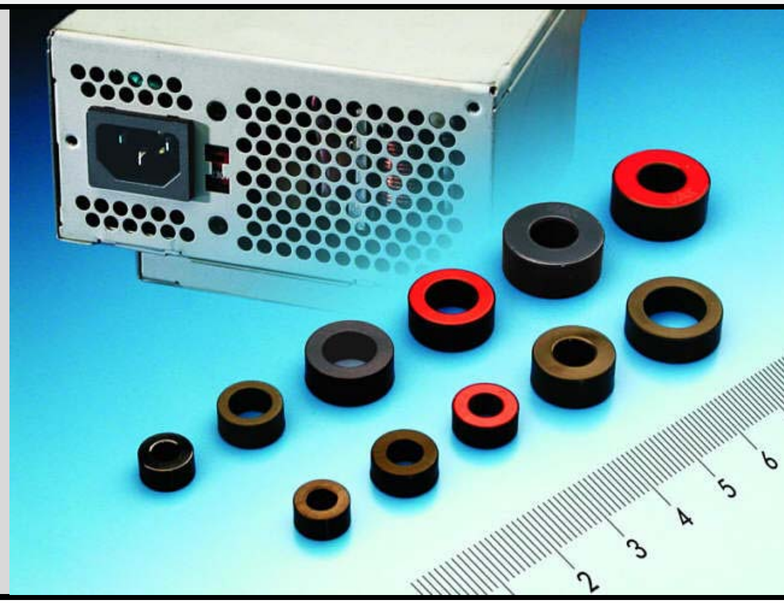
Tape-Wound Cores for Magnetic Amplifier Chokes

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.

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**

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.

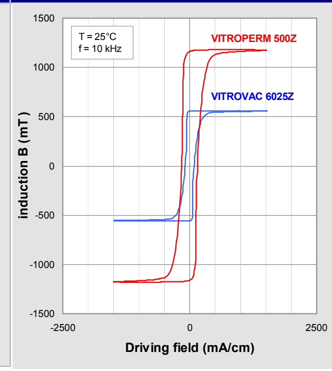
Making use of the specific material properties of nanocrystalline VITROPERM 500 Z enables reliable MagAmp circuits with good performance in smallest component sizes at significantly reduced costs. Thus, the MagAmp Regulation principle becomes even more attractive in future projects.

The unique property profile of nanocrystalline VITROPERM with flat hysteresis loop prooved 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 ΔB_{rs}, high squareness) is the ideal choice for engineers to design MagAmp circuits which are highly reliable and cost-effective.

Material data, magnetic properties	VITROPERM 500 Z[#]	VITROVAC 6025 Z
Material base	**nanocrystalline Fe-based**	**amorphous Co-based**
Saturation flux density (25°C), B_s	**1.2 T**	0.58 T
Bipolar flux density swing (25°C), $\Delta B_{ss,\,25°C}$	**2.35 T**	1.15 T
Bipolar flux density swing (90°C) , $\Delta B_{ss,\,90°C}$	**2.15 T**	1.0 T
Squareness, B_r / B_s (typical value)	**> 94%**	> 96%
Core losses P_{Fe} (typ. value at f = 50 kHz, ΔB = 0.8 T)	**100 W/kg**	60 W/kg
Static coercivity H_c	**< 10 mA/cm**	3 mA/cm
Saturation magnetostriction (25°C)	**< 0.5 x 10^{-6}**	< 0.2 x 10^{-6}
Curie temperature, T_c	**> 600°C**	240°C
Continuous upper operation temperature	**120°C**	90°C
Specific electrical resistivity	**1.20 µΩm**	1.35 µΩm
Density	**7.35 g/cm³**	7.70 g/cm³

typ. hysteresis loops



[#] 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

Core type series of nanocrystalline VITROPERM 500 Z MagAmp cores

core dimensions $d_{a,Core}$ x $d_{i,Core}$ x h_{Core}	finished dimensions (limiting values) O.D.	I.D.	H	core cross-section A_{Fe}	mean core path length l_{Fe}	core mass m_{Fe}	total flux [1] 25°C ϕ_{ss}	total flux [1] 90°C $\phi_{ss,\,90°C}$	core area [2] product $W_a \times A_{Fe}$	eff. Cu-winding area A_{Cu}	mean Cu-path length l_{Cu}	heat transfer Resis-tance R_{th}	part number, order code
	mm	mm	mm	cm²	cm	g	µWb	µWb	cm⁴	cm²	cm	K/W	T6000...
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] $W_a \times A_{Fe}$: core area product in cm⁴, W_a is the available winding area of the case

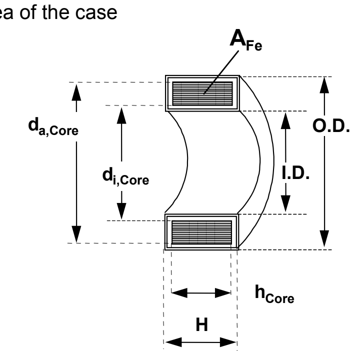
Our MagAmp cores of VITROPERM 500 Z are preferrably supplied in plastic protection boxes, adding silicone rubber (Fix 022). The new material can be identified according to following color scheme:

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)
• **squareness ΔB_{rs}**	measurement of residual flux density swing ΔB_{rs} from remanence to saturation with unipolar current pulses (corr. $\hat{H}$ = 200 A/m), repetition frequency f_p = 1 kHz.	**≤ 150 mT**
• **core losses P_{Fe}**	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 ΔB_{rs} of nanocrystalline VITROPERM 500 Z MagAmp cores (T = 25°C)

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

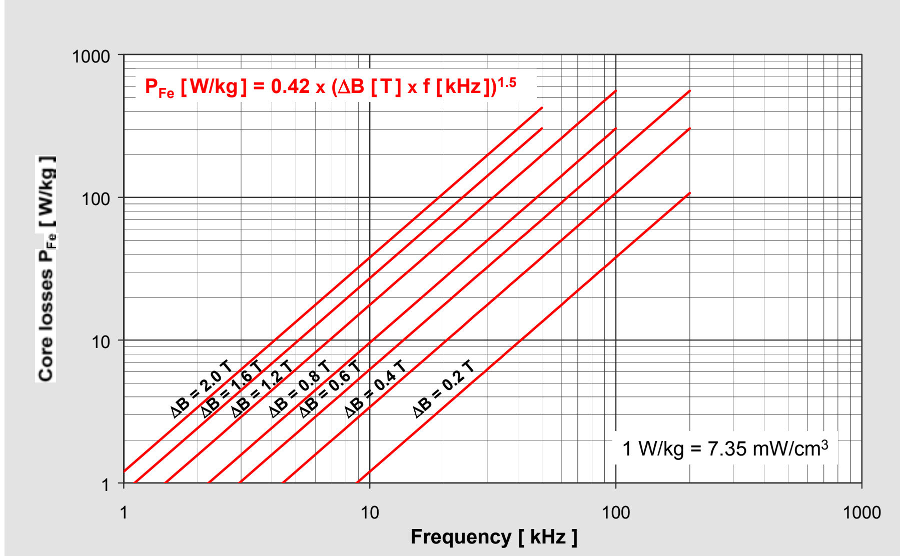
Typical values for frequencies up to about 200 kHz can be determined from the graph directly or calculated with the help of the following estimation formulae:

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

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

with flux density swing ΔB in T and frequency f in kHz.

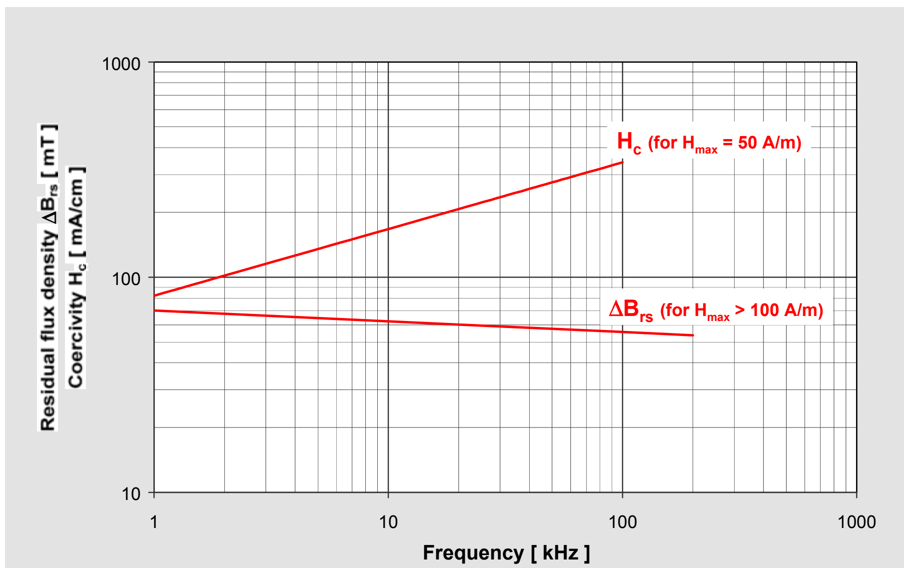
However, unfavorable voltage wave form factors or operation of the cores far into their saturation can, in practice, offer somewhat higher losses.



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 ΔB_{rs}.

Typical ΔB_{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.

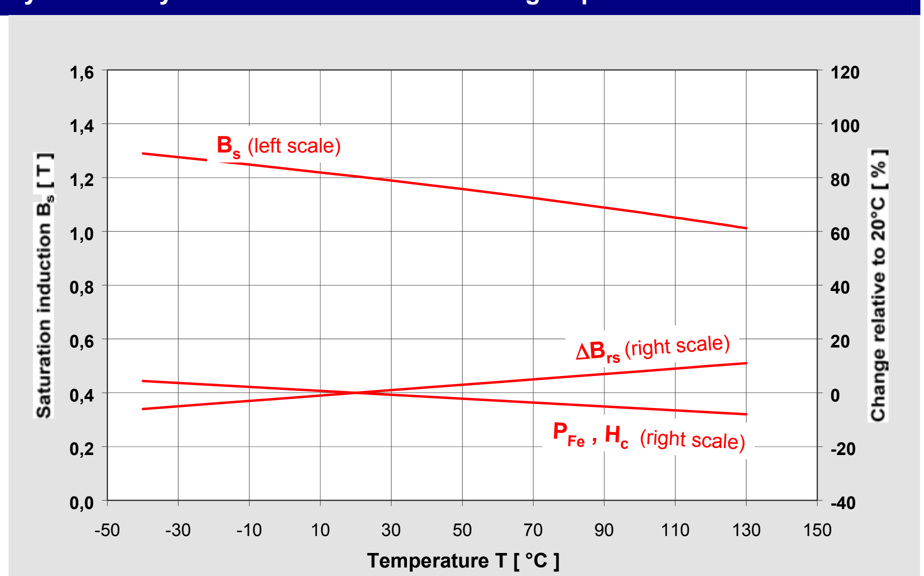


Thermal stability of nanocrystalline VITROPERM 500 Z MagAmp cores

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

Even at operational temperatures of 120°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 ΔB_{rs} are typically below 10 - 15% in the temperature range from - 40°C to + 130°C.



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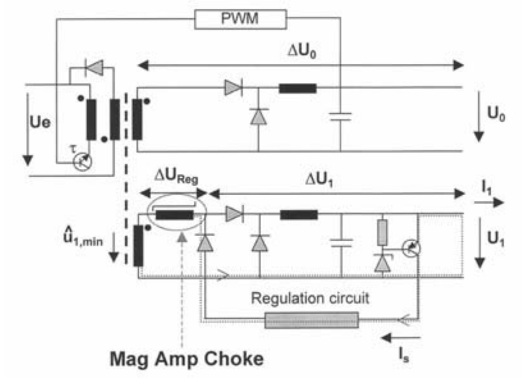
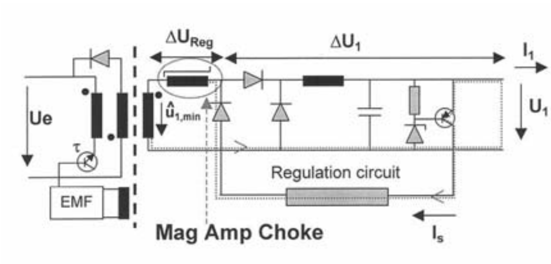
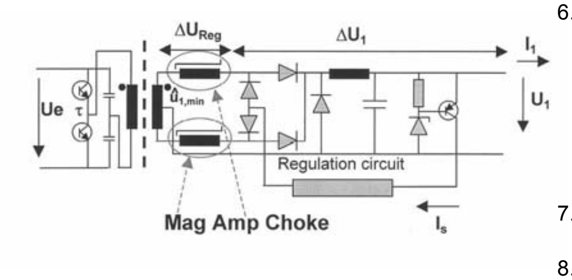
Application Notes, Design Informations and further Calculation formulae



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 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/mm²) and calculate wire size and wire cross section a_{Cu}:

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

2. Calculate regulation voltage U_{Reg} of MagAmp Choke:
τ_{max} = max. pulse duty ratio of primary switch, $\hat{u}_{1,min}$ = peak value of transformer output voltage
(α = 1 for forward converters, α = 2 for push pull converters with 2 MagAmps)

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

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

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

4. Check winding space of selected core (A_{Cu} [cm²] ≥ a_{Cu} [cm²] x N) or recalculate min. no. of turns for next bigger core size.

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

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

6. Calculate temperature rise

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

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

and core ΔT_{Fe}

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

7. Estimate reset current I_S:

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

8. Experimental testing*.

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

	$I_{1,max}$ = 10 A	$I_{1,max}$ = 15 A	$I_{1,max}$ = 20 A	$I_{1,max}$ = 25 A	$I_{1,max}$ = 30 A
U_1 = 3,3 V	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
U_1 = 5 V	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
U_1 = 12 V	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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