SEKELS

MAGNETIC SHIELDING

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Magnetic Shielding

This brochure deals with the shielding of magnetic static fields and low-frequency fields. These shielding tasks employ mainly soft magnetic materials.

Electromagnetic fields can influence electrical equipment, magnetic systems and also living things. Shielding is used to reduce or prevent this interaction. A shielding measure involves enclosing either the origin of the field (interference source) or the disturbed unit (susceptible device) with suitable materials.

While electromagnetic fields with frequencies above approx. 1 kHz can be very well shielded by thin metal foil or meshes made of materials with high electrical conductivity (Faraday cage principle), static or low-frequency electromagnetic fields require more effort. If the frequencies are sufficiently low, the electric and magnetic fields must be considered and shielded independently of each other.

Since in contrast to electrical fields no isolated magnetic charges (monopoles) exist, magnetic flux lines are always self-contained; they have no beginning and no end. Consequently there is no such thing as a magnetic insulator (the principle of superconductivity is excluded here).

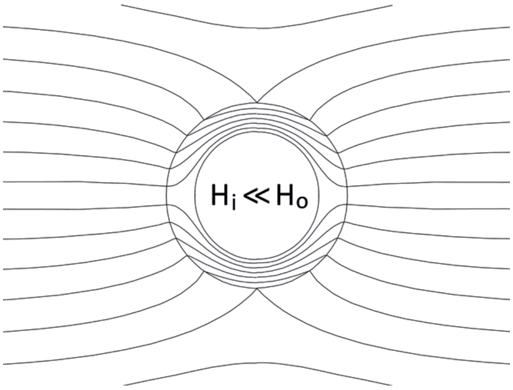


Figure 1: Principle of flux diversion (schematic).

The shielding of low-frequency magnetic fields is based on the principle of “field diversion” by means of magnetically conductive materials. The magnetic flux is kept away from the protected area because it follows the easier path in the magnetic shielding. This creates a field depletion in the shielded area.

Typical applications for magnetic shielding range from static fields (the earth’s magnetic field, industrial DC cables, nuclear spin tomography, etc.) through 16 2/3 Hz (railway technology), network frequencies (50/60 Hz) into the 91 kHz range (e. g. for compliance with occupational safety limits under BGR B11). (Additional) shielding made of materials with high electrical conductivity is used for higher frequencies.

The field strengths that require shielding cover many orders of magnitude from the nT to the mT range. Practically field-free spaces are required for scientific experiments, through very low field strength limits for delicate sensors or electronics, to moderate field strengths to avoid force effects on ferromagnetic objects.

A special case is the “human system”. The trade association rules for health and safety at work lay down limit values for various ranges of exposure in BGR B11. Even if these limit values are considerably higher than those recommended for the general public by the German Federal Immission Control Act, they can often only be complied with by elaborate shielding measures.

Shielding Design

Simple shielding can be carried out using standardised or near-standard products.

Foil made from the materials VITROVAC® 6025 X or MUMETALL® is particularly suitable for initial experiments. As a rule, however, production of shielding will be preceded by a planning and design phase.

Different problems demand different solutions – and this also applies to magnetic shielding.

Among the determining criteria for a suitable shielding solution are:

- Magnetic field force and field flux
- Magnetic field frequency
- Spatial limitations
- Environmental conditions such as temperature, humidity etc.
- Visual impression
- Cost

The theoretical bases for the calculation of shielding factors

Some of the scientific considerations that allow a cohesive description of this subject are more than 100 years old.

Nevertheless, a reading of the "old masters" is of more than just historical interest. The formulae they developed then are still used to work out simple shielding problems today. Strictly speaking, the later scientific literature has added little in terms of new analysis.

However, the theoretical consideration of low-frequency magnetic interference fields is only capable of analysing simple geometrical models. For most real shielding tasks with adapted geometries, openings etc. there is no such thing as an analytical solution.

The shielding effect of a housing depends on the permeability of its material, the form and size of the housing as well as on the thickness of its walls. Analytical calculation provides a solution for only a few forms. Those results can however be used as reference when estimating the shielding effect of other housings.

Shielding factors of cylinders

The formulae given in the following apply under the condition that the shielding has a thin-walled structure. The static shielding effect of a long cylindrical shielding tube in a transverse field can be estimated as follows:

$$S_t = \mu_r \frac{d}{D} + 1$$

S_t: Shielding factor in transverse field
μ_r: Relative material permeability
d: Wall thickness
D: Cylinder diameter

This simple formula neglects effects that arise from covers on the cylinder ends.

For fields along the axis the shielding effect additionally depends on the relationship of length L to diameter D of the tube. As an approximation:

$$S_l = \frac{4N(S_t-1)}{1 + \frac{D}{2L}} + 1$$

S_l: Shielding factor in longitudinal field
L: Length of cylindrical tube
N: Demagnetisation factor.

For cylinders closed at both ends the following approximation applies in the area L/D = 1 to 10:

$$N \approx 0.38(L/D)^{-1,3}$$

The (scalar) shielding factor S is the designation for the relationship of the values of the unshielded field H_o to the remaining residual field H_i inside a magnetic shield:

$$S = \frac{H_o}{H_i}$$

Shielding factors for spheres, cuboids and cubes

For a closed sphere with diameter D and wall thickness d the formula is:

$$S = \frac{4}{3} \mu_r \frac{d}{D} + 1$$

The shielding effect of cubes with edge length a is not constant over the whole interior. S is smaller in the centre than near the walls. An average shielding factor can be estimated with the following formula:

$$S = \frac{4}{5} \mu_r \frac{d}{a} + 1$$

a: Edge length

The formula for spheres can be used for cuboid housings as long as the difference in the three edge lengths is not too great. The spatial diagonal of the cuboid should then be chosen as the “diameter”.

Multiple shielding

To improve the shielding factor using a minimum of material, multiple shielding can be used. The shielding factors of the various individual shells act approximately multiplicatively if the gaps are sufficiently large.

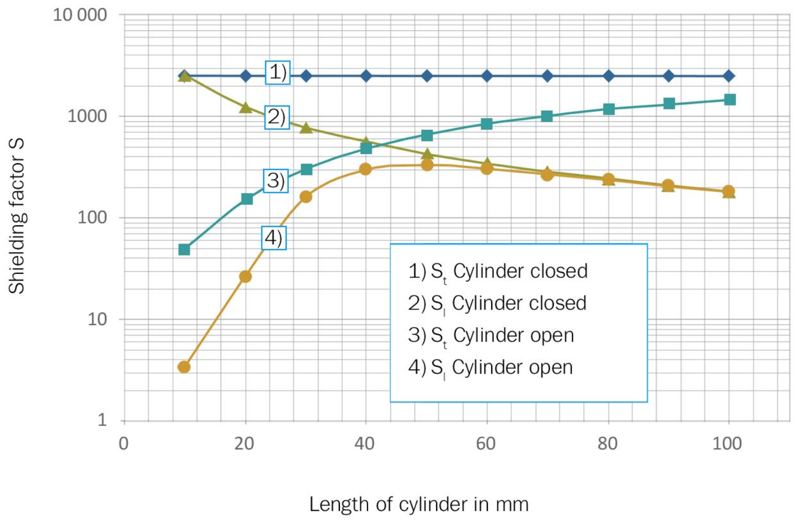


Figure 2: Magnetostatic shielding factors of thin-walled cylinders (D = 10 mm, d = 1 mm), calculated with the stated approximation formulae for μ_r = 25 000 in transverse (S_t) and longitudinal field (S_l).

Influence of openings

In many cases openings have to be provided in shielding for technical reasons. Research on open cylindrical shielding tubes can be used as reference to estimate the influence of these openings on the shielding factor. The outer field can penetrate the interior in one of two ways, either through the sheathing or through the openings. The opening field drops off exponentially according to distance from the opening plane.

These relationships are shown in Figure 2 for closed and open cylinders in the longitudinal and transverse fields.

A qualitative impression of the effects of gaps in shielding is shown in Figure 3. High field strengths are shown in red, while weaker fields are shown (in descending order) through the colours yellow, green and blue. The underlying simulations according to the finite element method (FEM) presuppose two gaps with widths of 10 mm (left above) and 1 mm (left below) in a MUMETALL® box. Even at some distance from the gaps the residual magnetic field inside the shielding is noticeably higher than with closed shielding.

The influence of openings on the shielding effect can be reduced with meshes or better with funnels.

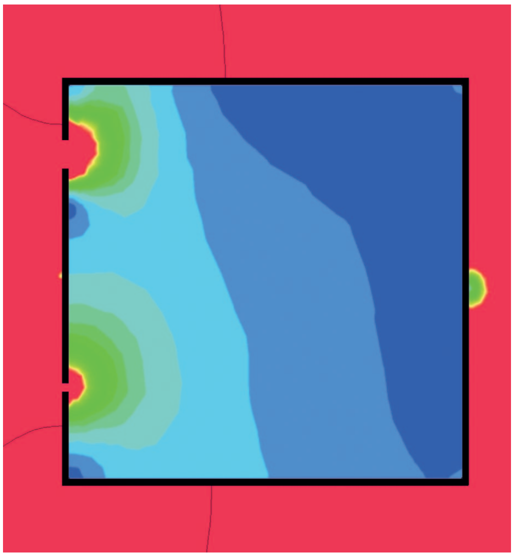


Figure 3: Effect of gaps in a MUMETALL® shielding box on the field strength inside. The external interference source is located in the area to the left (not shown). Red = high field strength, blue = low field strength.

Wide area shielding

Geometry is of great importance for the effectiveness of shielding. The FEM-simulated shielding scenarios in the following diagrams show this clearly. The colour red again indicates a strong magnetic field; the colours yellow, green and blue denote reductions of the magnetic field in that order.

Diagram (A)

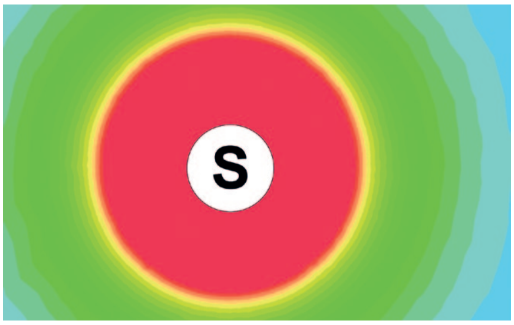
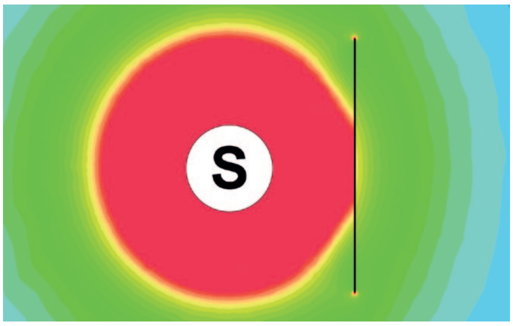


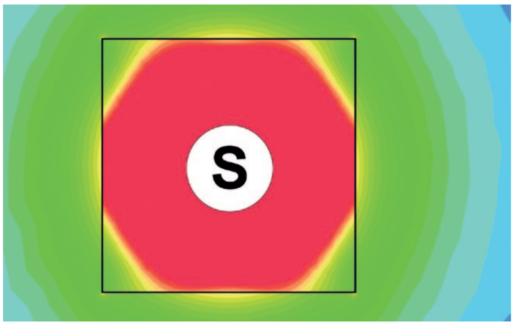
Diagram (A) shows the field strength distribution around an unshielded low frequency magnetic interference source (S).

Diagram (B)



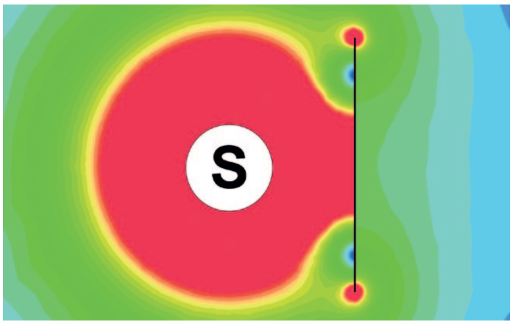
In Diagram (B) a shielding plate 5 m wide and 1 mm thick with a relative permeability of $\mu_r = 500$ was added at a distance of 2.5 m from the source. The field profile is only slightly altered by this.

Diagram (C)



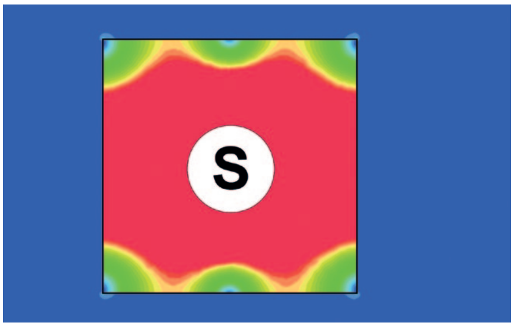
A closed box of the same material as in Diagram (B) around the interference source likewise causes only slight alterations.

Diagram (D)



In Diagram (D) the plate with $\mu_r = 500$ was replaced by one with $\mu_r = 50\,000$. The shielding effect in the area directly adjacent to the shielding plate is markedly higher. At some metres' distance from the plate however the field, as in Diagrams (B) and (C), is hardly reduced. Apart from this, the plate in Diagram (D) causes clearly discernible stray fields at its edges.

Diagram (E)



Only a closed shield of highly permeable material ($\mu_r = 50\,000$) as in Diagram (E) causes a significant reduction in the field strength outside the shielding.

It should be noted that the magnetic field strength falls off even in the areas with identical colour depiction. This is however not discernible here due to the scaling.

Figure 4 (Diagrams A, B, C, D, E): Effect of various types of shielding on a magnetic interference field, simulated by FEM.

The shielding effect of open shielding plates is thus deceptive. Near the plate a good shielding effect can be determined. At greater distances from the plate, however, the field strength is almost identical to that of an unshielded source. The shielding of spaces with a plate between disturber and measuring equipment or people is thus only effective in direct proximity to the shield. On the other hand, an increased stray field must actually be expected at the plate edges.

The shielding effect at some distance from shield plates is largely independent of the material used, no matter whether this is highly permeable MUMETALL® or shielding materials with lower permeability. Permeability plays only a subsidiary role for the effectiveness of an open shield, since geometry dominates the shielding effect in this case (analogously to Figure 2).

The (highly geometry-dependent) shielding factor near shielding plates is usually in the area of 2 - 3 for spatial shielding (corresponding to about 6 - 10 dB); a simply constructed closed shield of MUMETALL® on the other hand can reach shielding factors of over 10 (20 dB). More sophisticated materials and construction can achieve shielding effects of up to 70 000 (approx. 96 dB). Such large structures however require the use of numerous nested MUMETALL® shields.

At all events a consultation is recommendable to find the optimum and most economic solution depending on the problem.

Influence of frequency

In electrically and magnetically closed shielding the shielding effectiveness improves with increasing frequencies. This is caused by eddy currents induced in the material, which create a magnetic counterfield. The skin effect means the induced currents are forced to the surface and the current density becomes less in the interior of the material. At the so-called penetration depth the current density falls off to e^{-1} of the value near the surface.

The penetration depth of the electromagnetic alternating field is calculated at:

$$\delta = \sqrt{\frac{\rho}{\mu_r \mu_0 \pi f}}$$

δ: Penetration depth
ρ: Specific electrical resistance
μ_0: Permeability constant
f: Frequency

This effect comes into force when the penetration depth is smaller than or equal to half the wall thickness. For MUMETALL® at a wall thickness of 1 mm and an initial permeability of 25 000 this begins at approx. 20 Hz.

Calculation by FEM (finite element method)

2D FEM programs not only make very rapid initial estimations possible, but in conjunction with analytical/empirical calculation programs also lead to practicable problem-solving approaches. For more complex problems 3D programs can be used, although they involve considerably increased calculation and high software investment costs. Moreover, results can depend heavily on the definition of particular, sometimes program-specific boundary conditions, the correct selection of which is not always clearly obvious from the concrete problem. It is thus not always possible to assume, even after a successful FEM simulation, that the result arrived at corresponds to reality.

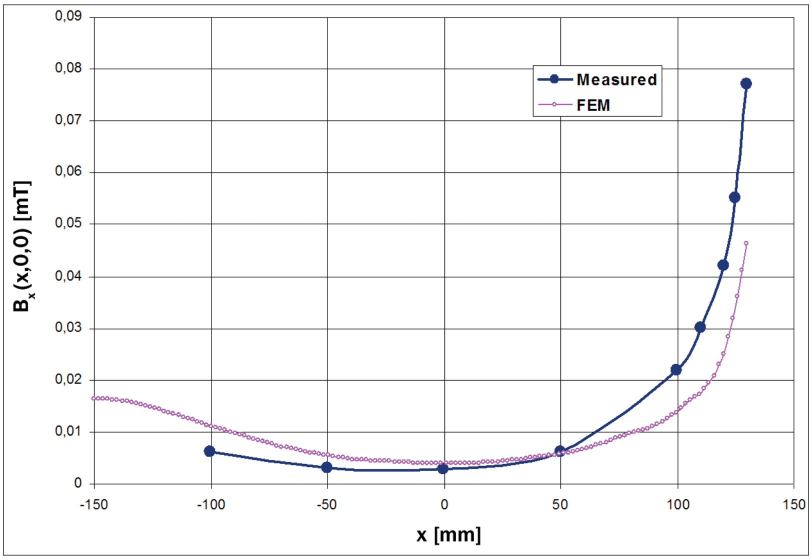


Figure 5: Measured and simulated axial magnetic field profile B_x (x) along the symmetry axis of a MUMETALL® circular cylinder with two rimmed lids. The right lid has a circular opening. The cylinder is coaxially aligned in the centre (x = 0) of a field-generating Helmholtz coil system.

Unfortunately, small details are often the critical points. It is precisely here that real shields often show considerable deviations in their effectiveness from the simulated result.

These deviations are caused for example by insufficient consideration of mechanical tolerances in the shielding or spatial fluctuations in magnetic material properties after final magnetic annealing.

This is particularly true of very large shields. Various mechanical working processes can also lead to differences in the effectiveness of a shield.

Figure 5 shows a comparison of the experimentally determined and FEM-calculated axial field profiles for a MUMETALL® cylinder closed at both ends by a rimmed lid. While in comparative measurements without lids the FEM results are almost identical to the measured values (not shown here), it can be clearly seen that the influence of the lid opening (at x = 150 mm) in the measurement is considerably stronger than expected from the simulation. Thus the measured residual field amplitude B_x near the opening is about double that in the simulation.

Soft Magnetic Alloys

Magnetic shielding is often associated with MUMETALL® (also called Mumetal, MuMetal, µ-metal, etc.), an 80 % NiFe alloy with very high permeability. In the appropriate dimensions and with the mandatory magnetic annealing, MUMETALL® often represents a very good choice. However, some problems have better solutions.

The effectiveness of shielding materials is often judged by the maximum permeability of the soft magnetic substances used. There are other parameters, which are also important and should be considered with regard to efficient and economic shielding.

Thus the strength of the magnetic field plays a large role. The material used may not be driven to saturation by an excessively strong magnetic field, since in this case it has no further shielding power. The frequency of the magnetic field is also important. The higher it is, the less the shielding effect is achieved through magnetic flux conduction (Figure 1), and the more important is the electrical conductivity of the shield material. Other aspects are size, weight, corrosion resistance, processability and many more.

Apart from MUMETALL® we have a large selection of different shielding materials, such as amorphous VITROVAC®, PERMENORM®, SiFe electric sheeting, pure iron, and CRYOPERM® for low temperature applications.

We are experienced in material-specific processing methods, from the production of simple cuts through final magnetic annealing to sophisticated composite systems.

The following table summarises the most important figures for our magnetic shielding materials. Please note that properties depend on size, thickness, form and the parameters of thermal treatment. The following sections give some indications of the possibilities for use of our soft magnetic alloys.

Alloy	**Composition**	**μ_4**	**$H_{c,\,stat}$**	**B_s**	**T_c**	**Density**
		(static)	**[A/m]**	**[T]**	**[°C]**	**[g/cm³]**
MUMETALL®	80 % NiFe	30 000	3	0,8	400	8,7
CRYOPERM® 10	80 % NiFe	*	*	*	430	8,7
PERMENORM® 5000 H2	50 % NiFe	4000	10	1,55	440	8,25
Pure Iron	99,9% Fe	500**	80	2,15	770	7,86
Silicon iron	97 % Fe	1000**	20	2,03	745	7,65
VACOFLUX® 50	50% CoFe	1000**	200	2,35	950	8,12
VITROVAC® 6025X	80% Co	20 000	1	0,55	225	7,7

$\mu_4 = \mu_r$ at 0.4 A/m;
* At 4.2 K or 77 K similar properties to MUMETALL® at room temperature.
** $\mu_4 = \mu_r$ at 4 A/m

MUMETALL®

The nickel-iron alloy MUMETALL® is particularly well suited for applications requiring medium magnetic saturation induction, low magnetic coercive field strength and high permeability. Its high nickel content makes the mechanical working of MUMETALL® not unproblematic. Its magnetic properties however make the material one of the commonest shielding materials. The high nickel content also means that there is usually no need to treat the surface to protect against corrosion.

Among the commonest applications of MUMETALL® are shielding for medium field strengths, multi-layer shielding, actuators and lamination stacks. As well as finished parts, MUMETALL® can be obtained through SEKELS GmbH as sheets, strip stock, final magnetically annealed foil, or rods.

CRYOPERM® 10

With a similar composition to MUMETALL®, but treated with a special initial annealing process, CRYOPERM® 10 is an optimised shielding material for temperatures in the range of liquid nitrogen (approx. 77 K) or liquid helium (approx. 4,2 K). The magnetic properties of CRYOPERM® 10 at low temperatures are comparable to those of MUMETALL® at room temperature (see Figure 6). This makes CRYOPERM® 10 the appropriate material for creating magnetic shielding for superconductors (especially SQUID sensors).

CRYOPERM® 10 is manufactured as a strip in thicknesses from 0,5 - 2,0 mm and widths of approx. 270 - 280 mm.

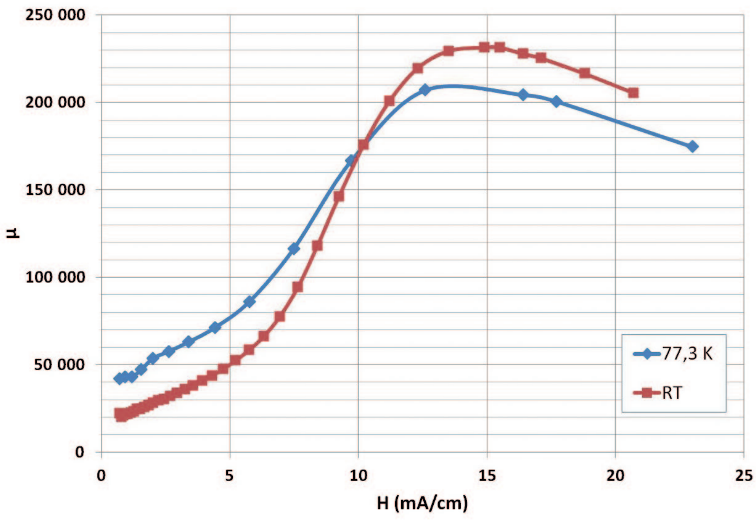


Figure 6: μ(H) characteristic curves of CRYOPERM® 10

PERMENORM® 5000 H2

Compared to MUMETALL®, PERMENORM® 5000 H2 with its higher iron content has a higher saturation magnetisation and is therefore suitable primarily for applications in which stronger magnetic fields play a role. PERMENORM® 5000 H2 too does not usually need surface treatment to protect against corrosion.

The higher iron content also has disadvantages, however. Its dynamic properties (at higher magnetic field frequencies) are not as good as with MUMETALL®, and coercive field strength and therefore core losses are greater.

Apart from actuators and yokes, PERMENORM® 5000 H2 is often used in the area of magnetic shielding for medium and higher field strengths.

PERMENORM® 5000 H2 can be obtained from SEKELS GmbH in the form of sheets, strip stock, rods and finished parts.

Pure Iron

For applications that presuppose high saturation magnetisation but require defined magnetic properties, using a conventional iron substance or steel is not recommendable. Only painstaking processing and annealing can achieve reliable and reproducible magnetic material properties with pure iron.

Pure iron is employed principally in the area of magnetic systems, e. g. in pole shoes, yokes, as a magnetic anchoring mass and in the form of flux conductor plates. Pure iron shielding also makes it possible to control strong magnetic fields. Its high Curie temperature permits applications that would not be realisable with MUMETALL® or PERMENORM® 5000 H2, but coercive field strength and dynamic losses are distinctly higher than with the latter.

Pure iron can be obtained from SEKELS GmbH as finished parts and in the form of sheets and rods. We will also be happy to supply suitable surface coatings for corrosion protection.

VACOFLUX® 50

The cobalt-iron alloy VACOFLUX® 50 is the appropriate alloy when saturation effects must be avoided even under the influence of very strong magnetic fields. VACOFLUX® 50 has the highest saturation magnetisation and the highest Curie temperature of all the soft magnetic materials in the SEKELS range.

The main fields of application for VACOFLUX® 50 lie in the areas of pole shoes, lens systems, relays, motors and generators.

VACOFLUX® 50 can be obtained in the strip and rod delivery forms as well as finished parts.

VITROVAC® 6025 X

The amorphous alloy VITROVAC® 6025 X from VACUUMSCHMELZE GmbH & Co. KG is only obtainable as a thin foil with thicknesses in the range of approx. 20 - 25 µm due to manufacturing conditions (see rapid solidification procedure, Figure 7). It combines excellent soft magnetic properties with an unusual mechanical hardness and flexibility. This means even very tight bending radii can be realised in this field with only very slight impairment of permeability. The fine strip thickness and comparatively very low electric conductivity permit effective shielding even of higher-frequency fields.

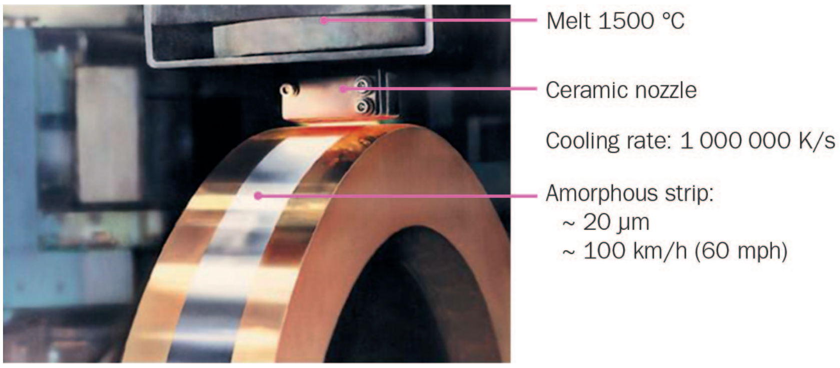
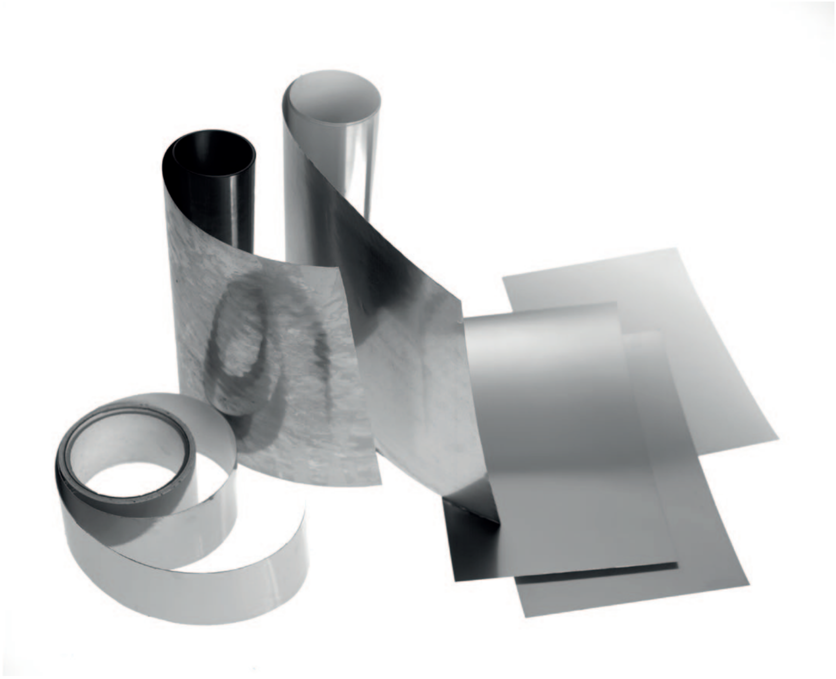


Figure 7: Rapid solidification procedure for manufacturing thin amorphous metallic foil

Delivery Forms

SEKELS GmbH keeps an extensive stock of soft magnetic semifinished products in the delivery forms listed below.



Magnetic shielding foil

Soft magnetic MUMETALL® or VITROVAC® 6025 X foil is suitable in many cases for initial trend experiments to find a reference point for constructive solutions that usually consist of finished shield housings (round plates, cups and the like) of a suitable wall thickness.

We stock MUMETALL® shielding foil by the metre with and without adhesive coating in strip thicknesses of 0,15/0,1/0,05 mm and in various strip widths. We deliver upwards of 1 m and would be happy to send you our price list on request. Or use our online shop to obtain samples.

Final magnetically annealed shielding foil in the amorphous alloy VITROVAC® 6025 X has an unusual combination of mechanical hardness and flexibility with a distinctly higher permeability compared to MUMETALL® foil of the same thickness. Another important property of VITROVAC® 6025 X is its substantial adaptability to elastic deformation. Its main applications are flexible shielded cables with small diameters and rapid and flexible solutions to problems at low field strengths. VITROVAC® 6025 X shielding foil is delivered in standard widths up to 50 mm in a thickness of approx. 0,02 mm determined by manufacturing conditions.

Shielding tubes

Tubes of highly permeable MUMETALL® alloy are ideal for shielding cables susceptible to interference or preventing electrical lines from dispersing. Such problems can arise for example in the cabling of airplanes or ships, in electromedical examinations and in data transfer. In contrast to traditional copper shielding meshes, the shielding effect of the magnetic shielding tubes starts at

static fields already but decreases with increasing frequencies. These flexible tubes wound from profiled strips (similar to VDE 0605) are available in standard nominal diameters from 6 to 32 mm. Threaded tube connections can be supplied as accessories with which the tubes can be connected to housings. With shielding factors around S = 200, MUMETALL® shielding tubes offer secure protection against low-frequency electromagnetic interspersions and dispersions. To achieve a shielding effect with shielding tubes, forward and return conductors must always be laid together in the same tube.

Shielding cups

Shielding cups are usually manufactured by deep drawing or as a welded part. They are then given a final magnetic annealing. This achieves an optimum shielding effect. Please ask us about available or customer-specific measurements.

Shielding plates, sheets and cuts

We stock sheets of MUMETALL® or PERMENORM® 5000 H2 with measurements of 600 - 700 mm x approx. 2500 mm in typical thicknesses of 0,35 - 3 mm. They can be supplied complete or cut according to your specifications. Please note that sheets, cuts and in particular parts made from them must be subjected to a final magnetic thermal treatment, which we will be happy to offer you.

Product	**Thickness/ diameter**	**Width**	**Length**	**Alloy**
	[mm]	**[mm]**	**[mm]**	**Add. Information**
Sheets/cuts	0,35 – 3	< 750*	< 3000*	MUMETALL® PERMENORM® 5000 H2 Pure iron
Foil (crystalline)	0,05 - 0,15	< 640*	On request	MUMETALL® Adhesive coating possible
Foil (amorphous)	approx. 0,02	2,5 - 50	On request	VITROVAC® 6025 X Adhesive coating possible
Rods	1 - 215	–	< 4000*	MUMETALL® VACOFLUX® 50 PERMENORM® 5000 H2 Pure iron
Tubes	6 - 25*	–	On request	MUMETALL®
Cups (round)	35 - 60*	–	35,5 – 62	MUMETALL® Round section
Cups (angular)	–	22,4 – 103,2**	19 – 105	MUMETALL® Rectangular section

* Smaller measurements on request

** Diameter/width

Material Processing and Production Possibilities

Processing the alloys described requires a precise knowledge of their specific properties. As well as the usual metal forming and joining processes we have extensive experience with various different compound systems and adhesive technologies.

The thin, very hard and relatively brittle amorphous VITROVAC® 6025 X foils are not plastically deformable, but can be cut to size with scissors and also stuck on with very tight bending radii without further thermal treatment. Nickeliferous alloys and pure iron "smear" if machine processed, but if the correct processing parameters are observed can be turned, milled, drilled (including with thread), deep drawn, lasered and welded. More critical in this respect is the brittle and coarse-grained alloy VACOFLUX® 50.

The manufacture of more complex shielding principally requires metal cutting, shaping and joining techniques.

The specific properties of the different materials should be taken into account, but also the possible influence of processing on shielding effectiveness. Even the incorrect choice of a welding electrode can, for example, create a magnetic weak point.

Besides the usual machining procedures we have laser facilities for cutting, various welding procedures, stamping and shaping technologies and can manufacture shields by deep drawing. Optimised adhesion procedures are used for manufacturing compound systems. We carry out shaping by sawing, eroding, milling and abrasion.

We have many years of experience in shaping shielding materials for both complex shields and systems.

Thermal Treatment

Mechanical processing of soft magnetic materials diminishes their magnetic properties. Final magnetic annealing is therefore mandatory after mechanical processing.

Final magnetic annealing is essential after shaping. Even unprocessed semifinished products need to undergo this process. On the one hand it reduces the mechanical tensions caused by processing, and on the other optimises magnetic parameters such as crystal anisotropy and magnetostriction. Temperatures range between 800°C und 1150°C depending on the annealing process. This thermal treatment usually takes place under hydrogen.

Even already “soft annealed” semifinished products need final magnetic annealing.

The relief of internal mechanical tensions can lead to “warping”, especially in larger shaped parts or housings. This must be taken into account in design layout and determination of tolerances. Reworking may be possible, but it has a negative influence on shielding effectiveness.

An impression of the importance of final annealing for magnetic properties can be gained from the example of a VACOFLUX® 50 component in Figure 8. It shows the hysteresis curves both with and without final annealing. The flux density without final annealing, even at 10 000 A/m, is lower than the saturation flux density by more than a factor of 2. The differences in coercive field strength are also significant. This has effects for example on hysteresis losses and remanence.

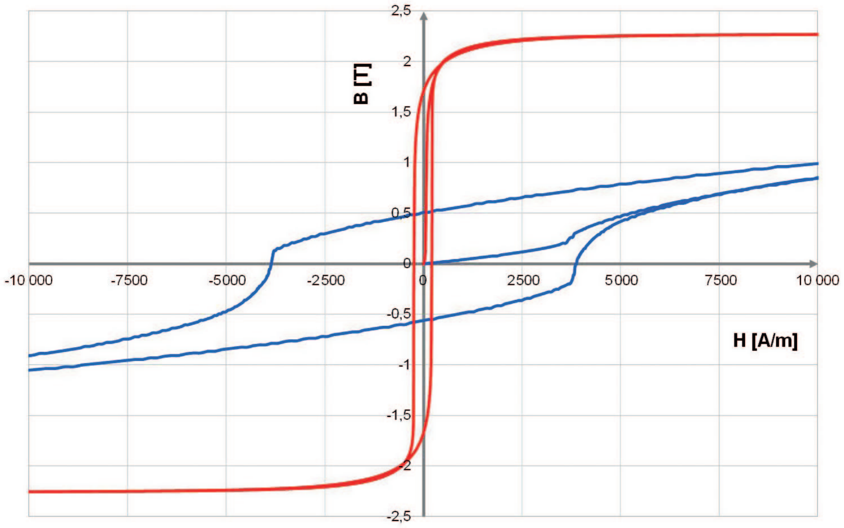


Figure 8: Influence of thermal treatment in VACOFLUX® 50 solid pieces (blue: not annealed, red: final magnetic annealed).

Measuring Systems and Services

Apart from theoretical calculation possibilities, we can also assess shielding experimentally. SEKELS GmbH has a well-equipped laboratory for materials characterisation.

Designing magnetic shielding and magnetic systems solely through simulation tools and calculations can often lead to unpleasant surprises. Even slight changes in a simple geometry (e.g. through openings, air gaps, overlaps, drilling, welding, etc.) can massively alter flux-conducting properties.

Our measuring laboratory can support you in optimising your shielding.

Competences and measuring services

- Magnetic and mechanical quality control of finished shielding
- Measurement of shielding factors as a contractual service
- Location and frequency-dispersed measurement of shielding factors in shields (up to 40 channels)
- On-site measurements for “larger” shielding problems
- Sensor selection to suit all problems (Hall effect, search coil, fluxgate, etc.)
- Optimisation analyses of existing shielding systems
- Demagnetisations (electromagnetic or thermal)
- Interference measurement of electronic equipment by impressed magnetic fields
- Materials characterisation by hysteresis measurement
- Measurement of coercive field strength
- Determination of core losses

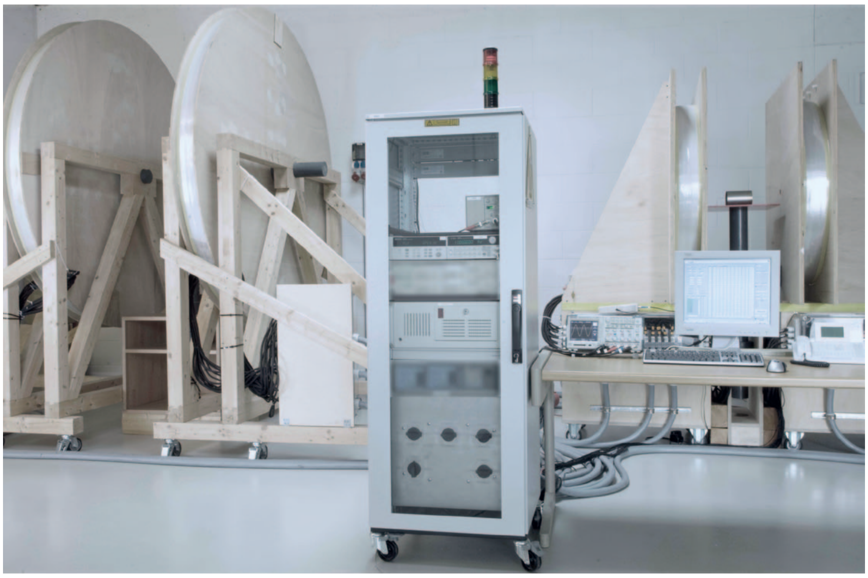


Figure 9: Helmholtz measuring station for the measurement of shielding factors

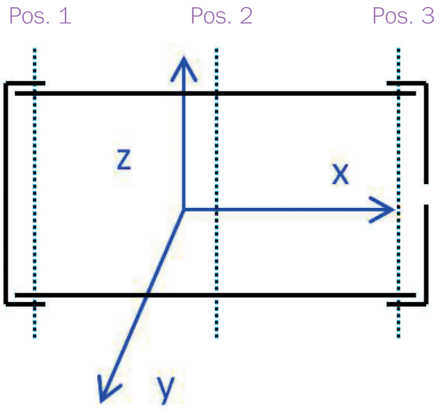
SEKELS GmbH has two Helmholtz coil pairs with diameters of 1 m and 2 m for impressing external magnetic fields. The field properties thus achievable can be seen in the table below.

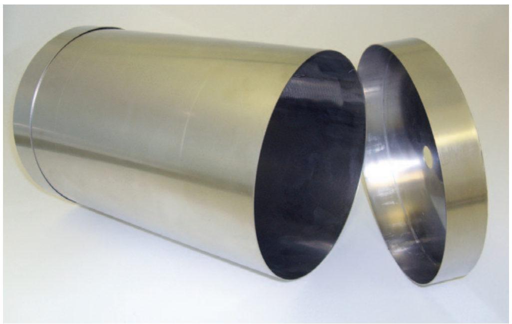
As well as quick routine measurements with few measuring points, we can also carry out repeating tests with a high spatial resolution, which can additionally cover several frequencies and field amplitudes. This is necessary for example to gain an exact picture of (residual) field distribution particularly at critical points.

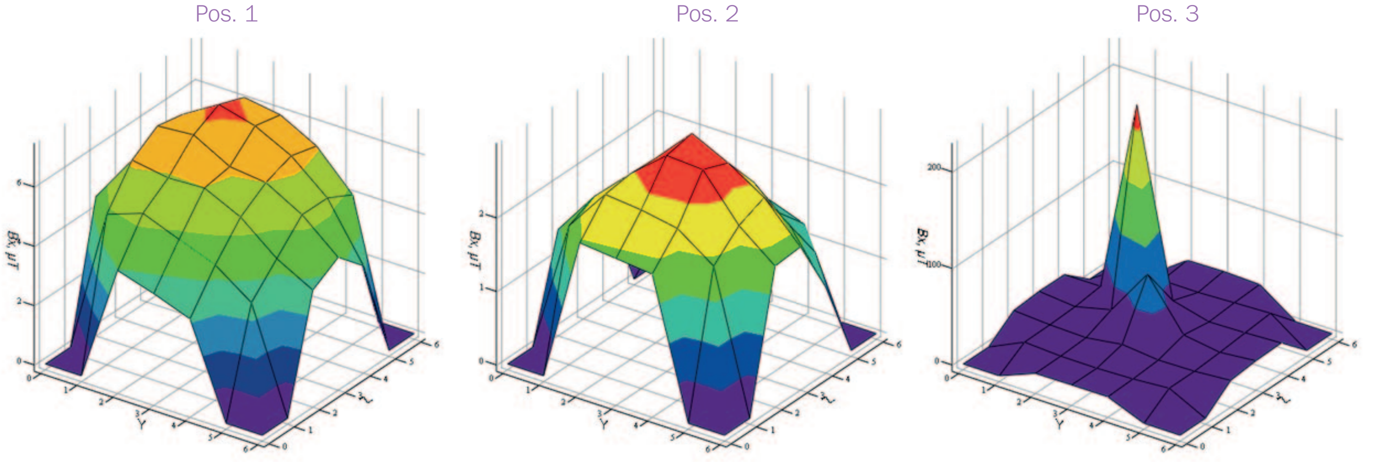
Figure 10 shows the field distribution in a cylindrical MUMETALL® shield with a hole in the right side cover.

Coil system	1000 mm	2000 mm
Frequency range	DC and 0,1 – 2000 Hz	DC and 0,1 – 2000 Hz
Amplitude range	7,74 mT (DC) – 0,08 mT (2000 Hz)	3,34 mT (DC) – 0,05 mT (2000 Hz)

Figure 10: Spatial field distribution in a shielding cylinder with an opening in the cover. Field strengths can be represented according to both magnitude and direction. The vertical axis is scaled differently in each case.







Quality Assurance

The effectiveness of shielding measures is determined at the latest when they are used. To avoid unpleasant surprises here, we offer the measurement of shielding factors as a final test.

Our measurement facilities allow a practical final test in many cases. This may be, for example, the measuring of the shielding factor at one or several points in the shield. The external interference fields are created with the aid of our Helmholtz coils (Figure 9).

An alternative to this is residual field measurement on site, if for example, the operating conditions cannot be reproduced in the laboratory.

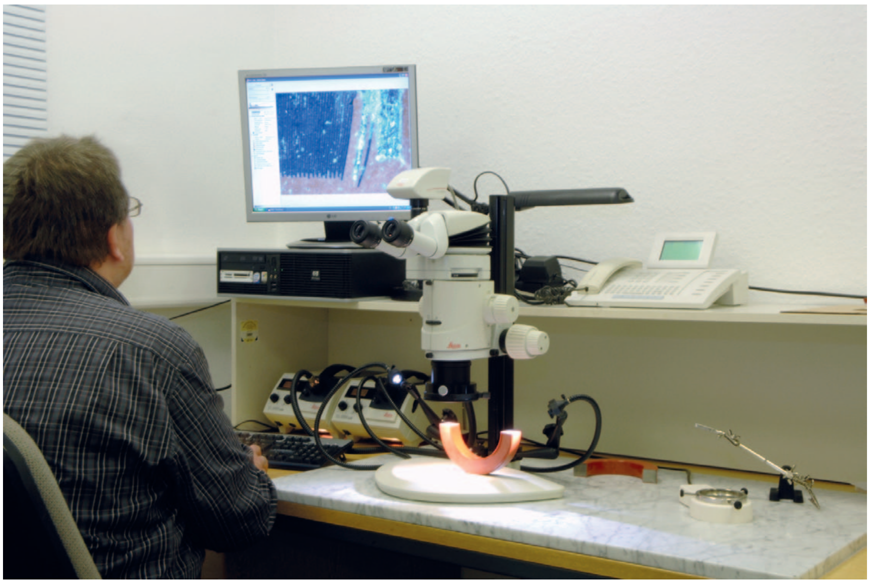


Figure 11: Optical microscope for quality assurance examinations

An important factor is the checking of mechanical tolerances particularly in larger shields after thermal treatment. SEKELS has an in-house measuring table available for this with a direct CAD link for 3D measurements.

Accompanying quality assurance measures are likewise routinely implemented, such as material tests in the annealing of shield housings to ensure the required material properties (coercive field strength, permeability).

The initial state of materials, e. g. for shaping processes is determined by a hardness test. Tensile strength can also be ascertained if required.

Examinations by optical microscope provide valuable indications for fault analyses

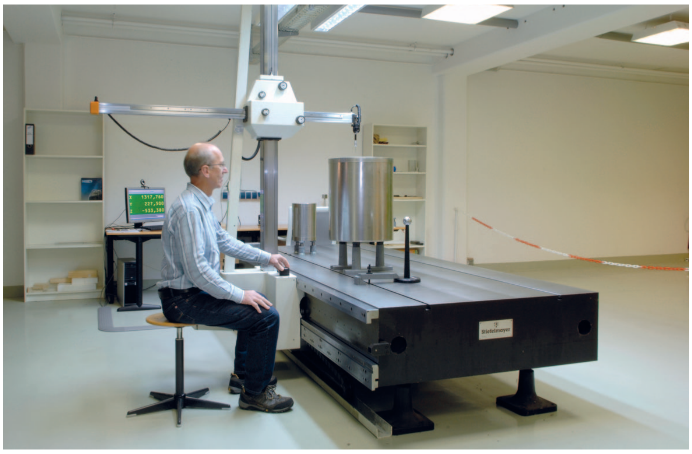


Figure 12: 3D measuring table for mechanical measurement

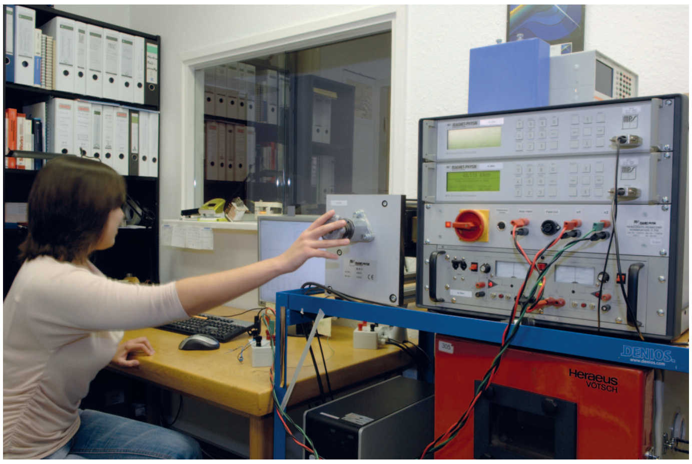


Figure 14: Measuring cabinet for temperature change and humidity tests.

Figure 13: Measuring station for hysteresis measurements (static/dynamic), including at various temperatures.

Terms and Definitions

Below is a summary of formula symbols used, with a short description.

Formula symbol	Unit	Description
B	T (= Vs/m²)	Magnetic flux density (induction) in tesla (1 T = 10 000 Gauss = 1000 mT = 1 000 000 µT = 1 000 000 000 nT) $B = \mu_r \mu_0 H$ in a magnetic material or $B = \mu_0 H$ in air
H	A/m	Magnetic field strength (1 A/m = 4π/1000 Oerstedt)
μ_r		Relative magnetic permeability
μ_0	Vs/Am	Magnetic field constant = $4\pi 10^{-7}$
S, S_t, S_l		Shielding factor (general, transverse, longitudinal) (= H_o/H_i or B_o/B_i)
H_o	A/m	Magnitude of magnetic field strength outside shielding
H_i	A/m	Magnitude of magnetic field strength inside shielding
B_o	T	Magnitude of magnetic flux density outside shielding
B_i	T	Magnitude of magnetic flux density inside shielding
N		Demagnetisation factor, takes account of geometry-dependent counterfield through the stray field in a magnetic body through its magnetisation
B_s	T	Saturation induction of a magnetic material (all magnetic moments are aligned parallel to the applied field)
H_c	A/m	Coercive field strength, corresponds to counterfield necessary after magnetisation to reset flux density in material back to zero value
T_c	°C	Curie temperature (disappearance of spontaneous magnetisation through thermal movement)
λ_s	ppm	Saturation magnetostriction (relative volume change)
ρ	Ωm	Specific electrical resistance
f	Hz	Frequency
δ	m	Penetration depth of electromagnetic alternating field
d	m	Plate thickness
D	m	Diameter
L	m	Length of a cylinder
a	m	Edge length of a cube

About Us

SEKELS GmbH develops, produces and deals in technical products in the field of magnetism.

With approx. 25 employees (more than half of them physicists and engineers), SEKELS currently supplies over 500 customers worldwide.

As specialist dealer in VACUUMSCHMELZE GmbH & Co. KG product lines, SEKELS offers its customers both an extensive inventory and comprehensive technical advice.

SEKELS develops, constructs and produces customer-specific solutions of laminations and lamination stacks, magnetic shields and shielding systems, inductive components and magnet systems - from prototype to mass-produced supply.

We offer:

- Magnetic shielding in MUMETALL®, PERMENORM®, CRYOPERM®, VACOFLUX®, TRAFOPERM® and pure iron.
- Semifinished products in MUMETALL®, PERMENORM®, CRYOPERM®, VACOFLUX®, TRAFOPERM® and pure iron.
- Qualified advance consultation
- Design and calculation of magnetic shielding, FEM simulations, measurements
- An extensive inventory of semifinished products, cores and components
- Amorphous and nanocrystalline toroidal cores (VITROPERM®, VITROVAC®)
- Chokes, current sensors, power and pulse transformers
- Laminations and lamination stacks
- VACODYM®, VACOMAX® permanent magnets
- Material processing, component and system production
- Magnetic thermal treatments
- Material examinations, basic development, systems development
- Measurement and development services

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