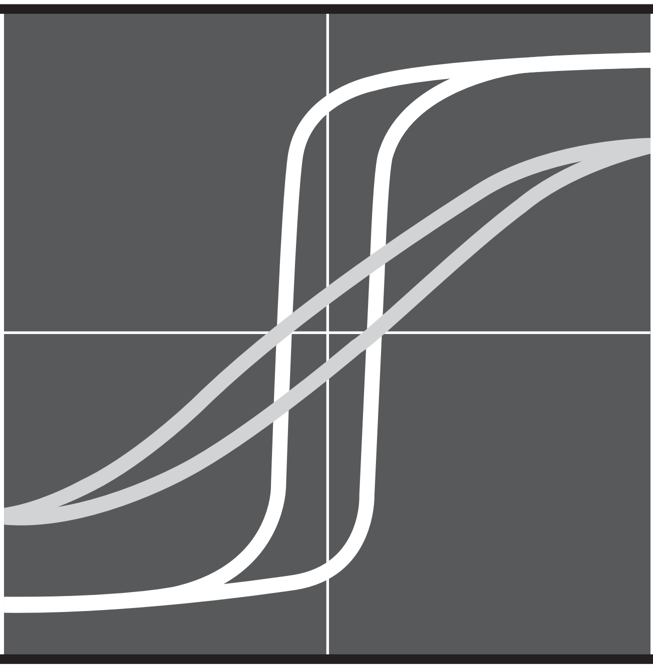
VACUUMSCHMELZE

Soft Magnetic Materials and Semi-finished Products



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Soft Magnetic Materials and Semi-finished Products

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1. Preface

The increasingly significant role played by soft magnetic materials in electrical engineering and electronics in recent years has led to the development of numerous special materials.

By using modern processes and our know-how in the fields of technology, metallurgy and physics we are currently in a position to produce a wide variety of high grade soft magnetic alloys.

This company publication focusses on ”semi-finished products“, the prime aim being to give the electrical industry a comprehensive overview of the properties and applications of our soft magnetic materials.

We sincerely hope that this publication will serve to enhance cooperation with our customers and associates and will prove useful in development work and planning.

2. Our Materials and their Applications

Soft magnetic materials are essential components in many devices and are indispensable in modern electrical engineering and electronics. The wide range of applications, the steadily rising demands on the quality of components, devices and plants and ever increasing specialization call for a careful selection from the materials available in order to achieve the optimum solution.

To simplify the selection process, we have classified our soft magnetic materials into groups. Each group is described in brief and reference made to the main fields of application.

Development in the field of soft magnetic materials has been rapid in the last few years, this latest issue includes several new alloys with remarkable properties.

New to this publication are the amorphous and nano-crystalline metals which both enlarge and supplement our range of soft magnetic alloys. Due to their structure and composition they exhibit very favourable and, in some cases, novel properties and combinations of properties.

2.1 NiFe Alloys with 72-83 % Ni

The alloys in this group are currently the softest magnetic materials available. They are characterized by high initial and maximum permeability and low coercivity but have relatively low saturation polarization (0.7 – 0.8 T). In addition, the shape of the hysteresis loop – only in strip-wound cores – can be varied over a wide range. Toroidal cores can be produced with a rectangular loop (Z), a round loop (R) or a flat loop (F) (see Fig. 1).

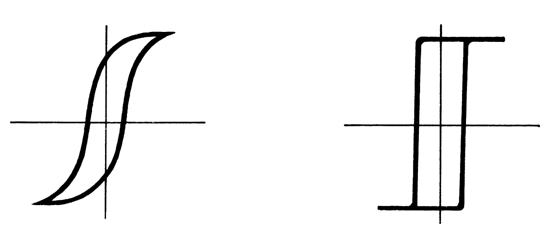


Fig. 1: Examples of Possible Hysteresis Loop Shapes in NiFe Alloys

Alloy	Remarks	Application
Materials with Round (R) Loop		
MUMETALL VACOPERM 100 ULTRAPERM 10 ULTRAPERM 200 ULTRAPERM 250	The principal difference in these alloys is the attainable initial and maximum permeability and the coercivity. ULTRAPERM 250 has the highest permeability and lowest coercivity. Saturation polarization is between 0.74 and 0.8 Tesla.	Null balance transformers and relay parts for residual current devices with high response sensitivity, transformers, measurement transducers, chokes, magnetic shielding, stator laminations for stepping motors in quartz watches
VACOPERM BS	VACOPERM BS is a special quality within this group featuring a higher saturation flux density (0.97 T).	Null balance transformers for pulse current sensitive residual current devices with medium response sensitivity
ULTRAPERM 91R	High permeability material with round loop and relatively low remanence over a wide temperature range, saturation polarization approx. 0.66 T.	Null-balance transformers for pulse current sensitive residual current devices with medium response sensitivity.
NiFe Alloys for Cryogenic Temperature Applications		
CRYOPERM 10	This special alloy was specially-developed for low temperature applications, e.g. liquid helium or nitrogen. Permeability attains maximum values in this temperature range.	Shielding for low temperature applications.
Materials with Increased Hardness		
RECOVAC BS	A high permeability material exhibiting substantially higher hardness and wear resistance. RECOVAC BS has relatively high saturation polarization (approx. 0.8 T).	Magnetic heads for tape recorders and magnetic storage with longer lifetime, magnetic-head shielding, relay parts.

2.2 NiFe Alloys with 54-68 % Ni

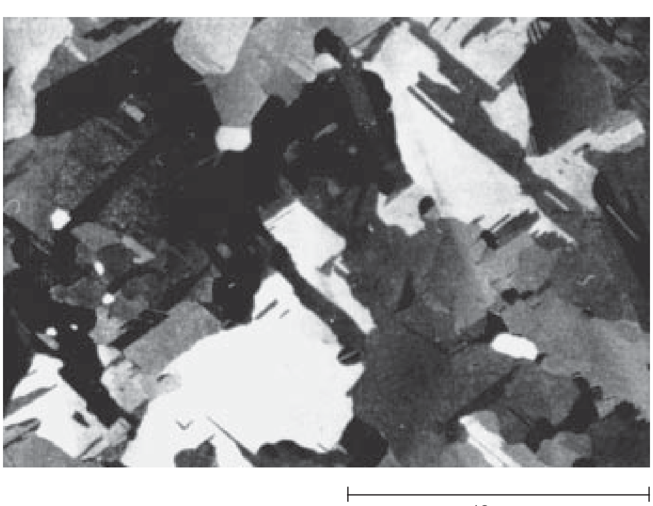
This alloy group covers materials which are used exclusively for toroidal cores. The saturation polarization is between 1.2 and 1.5 T. Depending on the requirements either high initial and maximum permeabilities of different shapes of flat hysteresis loop can be set by means of an included preferred direction (magnetic field tempering).

Alloy	Remarks	Application
Materials with Round (R) Loop Shape		
PERMAX M	Material combines high initial and maximum permeability with high saturation polarization (1.5 T).	Null balance transformer for residual current devices with medium response sensitivity, measurement transducers
Materials with Flat (F) Loop Shape		
PERMAX F	Material with especially flat hysteresis loop, relatively high useable flux density excursion and high pulse permeability.	Pulse transformers, thyristor protective chokes, transducer cores

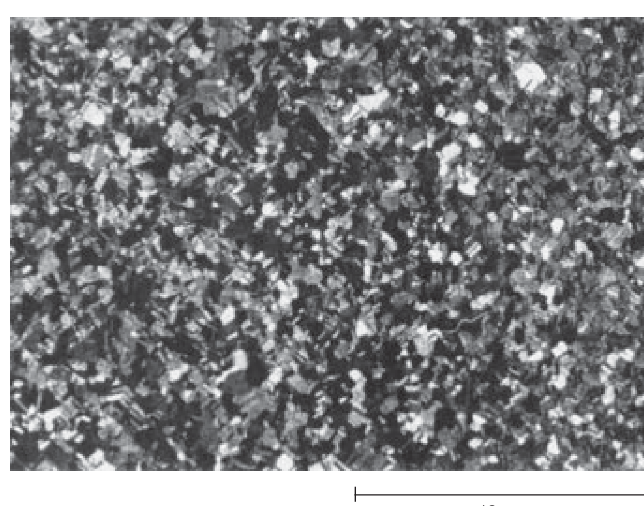
2.3 NiFe Alloys with 45-50 % Ni

In alloys with 45-50 % Ni the microstructure (Fig. 2) and thus the shape of the hysteresis loop can be altered over a wide range by selecting certain rolling or intermediate annealing steps. Thus with materials of almost identical composition it is possible to have very different magnetic properties.

Alloys	Remarks	Applications
Materials with Round (R) Loop		
PERMENORM 5000 H2 PERMENORM 5000 V5 PERMENORM 5000 S4	Alloy with relatively high saturation polarization (1.5-1.6 T) at medium initial and max. permeabilities. PERMENORM 5000 H2 has a coarse grained micro-structure. 5000 V5 and 5000 S4 are only available in larger thicknesses (>0.35 mm) and as solid material. 5000 S4 is a powder metallurgically produced material of highes purity and has the lowest coercivities in this group.	Null balance transformers and relay parts for residual current devices, measurement transducers, trans-formers, storage chokes, shielding, rotor and stator laminations, coil cores for stepping motors in quartz watches, flux conductors and pole pieces in magnetic valves.
RECOVAC 50	High wear resistance can be reached with this alloy after heat-treatment.	Printer, electro valves and relay parts.



Coarse Grained Microstructure of PERMENORM 5000 H2



Fine Grained Microstructure of PERMENORM 5000 V5

Fig. 2: Different Microstructures in 45-50 % NiFe alloys.

2.4 NiFe Alloys with 35-40 % Ni

The alloys in this group exhibit high electrical resistivity due to their composition. Permeability is relatively low. Saturization polarization is between 1.3-1.5 T.

Alloy	Remarks	Application
Materials with Round (R) Loop Shape		
PERMENORM 3601 K5	36 % NiFe with fine grained isotropic microstructure. High electrical resistivity, good ac properties coupled with low remagnetization losses. Further development of the former alloys PERMENORM 3601 K5 is PERMENORM 3601 K2 and PERMENORM 3601 K3.	Transformers, pulse transformers, chokes, relay and system parts, pole shoes provided requirements on saturation are not too stringent, shielding
MEGAPERM 40 L	40 % NiFe with high saturation and high electrical resistivity. This material is also supplied with a fine grained isotropic microstructure. For toroidal strip-wound cores a variant with a flat hysteresis loop can be made.	Relay and system parts, sensors, transformers, thyristor protective chokes, shielding
CHRONOPERM 36	NiFeCr-Alloy (saturation polarization about 0.75 T)	Stator laminations for step-motors in quartz watches.

2.5 NiFe Alloys with approx. 30 % Ni

NiFe alloys with 30 % Ni are soft magnetic materials with a Curie temperature only slightly above room temperature. Within this temperature range the saturation polarization is heavily dependent on the ambient temperature (Fig. 3).

Under the trade name THERMOFLUX we supply materials with Curie temperatures between 30° and 120°C. These can be accurately set by slight variations in composition. As standard alloy we recommend the material listed below in table 1.

Table 1: THERMOFLUX – Standard Alloy

Material	Curie temp. °C	Working field strength A/cm	Flux density at 20°C T
THERMOFLUX 55/100-G	55	80-100	0.22

Applications

THERMOFLUX is mainly used as a magnetic shunt to compensate temperature effects in permanent magnet assemblies like:

- electricity meters
- tachometers
- electronic scales
- measuring instruments

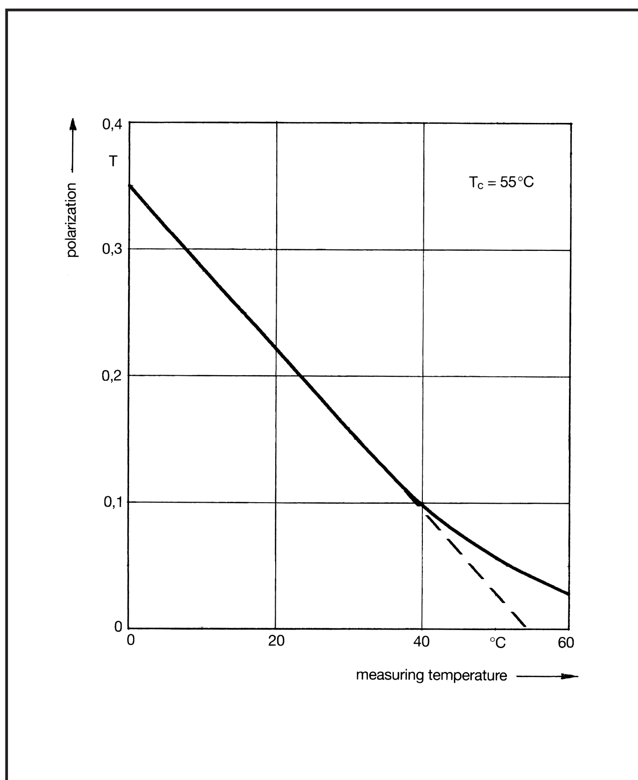


Fig. 3: Polarization Temperature Curve of THERMOFLUX 55/100-G.

2.6 SiFe Alloys with 3 % Si

From the large group of SiFe materials VAC supplies nearly isotropic 3 % SiFe. This falls under the category of electro-laminations.

The saturation of this material is only slightly below that of iron (RFe) whereas the electrical resistivity is four times higher (lower remagnetization losses).

Alloy	Remarks	Applications
Materials with Round (R) Loop Shape		
TRAFOPERM N3	For strip and solid material, strip thickness >0.1 to 1.8 mm	Relay parts, measurement systems, needle printers, pole shoes, flux conductors

2.7 Magnetic Ultrapure Iron

Under the trade name VACOFER we produce an iron alloy solely by sintering. The high purity of the material results in very low coercivities. It is used when high flux density values are required from low field strengths and in magnetic circuits with an air gap where a slight residual flux density is called for after switching off the field.

Owing to its purity and the absence of pores VACOFER offers major advantages in a high vacuum. The disadvantages are a poorer corrosion resistance and low electrical resistivity excluding it from use at higher frequencies.

Alloy	Remarks	Application
Materials with Round (R) Loop Shape		
VACOFER S1	A material of highest purity (99.98 %) and the lowest coercivities. Total absence of pores assured.	Pole shoes, yokes and armature bodies relay parts, flux conductors

2.8 CoFe Alloys with 17-50 % Co

With a value of 2.35 T cobalt iron alloys have the highest saturation polarization of all the known soft magnetic alloys.

Depending on composition and production processes, different properties and magnetization curves can be created.

Detailed information on our soft magnetic CoFe alloys is available in our company brochure PHT-004.

Alloy	Remarks	Application
Materials with Round (R) Loop Shape		
VACOFLUX 48	Material with low coercivity ($H_c \leq 0,4$ A/cm) and very low losses.	Special transformers with low losses at very high flux densities, high performance motors.
VACOFLUX 50	Material with a coercivity of $H_c \leq 0,8$ A/cm (up to 2 mm strip thickness).	Very high flux density pole-shoes, electro-magnets with maximum lifting force, magnetic lenses, needle printers, relays, motors and actuators with high torques and forces.
VACODUR 50	A further development of VACOFLUX 50 with respect to improved mechanical properties.	Alternators and generators with high rotation speed. Applications are comparable to VACOFLUX 50 with special requirements on mechanical properties.
VACOFLUX 17	Alloy with low Co-content and high saturation induction.	Devices and actuators for automotive industryturned parts, extruded parts etc.

Magnetic Properties after Final Annealing*)

	Static Values (strip material, thickness 0.35 mm)		Static Values (solide material)		J_s (T)	Curie-Temperature (°C)	λ_s
	H_c (A/cm)	μ_{max}	H_c (A/cm)	μ_{max}			
VACOFLUX 48	≤ 0.4	15000	–	–	2.35	950	$70 \cdot 10^{-6}$
VACOFLUX 50	≤ 0.8	13000	≤ 2.4	4500	2.35	950	$70 \cdot 10^{-6}$
VACODUR 50 with optimum magnetic properties	≤ 1.6	10000	–	–	2.3	950	$70 \cdot 10^{-6}$
VACODUR 50 with optimum mechanical properties	≤ 2.0	7000	–	–	2.3	950	$70 \cdot 10^{-6}$
VACOFLUX 17	≤ 2.0	3500	≤ 2.0	2500	2.22	920	$25 \cdot 10^{-6}$

H_c = Coercivity, μ_{max} = Maximum Permeability, J_s = Saturation Polarization, λ_s = Saturation Magnetostriction
*) Typical values

Static values for stacked rings (0.35 mm thickness*)

	B at 3 A/cm (T)	B at 8 A/cm (T)	B at 16 A/cm (T)	B at 40 A/cm (T)	B at 80 A/cm (T)	B at 160 A/cm (T)
VACOFLUX 48	2.05	2.15	2.25	2.27	2.3	–
VACOFLUX 50	1.9	2.1	2.2	2.25	2.27	2.3
VACODUR 50 with optimum magnetic properties	1.80	2.05	2.15	2.20	2.28	–
VACODUR 50 with optimum mechanical properties	1.70	2.00	2.1	2.18	2.25	–
VACOFLUX 17	1.2	1.5	1.6	1.75	1.9	2.05

B = Flux Density
*) Typical values

2.9 Amorphous and Nano-Crystalline Alloys

The highly interesting soft magnetic amorphous alloys VITROVAC and the nano-crystalline alloys VITROPERM are made up of transition metals (T), such as Fe, Co, Ni, and metalloids (M) like B, C, Si. Their composition roughly corresponds to the formula

$T_{70\text{-}80}\ M_{30\text{-}20}$.

To date, the Co-rich and Fe-rich alloys play a major role, especially those with F and Z loops (see fig. 4).

The main characteristic of the amorphous alloys is the absence of periodic crystalline arrangements of atoms. Their structure is unordered resembling the distribution of atoms in a melt. As a result, amorphous metals are soft magnetic while at the same time mechanically hard. This is a direct contradiction of the old school of thought on crystalline metals, i.e. that a magnetically soft material is mechanically soft and vice vers. In actual fact, the mechanical properties of amorphous metals reveal extreme hardness (HV approx. 900) and a high tensile strength (approx. 1500-2000 N/mm^2). The latter is an order of magnitude higher than in crystalline soft magnets.

The conditions under which the amorphous structure of the melt is retained after solidification are similar to those for common silica glasses. In both material groups atoms of the elements silicon, boron and other ”metalloids“ promote glass formation. These additions reduce the mobility of the atoms in the melt. However, while in silica glasses a cooling rate of 10 K/s is sufficient to achieve glass-like solidification, amorphous metals require approx. 10^6 K/s.

The prerequisite for these cooling rates is the appropriate production technology. Consequently, amorphous alloys are currently only available as thin metal ribbons (typ. strip thickness approx. 20 µm) or preferably made up as toroidal strip-wound cores. Further, we offer the semi-finished quality VITROVAC 6025 X which can be used without any further heat treatment. Variants of this alloy are also available, e.g. for flexible antennas in kHz band or for electro-magnetic anti-theft devices.

All the other amorphous alloys mentioned are primarily used as pre-material for toroidal cores. Accordingly the magnetic properties given below, in particular special shapes of hysteresis loops, apply to toroidal strip-wound cores after heat treatment. The reason for this being the relaxation and stabilization processes occuring during heat treatment which cause embrittlement. Please contact VAC for information on special applications of semi-finished products. Further details on ”amorphous“ toroidal cores are available in our company literature.

The alloys VC 6025, VC 6030 and VC 6150 are now available as pre-treated, semi-finished material with an F-loop. These new F-loop semi-finished qualities can be further processed – without any additional heat-treatment – to toroidal strip-wound cores, sensors or any other feasible form of application. The currently available qualities cover permeabilities from approx. $\mu \approx 2000$ (VC 6150 F), $\mu \approx 3000$ (VC 6030 F) and $\mu \approx 5000$ (VC 6025 F). Owing to a recently developed new heat-treatment process, qualities with even higher permeability values are possible. Laboratory scale samples are available on request.

Our nano-crystalline alloys VITROPERM resemble the amorphous Fe-based alloys in composition and production. Their special soft magnetic properties are set after a crystallization heat treatment. The structure obtained consists of crystal grains with a diameter of between approx. 10-15 nm surrounded by an amorphous residual phase. Nano-crystalline ribbons are extremely brittle; only the end product can be heat treated, as a rule this is a toroidal core.

As the crystal grains are so tiny, the magnetic behaviour of nano-crystalline alloys is basically „amorphous“ but offers additional freedom regarding the alloy design. As a result, toroidal cores made from nano-crystalline (Fe-base) alloys VITROPERM can match the peak values – permeability, coercivity and core losses – of the amorphous Co-based alloys or thin strip crystalline 80 % NiFe alloys and are superior in saturation flux density and temperature stability.

Further details on the properties of toroidal strip-wound cores made from VITROPERM are given in our literature on toroidal strip-wound cores.

Alloys	Remarks	Application
VITROVAC 6025	Magnetostriction-free Co-base alloy with very high permeability and exceptionally low core losses up to high frequencies. It can be produced as toroidal cores with various hysteresis loop shapes, in particular with Z and F loops. Saturation polarization dependent on variant between 0.53 and 0.59 T. nach Variante zwischen 0,53 und 0,59 T.	Medium frequency transformers and magnetic amplifiers for switched-mode power supplies, pulse transformers, FRI suppression chokes, anti-theft devices, magnetic field sensors, magnetic heads
VITROVAC 6025 X	Variant of VITROVAC 6025. This material can be used without heat treatment.	Magnetic shielding, especially cable shielding, magnetic heads
VITROVAC 6080/6070	Modified VITROVAC 6025 with a saturation polarization from 0.60 or 0.62 T. F loops with high permeabilities (60000 or 45000) and excellent linearity behaviour.	Signal transformers with high dc stability
VITROVAC 6030	Another Co-base alloy with high saturation (0.8 T). Also free of magnetostriction and excellently soft magnetic with very low core losses in the range from 50 to 500 kHz. Very pronounced F and Z loops can be set.	Transformers for switched-mode power supplies, magnetic switches in high performance pulse technology (e.g. for lasers)
VITROVAC 6150	Co-base alloy with even higher saturation (1.0 T), otherwise properties similar to VITROVAC 6030.	see VITROVAC 6030
VITROPERM 800	Low magnetostriction nano-crystalline alloy with high permeability and exceptionally low core losses. Saturation flux density 1.2 T. Form of supply: toroidal cores, VITROPERM 800 also as strip material.	Pulse current sensitive residual current devices, power transformers, signal transformers, pulse transformers, RFI suppression chokes.

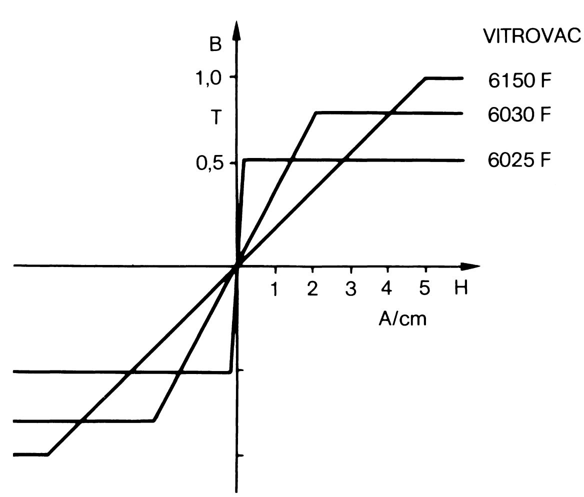


Fig. 4: Typical Hysteresis Loops of VITROVAC 6025 F, 6030 F and 6150 F (Semi-Schematic)

3. Forms of Supply

3.1 Overview

Soft magnetic materials are currently available in a wide variety of shapes and dimensions.

Finished parts are normally supplied in the final heat treated state. With regard to semi-finished products we recommend purchase of cold rolled or pre-annealed material (bendable or deep-drawable). Parts made from this can be returned to VAC for final annealing.

Where this is not possible for technical or organizational reasons, the guidelines on heat treatment of soft magnetic parts in section 4 should be adhered to.

Table 2 classifies our materials according to forms of supply.

Table 2: Classification of our Materials according to Forms of Supply

	Forms of Supply							
	Semi-finished Products		Finished Parts					
	Strips	Solid-profile-material rods, wires	strip-wound cores	SC-cores	Core laminations, stamped parts	laminated packages, EK-cores	Shielding, shielding foils	Solid and shaped parts
MUMETALL	●	●	●	●	●	●	●	●
VACOPERM 100	●	●	●	●	●	●	●	●
ULTRAPERM 10	●	–	●	–	–	–	–	–
ULTRAPERM 200	●	–	●	–	–	–	–	–
ULTRAPERM 250	●	–	●	–	–	–	–	–
VACOPERM BS	●	○	●	–	–	–	–	●
ULTRAPERM 91 R	●	–	●	–	○	–	–	–
CRYOPERM 10	●	–	–	–	–	–	●	–
RECOVAC BS	●	–	–	–	●	–	–	●
PERMAX M	○	–	●	–	–	–	–	–
PERMAX F	–	–	●	–	–	–	–	–
PERMENORM 5000 H2	●	●	●	●	●	●	●	●
PERMENORM 5000 V5	●	●	–	–	–	–	●	●
PERMENORM 5000 S4	●	●	–	–	–	–	○	●
PERMENORM 3601 K5	●	●	–	–	–	–	●	●
MEGAPERM 40 L	●	●	●	–	●	●	●	●
RECOVAC 50	●	–	–	–	–	–	–	–
CHRONOPERM 36	●	–	–	–	–	–	–	–
THERMOFLUX	●	●	–	–	●	–	–	●
TRAFOPERM N3	●	●	●	●	●	●	●	●
VACOFER S1	●	●	–	–	–	–	–	●
VACOFLUX 48	●	–	●	○	●	●	–	–
VACOFLUX 50	●	●	●	–	●	●	○	●
VACODUR 50	●	–	–	–	●	●	–	–
VACOFLUX 17	●	●	–	–	●	●	–	●
VITROVAC 6025	●	–	●	○	○	○	○	–
VITROVAC 6080/6070	●	–	●	–	–	–	–	–
VITROVAC 6030	●	–	●	○	–	–	–	–
VITROVAC 6150	●	–	●	–	–	–	–	–
VITROPERM 800	●	–	●	–	–	–	–	–

○ = available in special cases

3.2 Semi-finished Products

Semi-finished products are available in widely varying shapes and dimensions (fig. 5). Our product range includes:

– ribbons and strips
– slabs
– plates
– square sections
– flat sections
– rods/bars
– wire and flattened wire

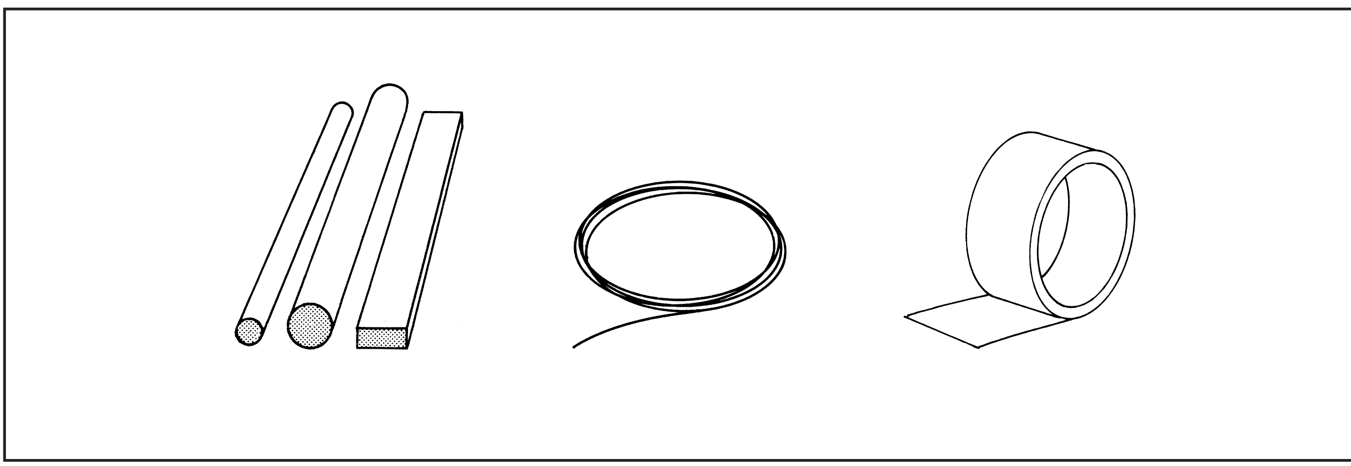


Fig. 5: Different Forms of Semi-finished Products

3.2.1 Ribbons and Strips

Table 3 gives the maximum manufacturing widths of ribbons and strips in various thicknesses.

Thickness tolerances:
- ribbons and strips from crystalline material, see EN 10140
- Ribbons from VITROVAC: ±0.003 mm

Table 3: Maximum Manufacturing Widths for Ribbons and Strips, Edges not Trimmed (Trimmed: ”–10 mm“ per Edge)

	Strip thickness in mm 1.5–2.0	0.5–1.0	0.35	0.2	0.1	0.05	0.025
	Strip width in mm						
MUMETALL	275	275	275	275	260	260	260
VACOPERM 100	275	275	265	265	265	265	265
ULTRAPERM 10/200	–	–	–	–	265	265	–
ULTRAPERM 250	–	–	–	–	–	265	–
VACOPERM BS	275	275	265	265	265	–	–
ULTRAPERM 91 R	–	–	–	–	265	265	–
CRYOPERM 10	275	275	265	265	265	–	–
RECOVAC BS	–	270	270	210	210	210	210
PERMAX M	–	–	–	270	260	–	–
PERMENORM 5000 H2	295	295	270	270	260	260	260
PERMENORM 5000 V5	295	295	270	270	270	260	–
PERMENORM 5000 S4	220	220	220	220	220	220	–
RECOVAC 50	300	270	270	270	260	260	–
PERMENORM 3601 K5	300	270	270	270	260	260	260
MEGAPERM 40 L	285	260	260	260	260	260	–
CHRONOPERM 36	270	270	270	270	260	260	250
THERMOFLUX 55/100 G	300	300	270	270	260	–	–
TRAFOPERM N3	300	300	270	270	270	–	–
VACOFER S1	240	240	240	240	–	–	–
VACOFLUX 48	235	235	235	210	200	200	200
VACOFLUX 50	235	235	235	210	200	200	200
VACODUR 50	235	235	235	210	200	200	–
VACOFLUX 17	300	270	270	260	250	250	250

3.2.2 Other Forms of Supply

VAC also supplies a number of other semi-finished products made from the alloys listed in table 2. They differ in shape and dimensional range (table 4).

The dimensional tolerances are given in table 5 under DIN standards.

Table 4: Shapes and Dimensions of Other Semi-finished Products of Crystalline Alloys

Shape	Hot Rolled[1])	Cold Rolled[3])	Sintered Material[1])
Slabs	50 to 300 mm width >40 to 200 mm thickness		rectangular cross-sections up to 260 mm x 240 mm[2])
Plates	50 to 300 mm width 10 to 40 mm thickness		
Rectangular rods	15 mm x 15 mm to 180 mm x 180 mm	0.5 mm x 0.5 mm to 15 mm x 15 mm	
Flat sections	15 mm to 75 mm width 4.5 mm to 41 mm thickness	1.0 mm to 40 mm width 0.2 mm to 9 mm thickness	
Rods, bars	Ø 12.5 to Ø 215 mm after surface treatment Ø 12.5 to Ø 200 mm	Ø 2.0 to Ø 55.0 mm	to Ø 200 mm[4])
Wire	Ø 5.0 to Ø 27.0 mm[5])	Ø 0.2 to Ø 5.0 mm	

[1]) Dimensions and lengths on request.
[2]) VACOFER max. 225 mm x 85 mm.
[3]) VACOFLUX 50, but no cross-sections >30 mm^2.
[4]) Semi-finished products of TRAFOPERM N3 on request.
[5]) VACOFLUX 50 max. Ø 7.0 mm.

Table 5: DIN Standards for Measurement Tolerances of Semi-finished Products

Data Sheet	Title
EN 10278	Bright flat steel; measurements, permissible deviations, . . .
EN 10218	Steel wire cold drawn; measurements, permissible deviations, . . .
EN 10278	Bright rectangular steel; measurements, permissible deviations, . . .
EN 10278	Bright round steel; measurements, permissible deviations, . . .
EN 10140	Cold rolled strip of steel; measurements, . . .
DIN 59 746	Strips and strip sections of nickel and wrought nickel alloys, cold rolled, measurements, permissible deviations,
DIN 59 781	Round wires of nickel and wrought nickel alloys; drawn, measurements, permissible deviations
IEC 404-8-6	Magnetic materials, Section „Measurement Tolerances for Strips, Bars and Wire“.

4. State of Material

Crystalline soft magnetic semi-finished products are available in the following states for further processing.

- hot worked:
  for slabs, plates, sections, round rods
- cold worked:
  for strips, rods, wires (see 3.2.1; 3.2.2)
- soft bendable or pre-annealed for bending:
  for strips, rods, wires (see 3.2.1; 3.2.2)
- soft deep-drawable or pre-annealed for deep-drawing:
  for strips (see 3.2.1)
- semi-hard:
  On request strips made from some of the alloys can be set with a certain degree of hardness, i.e. between „cold-worked“ and „soft bendable“ this is, for instance, required to produce stamped-bent parts.

The state of supply „final heat treated“ is not usual for crystalline semi-finished products (exception: THERMOFLUX and MUMETALL), as mechanical stress and plastic deformation during further processing cause severe magnetic damage (see also section „Heat Treatment“).

Table 6 gives the hardness ranges for the above described states of delivery (provided available).

Table 6: State of Supply and Hardness Ranges for Crystalline Soft Magnetic Semi-finished Products (for cold rolled strips resp. lengths of strips)

Alloys	Vickers Hardness (HV) to DIN 50133		
	cold worked	soft bendable deep-drawable	semihard
MUMETALL VACOPERM 100 ULTRAPERM 10, 200, 250 VACOPERM BS ULTRAPERM 91 R CRYOPERM 10	270 – 400	120 – 180	180 – 230
RECOVAC BS	300 – 350	120 – 160	–
PERMENORM 5000 H2	220 – 300		
PERMENORM 5000 V5 PERMENORM 5000 S4	220 – 280	120 – 160	180 – 220
RECOVAC 50	220 – 280	–	–
RECOVAC 98	350 – 400	160 – 200	–
PERMAX F; M; LGF;	220 – 280	110 – 150	–
PERMENORM 3601 K5	220 – 280	110 – 150	
MEGAPERM 40 L	220 – 280	110 – 150	180 – 220
CHRONOPERM 36	220 – 280		
THERMOFLUX (all qualities)	210 – 250	90 – 150	–
TRAFOPERM N3	250 – 330	150 – 210	–
VACOFER S1	60 – 120	–	–
VACOFLUX 48	280 – 550	–	–
VACOFLUX 50	280 – 550	–	–
VACODUR 50	280 – 550	–	–
VACOFLUX 17	220 – 280	120 – 180*	–

* only in soft bendable

For hot worked products (rods, bars, slabs) the hardness range is similar to the state of delivery „soft or deep-drawable“.

Hardness values for wire/rods (cold drawn) on request.

5. Heat Treatment

5.1 Crystalline Alloys

5.1.1 Soft Annealing (Pre-Annealing)

If cold rolled or drawn material has to undergo further processing, e.g. bending or deep-drawing, prior to final heat treatment, pre-annealing is recommended to increase workability. When severe shaping is necessary, the material must often be annealed between the individual processing steps.

In almost all cases adequate workability is attained by soft-annealing at temperatures above recrystallization, approx. 700 – 800°C for 2 – 5 hours. We recommend hydrogen as annealing atmosphere for soft annealing. Alternatively this type of annealing can be performed in dry nitrogen or a vacuum.

5.1.2 Final Heat Treatment

Final heat treatment sets the optimum magnetic properties. The duration, temperature and, in many cases, the cooling conditions must be strictly adhered to. Fig. 6 illustrates the effect of final heat treatment on the magnetic properties using MUMETALL as examples.

Hydrogen is the preferred protective gas. It prevents scaling and interacts chemically with the metal, for instance removing impurities. This is, of course, providing the protective gas itself is free of harmful impurities, above all the water vapour and oxygen content must be low (dew point <–50°C).

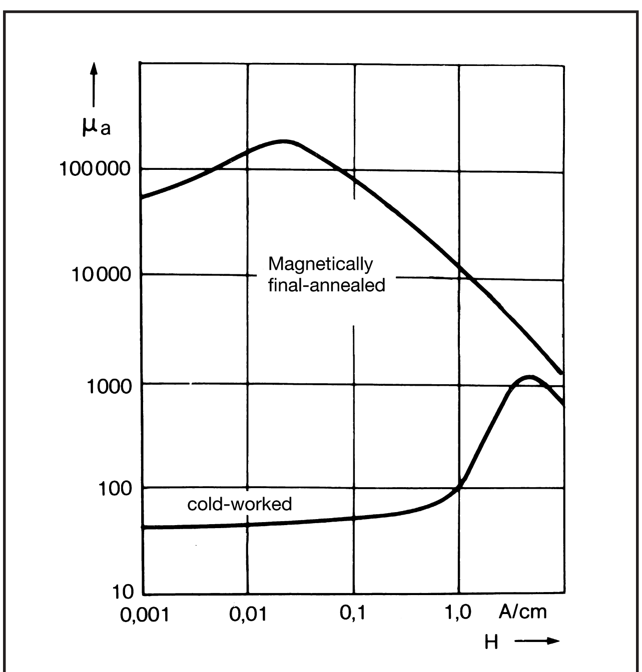


Fig. 6: The Effect of Final Heat Treatment on MUMETALL

Heat treatments with dissociated ammonia (25 % nitrogen, 75 % hydrogen) or nitrogen are possible in some cases. However, when compared to heat treatments under hydrogen, the magnetic quality is generally lower.

Table 7 provides data on the final heat treatments commonly employed at VAC.

5.2 Amorphous Materials

The intermediate and soft annealing steps associated with the crystalline alloys are irrevelant for amorphous metals. These are cast in one step from the molten state in their final dimensions (thickness approx. 0.020 mm, width approx. 1 to 50 mm).

Due to their homogeneous and isotropic structure the thin amorphous metal ribbons already have good magnetic properties directly after casting. This is especially true in case of the zero magnetostriction Co-based alloys which, in the „as manufactured“ state, exhibit coercivities of 10 mA/cm and below and where initial permeabilities of around 5000 and higher are no exception.

Besides optimizing the magnetic properties, the heat treatment of amorphous metals also stabilizes the amorphous structure and the magnetic properties set.

Toroidal Cores
Ideally the material is initially stress relief annealed above the Curie temperature (approx. 400°C). Here it is crucial that the crystallization temperature is not exceeded to avoid crystalline precipitation and the correlated deterioration in the magnetic values. Subsequently, the material is annealed in a magnetic field in a range below the Curie temperature, approx. 200–350°C. Depending on the direction of the magnetic field an F or Z-loop can be set and tailored to meet the permeability level required by the particular application. This type of optimized heat-treatment is used to attain the best and most reproducible magnetic values (e.g. with VC 6025 initial permeabilities far above 100000). However, it must be conducted in the final form (typically on toroidal cores) as the material becomes brittle at raised annealing temperatures and subsequent shaping may impair the magnetic values.

Heat-Treatment Semi-Finished Products
On the other hand, it is also possible to heat-treat at moderate annealing temperatures or for relatively short annealing times so that the annealed strip remains largely ductile. As with the optimized heat-treatment for toroidal cores a magnetic field can be used to set a Z or F loop. Semi-finished products pretreated in this manner offer a good compromise between the good, reproducible soft magnetic properties, on the one hand, and mechanical further processing capability of the strip, on the other hand. It can be further processed and used without any additional heat-treatment, in the meantime it is also available with an F loop.

5.3 Nanocrystalline Materials

With nanocrystalline materials (VITROPERM) heat-treatment of the amorphous base material is essential. To set the nanocrystalline structure and the associated soft magnetic properties heat treatment at temperatures of typically 540°C to 600°C must be carried out initially. Here care must be taken to ensure that the upper limiting temperature of approx. 600°C is not exceeded as otherwise this leads to precipitation of hard magnetic phases which severely impair the soft magnetic properties. After transition to the nanocrystalline state there is typically a round hysteris loop with an initial permeability in the range 50000 – 100000 as a function of composition. Subsequently, as is the case with amorphous metals, an F or Z loop can be set by heat treatment in a magnetic field. By selecting the annealing temperature in the transverse field this process is used, e.g. to set target permeability values for an F loop over a wide range from approx. μ = 20000 to over μ = 100000.

In contrast to the amorphous metals, nanocrystalline strip is not available as pre-treated material as the transition into the nanocrystalline state is inseparably coupled with an appreciable increase in brittleness making any type of mechanical further processing more or less impossible. As a result the material can only be heat-treated in its final shape, i.e. generally as toroidal cores.

Table 7: Data on Magnetic Final Annealing

Alloy	Time h	Temperature °C	Cooling in furnace, then in the air °C
MUMETALL	2 – 5	1000 – 1100	to 200
VACOPERM 100			
ULTRAPERM 10/200/250	2 – 5	1150	to 480 (1 h)**
ULTRAPERM 91 R			
CRYOPERM 10	2 – 5	1100 – 1150	to 460 – 480 (4 h)***
VACOPERM BS	2 – 5	1150	to 510 (1 h)
RECOVAC BS	2	1000	to 620 (2 h)
PERMENORM 5000 H2	5	1150	
PERMENORM 5000 V5	2 – 5	1150	to 200
PERMENORM 5000 S4	2 – 5	1150	
RECOVAC 50	2 – 5	1150	to 650 (4 h), then cooling in H_2
PERMENORM 3601 K5	2 – 5	1000 – 1100	to 200
MEGAPERM 40L	2 – 5	1000 – 1100	
CHRONOPERM 36	2 – 5	1150	to 200
THERMOFLUX 55/100 G	2 – 5	650 – 700	to 200
TRAFOPERM N3	3 – 6	1200	to 100
VACOFER S1	3 – 5	850*	to 100
VACOFLUX 48	10	880	to 200
VACOFLUX 50	3 – 10	800 – 820	to 200
VACODUR 50[1])	2 – 5	820	to 200
VACODUR 50[2])	2 – 5	750	to 200
VACOFLUX 17	10	850	to 200

*) Insert at temperatures <500°C.
**) To reach optimal magnetic properties please choose a relatively long annealing time
***) Annealing time 4h 460 – 480°C
[1]) With optimum magnetic properties
[2]) With optimum mechanical properties

6. Properties

This section deals with the most important properties of the VAC soft magnetic materials supplied as semi-finished products. The data given are mean values determined from a large number of measurements. In order to achieve certain minimum or maximum values the magnetic qualities listed in section 7 are decisive.

The static properties are particularly interesting when soft magnetic materials are to be used with dc fields. This type of application usually calls for parts of greater thickness (shaped and solid parts) and places special requirements on static permeability and coercivity. Semi-finished products with thinner dimensions (strips) are mostly used with ac fields, above all with mains frequency. Thus, in this case the data and characteristics are given for 50 Hz.

And finally table 9 presents the most important physical and technological properties of our semi-finished products.

6.1 Static Properties of Solid Material (Strip Thickness >0.3 mm)

Table 8 and Fig. 7 give an overview of the static properties of the VAC alloys supplied as semi-finished products (strip thickness >0,3 mm). The values were measured on 1 mm thick stamped rings after optimum heat treatment. Depending on the form of supply and strip thickness certain deviations from these values may occur both upwards and downwards.

Table 8: Static Properties of Solid Material. Measured on Stamped Rings, Strip Thickness: 1 mm

Material	Permeability μ_4	Permeability $\mu_{max.}$	Coercivity (A/cm)	Saturation polarization (T)
MUMETALL	60000	250000	0.015	0.80
VACOPERM 100	200000	350000	0.01	0.74
PERMENORM 5000 H2	7000	120000	0.05	1.55
PERMENORM 5000 V5	9000	135000	0.04	1.55
PERMENORM 5000 S4	15000	150000	0.025	1.60
RECOVAC 50	3500	30000	0.15	1.35
MEGAPERM 40L	6000	80000	0.06	1.48
CHRONOPERM 36	6000	50000	0.05	0.75
PERMENORM 3601 K5	4000	50000	0.1	1.30
TRAFOPERM N3	1000	30000	0.2	2.03
VACOFER S1	2000	40000	0.06	2.15
VACOFLUX 50	1000	9000	1.4	2.35
VACOFLUX 17	600	4000	1.5	2.22

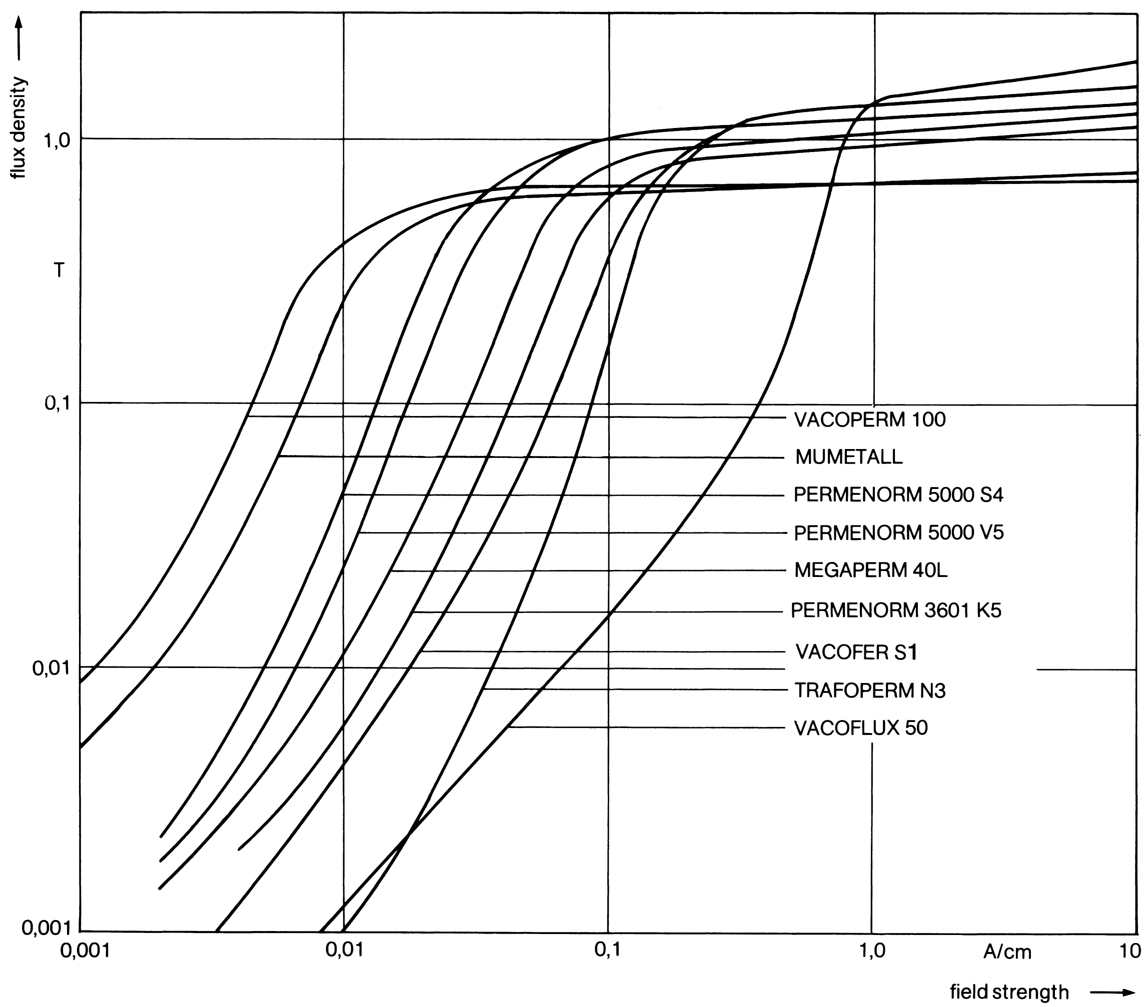


Fig. 7: Static Flux Density Field Strength Curves of Solid Material. Measured on Stamped Rings, Strip Thickness 1 mm.

6.2 Dynamic (50 Hz) Properties of Strips (Strip Thickness ≤0,3 mm)

In the vast majority of cases, strips (strip thickness ≤0.3 mm) made of soft magnetic materials are used in ac fields, especially in mains frequencies.

Table 9 below, and figs. 8 and 9 present the dynamic properties at 50 Hz. These values are also average values measured on toroidal cores of typical thickness for these alloys.

Table 9: Dynamic (50 Hz) Properties of Strips. Measured on Toroidal Cores, Strip Thickness: See Table

Material	Strip thickness mm	Permeability μ_4	$\mu_{max.}$	Losses[1] (W/kg)	Saturation Polarization (T)
MUMETALL	0.2	60000	150000	$p_{0,5}$ = 0.025	0.80
VACOPERM BS		30000	150000	$p_{0,5}$ = 0.03	0.97
VACOPERM 100	0.1	100000	250000	$p_{0,5}$ = 0.015	0.74
ULTRAPERM 10	0.1	150000	300000	$p_{0,5}$ = 0.01	0.74
ULTRAPERM 200	0.05 – 0.1	250000	350000	$p_{0,5}$ = 0.005	0.74
ULTRAPERM 250	0.05	270000	400000	$p_{0,5}$ = 0.005	0.74
ULTRAPERM 91R	0.1	150000	250000	$p_{0,5}$ = 0.015	0.66
CRYOPERM 10	0.1[2]	65000[2]	160000[2]	–	0.90[2]
RECOVAC BS	0.1	25000	50000	$p_{0,3}$ = 0.01	0.80
PERMAX M	0.2	50000	110000	$p_{1,0}$ = 0.1	1.50
PERMENORM 5000 H2	0.2	12000	90000	$p_{1,0}$ = 0.25	1.55
MEGAPERM 40 L	0.2	9000	75000	$p_{1,0}$ = 0.2	1.48
PERMENORM 3601 K5	0.2	4000	50000	$p_{1,0}$ = 0.3	1.30
TRAFOPERM N3	0.3	700	13000	$p_{1,0}$ = 1.0	2.03
VACOFLUX 48	0.35	1200	20000	$p_{2,0}$ = 60[5]	2.35
VACOFLUX 50	0.35	1000	12000	$p_{2,0}$ = 64[5]	2.35
VACODUR 50[3]	0.35	–	–	$p_{2,0}$ = 92[5]	2.3
VACODUR 50[4]	0.35	–	–	$p_{2,0}$ = 75[5]	2.3
VACOFLUX 17	0.35	600	4000	$p_{2,0}$ = 90[5]	2.22

[1]) $p_{0,5}$ = specific core losses at 0.5 T etc.
[2]) Magnetic properties at 77.3 K resp. 4.2 K
[3]) With optimum mechanical properties
[4]) With optimum magnetic properties
[5]) Losses at 400 Hz

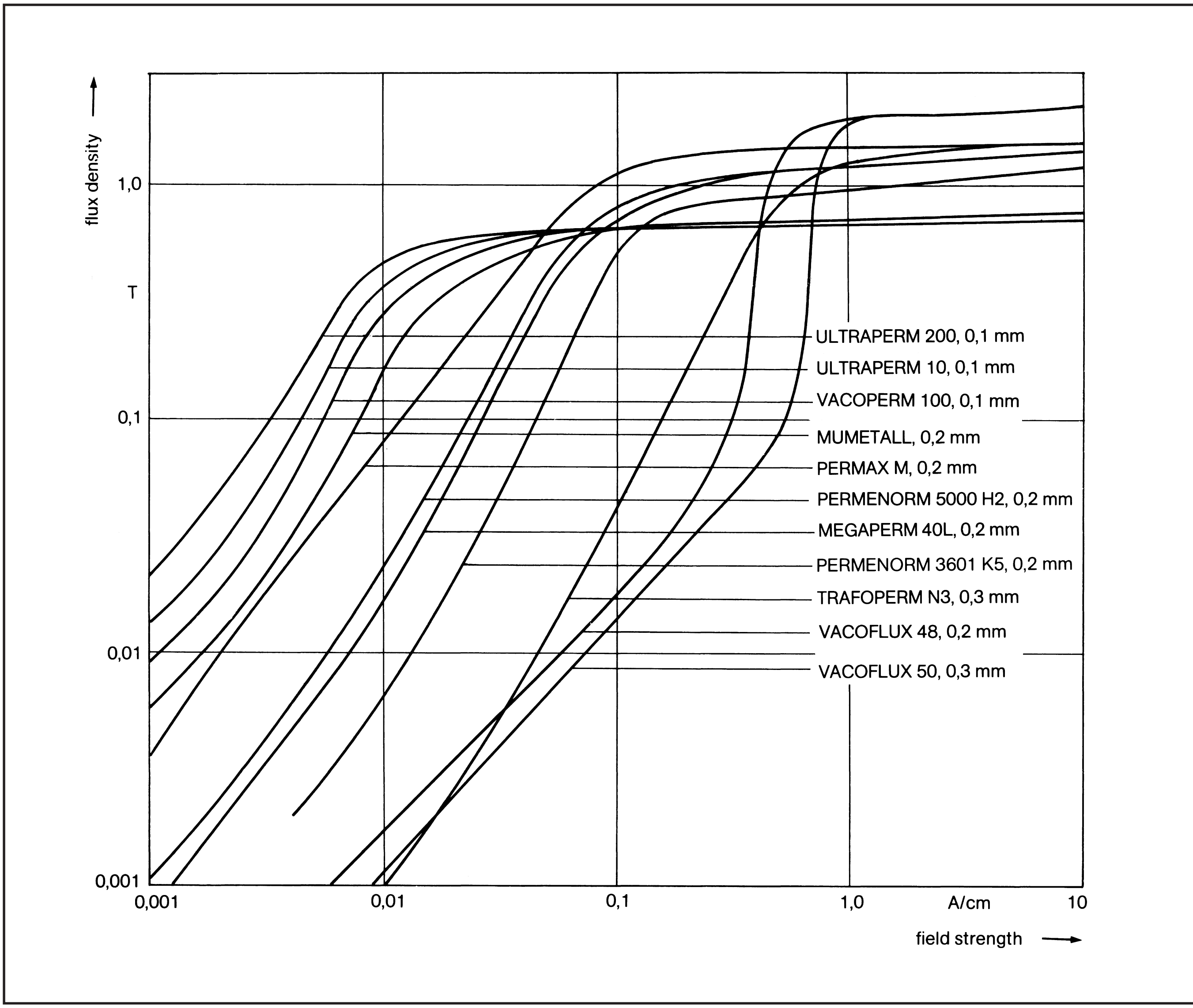


Fig. 8: Dynamic (50 Hz) Flux Density Field Strength Curves of Strips, Strip Thickness: ≤0.3 mm. Measured on Toroidal Cores

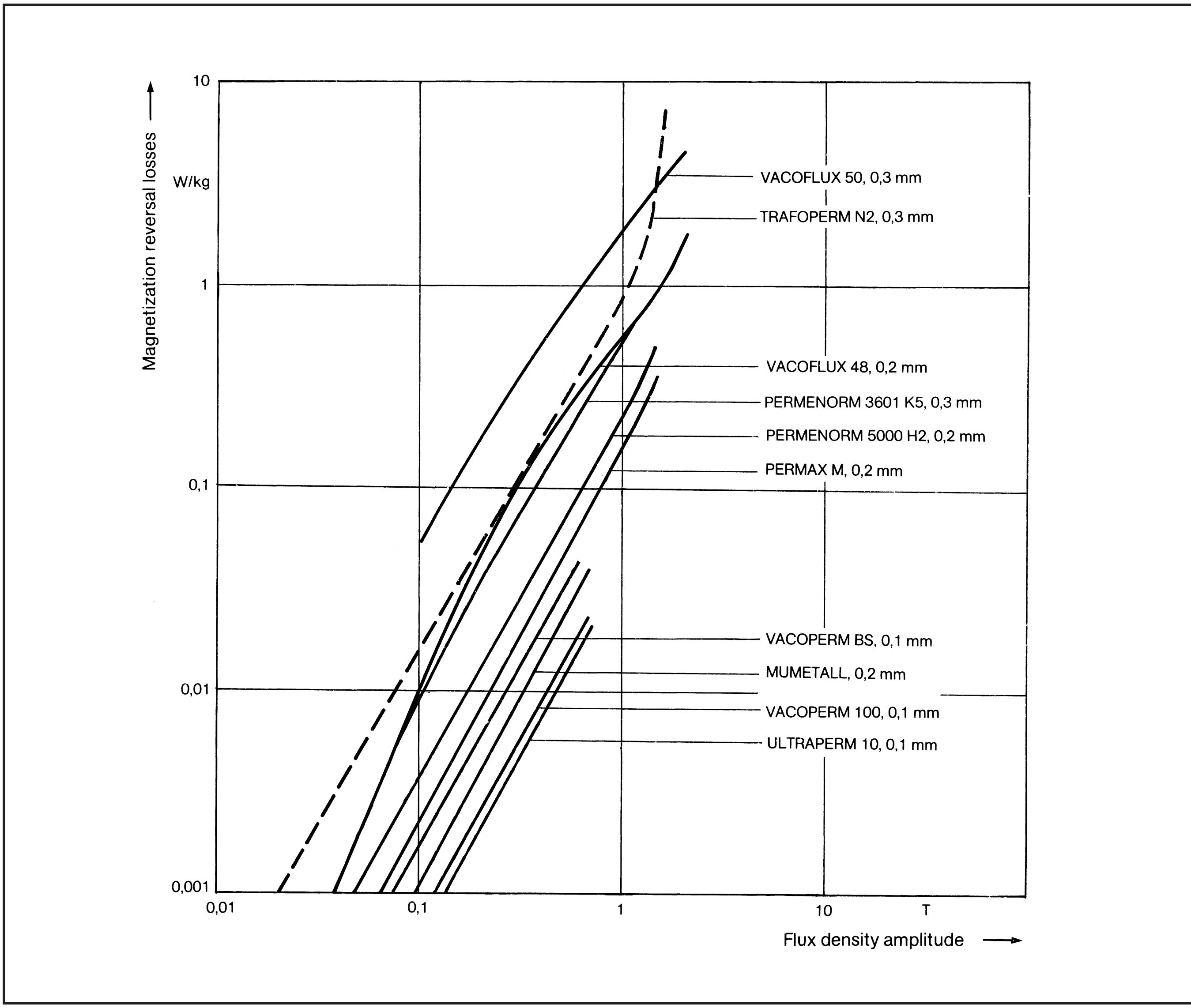


Fig. 9: Remagnetization Losses (f = 50 Hz) of different Soft Magnetic Materials

6.3 Physical and Technological Properties of our Semi-finished Products

Several of the important physical and technological properties of our soft magnetic materials are compiled in table 9.

Section 4 (state of delivery) lists the feasible hardness values.

6.4 Temperature Dependence of the Magnetic Properties

The Curie point of a magnetic material is largely governed by the alloy composition. The temperature dependence of saturation polarization obeys the same function in almost all materials. Fig. 10 shows the saturation polarization curve as a function of temperature for the most important soft magnetic alloys. The Curie temperatures T_c can be read off table 9.

Table 9: Physical and Technological Properties of Crystalline Materials

Material	Density g/cm³	El. resistivity Ω mm²/m	Thermal conductivity W/Km	Curie temperature °C	Young's modulus[1]) kN/mm²	Cupping[2]) (DIN 50 101) mm	Coefficient of thermal expansion (20-100°C) in 10^{-6}/K
MUMETALL	8.7	0.55	17 – 19	400	200	> 8	13.5
VACOPERM 100	8.7	0.60	17 – 19	360	170	> 8	13.5
ULTRAPERM 10	8.7	0.60	17 – 19	360	170	> 8	13.5
ULTRAPERM 200	8.7	0.60	17 – 19	360	170	–	13.5
ULTRAPERM 250	8.7	0.60	17 – 19	360	170	–	13.5
ULTRAPERM 91R	8.7	0.60	17 – 19	370	170	> 8	13.5
CRYOPERM 10[3])	8.7	0.35[3])	17 – 19	430	–	–	13.5
VACOPERM BS	8.7	0.60	17 – 19	500	170	> 8	13.5
RECOVAC BS	8.7	0.48	17 – 19	440	195	> 8	12.0
PERMENORM 5000 H2	8.25	0.45	13 – 14	440	140	> 8	10.0
PERMENORM 5000 V5	8.25	0.45	13 – 14	440	140	> 8	10.0
PERMENORM 5000 S4	8.25	0.40	13 – 14	500	160	> 8	10.0
RECOVAC 50	8.15	0.65	–	400	150	–	8.0
PERMENORM 3601 K5	8.15	0.75	13 – 14	250	135	> 8	4.0
MEGAPERM 40 L	8.20	0.60	13 – 14	310	100	> 8	4.0
CHRONOPERM 36	8.20	0.93	–	180	170	–	6.3
THERMOFLUX 55/100 G	8.15						
TRAFOPERM N3	7.65	0.40	31	750	180	not for deep drawing	12.0
VACOFER S1	7.87	0,10	72	770	200	9 – 11	13.0
VACOFLUX 48	8.12	0.44	30	950	200	not for deep drawing	9.5
VACOFLUX 50	8.12	0.44	30	950	210	not for deep drawing	9.5
VACODUR 50	8.12	0.42	–	950	250	not for deep drawing	10.2
VACOFLUX 17	7.94	0.39	–	920	200	6 – 8	10.8

[1]) Magnetically final annealed
[2]) State of delivery: soft-deep drawable
[3]) Magnetic properties at 77.3 K resp. 4.2 K

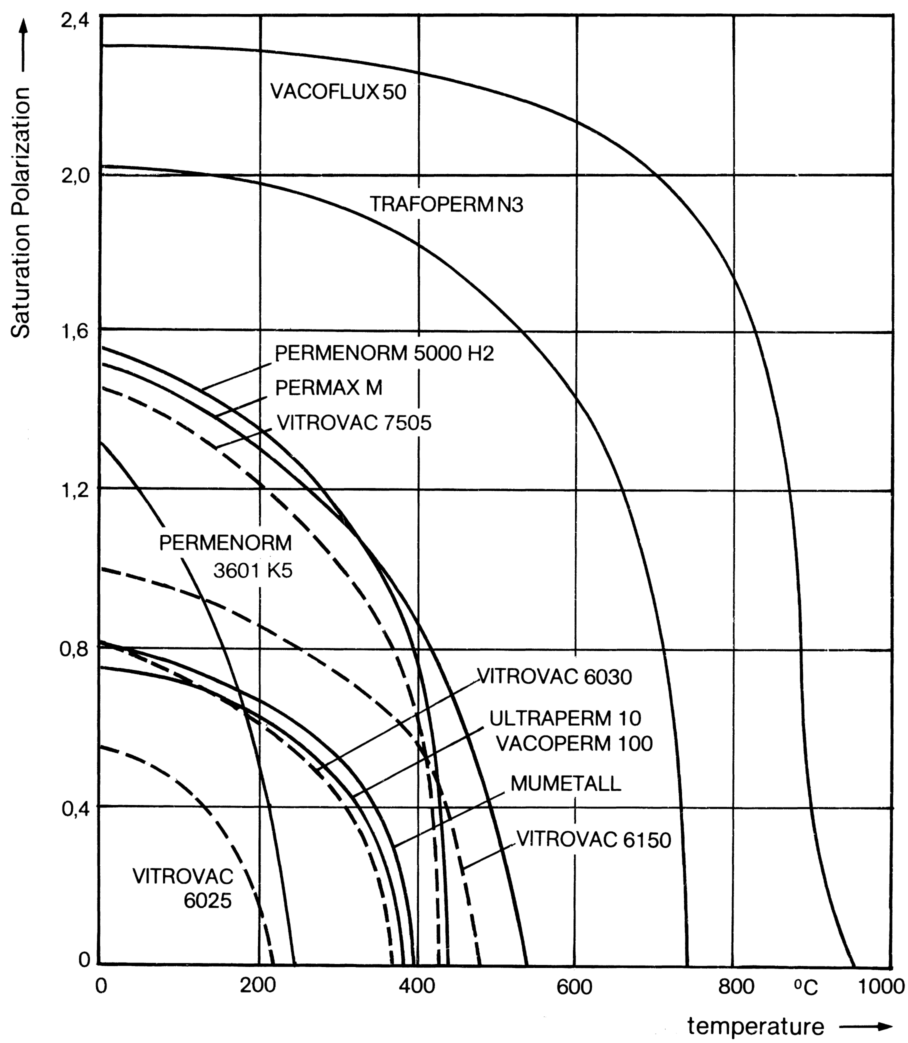


Fig. 10: Polarization Temperature Curves of Various Soft Magnetic Alloys.

Please note that because the magnetic properties are temperature dependent more detailed information may be required for some applications.

Using PERMENORM 5000 V5, PERMENORM 5000 S4 and VACOPERM 100 as examples, fig. 11 presents the relative temperature dependency of the H_c values on the ambient temperature within the range –30°C to 100°C.

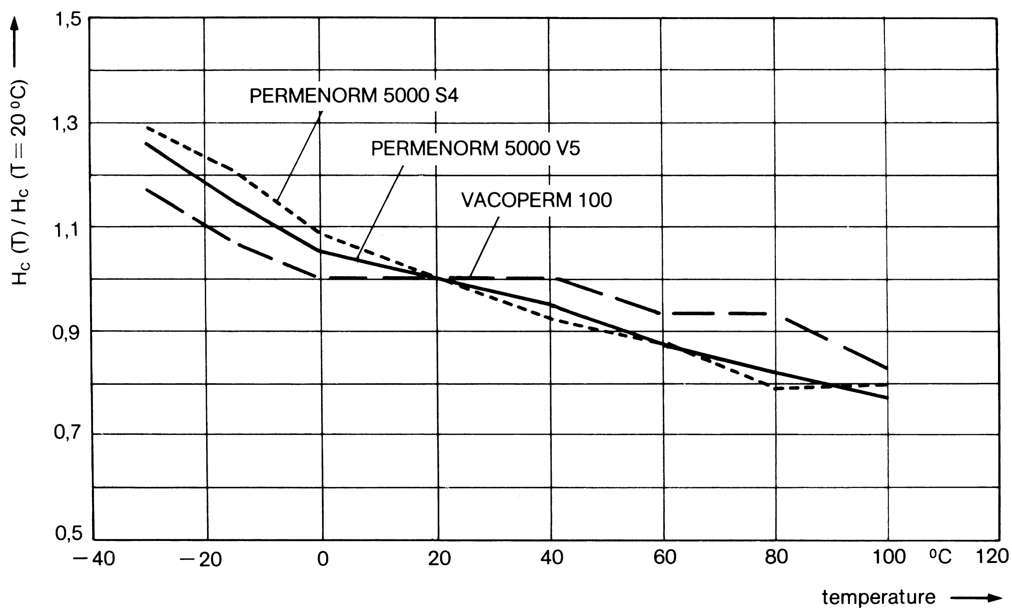


Fig. 11: Relative Temperature Dependency of Coercivity H_c (Standardized to 20°C) of PERMENORM 5000 V5, PERMENORM 5000 S4 and VACOPERM 100.

6.5 Properties of Special Soft Magnetic Materials

6.5.1 THERMOFLUX

Temperature compensation in permanent magnet systems (e.g. electricity meters, tachometers, electronic scales etc.) requires soft magnetic materials with a Curie temperature only slightly above room temperature. This ensures that within this temperature range the flux density is heavily dependent on the ambient temperature.

For this purpose VAC supplies THERMOFLUX a 30 % NiFe alloy whose Curie temperature can be set between +30°C and +120°C by varying the composition slightly. The different variants of THERMOFLUX are designated by two numbers and a letter, e.g. 55/100 G. The first number indicates the Curie temperature in °C, the second the measurement field strength in Oe (100 Oe = 80 A/cm). The letter G indicates that within a defined temperature range the flux density temperature curve is straight. For other applications, e.g. temperature sensitive switches and relays an alloy variant of S-quality (e.g. 55/100 S) is available. The letter S indicates that a sleeply falling flux density temperature curve is set in the vicinity of the Curie temperature.

Although as initially mentioned the Curie temperature of THERMOFLUX can be varied within a certain range, we recommend the following standard alloy – based on our experience – for temperature compensation in permanent magnet systems:

THERMOFLUX 55/100 G.

With a given composition and heat treatment both the Curie temperature and the curve are still, to a certain extent, dependent on the working field strength.

As an example fig. 13 shows the flux density temperature curve of THERMOFLUX 55/100 G as a function of field strength.

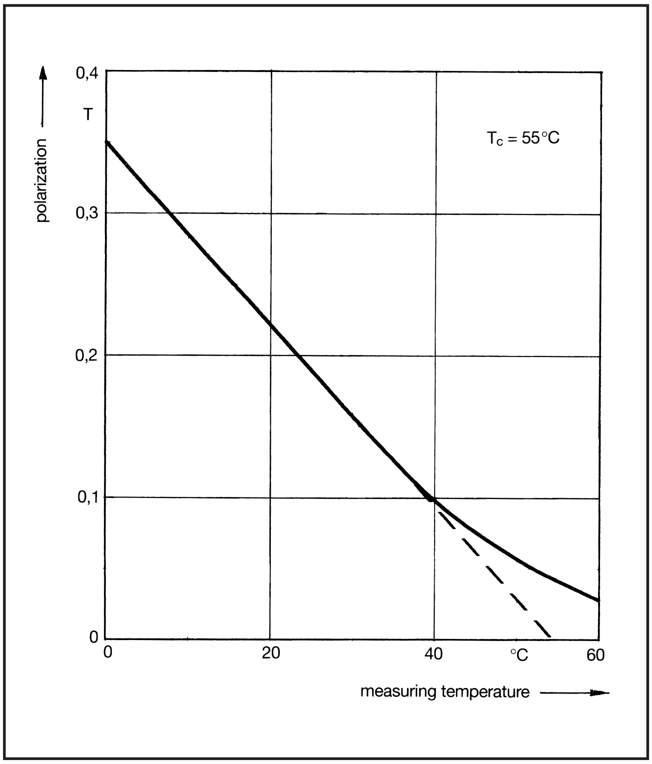


Fig. 12: Polarization Temperature Curve of THERMOFLUX 55/100 G

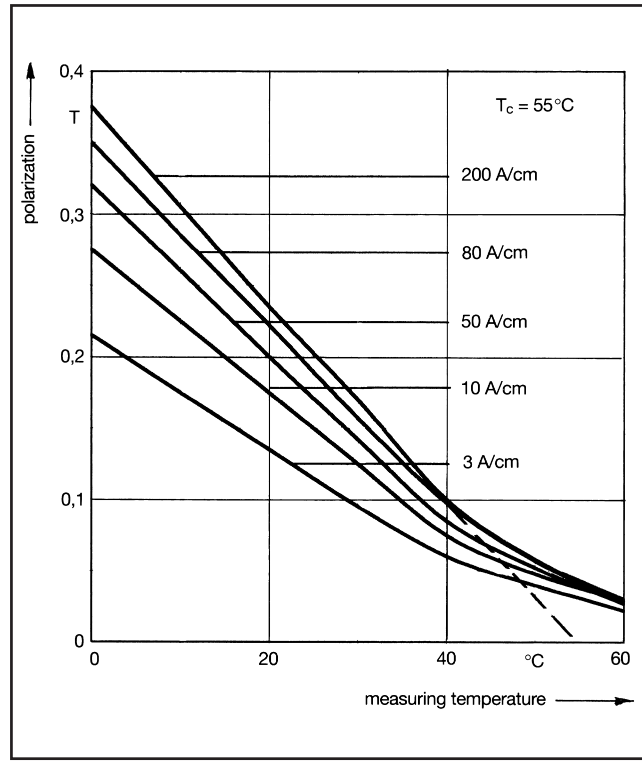


Fig. 13: Polarization Temperature Curves of THERMOFLUX 55/100 G as a Function of Field Strength (f = 50 Hz)

7. Warranty of Magnetic Properties

We have introduced a number of magnetic qualities for our different alloys and forms of supply. These cover the important characteristic magnetic parameters and are classified according to fields of application. Within each alloy group we offer different quality grades.

On the basis of individual agreements with customers we can draw up test guidelines – in addition to the magnetic qualities – which specify the inspection procedures and the measurement points in question.

On request, certificates to DIN 50 049, listing the material test results, can be issued by the authorized departments.

7.1 Magnetic Qualities for Semi-finished Products (Strips, Strip Thickness ≤0.3 mm)

The testing of strips is normally based on the magnetic qualities for toroidal strip-wound cores. The quality grade is determined by the preliminary batch test on toroidal cores. Depending on the specification, the values can also be directly measured on the product to be supplied.

In all cases appropriate limiting values should be agreed for the details concerning the test object, test procedure and the measurement points in question.

Table 10 gives a number of the typical magnetic qualities for strip material made of the different soft magnetic alloys. Apart from these general magnetic qualities, individual agreements can be drawn up for special applications.

Table 10: Magnetic Qualities for Semi-Finished Products (Examples) · Strips, Strip Thickness ≤ 0.3 mm.
(measured on toroidal cores after the usual heat treatment)

Material	Magnetic quality	Strip thickness mm	Measurement frequency	Permeability¹) μ	Field strength H_{eff} (A/cm)	Minimum flux density $\hat{B}$ (T)
MUMETALL	A-006	0.2 0.3	50 Hz 50 Hz	$\mu_4 \geq$ 40000 $\mu_4 \geq$ 40000	0.019 0.023	0.3 0.3
VACOPERM 100	B-020	0.1	50 Hz	$\mu_4 \geq$ 80000	0.009	0.3
ULTRAPERM 10	U-020	0.05 – 0.1	50 Hz	$\mu_4 \geq$ 150000	0.006	0.3
ULTRAPERM 200	U-022	0.05 – 0.1	50 Hz	$\mu_4 \geq$ 200000	0.005	0.26
ULTRAPERM 250	U-025	0.05	50 Hz	$\mu_4 \geq$ 250000	0.004	0.26
PERMAX M	P-003	0.1 0.2	50 Hz 50 Hz	$\mu_4 \geq$ 50000 $\mu_4 \geq$ 40000	0.018 0.028	0.3 0.3
PERMENORM 5000 H2	H2-006	0.05 – 0.1 0.2	50 Hz 50 Hz	$\mu_4 \geq$ 6000 $\mu_4 \geq$ 6000	0.055 0.080	0.6 0.6
MEGAPERM 40 L	MP-003	0.05 – 0.2	50 Hz	$\mu_4 \geq$ 5000	–	–
PERMENORM 3601 K5	K2-004	0.1 – 0.3	50 Hz	$\mu_{16} \geq$ 2900	–	–
VACOFLUX 50	V-050	0.05 – 2.0	DC field	–	H = 3 A/cm H = 8 A/cm	1.7 2.0
VACOFLUX 48	V-055	0.1 – 2.0	DC field DC field	–	H = 3 A/cm H = 8 A/cm	1.8 2.1
RECOVAC BS	RC-003	0.1 – 4.0	50 Hz	$\mu_4 \geq$ 20000	–	–
THERMOFLUX²)	T-001	0.05 – 0.3	50 Hz	–	H = 80 A/cm	nominal Curie temp. ± 5°C

¹) index = H (mA/cm)
²) THERMOFLUX, strip thickness: >0.3 mm see table 11 (solid material)

7.2 Magnetic Qualities for Semifinished Products (Examples): Strips, Strip Thickness >0.3 mm, Profile Material, Rods, Wires

To ensure that the magnetic qualities of consignments of semi-finished products made of solid material are fulfilled, the material is tested after the specified heat treatment, as a rule by measuring the static coercivity on appropriate strips or rod sections. On request, ring samples can be produced on which the permeability or flux density values are checked. These can be measured as described in section 7.1, either in the preliminary batch test or directly on the strip to be delivered.

Here again, we recommend exact specification for the test object, test procedure and measurement points.

The current magnetic qualities for consignments of solid material are listed in table 11.

Table 11: Magnetic Qualities for Semi-finished Products (Examples): Strips, Strip Thickness ≥0.3 mm, Profile Material, Rods, Wires

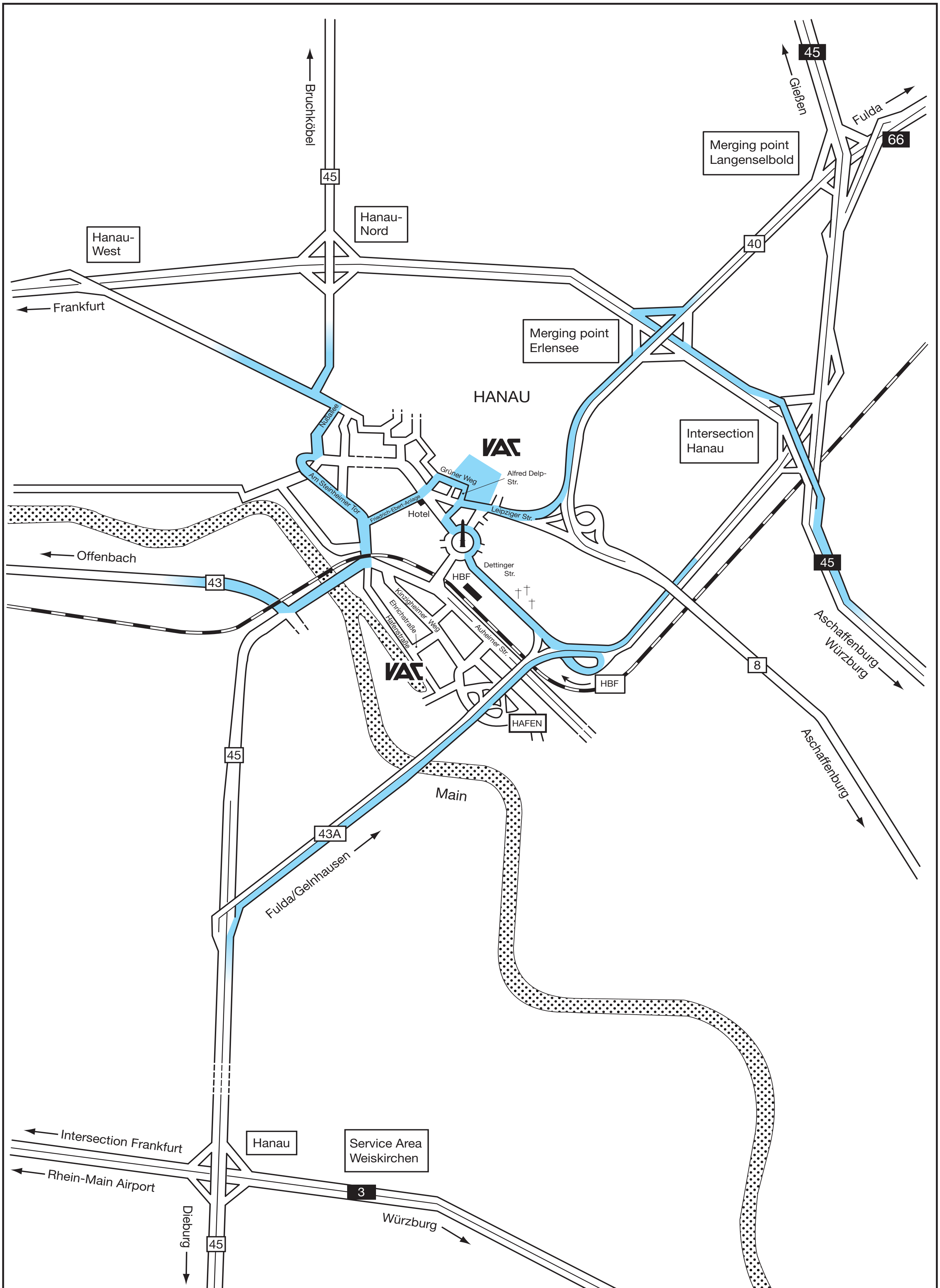
Material	Material type to DIN 17 405 (1979)	Quality grade	Magnetic quality	Type to DIN-IEC 404-8-6	Magnetic Test Values: coercivity A/cm	min. values for flux denstiy[1]) in T for field strengths in A/cm: 0.2	0.5	1.0	2.0	3.0	5.0	10	40
MUMETALL	R Ni 5	○	A-090	E 11-60	$H_c \leq 0.04$	0.5	0.65	0.7	–	–	0.73	–	0.74
	–	●	A-091	–	$H_c \leq 0.03$								
VACOPERM 100	R Ni 2	○	B-090	–	$H_c \leq 0.025$	0.5	0.65	0.7	–	–	0.73	–	0.74
	–	●	B-091	E 11-100	$H_c \leq 0.015$								
VACOPERM BS		○	BS-090		$H_c \leq 0.025$								0.97
RECOVAC BS					$H_c \leq 0.025$	0.5		0.7					0.74
PERMENORM 5000 H2	R Ni 12	○	H3-090	–	$H_c \leq 0.12$[2])	0.5	0.9	1.1	–	1.25	1.35	–	1.45
	–	●	H3-091	E 31-6	$H_c \leq 0.08$[2])								
PERMENORM 5000 V5	R Ni 8	○	V5-090	E 31-10	$H_c \leq 0.06$								
PERMENORM 5000 S4	R Ni 8	○	S4-090	–	$H_c \leq 0.045$								
RECOVAC 50					$H_c \leq 0.15$	1.35 T at 10 A/cm					$\mu_{max} > 25.000$		
PERMENORM 3601 K5	R Ni 24	○	K5-090	E 41-03	$H_c \leq 0.24$	0.2	0.45	0.7	–	0.9	1.0	–	1.18
MEGAPERM 40 L					$H_c \leq 0.06$	1.38 T at 10 A/cm					$\mu_{max} > 75.000$		
CHRONOPERM 36					$H_c \leq 0.04$	0.7-0.85 T at 10 A/cm					$\mu_{max} > 50.000$		
THERMOFLUX 55/100 G	–	○	T-001	–	nominal Curie temperature 55 ± 5°C								
TRAFOPERM N3	R Si 24	○	N3-090	C 1-24	$H_c \leq 0.24$	–	–	1.2	–	1.3	1.35	–	1.5
	R Si 12	●	N3-091	C 1-12	$H_c \leq 0.12$[3])								
VACOFER S1	R Fe 12	●	S-092	A-12	$H_c \leq 0.12$	–	–	1.15	1.25	1.3	1.4	1.45	1.6
VACOFLUX 48 Band[4])	–			F 11-60	$H_c \leq 0.4$					1.8	2.0	2.2	2.25
VACOFLUX 50 Band[4])	–	○	V-050	F 11	$H_c \leq 0.8$					1.7	1.9	2.1	2.2
VACOFLUX 50 Massiv	–	○	V-090	F 11	$H_c \leq 2.4$							1.95	
VACODUR 50 Band[5])				F 1	$H_c \leq 1.6$								
VACODUR 50 Band[6])				F 1	$H_c \leq 2.0$								
VACOFLUX 17					$H_c \leq 2.0$	Induction 2.0 T at field strength 160 A/cm							

[1]) Values to DIN 17 405 and DIN-IEC 404-8-6 (except VACOFLUX)
[2]) For ground and lapped small parts $H_c \leq 0.14$ respectively 0.10 A/cm
[3]) For parts with thickness below 2 mm and complex shapes $H_c \leq 0.15$ A/cm
[4]) Also ASTM A801 Alloy Type 1 add. max 0,4 % Ni, former MIL-A-47182 cancelled Oct. 1981
[5]) With optimum magnetic properties
[6]) With optimum mechanical properties

_N.B._
Besides these general magnetic qualities, special arrangements can be made for customer-specific applications.

○ standard quality
● special quality

You will find us:



Product Survey

Rare-Earth Permanent Magnets

Magnets on Sm-Co and Nd-Fe-B Base

Magnet Assemblies

Semi-Finished Products and Parts

Metallic Semi-Finished Products
Soft magnetic alloys
Magnetically semi-hard alloys
Ductile permanent magnets
Thermobimetals
Spring alloys
Glass/ceramic-to-metal sealing alloys

Parts
Stamped/bent parts
Laminations
Magnetic shielding

Superconductors

Cores and Components

Magnetic Cores
Tape-wound cores made of crystalline, amorphous and nano-crystalline alloys

Inductive Components
for xDSL, ISDN and switched-mode power supplies, for current detection and for driving power semiconductors

VACUUMSCHMELZE GMBH & Co. KG

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Advanced Materials – The Key to Progress

P.O.B. 22 53
D-63412 Hanau
☏ (**49) 61 81 / 38-0
Fax (**49) 61 81 / 38-26 45
Internet: www.vacuumschmelze.com
eMail: info@vacuumschmelze.com

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