AMORPHOUS C-CORES

High saturation density
Low losses
Small size
Flexible due to individual air gaps

Content

Some remarks about this brochure

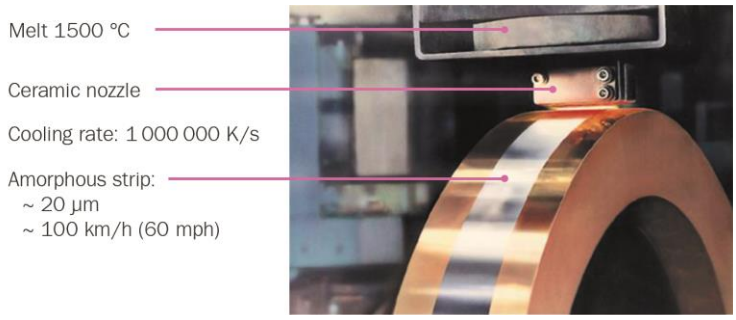
This brochure describes the properties of c-cores from amorphous Fe-based alloys and proposes a design approach for storage chokes or PFC chokes. The given formulae and approximation formulae have been developed on basis of design examples and extra- and interpolations. Due to the huge variety of frame conditions and design options these formulae can only work with a limited strike probability and therefore may be considered as an „intelligent guess“ in order to find a suitable start version quickly. We are thankful for any comment on possible bigger deviations from the truth and will of course consider any hint in the next issue of this brochure.

All formulae require SI units or derived SI units in order to deliver the correct results, although some of the values in the tables are given in more descriptive units like e. g. A_{Fe} in cm², l_{Cu} in cm, etc. This means that in the formulae A_{Fe} has to be transferred in **m²**, l_{Cu} in **m**, etc. Exceptions are explicitly mentioned (e. g. p. 14).

C-cores, bobbins and clamping straps are commodities from our Chinese partners who are solely responsible for all quality issues. We are however selecting our partners very carefully with a strong focus on product quality. Additional sample testing at our lab including e. g. tensile testing of clamping straps, loss measurements of c-cores or climate cycle testing ensure a good and reliable product quality.

Amorphous Fe-based metals

Amorphous metals are characterized by the lack of a crystalline structure with grains and grain boundaries. This is of advantage for soft magnetic behavior as disturbances like crystal anisotropies or domain wall pinning at grain boundaries are eliminated.



They are produced in only one step from a hot melt (of about 1500 °C) to a thin metallic foil of about 25 µm thickness, with widths up to more than 200 mm. Cooling rates of about 1.000.000 K per second are necessary to avoid crystallization and to achieve the (meta-stable) amorphous condition. Furthermore “adders” like Boron or Silicon are required to reduce the mobility of the atoms in the melt when freezing the metal. Usually amorphous foils are produced by pressing the melt via a ceramic nozzle on a fast rotating water-cooled cooper wheel.

The thin foils are processed to toroidal or c-cores by core winders. In a next step the cores are “annealed” to reduce internal stresses and improve the magnetic properties. This is typically done somewhat below the crystallization temperature which is about 500 °C.

Fe-based amorphous alloys have excellent magnetic properties, however they do not reach the low losses or high permeabilities of nanocrystalline alloys due to the relatively high magnetostriction. The advantages are a higher saturation flux density and lower costs.

Basic material data

Saturation Flux Density	B_s B_s	RT 130 °C	[T]	**1,56** **1,44**
Curie Temperature	T_c		[°C]	**399**
Cristallisation Temperature			[°C]	**508**
Upper Application Temperature			[°C]	**ca. 130**
Magnetostriction	λ_s		ppm	**27**
Spez. Electrical Resistivity	ρ_{el}	RT	[µΩm]	**1,3**
Density	ρ		[g/cm³]	**7,18**
Core Losses	P_{Fe}	(0.1T, 25 kHz)	[W/kg]	**ca. 15**
Core Losses	P_{Fe}	(0.3T, 50 kHz)	[W/kg]	**ca. 300**

Tab. 1: *Material data and core properties (losses)*

Mechanical design

Amorphous c-cores are impregnated with an epoxy-type of glue for mechanical stabilization after annealing. Thus they are a composite of about 80 % metal and about 20 % plastic material.

A mechanical stable design needs to consider thermal movement due to different thermal expansion coefficients as well as reversible softening of the epoxy system at higher temperatures. Both effects can influence the air gap and change the inductivity

Typically metallic clamping straps are used for mechanic stabilization. A clamping force of about 0,8 N/mm² is recommended. The air gap filler should be bonded with the core.

A more reliable mechanical stabilization is achieved by encapsulating the choke in a plastic or aluminum case. Using a relatively soft filler material like PU (polyurethane) can also positively influence the noise behavior.

Fig. 1: *Example of a choke with upright type of copper bars, standard bobbins, clamping strap and metallic fixing bracket. Core size SU 75b, copper bars 10x2,5 mm², 52 turns*

Noise is a consequence of the attracting and repellent forces between the core halves and magnetostrictive size and volume changes due to the magnetostriction of the alloy. In case of problems (when driving the chokes with relatively low frequencies) measures like introducing a mechanical damping between choke and board or case can help.

Like with SiFe c-cores the main content of amorphous c-cores is iron. They are therefore similarly sensitive to corrosion. Mostly this is more or less an “optical problem”, however should be considered. If required we can offer temperature-humidity testing as a service.

The amorphous strip is fairly brittle after annealing. Please use protecting means like cloves and glasses when handling the cores.

Slight core flaking of the inner and outer strip layer is not possible to avoid and no quality criteria. Magnetic properties are not influenced by broken outer and inner layers.

Sizes, tolerances and magnetic dimensions

C-cores from amorphous alloys produced by rapid solidification are preferably offered in the American AMCC type series. However the „European" IEC 329 types, like the SU series, are also available.

C-cores are tape-wound cores from a thin metallic foil with surface roughness, thickness tolerances and possible slight thickness variations along the width. Consequently higher size tolerances compared with e. g. machined parts need to be considered.

The notation of the mechanical dimensions in this brochure follows the IEC 329 system. The AMCC uses different indications, and to some extend ± tolerances where the IEC indicates only a maximum value. IEC and AMCC notations are compared in the following:

	IEC 329		AMCC	
Outer length	a	max	f	± x
Outer width	b	max	e	± x
Core build	c	- x	a	± x
Window length	e	min	c	min
Core height	f	- x	d	± x
Window width	g	min	b	min
Corner radius	r	max	n.d.	

Tab. 2: *Comparison of notations for c-cores acc. to IEC 329 and the AMCC standard*

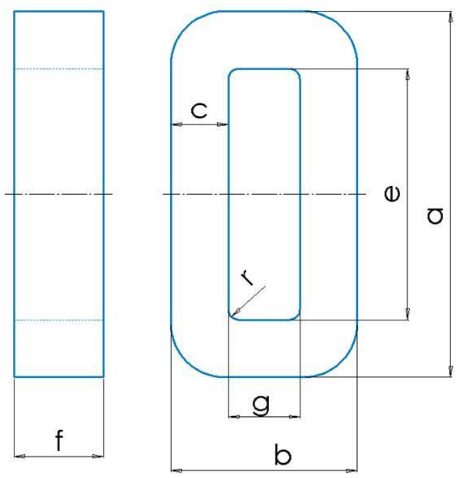


Fig. 2: *Notations acc. to IEC 329*

The magnetic dimensions can be calculated using the following formulae:

Sizes acc. to IEC 329

$$A_{Fe,min} = c_{min} * f_{min} * FF$$
$$l_{Fe} \approx a + b + e + g - 1{,}72 * \left(r + \frac{c}{2}\right)$$
$$m_{Fe} = A_{Fe} * l_{Fe} * \rho$$

Sizes acc. to AMCC

$$A_{Fe,min} = a_{min} * d_{min} * FF$$
$$l_{Fe} \approx 2(f_{max} - 2a) + 2(e_{max} - 2a) + \pi * a_{max}$$
$$m_{Fe} = A_{Fe} * l_{Fe} * \rho$$

A_{Fe}: effective iron cross section

l_{Fe}: mean magnetic path length

m_{Fe}: nominal core weight

FF: stacking factor ≈ 0,82

ρ: density = 7,18 g/cm³

Standard series

We offer preferred types of the AMCC and SU series as well as customer-specific sizes. Please ask for bobbins and other standard types.

The following table shows examples from the AMCC and SU series. Please ask for stock availability and further types.

Type	**a**	**b**	**f**		**e**	**g**	**c**		**l_{Fe}**	**A_{Fe}**	**m_{Fe}**	**$A_{cu,50\%}$**	**l_{Cu}**	**O** ca.	**LI^2** typ
AMCC	[mm] max	[mm] max	[mm]	±	[mm] min	[mm] min	[mm]	±	[cm]	[cm²]	[g]	[cm²]	[cm]	[cm²]	[VAs]
4	52,5	29,5	15	0,5	32,8	10	9	0,5	12,2	1,1	99	1,64	8,8	85	0,08
6.3	55	33	20	0,5	33	11	10	0,5	12,8	1,6	154	1,82	10,4	110	0,12
8	54	36	20	0,5	30	13	11	0,8	13,0	1,8	172	1,95	11,4	120	0,14
10	64	36	20	0,5	40	13	11	0,8	15,0	1,8	198	2,60	11,4	135	0,17
16A	64	36	25	0,5	40	13	11	0,8	15,0	2,3	248	2,60	12,4	145	0,22
16B	74	36	25	0,5	50	13	11	0,8	17,0	2,3	281	3,25	12,4	165	0,26
20	74	36	30	0,5	50	13	11	0,8	17,0	2,7	337	3,25	13,4	170	0,30
25	84	42	25	0,5	56	15	13	0,8	19,4	2,7	379	4,20	13,6	200	0,37
32	84	42	30	0,5	56	15	13	0,8	19,4	3,2	454	4,20	14,6	220	0,44
40	84	42	35	0,5	56	15	13	0,8	19,4	3,7	530	4,20	15,6	235	0,51
50	105	53	25	0,5	70	20	16	1,0	24,4	3,3	586	7,00	16,2	310	0,66
63	105	53	30	0,5	70	20	16	1,0	24,4	3,9	703	7,00	17,2	330	0,75
80	105	53	40	1,0	70	20	16	1,0	24,4	5,2	938	7,00	19,2	350	0,95
100	105	53	45	1,0	70	20	16	1,0	24,4	5,9	1055	7,00	20,2	370	1,1
125	124	64	35	1,0	83	25	19	1,0	29,2	5,5	1166	10,4	20,8	460	1,35
160	124	64	40	1,0	83	25	19	1,0	29,2	6,2	1333	10,4	21,8	495	1,4
200	124	64	50	1,0	83	25	19	1,0	29,8	7,8	1670	10,4	23,8	540	1,75
250	131	64	60	1,0	90	25	19	1,0	30,8	9,3	2095	11,25	25,8	595	2,2
320	133	80	50	1,0	85	35	22	1,0	32,8	9,0	2167	14,9	28,4	700	2,6
400	129	79	65	1,0	85	35	22	1,0	30,2	11,7	2658	14,9	31,4	780	3,2
500	139	91	55	1,0	85	40	25	1,0	35,0	11,3	2890	17,00	32,0	850	3,4
630	139	91	70	1,0	85	40	25	1,0	35,0	14,4	3678	17,00	35,0	930	4,0
800A	139	91	85	1,5	85	40	25	1,0	35,0	17,4	4466	17,00	38,0	1010	4,6
800B	159	101	85	1,5	95	40	30	1,0	39,0	20,9	5972	19,00	39,0	1175	5,7
1000	176	107	85	1,5	105	40	33	1,0	42,2	23,0	7109	21,00	39,6	1290	6,4
SU	[mm] max	[mm] max	[mm]	-	[mm]	[mm] min	[mm] min	.	[cm]	[cm²]	[g]	[cm²]	[cm]	[cm²]	[VAs]
75b	128,6	75	41,1	1,1	78	25	24,7	1,0	27,9	7,7	1539	9,75	23,2	550	2,2
90a	155,8	90	30,9	1,4	95	30	29,6	1,1	33,9	6,9	1678	14,25	24,1	700	2,8
90b	155,8	90	50,9	1,4	95	30	29,6	1,1	33,9	11,6	2824	14,25	28,1	800	4,8

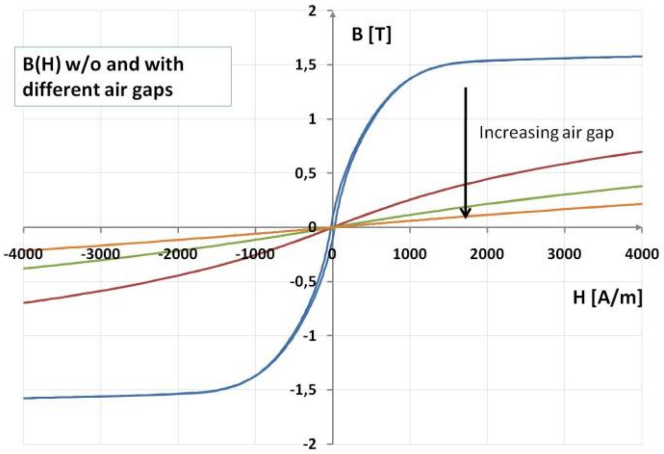
Tab. 3: *Mechanical and magnetic nominal and guidance values of series types.* ***O*** *is the surface of a (hypothetical) cubic casing without the ground face. The energy storage capacity* ***LI^2*** *may be significantly different depending on the frame and design conditions. More explanations and comments can be found on the following.*

Basic application notes

C-cores made from amorphous Fe-based alloys offer an interesting combination of a high saturation flux density and low magnetization losses.

The main applications for amorphous c-cores are storage chokes or power factor correction (PFC) chokes in the frequency range of about 20 to 50 kHz. The relatively high operational induction and the low losses enable the design of size-optimized solutions.

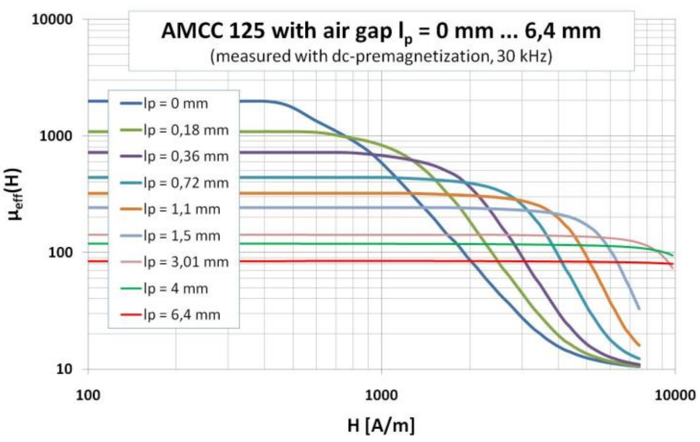
Choke designs are based on the fact that the inductivity **L** is proportional to the square of the number of turns **N**, whereas the field strength in the core increases only linear with **N**. Consequently alloys with low permeability are used to avoid saturation of the core. The required inductivity is achieved by an appropriate number of turns.



Amorphous alloys typically have high permeabilities, thus the cores need to be „sheared" by introducing one or several air gaps.

Fig. 2 shows the B(H) characteristic of a typical amorphous c-core, w/o air gap and with increasing air gaps to demonstrate the influence. An optimized air gap corresponds with a size optimized design.

Fig. 3: *B(H) characteristic of amorphous c-cores*



Increasing the air gap decreases the permeability and allows higher currents (field strengths). Higher number of turns are necessary to achieve the required inductivity. Bigger air gaps will however negatively influence copper and core losses by interactions with the stray field.

Fig. 4: *Effective permeability for different air gaps*

Basic design notes

Designs close to the optimum storage energy minimize size and costs. This can be achieved by the best possible use of the winding area and the magnetic performance of the material.

The energy storage capacity $\mathbf{E_{Choke}}$ is determined by the inductivity **L** of the choke and the square of the current **I**. The storage capacity is adequate to the work which is necessary to magnetize the choke:

$$E_{Choke} = \frac{1}{2} * L * I^2$$

The relation is valid as long as the choke or the core is not saturated. For storage chokes and power factor correction chokes (PFC) the following correlation between $\mathbf{LI^2}$, the basic data of the core and the electrical and magnetic application data can be used:

$$LI^2 \approx S_{eff} * A_{Cu} * A_{Fe} * \widehat{B}_{max}$$

The value „$\mathbf{I^2}$" consists of 2 parts: the maximum thermal current $\mathbf{I_{eff,tot}}$ (as effective current), and the maximum magnetic current $\mathbf{\hat{I}_{max,mag}}$ (as peak value) to neither "railroad" the choke thermal and magnetically.

The corresponding terms in the formula are the current density $\mathbf{S_{eff}}$, the maximum (possible) flux density $\mathbf{\widehat{B}_{max}}$ and the effective permeability $\mathbf{\mu_{eff}}$ (as a function of the air gap).

$$S_{eff} = \frac{I_{eff,tot} * N}{A_{Cu}}$$

$$\hat{B}_{max} = \mu_0 * \mu_{eff} * \frac{\hat{I}_{max,mag} * N}{l_{Fe}}$$

The possible current density depends on the size of the choke, the cooling conditions and of course the copper losses. These consist of the ohmic part and additional losses due to skin and proximity effects and stray field influences in the neighborhood of the air gap.

Design options and the relationship of all these parameters are manifold. Nevertheless we have tried to develop approximation formulae to allow a quick design approach in the next chapter. Please carefully note that the formulae include inevitable uncertainties and a careful experimental validation of the design is mandatory. Please also note that the formulae are given without warranty.

Currents in storage and PFC chokes

The current values, frequency and wave forms determine both the requirements for the winding and wires as well as for the choke material and core size.

In storage chokes the current consists of a DC part with a high frequency ripple, in PFC chokes the current consists of a lower frequency sinusoidal part superimposed by a high frequency ripple. For the design of a choke it is necessary to know the total effective current which determines the losses and thus the temperature raise and the maximum peak value which determines the maximum induction in the core. These values are

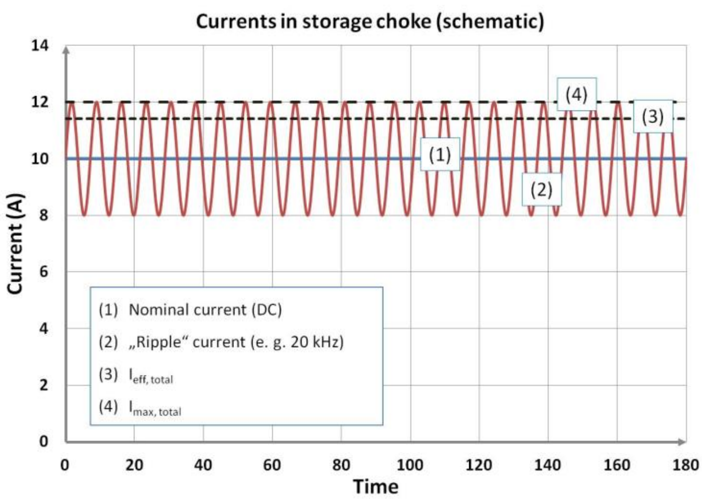


Fig. 5:*Currents in a storage choke (schematic)*

for storage chokes:

$$\hat{I}_{max} = I_{N,DC} + \frac{I_{R,ss}}{2}$$

$$I_{eff,ges} = \sqrt{(I_{N,DC})^2 + \left(\frac{1/_2 * I_{R,ss}}{\sqrt{2}}\right)^2}$$

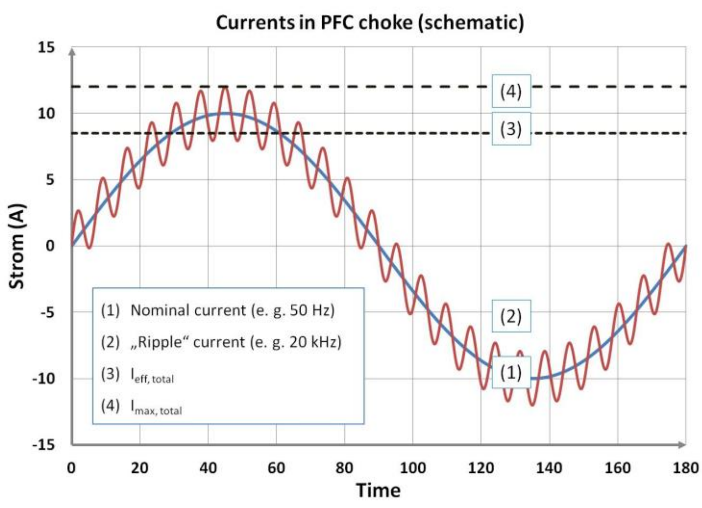


Fig 6: *Currents in a PFC choke (schematic)*

for PFC chokes:

$$\hat{I}_{max} = I_{N,eff} * \sqrt{2} + \frac{I_{R,ss}}{2}$$

$$I_{eff,ges} = \sqrt{(I_{N,eff})^2 + \left(\frac{1/_2 * I_{R,ss}}{\sqrt{2}}\right)^2}$$

Determination of the maximum induction

The magnetic field is determined by the number of turns multiplied by the current and divided by the magnetic path. The corresponding induction is determined by the effective permeability and thus by the air gap.

Amorphous c-cores feature a significantly less pronounced drop of the inductivity with the field strength compared to powder alloys. This allows the design of size optimized chokes with a high “stiffness”.

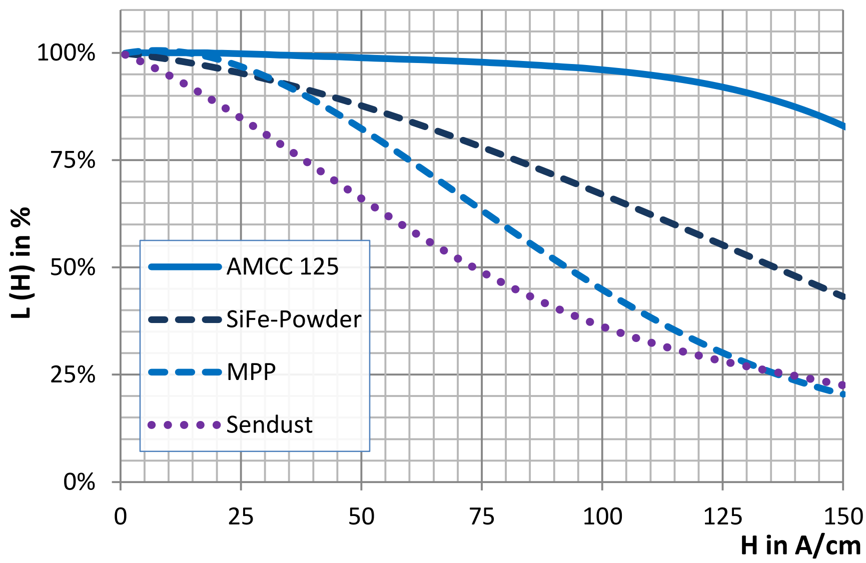


Fig. 7: *Inductivity vs field strength for different choke alloys (typical values for $\mu_{eff} \approx 60$)*

The maximum possible energy storage capacity of a choke is reached in the vertex of the graph $\mathbf{E = \frac{1}{2} \cdot \mu_0 \cdot \mu_{eff}(H) \cdot H^2 \cdot V}$, with **V** being the effective volume of the core. The drop of the effective permeability in this point is about 30% (typically more for other alloys). Usually a more careful design approach is chosen with about ≤ 20% permeability drop.

When plotting a graph $\mathbf{B = \mu_0 \cdot \mu(H) \cdot H}$ with µ(H) being the differential permeability, the maximum is reached at a permeability drop of about 20 % and a virtual induction of about 1,15 T (virtual, as the real induction requires the absolute permeability in the formula and not the differential permeability). Without the permeability drop the induction in this point (at this field strength) would be about 1,4 T at room temperature, or about 1,3 T at 130 °C. This is shown in **Fig. 8**.

As this relation is not very strongly dependent from the actual core size and the air gap, a design approach can be chosen assuming a (maximum) induction of 1,3 T and a linear permeability. The real induction will be somewhat lower, as well as the real permeability in this point, however within a maximum permeability drop of about 20 %.

This allows the direct approximation of the maximum possible effective permeability for a given maximum current **$\hat{I}_{max}$** times the no. **N** of turns without being dependent from individual characteristics for each core size and different air gaps:

$$\hat{B}_{max} \approx 1.3 = \mu_0 * \mu_{eff} * \frac{\hat{I}_{max} * N}{l_{Fe}}$$

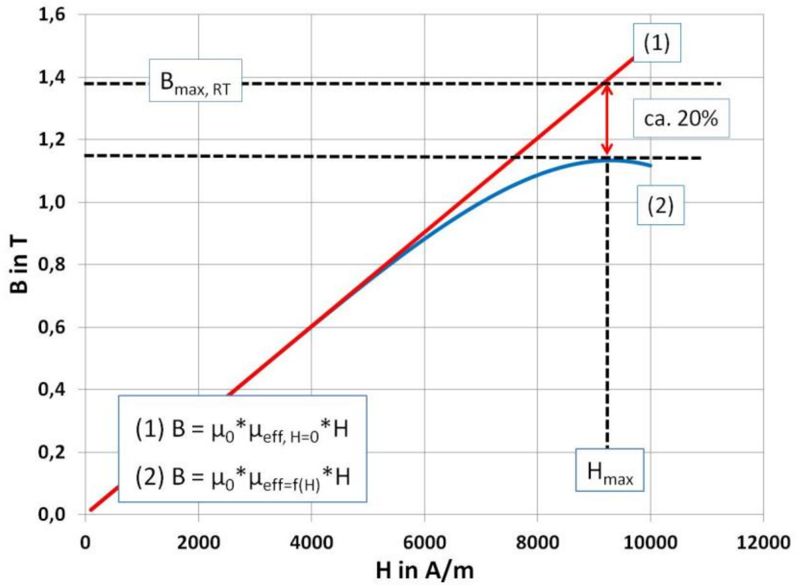


Fig. 8: *Typical saturation behavior of amorphous c-cores with air gap. The effective permeability μ_{eff} is dropping after a constant region when approaching saturation. $\mu_{eff,H=0}$ is the effective permeability determined by the air gap(s) in the linear region.*

Determination of the number of turns

For a given inductivity value L, a too low number of turns will saturate the core as a too high effective permeability is required. Too high number of turns can cause thermal problems on the other hand.

As shown in the previous chapter choosing a maximum induction $\hat{B}_{max}$ of about **1,3 T**, and assuming a constant permeability is a good starting point. This allows the calculation of the maximum number of turns **N_{mag}** for a given permeability.

The second limitation for the number of turns **N_{therm}** is the available effective winding area **A_{Cu}** of a concrete core size and the possible current density depending from the absolute current and the cooling options.

The ideal number of turns for each core size neither over-stresses the core magnetically nor thermally, resulting in a maximum for LI². These basic correlations are shown in **figure 9**.

$$N_{mag} \approx \frac{\hat{B}_{max} * l_{Fe}}{\mu_0 * \mu_{eff} * \hat{I}_{max}}$$

$$N_{therm} \approx S_{eff} * \frac{A_{Cu}}{I_{eff,therm}}$$

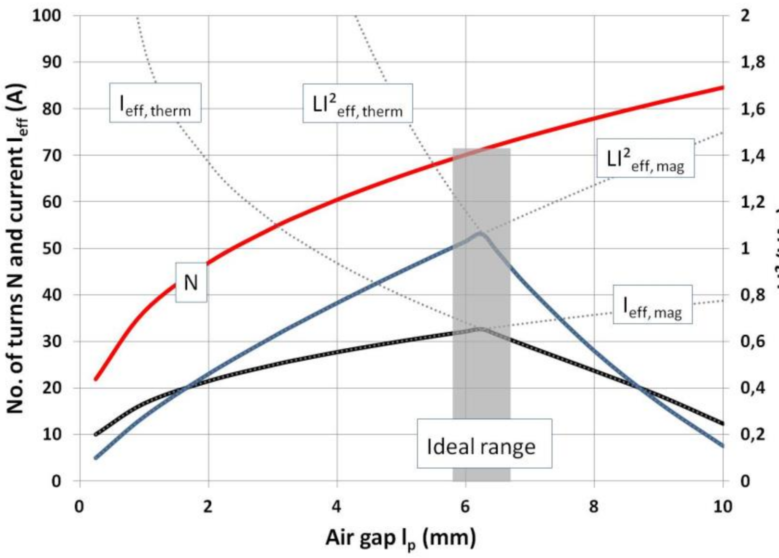


Fig. 9: *Estimation of the permissible „thermal“ and „magnetic“ currents in a PFC choke. The calculations have been made for core type AMCC125, inductivity L=0,6 mH, frequency f=20 kHz, 20 % current ripple and a temperature raise of 75 K*

Using these correlations and equaling $\mathbf{N_{mag} = N_{therm}}$, it is possible to calculate for each core size the required effective permeability for a given current density $\mathbf{S_{eff}}$:

$$\mu_{eff} \approx \frac{\hat{B}_{max} * l_{Fe} * I_{eff,therm}}{\mu_0 * \hat{I}_{max} * S_{eff} * A_{Cu}}$$

For $\hat{\boldsymbol{B}}_{\mathbf{max}}$ it is either possible to use the estimation 1,3 T, or smaller values if a more linear characteristic is desired. Please note that the lower $\hat{\boldsymbol{B}}_{\mathbf{max}}$ is chosen the lower the effective permeability will be with disadvantages especially with respect to total losses.

Leaves $\mathbf{S_{eff}}$ to determine $\boldsymbol{\mu}_{\mathbf{eff}}$ and the no. of turns **N**. Typical current densities are from < 1 A/mm² for high currents and free convection up to about 5 - 10 A/mm² for small currents and or additional cooling measures.

Which current density to start with? You may either use a starting value from your experience or use the following equation for an estimation:

$$S_{eff} \approx \sqrt{\frac{v * O * \left(\frac{\Delta T}{c_2}\right)^{\frac{1}{0,85}}}{c_1 * \rho_{el} * l_{Cu} * A_{Cu} * K_{prox}}}$$

S_{eff}: effective current density in A/m²

v: share of copper losses, e. g. 0,5 when they are equal with the core losses, or e. g. 0,7 for a “copper dominated” design approach

O: surface of a (hypothetical) cubic casing of the choke w/o ground face in **m²** (s. tab. 3)

ΔT: temperature raise in **K** for free convection

P_{el}: Specific electrical resistance of Cu winding in **Ωm**

l_{Cu}: mean length of a copper winding in **m** (see tab. 3)

A_{Cu}: effective copper total cross section in **m²** (see tab. 3)

K_{prox}: frequency and wire dependent correction factor for the copper losses. Typical values are about 2-3 at 20 kHz (s. chapter “Losses and temperature raise”)

C_1, C_2: correction factor from the empirical formula for the temperature raise as a function of the surface and the losses. c_1 = 0,1*m²/W and c_2 = 1*K (K = Kelvin). See p. 14.

With a carefully choosen starting value for the effective current density, the design can be started by calculating **μ_{eff}** using the formula on page 12. The number of turns is then:

$$N \approx \frac{\hat{B}_{max} * l_{Fe}}{\mu_0 * \mu_{eff} * \hat{I}_{max}}$$

The inductivity is given by:

$$L \approx N^2 * \mu_0 * \mu_{eff} * \frac{A_{Fe}}{l_{Fe}}$$

The air gap **l_p** (total air gap) can be roughly approximated from the effective permeability. The following correlation has been developed from measurements with core size AMCC 125. Other sizes show bigger deviations from this approximation. Empirical testing is necessary anyway.

$$l_p \approx l_{Fe} * c * \left(\frac{\mu_{eff}}{a}\right)^{\frac{1}{b}}$$

a: ca. **1,9** (range ca.1,5 – 3); **b**: ca. **-0,7** (range ca. -0,6 - -0,8); **c** = l_{Fe} (cm)/A_{Fe} (cm²)

If the required inductivity **L** is not reached, a bigger core has to be taken into consideration. If the estimation delivers a higher **L** than required a smaller core might be an option.

With „just" the current density to be estimated as a starting point it is possible to calculate with a few iterations a „possible" design. Of course the chosen type of wire (litze wire, massive round wire, copper bars) has not only an influence on the effective winding area (by different filling factors), but more on the total losses due to skin and proximity effects. For chokes with air gaps the stray flux of air gap strongly influences both core and copper losses.

The approximations in the next chapter shall help to roughly calculate and consider these effects. However the physical mechanisms are fairly complex and it should be clear that it is only a rough approach.

Losses and temperature raise

Copper losses depend on the frequency, the type of wire, the number of turns and the concrete winding design. Furthermore copper and core losses depend on interactions with the stray field of the air gap. The approximation of these effects allows the estimation of the temperature raise.

The copper losses consist of the ohmic part plus additional losses due to skin and proximity effects:

$$P_{Cu} \approx \left(\frac{\rho_{el} * l_{Cu} * N^2 * I^2{}_{eff}}{A_{Cu}} \right) * K_{Prox}$$

The correction factor $\mathbf{K_{Prox}}$ depends on the frequency, the type of wire, number of turns and the concrete winding design (one or more layers). Typical values are about 2 - 3 in the frequency range of about 20 kHz.

In the literature an approximation formula for the core losses of amorphous c-cores can be found, which delivers reasonable results in the frequency range of 10 - 30 kHz for typical current ripples of 10 - 30 %. However the influence of an air gap is not considered in this formula:

$$P_K \approx m_{Fe} * 6{,}5 * f^{1{,}51} * \hat{B}_{ripple}{}^{1{,}74}$$

Please note to use **f** in **kHz** in this formula. With $\mathbf{m_{Fe}}$ in **kg** and $\hat{\boldsymbol{B}}$ in **T** the core losses $\mathbf{P_K}$ are calculated in **W**.

At lower frequencies hysteresis losses win more and more influence. Losses at 50 Hz are about a factor 5 higher than calculated with above formula.

The ripple induction $\mathbf{B_{ripple}}$ can be calculated by:

$$\hat{B}_{Ripple} = \frac{\mu_0 * \mu_{eff} * 0{,}5 * N * I_{R,pp}}{l_{Fe}}$$

$\mathbf{I_{R,pp}}$ is the ripple current (Peak-peak). The stray field of the air gap increases both core and copper losses. The main parameter is of course the size of the air gap, but as already mentioned also the used winding parameters. For cores consisting of two halves (one air gap at each leg) the following rough estimation can be used:

$$\mathbf{P_{Total} \approx (P_K + P_{Cu}) * K_L} \qquad \mathbf{K_L \approx 100 * (\mu_{eff})^{-0{,}8};}\ K_L \geq 1$$

The correction factor $\mathbf{K_L}$ has been developed for litze wire and effective permeabilities in the range of 50 **-** 250. For other configurations the total losses may strongly deviate from the approximation.

In the literature the following estimation for the temperature raise of chokes with amorphous c-cores can be found:

$$\Delta T[K] \approx \left(\frac{c_1 * P_{Total}}{O}\right)^{0{,}85} * c_2$$

O in this estimation is the surface of a (hypothetical) cubic casing of the choke without the ground face in **m²**. Guidance values can be found in Tab. 3. $\mathbf{P_{Total}}$ are the total losses in **W**. $\mathbf{c_1}$ and $\mathbf{c_2}$ are „unit correction factors". $\mathbf{c_1 = 0{,}1*m^2/W}$ und $\mathbf{c_2 = 1*K}$ (K = Kelvin).

As already mentioned a few times experimental testing is essential. The "tolerances" of the approximations may add to significant deviations. Furthermore the concrete cooling conditions play an important role.

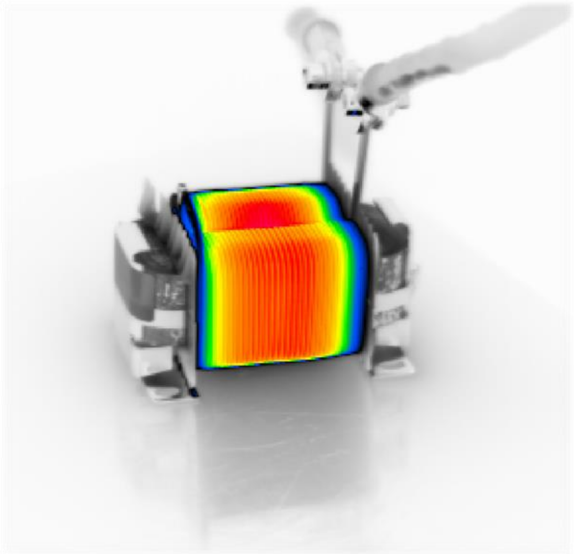


Fig. 10: *Thermal image of a choke with upright copper bars with „just" dc-current and free convection. In this case the critical range (even without the current ripple) is reached at about 50 A, about 10 % lower than predicted by the approximations.*

Bobbins and clamping straps

For most of the standard sizes bobbins and clamping straps are offered. The bobbins are made from glass-filled PA 6.6 material. Sizes and dimensions are listed in tab. 6.

Typ	A	B	C	D	E	F	G
AMCC 8	32	28	12	24	34	20,6	1,7
AMCC 20	51	47	12	24	44	30,5	1,8
AMCC 32	57	54	14	28	49,5	30,5	2,5
AMCC 40	57	53	14	28	55	36	2,7
AMCC 50	71	68	17	36	49,5	26	2,8
AMCC 80	71	67	17	35,5	63	41	2,7
AMCC 100	71	67	18	35,5	70	47	2,7
AMCC 125	85	80	20	40	55	36	2,7
AMCC 160	84	80	20	40	60	41	2,7
AMCC 500	83	77	27	62	92	57	9

***Tab. 6**: Nominal sizes of standard bobbins (in mm), subject to small changes*

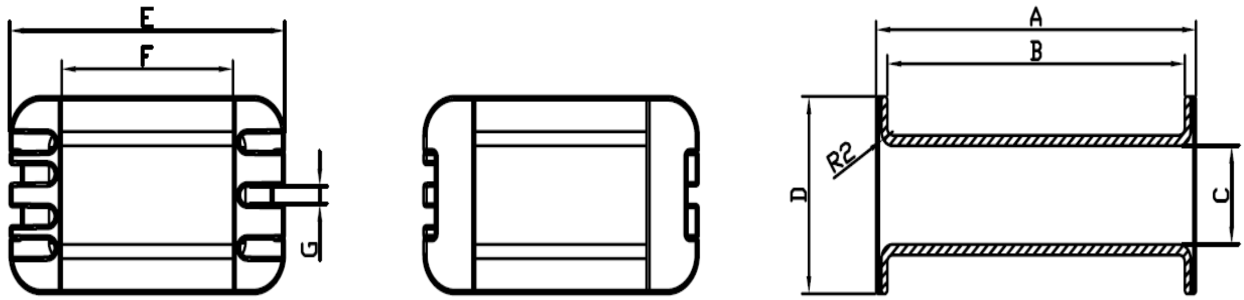


***Fig. 11:** Dimensions of bobbins*

Clamping straps from non-magnetic stainless steel are offered in a width of 6,2 mm with hexagon socket screws.

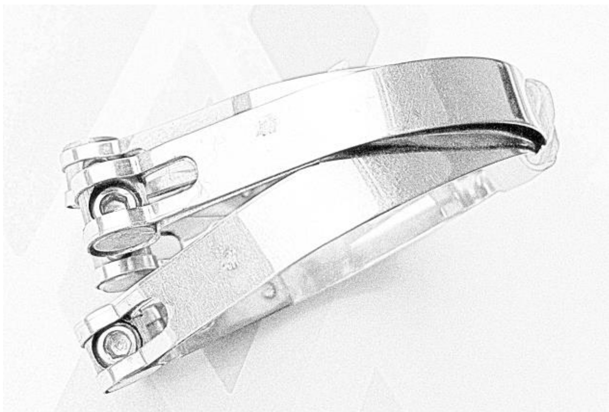


***Fig. 12:** Clamping straps*

Terms and definitions

Following we listed a summary of the used symbols with a short explanation.

Symbol	Unit	Description
B	T (= Vs/m²)	Magnetic flux density (Induction) in Tesla (1 T = 10 000 Gauß = 1000 mT = 1000 000 µT = 1 000 000 000 nT)
H	A/m	Magnetic field strength (1 A/m = 4π/1000 Oerstedt)
μ_{eff}		Effective relative magnetic permeability of a magnetic core with air gap
μ_0	Vs/Am	Magnetic field constant = $4\pi*10^{-7}$
		$B = \mu_r\mu_0 H$ in a magnetic material, $B = \mu_0 H$ in air
B_s	T	Saturation induction at high field strengths and $\mu_{eff} \approx 1$
T_c	°C	Curie-Temperature (disappearance of the spontaneous magnetization due to thermal agitation)
λ_s	ppm	Saturation magnetostriction (relative length and volume change)
ρ_{el}	Ωm	Specific electrical resistance. Cu: ≈ $1,724*10^{-6}*(1+0,0042*(T (°C) - 20 °C))$
ρ	Kg/m³	Specific material density
A_{Fe}	m²	Effective magnetic cross-section of a core
l_{Fe}	m	Mean magnetic path length of a core
FF	%	Stacking factor = relation of effective cross-section to geometric cross-section
A_{Cu}	m²	Effective copper cross section of winding area
l_{Cu}	m	Mean length of a copper winding
O	cm²	Surface of a (hypothetical) cubic casing of the choke without the ground face
E_{choke} or LI^2	VAs	Energy storage capacity, adequate to the work which is necessary to magnetize the choke
L	H (= Vs/A)	Inductivity of a choke. A inductance of one H (Henry) is given, if a voltage of one volt is induced while altering the current by one ampere per second
$\hat{I}_{max}$	A	Maximum peak current of all (superimposed) currents
$I_{eff,ges}$	A	Thermally effective value of all (superimposed) currents
N		Number of turns of copper winding
S_{eff}	A/m²	Current density (effective)
l_p	m	Total air gap of a c-core
P_{Cu}	W	Copper losses
P_{Fe}	W	Core (or iron) losses
K_{Prox}, K_L		Correction factors for copper and total losses
V	m³	Effective volume of the c-core = $A_{Fe} * l_{Fe}$

About us

SEKELS GmbH develops, produces and trades technical products which are mostly related with magnetism. With a team of about 25 employees, more than half of them being physicists or engineers, SEKELS presently serves more than 600 customers worldwide.

Since more than 25 years we are familiar with amorphous and nanocrystalline alloys and their applications. Our service includes technical consultation, comprehensive stock keeping and worldwide logistics.

SEKELS develops, designs and produces customer-specific laminations and core packages, magnetic shielding and shielding systems, inductive components and magnet systems - from prototyping to series deliveries. We are DIN EN ISO 9001:2008 certified.

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Issue 11/2013