

**New**

# Tape-Wound Cores for Magnetic Amplifier Chokes

## nanocrystalline VITROPERM 500 Z



### New core material

VITROPERM® 500 Z - a new class of Fe-based nanocrystalline soft magnetic material developed specially for use in Saturable Reactors and Magnetic Amplifiers is another innovative development by VACUUMSCHMELZE GmbH & Co. KG to meet the ever increasing demands of the marketplace.

This newly developed material complements the already existing amorphous material - Co-based high-squareness VITROVAC® 6025 Z. This is presently being widely used in Magnetic Amplifier Chokes (MagAmps) for secondary output voltage regulation in various kinds of SMPS with multiple outputs.

Making use of the specific material properties of nanocrystalline VITROPERM 500 Z enables reliable MagAmp circuits with good performance in smallest component sizes at significantly reduced costs. Thus, the MagAmp Regulation principle becomes even more attractive in future projects.

The unique property profile of nanocrystalline VITROPERM with flat hysteresis loop proved to be the most advantageous core material in noise suppression and power conversion, as well as current detection in many different industrial and domestic applications. It combines excellent soft magnetic properties with a very high saturation induction of 1.2 Tesla making this nanocrystalline material all the more interesting where volume and cost matter most.

Furthermore, the thermal stability of the nanocrystalline structure is superior to amorphous materials thereby allowing continuous operating temperatures of up to 120°C and more. With these unbeatable properties, our new square-loop VITROPERM 500 Z with its very high remanence ratio (low  $\Delta B_r$ , high squareness) is the ideal choice for engineers to design MagAmp circuits which are highly reliable and cost-effective.

#### Benefits of nanocrystalline MagAmp cores

- ☑ **high squareness** – enabling good regulation behaviour and reduced dead-time of MagAmp Choke
  - ☑ **very high induction swing** - high magnetic flux in small core sizes
  - ☑ **extended temperature range** up to 120°C
  - ☑ **low coercivity** - enabling small reset currents
  - ☑ **low core losses** – for operation at high frequencies
- ➔ **reduction of weight, volume and costs**

Material data, magnetic properties	VITROPERM 500 Z <sup>#</sup>	VITROVAC 6025 Z	typ. hysteresis loops
Material base	<b>nanocrystalline Fe-based</b>	<b>amorphous Co-based</b>	
Saturation flux density (25°C), B <sub>s</sub>	<b>1.2 T</b>	0.58 T	
Bipolar flux density swing (25°C), ΔB <sub>ss, 25°C</sub>	<b>2.35 T</b>	1.15 T	
Bipolar flux density swing (90°C), ΔB <sub>ss, 90°C</sub>	<b>2.15 T</b>	1.0 T	
Squareness, B <sub>r</sub> / B <sub>s</sub> (typical value)	<b>&gt; 94%</b>	> 96%	
Core losses P <sub>Fe</sub> (typ. value at f = 50 kHz, ΔB = 0.8 T)	<b>100 W/kg</b>	60 W/kg	
Static coercivity H <sub>c</sub>	<b>&lt; 10 mA/cm</b>	3 mA/cm	
Saturation magnetostriction (25°C)	<b>&lt; 0.5 × 10<sup>-6</sup></b>	< 0.2 × 10 <sup>-6</sup>	
Curie temperature, T <sub>c</sub>	<b>&gt; 600°C</b>	240°C	
Continuous upper operation temperature	<b>120°C</b>	90°C	
Specific electrical resistivity	<b>1.20 μΩm</b>	1.35 μΩm	
Density	<b>7.35 g/cm<sup>3</sup></b>	7.70 g/cm <sup>3</sup>	

<sup>#</sup> All material data are typical values and preliminary. Deviations to these material characteristics are permitted due to product shape and size.

The following table describes our standard core series of nanocrystalline VITROPERM 500 Z cores. As this standard core range is supplemented continuously, we recommend to contact us for an updated list or to visit our web page: [www.vacuumschmelze.com](http://www.vacuumschmelze.com)

Core type series of nanocrystalline VITROPERM 500 Z MagAmp cores													
core dimensions d <sub>a,Core</sub> × d <sub>i,Core</sub> × h <sub>Core</sub>	finished dimensions (limiting values)			core cross-section A <sub>Fe</sub>	mean core path length l <sub>Fe</sub>	core mass m <sub>Fe</sub>	total flux <sup>1</sup>		core area <sup>2</sup> product W <sub>a</sub> × A <sub>Fe</sub>	eff. Cu-winding area A <sub>Cu</sub>	mean Cu-path length l <sub>Cu</sub>	heat transfer Resistance R <sub>th</sub>	part number, order code
	O.D.	I.D.	H				25°C	90°C					
	mm	mm	mm				μWb	μWb					
10×7×4.5	11.7	5.5	6.1	0.054	2.67	1.1	12.7	11.9	0.013	0.059	2.27	57	6-L2010-W759
11×8×4.5	14.1	6.6	6.3	0.054	2.98	1.2	12.7	11.9	0.018	0.085	2.53	46	6-L2011-W760
12×8×4.5	14.1	6.6	6.3	0.072	3.14	1.7	16.9	15.8	0.025	0.085	2.53	46	6-L2012-W761
12.5×10×4.5	14.1	8.5	6.8	0.045	3.53	1.2	10.6	9.9	0.026	0.140	2.59	42	6-L2012-W762
12.8×9.5×3.2	14.7	7.9	4.8	0.042	3.50	1.1	9.9	9.3	0.021	0.121	2.26	44	6-L2012-W803
16×10×6	18.0	8.0	8.1	0.144	4.08	4.3	33.8	31.7	0.072	0.124	3.25	34	6-L2016-W763
16.5×12.5×6	19.1	10.9	8.1	0.096	4.56	3.2	22.6	21.1	0.090	0.231	3.30	30	6-L2016-W764
17.5×12.5×6	19.1	10.9	8.1	0.120	4.71	4.2	28.8	26.4	0.112	0.231	3.30	30	6-L2017-W765
19×15.2×4.5	21.2	12.9	7.2	0.068	5.37	2.7	16.1	15.0	0.089	0.323	3.28	27	6-L2019-W766
20×15×8	22.6	10.3	10.2	0.160	5.50	6.5	37.6	35.2	0.133	0.206	4.08	26	6-L2020-W767
20×12.5×8	22.6	10.3	10.2	0.240	5.11	9.0	56.4	52.8	0.200	0.206	4.08	26	6-L2020-W768

$$^1 \Phi_{ss} = 2 \times B_s \times A_{Fe}$$

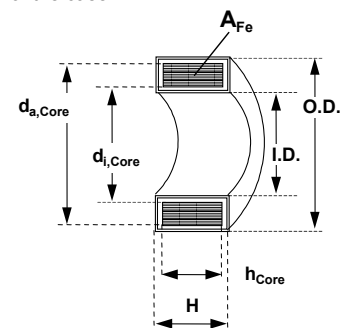
$$^2 W_a \times A_{Fe} : \text{core area product in cm}^4, W_a \text{ is the available winding area of the case}$$

Our MagAmp cores of VITROPERM 500 Z are preferably supplied in plastic protection boxes, adding silicone rubber (Fix 022). The new material can be identified according to following color scheme:

- Plastic case: - dark grey (all)
- Plastic cover: - black (W759, W761, W762, W763, W765, W766, W768)
- brown (W760, W764, W767)

Our plastic boxes are suitable for direct winding (even with thick copper wires) and offer optimum mechanical protection for the nanocrystalline core material. This guarantees best magnetic properties. All materials are according UL94V-1/0 (UL-file no. E41871).

Epoxy coated and further core sizes are available upon request.



Magnetic quality, Test specification		
Testing property	Testing method, Test conditions	Testing value cased cores
• <b>squareness</b> ΔB <sub>rs</sub>	measurement of residual flux density swing ΔB <sub>rs</sub> from remanence to saturation with unipolar current pulses (corr. $\dot{H} = 200$ A/m), repetition frequency f <sub>p</sub> = 1 kHz.	≤ 150 mT
• <b>core losses</b> P <sub>Fe</sub>	measured with sinusoidal driving voltage (f = 50 kHz) and flux density amplitude swing ΔB = 0.8 T.	≤ 120 W/kg

The Magnetic Quality defines test conditions, test scope and permitted limiting values during final inspection of VITROPERM 500 Z cores.

Additionally, the total magnetic flux of each single core is measured on-line during core production to ensure proper and reliable operation in MagAmp Choke applications.

## Frequency behavior of $P_{Fe}$ , $H_c$ and $\Delta B_{rs}$ of nanocrystalline VITROPERM 500 Z MagAmp cores ( $T = 25^\circ C$ ) #

The plotted magnetic reversal losses (core losses)  $P_{Fe}$  are measured with sine-wave induction.

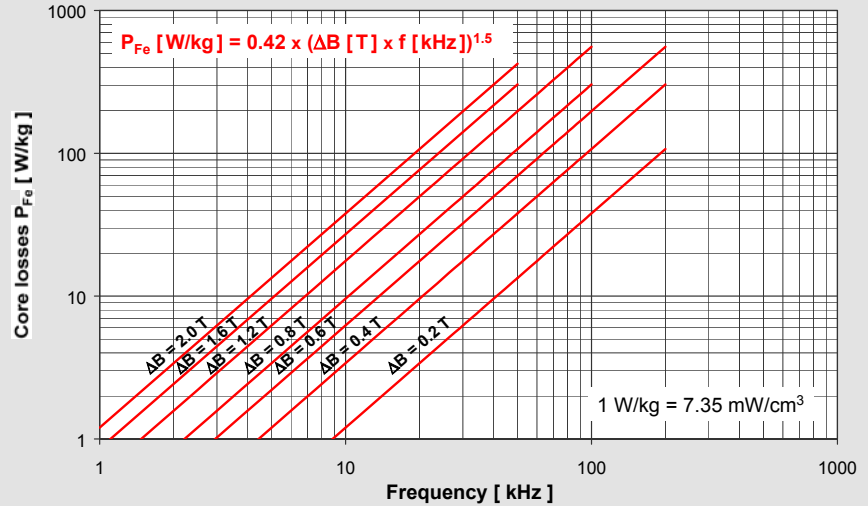
Typical values for frequencies up to about 200 kHz can be determined from the graph directly or calculated with the help of the following estimation formulae:

$$P_{Fe} [W/kg] = 0.42 \times (\Delta B \times f)^{1.5}$$

$$P_{Fe} [mW/cm^3] = 3.09 \times (\Delta B \times f)^{1.5}$$

with flux density swing  $\Delta B$  in T and frequency  $f$  in kHz.

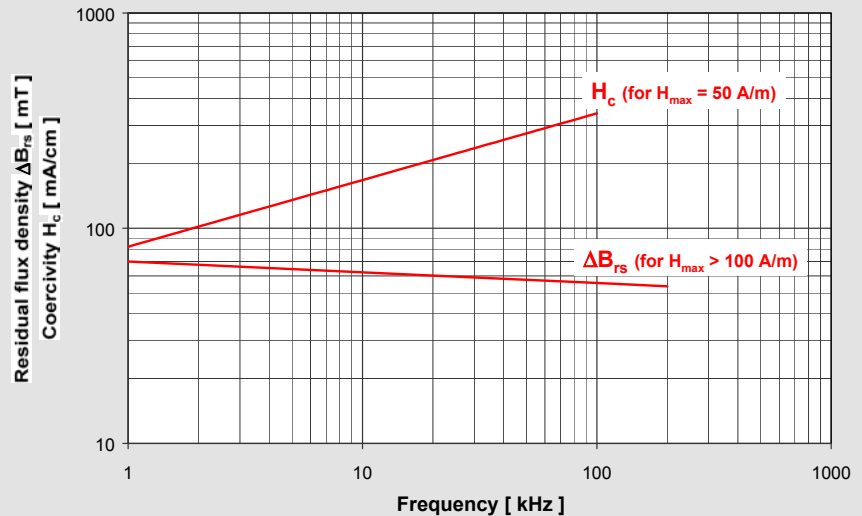
However, unfavorable voltage wave form factors or operation of the cores far into their saturation can, in practice, offer somewhat higher losses.



The pronounced squareness of the hysteresis loop of nanocrystalline VITROPERM 500 Z MagAmp cores will improve even further with increasing frequency by a dynamic reduction of the residual flux density  $\Delta B_{rs}$ .

Typical  $\Delta B_{rs}$  values are between 50 and 70 mT at switching frequencies of 100 kHz, which corresponds to a squareness ratio of  $> 94\%$ . These properties enable short „dead times“ in MagAmp chokes and thus good regulation behavior even at high switching frequencies.

MagAmp cores of nanocrystalline VITROPERM 500 Z offer reasonably small  $H_c$  values enabling small reset currents of the regulation circuit.

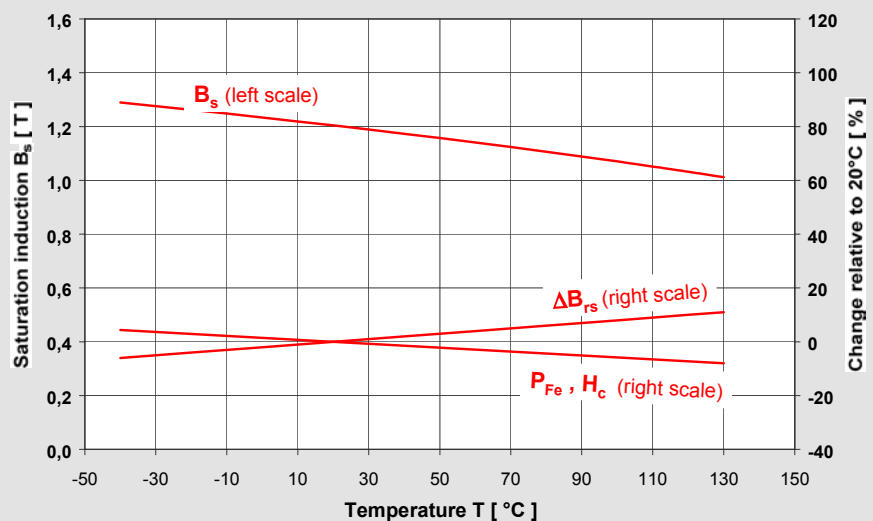


## Thermal stability of nanocrystalline VITROPERM 500 Z MagAmp cores #

VITROPERM 500Z tape-wound cores can be operated at upper continuous temperatures of  $120^\circ C$  and „hot spot“ temperatures of up to  $140^\circ C$  due to the excellent thermal stability of the nanocrystalline material structure.

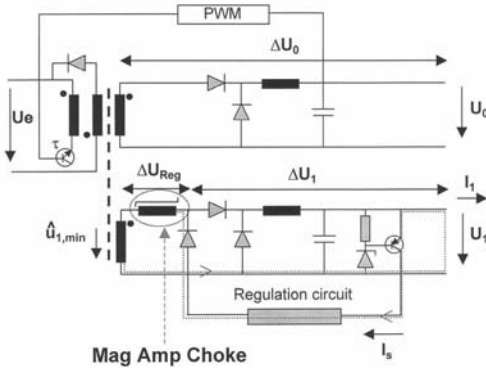
Even at operational temperatures of  $120^\circ C$ , the saturation induction of VITROPERM 500 Z exceeds 1.0 T, allowing max. bipolar flux density swings of about 2.0 T.

The reversible temperature changes of coercivity  $H_c$ , core losses  $P_{Fe}$  and residual flux density  $\Delta B_{rs}$  are typically below 10 - 15% in the temperature range from  $-40^\circ C$  to  $+130^\circ C$ .

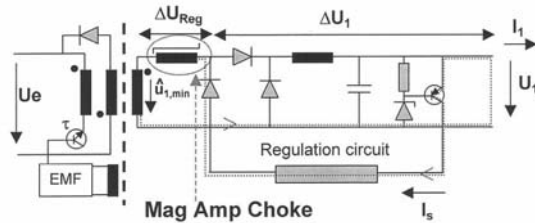


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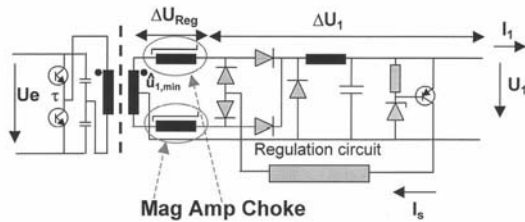
## Application Notes, Design Informations and further Calculation formulae



Forward Converter with MagAmp Choke, Master – Slave Type



Forward Converter with MagAmp Choke, Modular SMPS Type



Push-Pull Converter with 2 MagAmp Chokes, Half-Bridge

Some different calculation methods are commonly used for MagAmp Choke design. The most important core data are given in the type series table (see previous page). More detailed application notes and calculation notes are described in our leaflet PK-002 (Tape-Wound Cores for Magnetic Amplifier Chokes, VITROVAC 6025 Z). The following calculation steps\* should be used for a first selection of cores made of VITROPERM 500 Z and winding for short circuit proof designs. More accurate results are possible with our design software tool VAC MagAmp Calculator\* (operating under Microsoft EXCEL® 97/ 2000).

1. Determine wire current density S (typically S = 5 – 10 A/mm<sup>2</sup>) and calculate wire size and wire cross section a<sub>Cu</sub>:

$$a_{Cu} [\text{mm}^2] = \frac{I_{1,RMS} [\text{A}]}{S [\text{A/mm}^2]}$$

2. Calculate regulation voltage U<sub>Reg</sub> of MagAmp Choke:

$\tau_{max}$  = max. pulse duty ratio of primary switch,  $\hat{u}_{1,min}$   
= peak value of transformer output voltage  
( $\alpha = 1$  for forward converters,  $\alpha = 2$  for push pull converters with 2 MagAmps)

$$U_{Reg} [\text{V}] = \alpha \times \tau_{max} \times \hat{u}_{1,min} [\text{V}]$$

3. Select core (start with small core) and calculate no. of turns (min. value):

$$N \geq \frac{10 \times U_{Reg} [\text{V}]}{\alpha \times 2.0 [\text{T}] \times A_{Fe} [\text{cm}^2] \times f [\text{kHz}]}$$

4. Check winding space of selected core ( $A_{Cu} [\text{cm}^2] \geq a_{Cu} [\text{cm}^2] \times N$ ) or recalculate min. no. of turns for next bigger core size.

5. Calculate regulation flux density swing  $\Delta B_{Reg}$   
(criterion:  $\Delta B_{Reg} < (2 \times B_S) - \Delta B_{rs}$ )

$$\Delta B_{Reg} [\text{T}] \geq \frac{10 \times U_{Reg} [\text{V}]}{\alpha \times N \times A_{Fe} [\text{cm}^2] \times f [\text{kHz}]}$$

6. Calculate temperature rise

of winding  $\Delta T_{Cu}$   
( $\rho_{Cu} \approx 2.27 \times 10^{-6} \Omega\text{m}$ )

$$\Delta T_{Cu} [\text{K}] = \frac{R_{th} [\text{K/W}] \times I_{1,RMS} [\text{A}]^2 \times N^2 \times l_{Cu} [\text{cm}] \times \rho_{Cu} [\Omega\text{m}]}{20 \times A_{Cu} [\text{cm}^2]}$$

and core  $\Delta T_{Fe}$

$$\Delta T_{Fe} [\text{K}] = 0.42 \times m_{Fe} [\text{kg}] \times R_{th} [\text{K/W}] \times \Delta B_{Reg} [\text{T}]^{1.5} \times f [\text{kHz}]^{1.5}$$

7. Estimate reset current I<sub>S</sub>:

$$I_S (\text{mA}) \approx \frac{25 \times \Delta B_{Reg} [\text{T}]^{0.45} \times f [\text{kHz}]^{0.53} \times l_{Fe} [\text{cm}]}{N}$$

8. Experimental testing\*.

**Design Examples of MagAmps\*** (Forward Converter, short circuit proof design, 100 kHz,  $\tau_{max} = 0.4$ , ambient temperature 45 – 50°C)

	I <sub>1,max</sub> = 10 A	I <sub>1,max</sub> = 15 A	I <sub>1,max</sub> = 20 A	I <sub>1,max</sub> = 25 A	I <sub>1,max</sub> = 30 A
<b>U<sub>1</sub> = 3,3 V</b>	W759, N = 10 W760, N = 11	W759, N = 8 W760, N = 9	W759, N = 6 W760, N = 7 W761, N = 7	W760, N = 6 W761, N = 6	W760, N = 5 W761, N = 5 W762, N = 6
<b>U<sub>1</sub> = 5 V</b>	W759, N = 11 W760, N = 12 W761, N = 12	W759, N = 9 W760, N = 10 W761, N = 10	W760, N = 8 W761, N = 8	W761, N = 6 W762, N = 8 W764, N = 8	W764, N = 8 W763, N = 6 W765, N = 8
<b>U<sub>1</sub> = 12 V</b>	W761, N = 14 W764, N = 20	W764, N = 16 W763, N = 12	W764, N = 14 W765, N = 14	W765, N = 12 W766, N = 15 W767, N = 12	W768, N = 10

\* Experimental circuit testing is recommended in any case

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