Parts and Components

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Parts and Components

Contents

1. Preface

This company brochure underlines the significance attributed by VACUUMSCHMELZE to their product division, Parts and Components. Our aim is to give our customers – who are primarily involved in the automotive supplier industry, textile and spinning mill machinery manufacture, printer industry, electric and residual current device technology as well as the watch and clock making industry – a comprehensive overview of our production and delivery possibilities.

2. Parts and Components

2.1 Definition of Expressions

VACUUMSCHMELZE is a leading producer of parts and components with special magnetic and mechanical properties and our new brochure a tribute to the significance of this field. At the same time, it reveals that parts of soft magnetic and magnetically semi- hard materials are the focal point of this business. Prior to discussing dimensioning, production and material technology in detail, the expressions “part” and “component” are explained allowing for their required magnetic function.

A “part” made of magnetically soft or semi-hard material is the smallest possible functional part – which cannot be further broken down – with magnetic properties.

The following pictures show several examples of our parts.

Those selected illustrate the wide range of dimensions. For instance, parts with a filigree structure (Fig. 3) and dimensions in the mm range as well as magnet poles of several decimeters.

From the definition of a part, we have established, on its own, it has no independent function (as actuator or sensor).

The smallest unit which takes over a part-function in a more complex system is a component. In general, this consists of different soft magnetic and/or semi-hard parts which can be fitted with a copper winding to act as a drive. Assembly is either manual, semi or fully automatic

For assembly purposes we also use parts of non-magnetic materials. A good example is our “ZUS-magnet”. This consists of an interlocked lamination package of CROVAC platelets, a THERMOFLUX disc and an aluminium carrier/rivet (see Fig. 8). Assembly is fully automatic and, moreover, the machine automatically makes a “GOOD/BAD” selection.

Pre-condition for VACUUMSCHMELZE to supply components is that the component is largely made of VAC materials.

2.2 Customer Benefits

At VAC close cooperation with our customers is one of our top priorities. Our customers reap the following benefits:

- utilization of our experience and knowledge as one of the market leaders for magnetic materials
- assistance from our laboratory in analysing problems and optimizing products
- utilization of our production know-how
- utilization of our facilities and experience in setting the magnetic properties.

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Fig. 1: Stamped - bent part for car injection valve

Fig. 2: Parts of VACOFLUX for matrix printers

Fig. 3: Parts of a magnetic injection valve

Fig. 4: Discs and profiled parts of CROVAC

Fig. 5: Magnet pole of VACOFLUX (milled part)

Fig. 6: Precision stamped part of MUMETALL

Fig. 7: Shielding cans for display instruments

Fig. 8: ZUS-magnet

Fig. 9: Assembly line for ZUS-magnet

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3. Material Overview

Our soft magnetic materials are the basis from which parts and components are further processed. Close cooperation with our customers from the early stages of development ensures individual optimum solutions even for novel applications.

3.1 Material Selection Criteria

The physical and mechanical properties of our materials are of fundamental significance to an application. The most important criteria are:

Soft Magnetic Materials

- low H_c values
- high saturation magnetization
- good dynamic properties

Ductile Permanent Magnet Materials

- H_c values in the range 250-550 A/cm
- remanence in the range 0.9-1.3 Tesla

Common criteria to both material groups are:

- corrosion resistance
- appropriate cost to efficiency ratio

Our spectrum ranges from high nickel content (70-83 % Ni) alloys, such as MUMETALL and VACOPERM through MEGAPERM with a 40 % Ni content to our PERMENORM alloys with a Ni content of 36 % upwards. For applications demanding high saturation magnetization we offer the Co-Fe alloys VACOFLUX 17, VACOFLUX 48/50 or VACODUR 50.

VACOFLUX 17 is a recent addition to our product range. Typical applications for this alloy which contains less cobalt than VACOFLUX 50 are found in **“Parts”** such as:

- Pole shoes with maximum flux density
- Electromagnets with maximum force
- Flux conductors with high induction
- Actuators for miniaturized valves
  and in **“laminated packages”**, e.g.:
- High performance motors
- Generators, e.g. avionics
- High speed matrix printers

Our magnetically semi-hard CoCrFe alloys, CROVAC and MAGNETOFLEX round off this product range.

Maraging Spring Steel

MARVAC 125 is a new high strength stainless Maraging Steel, characterized by optimum spring properties, corrosion resistance and superior isotropic shaping capability in the annealed state. Typical/potential applications are:

- Elastic clamps in car-headlights etc.
- Temperature resistant elastic fasteners
- Separating diaphragms tubular springs and friction elements for fuel-injection-systems
- Deep drawn parts and tubes for high strength vessels
- Complex stamped/bent parts for watches etc.
- Springs for dot matrix printers and relays

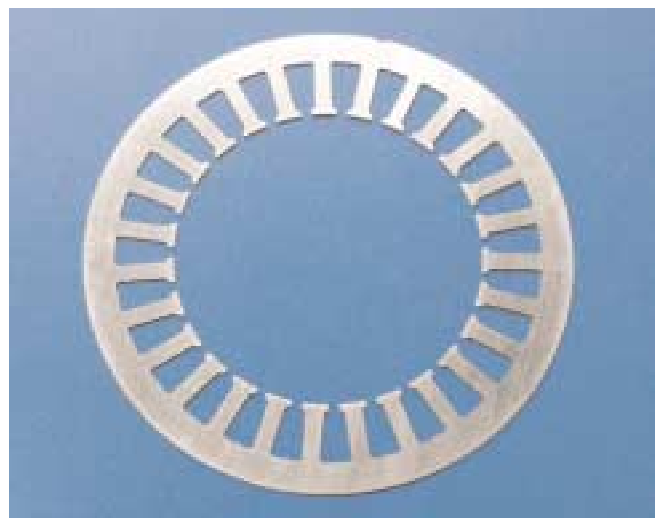


Fig. 10: Motor lamination made from VACOFLUX 50

3.2 Examples of Material Selection for Different Applications

Relay Parts

VACOPERM 100, PERMENORM 5000 V5, RECOVAC 50, RECOVAC BS, CROVAC 12, CROVAC 16

Advantages:

- good corrosion resistance
- long lifetime

Shielding for Display Instruments

PERMENORM 3601, MEGAPERM 40L, MUMETALL

Advantage:

- higher shielding factor than steel shieldings

Automotive Technology

PERMENORM 5000 V5, PERMENORN 5000 H2, THERMO-FLUX, MEGAPERM 40L, VACOFLUX 50, VACOFLUX 17, CROVAC 10, CROVAC 12

Advantages:

- suitable H_c
- high induction
- strong forces

Looms

RECOVAC

Hysteresis Couplings/Brakes

CROVAC 10, MAGNETOFLEX 35H

Dot matrix printer

VACOFLUX 50, VACOFLUX 17

Advantages:

- high induction
- strong forces
- good dynamic properties with lamination packages

Aircraft industry

VACOFLUX 48, VACOFLUX 50, VACODUR 50

Advantages:

- high force
- reduction of weight

4. Production Processes

Parts or components made from magnetically soft or semi-hard materials are widely used in engineering in governing functions. In principle, the production processes are the same as for other ferrous alloys. Our processing methods are:

- turning, milling and drilling
- stamping and deep-drawing
- stamped lamination packaging
- extrusion
- mechanical finishing

Our alloys differ from other alloys, such as VA-steels, as a result of the final heat treatment to set the magnetic properties and the effect of the production process on the magnetic properties.

4.1 Turned and Milled Parts

To produce or further process soft magnetic parts, the machining techniques turning, milling and drilling are available. Table 1 classifies the alloys according to production techniques, and includes dimensions, batch sizes and tolerance ranges.

4.2 Stamped and Deep-Drawn Parts

The following illustrates the strategy of VACUUMSCHMELZE in the important sector of “Parts and Components”:

Tab. 1 Classification of alloys and dimensions according to machine processing

Processing/ machining method	Dimensional range[3]	Alloy[2]	Batch Size range
Turning	∅ ≥ 1 mm	MUMETALL PERMENORM 5000 H2 PERMENORM 5000 V5 PERMENORM 3601 VACOZET VACOFLUX 50 VACODIL 36	● single pieces ● small and medium series, typ. up to ≈ 5000 pcs, depending on geometry of part also up to 100 000 pcs
Milling	jig up to max. 400 mm	MUMETALL PERMENORM 5000 H2 PERMENORM 5000 V5 PERMENORM 3601 VACOFLUX 50 VACODIL 36	● single pieces ● small and medium series, Standard: up to 5000 pcs, depending on geometry of part larger batches also possible
Drilling	jig for work pieces[1] up to – 1000 mm (grinding) – 500 mm (drilling)	MUMETALL PERMENORM 5000 H2 PERMENORM 5000 V5 PERMENORM 3601 VACOFLUX 50 VACODIL 36	● single pieces ● small and medium series, Standard: up to 5000 pcs, depending on geometry of part larger batches also possible

[1] upper limit of workpiece dependent on alloy
[2] other alloys on request
[3] Tolerance ISO 2768, closer tolerances on request

Intelligent Tool Designs

Modern Machines and Plants

Optimum Capability and
Optimum Efficiency for the Benefit
of our Customers

Recognized Experts

Materials (Selection)

VACOPERM 100
PERMENORM 5000 V5
MEGAPERM 40 L
VACOFLUX 50
CROVAC

Optimized Materials

Tab. 2 Overview of production facilities in the stamping and deep-drawing sector

Machine-/Plant Description	Main Field of Use	Workable Strip Thickness
Progressive press 12 stages each with 7.5 t force, zigzag feed, stroke: 200 strokes/min	Production of deep-drawn cans	typical 0.2 - 0.4 mm
Excenter pressing each with 50 t force, stroke: 80 - 1200 strokes/min	Production of stamped and stamped-shaped parts, to produce parts with progessive combined die, interlocked lamination packages	from 0.1 - 3 mm
Stamping-, bending- and assembly machine, 7 t force, 5 t force in bending aggregate stroke: 350 strokes/min	Stamped and stamped-shaped parts, rings, Production of parts with thread Assembly work possible	from 0.1 - 2 mm
Precision blanking machine force: 100 t or 160 t	Soft magnetic parts, e.g. magnet yokes, pole shoes, armatures etc.	Material dependent; examples of end sheet thicknesses of different materials: PERMENORM 5000 H2 ≈ 5.0 mm R FE 80 ≈ 4.0 mm VACOFLUX 50 ≈ 1.8 mm

4.3 Interlocking / Bonding

Due to the rising working frequencies and the problems with too high eddy current losses, solid parts are being replaced to an increasing extent by laminated parts. The main fields of application include vehicles, printers and motors.

The manufacture of larger series is possible extremely rationally with the latest high-performance presses and multi-stage operation dies making use of the interlocking technology.

Depending on the part geometry, for instance, angularity and flatness tolerances of clearly < 0.1 mm as well as a lamination offset of < 0.01 mm can be maintained with interlocked laminated cores.

Lamination thickness > 0.1 mm can be interlocked securely and openings transversely to the stacking direction can be attained.

Additional strengthening is achieved by the final heat treatment.

Insulated laminations are used for especially high dynamic requirements.

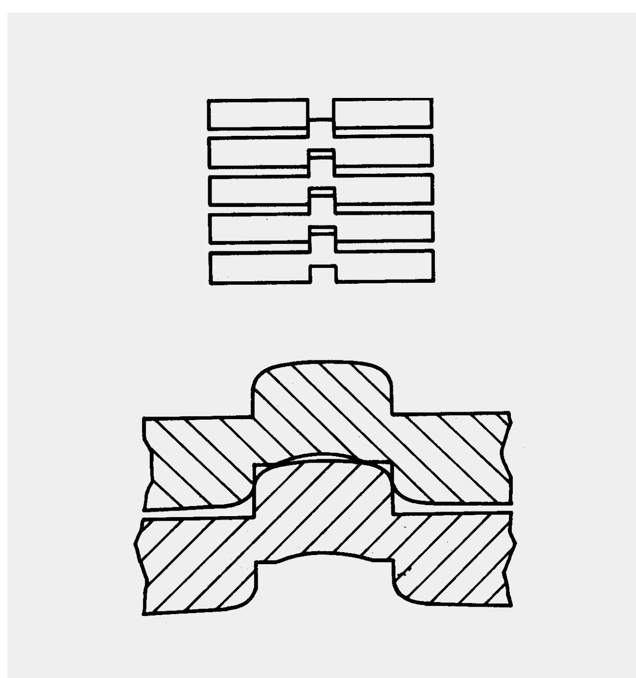


Fig. 11: Schematic drawing of interlocking technology

The manufacture of permanent magnets made of CROVAC as a substitute for AlNiCo materials is possible within close tolerances with the interlocking system without further finishing being required.

Bonded cores are manufactured for applications with smaller series or specific requirements.

Insulating adhesives which can be applied at up to approx. 200 °C are used.

Fig. 12: Lamination packages for different applications

4.4 Extrusion

Austenitic Fe-Ni or ferritic Fe-Co alloys for soft magnetic applications are altogether difficult to machine. The alloys are exceptionally hard. As a result turning, milling or drilling tools show extreme wear and chip removal is difficult. VACOFLUX 50, for instance, is already very hard in the magnetically soft state. Furthermore, the actual material value of the alloy is relatively high so that in many cases it is more economic to use non-cutting shaping methods such as extrusion. This method is excellent for making radially symmetrical parts to tight tolerances.

Fig. 13 shows the strength vs. temperature curve of our alloys, in principle. Moreover, cold working increases the strength thus shaping at higher temperatures is to be preferred (semi-cold extrusion).

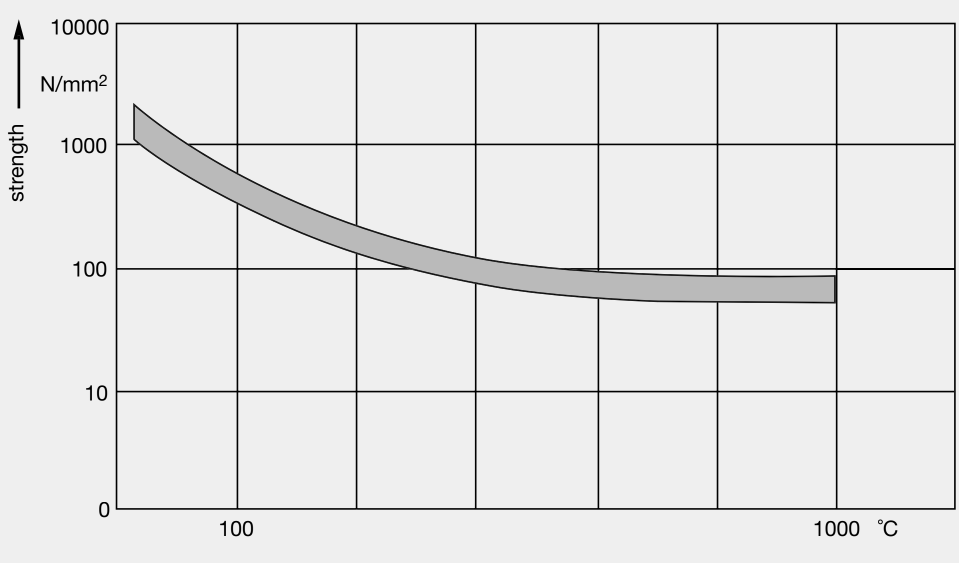


Fig. 13: Basic representation of strength as a function of temperature for soft magnetic alloys

4.5 Mechanical Finishing, Coating and Packing

At VAC the most important finishing processes for turned, milled, stamped and deep-drawn parts are:

Deburring

- Manual and semi-automatic processes like removing burrs by hand or brushing. These methods are used when localized deburring is required.
- Chemical and electrochemical deburring
- Tumble deburring
  Various methods like tumble deburring with vibrators, bell-shaped drums or centrifuges are available. This type of deburring causes rounding off of edges.

In some cases, the most suitable method is chosen together with the customer.

Grinding, Lapping

The following facilities are available: 2 disk-grinders, continuous and swing grinding machines.

Washing of Parts

To clean slurry from parts we use a modern washing plant and and CFC-free detergent.

Coating

We coat parts by electroplating with gold, silver or nickel-palladium. Our speciality is very thin homogeneous coating in the range 0.8 µm ± 50 %.

Chemical nickel plating is possible too.

Packing

The most suitable packing is selected together with the customer.

Examples:

- Bulk goods in cartons or plastic containers, e.g. shielding cans for automotive industry
- Packing in layers, e.g. relay parts for residual current devices
- Different types of plastic moulded trays, e.g. with individual pockets to separate parts
- Blister packing, e.g. for automatic machine feed

Fig. 14: Soft magnetic parts packed in layers

5. Quality Assurance and Magnetic Quality of Parts

5.1 Quality Assurance System

The quality system at VACUUMSCHMELZE is certified according to DIN EN ISO 9001:2000 on the requirements of automotive industrie ISO TS 16949. Together with the customer, the inspection characteristics are laid down for each part.

In the stamping centres and the grinding area the production inspection is computer aided (SPC).

5.2 Magnetic Qualities of Soft Magnetic Parts

The standard magnetic qualities are compiled in Table 3 Special arrangements can be made for specific applications.

Fig. 15: Computer-aided measuring system

Tab. 3 Magnetic qualities of soft magnetic parts

Material	Material grade to DIN 17405 (1979)	Magnetic quality	Coercivity A/cm	Grade to DIN-IEC 404-8-6	Magnetic Test Values[1] Min. values for flux density in T for field strength in A/cm 0.2	0.5	1.0	2.0	3.0	5.0	10	40
MUMETALL	R Ni 5 –	A-090 A-091	$H_C \le 0.04$ $H_C \le 0.03$	E11/60 –	0.5	0.65	0.70	–	–	0.73	–	0.74
VACOPERM 100	R Ni 2 –	B-090 B-091	$H_C \le 0.025$ $H_C \le 0.015$	– E11-100	0.5	0.65	0.70	–	–	0.73	–	0.74
PERMENORM 5000 H2 PERMENORM 5000 V5 PERMENORM 5000 S4	R Ni 12 R Ni 8 – –	H3-090 H3-091 V5-090 S4-090	$H_C \le 0.12$[2] $H_C \le 0.08$[2] $H_C \le 0.06$ $H_C \le 0.045$	– E31-06 E31-10 –	0.5	0.9	1.1	–	1.25	1.35	–	1.45
PERMENORM 3601 K5	R Ni 24	K5-090	$H_C \le 0.24$	E41-03	0.2	0.45	0.70	–	0.9	1.0	–	1.18
THERMOFLUX	–	T-001	desired Curie point ± 5 °C[3]	–	case dependent agreement on rise and linearity of B(T) curve							
VACOFLUX 50[5]	–	V-050	$H_C \le 0.8$	F11	–	–	–	–	1.7	–	2.05	–
VACOFLUX 48[5]	–	V-055	$H_C \le 0.4$	F11-60	–	–	–	–	1.8	–	2.15	–
VACOFLUX 17	–	–	$H_C \le 2$	–	–	–	$B \ge 2T$ at 160 A/cm					
VACODUR 50[6]	–	–	$H_C \le 2$	F1	–	–	$R_{P\,0.2} \ge 400$ MPa					

[1] Values referred to DIN 17405 and DIN-IEC 404-8-6 (without VACOFLUX)
[2] For grinded and lapped small-parts: $H_C \le 0.14$ resp. 0.10 A/cm
[3] Curie-points over 100 °C: ± 7.5 °C[6]
[4] For parts with thicknesses less than 2 mm and disadvantagous shapes $H_C \le 0.15$ A/cm
[5] Parts made of strip, strip thickness ≤ 0.8 mm
[6] not proposed for applications with $R_{P\,0.2} > 550$ MPa

Appendix A:
Materials for Parts and Components

A1. Survey of Physical and Mechanical Properties

A1.1 Soft Magnetic Materials

Tab. 4 Physical properties of soft magnetic materials commonly used for parts, guaranteed values[1] for magnetically optimized final heat treated solid material (typical values in brackets)

Material	Main constituent balance iron	Density	Static coercive field strength	Saturation polarization	Curie-temperature	Spec el. resistivity	Thermal conductivity	Expansion coefficient at 20-100 °C
		g/cm³	A/cm	T	°C	Ω · mm²/m	W/K · m	10^{-6}/K
MUMETALL	72-83 % Ni	8.7	0.03 (0.02)	0.8	400	0.55	17-19	13.5
VACOPERM 100	additions of Cu		0.015 (0.01)	0.74	360	0.6	17-19	13.5
VACOPERM BS	Mo etc.		(0.025)	0.97	500	0.6	17-19	13.5
RECOVAC BS	Ni			0.8	440	0.48	17-19	12.0
(CRYOPERM 10)	additions of Cu Mo etc.			0.74	430	0.35 at T = 77.3 and 4.2 K	17-19	13.5
PERMENORM 5000 H2/V5	45-50 % Ni	8.25	0.06 (0.05)	1.55	440	0.45	13-14	10.0
PERMENORM 5000 S4			0.045 (0.02)	1.6	500	0.4	13-14	
PERMENORM 3601 K5	35-40 % Ni	8.15	0.24 (0.2)	1.3	250	0.75	13-14	2.0
MEGAPERM 40L		8.2		1.48	310	0.6	13-14	4.0
THERMOFLUX	approx. 30 % Ni	8.15	0.4 at 20 °C	0.22-0.35 at 20 °C	30-120	0.8	11-12	2.0
VACOFLUX 48[2]	47-50 % Co	8.12	0.4 (0.3)	2.35	950	0.44	30	9.5
VACOFLUX 50[2]	47-50 %	8.12	0.8 (0.5)	2.35	950	0.44	30	9.5
VACODUR 50[2]	47-50 %	8.12	2.0	2.3	950	0.43	≈30	10.2
VACOFLUX 17	15-20 % Co	7.94	2.0 (1.2)	≈2.28	920	0.39	–	10.8

[1] Any agreement on the magnetic values of complex geometries must be defined on a sample.

[2] Parts made of strip, strip thickness ≤ 0.8 mm

A1.2 Ductile Permanent Magnet Alloys

Tab. 5 Physical and magnetic properties of ductile permanent magnet alloys

Material	Main Components	Forms of supply Further forms of supply on demand		Remanence	Coercivity	Energy density (typ.)	Max. temperature of application	Rev. temperature-coefficient of remanence between -25 °C and 250 °C	Vickers-hardness
		Diameter of parts of wire	Thickness of parts of strip						
		mm	mm	T	kA/m	kJ/m³	°C	%/K	
CROVAC 12/160	FeCrCoMo	0.2-6	0.25-2.5	0.85-0.95	36-42	13	480	-0.03	480
CROVAC 16/160	FeCrCoMo		0.25-2.5	0.80-0.90	39-45	15	480	-0.03	480
CROVAC 12/500	FeCrCoMo	0.2-6	0.25-2.5	1.15-1.25	47-55	35	480	-0.03	480
CROVAC 16/550	FeCrCoMo		0.25-2.5	1.10-1.20	53-61	37	480	-0.03	480
MAGNETOFLEX 35	CoFeV	–	0.05-0.6	0.80-0.90	25-28	12	500	-0.01	950
MAGNETOFLEX 93	CoFeVCr	0.3-4.0	–	1.00-1.10	30-32	20	500	-0.01	950
VACOZET 258	CoFeNiALTi	0.3-7.0	0.05-0.6	>1.30	2.0-3.2	2.5	400	–	600
VACOZET 655	CoFeNiALTi	0.3-7.0	0.05-0.6	<1.20	2.5-4.8	4	400	–	650
SEMIVAC 90	FeCrCoNiMo	0.3-3.0	0.045-0.3	0.90-1.20	4-10	5	450	–	approx. 700
SENSORVAC	FeNiALTi	0.3-6.0	0.045-0.1	1.30-1.60	1.5-2.6	3	300	–	approx. 600

A1.3 Maraging Spring Steel

Tab. 6 Mechanical properties

Material	MARVAC 125	
Main components	Fe-13Cr-8Ni-1Mo-Be, Ti	
	soft	after aging 2h 470 °C
Tensile strength (MPa)	1100	2100
Yield strength (MPa)	800	1900
Elongation	4 %	3 %
Vickers hardness (HV)	330	> 600
Spring bend limit (MPa)	570	1650
Fatigue strength (MPa) (10^7 cycles, 1% fracture probability)		approx. 900
Max. application temperature		approx. 450 °C
Shrinkage during aging		isotropic < 0.05 %

Tab. 7 Magnetic properties

Material	MARVAC 125	
Main components	Fe-13Cr-8Ni-1Mo-Be, Ti	
	soft	after aging
Static coercive field strength (A/m)	15-18	10-19*
Saturation polarization (T)	1.6	1.65
Remanence (T)	0.75	0.25-0.65*

*depending on thickness

Tab. 8 Physical properties

Material	MARVAC 125					
Main components	Fe-13Cr-8Ni-1Mo-Be, Ti					
Density (g/cm^3)	7.8					
Electrical resistivity (µΩm)	0.9					
Thermal conductivity	14					
Average thermal expansion (10^{-6} K^{-1})	RT	100 °C 10.3	200 °C 10.6	300 °C 11.0	400 °C 11.4	500 °C 11.6

Tab. 9 Mechanical properties of soft magnetic materials for parts and components

Material	Vickers hardness HV to DIN EN ISO 6507			Deep-Drawing index to DIN 50101	Young's Modulus	Yield Strength to DIN EN 10002
	cold worked	soft annealed	final magnetic annealing	mm	N/mm²	N/mm²
MUMETALL	270-400	120-180	100-120	> 8	200	140
VACOPERM 100					170	150
VACOPERM BS					170	150
RECOVAC BS	300-350	120-160	150			
CRYOPERM 10	270-400	120-180	100-120			
PERMENORM 5000 H2	220-300	120-160	90-120	> 8	130-150	140
PERMENORM 5000 V5	220-280	120-160				
PERMENORM 5000 S4	220-280	120-160			≈160	≈200
PERMENORM 3601 K5	220-280	110-150	90-120	> 8	135	250
MEGAPERM 40L	220-280	110-150	90-120	> 8	100	200
THERMOFLUX	210-250		90-150	> 8	80-190	160-210
VACOFLUX 48	300		180	not deep-	200	200
VACOFLUX 50	300-350		180-210	drawable	210	250
VACODUR 50			210-230		250	390-450
VACOFLUX 17	220-350	145	130	6-8	200	250

2. Geometrical Influences on the Magnetic Properties of Soft Magnetic Parts

The magnetic data and material curves listed in tables and shown in diagrams refer almost exclusively to closed magnetic circuits. In almost all practical applications of soft magnetic parts it is typical that the flux closes only across more or less broad air gaps. Besides the magnetic parameters then also the sample shape and geometric data like length of the air gap and length of the circuit influence the magnetic data of the magnetic circuit.

State-of-the-art procedure to analyse or design magnetic circuits is the use of numerical methods such as FEM calculations. VACUUMSCHMELZE offer their customers assistance in designing circuits by means of such calculations. These, in turn, are based on a Performance/Specification File drawn up in close cooperation.

For a basic understanding and a first estimation the connections and formulae, explained in the following, are helpful.

The cause for the big influence on the characteristic curves integrating an air gap in a magnetic circuit or considering open sample shapes like strips or rods, stands upon the fact that at the transition from material to the air the magnetization ends and the magnetic field emerging from the free poles diminishes as demagnetizing field H_N the externally applied field H_a (see Fig. 16).

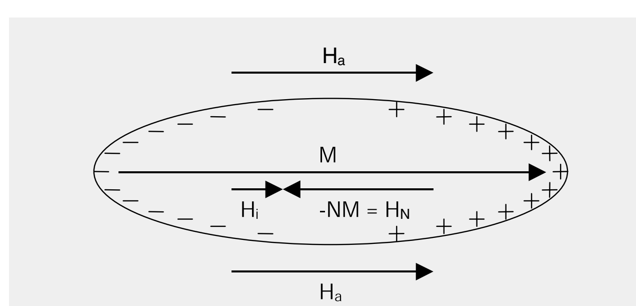


Fig. 16: Emerging of the demagnetizing field on a sample in an external field

On simple cases like a short air gap in a circuit or a simple sample shape the connection between magnetization and H_N can be expressed by a proportionality factor N called demagnetization factor. The fact that H_N is opponent to the magnetization is considered by the negative sign.

$$H_N = -N\,M = -N\,J/\mu_0$$

The demagnetization factor N can take the values between 0 and 1. The extremes correspond to the closed magnetic circuit or also to an extremely long and thin wire in a longitudinal field (N=0) or to a thin sheet in a field directed vertically to it (N=1). For a sample with an ellipsoidal shape the following formula holds for the demagnetization factors along the three main axes x, y, z:

$$N_x + N_y + N_z = 1$$

The field acting inside the material H_i is a superposition of the field applied from outside by a coil H_a and the field H_N:

$$H_i = H_a + H_N = H_a - N\,M$$

In case of a linear dependency of M on H_i it follows:

$$M = (\mu_r - 1)\,H_i \text{ and therefore: } H_i = H_a - N\,(\mu_r - 1)\,H_i$$

Thus follows: $$H_i = \frac{H_a}{1 + N\,(\mu_r - 1)}$$

Only in the case of $\mu_r = 1$ or N=0 the internal field equals the external. If μ_r >>1 H_i depending on N can be much smaller than H_a.

With linear equations for the induction B in the material and the equation for H_i above it follows:

$$B = \mu_0\mu_r H_i = \mu_0 \frac{\mu_r}{1 + N\,(\mu_r - 1)} H_a = \mu_0\mu^* H_a$$

with $\mu^* = \dfrac{\mu_r}{1 + N\,(\mu_r - 1)}$ as sheared permeability.

Only if N=0, that is in a closed magnetic circuit, $H_i = H_a$ and $\mu^* = \mu_r$ hold.

For special simple arrangements only, N can be derived from geometric data:

1. The sample is a rotational ellipsoid with length L and diameter D. For N_z along the rotational axis follows:

   - for p = L/D > 1:
     $$N_z = \frac{1}{p^2 - 1}\left\{\frac{p}{\sqrt{p^2 - 1}} \ln\left(p + \sqrt{p^2 - 1}\right) - 1\right\}$$
   - for p = L/D = 1:
     $N_z = 1/3$
   - for p = L/D < 1:
     $$N_z = \frac{1}{1 - p^2}\left\{1 - \frac{p\,\arccos(p)}{\sqrt{1 - p^2}}\right\}$$

   The demagnetization factors $N_x = N_y$ perpendicular to N_z can be evaluated by $N_{x,y} = (1 - N_z)/2$.

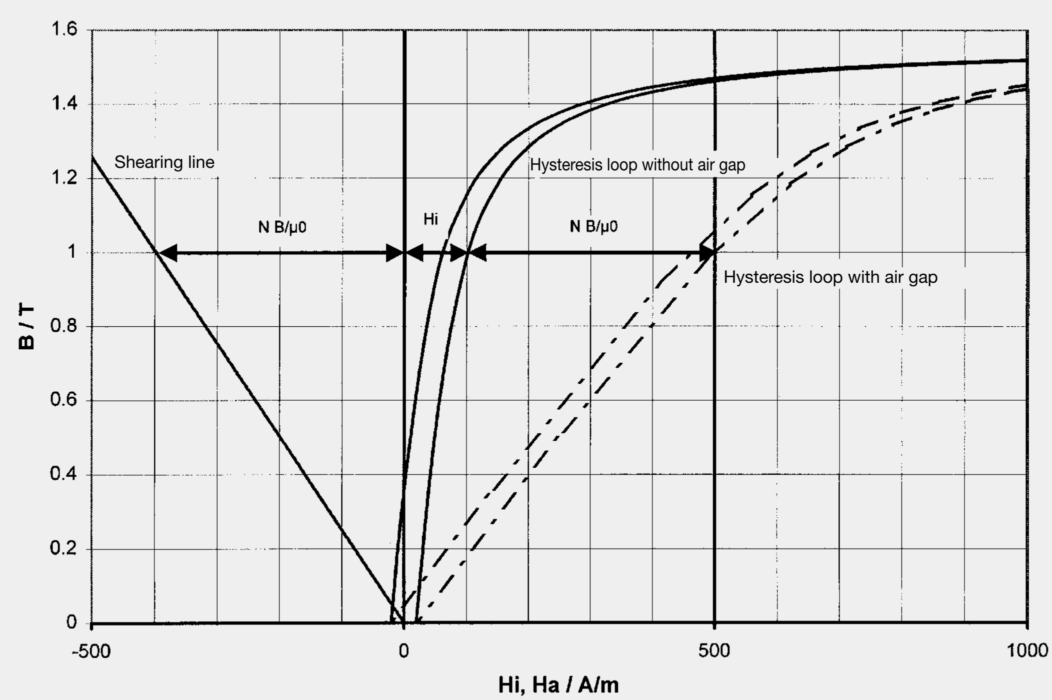


Fig. 17: Influence of an air gap on the hysteresis loop of a soft magnetic material

2. Magnetic circuit of total length l with a short air gap l_L ($l_L << l$):

- $N = \frac{l_L}{l}$

The material curves, measured in closed magnetic circuits, can be transformed by "shearing" to curves that are valid for the circuit with air gap. The shearing line is the measure for how much additional external magnetic field must be applied to balance the demagnetizing field, that is caused by the magnetization (polarization) of the material. For soft magnetic material and not too heavy shearing $H_N = -N\ J/\mu_0 \approx -N\ B/\mu_0$ holds. The effect on the hysteresis loop is shown in Fig. 17.

A3. Dynamic Properties of Soft Magnetic Materials (Principle)

Favourable soft magnetic properties mean low coercivities H_c, as a rule, at relatively high remanence values B_r. As low coercivities are equivalent to low remagnetization losses, this can be considered as an indication for the grade of a soft magnetic material for the majority of applications. The remagnetization losses p_{Fe} are essentially made up of the hysteresis losses p_h and the eddy current losses p_w:

$$p_{Fe} = p_h + p_w = c_1 \cdot \hat{B}^p \cdot f + C_2 \cdot f^2 \cdot \hat{B}^q$$

c1, c2: loss factors
p, q: exponents between 1 and 3 (mostly close to 2)
$\hat{B}$: flux density value
f: frequency

From this equation it is clear that the size of the hysteresis losses reveals information on the magnetic grade of a material in a purely static case ($f \rightarrow 0$). In the dynamic case the size of the eddy current losses for sheet metal is calculated from:

$$P_w = \frac{\pi^2 \cdot d^2 \cdot B^2 \cdot f^2}{6 \cdot \rho \cdot \gamma \cdot \pi}$$

d: sheet thickness
B: flux density
f: frequency
ρ: el. resistivity
γ: density

i.e. the eddy current losses increase with the square of the excitation frequency. This has a decisive influence on the choice of a material for a particular application. Whereas high permeability alloys are preferred for purely static applications, alloys with higher electrical resistivity are more suitabel for dynamic applications.

A4. Heat Treatment

Apart from the actual alloy, the other decisive criterion in selecting a material for an application is the “right” heat treatment. Table 6 shows the relevant parameters of heat treatment for getting optimized magnetic properties. A variation of these parameters results in a change of the mechanical properties.

The final heat treatment serves exclusively to set the desired magnetic and mechanical properties. Table 6 gives the essential parameters for the final heat treatment which results in optimized magnetic properties. At this stage, we have to point out that we only guarantee the properties of our parts and components provided the final heat treatment is conducted at our works. Sub-contracted annealing can only be recommended in less critical cases.

A5. Corrosion Resistance

The term “corrosion resistance” has to be defined for each individual application. In the majority of cases a corrosion resistance value tested in accordance with DIN IEC 68, part 2-30 is considered adequate. This standard covers general humidity effects which are tested under temperature cycles in the range up to 55 °C over a longer period. It also differentiates between several degrees of severity which are expressed in different holding times and temperatures. With our nickel-iron materials we can achieve a corrosion resistance which is fully effective against ambient influences without any additional coating. Neverthless, please note that alloys with a lower Ni-content may not be exposed to such severe conditions as materials with a nickel content above 45 %. There are two main advantages in this method, on the one hand, lower costs and, on the other, corrosion resistant material without coating is easier to further process*. In contrast, corrosion resistance fulfilling the spray test to DIN 50021 or damp heat to DIN 50018 can only be achieved with coating. Table 8 compares some of the coating methods.

In principle, Duplex-coating can also be applied, e.g. using the DELTA-MAGNI or DACROMET process.

Generally speaking, it cannot be excluded that coating affects the magnetic properties of parts or components. As a result, to meet requirements, the optimized process must be adapted to the individual application.

*Apart from coating processes to inhibit corrosion, it is possible, e.g. with relay parts to coat the contacts with Pd/Ni alloys, hard gold or silver.

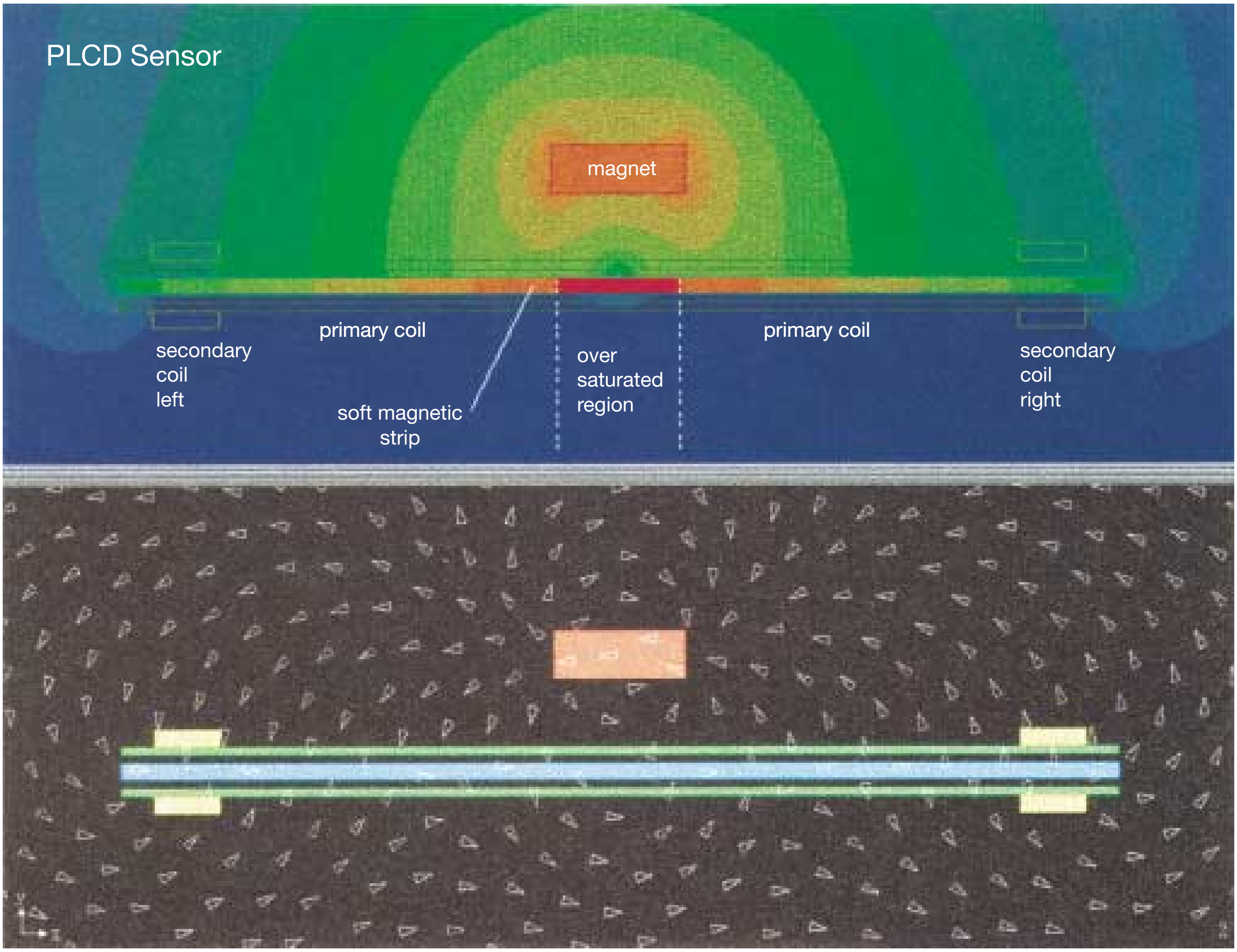
Tab. 10 Parameter for final heat treatment to set optimized magnetic values of soft magnetic alloys

Material	Time h	Temperature °C	Cooling in Furnace to °C
MUMETALL	2-5	1000-1100	200
VACOPERM 100		1150	
VACOPERM BS		1150	
RECOVAC BS	2-5	1000	200*
CRYOPERM 10	2-5	1150	200
PERMENORM 5000 H2/V5			
PERMENORM 5000 S4			
PERMENORM 3601 K5		1100	
MEGAPERM 40L			
THERMOFLUX		650-700	
VACOFLUX 48	10	880	200
VACOFLUX 50	4-10	820	200
VACOFLUX 17	10	850	200
VACODUR 50	2-5	750-820	200

Tab. 11 Surface coating to achieve corrosion resistance in accordance with tests to DIN 50018 und 50021

Surface	Colour	Hardness (nominal values)	Resistance to solvents	Temperatures up to	Corrosion resistance approx.
Tin	silver glossy	HV 20	very good	< 160 °C	very good in humid atmos
Nickel	silver glossy	HV 350	very good	< 350 °C	very good in humid atmos*
Zinc + Yellow chromating	yellow glossy	HV 120	very good	< 80 °C	very good against salt spray
Cathodic electrodip coat	black	up to 4H (pencil hard)	very good	< 130 °C	good in atmos and against salt spray

* for electroless plating, best corrosion protection and very homogeneous coating thickness



VACUUMSCHMELZE offer their customers assistance in establishing the optimum design of magnetic circuits by means of FEM calculations. These, in turn, are based on a performance/specification file which is drawn up in close cooperation with our customers.

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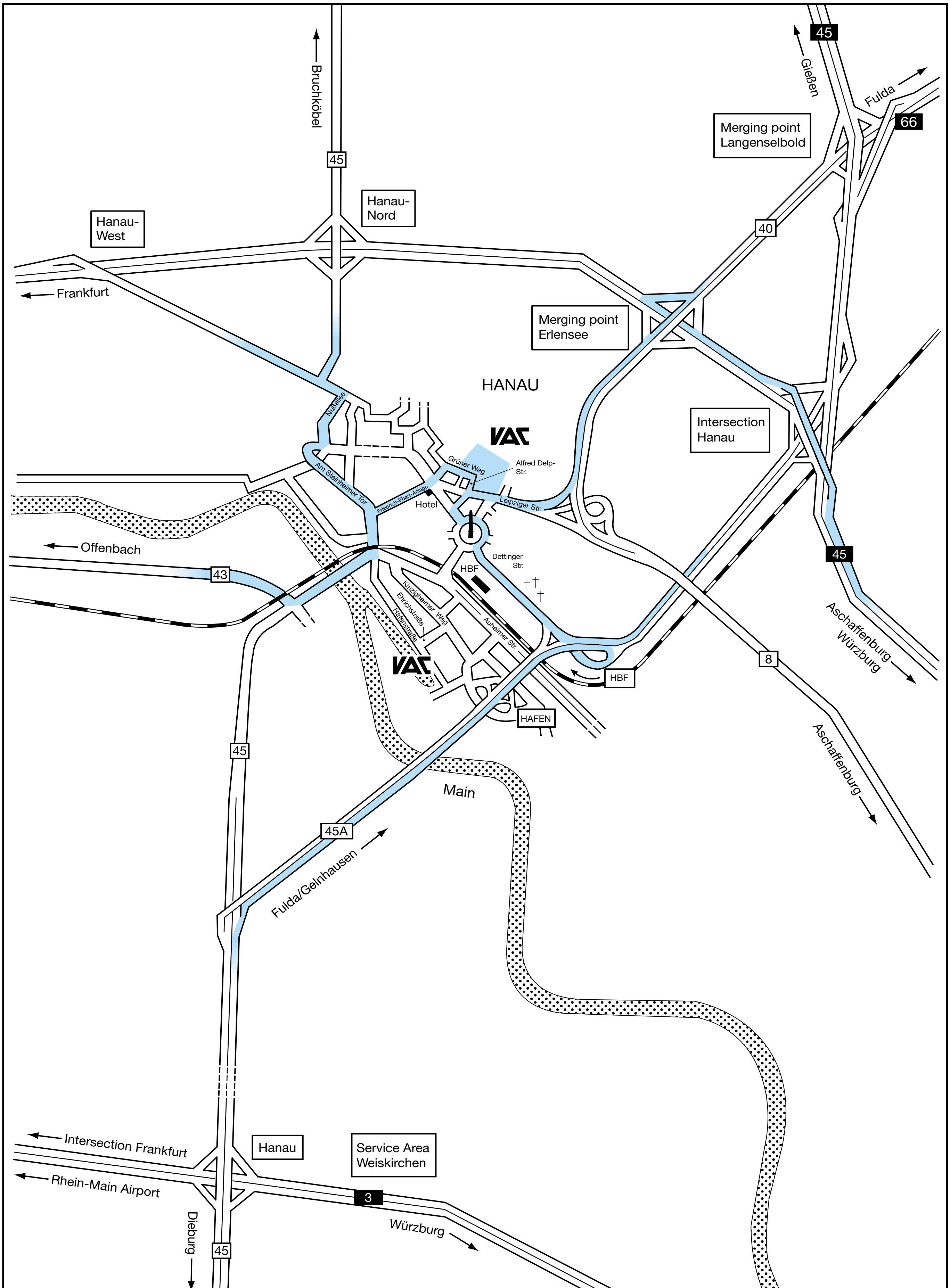

Product Survey

Semi-Finished Products and Parts

Semi-Finished Products
Soft magnetic materials
Ductile permanent magnets
Thermobimetals
Spring alloys
Glass/ceramic-to-metal sealing alloys

Parts
Stamped/bent parts
Magnetic shielding

Lamination Packages

Cores and Components

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

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

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Magnet assemblies

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