206	1,274	-0,021

Example data log file

Pv_Cal(mW)	Pv_Corrected	Pv_Final	PvmW/cm3	u_rev
22,40	30,69	30,11	0,57	27,5
95,67	128,64	128,68	2,44	26,0
27,32	48,95	49,08	0,93	27,6
189,47	277,15	276,67	5,24	25,9
15,37	24,72	24,63	0,47	27,4
84,93	132,14	133,44	2,53	20,1
9,20	33,79	34,25	0,65	27,5
155,45	281,27	280,38	5,31	20,1

loss map (f, ***B***, T, H_{DC}) ← μ_{rev}



L_{diff}