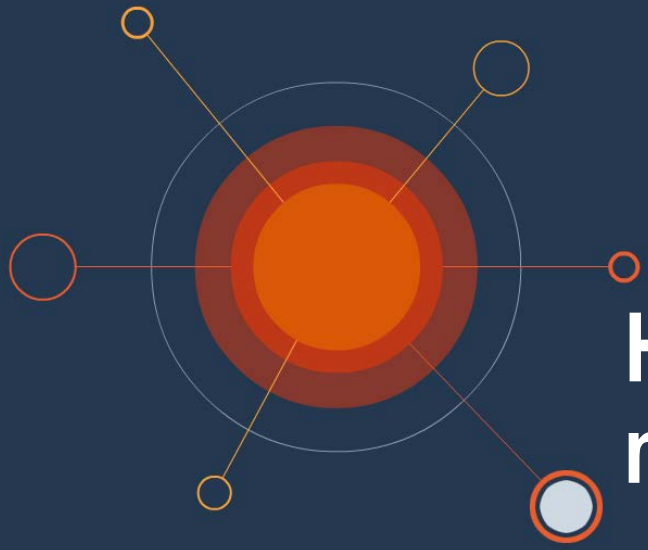

High strength iron-cobalt materials for magnetic bearings

14th International Symposium on Magnetic Bearings
August 11- 14, 2014, Linz, Austria

Frederik Fohr, Niklas Volbers, Joachim Gerster

VACUUMSCHMELZE

ADVANCED MATERIALS – THE KEY TO PROGRESS

Content

- General properties of 49%Fe 49%Co 2%V iron- cobalt alloys
- High strength iron- cobalt alloys for high speed rotors
- Micrometer rolled laminations for smallest losses at high frequencies

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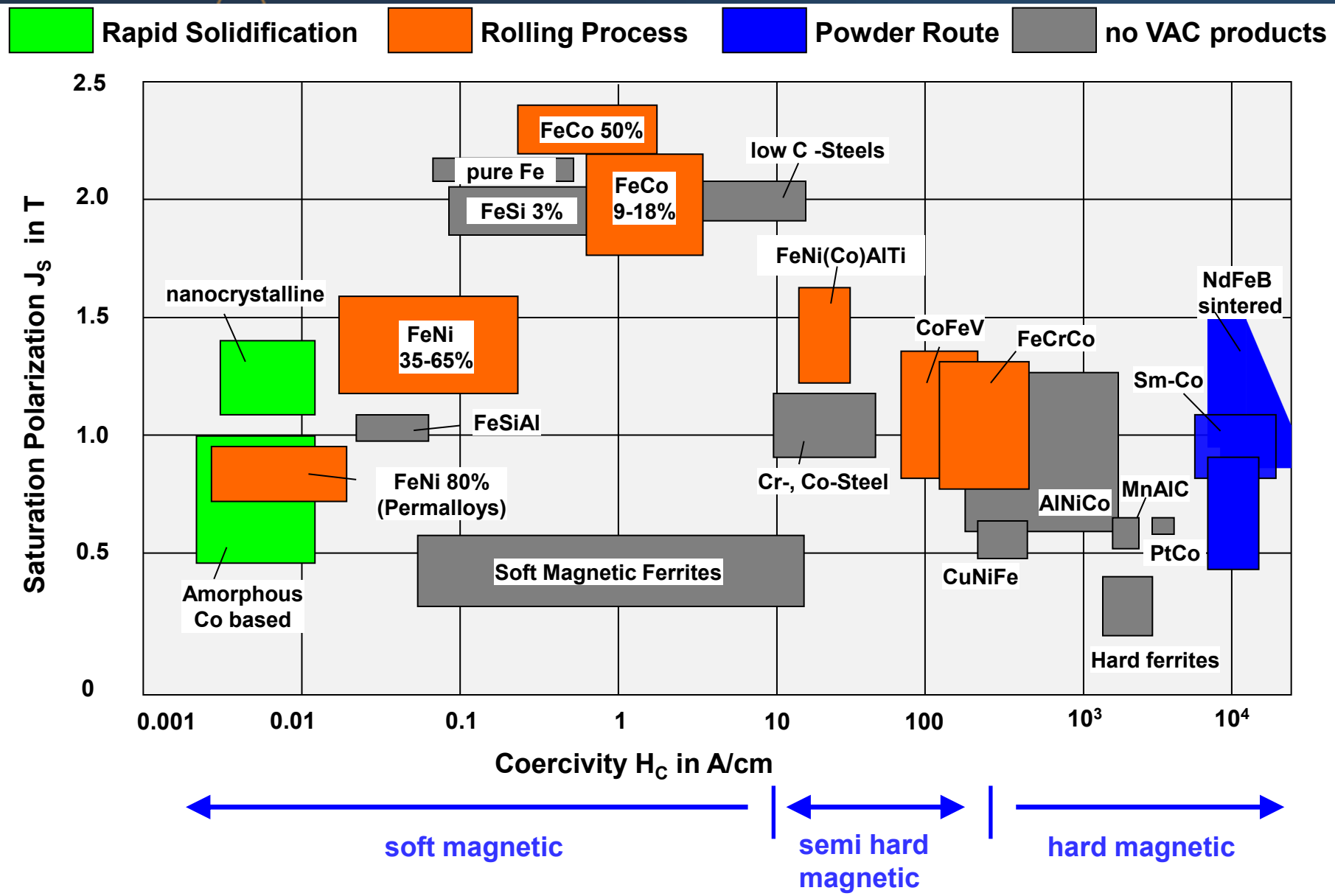
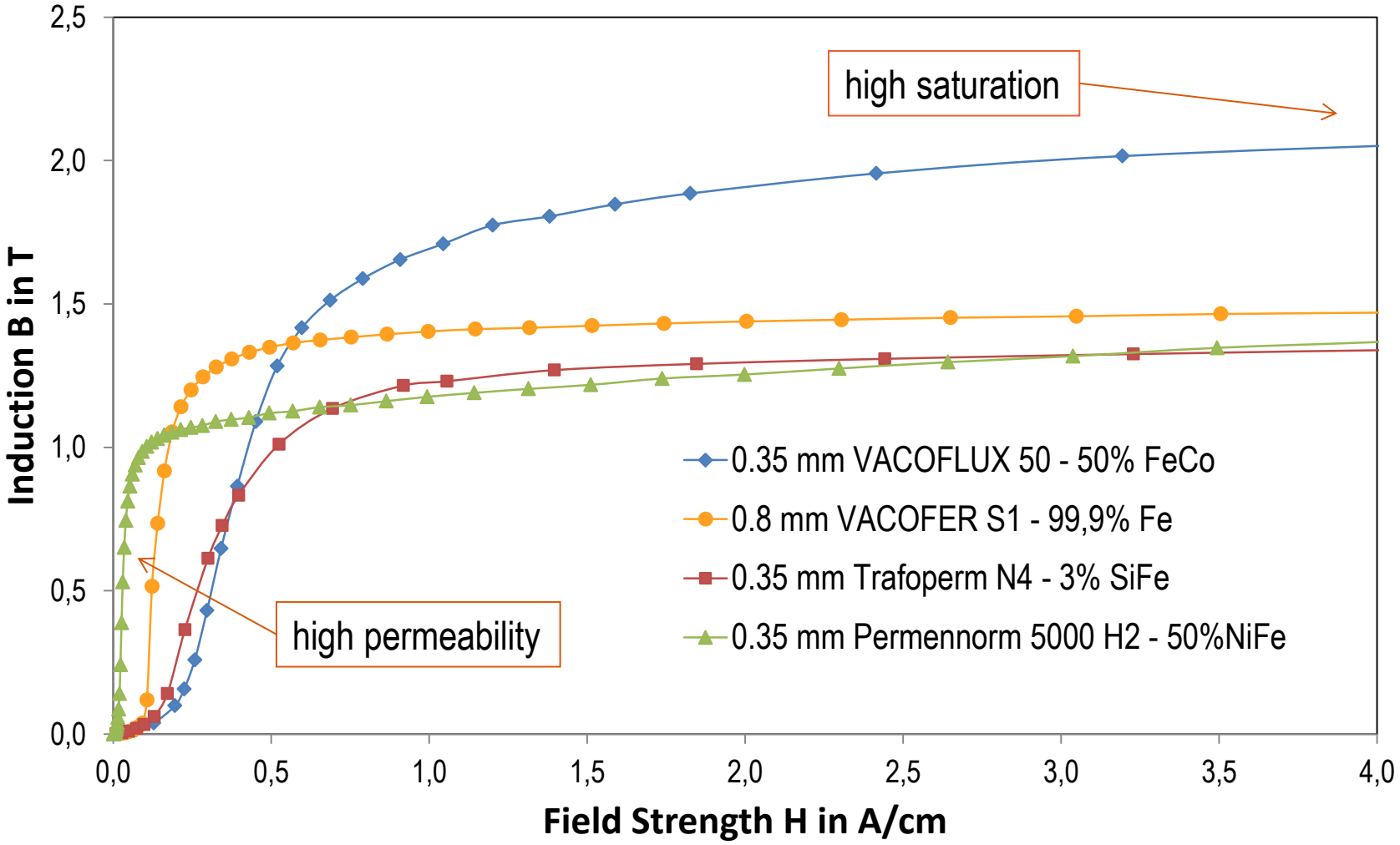

Rapid Solidification
Rolling Process
Powder Route
no VAC products
Saturation Polarization J_S in T
2.5
2.0
1.5
1.0
0.5
0
FeCo 50%
pure Fe
FeSi 3%
FeCo 9-18%
low C -Steels
FeNi(Co)AlTi
nanocrystalline
FeNi 35-65%
NdFeB sintered
CoFeV
FeCrCo
Sm-Co
FeSiAl
FeNi 80% (Permalloys)
Cr-, Co-Steel
AlNiCo
MnAlC
PtCo
Soft Magnetic Ferrites
CuNiFe
Amorphous Co based
Hard ferrites
0.001
0.01
0.1
1
10
100
10^3
10^4
Coercivity H_C in A/cm
soft magnetic
semi hard magnetic
hard magnetic

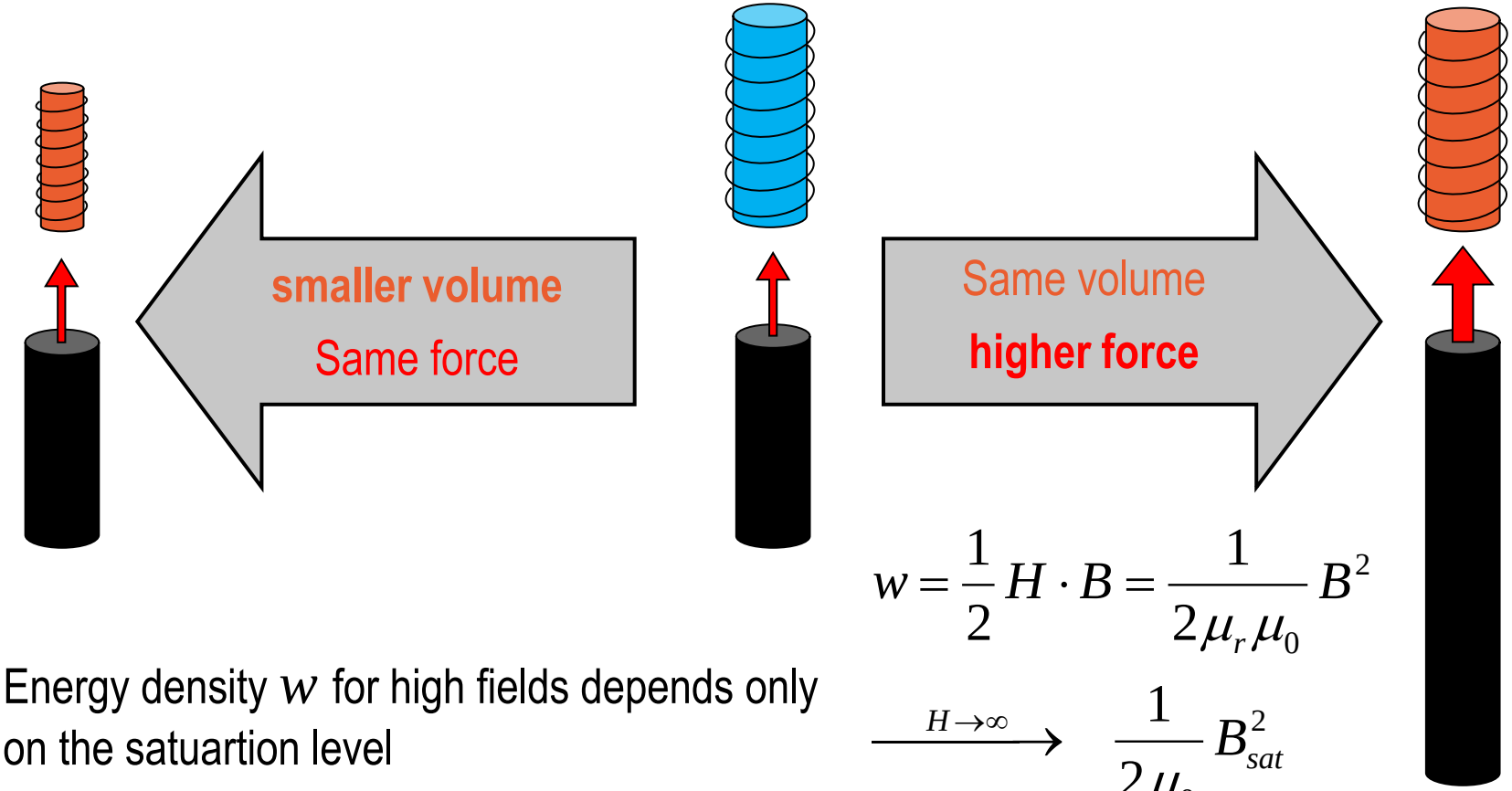
Comparison of inductions of different soft magnetic alloys



VACOFLUX© 50
B_{sat} = 2,35 T

Electrical 3%SiFe steel
B_{sat} = 2,03 T

VACOFLUX© 50
B_{sat} = 2,35 T



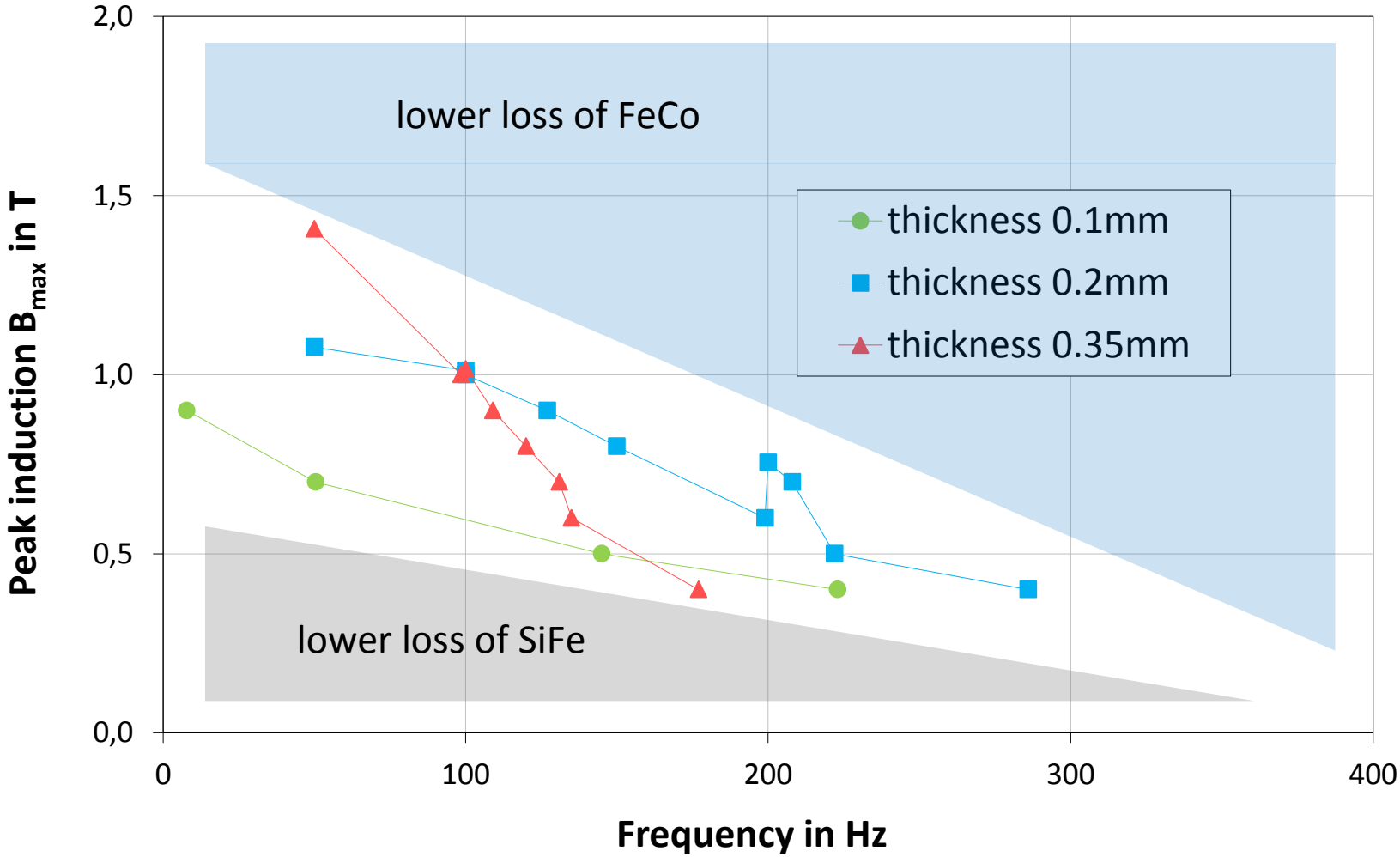
Energy density w for high fields depends only on the satuartion level

$$w = \frac{1}{2} H \cdot B = \frac{1}{2\mu_r \mu_0} B^2$$

$$\xrightarrow{H \to \infty} \quad \frac{1}{2\mu_0} B_{sat}^2$$

$$\Rightarrow +34\% \textit{ energy density}$$

Comparison of losses of 50% FeCo and 3% SiFe



Ref.: W. Pieper, J. Gerster, JAP, Vol. 109, No. 7, April 2011

Comparison of soft magnetic alloys for magnetic bearings

	Material	Saturation in T	Curie Temp. T_c in °C	Yield Strength in MPa	Electrical Resistivity in µΩm
cold rolling	FeCo 50wt%	2.35	950	200 - 800	0.40
	Pure Iron	2.15	770	100	0.10
	SiFe 3wt%	2.03	740	300 - 400	0.40
	FeNi 50wt%	1.55	440	140 - 200	0.45
rapid solidification	Amorphous FeSiB	1.56	420	≈ 3000	1.30

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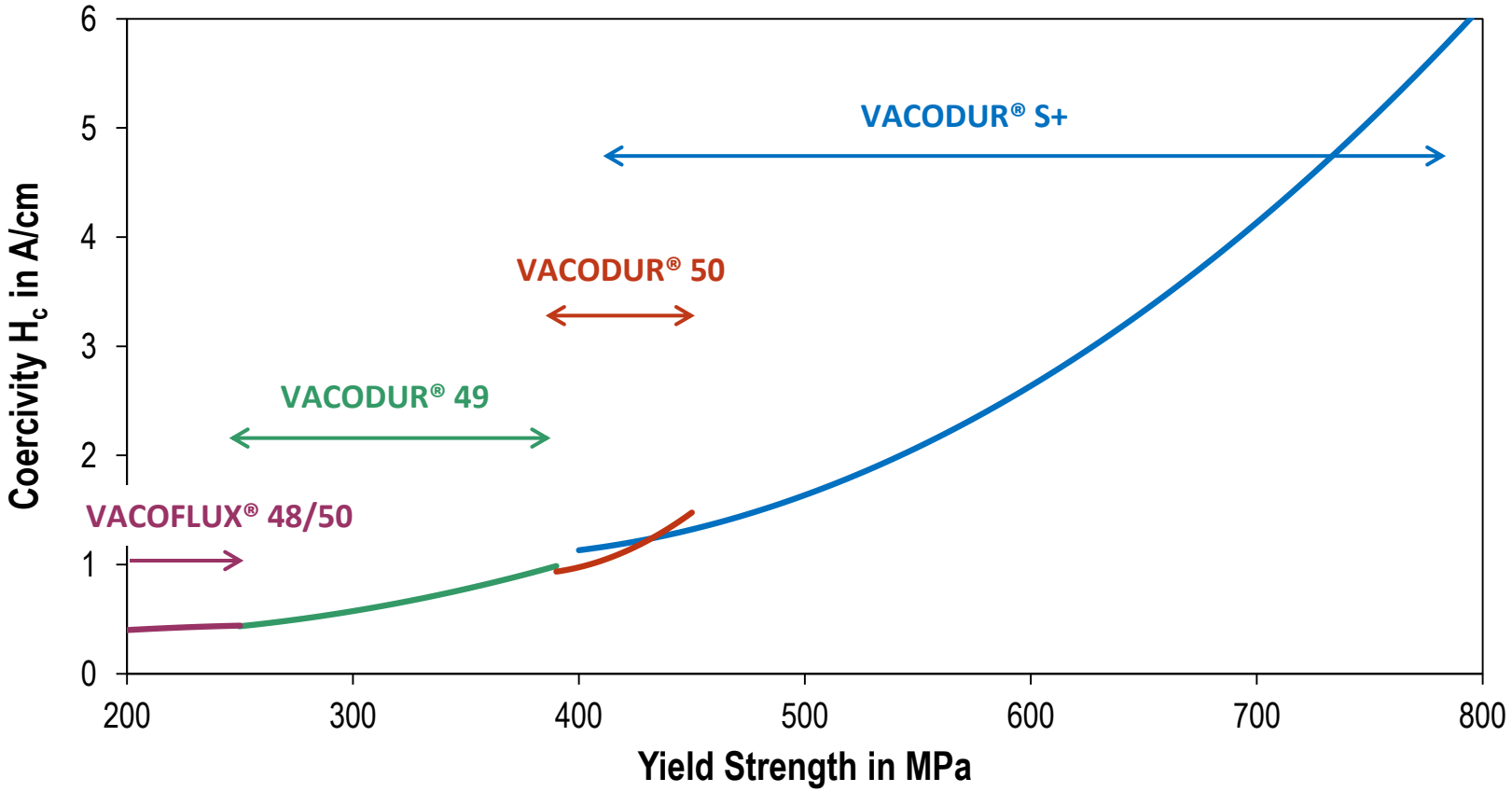
VACODUR® – high strength FeCo alloys

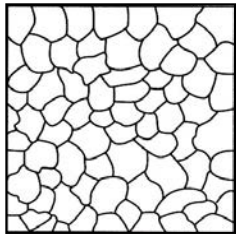


VAC covers the complete yield strength range from 200 to 800 MPa

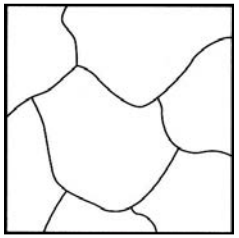
Adjustment of the yield strength by grain size

- **Coercivity:** Law by Mager $H_c = H_0 + \frac{m}{d}$

- **Yield Strength** (Hall-Petch relation) $R_{p0,2} = \sigma_0 + \frac{k}{\sqrt{d}}$



small grain
high Hc, high strength

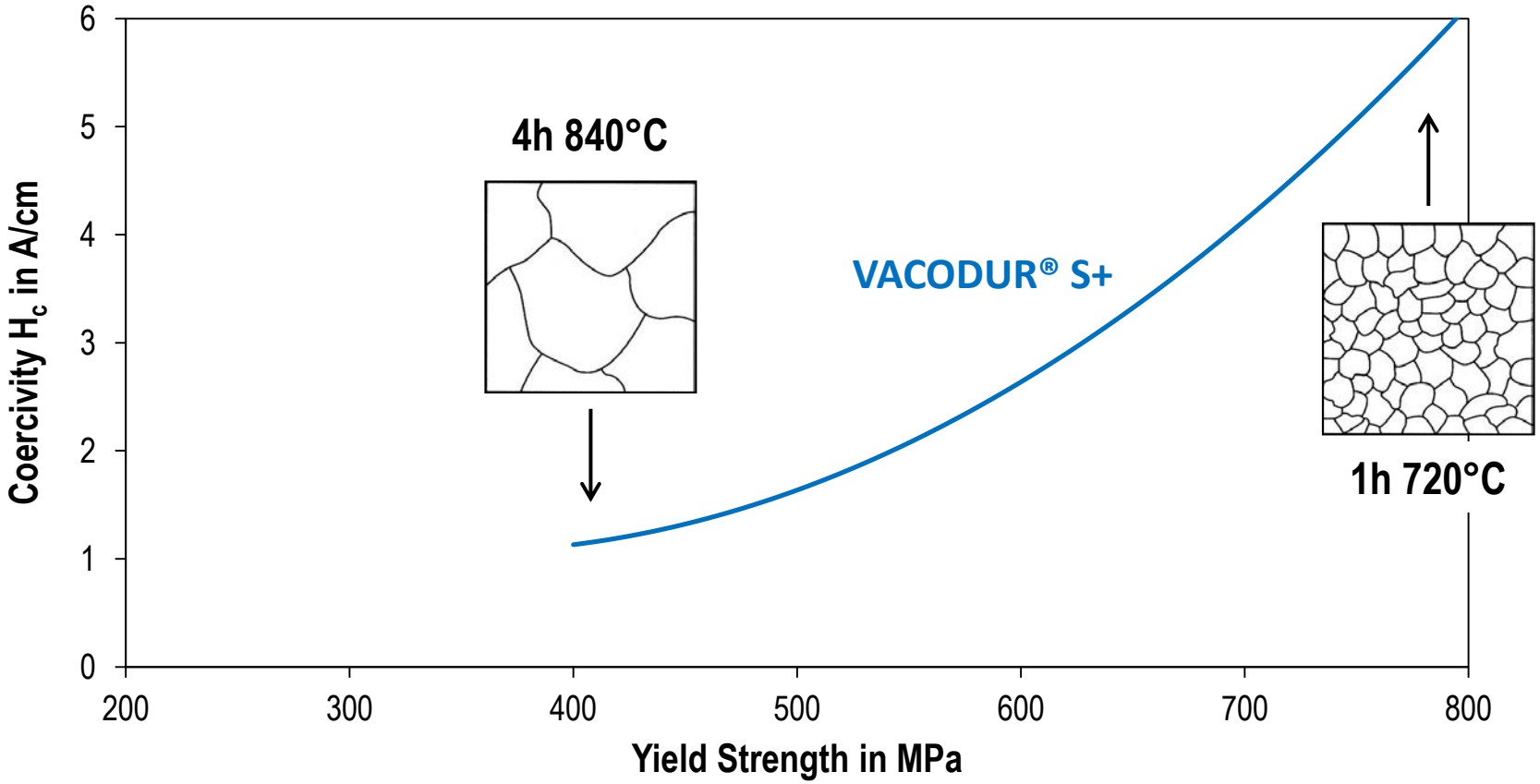


coarse grain
small Hc, low strength

$$H_c = H_0 + \frac{m}{k^2}(R_{p0.2} - \sigma_0)^2$$

Ref: E.O. Hall, Proc. Phys. Soc. **64** (1951). 742.747 / N.J.Petch: J. Iron Steel Inst. **174** (1963), 25-28 / A. Mager. Ann. Phys. 11 (1952), 11-12.

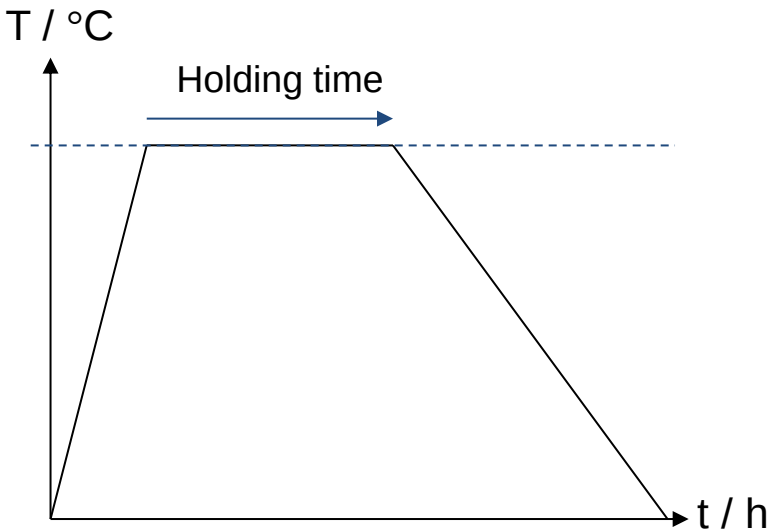
Adjustment of the grain size by final annealing



Grain size determines mechanical and magnetic properties

Adjustment of the grain size by final annealing

- Dry hydrogen atmosphere prevents oxidation and removes impurities
- Recovery from mechanical stress due to mechanical processing
- Grain size adjustment by variation of temperature and holding time
- Recrystallisation of the microstructure



Typical temperature profile

Hood type furnace

Content

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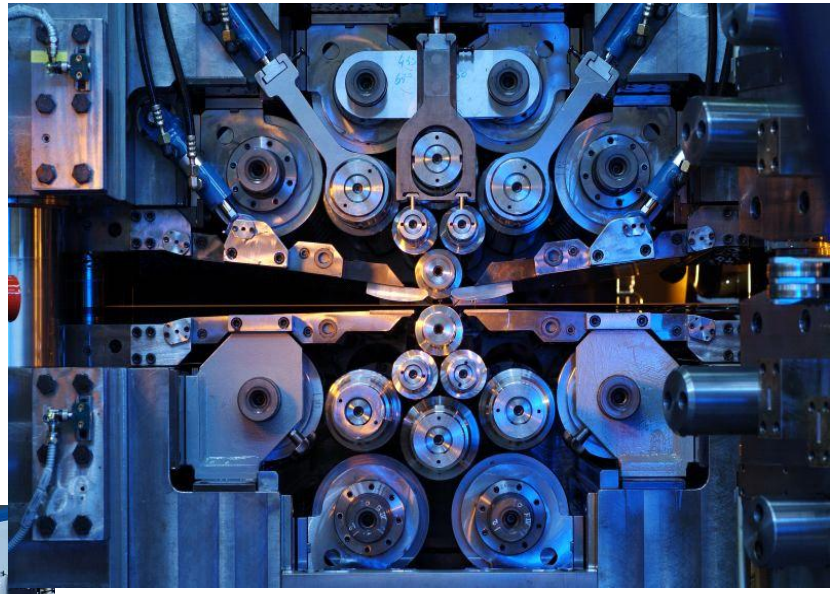
Cold rolling mill

- Mill- power is supplied by two small working rolls
- Small working rolls permit thin strip thicknesses
- The working rolls are backed by larger idling rolls
- Idling rolls permit the application of high pressure

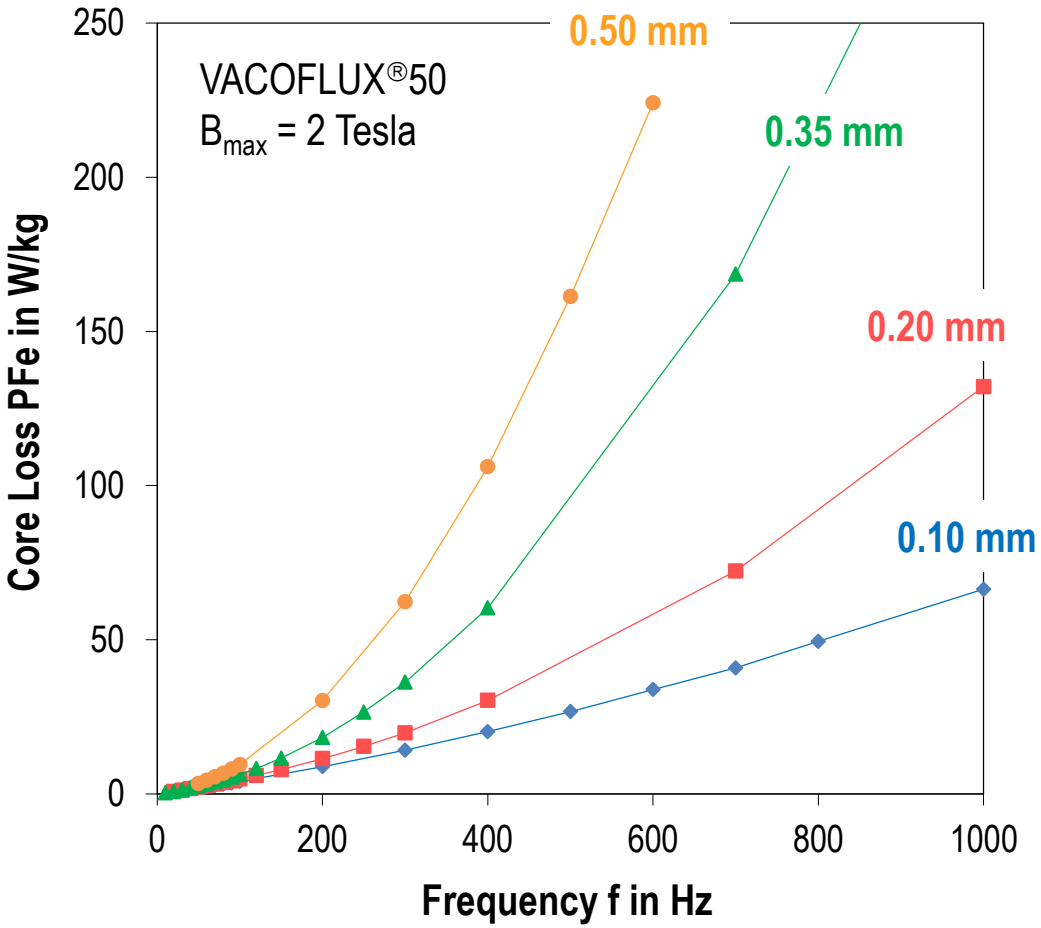


Arrangement of rolls

20-high Rohn mill

cold rolled coils

Core Loss reduction in thin strip material

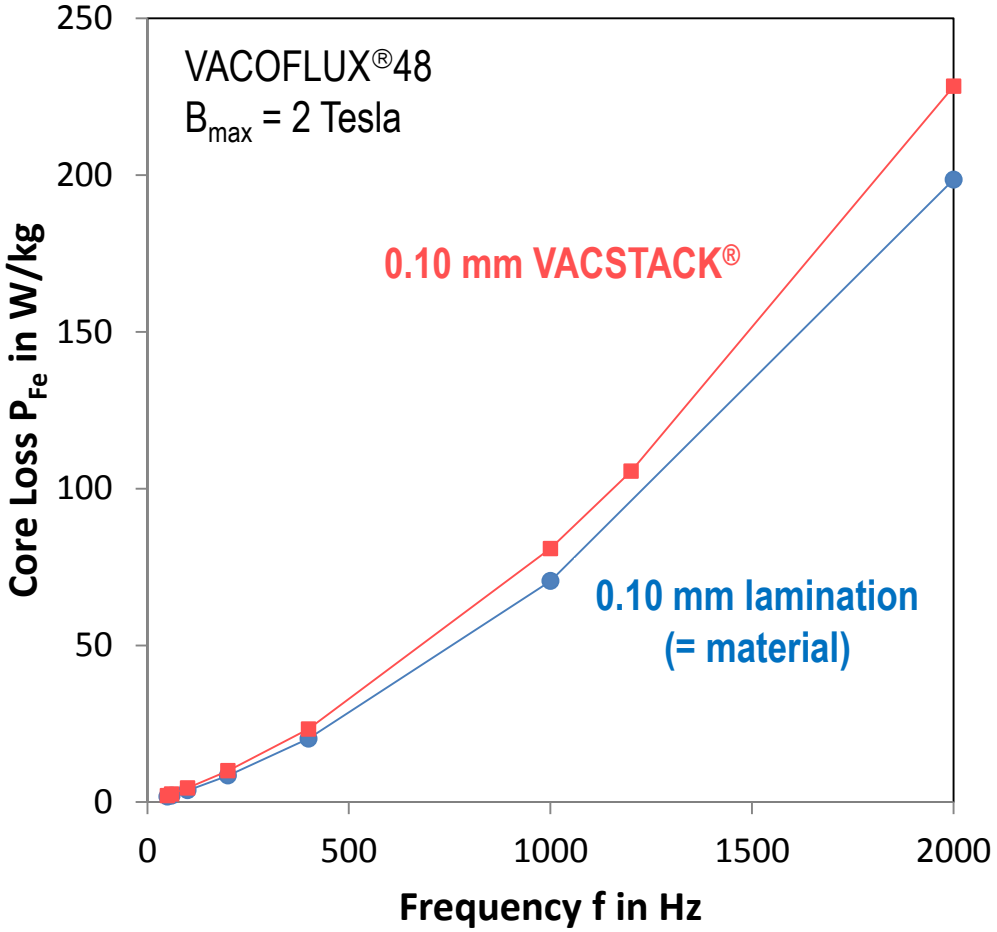


- Eddy currents decrease quadratically with smaller strip thickness

$$P_{ed} = \frac{\pi^2 \sigma \, d^2 B_{max}^{\ 2}}{6\rho} f^2$$

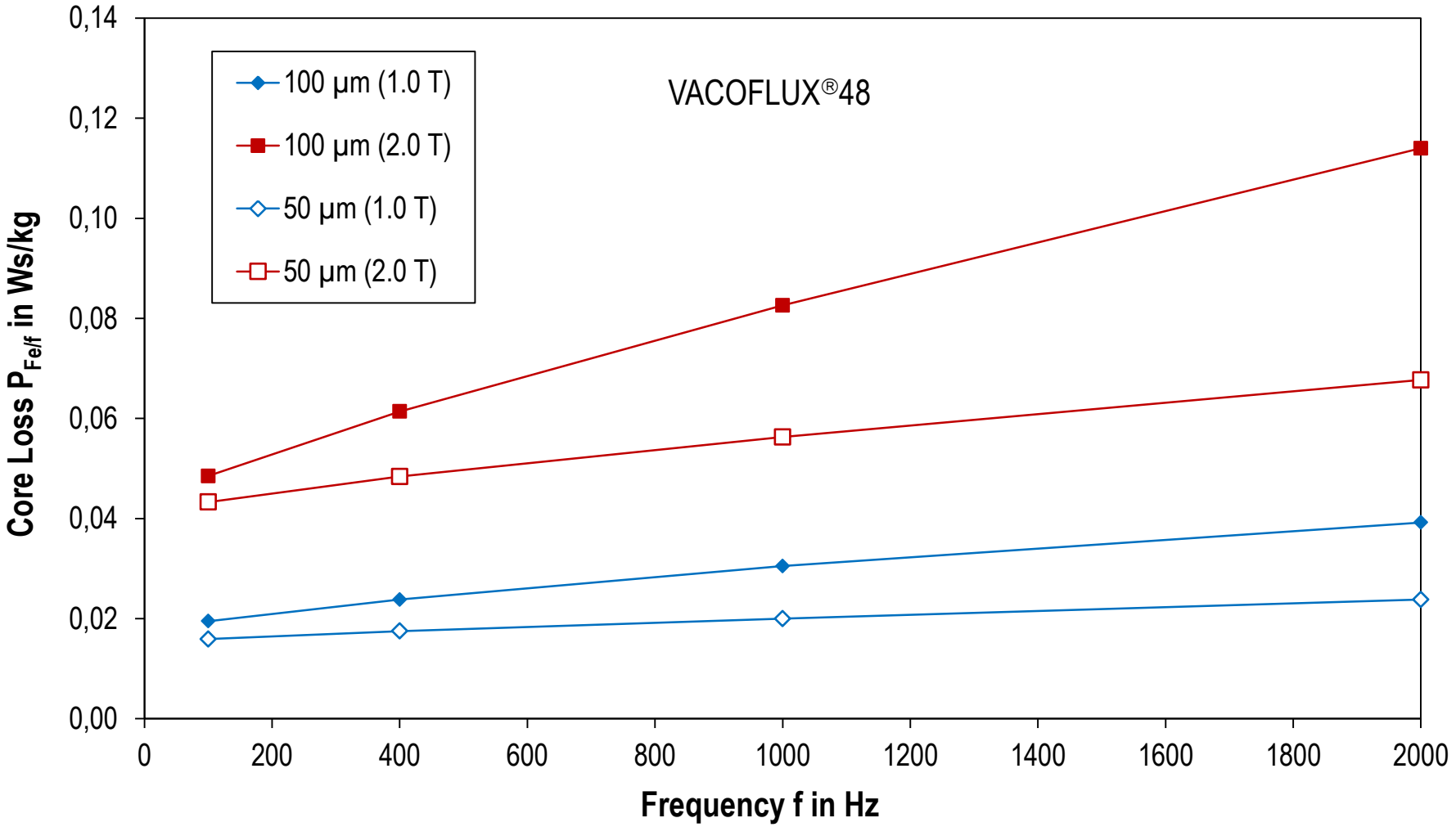
- Laminated FeCo- stacks with strip thickness down to 50 µm are in VAC series production (VACSTACK®)

VACSTACK®- VAC‘s laminated FeCo- Stacks



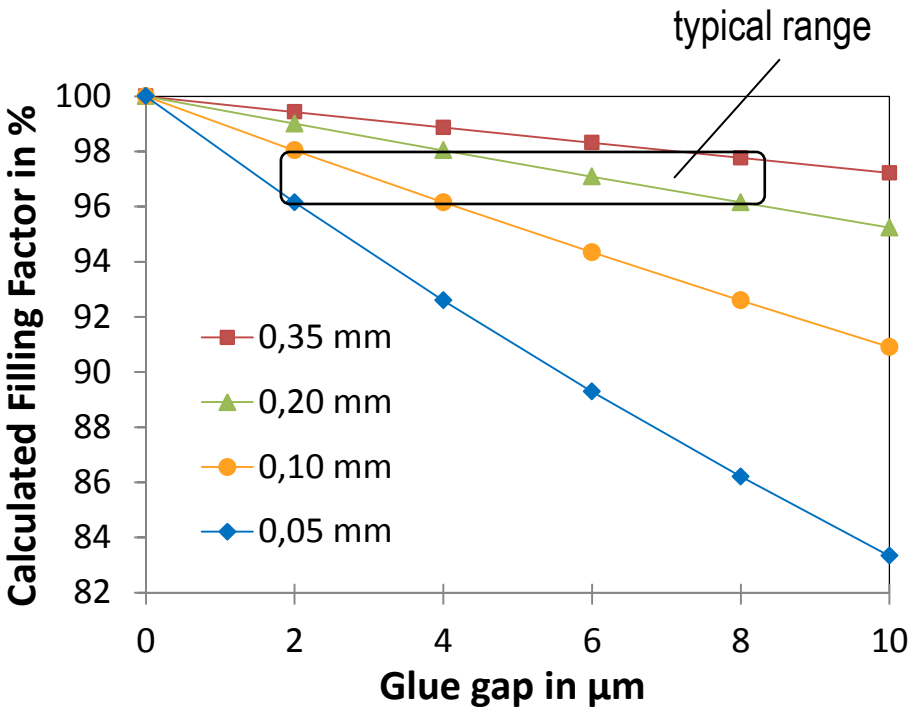
- VACSTACK® losses are close to the material losses
- VACSTACK® procedure ensures minimal deterioration of the magnetic properties
- High- precision packaging and tight tolerances

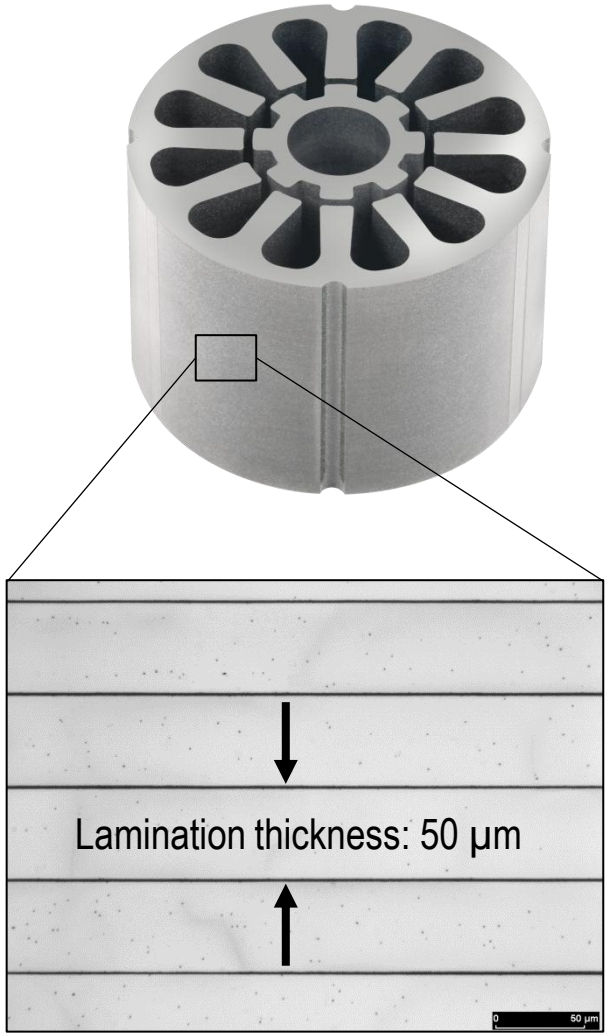
Comparison VACSTACK® in lamination thicknesses 0.10 mm and 0.05 mm



VACSTACK® filling factor

- Filling factor determines the total magnetic volume
- Typical VACSTACK® filling factors of 96- 98%
- Filling factor decreases with laminations thickness





Summary

VAC‘s iron- cobalt materials supply:

- Highest magnetic saturation for weight saving and/or highest forces – **VACOFLUX®**
- Improved tensile properties for high speed rotors – **VACODUR®**
- High performance stacks for motors & generators – **VACSTACK®**

Thank you for your attention

contact: frederik.fohr@vacuumschmelze.com

http://www.vacuumschmelze.com/en/downloads/ht-brochures/soft-magnetic-materials.html