# Magnifer® 7904

Material Data Sheet No. 9004

**Edition of August 2000**

## Soft-magnetic alloy


A company of
Krupp Thyssen
Stainless

**Krupp VDM**

ThyssenKrupp

# Magnifer® 7904

Magnifer 7904 is a soft magnetic nickel-iron alloy with about 80 % nickel, 4.2 - 5.2 % molybdenum, a saturation induction of approx. 0.8 T, the highest technically obtainable permeability, and a very low coercive force.

Typical applications of Magnifer 7904 are:

- Toroidal tape-wound cores – integrating current transformers for earth-leakage circuit breakers, instrument transformers, inductive components
- Laminations – transformer laminations, transformer cores for modems with special transformer characteristics, stamped rings for electronic earth-leakage circuit breakers
- Shieldings – to protect against magnetic interference, in the form of shielding films, shielding cans and spatial shielding arrangements
- Stepping motors – stamped parts for analogue watch mechanisms
- Relay parts – components for electromagnetic relays
- Other solid components – with a low coercive force

## Standards and specifications

| | | |
|---|---|---|
| DIN 17745 | Material no. 2.4545 | NiFe15Mo |
| DIN 740 | E11 | |
| DIN 17405 | R Ni 5, R Ni 2 | |
| DIN 41301 | E3, E4 | |
| DIN IEC 404 | E11 | |
| ASTM A753-97 | Alloy 4 | |
| MIL-N-14411C (MR) | Alloy 1 | |
| JIS C 2531 | PC | |

*Table 1– Standards and specifications for Magnifer 7904*

## Physical properties

| | | |
|---|---|---|
| Saturation induction | 0.8 T | 8000 G |
| Curie temperature | 410 °C | 830 °F |
| Saturation magnetostriction | + 1 · $10^{-6}$ | +1 · $10^{-6}$ |
| Electrical resistivity | 55 µΩcm | 349 ohm circ mil/ft |
| Relative density | 8.7 g/$cm^3$ | 0.316 lb/$in^3$ |
| Thermal conductivity | 0.32 W/cm K | 134 (BTU in)/(ft hr °F) |
| Mean coefficient of thermal expansion (20–100 °C) | 12 x $10^{-6}$/K | 7 x $10^{-6}$/°F |

*Table 2– Physical properties of Magnifer 7904, typical values*

## Mechanical properties

| | cold rolled | deep drawable, soft annealed*) | after final anneal |
|---|---|---|---|
| Tensile strength Rm (N/$mm^2$) | 1100 | 630 | 450 |
| Yield stress Rp0.2 (N/$mm^2$) | 900 | 260 | 170 |
| Elongation A5 (%) | 4 | 40 | 30 |
| Hardness HV5 | 335 | 130–170 | 90–120 |

*) The required condition, deep drawable or soft annealed, should be stated when ordering

*Table 3 – Mechanical properties of Magnifer 7904, typical values*

**Chemical composition**

| Material | Ni | Mo | Mn | Si | C | Fe | Applications |
|---|---|---|---|---|---|---|---|
| Magnifer 7904 | 80 | 4.9 | 0.5 | 0.3 | 0.02 | balance | shieldings, laminations, toroidal tape-wound cores, stamped parts |
| Magnifer 7904 nMo | 80 | 4.3 | 0.5 | 0.3 | 0.02 | balance | shieldings, laminations |
| Magnifer 7904 hMo | 80 | 5.1 | 0.5 | 0.3 | 0.02 | balance | toroidal tape-wound cores, laminations |

*Table 4 – Chemical composition (%) of Magnifer 7904 and variants, typical values*

**General magnetic properties**

The magnetic properties of Magnifer 7904 can be varied by appropriate heat treatments. In toroidal tape-wound cores, the initial permeability μ4 can reach 160 000 to 380 000 and the maximum permeability 320 000 to 480 000 at a frequency of 50 Hz and a strip thickness of 0.065 mm. The static coercive force is then typically Hc ≤ 1 A/m. The hysteresis loop can be set to curved, rectangular or flat.

Figure 1 shows typical induction/field strength curves for Magnifer 7904 for 0 Hz and 50 Hz, measured using toroidal tape-wound cores of 0.065 mm strip thickness. Figures 2, 3 and 4 show typical induction/field strength curves for Magnifer 7904 for various frequencies, measured using toroidal tape-wound cores of 0.065, 0.10 and 0.35 mm strip thickness. The initial permeability μ4 is shown in relation to frequency in Fig. 5 (impedance permeability) and Fig. 6 (inductance permeability).

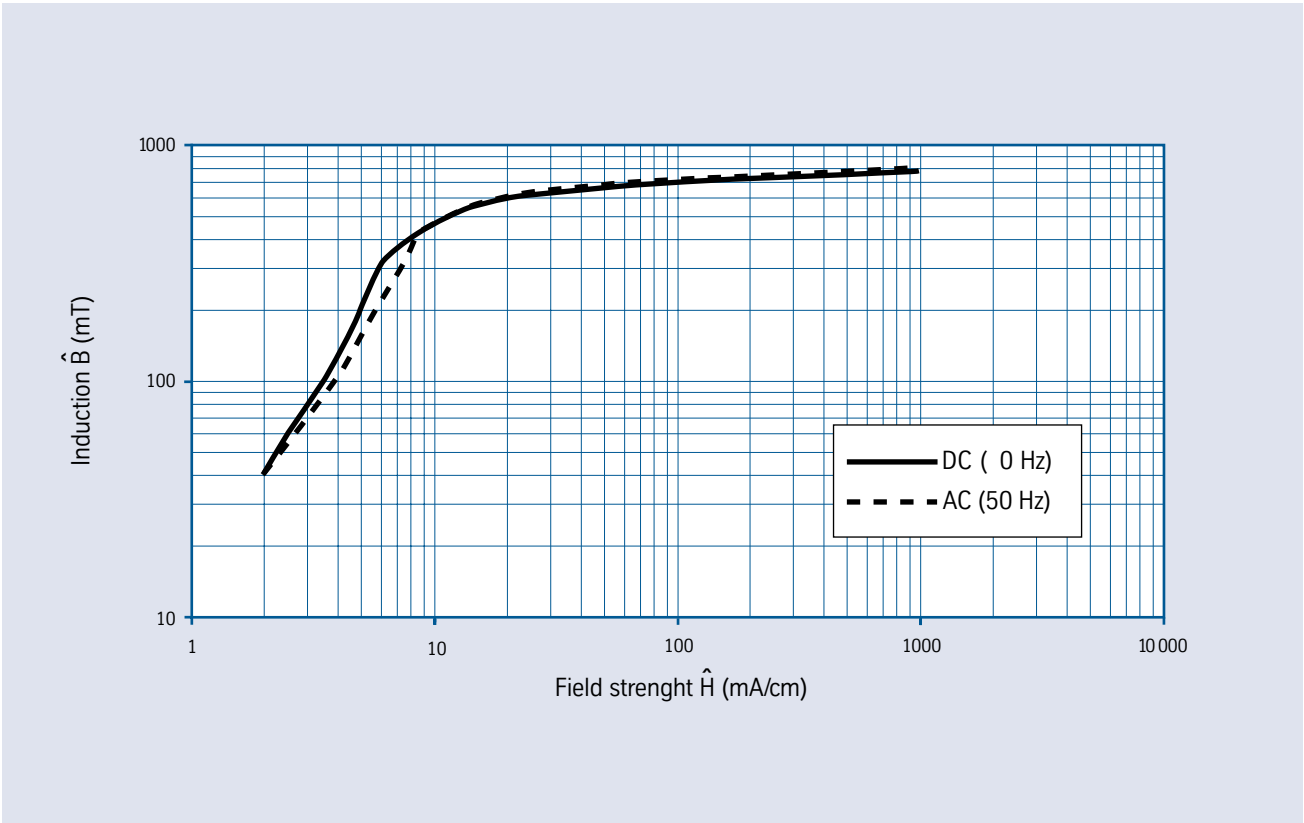


*Fig. 1 - Typical induction/field strength curves for Magnifer 7904, measured using toroidal tape-wound cores of 0.065 mm strip thickness.*

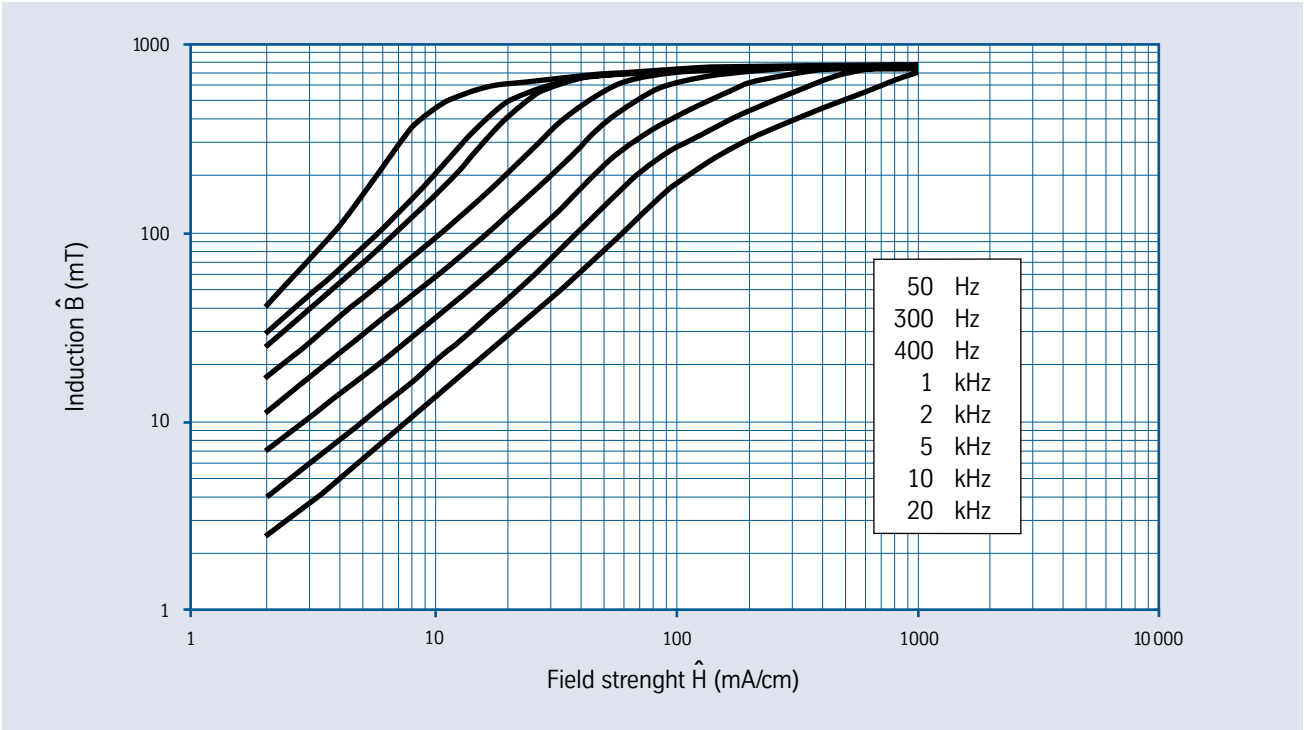


*Fig. 2 - Typical induction/field strength curves for Magnifer 7904, measured using toroidal tape-wound cores of 0.065 mm strip thickness.*

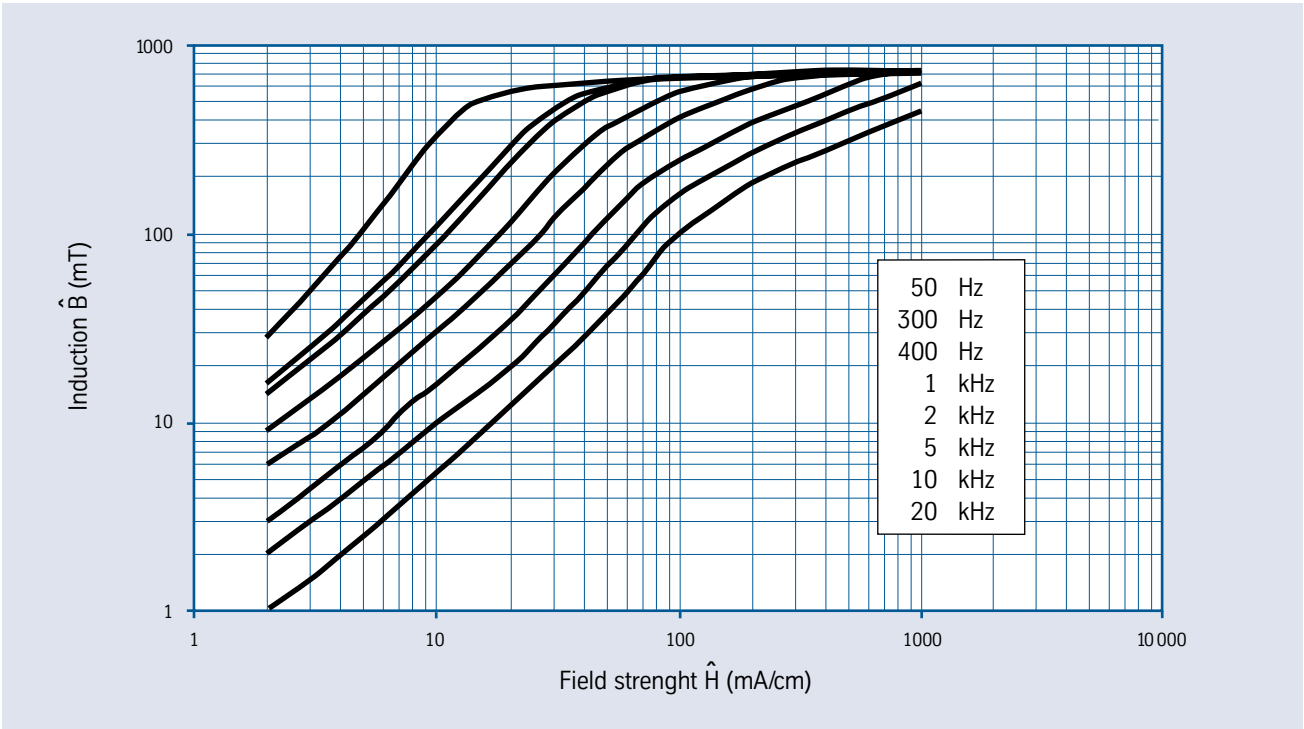


*Fig. 3 - Typical induction/field strength curves for Magnifer 7904, measured using toroidal tape-wound cores of 0.10 mm strip thickness.*

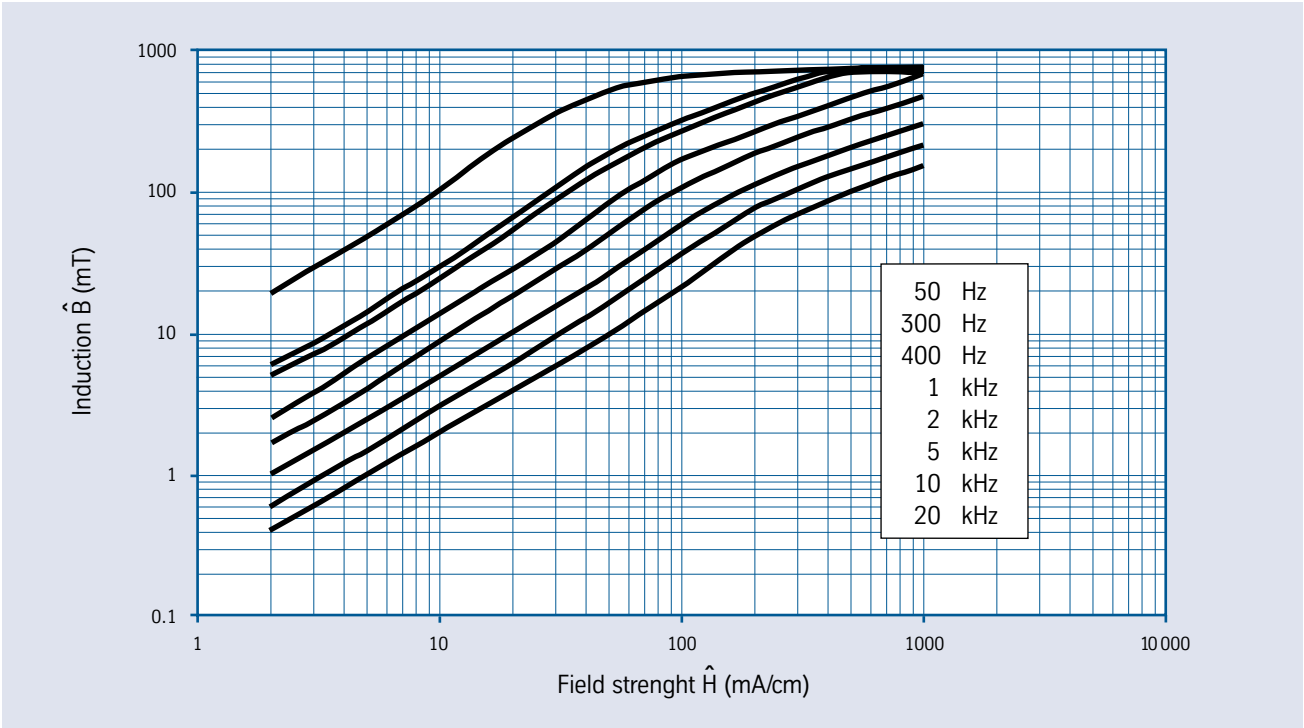


*Fig. 4 - Typical induction/field strength curves for Magnifer 7904, measured using toroidal tape-wound cores of 0.35 mm strip thickness.*

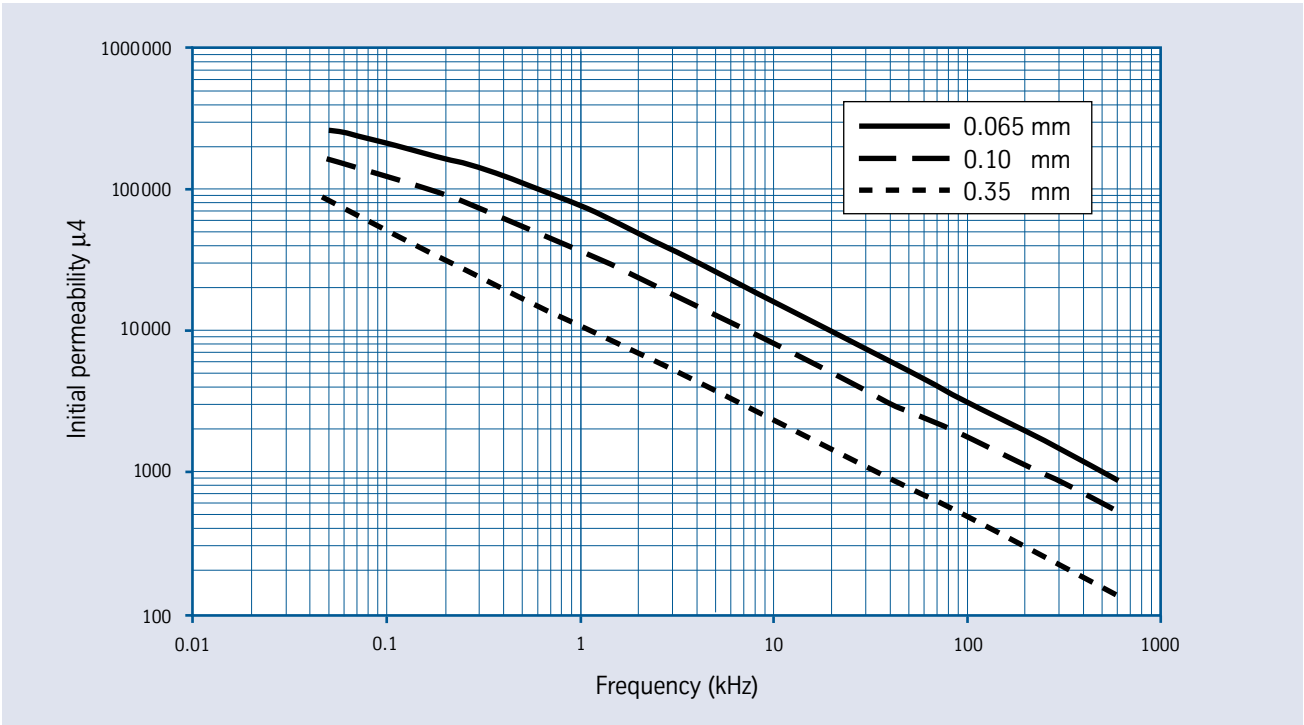


*Fig. 5 - Initial permeability µ4 of Magnifer 7904 in relation to frequency, measured using toroidal tape-wound cores of various strip thicknesses.*

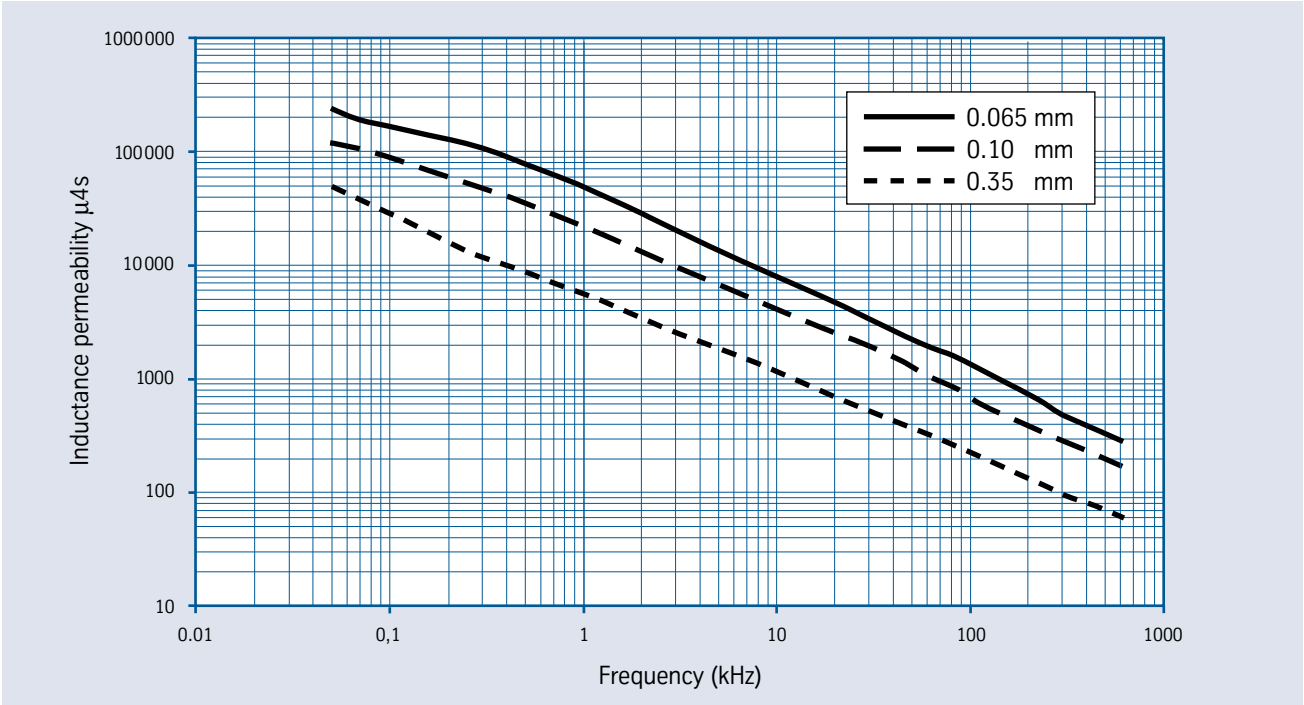


*Fig. 6 - Inductance permeability µ4s of Magnifer 7904 in relation to frequency, measured using toroidal tape-wound cores of various strip thicknesses.*

## Application-specific magnetic properties

### Toroidal tape-wound cores

After appropriate final annealing, at 50 Hz the initial permeability lies between 320 000 and 480 000 at a strip thickness of 0.065 mm. The static coercive force is then typically $H_c < 0.5$ A/m.

Besides Magnifer 7904, the variant Magnifer 7904 hMo is used, especially for very demanding requirements.

The magnetic properties of Magnifer 7904 depend on the final heat treatment. Good annealing conditions produce a definite improvement in the attainable levels of permeability and a considerable improvement in the coercive force. Controlled heat treatment enables the shape of the hysteresis loop and the relationship of the permeability to temperature to be adjusted (Fig. 7 and 8). The result is the following special grades of Magnifer 7904:

### Magnifer 7904 F

Grade with a flat hysteresis loop. The shape of the hysteresis loop may be modified from the usual curve to a very flat pattern by controlled heat treatment with and without a magnetic field. For most applications, the variation of induction B and of induction ΔB is of interest. Magnifer 7904 F is produced in three application-oriented conditions – F15, F25 and F50 – in the form of toroidal tape-wound cores, the increasing indices denoting an increasing induction ΔB. Examples for the alloy conditions F15, F25 and F50 are shown in Figures 9 to 11. For special applications, the shape of the hysteresis loop can be adapted to lie between those of F15 and F50.

### Magnifer 7904 TK

Grade with low temperature coefficients for induction between −25 °C and +80 °C.

Limit values for individual grades are listed in Tables 5 and 6.

Figures 9 - 16 illustrate the magnetic properties of Magnifer 7904, Magnifer 7904 F and Magnifer 7904 TK in relation to various parameters, so that the user may select the most important data required for dimensioning. The properties in question are typical properties of the alloy.

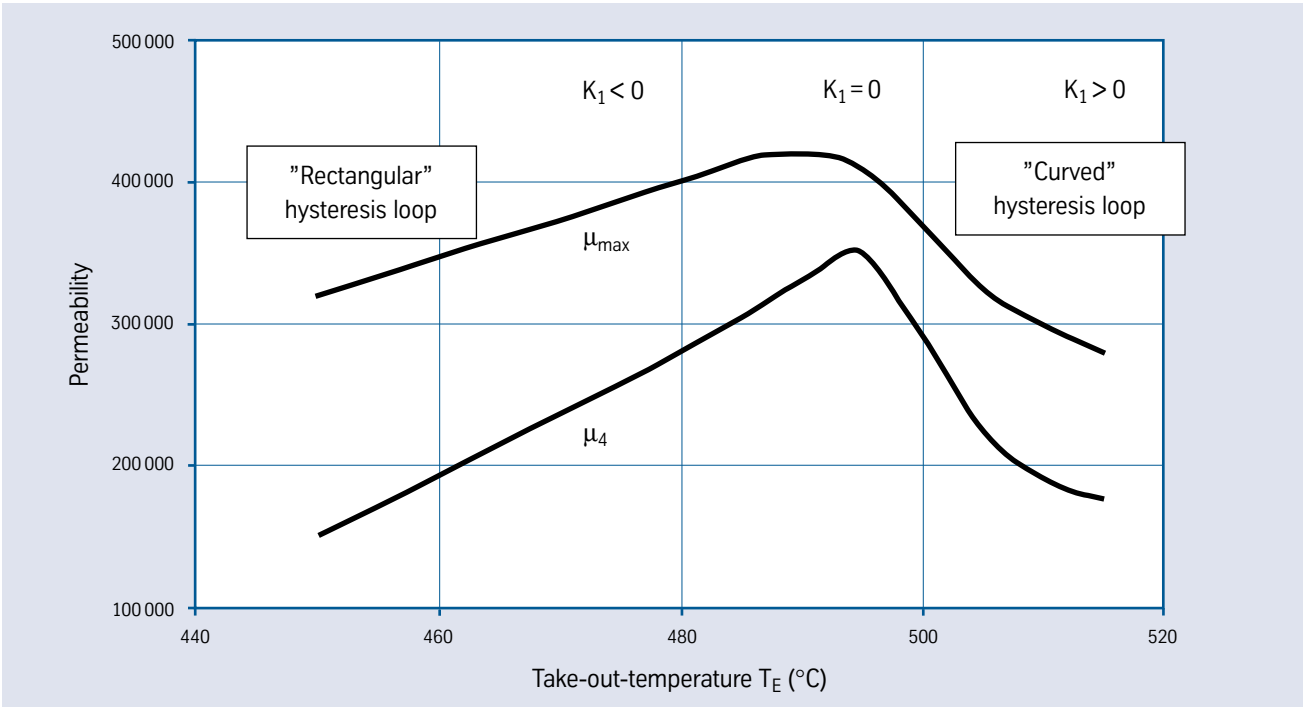


*Fig. 7 - Initial permeability μ4 and maximum permeability μmax (50 Hz) as a function of the take-out temperature for Magnifer 7904, measured using toroidal tape-wound cores of 0.065 mm strip thickness after annealing treatment for four hours at 1200 °C followed by cooling at a rate of 0.9 K/min up to take-out.*

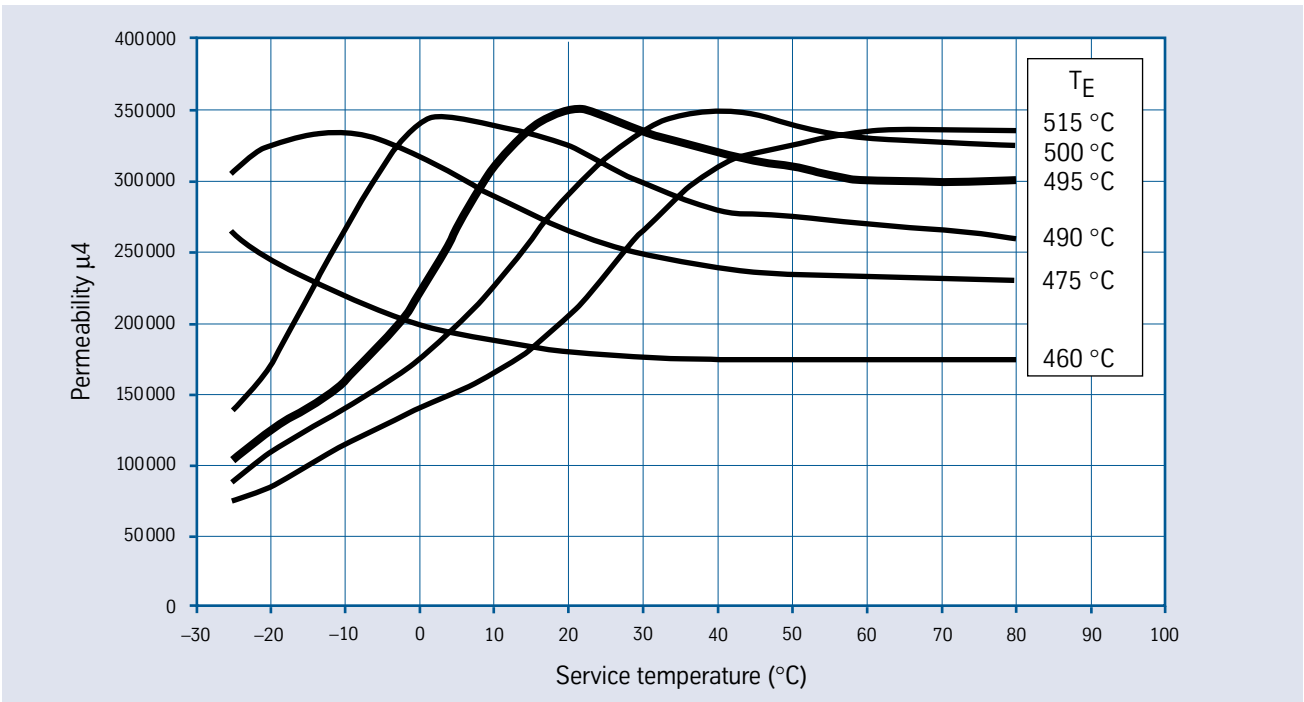


*Fig. 8 - Initial permeability μ4 (50 Hz) as a function of the service temperature for Magnifer 7904, measured using toroidal tape-wound cores of 0.065 mm strip thickness after annealing treatment for four hours at 1200 °C followed by cooling at a rate of 0.9 K/min up to take-out. The curves for various take-out temperatures (followed by rapid cooling) are plotted as parameters.*

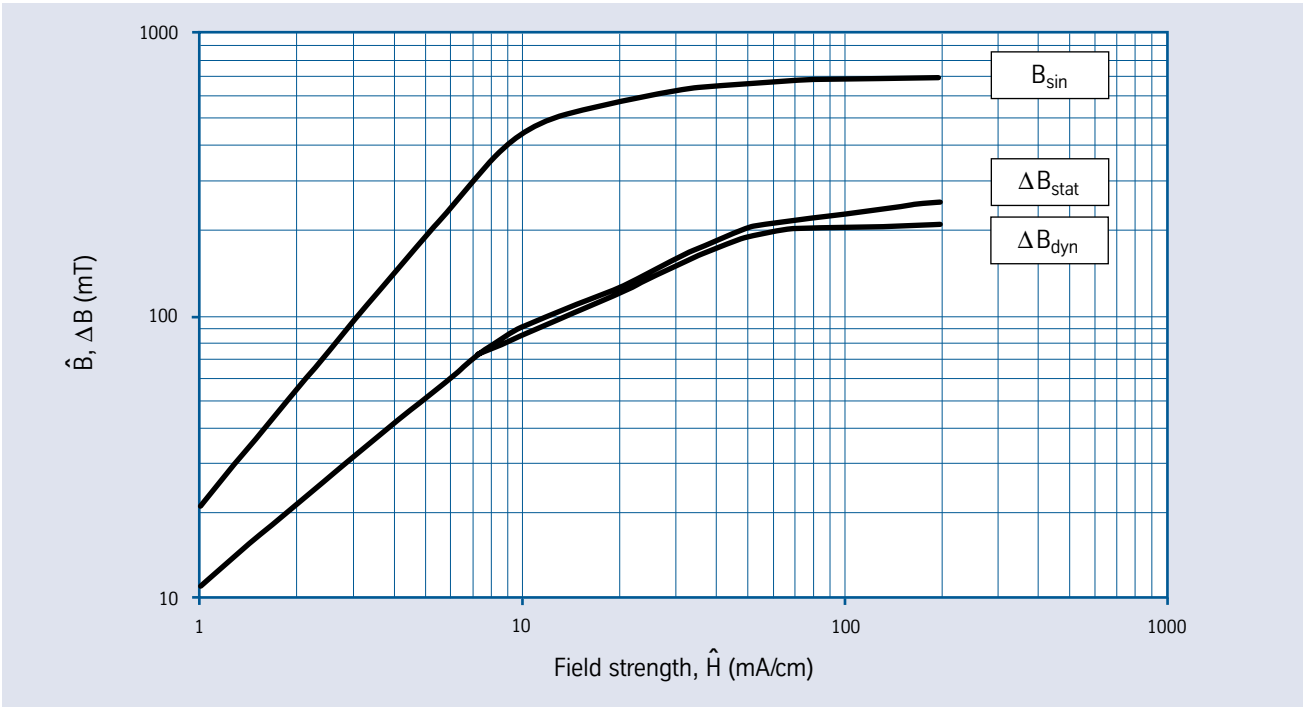


*Fig. 9 - Typical curves of induction $\hat{B}$ and $\Delta B$ (50 Hz) in relation to field strength for Magnifer 7904 F15, measured using toroidal tape-wound cores of 0.065 mm strip thickness. The curves for $\Delta B_{stat}$ and $\Delta B_{dyn}$ were recorded in the pre-magnetized state.*

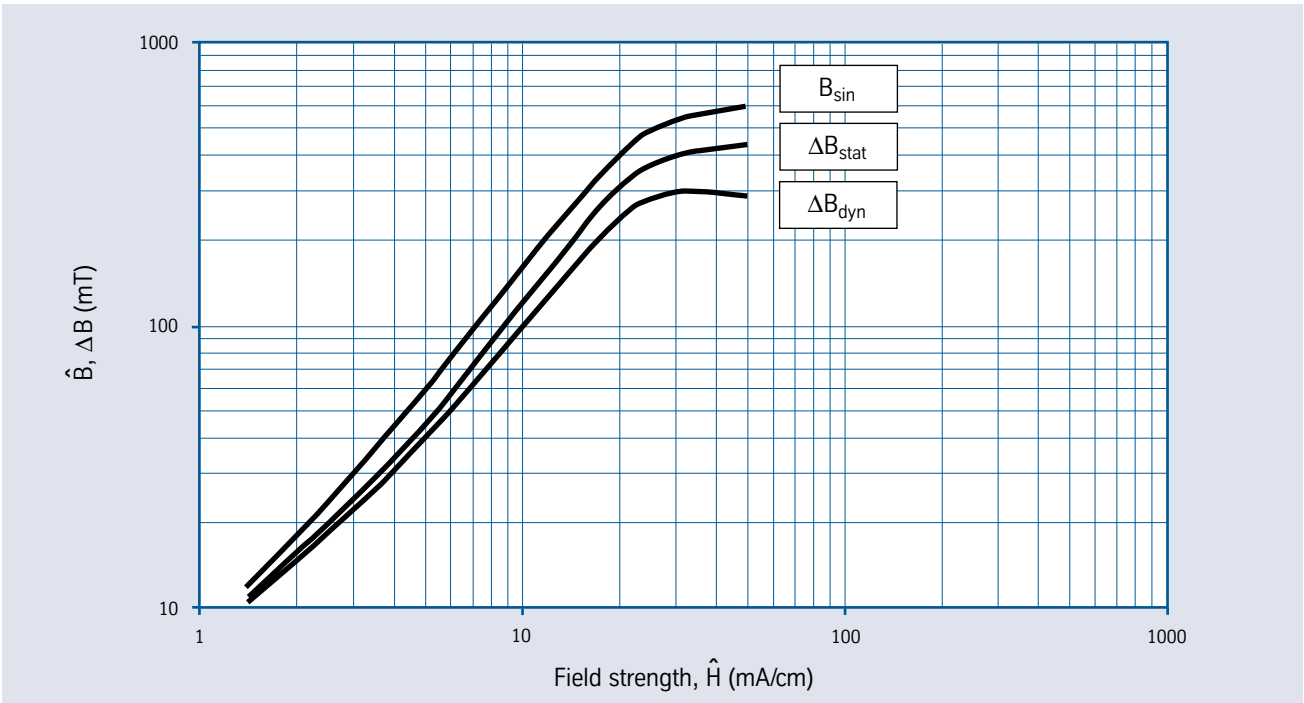


*Fig. 10 - Typical curves of induction $\hat{B}$ and $\Delta B$ (50 Hz) in relation to field strength for Magnifer 7904 F25, measured using toroidal tape-wound cores of 0.065 mm strip thickness.*

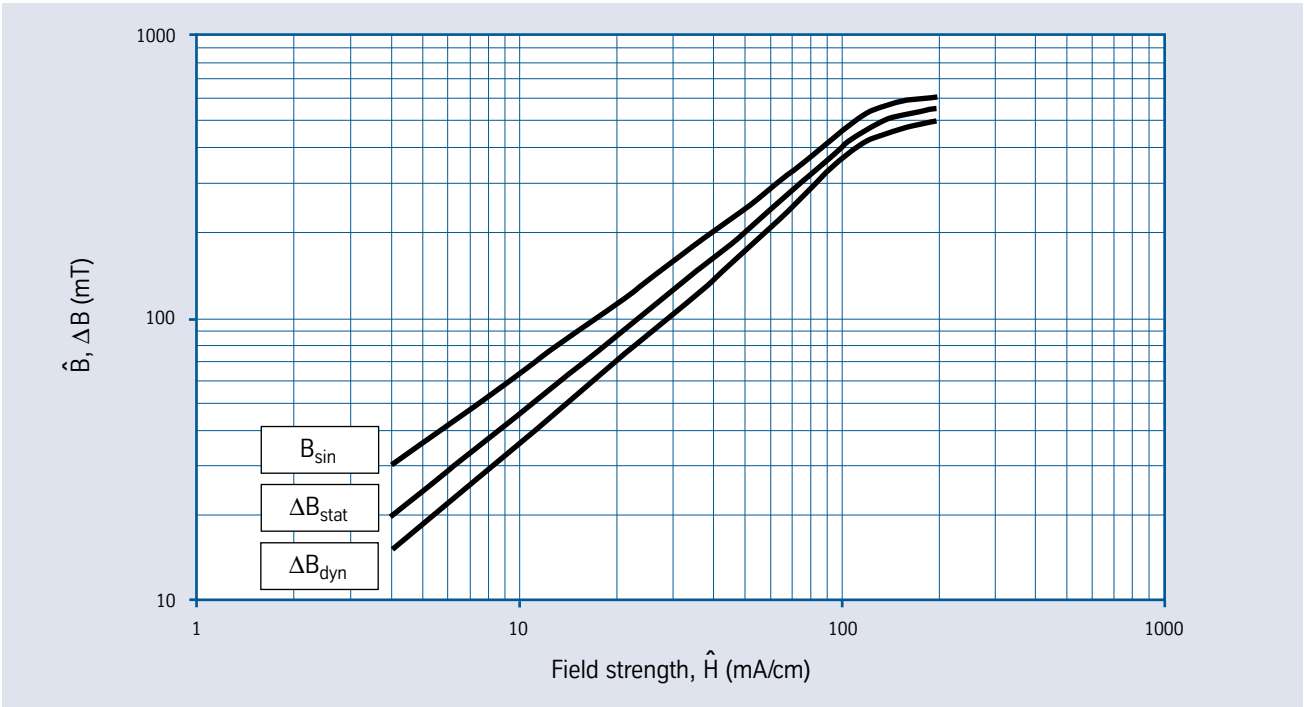


*Fig. 11 - Typical curves of induction $\hat{B}$ and $\Delta B$ (50 Hz) in relation to field strength for Magnifer 7904 F25, measured using toroidal tape-wound cores of 0.065 mm strip thickness.*

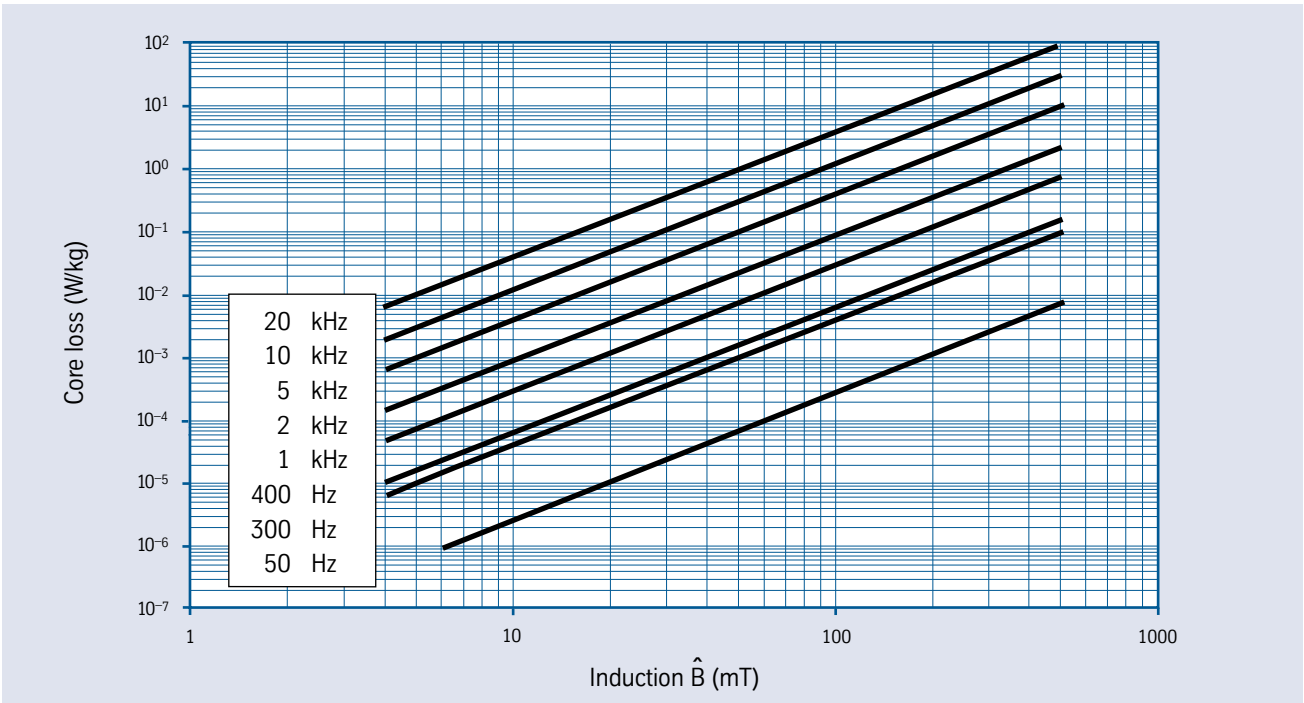


*Fig. 12 - Core loss of Magnifer 7904, measured using toroidal tape-wound cores of 0.065 mm strip thickness at various frequencies.*

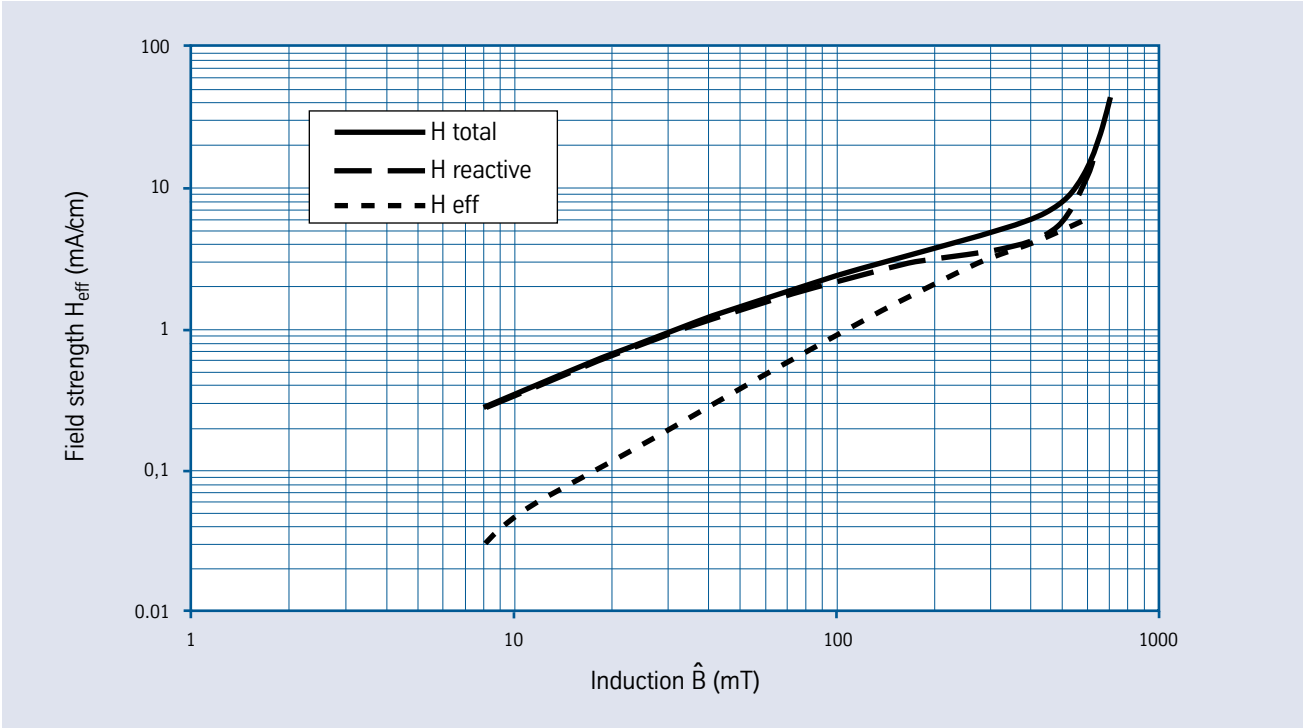


*Fig. 13 - Components of the magnetization curve of Magnifer 7904, measured using toroidal tape-wound cores of 0.065 mm strip thickness at 50 Hz frequency.*

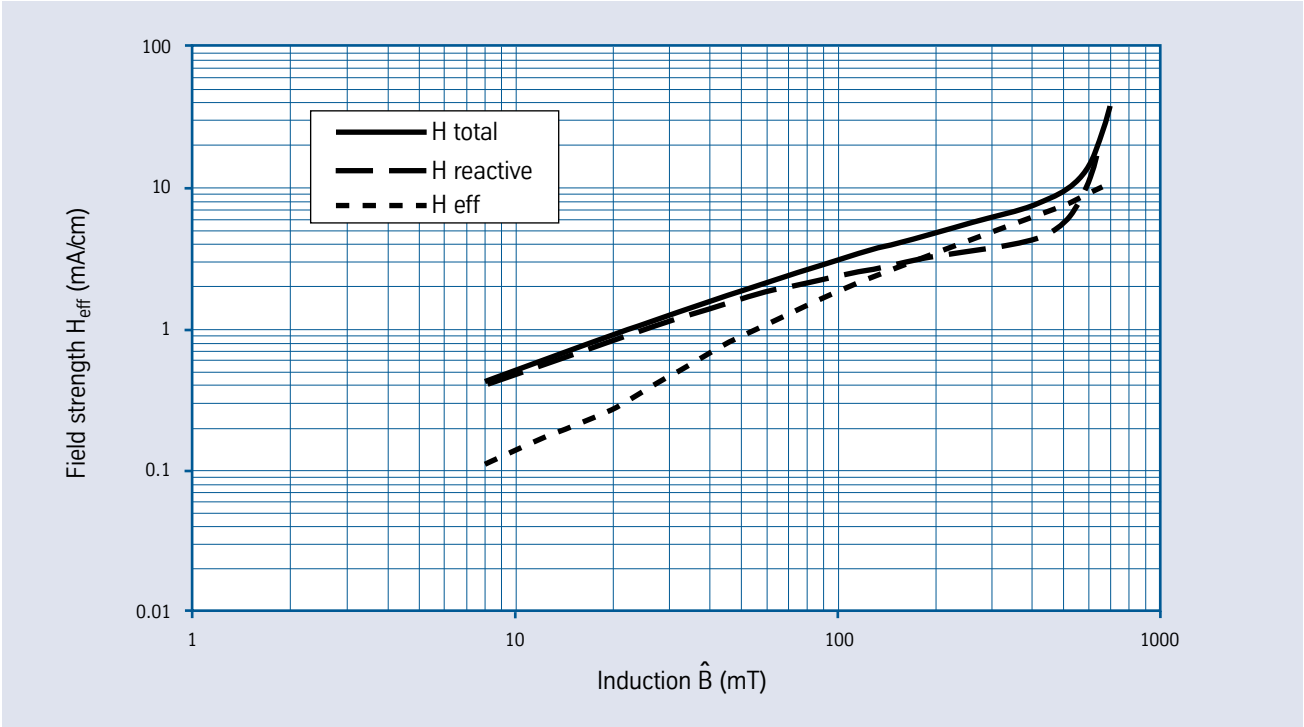


*Fig. 14 - Components of the magnetization curve of Magnifer 7904, measured using toroidal tape-wound cores of 0.1 mm strip thickness at 50 Hz frequency.*

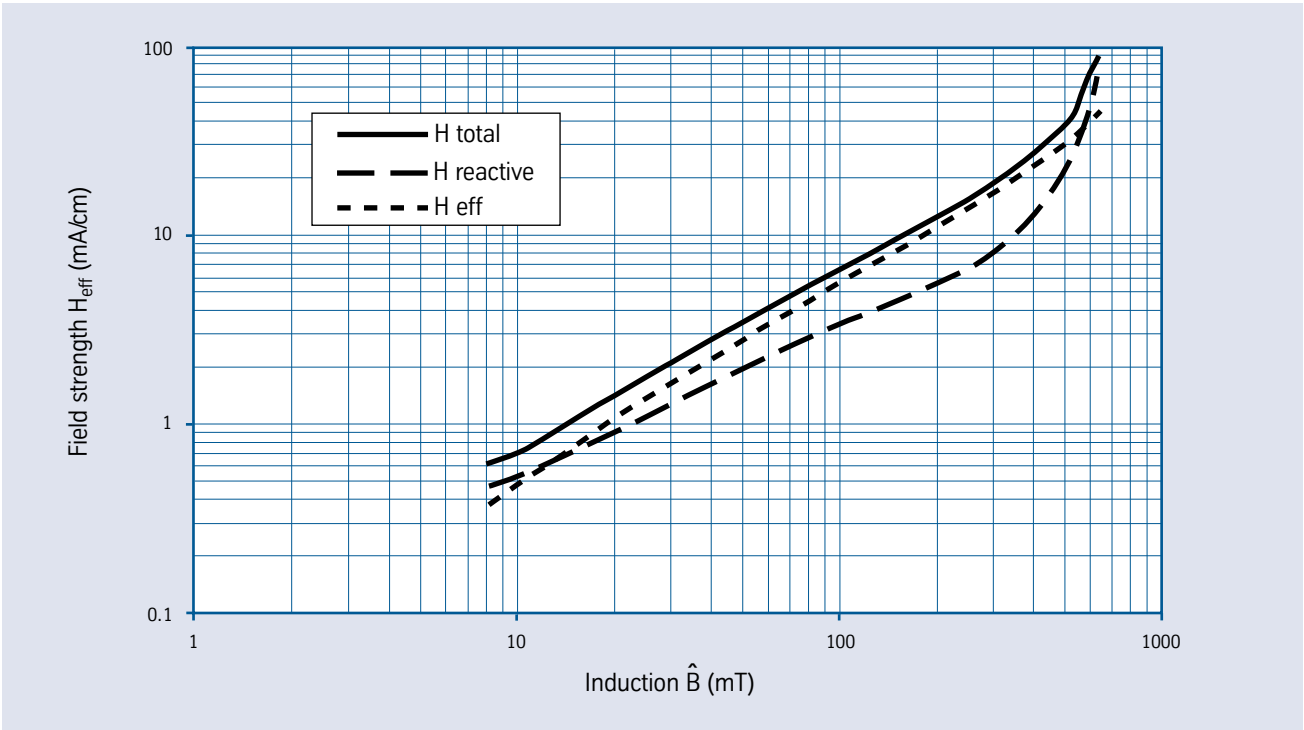


*Fig. 15 - Components of the magnetization curve of Magnifer 7904, measured using toroidal tape-wound cores of 0.35 mm strip thickness at 50 Hz frequency.*

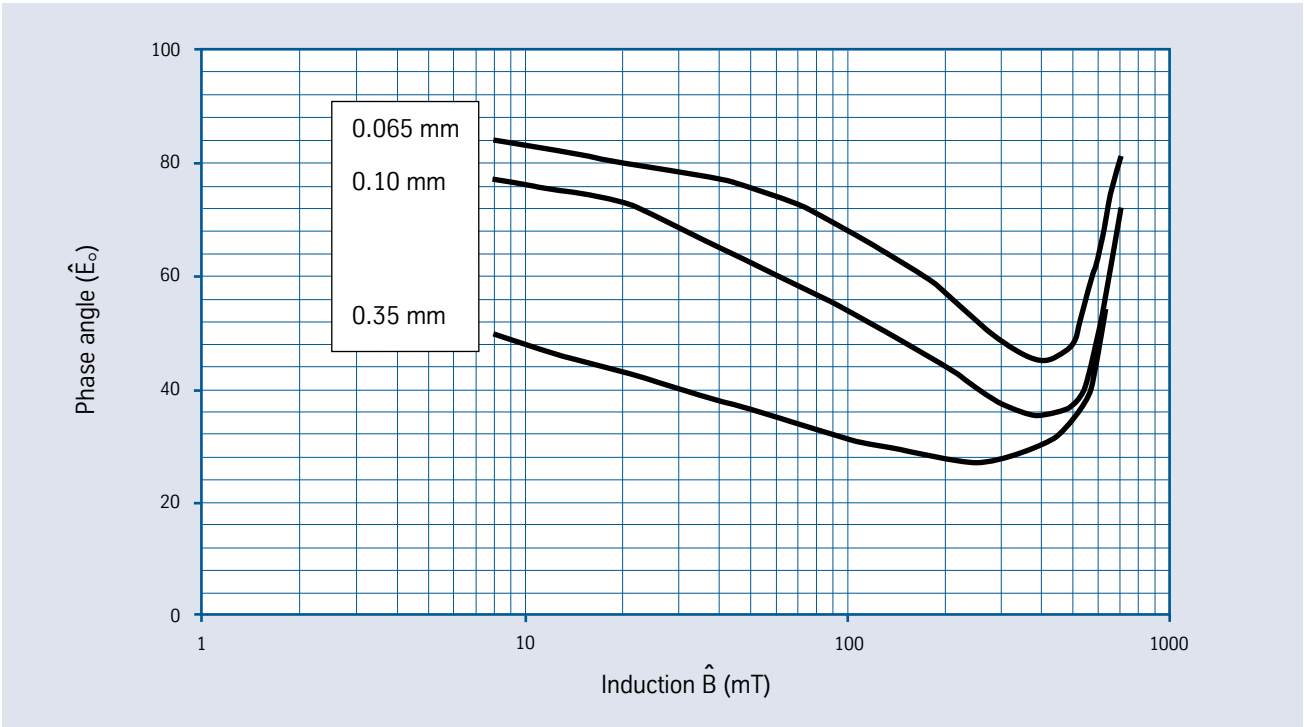


*Fig. 16 - Phase angle $\varphi_o$ of Magnifer 7904, measured using toroidal tape-wound cores of strip thicknesses 0.065 mm, 0.10 mm and 0.35 mm at 50 Hz.*

| Alloy | Grade | Permeability[1] | | Coercive force[2] | Induction $\hat{B}$ (mT) at $H_{eff}$ = | Core loss[3] $V_5$ = |
|---|---|---|---|---|---|---|
| | | μ4 | μmax | Hc (A/m) | 15 mA/cm | W/kg |
| Magnifer 7904 | MP 130 | ≥ 130000 | ≥ | 260000 | ≥ 450 | ≤ 0.01 |
| | MP 160 | ≥ 160000 | ≥ | 300000 | | |
| | MP 200 | ≥ 200000 | ≥ | 350000 | | |
| | MP 220 | ≥ 220000 | ≥ | 375000 | | |
| | MP 240 | ≥ 240000 | ≥ | 400000 | ≥ 550 | ≤ 0.01 |
| | MP 280 | ≥ 280000 | ≥ | 400000 | | |
| | MP H1 | bulk material | | < 1.0 | | |
| Magnifer 7904 R | | rectangular hysteresis loop Br/Bm ≥ 0.90 with $\hat{H}$ max = 0.1 A/cm | | | | |
| Magnifer 7904 TK | | low dependence of permeability on temperature | | | | |

[1] measured using toroidal tape-wound cores 22 x 15.5 x 20 mm at 50 Hz
[2] static measurement after magnetization to saturation
[3] measured at B = 0.5 T

*Table 5 - Magnetic properties of Magnifer 7904, 7904 R, 7904 TK.*
*The magnetic data refer to 0.065 mm strip thickness. Data for other strip thicknesses can be supplied on request.*
*The grade MP H1 refers to bulk material.*

| Magnifer 7904 F | $\hat{H}$ = 10 mA/cm Induction $\hat{B}$ (mT) | Static induction ΔB (mT) | $\hat{H}$ = 20 mA/cm $\hat{B}$ (mT) | Static induction ΔB (mT) | $\hat{H}$ = 100 mA/cm induction $\hat{B}$ (mT) | Static induction ΔB (mT) |
|---|---|---|---|---|---|---|
| F15 | 470 | 90[1] | 570 | 140[1] | | |
| F25 | 150 | 120 | 420 | 320 | | |
| F50 | | | 90 | 70 | 460 | 390 |

[1] Measured using a pre-magnetized core

*Table 6 - Typical magnetic properties of Magnifer 7904 F for sinusoidal current and half-wave rectification, measured using toroidal tape-wound cores of 0.065 mm strip thickness.*

## Laminations

Magnifer 7904 is used in conventional laminations such as EI-cuts and also in stamped rings with a constant relationship of permeability to temperature and are especially suitable for electronic earth-leakage circuit breakers.

| Strip thickness | μ4 (60 Hz) |
|---|---|
| 0.20 mm | > 80000 |
| 0.35 mm | > 60000 |

*Table 7 - Magnetic properties of Magnifer 7904*

Magnifer 7904 in the form of laminations is increasingly being used for transformer cores in modems. Here, for error-free data transmission a transmission function is required with the maximum possible freedom from distortion, expressed as "Total Harmonic Distortion" (especially taking the second and third harmonics into account), which can be determined with an audio-analyser. Typical levels are < -76 dB to < -90 dB at a strip thickness of 0.20 mm at frequencies between 200 and 600 Hz, depending on the type of lamination and the level control (Fig.17).

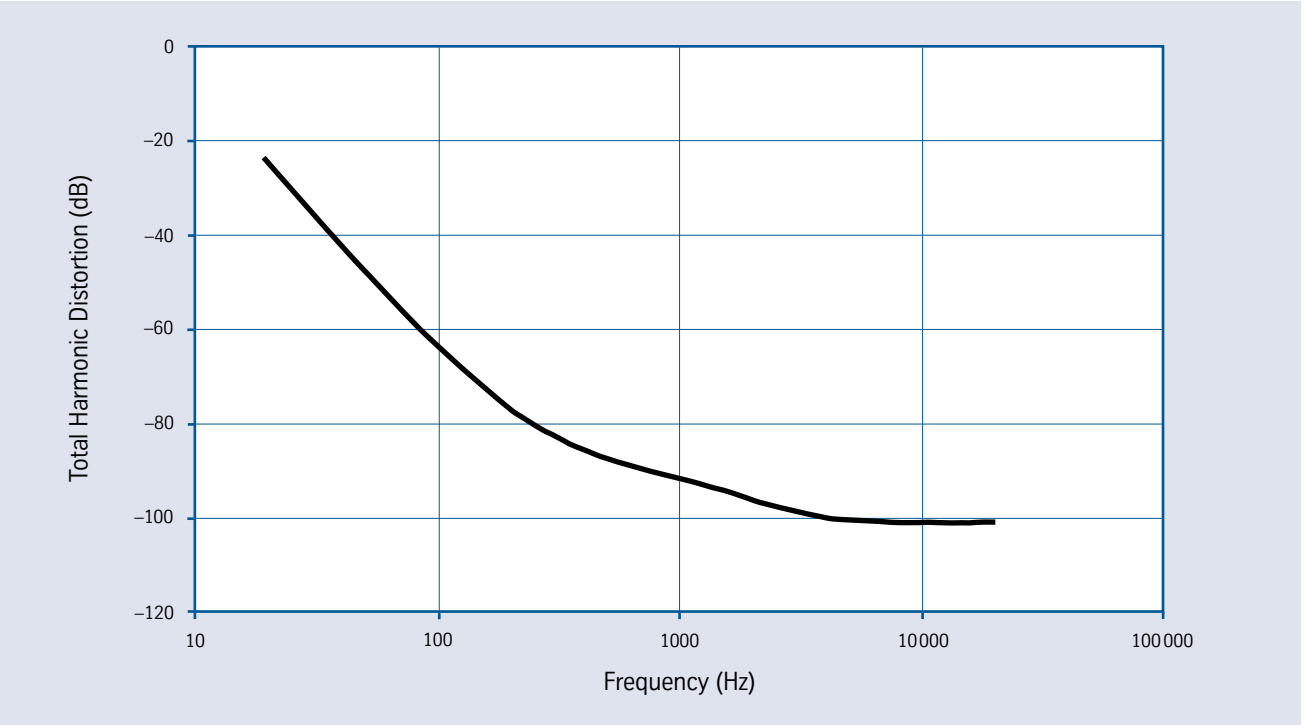


*Fig. 17 - Typical curve of Total Harmonic Distortion as a function of frequency for Magnifer 7904, measured with an ED-8 transformer lamination packet of strip thickness 0.20 mm.*

## Shieldings

Magnifer 7904 alloys are used as shieldings against low-frequency magnetic interference.

| μ4 (50 Hz) | μmax (50 Hz) | μB40 (DC) | μmax (DC) | B (μmax (DC)) (T) | HC (A/m) |
|---|---|---|---|---|---|
| ≥ 55000 | ≥ 90000 | ≥ 80000 | ≥ 300000 | | ≤ 1 |
| 70000[1)] | 100000[1)] | 100000[1)] | 400000[1)] | 0.3[1)] | 0.4[1)] |

[1)] typical values

Magnetic properties for Magnifer 7904 when used as shieldings, measured using stamped rings of 0.35 mm strip thickness after heat treatment at 1100 - 1180 °C,
μ4, i.e. μ at $\hat{H}$, = 4 mA/cm, μB40, i.e. μ at $\hat{B}$, = 40 G = 4 mT

| Shielding factor Sm | Shielding attenuation aS (dB) |
|---|---|
| 500 – 4000 | 55 – 72 |

Shielding factors for frequency 50 Hz (see also Fig. 18), measured using cylinders (length 300 mm, diameter 80 mm, wall thickness 0.35 mm) in the cross-field over the level control range of 80 - 800 A/m (1 - 10 Oe)

*Table 8 - Magnetic properties, shielding factor and shielding attenuation of Magnifer 7904.*

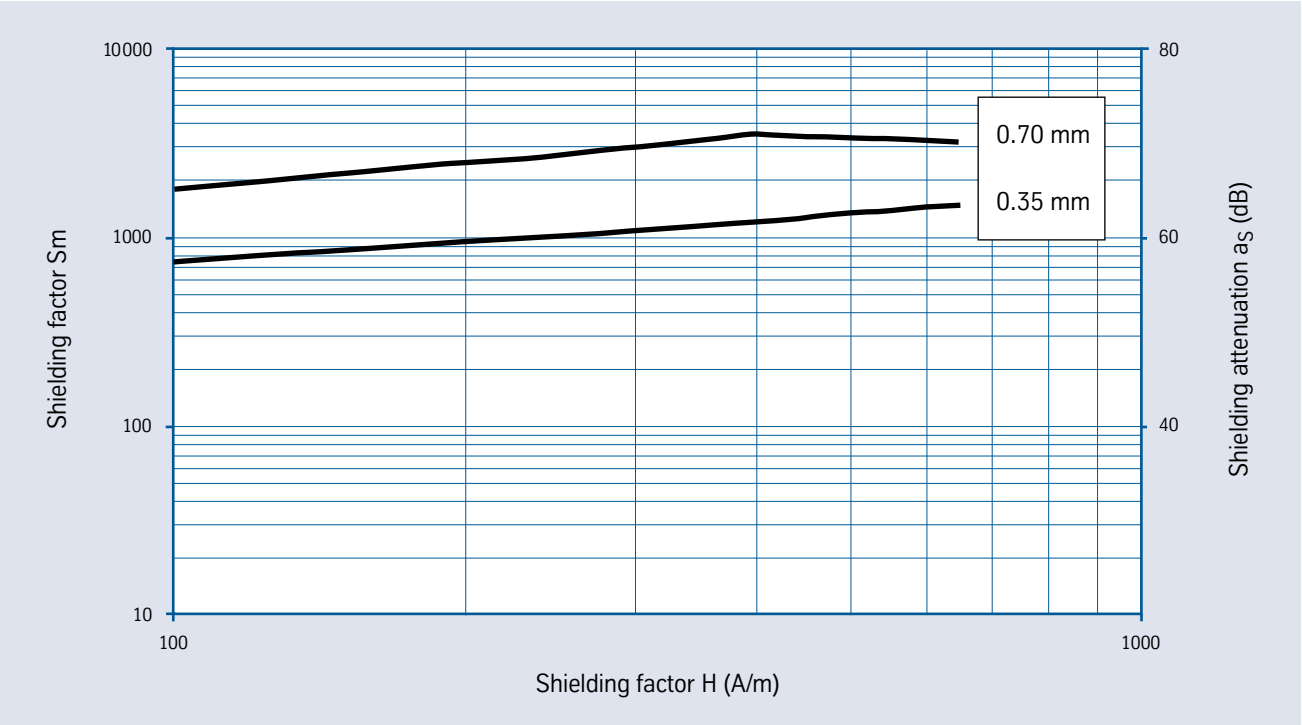


*Fig. 18 - Shielding factor Sm and shielding attenuation $a_s$ as a function of the field strength of Magnifer 7904 for strip thicknesses 0.70 mm and 0.35 mm (measuring parameters: see text relating to Table 8).*

Figure 18 shows values for the shielding factor Sm and the shielding attenuation $a_s$ of Magnifer 7904 plotted as a function of the field strength for strip thicknesses 0.70 mm and 0.35 mm (see text relating to Table 8 for the measuring parameters).

**Stepping motors**
Magnifer 7904 is used for rotor stampings for analogue quartz watches. The requirements are a low coercive force and high permeability. The dependence of the saturation induction on temperature is also important. The alloy Magnifer 4008 (Material Data Sheet no. 9007) can also be chosen as an alternative.

**Relay parts and other stamped parts**
Magnifer 7904 is used for stamped parts in electromagnetic relays. The critical requirements are a very low coercive force and very good resistance to corrosion, especially to atmospheric humidity.

The alloy Magnifer 77 TiNb So can also be chosen as an alternative.

**Final annealing for obtaining the desired magnetic properties**
The magnetic properties quoted in this Data Sheet are obtainable by means of a special final annealing treatment. Annealing should be carried out in dry hydrogen or cracked ammonia (dew point < -40 °C). The appropriate annealing temperature range for Magnifer 7904 is 1050 – 1200 °C with an annealing time of 2 to 8 hours. Especially important in the case of Magnifer 7904 is cooling in the temperature range 300 – 600 °C, as this influences the magnetic properties considerably.

The chemical composition of Magnifer 7904 is such that furnace cooling to approx. 480 °C over 5 – 6 hours results in good magnetic properties. Furnace cooling down to 300 °C at a rate of 3 – 6 K/min followed by cooling in air results in high maximum permeabilities. To achieve a particularly high initial permeability, it must be taken out of the furnace at a higher temperature, depending on the cooling rate.

The parts must not be subjected to further mechanical stress after the final annealing treatment, as any plastic deformation leads to a substantial loss of magnetic properties.

Different chemical compositions, especially in terms of the contents of the elements Ni and Mo, influence the most favourable annealing parameters such as the cooling rate and the take-out or tempering temperature in order to obtain optimum magnetic properties. For information on the alloy Magnifer 8105, which owing to its slightly higher nickel content of about 81 % has a negative saturation magnetostriction and therefore has beneficial properties for use in recording heads, please refer to the Krupp VDM Material Data Sheet "Magnifer 8105" (soft magnetic alloy for use in recording heads). Magnifer 7904 alloys are available with various Mo contents (between approx. 4 % and 6 %), with which the best magnetic properties are obtained under different annealing conditions, such as apply, for example, to annealing in a bell-type furnace or a continuous furnace. Details are given in the relevant sections of this Data Sheet and should be discussed with our technical staff.

## Fabrication

### Forming
The usual processes can be used. Fabrication data may be obtained from the table of mechanical properties. In the "annealed for deep drawing" condition, the minimum Erichsen depth is 8 for sheets of 1 mm thickness. The magnetic condition after final annealing is exclusively the final condition for fabrication of certain parts. It is not suitable as the initial condition for any further working operations, as the magnetic properties would be drastically lowered. The cold-rolled state is the most suitable for stamping.

### Machining
The cold-worked condition is best suited for machining operations. The material exhibits characteristics similar to those of stainless steels. Low cutting speeds, cooling cutting oils, and carbide or high-speed-steel cutting tools are required; the latter must be kept sharp.

After machining is completed, residual films of oil, grease or dirt must be removed as completely as possible before annealing the parts. Oils with added sulphur are entirely unsuitable.

### Welding
The best process is usually spot welding, although other welding processes are also suitable in principle. We are pleased to advise on the best process in special cases.

## Corrosion resistance
Corrosion resistance in a humid atmosphere is good, but this is not the case in aggressive media.

## Forms supplied
Mill products: strip, ribbon, sheet, bar and wire.

Fabricated parts: toroidal tape-wound cores up to 750 mm O.D., laminations, relay parts and shieldings.

Components: saturable transformers.

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