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Measurement of magnetic materials at room and cryogenic temperature for their application to superconducting wind generators

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INSTITUTE FOR TECHNICAL PHYSICS

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  - reduce the reluctance in the magnetic circuit
  - confine the flux in the generator

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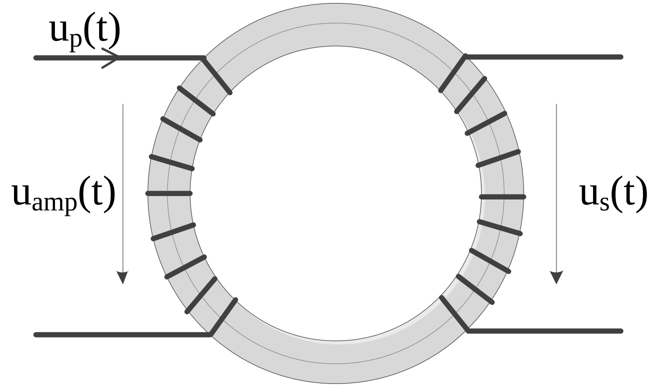
  - iron losses, higher cooling power and longer cool down time ☹
  - effective airgap is reduced greatly, as a result, reluctance is reduced and superconductor is saved ☺
  - cold iron contributes to the cold mass and enhance thermal capability of the system ☺
- There is not much investigation on the ***B-H*** **curve** and **losses behavior** of iron materials for rotating machines at cryogenic temperatures

Measurement setup

- General principle

Primary winding

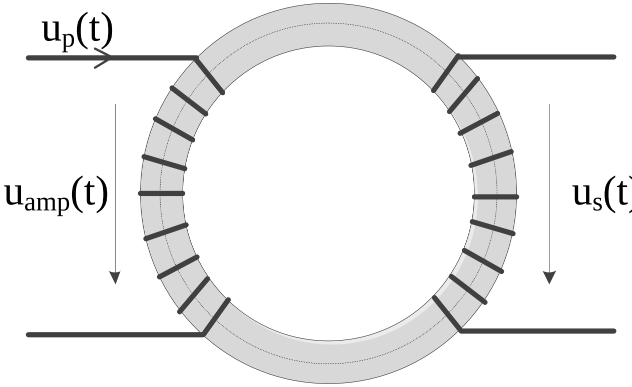


Secondary winding

- Main data
  - Magnetic Field 0 - 1.5 T
  - Frequency 0 - 1 kHz
  - Op. Temp. RT and 77 K

Measurement setup

- General principle

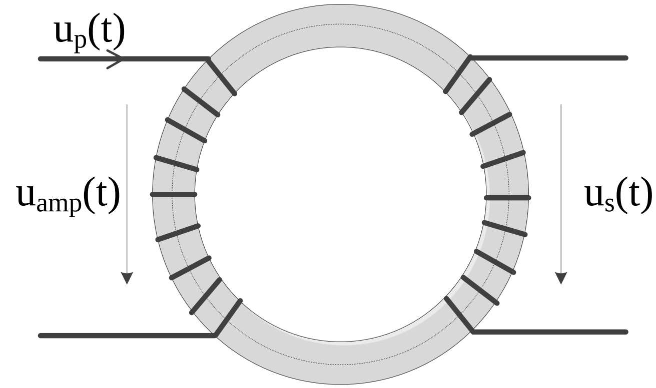


- Applying Faraday's induction law to the secondary winding, the flux density in the toroid core is calculated by measuring induced voltage.
- Applying Ampere's law to the primary winding, the magnetic strength is obtained by measuring the current.

→ ***B*-*H* curve**

Measurement setup

- General principle



Based on the Ohm's law and Faraday's induction law, the power absorbed by the toroid core:

$$\underbrace{u_{\mathrm{amp}}(t)\cdot i_{\mathrm{p}}(t)}_{A} = \underbrace{R_{\mathrm{p}}\cdot {i_{\mathrm{p}}}^{2}(t)}_{B} + \underbrace{\frac{N_{\mathrm{s}}}{N_{\mathrm{p}}}\cdot u_{\mathrm{s,ind}}(t)\cdot i_{\mathrm{p}}(t)}_{C}$$

$u_{amp}(t)$: amplifier voltage,
$i_p(t)$: primary winding current,
R_p: resistance of the primary winding,
$u_{s,ind}(t)$: induced voltage of primary winding,
N_s: number of turns of secondary winding,
N_p: number of turns of primary winding,

A: input power to the toroid core,
B: the ohmic losses in the primary winding,
C: core magnetization and core losses

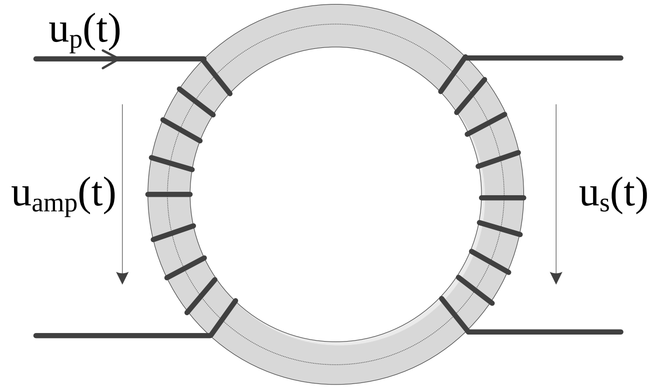
Loss behavior

Measurement setup

- Measured samples

M330-35A

Losses Thickness

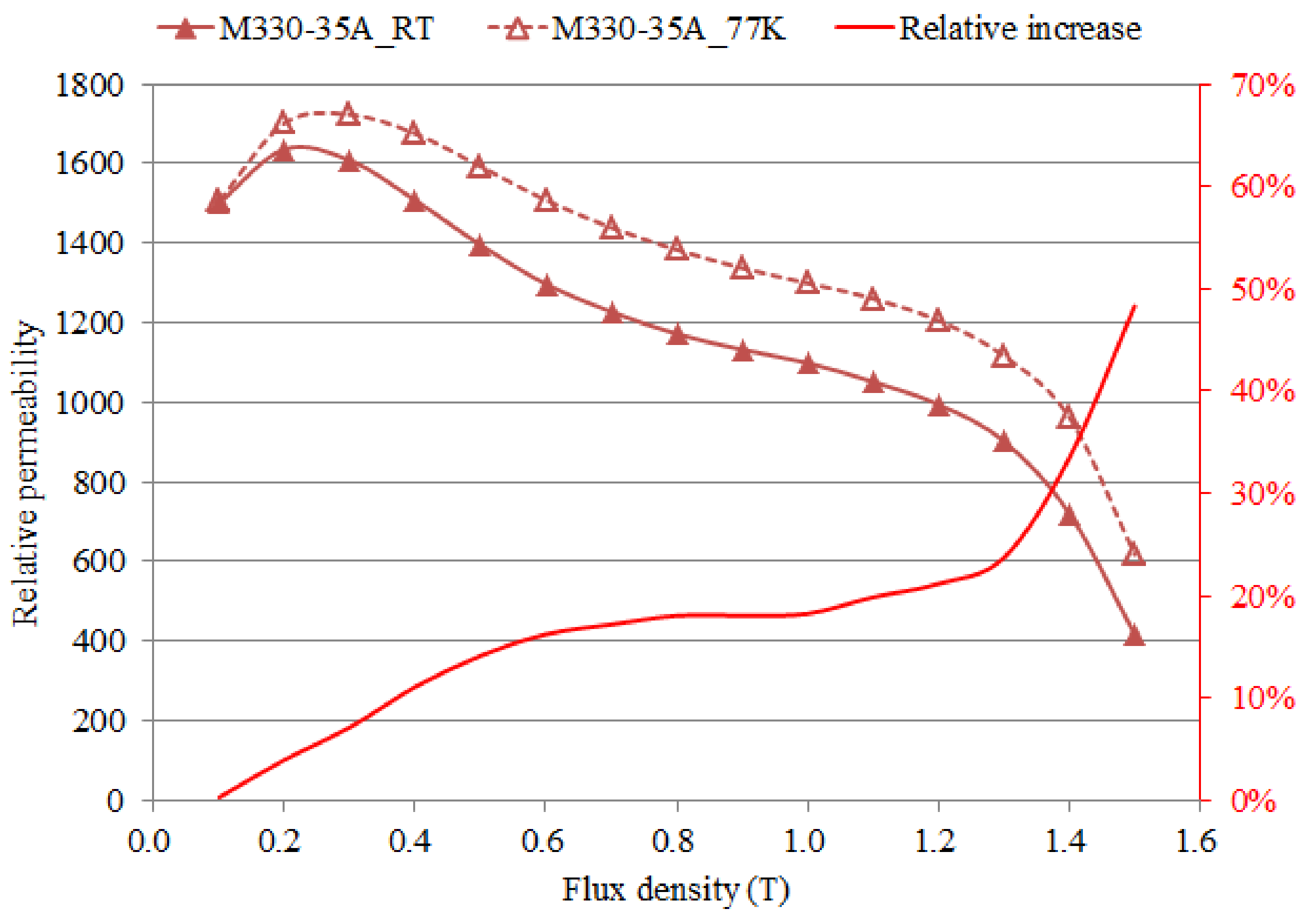


Specification of Samples

Cobalt iron

	M330-35A	M330-50A	M235-35A	Vacodur49
Density	7620kg/m^3	7650kg/m^3	7600kg/m^3	8120 kg/m^3
Thickness	0.35 mm	0.50 mm	0.35mm	0.27 mm
Conductivity at RT	2.29×10^6 S/m	2.33×10^6 S/m	1.92×10^6 S/m	2.35×10^6 S/m
Conductivity at 77K	2.90×10^6 S/m	2.93×10^6 S/m	2.11×10^6 S/m	2.59×10^6 S/m
Saturation point	1.5 T	1.5 T	1.5 T	2.3 T

Test results - Relative permeability



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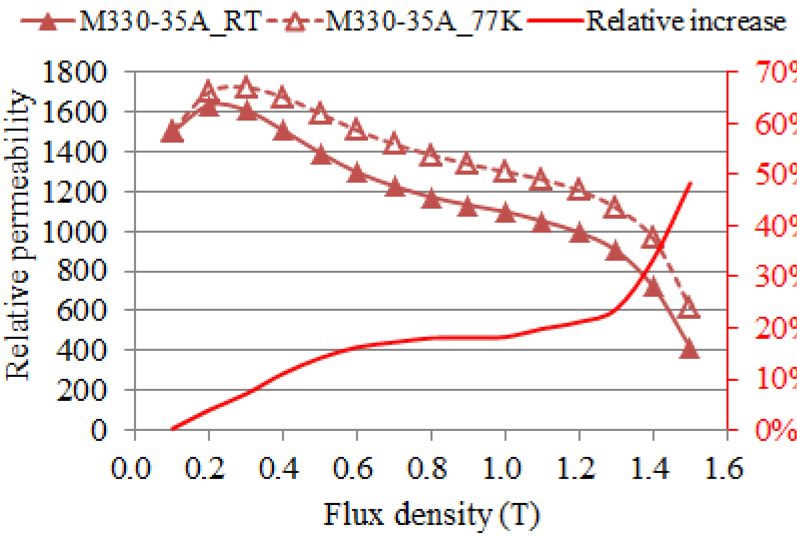
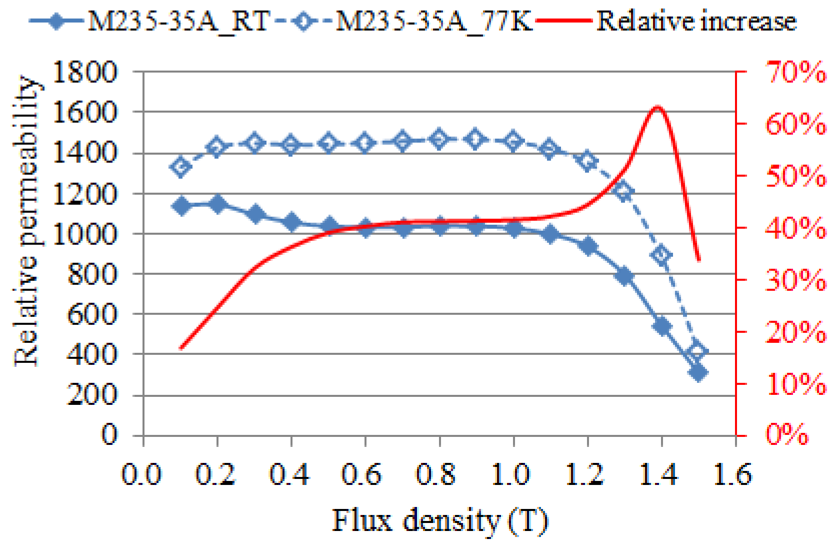
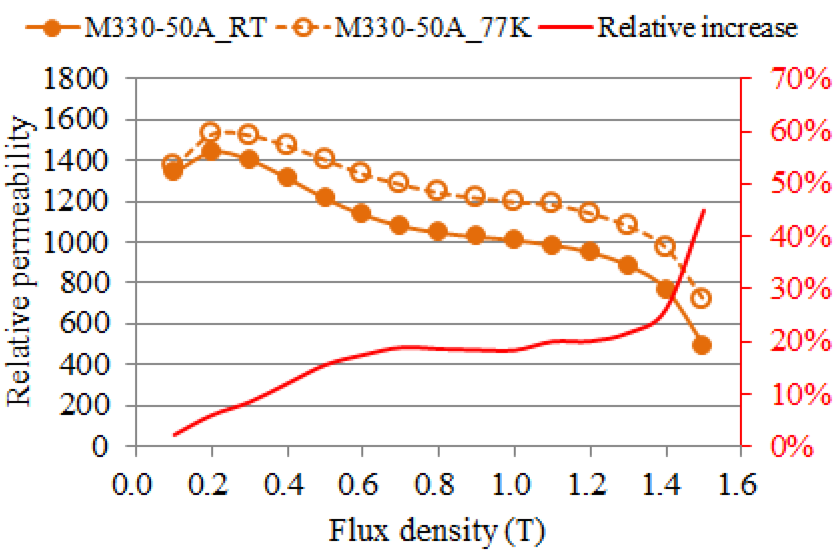
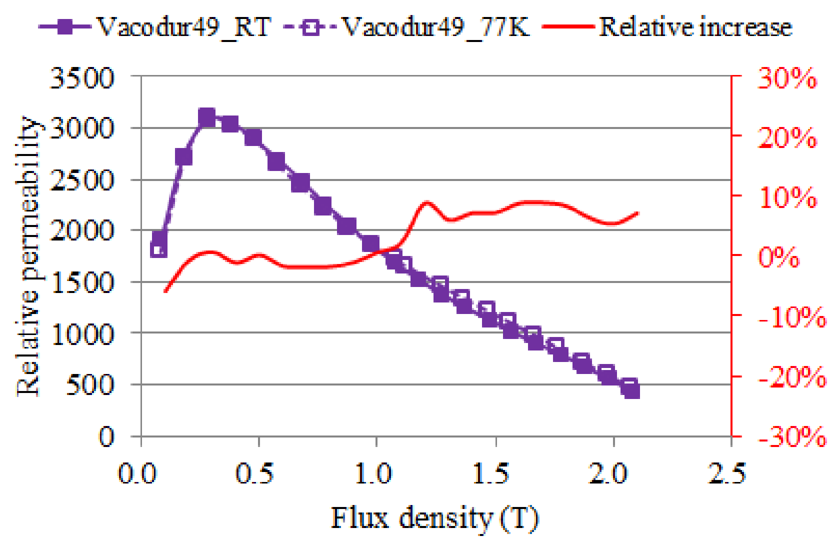
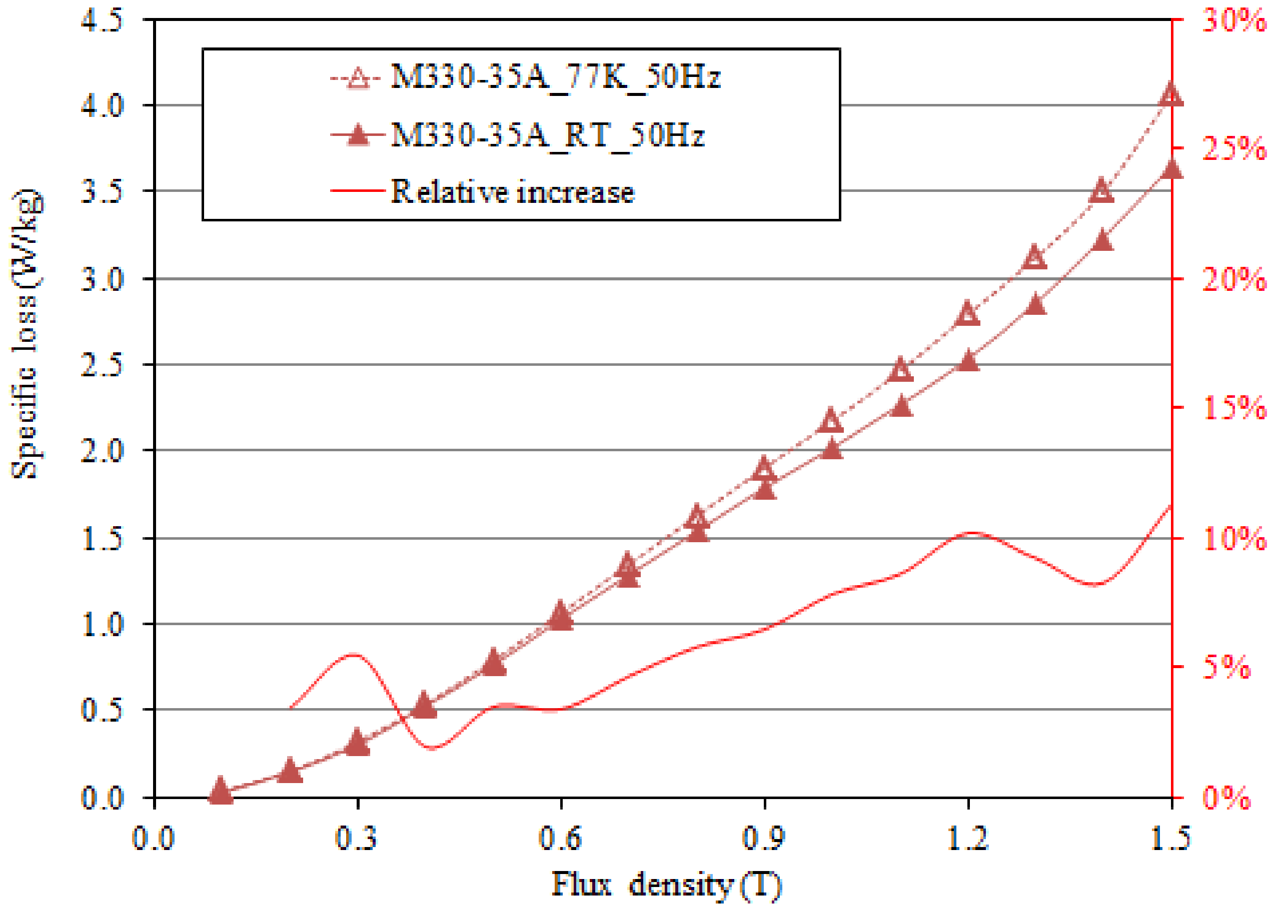








Losses as a function of flux density



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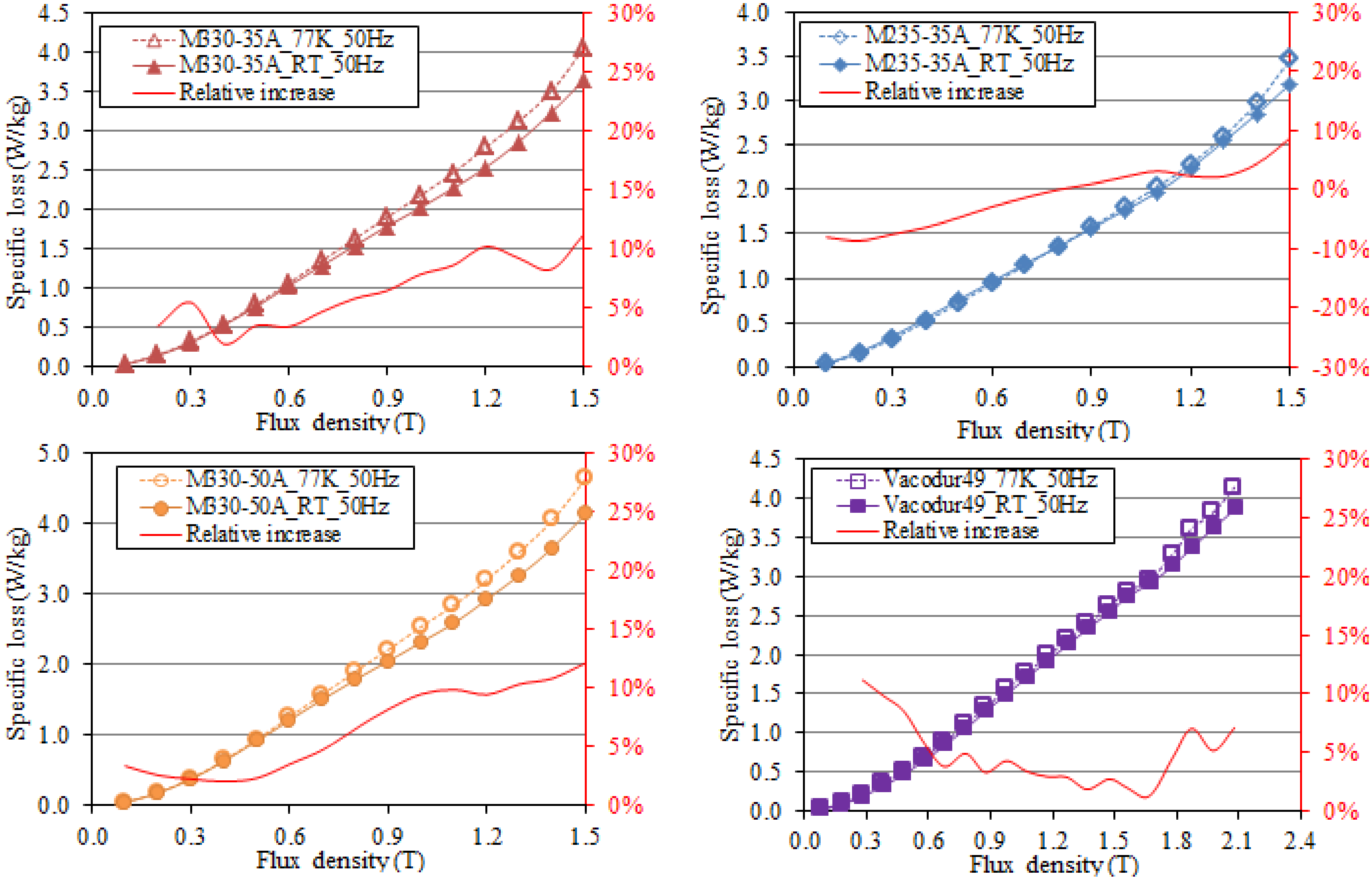
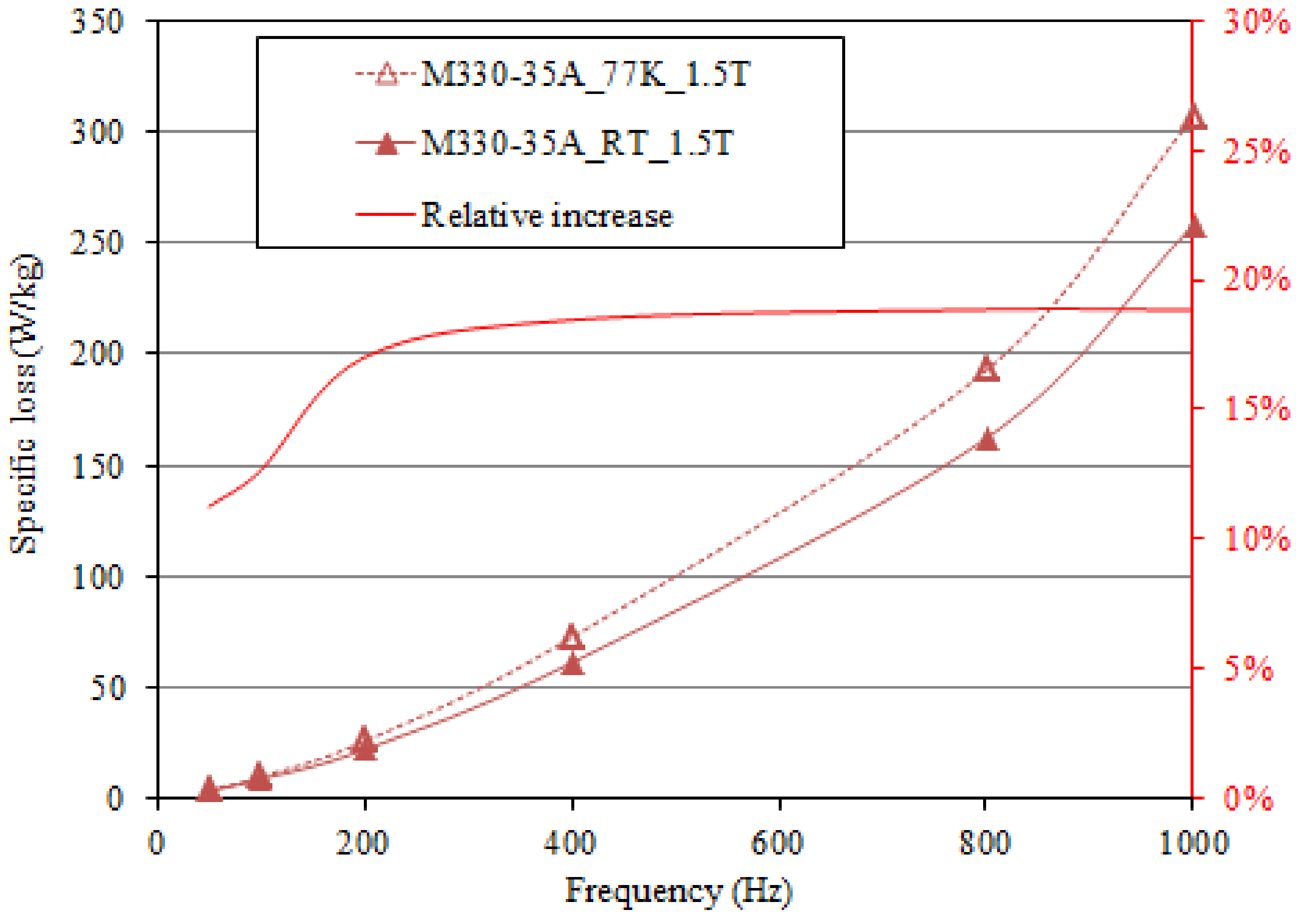


Losses as a function of frequency



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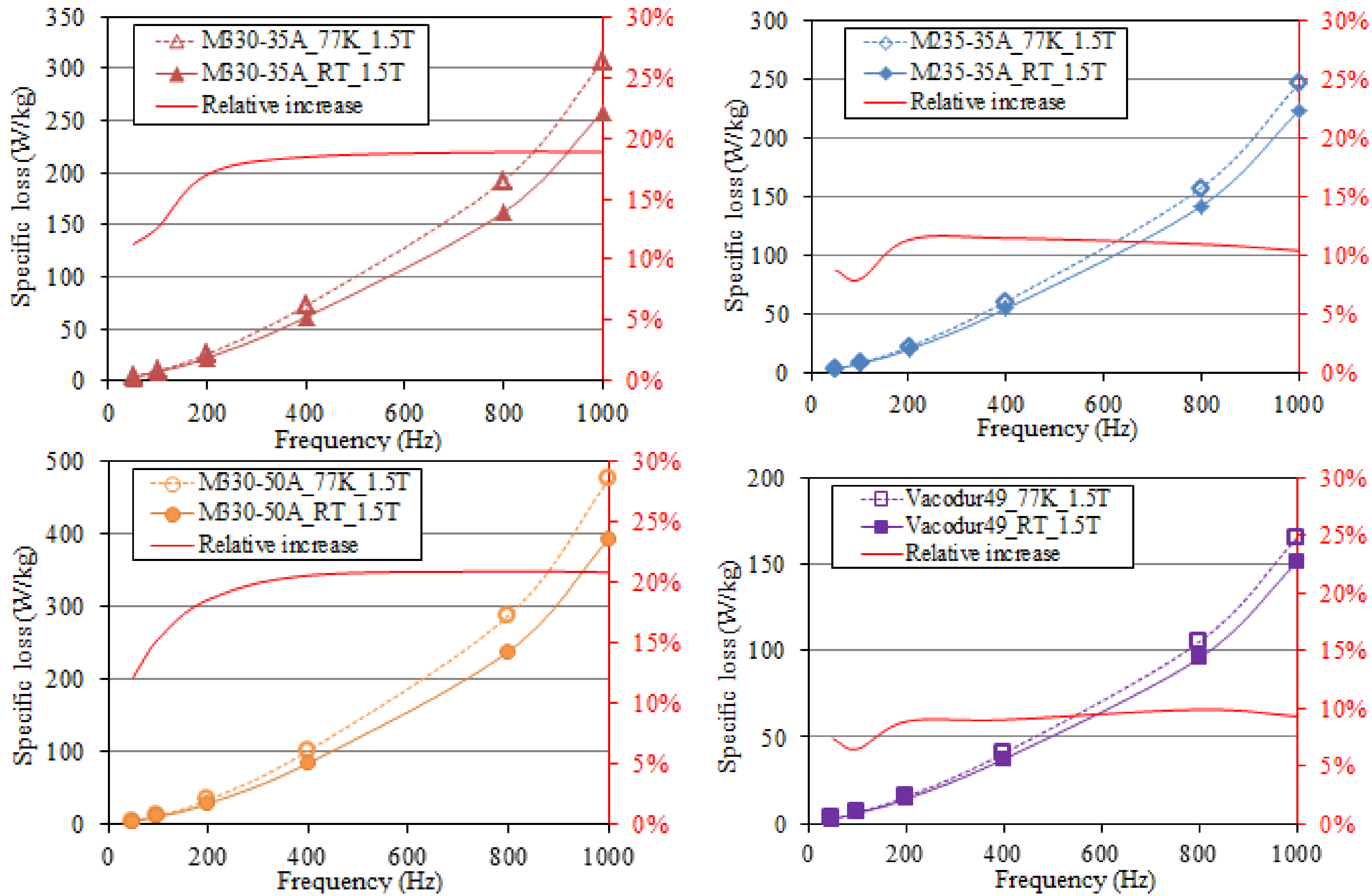

Parameters for iron loss model < 400Hz

Bertotti developed an iron loss model to describe the loss behavior with flux density, frequency and empirical factors.

$$p_{Fe} = C_{hyst} f B_p^2 + C_{ec} f^2 B_p^2 + C_{exc} f^{1.5} B_p^{1.5}$$

p_{Fe}: iron loss,
f: frequency,
B_p: amplitude of the flux density,

C_{hyst}, C_{ec}, and C_{exc} : coefficients of hysteresis loss, eddy current loss and excess loss.

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Fitting Coefficients of Iron Loss Model

	M330-35A	M330-50A	M235-35A	Vacodur49
C_{hyst} RT	2.62E-2	2.89E-2	2.00E-2	2.03E-2
C_{ec} RT	6.06E-5	1.25E-4	5.09E-5	2.84E-5
C_{exc} RT	1.24E-3	1.18E-3	1.46E-3	9.08E-4
C_{hyst} 77K	2.64E-2	2.89E-2	2.09E-2	2.07E-2
C_{ec} 77K	7.67E-5	1.58E-4	5.59E-5	3.12E-5
C_{exc} 77K	1.62E-3	1.56E-3	1.73E-3	1.25E-2

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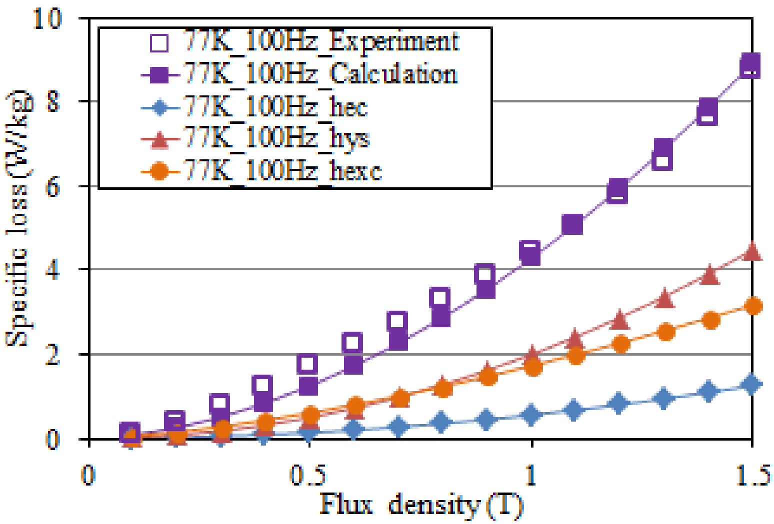

Conclusion

- In general, the relative permeability is increased by cooling down the iron materials.
  - M235 and M330 can increase over 50%, while cooling down in liquid nitrogen has small influence on the relative permeability of cobalt iron, we can increase over 5%
- Losses are increased by cooling down the iron materials.
  - At 50Hz around saturation point losses can increase around 10%
- Fitting parameters and *B-H* data are available now and can be used for simulation in commercial finite element software, such as Comsol and Maxwell.

Thank you for your attention

Any questions ?