PHILIPS

Data handbook

Electronic components and materials

Components and materials

Part 16 January 1982

Piezoelectric ceramics

Permanent magnet materials

COMPONENTS AND MATERIALS

PART 16 - JANUARY 1982

PIEZOELECTRIC CERAMICS and PERMANENT MAGNET MATERIALS

PIEZOELECTRIC CERAMICS A

PERMANENT MAGNET MATERIALS B

DATA HANDBOOK SYSTEM

Our Data Handbook System is a comprehensive source of information on electronic components, subassemblies and materials; it is made up of four series of handbooks each comprising several parts.

ELECTRON TUBES	BLUE
SEMICONDUCTORS	RED
INTEGRATED CIRCUITS	PURPLE
COMPONENTS AND MATERIALS	GREEN

The several parts contain all pertinent data available at the time of publication, and each is revised and reissued periodically.

Where ratings or specifications differ from those published in the preceding edition they are pointed out by arrows. Where application information is given it is advisory and does not form part of the product specification.

If you need confirmation that the published data about any of our products are the latest available, please contact our representative. He is at your service and will be glad to answer your inquiries.

ELECTRON TUBES (BLUE SERIES)

Starting in 1980, new part numbers and corresponding codes are being introduced. The former code of the preceding issue is given in brackets under the new code.

Part 1	February 1980	T1 02-80 (ET1a 12-75)	**Tubes for r.f. heating**
Part 2	April 1980	T2 04-80 (ET1b 08-77)	**Transmitting tubes for communications**
Part 2b	May 1978	ET2b 05-78	**Microwave semiconductors and components** Gunn, Impatt and noise diodes, mixer and detector diodes, backward diodes, varactor diodes, Gunn oscillators, sub-assemblies, circulators and isolators.
Part 3	June 1980	T3 06-80 (ET2a 11-77)	**Klystrons, travelling-wave tubes, microwave diodes**
Part 3	January 1975	ET3 01-75	**Special Quality tubes, miscellaneous devices**
Part 4	September 1980	T4 09-80 (ET2a 11-77)	**Magnetrons**
Part 5	August 1981	T5 08-81 (ET5a 10-79)	**Cathode-ray tubes** Instrument tubes, monitor and display tubes, C.R. tubes for special applications.
Part 6	July 1980	T6 07-80 (ET6 01-77)	**Geiger-Müller tubes**
Part 7a	March 1977	ET7a 03-77	**Gas-filled tubes** Thyratrons, industrial tubes, ignitrons, high-voltage rectifying tubes.
Part 7b	May 1979	ET7b 05-79	**Gas-filled tubes** Segment indicator tubes, indicator tubes, switching diodes, dry reed contact units.
Part 8	February 1982	T8 02-82 (ET8 07-79)	**Picture tubes and components** Colour TV picture tubes, black and white TV picture tubes, colour monitor tubes for data graphic display, monochrome monitor tubes for data graphic display, components for colour television, components for black and white television and monochrome data graphic display.
Part 9	June 1980	T9 06-80 (ET9 03-78)	**Photo and electron multipliers** Photomultiplier tubes, phototubes, single channel electron multipliers, channel electron multiplier plates.
Part 10	May 1981	T10 05-81 (ET5b 12-78)	**Camera tubes and accessories, image intensifiers**

SEMICONDUCTORS (RED SERIES)

Starting in 1980, new part numbers and corresponding codes are being introduced. The former code of the preceding issue is given in brackets under the new code.

Part 1	**March 1980**	**S1 03-80** **(SC1b 05-77)**	**Diodes** Small-signal germanium diodes, small-signal silicon diodes, special diodes, voltage regulator diodes (< 1,5 W), voltage reference diodes, tuner diodes, rectifier diodes
Part 2	**May 1980**	**S2 05-80** **(SC1a 08-78)**	**Power diodes, thyristors, triacs** Rectifier diodes, voltage regulator diodes (> 1,5 W), rectifier stacks, thyristors, triacs
Part 3	**April 1980**	**S3 04-80** **(SC2 11-77, partly)** **(SC3 01-78, partly)**	**Small-signal transistors**
Part 4	**September 1981**	**S4 09-81** **(SC2 06-79)**	**Low-frequency power transistors**
Part 4a	**December 1978**	**SC4a12-78**	**Transmitting transistors and modules**
Part 5	**October 1980**	**S5 10-80** **(SC3 01-78, partly)**	**Field-effect transistors**
Part 7	**December 1980**	**S7 12-80** **(SC4c 07-78)**	**Microminiature semiconductors for hybrid circuits**
Part 8	**April 1980**	**S8 06-81** **(SC4b 09-78)**	**Devices for optoelectronics** Photosensitive diodes and transistors, light-emitting diodes, displays, photocouplers, infrared sensitive devices, photoconductive devices
Part 10	**September 1981**	**S10 09-81** **(SC3 01-78, partly)**	**Wideband transistors and wideband hybrid IC modules**

INTEGRATED CIRCUITS (PURPLE SERIES)

Starting in 1980, new part numbers and corresponding codes are being introduced. The former code of the preceding issue is given in brackets under the new code. Books with the purple cover will replace existing red covered editions as each is revised.

Part 1	**May 1980**	**IC1 05-80** **(SC5b 03-77)**	**Bipolar ICs for radio and audio equipment**
Part 2	**May 1980**	**IC2 05-80** **(SC5b 03-77)**	**Bipolar ICs for video equipment**
Part 5a	**November 1976**	**SC5a 11-76**	**Professional analogue integrated circuits**
Part 4	**October 1980**	**IC4 10-80** **(SC6 10-77)**	**Digital integrated circuits** LOCMOS HE4000B family
Part 6b	**August 1979**	**SC6b 08-79**	**ICs for digital systems in radio and television receivers**
Part 7	**May 1981**	**IC7 05-81**	**Signetics Bipolar memories**
Part 8	**May 1981**	**IC8 05-81**	**Signetics Analogue circuits**
Part 9	**November 1981**	**IC9 11-81**	**Signetics TTL Logic**

COMPONENTS AND MATERIALS (GREEN SERIES)

Starting in 1980, new part numbers and corresponding codes are being introduced. The former code of the preceding issue is given in brackets under the new code.

Part 1	**October 1981**	**C1 10-81**	**Assemblies for industrial use** PLC modules, PC20 modules, HNIL FZ/30 series, NORbits 60-, 61-, 90-series, input devices, hybrid ICs, peripheral devices
Part 2	**June 1981**	**C2 06-81** **(CM3a 09-78)**	**FM tuners, television tuners, video modulators, surface acoustic wave filters**
Part 3	**January 1981**	**C3 01-81** **(CM3b 10-78)**	**Loudspeakers**
Part 4	**December 1981**	**C4 12-81**	**Ferroxcube potcores, square cores and cross cores**
Part 4a	**November 1978**	**CM4a 11-78**	**Soft Ferrites** Ferrites for radio, audio and television, beads and chokes, FXC potcores and square cores, FXC transformer cores
Part 6	**May 1981**	**C6 05-81** **(CM6 04-77)**	**Electric motors and accessories** Permanent magnet synchronous motors, stepping motors, direct current motors
Part 7a	**January 1979**	**CM7a 01-79**	**Assemblies** Circuit blocks 40-series and CSA70 (L), counter modules 50-series, input/output devices
Part 8	**September 1981**	**C8 09-81** **(CM8 06-79)**	**Variable mains transformers**
Part 9	**August 1979**	**CM08-79**	**Piezoelectric quartz devices** Quartz crystal units, temperature compensated crystal oscillators
Part 10	**October 1980**	**C10 10-80**	**Connectors**
Part 11	**December 1979**	**CM11 12-79**	**Non-linear resistors** Voltage dependent resistors (VDR), light dependent resistors (LDR), negative temperature coefficient thermistors (NTC), positive temperature coefficient thermistors (PTC)
Part 12	**November 1979**	**CM12 11-79**	**Variable resistors and test switches**
Part 13	**December 1979**	**CM13 12-79**	**Fixed resistors**
Part 14	**April 1980**	**C14 04-80** **(CM2b 02-78)**	**Electrolytic and solid capacitors**
Part 15	**May 1980**	**C15 05-80** **(CM2b 02-78)**	**Film capacitors, ceramic capacitors, variable capacitors**
Part 16	**January 1982**	**C16 01-82** **(CM4b 02-79)**	**Piezoelectric ceramics, permanent magnet materials**

PIEZOELECTRIC CERAMICS A

INTRODUCTORY NOTES

PXE (piezoelectric ceramic) materials are suitable for many applications where electromechanical or mechano-electrical energy conversion is required. Because of their ceramic nature, PXE components may be made in almost any required shape or size, and the direction of polarization may be freely chosen. It is also possible to modify the piezoelectric and other properties by minor variations in composition, and several different material grades are produced to meet typical requirements.

As well as exhibiting a large piezoelectric effect, PXE materials are hard, strong, chemically inert and immune to humidity.

MATERIALS AND GRADES

PXE ceramics are ferroelectric materials which all have the perovskite crystal structure and the general chemical formula ABO_3, where A usually signifies a large divalent metal ion, such as Pb, Sr, or Ba, whilst B is a small tetravalent metal ion such as Zr or Ti. The PXE grades are solid solutions of lead zirconate and lead titanate Pb (Ti, Zr) O_3 modified by other additions.

Ferroelectricity is the property possessed by some materials in having a built-in electric polarization which may be reversed or switched in certain directions by application of a high electric field. After manufacture, these ceramics are isotropic and exhibit no piezoelectricity. This is due to their being formed of a mass of randomly orientated crystallites and also because the individual crystallites themselves contain many domains in which the polarization takes up different alignments. They are rendered piezoelectric by a poling treatment which is the last stage of manufacture and which involves application of a high electric field in a heated oil bath at a temperature not far below the Curie point (ferroelectric transition temperature). Apart from the poling treatment, manufacture of piezoelectric ceramics is similar to that of the more common insulation ceramics, except that closer control is necessary to achieve the desired properties.

The following grades are available:

PXE 5: This material combines a high coupling coefficient and high piezoelectric charge constant. It is ideally suited for low-power applications. Among these are numerous non-resonant applications such as pick-up elements, fine movement control, feedback plates, microphones, pressure and acceleration sensors, and hydrophones. PXE 5 can also be used for low-power resonant applications (e.g. air transducers for remote control purposes). This grade has an excellent time stability characteristic, and a high electrical resistivity at high temperatures.

PXE 7: A grade with low permittivity and high temperature stability as well as a high shear coupling coefficient. Ageing of the permittivity of this material, and hence phase distortion of the electrical resonance circuit, is extremely low; it is therefore suitable for h.f. shear resonance applications where phase is important, e.g. in ultrasonic delay lines for colour television receivers.

PXE 21: A grade which has been developed for ignition purposes. It has a high voltage constant which ensures a high voltage output. This material is suitable for impact mechanisms used for the ignition of gases and explosives.

PXE 41: A low loss material for medium power applications. In particular, the high mechanical quality and low loss factor (even at intensive drive) make PXE 41 suitable for high power ultrasound applications at medium range temperatures and pre-stresses. Furthermore, PXE 41 can be exposed to high repetitive quasi-static loads and dynamic loads for ignition purposes.

PXE 42: A low loss material for high power applications. Its low dielectric loss and high mechanical quality factor, combined with a tolerance of high temperature and mechanical stress, make it particularly suitable for the generation of ultrasonic power. It is the recommended material for ultrasonic cleaning.

PXE 43: A low loss material for high power applications. Its low dielectric loss and high mechanical quality factor, combined with a very good behaviour at high electric fields and increased temperatures, make it suitable for ultrasonic welding.

PXE 52: A material with a higher permittivity and a higher charge constant than PXE 5. Due to its lower Curie point: it also has a lower time and temperature stability. The material is suitable for sensitive detection-tone generation and for fine movement control applications.

APPLICATIONS

High voltage generators (for ignition purposes):	gas appliances, cigarette lighters, fuzes for explosives, flash bulbs.
High power ultrasonic generators:	ultrasonic cleaning for industrial and domestic appliances, sonar, echo sounding, ultrasonic welding of plastics and metals, ultrasonic drilling and machining of brittle materials, ultrasonic soldering, atomization.
Transducers for sound and ultrasound in air:	microphones e.g. for telephones, intruder alarm systems, remote control, loudspeakers, e.g. tweeters, audio tone generators in signalling devices.
Pick-ups and sensors:	record players, accelerometers, detection systems in machinery, e.g. textile, medical equipment, motor cars, e.g. knock sensor.
Resonators and filters:	radio, television, telecommunications.
Delay lines:	colour television.
Push buttons and keyboards:	teleprinters, desk calculators and electronic computers, slot machines, telephones.
Miscellaneous:	ink jet printers, fine movement control, flow meters.

PIEZOELECTRIC RELATIONSHIPS

The electrical condition of an unstressed medium placed under the influence of an electric field is defined by two quantities – the field strength E and the dielectric displacement D. Their relationship is:

$$D = \epsilon E \qquad (1)$$

where ϵ is the permittivity of the medium.

The mechanical condition of the same medium at zero electric field strength is defined by two mechanical quantities – the applied stress T and the strain S. The relationship is:

$$S = sT \qquad (2)$$

where s denotes the compliance of the medium.

Piezoelectricity involves the interaction between the electrical and mechanical behaviour of the medium. Approximately, this interaction can be described by linear relations between two electrical and mechanical variables:

$$S = s^E T + dE \qquad (3)$$

$$D = dT + \epsilon^T E \qquad (4)$$

The choice of independent variables (one mechanical, T, and one electrical, E,) is arbitrary. A given pair of piezoelectric equations corresponds to a particular choice of independent variables. Similarly, it is possible to arrive at the following equations:

$$E = -gT + \frac{D}{\epsilon^T} \qquad (5)$$

$$S = s^D T + gD \qquad (6)$$

In these equations, s^D, s^E, ϵ^T, d and g are the main practical constants and they require further explanation. The superscript to the symbols denotes the quantity kept constant under boundary conditions. For instance if, by short-circuiting the electrodes, the electric field across the piezoelectric body is kept constant, superscript E is used. By keeping the electrodes open circuit, the dielectric displacement is kept constant and superscript D is used. So s^D and s^E are specific elastic compliances (strain-to-stress ratio) for a constant electric charge density and constant electric field respectively.

ϵ^T is the permittivity (electric displacement-to-field strength ratio) at constant stress.

It follows from equations 3, 4 and 5, 6 that there are two ways of defining the piezoelectric (strain) constants d and g. Thus d can be defined as a quotient of either S and E or D and T; similarly g can be defined from two other quotients.

Piezoelectric constants d and g

constant	definition	units (SI)	symbol
d	$\frac{\text{dielectric displacement developed}}{\text{applied mechanical stress}}$ (E = constant)	$\frac{\text{coulomb per metre}^2}{\text{pascal}}$	C/N
	$\frac{\text{strain developed}}{\text{applied field}}$ (T = constant)	$\frac{\text{metre per metre}}{\text{volt per metre}}$	m/V
g	$\frac{\text{field developed}}{\text{applied mechanical stress}}$ (D = constant)	$\frac{\text{volt per metre}}{\text{pascal}}$	Vm/N
	$\frac{\text{strain developed}}{\text{applied dielectric displacement}}$ (T = constant)	$\frac{\text{metre per metre}}{\text{coulomb per metre}^2}$	m^2/C

It can be shown that both units for the same constant have the same dimensions and, in SI units, they are also numerically the same.

$$d = \epsilon^T g \quad (7)$$

and

$$s^D = (1 - k^2)s^E \quad (8)$$

if k is defined by

$$k^2 = \frac{d^2}{s^E \epsilon^T} \text{ or } \frac{k^2}{1 - k^2} = \frac{g^2 \epsilon^T}{s^D} \quad (9)$$

Coupling factor

Being introduced like this, k can be considered merely as a convenient numerical quantity. It has, however, a basic physical meaning. At frequencies far below the mechanical resonant frequency, k^2 can be expressed as:

$$k^2 = \left[\frac{\text{stored energy converted}}{\text{stored input energy}}\right] \text{low frequency}$$

where k is referred to as coupling factor.

This formula holds for electro-mechanical and mechano-electrical energy conversions. A study of the value k, quoted in the table of principle properties, shows that up to 50% of the stored energy can be converted at low frequencies. The value of k^2 is the theoretical maximum, but in practical transducers the conversion is usually lower, depending upon the design.

Although a high value of k is desirable for efficient transduction, k^2 should not be thought of as an efficiency. Equations 3 to 6 do not take dissipative mechanisms into account. In principle, the energy which is not converted can be recovered. For instance, in electro-mechanical action, the unconverted energy which is not converted can be recovered. For instance, in electro-mechanical action, the unconverted energy remains as a charge in the capacitance of the PXE.

The efficiency is defined as the ratio of usefully converted power to the input power. Properly tuned and matched piezoelectric ceramic transducers, operating at resonance, can achieve efficiencies well over 90%. When not operated at resonance, or if not properly matched, the efficiency can be very low indeed.

DIRECTION DEPENDENCE

In piezoelectric materials, the constants depend on the directions of electric field, displacement, stress, and strain; therefore subscripts, indicating direction, are added to the symbols.

For piezoelectric ceramic materials, the direction of positive polarization is usually taken to be that of the Z-axis of a right hand orthogonal crystallographic axial set X, Y, Z. Since these materials have complete symmetry about the polar axis, the senses of X and Y, chosen in an element, are not important. If, as shown below, the direction of X, Y and Z are represented by 1, 2 and 3 respectively, and the shear about these axes as 4, 5 and 6 respectively, the various related parameters may be written with subscripts referring to these.

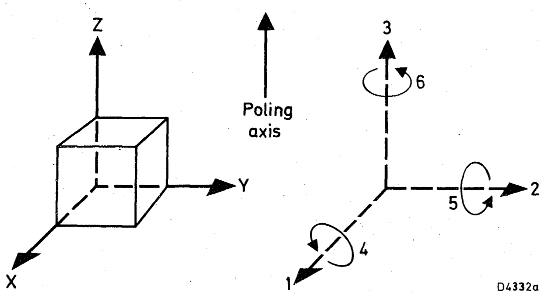


Fig. 1.

Permittivity ϵ

The first subscript gives the direction of the dielectric displacement; the second indicates the direction of the electric field. For example:

$\epsilon_{11}{}^T$ is the permittivity for dielectric displacement and field in the 1-direction under conditions of constant stress (T = 0).

$\epsilon_{33}{}^T$ is the permittivity for dielectric displacement and field in the 3-direction under conditions of constant stress.

The table of principle properties gives values for the relative permittivity ϵ/ϵ_0, i.e. the ratio of the absolute permittivity ϵ to the permittivity of vacuum ϵ_0, the latter being 8,85 x 10^{-12} farad per metre.

Compliance s = 1/Y

The first subscript refers to the direction of the strain and the second gives the direction of stress. Y is the modulus of elasticity. For example:

$s_{33}{}^E = 1/Y_{33}{}^E$ is the strain-to-stress ratio in the 3-direction at a constant electric field (E = 0).

$s_{55}{}^D = 1/Y_{55}{}^D$ is the shear-strain to shear-stress ratio at constant electric displacement (D = 0) for shear about an axis perpendicular to the poling direction.

Piezoelectric constants d, g and k

The first subscript refers to the direction of the electric field or displacement, and the second gives the direction of the mechanical stress or strain. For example:

d_{33} is the ratio of strain in the 3-direction to the field applied in the 3-direction, the piezoelectric body being mechanically free and not subjected to fields in the 1- and 2-directions. It also denotes the ratio of the charge per unit area flowing in the 3-direction when the electrodes are short-circuited, to the stress applied in the 3-direction; again, the material should be free from any other stresses.

g_{31} is the ratio of the field developed in the 3-direction to the stress applied in the 1-direction when there are no other external stresses and when there are no charges applied either in the 3-direction or in the 1- and 2-directions. It also denotes the ratio of the strain in the 1-direction to the density of the charge applied to the electrodes which are positioned at right angles to the 3-axis, provided the piezoelectric material is again free in all directions, and no charges are applied in the 1- and 2-directions.

k_{31} is the coupling factor between the stored mechanical energy input in the 1-direction and the stored electrical energy converted in the 3-direction, or vice versa.

Special cases k_p and k_t

The planar coupling factor k_p of a thin disc denotes the coupling between the electric field in the 3-direction (thickness direction), and the simultaneous mechanical actions in the 1- and 2-directions (Fig. 2, which results in radial vibration; hence the term radial coupling ($k_r = k_p$).

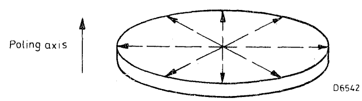


Fig. 2.

The thickness coupling factor k_t of a thin disc with arbitrary contour denotes the coupling between the electric field in the 3-direction (thickness direction) and the mechanical vibration in the 3-direction. This is smaller than k_{33} because of the constraint imposed by the large lateral dimensions of the disc relative to the thickness.

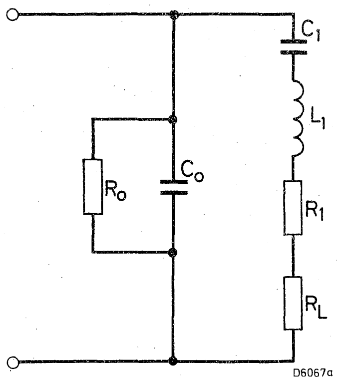
Frequency constant N

The frequency constant is the product of a resonant frequency and the linear dimension governing the resonance. If the applied electric field is perpendicular to the direction of vibration, then the resonance is the series resonance. If the field is parallel, then it is the parallel resonant frequency. Thus, for a 31 or 15 mode resonance and for the planar or radial mode resonance, the relevant frequency constants are $N_1{}^E$, $N_5{}^E$, and $N_p{}^E$. On the other hand, for 33 mode resonance, the frequency constant is $N_3{}^D$. Thus $N_1{}^E$, $N_5{}^E$, and $N_p{}^E$ give the minimum impedance, or series resonant frequency, whilst $N_3{}^D$ gives the maximum impedance, or parallel resonant frequency. If one wants to determine the length of a 33 resonator for a certain series resonant frequency, the equivalent parallel resonant frequency should first be determined, using the coupling coefficient k_{33}. The resonant length can be determined using $N_3{}^D$ and the parallel resonant frequency.

The frequency constant for longitudinal vibration of a long bar poled lengthwise is usually denoted by $N_3{}^D$. However, the frequency constant for extensional thickness vibration of a thin disc with arbitrary contour poled in the thickness direction, is usually denoted by $N_t{}^D$. For a disc, both $N_t{}^D$ and $N_p{}^E$ are of interest. The frequency constants are equal to half the governing sound velocity in the ceramic body, except for the constant $N_p{}^E$. Thus $N^D = \frac{1}{2}(s^D \rho_m)^{-\frac{1}{2}}$ and $N^E = \frac{1}{2}(s^E \rho_m)^{-\frac{1}{2}}$, where $s^D = s^E (1 - k^2)$, ρ_m = mass density, and the various constants have appropriate subscripts.

DYNAMIC BEHAVIOUR

A piezoelectric transducer, operating near or at the mechanical resonance frequency can be characterized by the following simple equivalent circuit.



C_o = capacitance of the clamped transducer.

R_o = dielectric loss of the transducer $[2\pi f (C_o + C_1) \tan \delta]^{-1}$.

R_1 represents the mechanical loss in the transducer.

R_L represents the acoustic or mechanical load.

C_1 and L_1 represent the rigidity and the mass of the material.

Fig. 3.

If the electrical admittance |Y| of the vibrating transducer is plotted against the frequency, one obtains the following resonant curve.

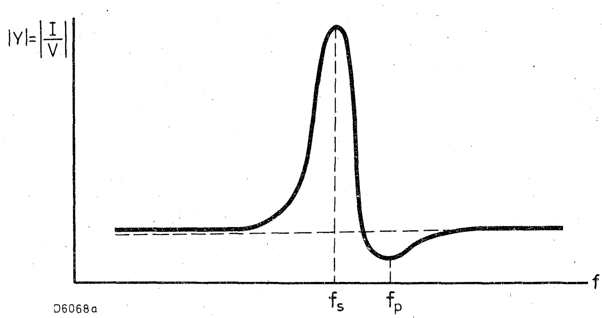


Fig. 4.

The frequency f_s, at which the admittance is maximum, is called the series resonance frequency. The minimum value of the admittance is found at the parallel resonance frequency f_p.

DEPOLARIZATION

The polarization (poling) of piezoelectric materials is permanent. However, when working with these materials, the following points should be borne in mind:

(1) The temperature of the material should be kept well below the Curie point.
(2) The material should not be exposed to very strong alternating electric fields or direct fields, opposing the direction of poling.
(3) Mechanical stress, exercised on the material, should not exceed specified limits.

Failure to comply with these three conditions may result in depolarization (depoling) of the material so that the piezoelectric properties become less pronounced or disappear completely.

STABILITY

The properties of piezoelectric elements are more or less temperature and time dependent. The stability, as a function of time, is of particular interest. Fortunately the poling ages approximately logarithmically (Fig. 5), so that the rate of change in permittivity, coupling factor, frequency constant, and so on, reduces rapidly in the course of time. Powerful ambient influences are likely to change the original ageing pattern. This applies particularly to the permittivity, the mechanical quality factor, and the dielectric loss factor, tan δ.

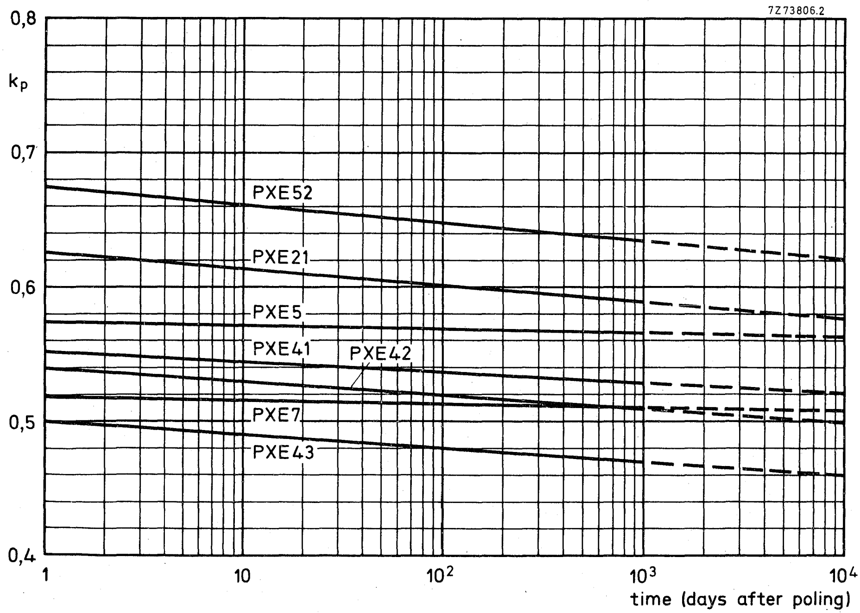


Fig. 5.

QUALITY GUARANTEE

The production batches of our piezoelectric ceramic products are inspected for mechanical, electrical and visual properties. The quality of the products is guaranteed in conformity with MIL-STD-105D.

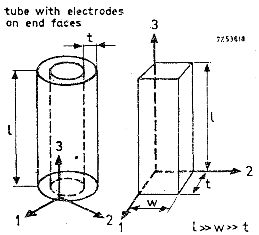
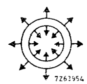
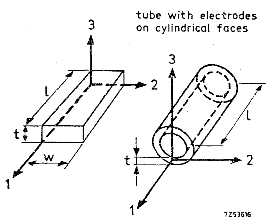
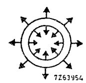
A.Q.L. values are laid down as follows:

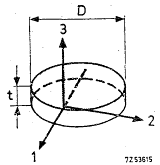
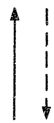
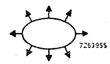
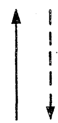
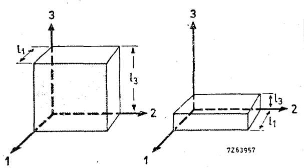
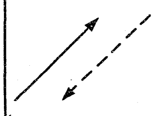
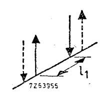
inspection	A.Q.L.	inspection level
mechanical	1	I
electrical	0,65	II
visual	1	I

Mechanical and visual inspections follow normal procedures, electrical inspection methods are laid down in I.R.E. standards on piezoelectric products.

For special applications, special requirements on the products are necessary: it is advised that the specification be determined in co-operation with the supplier.

MODES OF VIBRATION

resonant element with electrodes	biasing polarization	a.c. field and polarization	main component of a.c. stress and strain	conditions satisfied	pertinent coupling factor and frequency constant vibrational mode
	↑	E_3, D_3	T_3, S_3 (axial direction in tube)	$S_1 = S_2 = 0$ $T_1 = T_2 = 0$	$(k_{33})T_1T_2 = k_{33}$ $(N_3{}^E)T_1T_2 = N_3 = f_1l$ length mode with parallel excitation
			parallelepiped T_1, S_1  **tube** T and S in radial direction	$S_2 = S_3 = 0$ $T_2 = T_3 = 0$	$(k_{31})S_2S_3 = k_{31}{}^*$ $(N_1{}^E)S_2S_3 = N_1{}^* = f_rt$ thickness mode with transverse excitation
	↑	E_3, D_3	 **tube** T and S in radial direction **parallelepiped** T_3, S_3	$S_1 = S_2 = 0$ $T_1 = T_3 = 0$	$(k_{33})S_1S_2 = k_t$ $(N_3{}^E)S_1S_2 = N_t = f_rt$ thickness mode with parallel excitation
			T_1, S_1 (axial direction in tube)	$S_2 = S_3 = 0$ $T_2 = T_3 = 0$	$(k_{31})T_2T_3 = k_{31}$ $(N_1{}^E)T_2T_3 = N_1 = f_rl$ length mode with transverse excitation

		 E_3, D_3	 T_1, S_1 (radial direction) (also T_2, S_2 in circular direction)	$S_3 = 0$ $T_3 = 0$	$k_{31}\sqrt{2/(1-\sigma)} = k_p$ $N_p{}^E = N_p = P_r D$ planar mode with transverse excitation
			 T_3, S_3	$S_1 = S_2 = 0$ $T_1 = T_2 = 0$	$(k_{33})S_1S_2 = k_t$ $(N_3{}^E)S_1S_2 = N_t = f_r t$ thickness mode with parallel excitation
		 E_1, D_1	shear in 31-plane T_5, S_5 	propagation of shear waves in 1-direction if $l_1 = t \ll l_3$, in 3-direction if $l_3 = t \ll l_1$	k_5 $N_5{}^E = N_5 = f_r t$ thickness shear mode thickness t being l_1 or l_3 whichever is smaller

PRINCIPAL PROPERTIES

The following grades, consisting of modified lead zirconate titanates are distinguished according to their electrical and mechanical properties and field of application.
Unless otherwise stated, the specified values are measured at 20 ± 5 °C, 24 h after poling.

property and symbol		unit	PXE5	PXE52
thermal data				
Curie temperature		°C	285	170
specific heat		J/kg K	420	420
thermal conductivity		W/m K	1,2	1,2
mechanical data				
density ρ_m		10^3 kg/m³	7,65	7,90
compliance	s_{33}^E	10^{-12} /Pa	17,2	18,4
	s_{11}^E		15,3	14,7
	s_{55}^E		38,5	
Poisson's ratio σ			≈ 0,3	0,3
mechanical quality factor for radial mode Q_m^E			≈ 80	≈ 50
frequency constants	N_p^E	Hz m or m/s	2000	2000
	$N_3^D = \frac{1}{2}v_3^D$		1900	1920
	$N_1^E = \frac{1}{2}v_1^E$		1460	
	$N_5^E = \frac{1}{2}v_5^E$		930	
compressive strength		10^6 Pa	> 600	> 600
tensile strength			≈ 80	≈ 80
electrical data				
relative permittivity	$\epsilon_{33}^T/\epsilon_0$		1800	3500
(ϵ_0 = 8,85.10^{-12} F/m)	$\epsilon_{11}^T/\epsilon_0$		1800	
resistivity ρ_{el} (25 °C)		10^{12} Ωm	1	
time constant $\rho_{el}\,\epsilon_{33}^T$ (25 °C)		min	> 250	
dielectric loss factor tan δ		10^{-3}	20	22
electro-mechanical data				
coupling factor	k_p		0,60	0,63
	k_{33}		0,69	0,73
	k_{31}		0,35	0,37
	k_{15}		0,66	
piezoelectric charge constants	d_{33}	10^{-12} C/N or m/V	362	550
	d_{31}		− 175	− 250
	d_{15}		515	
piezoelectric voltage constants	g_{33}	10^{-3} Vm/N or m²/C	22,7	17,8
	g_{31}		− 11,0	− 8,1
	g_{15}		32,5	
time stability				
coupling factor k_p		relative change per time decade (%)	− 0,5	
permittivity ϵ_{33}^T			− 1	
frequency constant N_p^E			0,5	
quality factor Q_m^E				
dielectric loss factor tan δ				

The properties of components manufactured from PXE are dependent on the dimensions of the product and method of manufacture, and also on the measuring level. Therefore a meaningful interpretation of the properties of the material is best done in consultation with the supplier.

PXE7	PXE21	PXE41	PXE42	PXE43
320	270	315	325	300
420	420	420	420	420
1,2	1,2	1,2	1,2	1,2
7,75	7,75	7,90	7,70	7,70
15,8	18,6	14,6	15,3	12,6
12,5	15,1	12,2	12,7	11,3
33,2		37,0		
≈ 0,3	≈ 0,3	≈ 0,3	≈ 0,3	0,3
≈ 80	≈ 80	≈ 1000	≈ 750	1000
2200	2000	2200	2200	2350
2000	1900	2000	2015	2050
1640		1620		
1025		950		
> 600	> 600	> 600	> 600	> 600
≈ 80	≈ 80	≈ 80	≈ 80	≈ 80
820	1750	1200	1300	1000
1200		1400		
1	0,1	0,05		
> 100	> 25	> 7		
20	18	2,5	2,5	2
0,56	0,62	0,58	0,58	0,50
0,70	0,72	0,68	0,68	0,63
0,32	0,37	0,34	0,34	0,30
0,64		0,70		
220	385	268	285	210
– 99	– 180	– 119	– 130	–95
405		480		
35,7	25,0	25,2	25,0	25,0
– 13,5	– 11,6	– 11,6	– 11,0	–10,7
38		38,5		
– 0,5	– 1,5	– 1,5	– 2,5	– 2
– 0,5	– 2	1	– 6,0	– 4,5
1,0	0,5	0,5	1,5	1
		10		
		– 10		

PIEZOELECTRIC CERAMICS FOR GAS IGNITION

PXE may be used for high-voltage generation for spark ignition in gas appliances, for example, flash-bulb ignition. It combines an almost infite life with foolproof ignition.

PXE BLOCKS IN IGNITION UNITS

The following parameters are of importance:

- Dimensions and linear tolerances of the blocks.
- Parallelism, squareness, flatness and roughness (geometric tolerances) of the end faces of the blocks.
- Material grade, coupling coefficient and permittivity.
- Mechanical strength.
- Resistance to depolarization.

INSULATION

To prevent flashover in the unit along the block surface, the blocks should be thoroughly cleaned and protected by an insulating compound, such as silicone grease or oil.

MATERIAL GRADES AND PROPERTIES

The material grades suitable for ignition are PXE21 and PXE41. When a poled PXE block is subjected to a stress T_3, a voltage V_3 will be produced between electrodes on its end faces: $V_3 = -g_{33} T_3 \cdot \ell$, where:

V_3 = total voltage parallel to direction of poling,
g_{33} = piezoelectric voltage constant,
T_3 = mechanical stress in the poling direction,
ℓ = length of the block.

The maximum available energy for the spark, can be calculated from:

$W_{tot} = \frac{1}{2} C V_b^2$, where:
C = capacitance of the unit at low frequencies,
V_b = breakdown voltage of the spark gap.

The energy per unit volume can be calculated from: $W_{tot} = \frac{1}{2} (\epsilon_{33}^T \cdot g_{33}^2 \cdot T_3^2)$.

DEPOLARIZATION

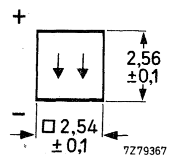
Mechanical depolarization occurs when the stress on piezoelectric ceramics becomes too high. Permanent disorientation of the dipoles can result in a significant reduction of piezoelectric properties. The maximum permissible static stress is 28 MPa for PXE 21 and 90 MPa for PXE 41. Hence PXE 41 is the most suitable material for static stress or squeeze applications. For applications in which the available space and mechanical pressure are limited, a dynamic stress, e.g. a short impact applied by means of a hammer spring system, is preferred. The duration of the voltage pulse is determined mainly by the striker mechanism (about 20 to 50 μs). An important advantage of short impact is that the maximum stress, at which depolarization is still reversible, shifts towards higher values (about 50 MPa for PXE 21). For normal size impact mechanisms for domestic and industrial appliances, PXE 21 is the most suitable material. However, for high impacts in small ignition mechanisms, PXE 41 is the recommended material (maximum dynamic stress 130 MPa).

PIEZOELECTRIC BLOCKS

for impact mechanisms

The electrodes are silver plated. The electrode which has been connected to the positive terminal of the polarizing apparatus is identified. The direction of polarization is axial.

Catalogue number	4322 020 07310
Dimensions	2,54 x 2,54 x 2,56 mm
Material	PXE 21
Nominal capacitance	39 pF
Coupling coefficient k_{33}	$\geqslant$ 0,68
Charge constant d_{33}	$\geqslant 350 \times 10^{-12}$ C/N
Voltage constant g_{33}	$\geqslant 22 \times 10^{-3}$ Vm/N
Application	for flash-bulb ignition



PIEZOELECTRIC CERAMICS FOR ULTRASONIC TRANSDUCERS

INTRODUCTION

PXE, usually in the form of axially poled discs or rings, may be used in high-intensity ultrasonic transducers. Typical applications are echo-sounding (PXE 41), ultrasonic cleaning (PXE 42), and ultrasonic welding and machining (PXE 43).

For echo-sounding, a disc is driven in the 33 thickness mode and is usually housed in a protective plastic encapsulation. The preferred operating frequency lies between 150 and 200 kHz which gives a compact transducer with adequate directivity and reasonable range.

A simple ultrasonic cleaning transducer is formed by a PXE disc, bonded to a metal disc which is itself bonded to the underside of a cleaning tank. The disc is driven in the radial mode at a frequency in the range 40 kHz to 60 kHz and causes the tank wall to vibrate in complex flexure modes, radiating ultrasound in to the tank. For highest ultrasonic intensities, it is advisable to adopt a pre-stressed sandwich construction in which two PXE discs or rings, separated by a thin metal shim, are sandwiched between two metal blocks. The PXE elements are driven in the 33 thickness mode and the complete assembly constitutes a half wave resonator. The whole structure is held together by bolts which subject the ceramic to a compressive force. In this way the ceramic is prevented from going into tension when vibrating. This structure also has the advantages of good heat dissipation, reduced losses owing to the good mechanical properties of metals, and a piezoelectric coupling which need not be much lower than that of a single-piece ceramic transducer. Such sandwich transducers operate in the frequency range 20 kHz to 50 kHz. They may be used for ultrasonic cleaning, in which case they are bonded to the underside of the cleaning tank. For welding or machining, the transducer is bolted to an additional mechanical transformer (horn) which serves to match the output to the acoustic load.

ACOUSTIC MATCHING OF TRANSDUCERS

When a transducer is coupled to a solid load, matching is usually achieved by means of a horn transformer. For matching to a liquid load, an extra layer with a thickness of one-quarter wavelength may be interposed between transducer and liquid. This interface layer should have an acoustic impedance, intermediate between that of the transducer and the liquid. Many synthetic materials, such as epoxy resins and other plastics, fall within this range.

In sandwich transducers, matching with liquids may also be assisted by forming the radiating metal block from a metal of low acoustic impedance, such as aluminium or magnesium alloy.

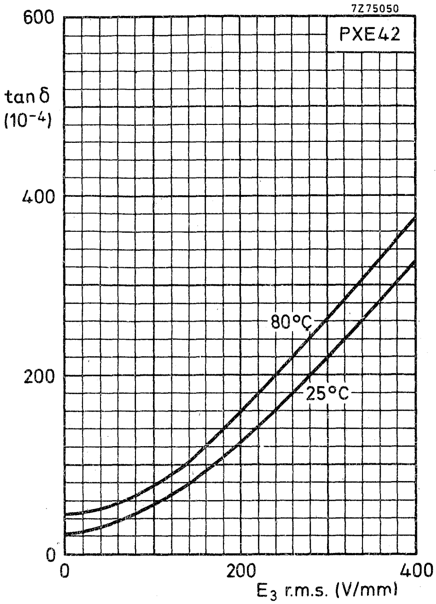
DYNAMIC BEHAVIOUR OF THE TRANSDUCER

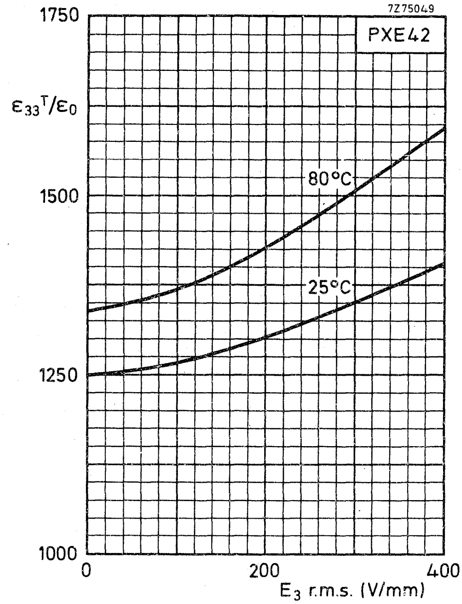
High intensity transducers are normally driven at resonance, and the equivalent circuit is as in Fig. 3*. For maximum efficiency, the transducer should be tuned electrically by means of an inductance given by $L = 1/(4\pi^2 f^2 C_O)$. The impedance of the transducer then appears as purely ohmic.

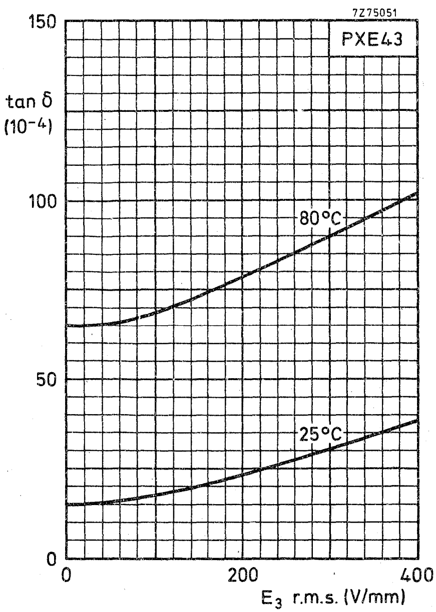
* See Introductory Notes.

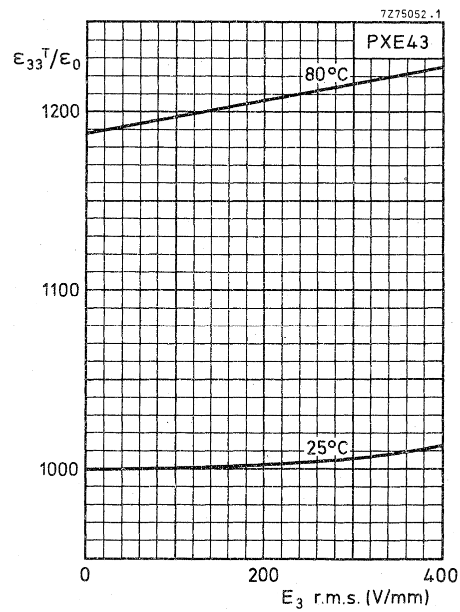
LARGE-SIGNAL PROPERTIES OF PXE 42 AND PXE 43

Behaviour of tan δ and relative permittivity $\epsilon_{33}{}^{T}/\epsilon_0$ under large driving fields.

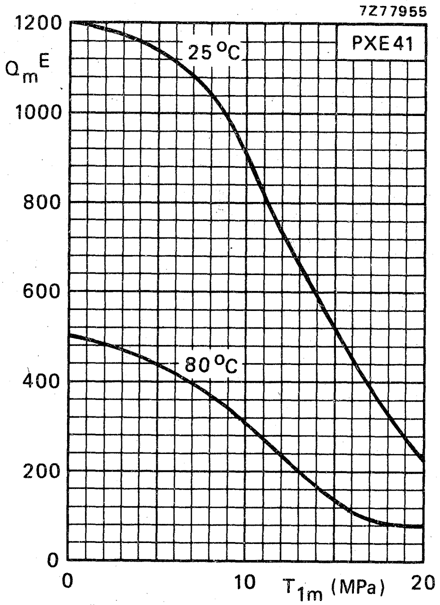


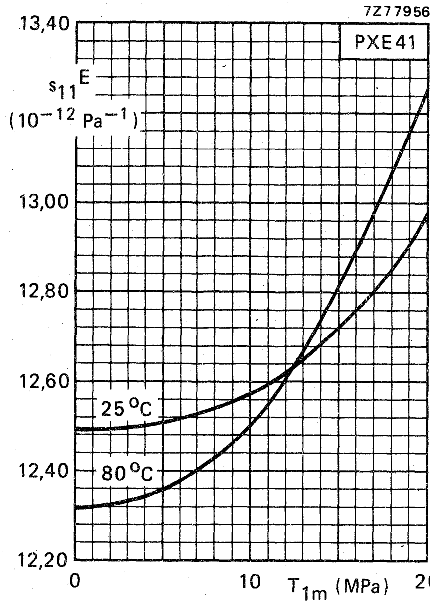


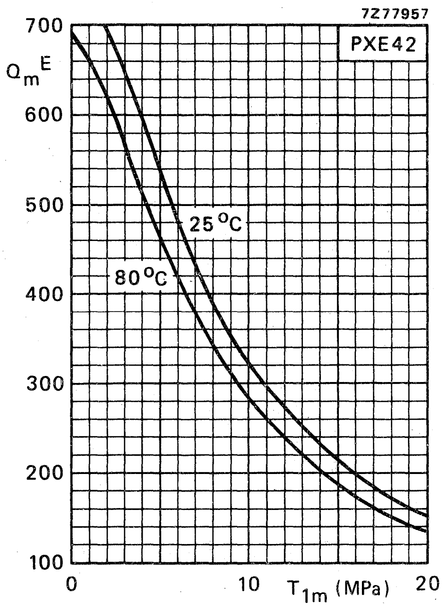


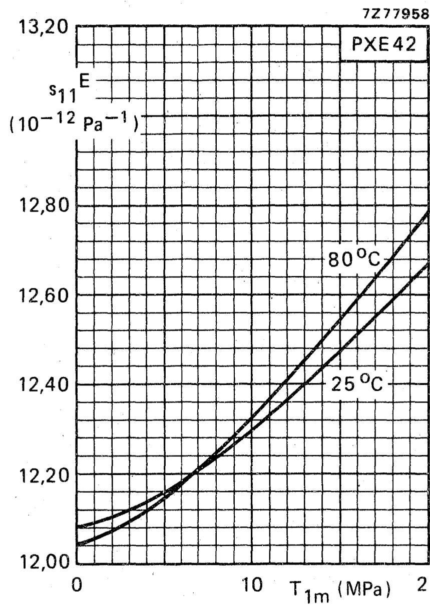


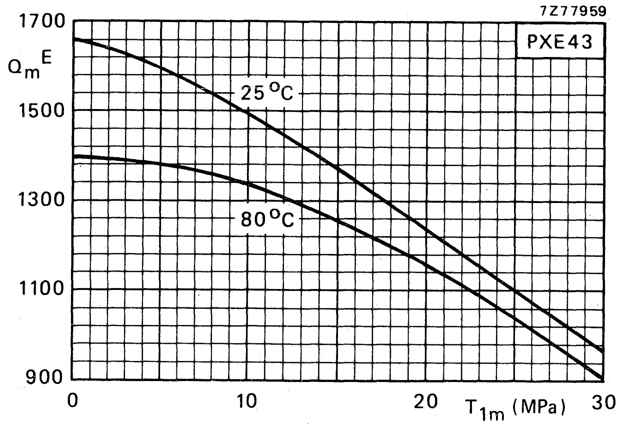
Variation of mechanical quality factor Q_mE and elastic compliance $s_{11}E$ with dynamic stress in PXE 41, PXE 42, PXE 43.

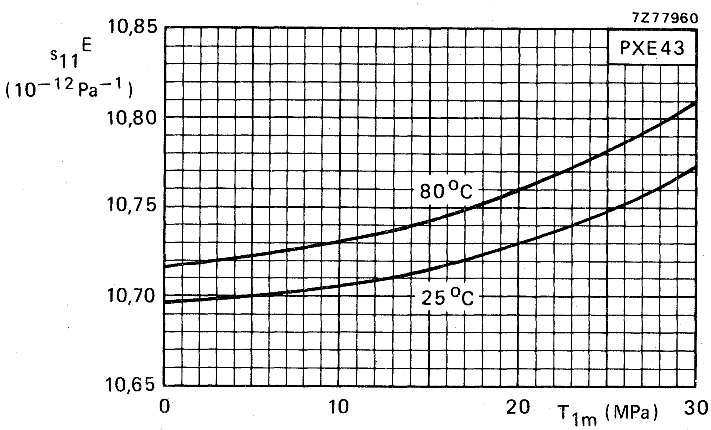









7Z77959
PXE43
Q_m^E
1700
1500
1300
1100
900
25 °C
80 °C
0
10
20
30
T_{1m} (MPa)


7Z77960
PXE43
s_{11}^E
(10^{-12} Pa^{-1})
10,85
10,80
10,75
10,70
10,65
80 °C
25 °C
0
10
20
30
T_{1m} (MPa)

PIEZOELECTRIC RINGS
for ultrasonic applications

The electrodes of the rings are silver plated. The electrode which has been connected to the positive terminal of the polarizing apparatus is identified. The direction of polarization is axial.

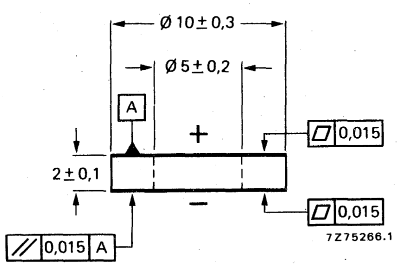
TECHNICAL DATA

Catalogue number	4322 020 06060	4322 020 06130	4322 020 06170
Dimensions in mm	ϕ 10 x ϕ 5 x 2	ϕ 20 x ϕ 6 x 5	ϕ 20 x ϕ 6 x 5
Material	PXE 41	PXE 42	PXE 41
f_p/f_s	⩾ 1,05	⩾ 1,05	⩾ 1,05
Nominal capacitance (pF)	320	650	650
Tan δ max.	4,0	4,0	4,0 x 10^{-3}

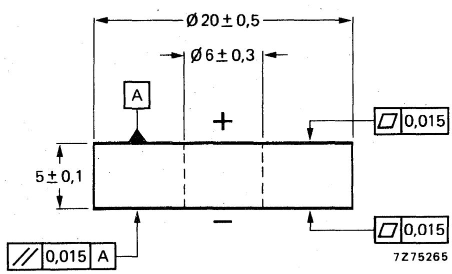
APPLICATIONS

For use in a wide range of applications, e.g.:
- low-power ultrasonic microbonding in semiconductor processes;
- ultrasonic drilling of small holes;
- ultrasonic dental descalers;
- small ultrasonic cleaning devices;
- underwater acoustics.

MECHANICAL DATA



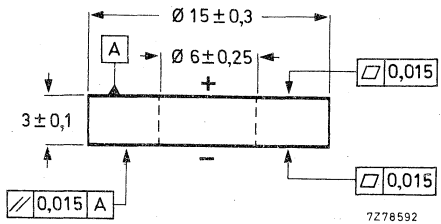
Type 4322 020 06060



Types 4322 020 06130 and 4322 020 06170

PIEZOELECTRIC RING
for ultrasonic atomisers

The electrodes of the ring are silver plated. The electrode which has been connected to the positive terminal of the polarizing apparatus, is identified. The direction of polarization is axial.

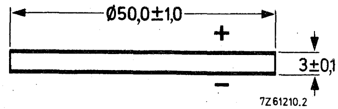


Material	PXE 42
f_p/f_s	⩾ 1,06
Nominal capacitance	550 pF
→ Tan δ max.	$4{,}0 \times 10^{-3}$
Catalogue number	8222 293 24720

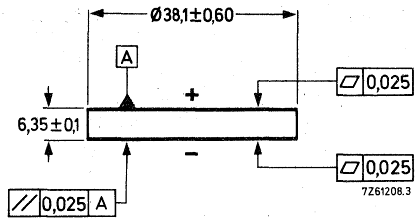
PIEZOELECTRIC DISCS
for ultrasonic cleaning

The electrodes of the discs are silver plated. The electrode which has been connected to the positive terminal of the polarizing apparatus, is identified. The direction of polarization is axial.

Material: PXE 41
Nominal capacitance: 7200 pF
Catalogue number: 4322 020 05590

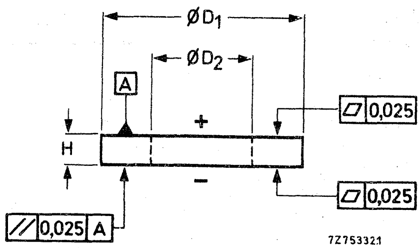


Material: PXE 42
Nominal capacitance: 2000 pF
Catalogue number: 4322 020 05660



PIEZOELECTRIC RINGS
for ultrasonic cleaning

The electrodes of the rings are silver plated. The electrode which has been connected to the positive terminal of the polarizing apparatus, is identified. The direction of polarization is axial.

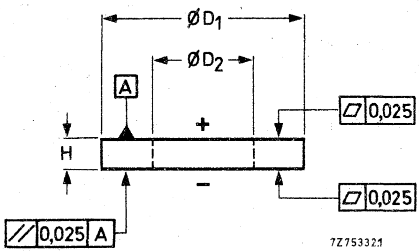


Material: PXE 42

D_1 mm	D_2 mm	H mm	nom. capacitance pF	catalogue number
38,1 ± 0,6	12,7 ± 0,35	4 ± 0,1	2800	4322 020 06090
38,1 ± 0,6	12,7 ± 0,35	6,35 ± 0,1	1800	4322 020 06040
38,1 ± 0,6	19,1 ± 0,5	6,35 ± 0,1	1500	4322 020 06070
50 ± 1	20 ± 0,5	6 ± 0,1	3000	4322 020 06050
50,5 ± 1	17,0 ± 0,5	6,35 ± 0,1	3100	4322 020 06120

PIEZOELECTRIC RINGS
for ultrasonic welding

The electrodes of the rings are silver plated. The electrode which has been connected to the positive terminal of the polarizing apparatus, is identified. The direction of polarization is axial.



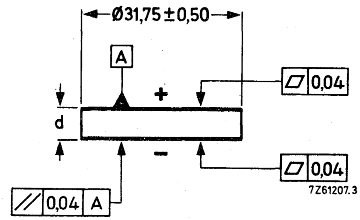
Material: PXE 43

D1 mm	D2 mm	H mm	nom. capacitance pF	catalogue number
20 ± 0,5	6 ± 0,3	5 ± 0,1	500	4322 020 06290
25 ± 0,6	10 ± 0,3	5 ± 0,1	725	4322 020 06280
38,1 ± 0,6	12,7 ± 0,35	6,35 ± 0,1	1400	4322 020 06270
38,1 ± 0,6	19 ± 0,5	5 ± 0,1	1500	4322 020 06160
50 ± 1	20 ± 0,5	5 ± 0,1	2900	4322 020 06150
50 ± 1	20 ± 0,5	6 ± 0,1	2400	4322 020 06140

PIEZOELECTRIC DISCS
for echo sounding probes

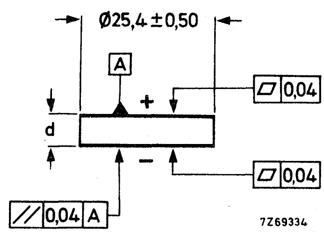
The electrodes of the discs are silver plated. The electrode that has been connected to the positive terminal of the polarizing apparatus, is identified. The direction of polarization is axial.

Material	:	PXE 41
Resonant frequency	:	151 ± 5 kHz (thickness mode)
Thickness (d)	:	approx. 14,3 mm (adapted to resonant frequency)
Nominal capacitance	:	approx. 620 pF
Catalogue number	:	4322 020 05240



Dimensions in mm

Material	:	PXE 41
Resonant frequency	:	200 ± 10 kHz (thickness mode)
Thickness (d)	:	approx. 10,2 mm (adapted to resonant frequency)
Nominal capacitance	:	approx. 520 pF
Catalogue number	:	4322 020 05750



PIEZOELECTRIC CERAMICS FOR FLEXURE ELEMENTS

INTRODUCTION

Simple PXE transducers operating in the 31 or the 33 mode have a very low compliance. This means that the voltage generated by a small force, is very low; also that conversely, the displacements obtainable with these transducers are far too small for many applications and that the voltages and forces required to produce these displacements, are very high. They also present a considerable impedance mismatch to air, and therefore are not suitable for use as electro-acoustic transducers.

A much more compliant type of structure is the flexure element. This operates in a bending mode and the principle may be seen in Fig. 1 which shows a bilaminar strip, or 'bimorph' mounted as a cantilever. It consists of two thin PXE strips, bonded together with their poling directions opposed. A voltage, applied between the outer two electrodes, causes one strip to expand lengthwise by the 31 action, while the other contracts. The differential strain causes the cantilever to bend and the free end is displaced by a distance 'z'.

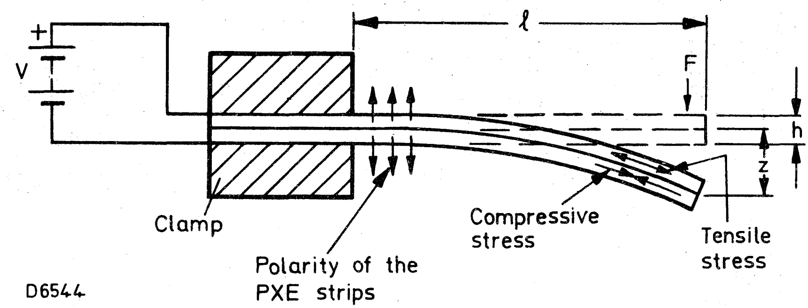


Fig. 1.

The 'multimorph' strip is a one piece ceramic extrusion which operates in exactly the same way. For electro-acoustic transducers (sonic and ultrasonic microphones and tone generators) one can employ the flexure element principle in square (or circular) 'bimorph' plates, or in a 'unimorph' diaphragm, a single PXE disc, bonded to the centre of a circular edge mounted aluminium diaphragm.

APPLICATIONS

Record player pick-ups.
ultrasonic air transducers for intruder alarms, remote control, etc.
small vibratory motors,
liquid level sensors,
fine movement control,
optical scanners and choppers,
pushbutton for keyboards.

MULTIMORPHS

Multimorphs are extrusions intended for high output pick-up heads. They can be used for both mono and stereo designs. In the latter case, two multimorphs are normally positioned at 90° to each other, and at 45° to the record surface. Multimorphs may also be used as electro-mechanical transducers to achieve small deflections at low forces.

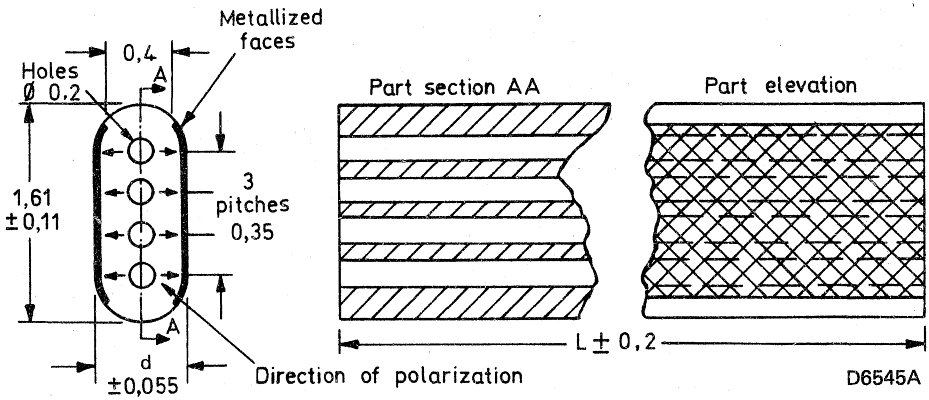


Fig. 1.

Material: PXE 5

L mm	catalogue number outer electrode negative	 outer electrode positive	d mm
9,6	4322 020 04760	4322 020 04750	0,675
12,7	4322 020 02480	4322 020 02460	0,675
15,5	4322 020 02490	4322 020 02470	0,675
70,0	4322 020 04840		0,63

ELECTRICAL AND MECHANICAL DATA

Sensitivity

There are two methods to support multimorphs serving most requirements; these are shown in Figs 2a and 2b. Figure 2a depicts a cantilever support in which the strip is clamped at one end and mechanical deflection takes place at the other. Figure 2b shows an ends-pinned support in which the strip is freely supported between two points, which are usually symmetrically placed, and the mechanical deflection takes place midway between these points. The cantilever is a more compliant structure for a given bent length.

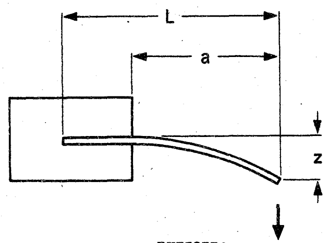


Fig. 2a.

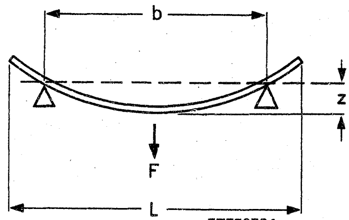


Fig. 2b.

mode of operation	parameter	unit	formula	
			cantilever support end drive (Fig. 2a)	ends pinned support centre drive (Fig. 2b)
mechano-electrical	electric charge output versus force F	μC/N	$0{,}74 \times 10^{-3} a^2$	$0{,}18 \times 10^{-3} b^2$
	electric charge output versus deflection z	μC/mm	5,7/a	23/b
electro-mechanical	deflection z versus applied voltage (force F = 0)	mm/V	$7{,}3 \times 10^{-7} a^2$	$1{,}8 \times 10^{-7} b^2$
	force F versus applied voltage (deflection z = 0)	N/V	$5 \times 10^{-3}/a$	$2 \times 10^{-2}/b$

a and b are active (bent) lengths of element in mm.

Notes

1. These sensitivities are accurate at low level, but the performance of multimorphs is very dependent on the nature of the support structure. When subjected to large deflections, forces, or voltages, multimorphs are somewhat non-linear in their behaviour due to creep in the ceramic. This is particularly noticeable under static conditions or at very low frequencies. However, even under these conditions, the formulae will give useful estimates of the sensitivities to be expected.
2. The electrical output is given in terms of the charge generated by a deflection or force. The voltage output may be calculated by dividing this by the total capacitance of the multimorph plus the effective shunt capacitance of any associated circuit.

Maximum capacitance of multimorph where L is the total length of the element in mm	52L pF
Maximum recommended bending moment If this value is exceeded, partial depoling may result	$1,6 \times 10^{-3}$ Nm
Minimum bending moment to fracture	$7,5 \times 10^{-3}$ Nm
Maximum recommended applied electric field strength Higher values may cause partial depoling	400 V/mm

Temperature dependence

The characteristics are virtually independent of temperature

Time stability

No appreciable ageing

Linearity

When used as a mechano-electrical pick-up, as in record players, second-harmonic distortion is negligible as compared with normal tracking distortion, but see note 1 on the previous page.

Resonance frequencies

mode	cantilever support	nodal support	ends-pinned support $b \simeq L$
fundamental	$f_o = \frac{0,32}{a^2} 10^6$ Hz	$f_o = \frac{2,1}{b^2} 10^6$ Hz (b = 0,55L)	$f_o = \frac{0,9}{b^2} 10^6$ Hz
1st overtone	$f_1 = 6,3f_o$	$f_1 = 2,8f_o$ (b = 0,28L)	$f_1 = 4f_o$
2nd overtone	$f_2 = 18f_o$	$f_2 = 5,4f_o$ (b = 0,95L)	$f_2 = 9f_o$
3rd overtone	$f_3 = 34f_o$	$f_3 = 8,9f_o$ (b = 0,67L)	$f_3 = 16f_o$

a = free length of strip for cantilever support (see Fig. 2a).

b = distance in mm between symmetrically placed support points for nodal or ends-pinned support (see Fig. 2b).

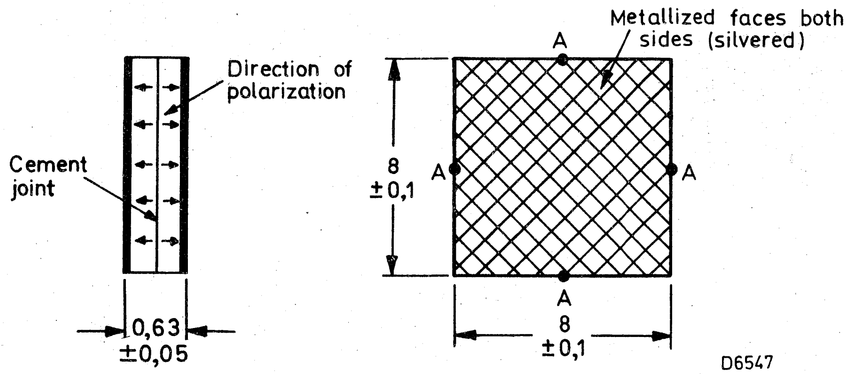
L = total length in mm.

Due to the comparatively low Q-factor of PXE 5, the undamped resonances are not sharp.

BIMORPH

ultrasonic air transducer

A bimorph plate used to generate or detect ultrasound in air, e.g. counting and monitoring (for example on a production line), level control of liquids and powders, movement detection, remote control of machines and equipment (for example TV receivers), and intruder alarms.



Material		PXE 5
Resonance frequency	f_s	34,5 ± 3,0 kHz
Capacitance at 1 kHz		1450 ± 290 pF
Catalogue number		4322 020 08120

DESCRIPTION

The transducer element forms an electromechanical resonator which has a resonance frequency f_s (impedance minimum) of typ. 34,5 kHz and an anti-resonance frequency f_p (impedance maximum) of typ. 37,2 kHz. The transducer can be operated efficiently at, or between, these frequencies. The frequency f_M at which maximum response is obtained depends upon the impedance connected across the terminals. At very low impedance f_M approaches f_s, whilst at very high impedance it approaches f_p. The plate has vibration nodes at the centres of the sides (points A). Electrical connection and support can be effected at these points without disturbing the vibration. The transducer plate radiates ultrasound in a direction perpendicular to its surface. The centre of the plate vibrates in anti-phase with the four corners. Therefore, the acoustic response of the transducer is much improved by masking the centre. This can be done by placing a small plate above the area within square AAAA (see drawing above). Electrical and acoustical performance will depend to some extent on the method of mounting and housing.

ELECTRICAL AND ACOUSTIC DATA

(Typical values for a device mounted in a well designed housing.)

Resonance data

Resonance frequency f_s	34,5 kHz
Impedance at resonance (measured at 3 V r.m.s.)	500 Ω
Sensititvity as a receiver (R_i = 10 Ω)	4 μA/Pa
Sound output* as a transmitter (when driven at 3 V r.m.s.)	0,37 Pa

Anti-resonance data

Anti-resonance frequency f_p	37,2 kHz
Impedance at anti-resonance (measured at 3 V r.m.s.)	49 kΩ
Sensitivity as a receiver (R_i = 1 MΩ)	21 mV/Pa
Sound output* as a transmitter (when driven at 60 μA r.m.s.)	86 mPa

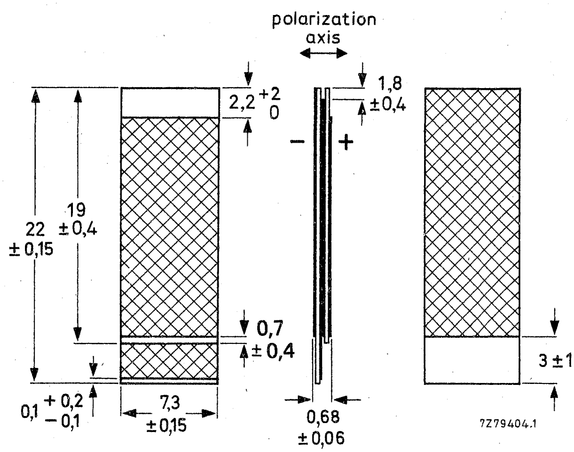
Bandwidth

The bandwidth of the transducer depends on the terminating impedance. At resonance or anti-resonance the 3 dB bandwidth is about 600 Hz. When terminated with a resistance of 3 kΩ, it is about 3 kHz, and the frequency of maximum response is midway between f_s and f_p. A further increase in bandwidth to about 10 kHz may be effected by inductive tuning (about 10 mH).

* Sound pressure (r.m.s.) measured at a distance 1 m in front of device.

BIMORPH
actuator

The product is normally used for dynamic track sensing in VCR equipment. Other applications are in all kinds of deflection equipment. It consists of two polarized plates connected together, each of them having its specific electrode pattern. The electrodes consist of a nickel-chromium-nickel layer.



Material: PXE 5

Catalogue number: 4322 020 07400

Resonance frequency: 1360 Hz $< f_s <$ 1800 Hz

Deflection: measured at 35 Hz with 270 V (peak to peak), free length: 13,2 mm

Deflection: 80 - 120 μm (peak to peak)

PIEZOELECTRIC DISCS AND PLATES

for various applications

PXE discs and plates can be used in a great number of miscellaneous applications, and electrical contact may be made by soldering, bonding or clamping wires to the electrodes which are usually made of silver.

SOLDERING

A strong joint between the silver and the ceramic body is made by firing a silver paste on to the ceramic surface. The resulting silver layer can be used for soldering wires if the following rules are observed.

The electrode surface should be free from grease and dust. If tarnished, the silver should be lightly cleaned. Suggested soldering prescription:

- soldering iron: standard 25 to 50 W type with copper bit,
- soldering iron temperature: 250 to 300 °C,
- preferred solder: Sn/Pb/Ag 60/37/3; otherwise Sn/Pb 60/40,
- soldering time: 3 ± 1 s,
- standard wire diameter: 0,3 mm or fine stranded flex.

The soldering time should be kept as short as possible; otherwise the disc or plate may be partly depolarized (to an extent depending on temperature and time). The use of a silver saturated solder is recommended to avoid dissolution of the silver layer, but this does involve a slightly higher soldering temperature than with normal lead-tin solder.

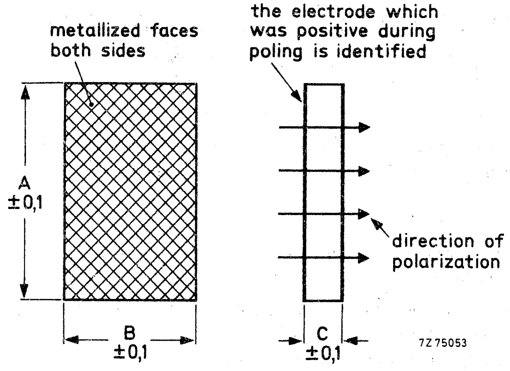
BONDING

Stranded wire may also be bonded to the electrode surface using a resin to give a good low resistance contact. Lacquered strands must of course be cleaned before bending and the strands should be splayed out and pressed on to the electrode surface while the epoxy resin is curing.

GENERAL NOTE

Where possible it is preferable to make electrical contact at the vibration node in resonant devices. In some application a simple spring or pressure contact may be quite adequate.

PLATES

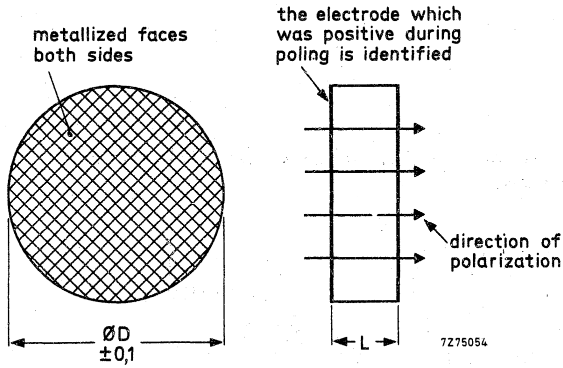


Material: PXE 5

Transverse planar coupling factor k_{31}: $\geqslant 0{,}30$

A mm	B mm	C mm	catalogue number
6,0	4,0	0,5	4322 020 07150
12,0	6,0	0,5	4322 020 07050
12,0	6,0	1,0	4322 020 07060
16,0	12,0	1,0	4322 020 02310

DISCS



Material: PXE 5

D mm	L mm	catalogue number
3,0	0,50 ± 0,05	4322 020 05250
5,0	0,20 ± 0,05	4322 020 05260
5,0	0,30 ± 0,05	4322 020 05270
5,0	0,50 ± 0,05	4322 020 05280
5,0	1,0 ± 0,1	4322 020 05300
5,0	2,0 ± 0,1	4322 020 05310
10,0	0,30 ± 0,05	4322 020 05330*
10,0	0,50 ± 0,05	4322 020 05340
10,0	1,0 ± 0,1	4322 020 02330
10,0	2,0 ± 0,1	4322 020 05350
10,0	3,0 ± 0,1	4322 020 05360
10,0	5,0 ± 0,1	4322 020 05370
16,0	0,30 ± 0,05	4322 020 05400
16,0	0,50 ± 0,05	4322 020 05410
16,0	1,1 ± 0,1	4322 020 02250
16,0	2,0 ± 0,1	4322 020 05420
16,0	3,0 ± 0,1	4322 020 02300
25,4	0,50 ± 0,05	4322 020 05430
25,4	1,0 ± 0,1	4322 020 05440
25,4	2,0 ± 0,1	4322 020 05450

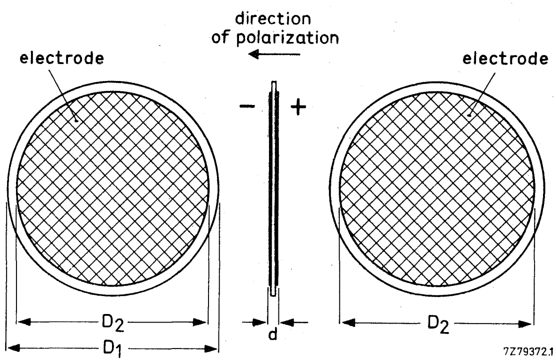
* These discs have a non-silvered edge of 1,5 mm.

DISCS FOR AUDIO APPLICATIONS

To be used in devices such as

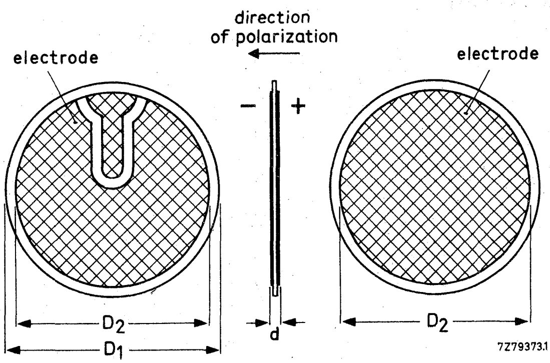
- clocks and watches
- smoke alarm devices
- audio alarms
- telephone/microphone
- small loudspeakers and tweeters

A PXE 5 or PXE 52 disc, mounted on a metal membrane is particularly suited for these types of application. It is simple, efficient and inexpensive.



Two electrode configuration.

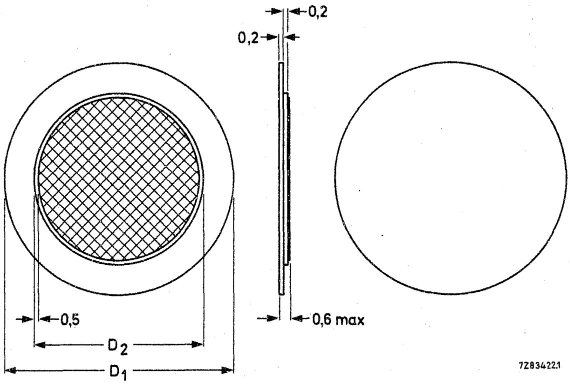
D_1 mm	D_2 mm	d mm	material	capacitance nF	catalogue number
10	9	0,2	PXE 5	5	4322 020 05320
10	9	0,2	PXE 52	8	8222 293 24140
16	15	0,2	PXE 52	20	4322 020 08430
16	15	0,2	PXE 5	13	4322 020 05390
20	19	0,2	PXE 52	33	8222 293 24050
25	24	0,2	PXE 52	53	8222 293 24030



Three electrode configuration.

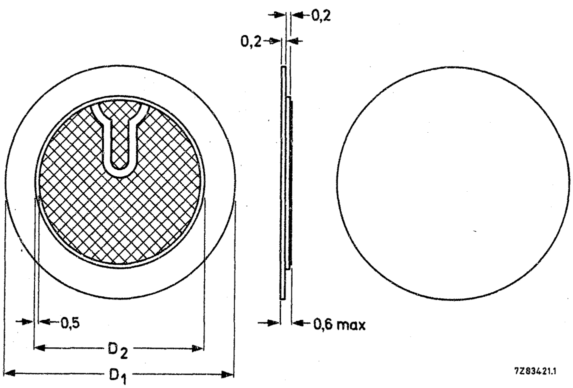
D_1 mm	D_2 mm	d mm	material	capacitance nF	catalogue number
16	15	0,2	PXE 52	16	4322 020 05970
16	15	0,2	PXE 5	11	4322 020 05960
20	19	0,2	PXE 52	30	8222 293 24060
25	24	0,2	PXE 52	47	8222 293 24040

DISCS GLUED ON MEMBRANE



Material: PXE 52

D1 mm	D2 mm	capacitance nF	catalogue number
12,5	10	6	4322 020 08860 (membrane thickness 0,1 mm)
20	16	15	4322 020 08820
27	20	25	4322 020 08840
35	25	40	4322 020 08850



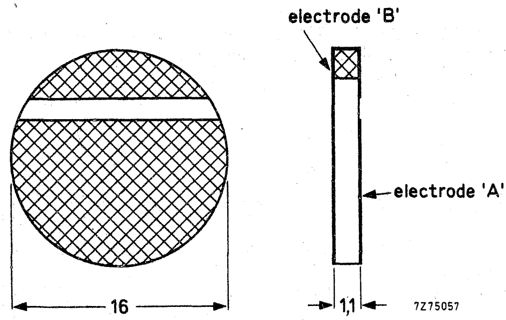
Material: PXE 52

D1 mm	D2 mm	capacitance nF	catalogue number
20	16	12	4322 020 08870
27	20	22	4322 020 08880
35	25	35	4322 020 08890

FEEDBACK DISCS AND PLATES

These feedback discs have provision for connection to both electrodes from one side by means of a wrap-round electrode as shown below; they are therefore particularly suitable for bonding to flat surfaces where electrical connection to the front face is difficult.

DISC



Material: PXE 5

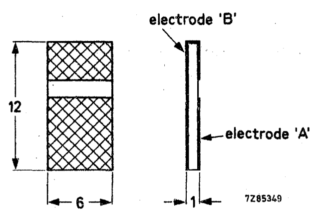
Effective coupling factor k_{eff}: ≥ 0,30

Catalogue numbers

Polarity of electrode 'A' during poling: negative – 4322 020 02260
positive – 4322 020 02270

The electrode which was positive during poling is identified.

PLATE



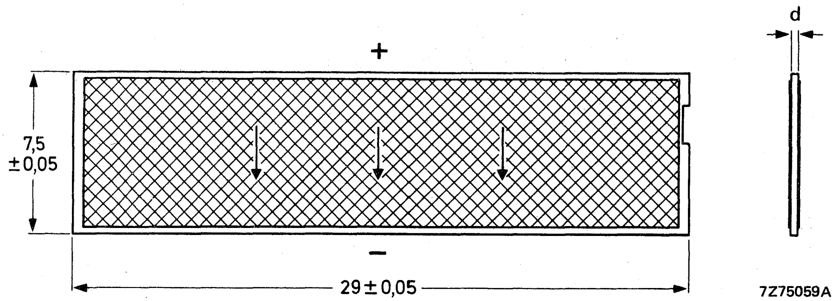
Material: PXE 5

Catalogue number 8222 293 27130

The electrode "A" which was positive during poling is identified.

TRANSDUCER FOR DELAY LINES

These products are used in modern acoustic delay systems with an electro-mechanical transducer which converts electric signals to acoustic signals and back again to electric signals, after having travelled through an acoustic delay medium. Example: colour television receivers.



7Z75059A

Material:	PXE 7
Resonant frequency:	4,1 ± 0,1 MHz
Thickness (d):	approx. 0,24 mm (adapted to resonant frequency)
Nominal capacitance:	8700 pF ± 20% (at 1 kHz ± 20%)
Catalogue number:	4322 040 02910

Material:	PXE 7
Resonant frequency:	3,3 ± 0,1 MHz
Thickness (d):	approx. 0,294 mm (adapted to resonant frequency)
Nominal capacitance:	7000 pF ± 20% (at 1 kHz ± 20%)
Catalogue number:	4322 040 02920

PERMANENT MAGNET MATERIALS B

INTRODUCTION

Modern magnets are far removed from the traditional idea of a U-shaped iron bar. Today, magnets are available in a variety of shapes to suit many applications, and the introduction of magnetic alloys and magnetic-oxide based ceramics has made the simple iron magnet the exception rather than the rule. Advances in magnet technology over the past 50 years have naturally led to an increase in the number of applications. According to some estimates, the modern household contains more than forty magnets, ranging from the refrigerator door catch to the field magnets of the record player motor.

Although essentially a bulk material property, magnetism is often explained using a model of the atomic structure of matter. In the classical atomic model, spinning negatively charged electrons revolve around a positively charged nucleus. The motion of these electrons can be regarded as a current loop which give rise to a magnetic dipole, in the same way as a current flowing through a conductor produces a magnetic field.

In a non-magnetic material, these magnetic dipoles are randomly oriented, and produce no net magnetic moment in the bulk material.

In a magnetic material, however, the dipoles align themselves locally, in regions called *domains.* These domains are usually aligned randomly throughout the material and so produce no net magnetic moment. In the presence of an external magnetic field, domains already aligned with the field grow at the expense of non-aligned domains. The bulk material then has a net magnetic moment and is said to be *polarized in* the field direction. As field strength increases, the aligned domains expand until, finally, no non-aligned domains remain. The material is then said to be *saturated.*

The ease with which a magnetic material can be polarized depends upon its microstructure. Likewise, this affects its behaviour when the magnetizing field is removed; the domains then resist returning to the previous disorganized state, and a residual polarization remains known as the *remanence.* To reduce the polarization to zero, a field in the reverse direction must be applied; the magnitude of this field is known as the *coercivity* of the material. This is an important property of a magnetic material, its value indicates the material's magnetic hardness. Soft magnetic materials, used, for example, in transformers and flux conductors, have coercivities of only a few amp/metre. Permanent magnets are produced from hard magnetic material, which is the general term for materials with coercivities exceeding 1 kA/m. This is the lower limit for hard magnetic materials; in general, the coercivities of such materials are considerably higher. Some of the hard magnetic materials in this data handbook have coercivities is excess of 1200 kA/m.

The creation of a permanent magnet requires energy. This energy is derived from the magnetizing field and is stored in the magnet, which thereafter can sustain a magnetic field itself, without power dissipation, power sources or electrical connections. A permanent magnet thus behaves as an energy source. The balance between internal energy and external energy depends on the magnetic load, which can consist of an air gap and/or an external magnetic field.

Normally, a magnet is an integral part of a construction, therefore mechanical as well as electrical properties have to be considered. Moreover, each application has its own special requirements, so a range of materials must be available if the user is to find one that fully satisfies his needs. The following sections provide the relevant data on our extensive range of magnetic materials, and give some application information to enable the user to make the most efficient use of the materials described. Should further information or technical assistance be needed, please contact our technical departments.

SURVEY OF PERMANENT MAGNET MATERIALS

There is a wide range of electrical and mechanical requirements encountered in magnetic systems, and no one material exists that satisfies all of them. However, it is usually possible to find a suitable material within our range. Selection will be based on magnetic and mechanical considerations, magnetic configuration and the cost effectiveness of the resulting system (not necessarily the same as magnet cost).

The family tree (next page shows our range of permanent magnet materials.

GENERAL NOTES

Units

In the following tables the main properties of the various materials are given in SI units. More detailed information is to be found in the relative data pages further down the book, where c.g.s. units are also listed.

Typical values

The term typical values ("typ.") denotes a value which frequently occurs. Typical values enable the user user to compare various grades; they are intended to be average or mean values.

Minimum values

The minimum values quoted are guaranteed for specified test pieces.

Minimum values of B_r and H_{cB} do not occur simultaneously. The minimum value of B_r coincides with an H_{cB} well above the quoted typical value, whereas the minimum value of H_{cB} is coupled with a high value of B_r.

Material designation

The material designation consists of the name of the material:

FXD (Ferroxdure),
Ticonal,
RES, REM (Rare Earth alloys)

followed by a type classification. Plastic bonded Ferroxdure grades include a letter for the bonding material:

P = flexible thermoplastic,
SP = rigid thermoplastic.

Where applicable, a suffix F indicates that the material is flame retardant to UL94V-1.

Rare Earth materials are available in sintered (RES) and matrix (REM) grades.

MANUFACTURING TECHNOLOGY

Magnets are often identified by the way they are made or by their construction. Knowledge of their manufacture is useful since it provides an indication of their mechanical properties and tolerances, as well as of the possible shapes they can be supplied in. Since the magnet is usually an integral part of its mechanical system, these factors must be considered when selecting a magnetic material for a particular application.

Our permanent magnets fall into two main groups: metal alloy and hard ferrite. These groups can be further subdivided according to the manufacturing technology: sintering, plastic bonding and casting. Finally, in every subdivision the magnets can be produced with isotropic or anisotropic magnetic properties, the latter being produced during manufacture by imparting an enhanced magnetic direction to the material using an external field. Limitations on the possible directions are discussed in the data section.

Sintered magnet production

Sintered magnets are formed by compacting powders, granules or slurry (powder/water mixture) under pressure, and then sintering the compact at controlled temperatures. On cooling, the powder grains fuse to produce a stable ceramic structure. During sintering, the material shrinks, the density increasing by as much as 40%. This increase in density improves the magnetic properties of the material considerably.

The compact is usually formed in a die, which is designed such that after sintering, the magnet can be shaped with minimum machining. For anisotropic magnets, an external magnetic field applied during the compaction stage imparts the enhanced magnetic direction.

The method of manufacture of these products and their ceramic nature restrict them to relatively simple shapes. Moreover, for anisotropic Ferroxdure magnets the direction of magnetization is normally restricted to the direction of compaction. Nevertheless, for most applications sintered magnets are the natural choice since they provide an excellent compromise between good magnetic properties and economy.

Plastic bonded and matrix magnets

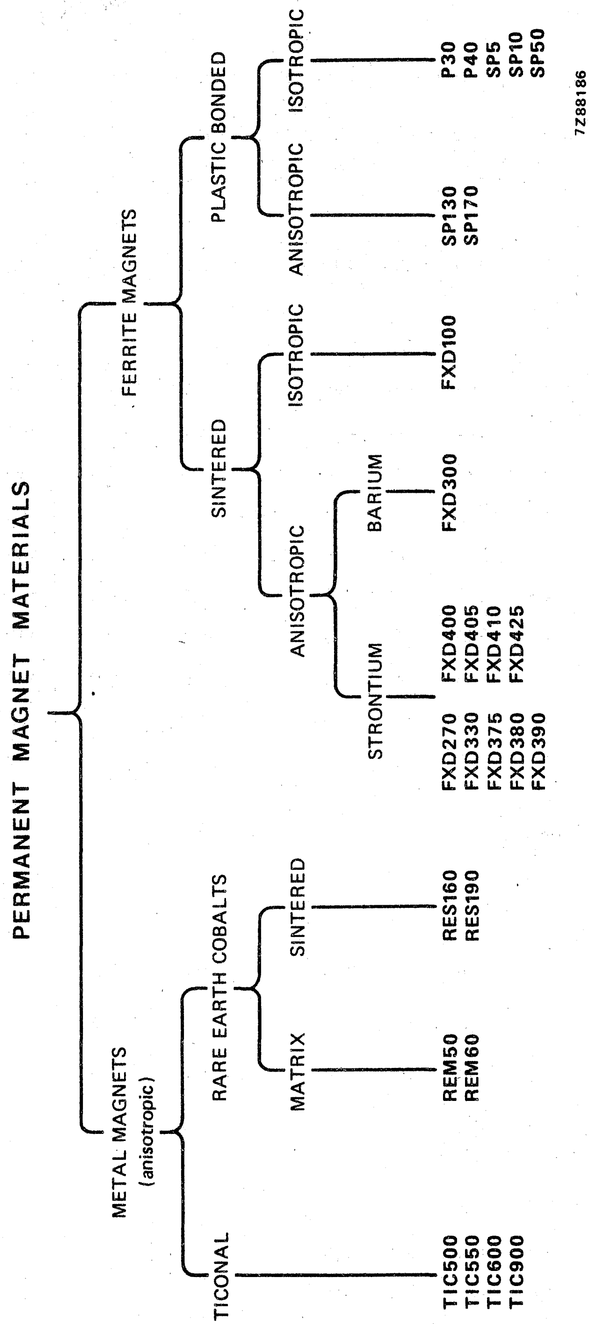
The magnets are produced from magnetic powders mixed with bonding agents, by methods common in the plastics industry, i.e. extrusion, injection moulding and pressing. In this way complex shapes are possible. Magnetic fields applied during the forming operation can provide anisotropic magnetic properties if these are required. If premagnetized granules are used, these can be aligned during shaping to allow the formation of complicated magnetizing patterns without the need for further magnetization.

Plastic bonded magnets can be made to very fine tolerances, and machining is rarely needed. Their density, however, is low compared with sintered magnets, so their magnetic properties are generally inferior. Nevertheless, they are ideal for applications requiring complex shapes and magnetization patterns.

Cast magnets (ticonal)

These magnets are made by casting an alloy, consisting mainly of iron, nickel, cobalt and aluminium using foundry techniques. To increase the magnetic hardness of the alloy, crystal growth is encouraged by heating and controlled cooling, often in magnetic fields. The heat treatment and its effect on the crystal structure does, however, impose certain limitations on dimensions and shape.

Cast magnets are strongly anisotropic. They can be made to fine tolerances, and usually only their pole faces need be ground. They are especially useful in applications requiring a high remanent flux density and/or extremely low temperature coefficient.


PERMANENT MAGNET MATERIALS
METAL MAGNETS
(anisotropic)
FERRITE MAGNETS
TICONAL
RARE EARTH COBALTS
SINTERED
PLASTIC BONDED
MATRIX
SINTERED
ANISOTROPIC
ISOTROPIC
ANISOTROPIC
ISOTROPIC
STRONTIUM
BARIUM
TIC500
TIC550
TIC600
TIC900
REM50
REM60
RES160
RES190
FXD270
FXD330
FXD375
FXD380
FXD390
FXD400
FXD405
FXD410
FXD425
FXD300
FXD100
SP130
SP170
P30
P40
SP5
SP10
SP50
7Z88186

FERROXDURE (sintered)

material designation	remanence BR (mT) typ.	remanence BR (mT) min.	coercivity H_cB (kA/m) typ.	coercivity H_cB (kA/m) min.	polarization coercivity H_cJ (kA/m) typ.	polarization coercivity H_cJ (kA/m) min.	max. BH product $(BH)_{max}$ (kJ/m^3) typ.	max. BH product $(BH)_{max}$ (kJ/m^3) min.	$B_R \times H_cJ$ (KJ/m^3) typ.	$B_R \times H_cJ$ (KJ/m^3) min.

Isotropic

material designation	BR typ.	BR min.	H_cB typ.	H_cB min.	H_cJ typ.	H_cJ min.	$(BH)_{max}$ typ.	$(BH)_{max}$ min.	$B_R \times H_cJ$ typ.	$B_R \times H_cJ$ min.
FXD100	220	210	135	130	220		7,6	7,2	48,4	

Anisotropic

material designation	BR typ.	BR min.	H_cB typ.	H_cB min.	H_cJ typ.	H_cJ min.	$(BH)_{max}$ typ.	$(BH)_{max}$ min.	$B_R \times H_cJ$ typ.	$B_R \times H_cJ$ min.
FXD300	400	390	160	145	165	150	29,5	27,8	66	58,5
FXD425	420	410	225	215	240	225	33,0	31,5	101	92,3
FXD330	370	360	240	225	245	230	25,5	24,0	90,6	82,8
FXD375	380	370	265	250	275	260	27,0	25,5	105	96,2
FXD380	390	380	265	250	275	260	28,5	27,0	107	98,8
FXD390	400	390	265	250	275	260	30,0	28,5	110	101
FXD400	410	400	265	250	275	260	31,5	30,0	113	104
FXD270	340	330	265	250	335	320	21,5	20,0	114	106
FXD405	360	350	270	255	340	325	24,0	22,5	122	114
FXD410	380	370	280	270	320	305	27,0	25,5	122	113

FERROXDURE (plastic bonded)

Isotropic

material designation	BR typ.	BR min.	H_cB typ.	H_cB min.	H_cJ typ.	H_cJ min.	$(BH)_{max}$ typ.	$(BH)_{max}$ min.	$B_R \times H_cJ$ typ.	$B_R \times H_cJ$ min.
FXD SP5F	65	60	50	45	190		0,7			
FXD SP10 / SP10F	80	75	58	54	190		0,9	0,8		
FXD P30	125	115	88	84	190		2,8	2,4		
FXD P40 / P40F	145	135	96	88	190		3,6	3,2		
FXD SP50	155	150	104	100	190		4,4	4		

Anisotropic

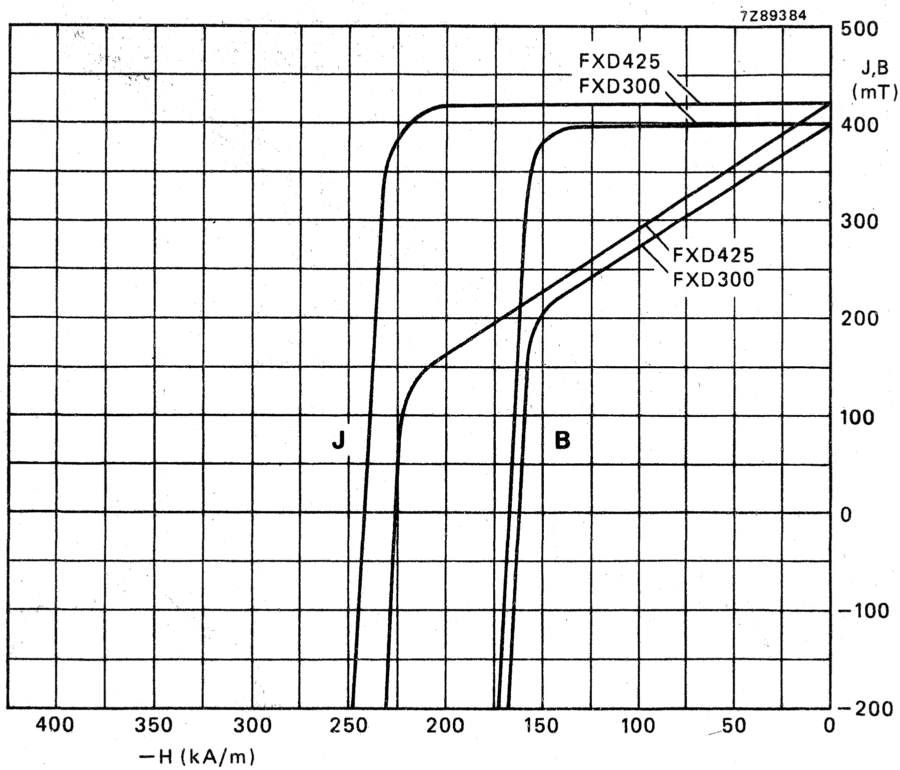
material designation	BR typ.	BR min.	H_cB typ.	H_cB min.	H_cJ typ.	H_cJ min.	$(BH)_{max}$ typ.	$(BH)_{max}$ min.	$B_R \times H_cJ$ typ.	$B_R \times H_cJ$ min.
FXD SP130	240	230	175	167	240		11	10		
FXD SP170	270	260	190	185	220					

TICONAL

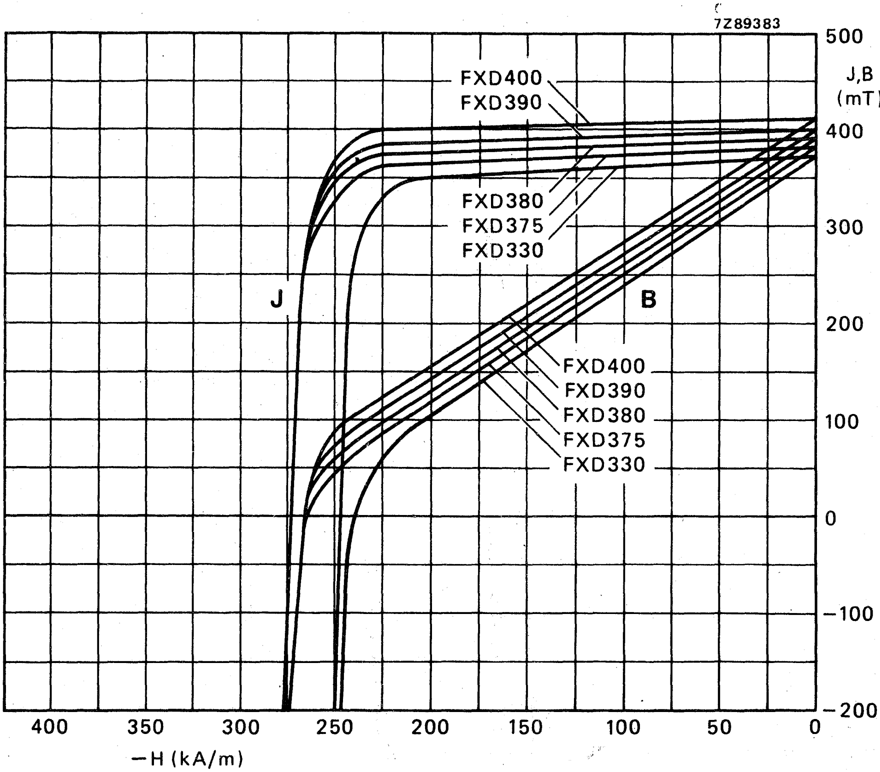
material designation	remanence BR (mT)		coercivity H_{cB} (kA/m)		polarization coercivity H_{cJ} (kA/m)		max. BH product $(BH)_{max}$ kJ/m³	
	typ.	min.	typ.	min.	typ.	min.	typ.	min.
Anisotropic								
Ticonal 500	**1250**	1200	**52,5**	50,1			**40,6**	37,4
Ticonal 550	**900**	850	**119**	111			**43,8**	39,8
Ticonal 600	**1310**	1260	**54,1**	51,7			**47,8**	43,8
Ticonal 900	**1100**	1000	**115**	111			**79,6**	67,7
RARE EARTH								
Sintered								
RES 160	**810**	790	**600**	560		1100	**128**	120
RES 190	**890**	870	**670**	620		1100	**154**	144
Matrix								
REM 50	**490**	470	**355**	345		1100	**46**	42
REM 60	**540**	510	**335**	325	**540**	520	**53**	48

TYPICAL DEMAGNETIZATION CURVES

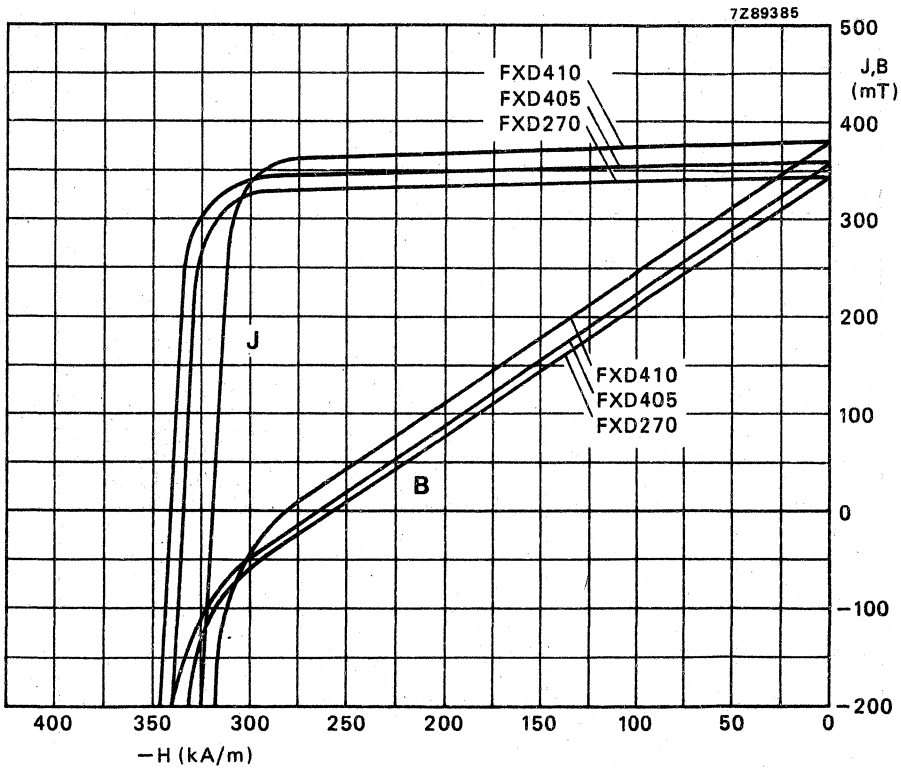
FERROXDURE



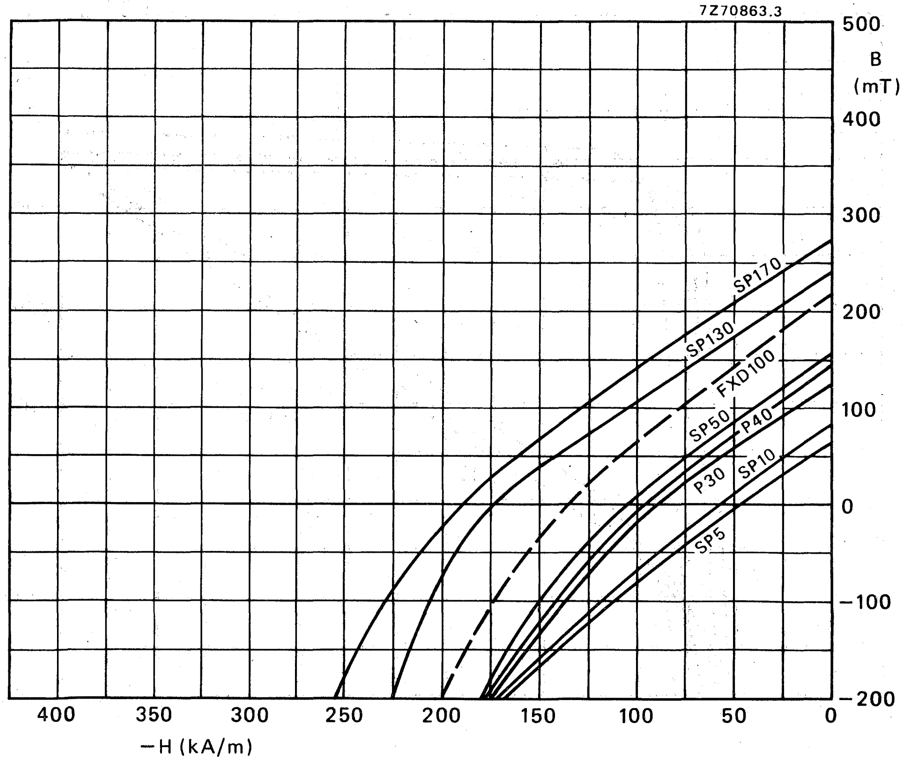
FERROXDURE


7Z89383
FXD400
FXD390
FXD380
FXD375
FXD330
J
B
FXD400
FXD390
FXD380
FXD375
FXD330
J,B
(mT)
500
400
300
200
100
0
−100
−200
400
350
300
250
200
150
100
50
0
−H (kA/m)

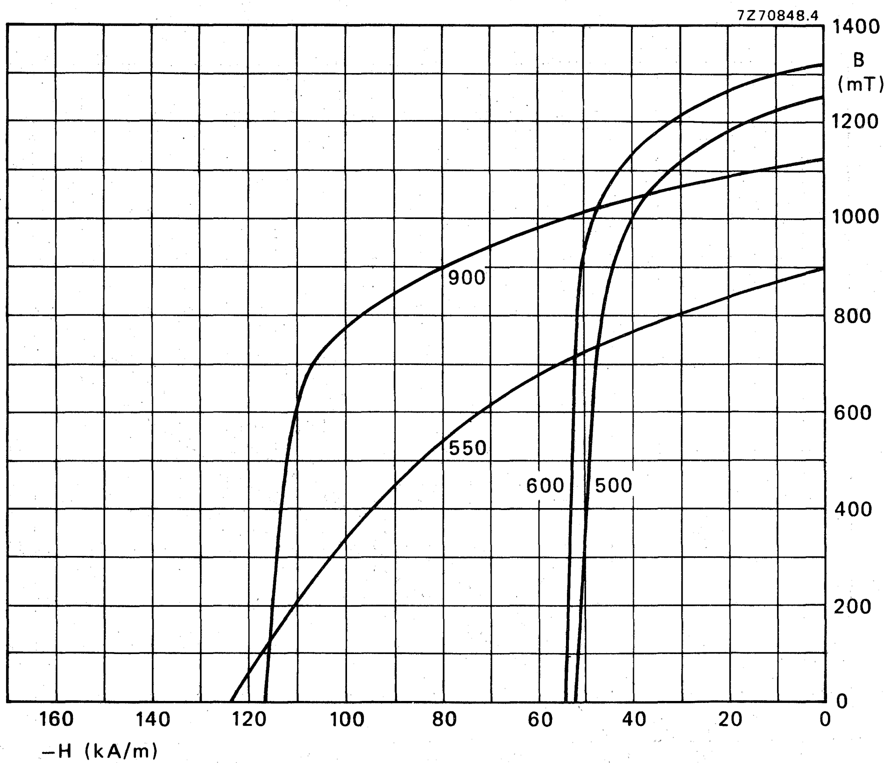
FERROXDURE


7Z89385
FXD410
FXD405
FXD270
J,B
(mT)
500
400
300
200
100
0
−100
−200
J
FXD410
FXD405
FXD270
B
400
350
300
250
200
150
100
50
0
−H (kA/m)

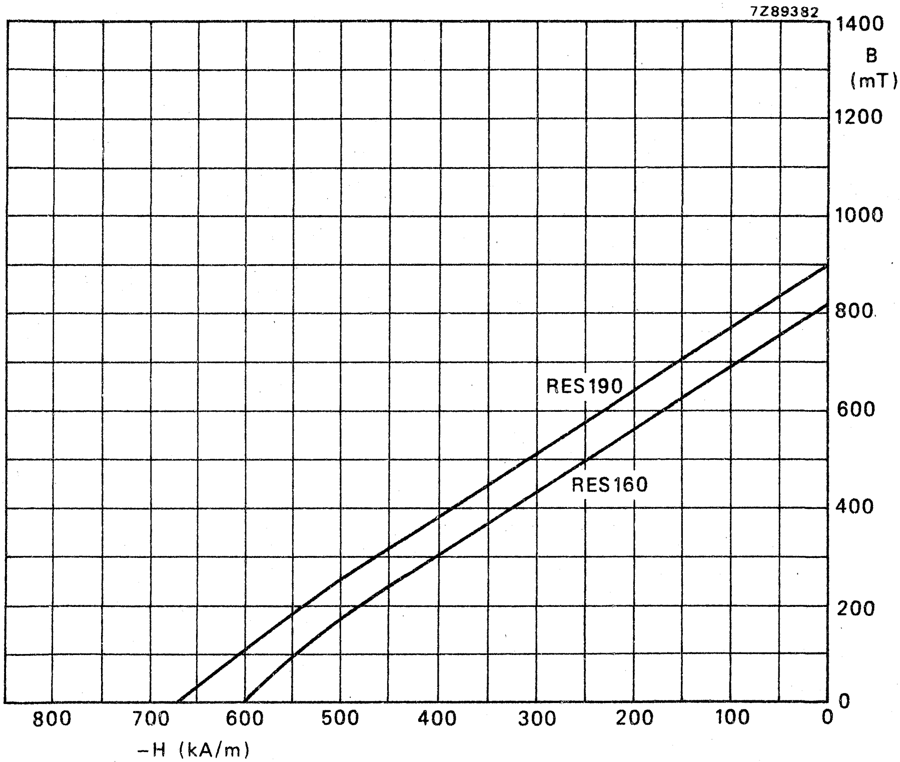
FERROXDURE


7Z70863.3
500
B
(mT)
400
300
200
100
0
−100
−200
SP170
SP130
FXD100
SP50
P40
P30
SP10
SP5
400
350
300
250
200
150
100
50
0
−H (kA/m)

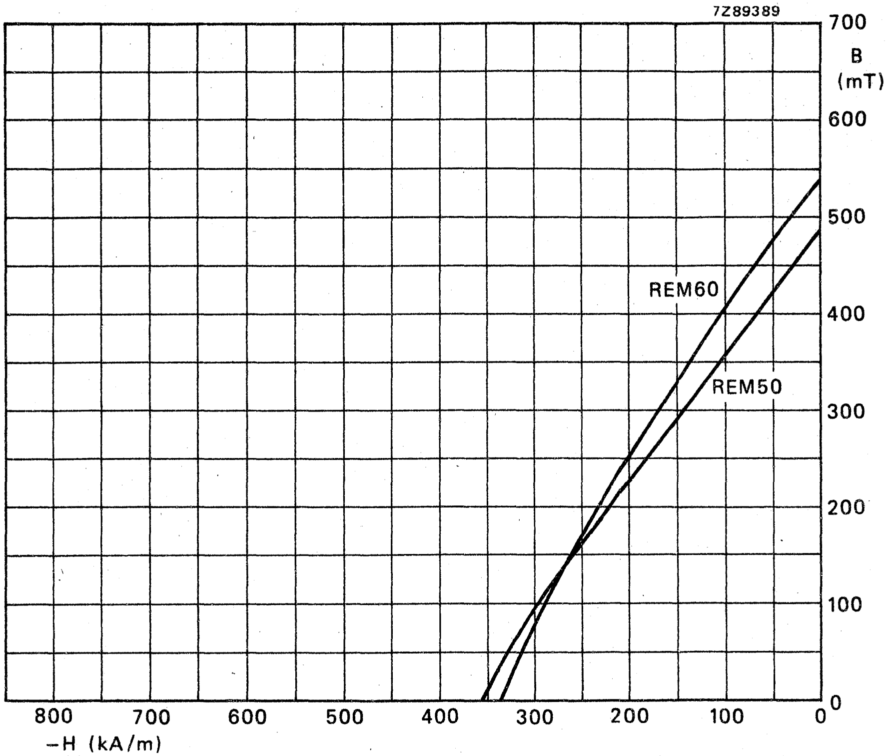
TICONAL


7Z70848.4
1400
B
(mT)
1200
1000
800
600
400
200
0
900
550
600
500
160
140
120
100
80
60
40
20
0
−H (kA/m)

COBALT RARE EARTH
(sintered)



COBALT RARE EARTH
(matrix)



PERMANENT MAGNET THEORY

UNITS AND DEFINITIONS

Permanent magnet engineering has been more affected by the adoption of SI units than most other branches of technology. For this reason, quantities and expressions will be given here in SI units followed by the equivalent for c.g.s. units in parentheses. Terms and definitions are those recommended by the IEC, taken from Publication 50, Chapter 901.

THE HYSTERESIS LOOP

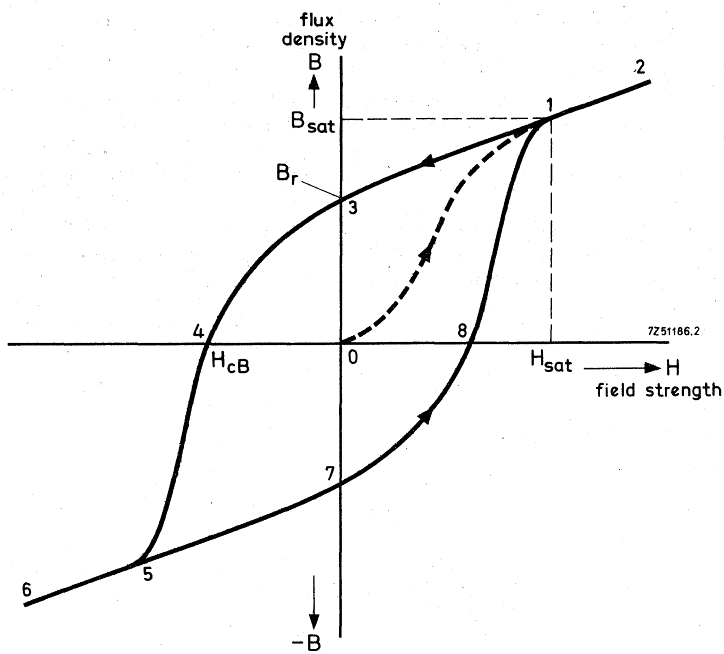


Fig. 1 Saturation hysteresis loop, variation of flux density with applied magnetic field strength H.

The reaction of a specimen of magnetic material to a magnetic field depends on the nature and history of the specimen and the magnitude and direction of the field. The behaviour can be described in terms of the applied field H and the resulting flux density B.

All possible combinations of B and H for a given material lie within a curve of the form shown in Fig. 1. This *hysteresis loop* represents the cycle of complete magnetization and demagnetization of the material. Within it, the working point of the material (BH) moves along minor loops and recoil lines.

The condition of a completely unmagnetized specimen can be represented by the origin of Fig. 1. If the applied field increases steadily from zero, the flux density in the specimen will increase so that the locus (BH) follows the curve 0-1, the initial magnetization curve. Further increase in H will cause B to increase at a rate that tends towards the permeability of free space $dB/dH = \mu_0$. Then the material no longer contributes to the increase in flux density and is said to be saturated. For practical purposes, saturation can be regarded as occurring at point 1: where the initial magnetization curve and the hysteresis loop start to coincide. The properties of the material corresponding to point 1 are *saturation flux density* and *saturation field strength.*

If, after saturation has been attained, the applied field is steadily reduced, the (BH) locus falls back along the line 2-3, reaching 3 when H = 0. The flux density that remains in the material, point 3, is termed the *remanence*, symbol B_r, of the material. Remanence is the flux density of a magnet in a closed magnetic circuit after saturation.

Increasing the applied field again, but in the reverse direction to the saturation field, causes the (BH) locus to follow the curve 3-4. This is the *demagnetization curve* or *second quadrant* of the hysteresis curve: the most important region in permanent magnet applications. When the value of reverse field is such as to cause the flux density in the material to reach zero, the field strength is termed the *coercivity*, symbol H_{cB}.

Further increasing the applied field drives the (BH) locus towards saturation (5 and 6) in the opposite direction. Once point 5 has been reached, the (BH) locus can be allowed to fall back to remanence at point 7 and so into the fourth quadrant.

INTRINSIC HYSTERESIS LOOP

The flux density plotted in Fig. 1 is the sum of the magnetic polarization J and the flux density B_0 due to the applied field:

$$B = J + B_0 = J + \mu_0 H$$

or, in c.g.s. units

$$B = 4\pi J + H.$$

J is also called the intrinsic flux density. If J is plotted against H, the effect of B_0 is excluded: the resultant loop is compared with the B-H loop in Fig. 2.

At saturation, the slope of the intrinsic hysteresis loop is zero. When the applied field is then removed, the polarization is the remaining flux density and hence the remanence of the material. The demagnetizing field necessary to remove the polarization is H_{cJ}, the intersection of the intrinsic loop and the H axis. It is called *polarization coercivity* and is greater than H_{cB}.

This difference depends on the slope of the loop near coercivity: if the slope is small the difference is large; if the slope approaches 90°, then the two coercivities for the material will be nearly the same.

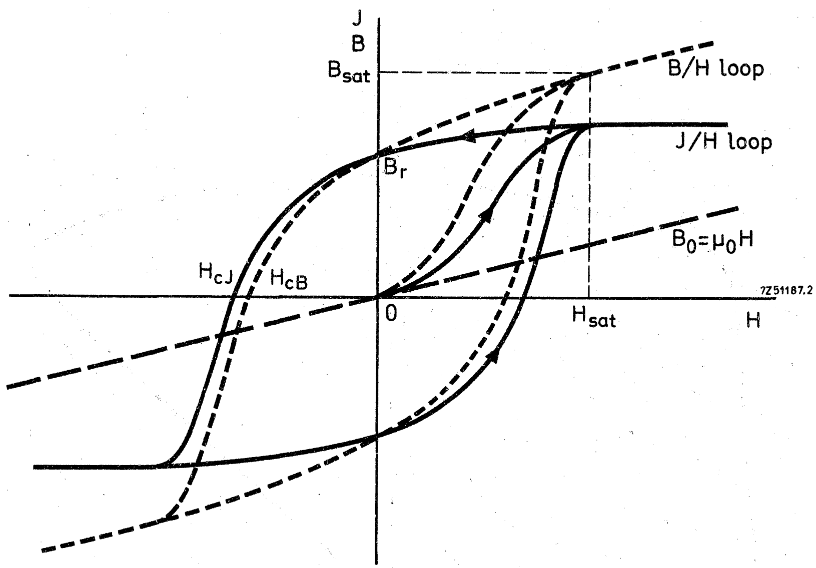


Fig. 2 Comparison of variations of flux density and polarization with applied field strength.

THE DEMAGNETIZATION CURVE

Complete hysteresis loops are important for soft magnetic materials where the material is usually subject to rapidly reversing applied fields, as in transformer cores. For hard (permanent) magnetic materials, which usually operate in a demagnetizing field (self or applied) the demagnetization characteristic is the more important. This lies in the second and fourth quandrants of the hysteresis loop, which are, in consequence, known as the demagnetization curve.

Figure 3 shows a typical demagnetization curve for a permanent magnet material. The graph is also marked with BH product contours. A curve of BH against B appears to the right of the B axis.

The value of BH indicates the energy stored in the field external to the magnet per unit volume of magnet material.

In the SI system: $W = BH/2$; in the c.g.s. system: $W = BH/8\pi$.

The maximum value of BH, also called the *maximum energy product* or $(BH)_{max}$, corresponds to the point (B_d, H_d); it represents the point of optimum utilization of the magnet material and is one of the criteria for comparing the performance of different materials.

The value of $(BH)_{max}$ is quoted in kilojoules per cubic metre (SI) or megagauss-oersted (c.g.s.).

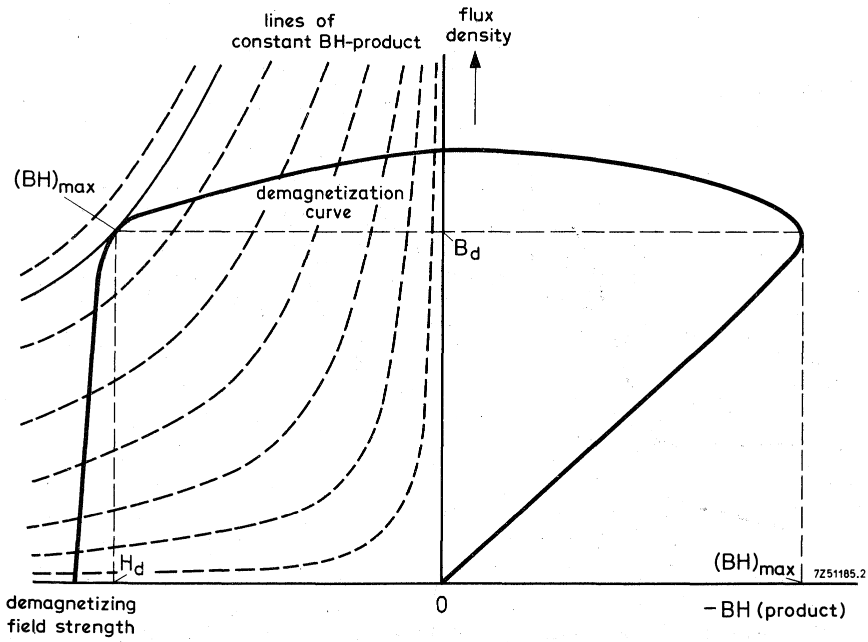


Fig. 3 Demagnetization curve with contours of constant BH-product, and BH-product curve.

RECOIL

The demagnetization curve represents the steady decrease in flux density with increasing demagnetization of the material. If a magnet is saturated and then subjected to a certain demagnetizing field less than the coercivity, the flux density in the magnet will be given for that reverse field by the demagnetization curve. Under practical conditions, however, the demagnetizing field experienced by the magnet is rarely constant: large or small variations will take place, depending on the application. What will happen if a magnet is subjected to a given value of demagnetizing field that is then reduced?

This situation is shown in Fig. 4. A saturated magnet is subjected to a demagnetizing field H_1. This field is then reduced. The working point of the material does not follow the demagnetization curve back towards remanence, but moves along the curve C. If the demagnetizing field is reduced to zero, the working point follows the curve C to B_0; restoring the original value of demagnetizing field causes the working point to fall back to A_1 (H_1, B_1). In doing this the working point follows the curve D, thus tracing out a small loop in the process.

If instead of reducing to zero, the demagnetizing field falls only to H_2, the working point moves to (B_2, H_2); restoring the original demagnetizing field causes a smaller loop to be traced.

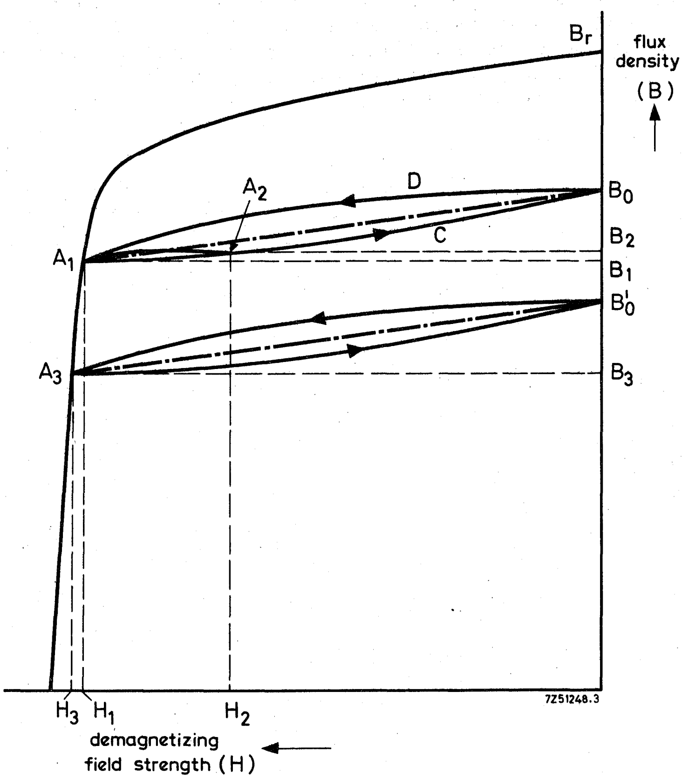


Fig. 4 Recoil lines.

For permanent magnet materials, these loops are usually of very small area, and can be represented as straight lines known as *recoil lines*. The slope of these recoil lines is the *recoil permeability*. The recoil permeability is usually about equal to the slope of the main demagnetizing curve at B_r.

If, after tracing out the loop $A_1CB_0DA_1$, the demagnetizing field is further increased to H_3, the working point will move down the main demagnetization curve to A_3 (B_3, H_3). Reducing the field to zero and then restoring it will cause the working point to follow the loop A_3B_0', which corresponds to another recoil line parallel to the first.

TEMPERATURE COEFFICIENT

The rate of change of remanence or coercivity of a permanent magnet material with temperature is generally quoted in percent per kelvin:

$$\alpha_{Br} = \frac{1}{B_r} \times \frac{dB_r}{dT} \times 100\%/K.$$

CURIE AND TRANSITION TEMPERATURES

At its Curie temperature a material becomes practically non-magnetic; any magnetization is lost and can only be restored by renewed saturation at a lower temperature. Most materials also exhibit a transition temperature. At this temperature their crystal structure is changed and magnetic properties permanently altered. The maximum permissible operating temperature of a permanent magnet material is set below the lower of these two temperatures.

MAGNETIC CIRCUIT DESIGN

The most common application of a permanent magnet material is the provision of a magnetic field to react with current-carrying conductors. Examples include loudspeakers, moving-coil meters and relays, and electric motors. In all cases, the cost of the final assembly depends on the size of the polarizing magnet, which depends, in turn, on the efficiency of the magnetic circuit.

In a given magnetic circuit, the size of the permanent magnet is at a minimum when the magnet is operated at its $(BH)_{max}$ point. At this point, the energy available from the magnet is at a maximum. Of this energy, only a fraction, usually less than half, can be concentrated in the useful air gap. Energy considerations are, however, secondary. The object of magnetic circuit design is the provision of a magnetic field of sufficient strength and stability over the volume, and with the uniformity required for the application. It is desirable to do this with the minimum sized magnet commensurate with the other (mechanical, electrical and environmental) design requirements.

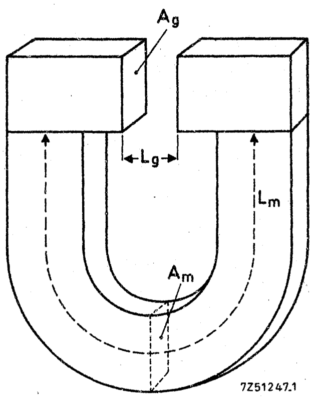


Fig. 5 Simple magnetic circuit.

Basic design method

Although computer-aided design methods have been in use for permanent-magnet systems for some time, it is possible, with practice, to form a close estimate of the design of a magnet system by simple manual calculation. This is usually done on the basis of a resistance analogue of the magnetic circuit. Magnetomotive force (the line integral of field strength, or, for a uniform field, field strength times length) is treated as voltage and total flux (the area integral of flux density, or, for a uniform field, flux density times area) is treated as current. In this analogy, reluctance (magnetomotive force divided by total flux) is the equivalent of resistance, and its reciprocal, permeance, is the equivalent of conductance.

These relationships can be applied to the simple magnetic circuit of Fig. 5. We assume that all the energy is concentrated in the air gap, that is, there is no leakage. Then, the total magnet flux will equal the total gap flux:

$$\phi = B_m A_m = B_g A_g.$$

The magnetomotive force (F_m) across the magnet will be the same as that across the air gap:

$$F_m = H_m L_m = H_g L_g.$$

Since

$$B_g = \mu_0 H_g$$

(in the c.g.s. system, μ_0 = 1 gauss/oersted; in the SI system, $\mu_0 = 4\pi 10^{-7}$ H/m)

$$B_m H_m = \mu_0 H_g A_g.$$

In practice, however, not all the flux passes through the useful air gap, and not all the magnetomotive force appears across the gap. It is usual to represent these losses by two factors p and q respectively:

$$B_m A_m = p\mu_0 H_g A_g \qquad (1)$$

and

$$H_m L_m = q H_g L_g. \qquad (2)$$

Leakage and loss factors

Factor p introduced above is the *leakage factor* of the system:

$$P = \frac{\text{total magnet flux}}{\text{total flux in useful air gap}}$$

where the total magnet flux is measured through the magnet area passing through the *neutral point* of the magnet. The neutral point is usually midway along the magnet. Estimates of leakage factor can be made by calculation but the usual procedure is to adopt known leakage factors of similar measured systems.

Factor q is the *loss factor*. It is due to the various reluctances in series with the air gap such as pole pieces and joints:

$$q = \frac{\text{magnet magnetomotive force}}{\text{gap magnetomotive force}}.$$

The value of q normally lies between 1,05 and 1,2 - it is usual to take q = 1, 1 as a first estimate, thus increasing the magnet length by 10%.

Working point and load line

Rearranging eqs (1) and (2) yields

$$A_m = \frac{p\mu_0 H_g}{B_m} A_g \qquad (3)$$

and

$$L_m = \frac{qH_g}{H_m} L_g. \qquad (4)$$

Multiplying eqs (3) and (4) gives

$$A_m L_m = V_m = \frac{pq\mu_0 H_g{}^2{}_g V_g}{B_m H_m} \qquad (5)$$

where V_m and V_g are the magnet and gap volumes respectively. The term $B_m H_m$ is the energy product of the material. It can be seen from eq. (5) that the magnet volume will be a minimum when the energy product is maximum, as stated previously. The components of the energy product are the *working point* of the magnet.

Equations (1) and (2) can also be combined to give

$$B_m = \frac{pA_g L_m}{qA_m L_g} \mu_0 H_m. \qquad (6)$$

For a given magnet and gap dimensions, eq. (6) is a straight line plotted in Fig. 6 as OP_1.
The slope of this line is

$$\cot\alpha = \frac{B_m}{H_m} = \frac{pA_gL_m\mu_0}{qA_mL_g}.$$

This line intersects the demagnetization curve for the material at the working point. The line itself is known as the load line for the application. Moreover, its slope, B_m/H_m, is the permeance of the magnetic circuit. For maximum efficiency (minimum magnet volume), the permeance should be B_d/H_d.

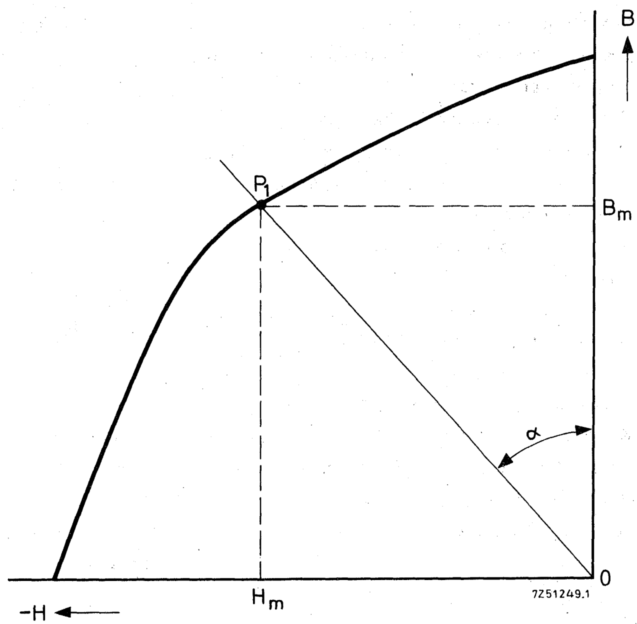


Fig. 6 Demagnetization curve with load line and recoil line.

SYMBOLS

αB_r = temperature coefficient of remanence
A_g = cross-sectional area of the air gap perpendicular to the lines of flux
A_m = cross-sectional area of permanent magnet perpendicular to direction of magnetization
B = (magnetic) flux density/(magnetic) induction
B_d = flux density at $(BH)_{max}$
B_g = flux density (induction) in the air gap
$(BH)_{max}$ = maximum BH product on the demagnetization curve
J = magnetic polarization
B_m = flux density (induction) in the magnet
B_r = remanence, residual flux density, residual induction
B_{sat}, B_s = saturation flux density/saturation induction
F_m = magnetomotive force
H = (magnetic) field strength
H_{cB} = coercivity
H_{cJ} = polarization coercivity
H_d = demagnetizing field strength at $(BH)_{max}$
H_g = field strength in the air gap
H_m = demagnetizing field strength in the magnet
H_{sat}, H_s = saturation field strength, field strength required for saturation
l_g (L_g) = length of the air gap parallel to the lines of flux
l_m (L_m) = effective magnetic length of magnet
N = total number of turns
Λ = permeance
R_m = reluctance
μ = permeability/normal permeability
μ_{rec} = recoil permeability
ϕ = magnetic flux/total flux

CONVERSION OF UNITS

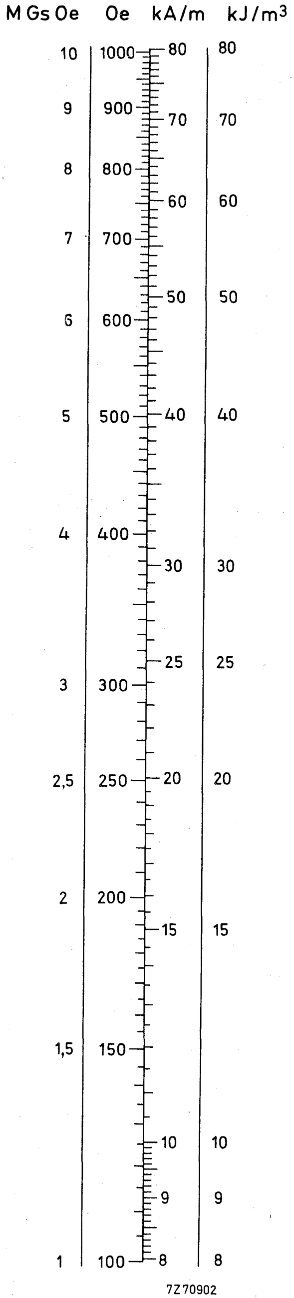
conversion scale is on next page

SI units →	c.g.s. units
1 T = 1 Wb/m^2 = 1 Vs/m^2	= 10^4 Gs = 10 kGs
1 mT	= 10 Gs
1 A/m	= $4\pi \times 10^{-3}$ Oe = 0,01257 Oe
1 kA/m	= 4π Oe = 12,57 Oe
1 Wb = 1 Vs = 1 Tm^2	= 10^8 Mx
1 μWb	= 100 Mx
$\mu_0 = 4\pi \times 10^{-7}$ H/m = 1,257 μH/m	μ_0 can be replaced by 1 Gs/Oe
1 H/m = 1 Vs/Am	
1 J/m^3 = 1 TA/m	= $4\pi \times 10$ GsOe = 125,7 GsOe
1 kJ/m^3 = 1 mJ/cm^3	= $4\pi \times 10^{-2}$ MGsOe = 0,1257 MGsOe
1 J = 1 Ws = 1 Nm	= 10^7 erg
1 N = 1 kgm/s^2 = 0,1019 kilogramme-force	= 10^5 dynes

SI units ←	c.g.s. units
10^{-4} = 0,1 mT	= 1 Gs (gauss)
0,1 T = 100 mT	= 1 kGs
$10^3/(4\pi)$ A/m = $1/(4\pi)$ kA/m = 0,07958 kA/m	= 1 Oe (oersted)
0,01 μWb	= 1 Mx (maxwell)
10 μWb	= 1000 Mx
$10^2/(4\pi)$ mJ/m^3 = 7,958 mJ/m^3	= 1 GsOe
$10^2/(4\pi)$ kJ/m^3 = 7,958 kJ/m^3	= 1 MGsOe
10^{-7} J	= 1 erg

Energy in the field external to the magnetic material, per unit volume of the permanent magnet:

SI system: BH/2 c.g.s. system: $BH/8\pi$



The range of this scale may be extended by multiplying the values on both sides by the same power of 10.

SIZE AND SHAPE TOLERANCES

In the interest of rational and economical manufacture, tolerances should be as wide as possible to avoid additional machining. Tolerances shown in these data are those which can be expected from our mass production techniques. Alternative tolerances, where required, are subject to agreement between manufacturer and user. The tolerances may be indicated as defined in ISO recommendation R1101 (see following pages).

SINTERED FERROXDURE AND RARE EARTH

Sintered magnets are manufactured by pressing or extrusion and subsequent sintering. During the sintering process the material shrinks, giving rise to relatively wide tolerances: shapes should be as simple as possible. Being hard and brittle, the magnets can be machined only by grinding.

Dimensional tolerances

Unground isotropic magnets (all dimensions)	
below 5 mm	± 0,3 mm
5 to 10 mm	± 0,4 mm
above 10 mm up to 25 mm	± 0,5 mm
above 25 mm	± 2,5%
Unground anisotropic magnets (dimensions perpendicular to Magnetic Axis)	
below 10 mm	± 0,25 mm
from 10 mm upwards	± 2 to ± 2,5% (product dependent)
Between two ground parallel faces	± 0,05 to 0,3 mm (product dependent)

Shape tolerances

In addition to dimensional inaccuracies, sintered magnets may exhibit shape inaccuracies due to shrinkage, such as out-of-parallelism, out-of-squareness and eccentricity. Specific requirements should be negotiated between manufacturer and user.

PLASTIC-BONDED FERROXDURE AND MATRIX-BONDED RARE EARTH

Bonded magnets are manufactured without sintering (no shrinkage) and therefore tolerances are smaller than in the case of sintered magnets. Machining after shaping should, for economic reasons, be avoided.

Dimensional tolerances

FXD-SP and REM magnets	
below 10 mm	± 0,05 to 0,1 mm
10 mm to 30 mm	± 0,2 to 0,2 mm
above 30 mm up to 60 mm	± 0,2 to 0,3 mm
above 60 mm	± 0,5%
FXD-P	
below 10 mm	± 0,2 to 0,3 mm
10 mm to 30 mm	± 0,3 to 0,4 mm
above 30 mm up to 50 mm	± 0,4 to 0,5 mm
above 50 mm	± 1%

Note: FXD-P magnets are subject to permanent deformation when compressed.

TICONAL

Ticonal magnets are usually manufactured by sand casting, shell moulding or by other modern techniques. Being hard and brittle they can be machined only by grinding, and it is recommended that such grinding be restricted to pole faces. Holes should be avoided, but can be produced by coring with sand and should allow a generous clearance. Accurate holes can be obtained by filling oversize cored holes with a low melting point alloy or by casting around a mild steel insert and subsequently drilling to size.

In magnets from Ticonal 570 and 600 holes have to be avoided and inserts cannot be used, otherwise the crystal orientation will be impaired during casting.

Dimensional tolerances

Unground magnets (cast or shell moulded)	
below 50 mm	± 0,5 mm
50 up to 100 mm	± 0,8 mm
above 100 mm	± 1 mm
Between two ground parallel faces (normal tolerance)	± 0,05 mm

Shape tolerances

In addition to dimensional inaccuracies, Ticonal magnets may exhibit shape inaccuracies such as out-of-parallelism, out-of-squareness and eccentricity. For guidance, the following tolerances can be given:

Tolerance on perpendicularity (squareness)	
between two ground faces	± 1°
between a ground and a cast or shell-moulded face	± 3°
Tolerance on parallelism	
between two ground faces	0,1 mm

Specific requirements should be negotiated between manufacturer and user.

INDICATION OF TOLERANCES ON ENGINEERING DRAWINGS (FORM AND POSITION)

This standard is in accordance with the ISO-Recommendation R1101-1969 "Tolerances of form and of position"

1. SCOPE

1.1 This document gives the principles of the symbolization and of the indication on technical drawings of tolerances of form and of position.

1.2 Although the system of indicating tolerances of form and of position is based on practical manufacture and inspection, such indications do not imply the use of any particular method or production, measurement or gauging.

For a general introduction on the subject of geometrical tolerances of form and of position, see UN-D 601.

2. GENERAL DEFINITIONS AND REMARKS

2.1 A tolerance of form or of position of a geometrical element (point, line, surface or median plane) defines the zone within which this element is to be contained (see note 1).

2.2 According to the characteristic which is to be toleranced and the manner in which it is dimensioned, the tolerance zone is one of the following:
- the area within a circle;
- the area between two concentric circles;
- the area between two parallel lines or two parallel straight lines;
- the space within a sphere;
- the space within a cylinder or between two coaxial cylinders;
- the space between two parallel surfaces or two parallel planes;
- the space within a parallelepiped.

2.3 In the absence of a more restrictive indication, an element may be of any form or orientation within this tolerance zone.
When necessary an explanatory note may be added to the symbol or may be given in the absence of an appropriate symbol.

2.4 Unless otherwise specified the tolerance applies to the whole length or surface of the considered feature.

2.5 The datum feature to which tolerances of orientation, position and run-out are related.

2.6 The form of a datum feature should be sufficiently accurate for its purpose and it may therefore be necessary, in some cases, to specify tolerances of form for the datum features (see note 2).

Notes

1. The form of a single feature is deemed to be correct, when the distance of its individual points from a superimposed surface of ideal geometrical form is equal to or less than the value of the specified tolerance. The orientation of the ideal surface should be chosen so that the maximum distance between it and the actual surface of the feature concerned is the least possible value.

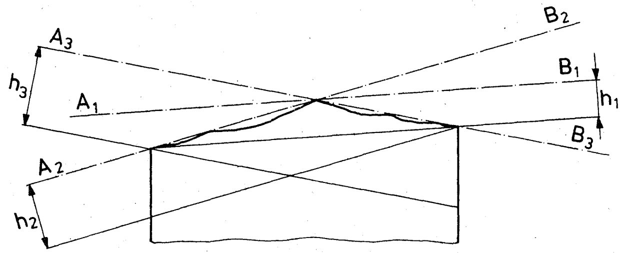


Fig. 1.

Possible orientations of the ideal surface:	A_1–B_1	A_2–B_2	A_3–B_3
Corresponding maximum distances:	h_1	h_2	h_3
In the case of Figure 1:	$h_1 <$	$h_2 <$	h_3

Therefore the orientation of the ideal surface is A_1–B_1, and h_1 is to be equal to or less than the specified tolerance.

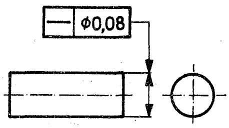
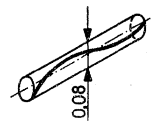
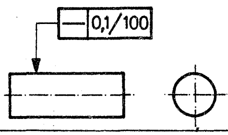
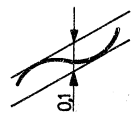
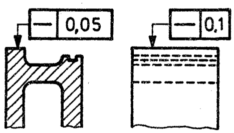
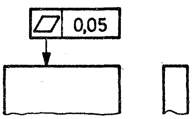
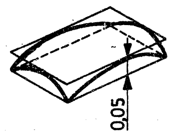
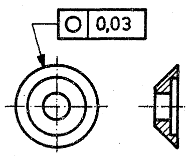
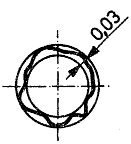
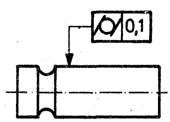
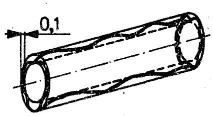
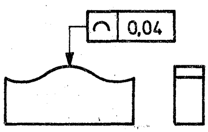
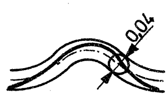
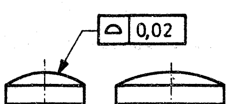
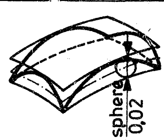
2. In some cases it may also be desirable to indicate the position of certain points which will possibly form a temporary datum feature for both manufacture and inspection.

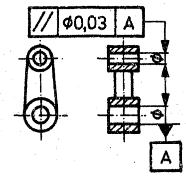
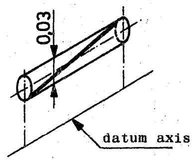
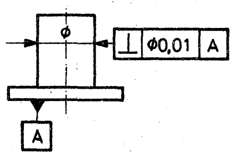
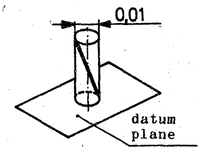
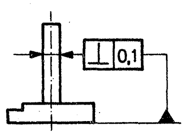
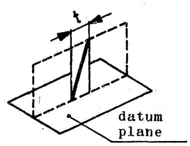
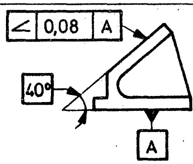
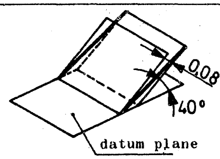
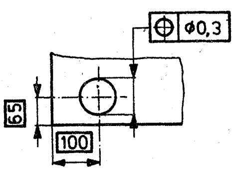
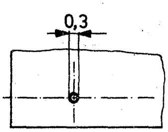
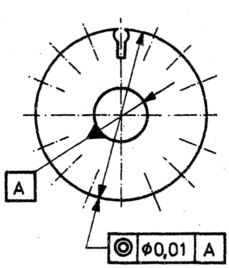
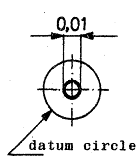
3. SYMBOLS

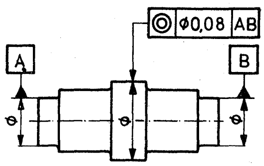
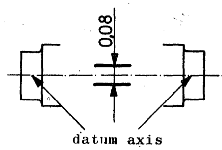
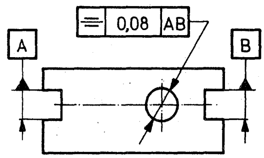
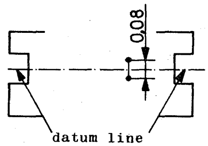
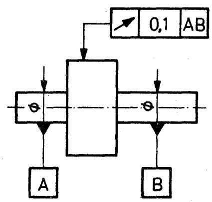
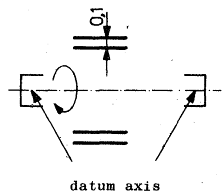
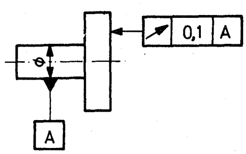
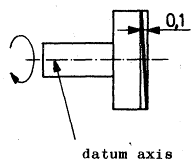
The following symbols represent the types of characteristics to be controlled by the tolerance.

Characteristics to be toleranced		Symbols
Form of single features	Straightness	—
	Flatness	▱
	Circularity (Roundness)	○
	Cylindricity	⌭
	Profile of any line	⌒
	Profile of any surface	⌓
Orientation of related features	Parallelism	//
	Perpendicularity (Squareness)	⊥
	Angularity	∠
Position of related features	Position	⌖
	Concentricity and coaxiality	◎
	Symmetry	⌯
Run-out		↗

4. EXAMPLES OF INDICATION AND INTERPRETATION OF TOLERANCES OF FORM AND OF POSITION

Characteristics to be toleranced	Example of indication	Interpretation	Description
Straightness			The axis of the cylinder to the dimension of which the tolerance frame is connected should be contained in a cylindrical zone of diameter 0,08.
			Any portion of length 100 of any generator of the cylindrical surface indicated by the arrow should be contained between two parallel straight lines, 0,1 apart.
			If two different straightness tolerances are applied to two directions on the same surface, the straightness tolerance zone of this surface is 0,05 in that direction shown on the left-hand view and 0,1 in that direction shown on the right-hand view
Flatness			The surface should be contained between two parallel planes 0,05 apart.
Circularity			The circumference of the disc should be contained between two co-planar concentric circles 0,03 apart.
Cylindricity			The considered surface should be contained between two coaxial cylinders the radii of which differ by 0,1.
Profile tolerance of any line			In each section, parallel to the plane of projection the considered profile should be contained between two lines enveloping circles of diameter 0,04 the centres of which are situated on a line having the geometrically correct profile.
Profile tolerance of any surface			The considered surface should be contained between two surfaces enveloping spheres of diameter 0,02 the centres of which are situated on a surface having the geometrically correct form.

Characteristics to be toleranced	Example of indication	Interpretation	Description
Parallelism			The upper axis should be contained in a cylindrical zone of diameter 0,03 parallel to the lower datum axis "A".
Perpendicularity			The axis of the cylinder to the dimension of which the tolerance frame is connected should be contained in a cylindrical zone of diameter 0,01 perpendicular to the datum surface "A" (datum plane).
			The axis of the cylinder to the dimension of which the tolerance frame is connected should be contained between two parallel straight lines 0,1 apart, perpendicular to the datum plane and lying in the plane shown on the drawing.
Angularity			The inclined surface should be contained between two parallel planes 0,08 apart which are inclined at 40° to the plane "A" (datum plane).
Position			The point of intersection should lie inside a circle of 0,3 diameter the centre of which coincides with the considered point of intersection.
Concentricity			The centre of the circle, to the dimension of which the tolerance frame is connected should be contained in a circle of diameter 0,01 concentric with the centre of the datum circle "A".

Characteristics to be toler-anced	Example of indication	Interpretation	Description
Coaxiality			The axis of the cylinder to the dimension of which the tolerance frame is connected should be contained in a cylindrical zone of diameter 0,08 coaxial with the datum axis "AB".
Symmetry			The actual axis of the hole should be contained between 2 parallel lines which are 0,08 apart and symmetrically disposed about the actual common median plane of the datum slots "A" and "B".
Run-out	radial run-out 		During one complete revolution around the datum axis "AB" radial runout should be not more than 0,1.
	axial run-out 		During one complete revolution about the datum axis "A" the axial runout should be not more than 0,1.

SPECIFYING THE MAGNETIC AXIS AND DIRECTION OF MAGNETIZATION

DRAWING SYMBOLS AND TERMINOLOGY

It is recommended that the magnetic axis, or the direction of magnetization be indicated on drawings by means of the following symbols:

For the magnetic axis, or the preferred direction of magnetization in unmagnetized anisotropic magnets: the symbol ◄– MA –►.

For the direction of magnetization in magnetized magnets: the symbol S ──► N.

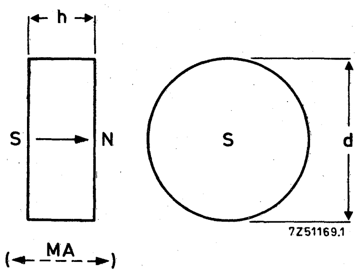
The recommended method of showing the magnetic axis or the direction(s) of magnetization is shown in the following examples:

NOTE

When ordering, please give the alphabetic designation and page date, e.g.: magnetization B, January 1981. Orientation of unmagnetized anisotropic magnets can be indicated by the prefix U, e.g.: orientation UB, January 1981. (Unmagnetized isotropic magnets: letter U.)

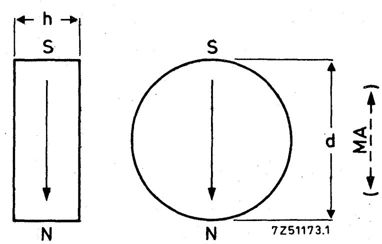
Magnetization for isotropic and anisotropic magnets

A



axial.*

B

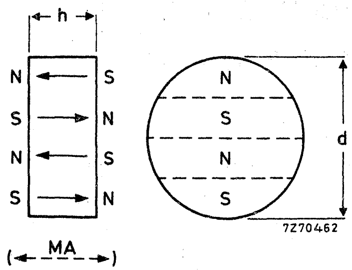


diametrical.*

* Also to be used for rings and cylinders.

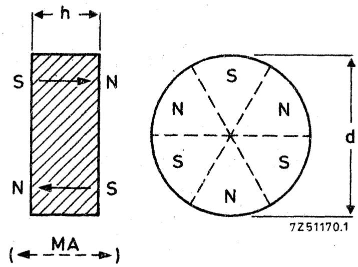
Magnetization for isotropic and anisotropic magnets (continued)

C



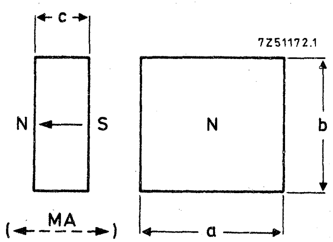
axial, n-poles,
neutral zones in parallel
(in the example n = 4).

D



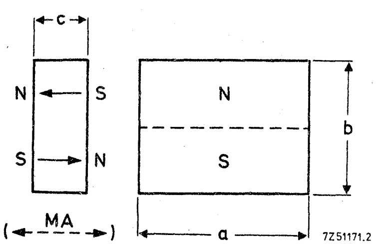
axial, n-poles,
neutral zones radial
(in the example n = 6).

E



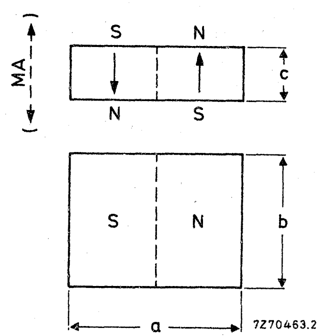
perpendicular to a x b.

F



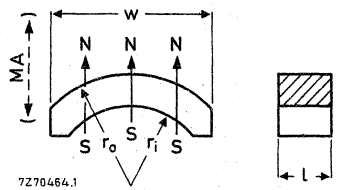
perpendicular to a x b, n-poles,
neutral zone parallel to **side a**
(in the example n = 2).

G



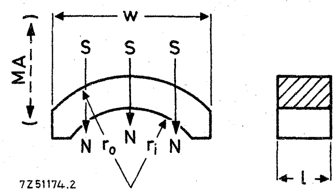
perpendicular to a x b, n-poles,
neutral zone parallel to **side b**
(in the example n = 2).

H



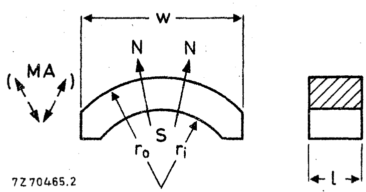
parallel (also called diametrical),
S-pole inside.

J



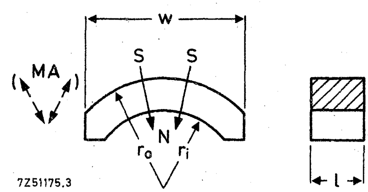
parallel (also called diametrical),
N-pole inside.

K



radial, S-pole inside.

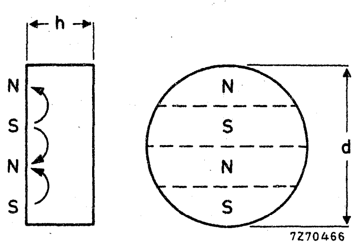
L



radial, N-pole inside.

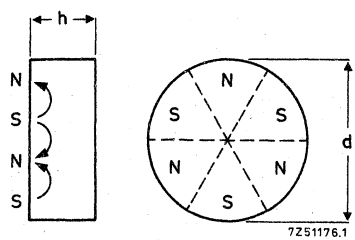
Magnetization for isotropic magnets only

M



lateral, n parallel poles on one face only,
(in the example n = 4).

N



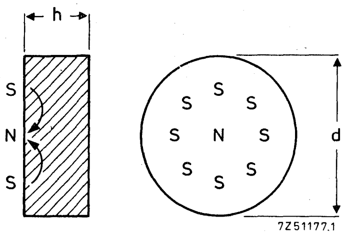
lateral, n-pole sectors on one face only,
(in the example n = 6).

NOTES

1. Multipole magnetization of K and L on both sides is possible; to be specified by user.
2. Magnetizations M and N can also be applied to both faces.
3. When magnetization M is required with an odd number of poles the polarity of the centre pole should be specified (e.g. N, S, or "don't care").

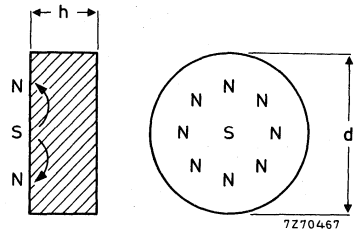
Magnetization for isotropic magnets only (continued)

O



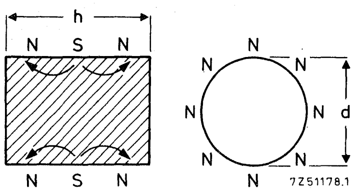
lateral, 2-poles on one face only, centred N-pole with concentric S-pole.

P



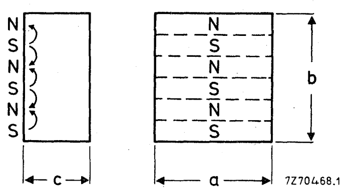
lateral, 2-poles on one face only, centred S-pole with concentric N-pole.

Q



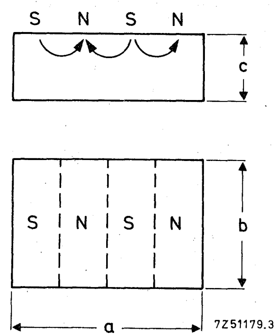
lateral, n annular poles (in the example n = 3).

R



lateral, n-poles on one a x b face, poles parallel to **side a** (in the example n = 6).

S

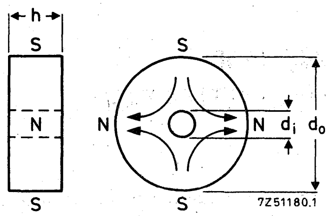


lateral, n-poles on one a x b face, poles parallel to **side b** (in the example n = 4).

NOTES

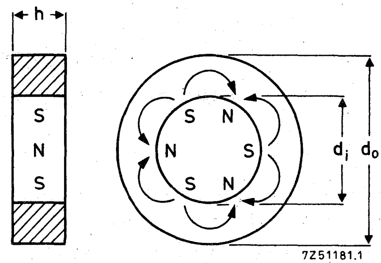
1. Magnetizations O, P, R and S can also be applied to both faces.
2. When magnetizations Q, R or S are required with an odd number of poles the polarity of the centre pole should be specified (e.g. N, S, or "don't care").

T



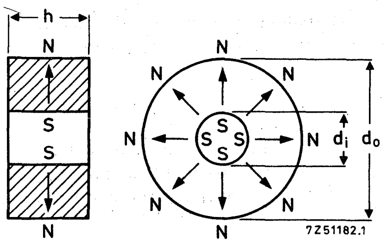
lateral, n-poles on outer circumference, neutral zones axial (in the example n = 4).

W



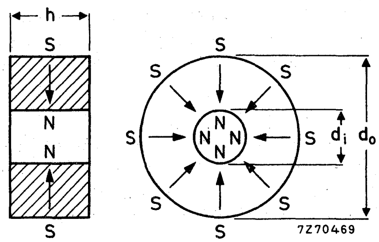
lateral, n-poles on inner circumference, neutral zones axial (in the example n = 6).

X



radial, S-pole inside.

Y



radial, N-pole inside.

U unmagnetized magnets

MARKING OF PERMANENT MAGNETS

If it is required to identify magnetized magnets of the same outline but with different directions of magnetization, a colour code is recommended.

The poles can then be marked by spots of paint or some other identification mark,

either South pole yellow
or North pole red
or neutral zone white.

If it is necessary to indicate the position of poles more accurately than may be obtained by spots of paint, another method, e.g. grooves, may be used.
The method of marking, if required, should be shown on the magnet drawing.

RECOMMENDATIONS FOR MAGNETIZATION AND DEMAGNETIZATION

Magnets are usually supplied unmagnetized, and are magnetized by the user during system assembly. This simplifies handling and manufacture considerably.

Most magnets can, however, be premagnetized, but this may result in some loss, the extent depending upon the relative recoil permeability of the material. This should be determined at the working point (i.e. the point on the hysteresis loop) corresponding to the highest demagnetizing field experienced by the magnet before assembly. For a magnet working under open-circuit conditions, the area in the middle of the pole-faces normally experiences a higher demagnetizing effect than the periphery. The working point under these conditions is determined by the size and shape of the magnet. In computing these losses, the minimum values for the characteristics at the lowest storage temperature should be assumed. For most currently used shapes, the expected losses (computed values) are available from us on request.

Note: some Ferroxdure and rare-earth cobalt materials have relative recoil permeabilities close to unity through a substantial part of the second quadrant of their hysteresis characteristics. Such materials show little loss when premagnetized.

MAGNETIZATION

A magnet is magnetized instantaneously by exposing it to an external unidirectional field, produced by a permanent magnet or, more usually, by a direct current (or pulsed current) flowing through a coil. The magnetizing field must not be less than the saturation field H_{sat} for the material, otherwise the full properties will not be obtained.

In some systems the requirement is not clear, for example the magnet may be shielded by other magnetic material which then must also be saturated. In practice the magnetizing field should be increased until no further increase in magnet flux can be measured. For magnetizers using steel poles, saturation of the equipment could occur before the magnets are fully saturated. An alternative can be to use ironless coils correctly positioned. Advice where required should be sought.

The required magnetizing current can be obtained from many alternative d.c. sources. Apart from obtaining the correct magnetizing field strength, the choice will depend on possible size of coil, temperature rise of conductors, repetition rate and other production circumstances. Where heat dissipation can be a problem with small coils, pulsed currents derived from discharging capacitors or other current sources is a solution. There are suppliers of power supplies for magnetizing equipment.

After magnetizing it is possible to equalize the performance of magnetic systems by partial demagnetization of the magnets (for Ticonal magnets this is usually worthwhile in any case, since it provides more stable performance). This can be done by applying an increasing d.c. field in the reverse direction until the magnetization falls to the required level, the field preferably being controlled by some means with the facility to measure the instantaneous magnetic flux density.

DEMAGNETIZATION

Modern magnetic materials have a high resistance to demagnetization, and complete demagnetization is usually difficult if not impossible. Sintered Ferroxdure magnets are best demagnetized by heating them above their Curie point (about 450 °C). Bonded or metal magnets need a magnetic field to demagnetize them, usually a gradually diminishing a.c. field whose initial value is great enough to force the magnet through its hysteresis cycle. For larger magnets, complete demagnetization is usually impossible.

INSPECTING PERMANENT MAGNETS

Permanent magnets are usually inspected for mechanical and magnetic properties and appearance. Mechanical inspection follows normal procedures, as does visual inspection. Magnetic inspection is best carried out by checking the performance under conditions which approximate as closely as possible the working conditions for which the magnet is intended. For this reason the inspection procedure of any type of magnet should be laid down in consultation with the customer. A simplified model of the magnetic circuit will often suffice for measuring flux, voltage, force of attraction, etc., according to the application.

VISUAL INSPECTION

The visual standards required are set by means of limit samples, photographs of which have been made. For each visual characteristic there should be two limit samples, one of which is the "worst acceptable" sample and marked "O", and the other, the "test reject" sample and marked "X". For most products, the photographs are already available.

MAGNETIC INSPECTION

Full determination of the magnetic properties of each magnet is too expensive for mass-production inspection. It has, therefore, become normal practice to perform comparison tests against a "minimum standard magnet", copies of which are supplied on request.

The minimum standard may have either
minimum remanence (B_r), a "minimum flux standard",
or minimum coercivity (H_{cB}), a "minimum coercivity standard".

These magnets will have the following dimensions:

— Blocks, segments and axially magnetized cylinders, discs and rings	
perpendicular to M.A.	bottom limit dimensions
parallel to M.A.	mid-limit (nominal)
— Diametrically magnetized cylinders and discs	bottom limit diameter and height
— Diametrically magnetized rings	bottom limit diameter, wall thickness and height

AQL SYSTEM

The quality of our permanent magnets is guaranteed in conformity with MIL-STD-105D. The AQL values are laid down as follows:

Attributes	AQL	Inspection level
Visual	0,65%	II
Dimensional	0,65%	II
Magnetic	0,65%	II

For the attributes reference is made to the magnet specification concerned.

DESIGN ADVISORY SERVICE

Our application engineers offer technical assistance on the use and design of permanent magnets and complete permanent-magnet systems. Guidance is also offered on ancillary problems such as installation, handling and magnetization. If you require more specific information than is provided here please send your enquiry to us.

Orders for new magnet shapes can be dealt with more easily if they are accompanied by the following information:

(1) The purpose for which the magnet is to be used.

(2) A sketch or drawing of the magnet showing its shape and dimensions, with tolerances.

(3) The direction of the magnetic axis or the arrangement of poles.

(4) Surfaces to be ground and shape tolerances.

(5) The material of the magnet.

(6) Whether the magnet is to be supplied magnetized or unmagnetized.

(7) The quantity required and the desired rate of delivery.

COMPUTER-AIDED DESIGN SERVICE

Traditional empirical and graphical permanent-magnet design methods are often laborious and, particularly for dynamic or complex systems, seldom result in a design whose performance is magnetically or economically optimum. Computer-aided design, due to the ability to perform iterative calculations quickly, can prove almost ideal for permanent-magnet systems. During the past ten years programs have been developed both for specific design problems such as loudspeakers and motors and for the detailed analysis of magnetic circuits. Based upon these programs, and backed by many years accumulated experience, it is now possible to provide users of our magnetic materials with a comprehensive design service.

THE MAGGY PROGRAM

The MAGGY program uses a mathematical expression of the permanent magnet as the basis for the computer analysis of two-dimensional magnetic systems. It is thus suitable for fundamental design analysis of rotationally-symmetrical magnet assemblies, such as loudspeaker units, Fig. 1; or assemblies which are long compared to the air gaps in the circuit, such as motors, Fig. 2. As these two plots generated by the MAGGY program show, the output is in the form of plots of equi-flux lines superimposed on a section through the assembly under analysis. The plot is supplemented by a print-out of flux densities over the system and surrounding space.

MAGGY is mainly used for the investigation of new magnetic arrangements or materials, such as the low-stray field loudspeaker design shown in Fig. 5. Using the information obtained from MAGGY, supplemented by extensive practical experience, programs have been developed for the design of systems for two of the main areas of magnet applications: loudspeakers and motors.

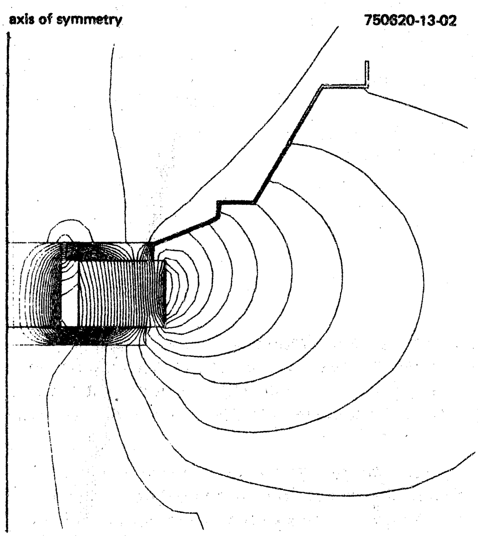


Fig. 1.

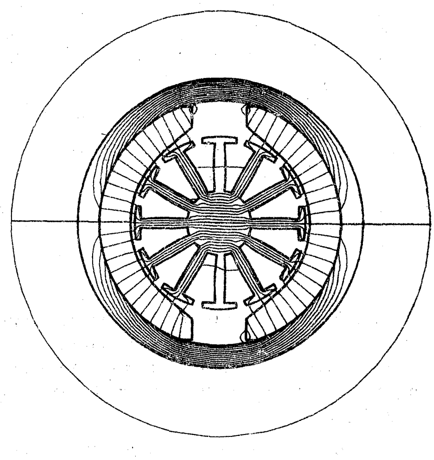


Fig. 2.

LOUDSPEAKER DESIGN

For the computer-aided design (CAD) of conventional loudspeaker motor unit magnets using Ferroxdure ring magnets, a dedicated program is available. This optimizes the design of a magnet system for minimum use of both hard and soft magnetic materials, subject to engineering limitations. The effect of ambient temperature range is taken into account.

Figure 3 and the table give the input data required for the design of a loudspeaker system using this program.

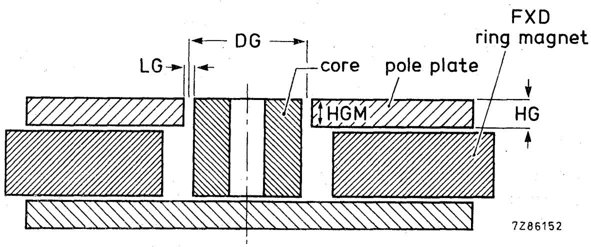


Fig. 3.

Input data for loudspeaker-design program

Air gap:	diameter	DG	= m
	length	LG	= m
	height	HG	= m
	field measurement height	HGM	= m
	induction over HGM		= T
	or flux over HGM		= Wb
General:	ambient temperature	TA	= K
	cold stability	KS	= K
	permissible flux loss after operation at KS		= %
Stray flux requirement:			
Other requirements:			

Where a design of loudspeaker that generates minimum stray field is required, for such applications as colour TV receivers, the traditional solution to the problem has been to use a totally-enclosed design based on a slug of metal-alloy permanent-magnet material such as Ticonal. The increasing cost of the raw materials for these alloys has made the use of screened or compensated designs based on Ferroxdure materials more attractive.

The plot of Fig. 1. shows the stray field generated by a conventional ring-magnet design, as plotted by means of MAGGY. The similar plots of Figs 4 and 5 show the reduction in stray field obtained by screening and the use of a compensating magnet. Both design problems would be extremely difficult to solve except by means of CAD.

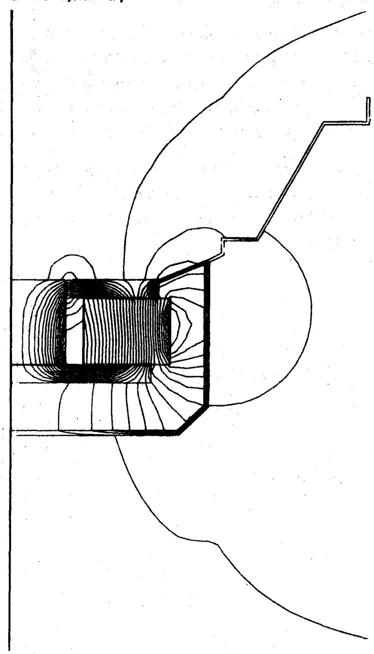


Fig. 4.

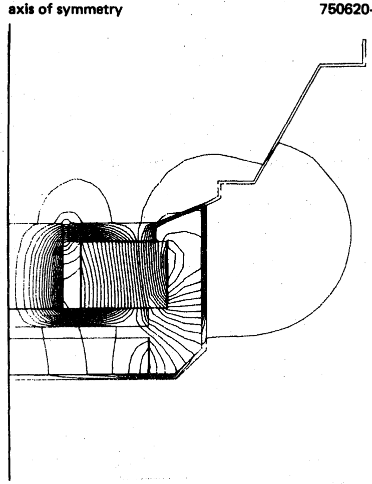


Fig. 5.

PERMANENT-MAGNET MOTOR DESIGN

The majority of permanent-magnet motors use anisotropic ferrite segments in the arrangement shown in Fig. 6. The magnets in such a system are subjected to varying demagnetizing forces according to the current flowing in the motor armature, which is greatest under stall or starting conditions. Moreover, the effect of these demagnetizing influences depends on the operating temperature of the permanent magnets themselves. These and other design factors are fully discussed in the Reference.*

Our dedicated motor-design program is capable of producing motor designs for minimum cost or weight and to a particular fixed dimension, such as length or diameter, for a particular application. Given the required motor parameters, with the aid of the program a design can be produced to satisfy a specific requirement. The necessary input data are:

LOAD

operating speed N_1	=	(r.p.m.)
operating torque at N_1 r.p.m.	=	(Nm)
mechanical efficiency at N_1 r.p.m.	=	(%)
and, if possible, a second point of the motor characteristic such as		
stall torque	=	(Nm)
or		
maximum output power	=	(W)
armature speed for maximum output power	=	(r.p.m.)

AMBIENT CONDITIONS

ambient temperature T_1	=	(^{o}C)
minimum temperature T_2	=	(^{o}C)

ELECTRICAL CIRCUIT

electromotive force of the power supply at T_1	=	(V)
internal resistance of the power supply at T_1	=	(Ω)
internal resistance of the power supply at T_2	=	(Ω)
series resistor at T_1	=	(Ω)
voltage drop across the brushes or the brush resistance	=	(Ω)
if the supplied voltage is an a.c. voltage the type of rectification (bridge, SMPS etc)		
supply frequency	=	(Hz)
fast current limit	yes/no	
if yes:		
maximum current	=	(A)

OTHER REQUIREMENTS

e.g. transmission ratio of a gearbox, efficiency of the gearbox etc.

* Reference: Heffen, H.J.H. van, 1980. Ceramic permanent magnets for d.c. motors. Electronic Components and Applications 3, 22-30 and 120-125 (Vols 1 and 2).

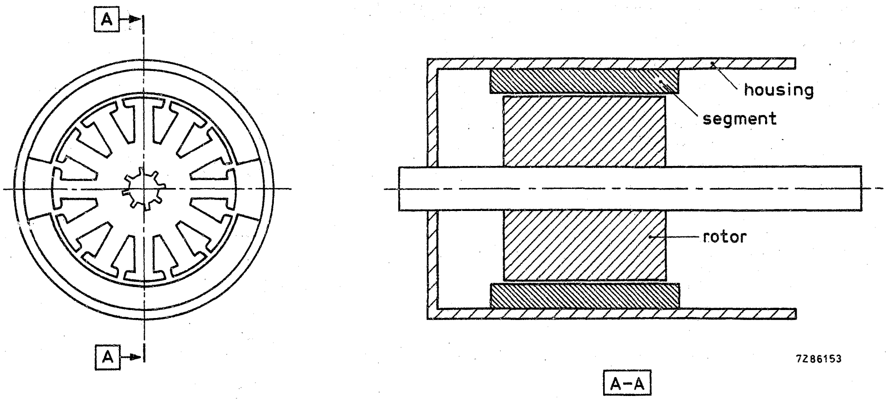


Fig. 6.

If required one or more of the following motor data can be fixed:

HOUSING:	outside diameter	= (mm)
	wall thickness	= (mm)
	saturation flux density	= (gauss)
MAGNET:	permanent magnet material	=
	outside radius	= (mm)
	inside radius	= (mm)
	thickness	= (mm)
	length	= (mm)
	angle	= (deg)
	shape of the segment feet	basic/radial
ROTOR:	diameter	= (mm)
	saturation flux density	= (gauss)
	loss factor of the rotor iron	= (W/kg)
	lamination thickness	= (mm)
	number of slots	=
	shape of the slots	parallel teeth/parallel slot
	width of the tooth	= (mm)
	shaft diameter	= (mm)
WINDING:	rotor winding	lap/wave
	slot span	=
	number of commutator bars	=
OTHER:	length of the air gap	= (mm)
	number of pole pairs	=
	pairs of parallel paths	=
	maximum fill factor of the slot	=
	maximum current density at the operating speed	= (A/mm^2)
	maximum rotor dissipation at the operating speed	= (W/cm^2)

Given this information, and depending on the optimization criteria (cost, weight, efficiency etc.), the program generates a recommended design in the following format:

HOUSING	outside diameter	=	mm
	inside diameter	=	mm
	thickness	=	mm
	length (min)	=	mm
	induction	=	gauss
	weight	=	g
SEGMENT	material	=	
	min. outside radius	=	mm
	inside radius	=	mm
	thickness + air gap	=	mm
	thickness	=	mm
	height	=	mm
	width	=	mm
	length	=	mm
	angle	=	deg
	total weight	=	g
ROTOR:	diameter	=	mm
	length (iron)	=	mm
	rotor material	=	
	stamping thickness	=	mm
	number of slots	=	
	width of slot bottom	=	mm
	width of slot top	=	mm
	depth of slot	=	mm
	slot area	=	mm^2
	tooth width	=	mm
	weight	=	g
WINDING	wire diameter	=	mm
	conductors per slot	=	
	number of conductors	=	
	turns per coil	=	
	winding angle	=	deg
	weight	=	g
OTHER DATA	overhang (LR/LM)	=	
	air gap length	=	mm
	number of polepairs	=	
	pairs of par. paths	=	
	ambient temperature	=	deg
	cold stability	=	deg
	rotor induction	=	g
	induction rotor core	=	g
	fill factor	=	
	current density	=	A/mm^2
	rotor dissipation	=	W/cm^2
	copper losses	=	W
	iron losses	=	W
	armature reaction	=	A/cm
	allowed backfield	=	A/cm
	total weight	=	g

MULTI-GRADE MOTOR SEGMENTS

The MAGGY plot of Fig. 7 shows how, when the armature is energized, the permanent magnet segments in a motor are subject to demagnetizing forces that vary over their circumference. In this plot, where the flux density is minimum the demagnetization is maximum.

A double-injection pressing technique for motor segments is available that allows an extra-high coercivity grade of Ferroxdure to be substituted for the standard grade in that part of the segment where demagnetization is greatest. This improves motor performance, especially efficiency, for a given motor diameter. Our CAD facilities enable us to optimize the design of such multi-grade segments for a specific application.

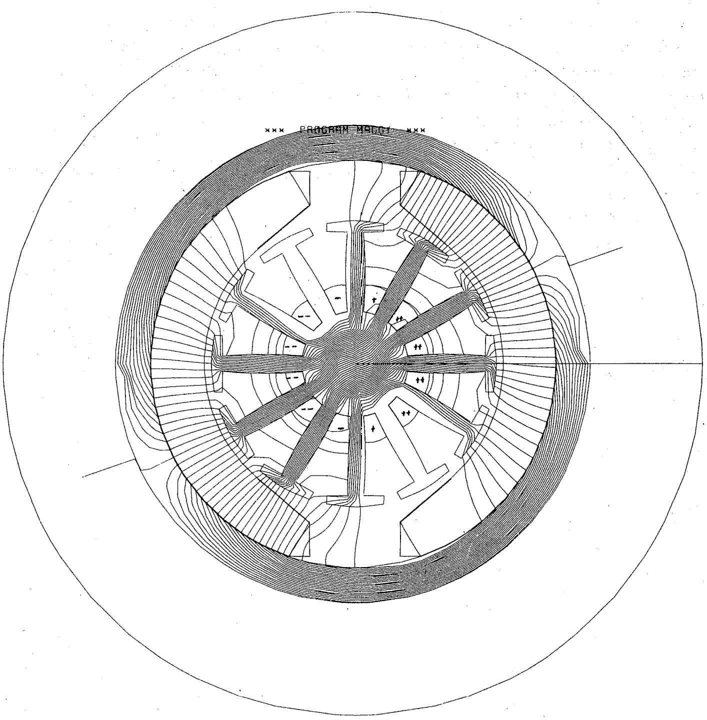


Fig. 7.

APPLICATIONS OF PERMANENT MAGNETS

CLASSIFICATION ACCORDING TO MAGNETIC FUNCTION

As a rule, permanent magnets function as energy transducers which convert energy from one kind into another, without permanently losing energy of their own. In keeping with this, permanent magnets may be classified as follows.

For the conversion of:

- electrical energy into mechanical
  such as in motors, meters, loudspeakers, beam deflectors, mass spectrometers;
- mechanical energy into electrical
  such as in generators, alternators, cycle dynamos, microphones, phonographic pick-ups, electric stringed instruments, magnetic detectors;
- mechanical energy into other mechanical energy
  such as for attraction and repulsion, holding and lifting (e.g. in industrial and household appliances, separators, chucks, thermostats, toys, etc.);
- mechanical energy into heat
  such as in hysteresis-torque and eddy-current instruments, e.g. speedometers, brakes of watt-hour meters, balances, etc.

Permanent magnets may also be used to accomplish special effects such as:

- Hall effect,
- magnetic resistance,
- nuclear magnetic resonance.

APPLICATION EXAMPLE

Loudspeaker systems using Ferroxdure rings

Figure 1 shows a relatively simple loudspeaker magnet system equipped with a Ferroxdure ring magnet. The arrangement illustrated provides high air gap flux densities and is able to take full advantage of the high coercivity of Ferroxdure, allowing flat and compact designs to be realized. Such systems can usually be analysed empirically. Below we illustrate how this can be done. The method described lends itself particularly well to analysis using small computers or programmable calculators.

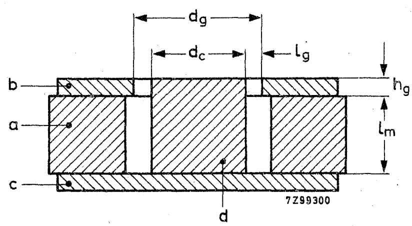


Fig. 1.

The system consists of:

(a) axially magnetized Ferroxdure ring;
(b) soft-iron ring serving as top pole plate;
(c) soft-iron disc serving as bottom pole plate;
(d) soft-iron cylindrical core.
The soft iron is of the free-cutting steel type.

Loudspeaker magnet systems can be characterized by:

$$d_c/h_g/B_g - l_g,$$

where: d_c = core diameter in mm;
h_c = height of air gap in mm;
B_g = flux density (induction) in the air gap in Gs (= 10^{-4} T)
l_g = width of air gap = $(d_g - d_c)/2$, in mm.

The pole plates b and c have a smaller outside diameter than the magnet ring a. A magnet overhang of 1 to 1,5 x dimension h_g is recommended since this will result in an optimum ratio of leakage to useful flux.

System design

We start by assuming that the iron parts of the system are unsaturated (this should be a prerequisite of the design, otherwise useful flux will be lost). The flux in the iron poles ϕ_{ST} can then be taken as the mean of the magnet flux ϕ_m and the air-gap flux ϕ_g.

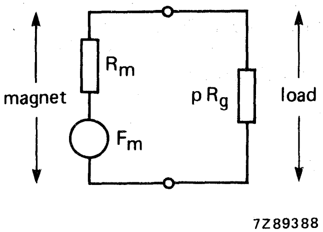


Fig. 2 Equivalent magnetic circuit.

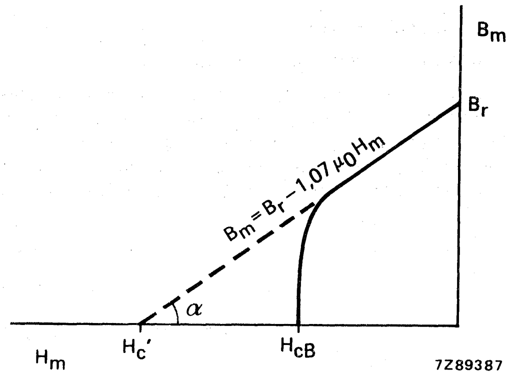


Fig. 3 Demagnetization curve of Ferroxdure.

Figure 2 shows the magnet equivalent circuit, the magnet being represented by an internal resistance (reluctance) R_m in series with a magnetomotive force F_m. We assume a linear demagnetization characteristic. This is shown in Fig. 3 and for Ferroxdure can be expressed as:

$$B_m = B_R - 1{,}07\ \mu_0 H_m \qquad (1)$$

in which H_m is the field strength of the magnet at some working point, B_R its remanence, B_m the magnetic flux density and μ_0 the permeability of free space. If the linear region of the characteristic is projected back, it intersects the H axis at H'_C, a value higher than the magnet's coercivity H_{CB}. So for a magnet of length L_m, $F_m = H'_C L_m$.

Although eq. (1) is not valid for the complete demagnetization characteristic, it does describe the relationship between B_m and H_m over the region of interest. Its validity is in fact limited to the reversible region of H_m, i.e. the region within which the value of B_m returns to B_R whenever H_m returns to zero.

Calculation of air-gap flux-density

If $B_m = 0$, then from Fig. 3 and eq. (1), $H'_C = H_m = B_R/1{,}07\ \mu_0$.
Therefore:

$$F_m = L_m B_R / 1{,}07\ \mu_0 \qquad (2)$$

From the equivalent circuit of Fig. 2, the magnet reluctance $R_m = F_m/B_R A_m$, where A_m is the cross-sectional area of the Ferroxdure ring. Therefore:

$$R_m = L_m / 1{,}07\ \mu_0 A_m \qquad (3)$$

The magnet's external load will include leakage paths as well as the intended air gap. For magnet systems like the one shown in Fig. 1, it has been found empirically that the useful air-gap flux

$$\phi_g = F_m/(pR_g + R_m) \qquad (4)$$

in which R_g is the reluctance of the useful air gap and ρ 27,5 $\mu_0 L_m R_m + 1{,}55$. For an air gap of length L_g and area A_g:

$$R_g = L_g/\mu_0 A_g. \qquad (5)$$

Combining eqs (2) and (5):

$$\phi_g = \frac{L_m B_R/1{,}07\ \mu_0}{(L_g/\mu_0 A_g)\ (27{,}5\ \mu_0 L_m R_m + 1{,}55) + L_m/1{,}07\ \mu_0 A_m} \qquad (6)$$

The effective air-gap flux density is then:

$$B_g = \phi_g/A_g$$

with $A_g = ½\pi\ (d_c + d_g)h_g = \pi(d_c + L_g)h_g$

Finding the magnet working point

Stable operation of the magnet over its specified operating temperature range can only be assured if the magnet operates at a suitable working point. For magnet systems of the type shown in Fig. 1, it has been found empirically that the total magnet flux

$$\phi_m = F_m/(R_m + R_g/\rho') \qquad (7)$$

where $\rho' = 8{,}5\ \mu_0 L_m R_m + 1{,}65$

The average magnetic induction $B_m = \phi_m/A_m$. Therefore combining eqs (2), (3) and (7):

$$B_m = DB_R$$

where

$$D = \frac{L_m/1{,}07\ \mu_0}{L_m/1{,}07\ \mu_0 A_m + (L_g/\mu_0 A_g)/(8{,}5\ \mu_0 L_m R_m + 1{,}65)}$$

and from eq. (1):

$$H_m = (1 - D)B_R/1{,}07\ \mu_0.$$

The magnet working point (H_m, B_m) at a given temperature can therefore be found as a function of its remanence B_R at that temperature. However, it is far more convenient to express the working point in terms of the remanence at ambient temperature (25 °C), since this is the value quoted in our data sheets. Now the induction of a magnet at temperature T is related to its ambient value $B_{(Ta)}$ by:

$$B_{(T)} = B_{(Ta)} \left\{ 1 + \alpha_B/100\ (T_a - T) \right\}$$

where α_B is the temperature coefficient of remanence. Note: this is a negative quantity which means that remanence increases with falling temperature. The working point at temperature T is then given by:

$$B_{m(T)} = DB_{R(Ta)} \left\{ 1 + \alpha_B/100\ (T_a - T) \right\} \qquad (8)$$

and

$$H_{m(T)} = (1 - D)B_{R(Ta)}/1{,}07\ \mu_0 \left\{ 1 + \alpha_B/100\ (T_a - T) \right\} \qquad (9)$$

Low temperature stability

The coercivity of a magnet varies with temperature according to the relation:

$$H_{CJ(T)} = H_{CJ(Ta)} \left\{ 1 + \alpha_H/100\ (T_a - T) \right\} \qquad (10)$$

in which α_H is the temperature coefficient of coercivity. As the magnet gets colder, H_{CJ} approaches H_m and the magnet working point gets closer to the knee of the demagnetization curve. At a certain temperature, T_{min}, the working point will be located precisely on the knee of the curve. Beyond this point, which can be assumed to occur at $H_{m(Tmin)} = 0{,}83\ H_{CJ(Tmin)}$ for FXD300, the magnet will almost certainly experience some demagnetization. Permanent loss of flux will therefore occur at temperatures below T_{min}.

Combining eqs (9) and (10), we arrive at the following expression for T_{min} (for FXD300):

$$T_{min} = T_a - \frac{0,83\, H_{CJ(Ta)} - (1 - D) B_{R(Ta)}/1,07\, \mu_0}{0,83\, \alpha_H H_{CJ(Ta)}/100 - \alpha_B B_{R(Ta)}/1,07\, \mu_0} \qquad (11)$$

Minimizing magnet volume

The design of a new loudspeaker magnet-system should seek to minimize magnet volume in order to make the most economic use of the magnetic material. Below we show how the minimum magnet volume can be calculated for a given air-gap size and flux-density.

From eq. (6), magnet volume V_m is given by:

$$V_m = A_m L_m = \frac{\phi_g (L_m^2 + 27,5\, \mu_0 R_g L_m^3)}{(L_m B_R - 1,66\, \mu_0 R_g \phi_g)} \qquad (12)$$

Differentiation of this expression with respect to L_m and equating to zero gives the condition for minimum magnetic volume, viz:

$$\frac{55\, L_m^2 B_R}{1,07} + \left\{ \frac{B_R}{1,07\, \mu_0 R_g} - 128\, \mu_0 R_g \phi_g \right\} L_m - 3,1\, \phi_g = 0 \qquad (13)$$

The positive root of this quadratic equation gives the value of L_m for minimum magnet volume. Substitution of this value into eq. (12) gives the magnet area A_m.

The value of L_m found from solving eq. (13) may be too small to allow the required coil movement in the final magnet system. L_m must then be increased and a new value of A_m calculated from eq. (12). In this case, of course, the magnet volume will no longer be minimized.

The newly designed system should be analysed to check its low temperature stability using the method described in the foregoing section. Should the magnet prove to be unstable at its working point, this again will necessitate an increase in L_m.

Note: it is normally possible to select a standard magnet from our range having dimensions sufficiently close to the calculated values.

FERROXDURE

INTRODUCTION

The largest volume production of industrial permanent magnet materials is in the ferro-magnetic oxides, one of which is the ceramic material known as Ferroxdure.

Ferroxdure, a ceramic material containing only non-critical raw materials, is distinguished by its high coercivity – up to about 400 kA/m – and such high electrical resistivity that it may be considered an insulator.

The high coercivity permits magnets of short magnetic lengths to be used without excessive self-demagnetization. The high electrical resistivity – some 10^{10} times that of iron – minimizes eddy current losses and thus makes Ferroxdure an ideal material for high frequency applications.

Ferroxdure corresponds approximately to the chemical formula $(M)Fe_{12}O_{19}$ where M stands for Ba, Sr, Pb etc.

Ferroxdure being a true ceramic material is hard and brittle, and close dimensional tolerances can only be achieved by grinding.

Isotropic sintered Ferroxdure permanent magnets are manufactured by milling the raw materials to a powder then mixing them together. The powder, in some cases after pre-firing, is granulated and formed to the required shape in dies by high pressure compaction or by extrusion. The fragile, compacted piece then undergoes an accurately controlled firing process in a special furnace from which it emerges as a black ceramic.

Anisotropic sintered Ferroxdure permanent magnets are produced by an extension of the manufacturing process for isotropic material. The isotropic Ferroxdure material is remilled after firing to a very fine powder. The powder or slurry is then formed to the required shape by high pressure compaction in dies with simultaneous application of an intense homogenous magnetic field. The pieces are now magnetically orientated.

After this magnetic treatment, the orientated compacted pieces are again fired in the furnace in which atmosphere and temperature are accurately controlled, and emerge with a ceramic structure.

Compared with isotropic Ferroxdure, the orientated or anisotropic Ferroxdure permanent magnets possess a very much improved performance in the direction of the magnetic field used during pressing.

Note: During sintering, the magnets shrink by about 15% (compared with the size of the pressed form).

INTRODUCTION (continued)

Plastic-bonded Ferroxdure, isotropic and anisotropic permanent magnets are manufactured from a mixture of isotropic Ferroxdure powder with either thermoplastic or thermosetting materials as bonding agents. Familiar plastics-manufacturing techniques such as extrusion, injection moulding and pressing are used for the shaping of the magnets.

The plastic-bonded Ferroxdure materials combine the magnetic properties of sintered Ferroxdure (but at a lower level) with the mechanical advantages of plastics. They can be used to make magnets which

- can be bent and even cut with a knife or scissors (P-grades);
- meet fine size tolerances without being machined (SP grade);
- have complicated shapes (all grades);
- can be machined with conventional tools (all grades);
- can possess inserted metal parts, such as shafts, plates and bushes (SP grade).

Thus, plastic-bonded Ferroxdure magnets can be used in applications from which permanent magnets were formerly excluded (for technical or economic reasons).

MATERIAL GRADES

Isotropic plastic-bonded Ferroxdure

Ferroxdure SP5F, SP10, SP10F and SP50 — Relatively rigid; shaped by injection moulding. F = flame retardant.

Ferroxdure P30, P40 and P40F — Soft, flexible and resilient; shaped by extrusion or injection moulding. F = flame retardant.

Anisotropic plastic-bonded Ferroxdure

Ferroxdure SP130, SP170 — Relatively rigid; shaped by injection moulding.

Isotropic sintered Ferroxdure

Ferroxdure 100

The individual crystals have a random orientation, and poles can therefore be induced wherever the application demands. The material is best suited to applications where high magnetic values are not essential or where isotropic properties are required.

Anisotropic sintered Ferroxdure

Ferroxdure 270, 330, 375, 380, 390, 400, 405, 410 and 425

The materials have high values of coercivity, and are therefore ideal for dynamic applications where strong demagnetizing influences are encountered, for example in radially oriented segments for use in d.c. motors. Segments are also available which combine two different materials (normally a high remanence and a high coercivity material).

Ferroxdure 300

This material is especially well suited to static applications when a high coercive force is not necessary. If the magnet is likely to be removed from its system, and/or if it is likely to be subjected to high flux, it should preferably be magnetized within its system.

CHEMICAL RESISTANCE

Sintered Ferroxdure is not attacked by:

- sodium chloride solutions, up to 30% concentration
- benzol and trichloroethylene solutions, up to 50% concentration
- petrol
- nitric acid, up to 50% concentration
- acetic acid
- creosol
- phenolic solutions
- sodium sulphate solutions.

It is slightly attacked by diluted sulphuric acid and by a solution of hydrochrotic acid, 50% concentration. It is attacked by concentrated hydrochloric acid.

Plastic-bonded Ferroxdure: see Material specifications.

FIXING SINTERED FERROXDURE MAGNETS

Sintered Ferroxdure magnets are normally fixed to other magnets by means of adhesives. Holes are difficult to incorporate. When selecting adhesives for fixing Ferroxdure magnets to metal components, such as pole pieces, it should be noted that the coefficient of linear expansion of sintered Ferroxdure is considerably smaller than that of most metals:

Sintered Ferroxdure	8 to $15 \cdot 10^{-6}/K$
Steel	11 to $20 \cdot 10^{-6}/K$
Brass	$18 \cdot 10^{-6}/K$

TEMPERATURE COEFFICIENTS

All grades of Ferroxdure have a negative temperature coefficient of remanence of about 0,2%/K and a positive temperature coefficient of coercivity of about 0,8 kA/m/K for Ba-ferrite and 0,95 kA/m/K for Sr-ferrite. For isotropic Ferroxdure, the effect of temperature on magnetic performance is reversible, i.e. after heating or cooling, the magnet will return to the point on the BH curve at which it started. Permanent demagnetization only occurs if the magnet is heated to a temperature above the Curie point.

When anisotropic Ferroxdure magnets are cooled, care should be taken to ensure that, at the lowest temperature, the working point is not below the knee of the demagnetization curve. If this happens, there will be a permanent loss of flux. This is because the published demagnetization curves are for materials at 25 °C; at other temperatures the magnetization curves will be different, Fig. 1.

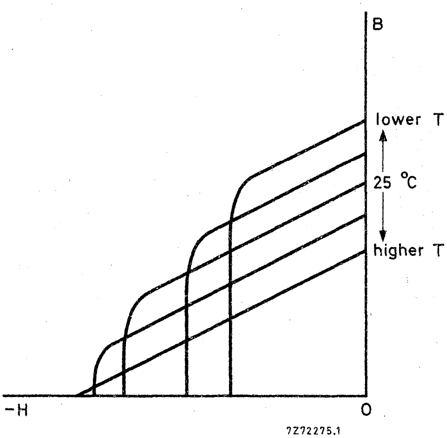


Fig. 1.

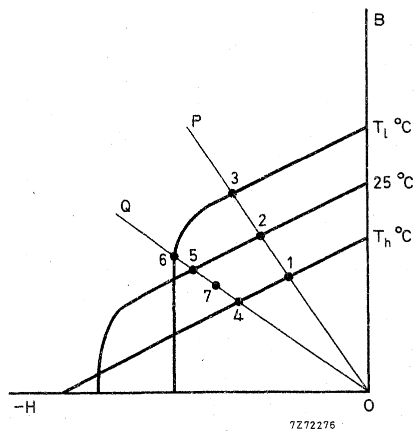


Fig. 2.

The working point on the demagnetization curve is determined by the slope of the "working line" (see Theory of Permanent Magnets section). As can be seen in Fig. 2, if the working line is OP, the working point is 2 at 25 °C, 1 at some higher temperature and 3 at some lower temperature. Since all three working points are on the upper straight line part of the demagnetization curve, the working point will return to point 2 after cycling.

If the working line is OQ, then, despite the fact that the working point is above the knee (point 5) at at 25 °C and at higher temperatures (point 4), it will go below the knee if the temperature falls sufficiently (point 6). If after cooling to T_ℓ, the temperature is raised to 25 °C, the working point will not return to point 5 but will recoil to point 7. The level of flux in the magnet will be permanently reduced.

The following expression defines the flux (B_{25}) remaining in the magnet after it has been cooled to T_ℓ °C and warmed to 25 °C:

$$B_{25} = \frac{B_\ell}{1{,}038 - 0{,}0019\ T_\ell}.$$

In this expression, B_ℓ is the flux density at T_ℓ °C. To find B_ℓ, plot the demagnetization curve of the material for a temperature of T_ℓ °C, and draw the working line for the magnet. Note: in plotting the demagnetization curves for temperatures other than 25 °C, the new values of B_r and H_{cb} can be calculated from the temperature coefficients given in the material specification, and the curves from B_r and H_{cB} plotted parallel to the 25 °C curve until they intersect. The point of intersection indicates the position of the new knee.

For high temperature operation, the working line should intersect the demagnetization line above the knee at room temperature; thus, it will then continue to do so as the temperature rises. Flux changes (due to temperature cycling) will then be reversible.

The upper temperature limit is the "maximum permissible temperature" (plastic-bonded Ferroxdure) or the Curie point (sintered Ferroxdure), as given in the material specifications.

FERROXDURE P30

isotropic plastic-bonded ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece is an extruded strip with a cross-section of approximately 11 mm x 3 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure P30 is a barium ferrite, the main constituent being $BaFe_{12}O_{19}$ with 15% (by weight) of thermoplastic material added.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	125	115	mT	1250	1150	Gs
Coercivity	H_{cB}	88	84	kA/m	1110	1050	Oe
Polarization coercivity	H_{cJ}	190		kA/m	2390		Oe
Maximum BH product	$(BH)_{max}$	2,8	2,4	kJ/m³	0,35	0,3	MGsOe
Temperature coefficient of B_r (−20 to +90 °C)		−0,2		%/K	−0,2		%/°C
Saturation field strength	H_{sat}	800		kA/m	10 000		Oe
Resistivity	ρ		10^7	Ωm		10^9	Ωcm

After storage of the magnetized test piece for 48 h at −30 °C and 48 h at +90 °C the changes in its magnetic properties do not exceed ± 3% of the initial values.

PHYSICAL PROPERTIES

Density	typ.	$3,1 \times 10^3$ kg/m³ (3,1 g/cm³)
Maximum temperature range (continuous)		−50 to +90 °C

PHYSICAL PROPERTIES (continued)

	Typical values at ambient temperature after 100 h storage at:			
	−50 ± 2 °C	25 ± 2 °C	70 ± 2 °C	
Shore C hardness after 10 s	55 ± 10	55 ± 10	70 ± 10	
Tensile strength at uniform speed of 50 mm/min	200	200	250	N/cm²
Diameter of mandrel around which the test piece can be bent without cracking or breaking; broad face in contact with mandrel	10	10	15	mm
Linear shrinkage	0,25	0,25	2	%

CHEMICAL RESISTANCE

	25 °C		70 °C	
	up to 5 h	life test	up to 5 h	life test
Water	+	+	+	+
Thinned acids	+	−	+	−
Concentrated acids	−	−	−	−
Thinned lyes	+	+	+	+
Concentrated lyes	+	−	+	−
Acetic acid 10%	+	−	−	−
Mineral oil	−	−	−	−
Light petrol	−	−	−	−
Ethyl alcohol	+	+	+	−
Acetone	−	−	−	−
Butyl acetate	−	−	−	−
Toluol	−	−	−	−
Carbon tetrachloride	−	−	−	−

A "+" means that in the chemical resistance test the test pieces showed no change in appearance and no weight change exceeding ± 3%.
Life test = 177 hours immersed.

MANUFACTURE OF MAGNETS

Magnets can be produced by rolling, calendering, transfer-moulding or extrusion, after which the magnets may be further processed by cutting tools, die-cutting machines, shears and high-speed diamond cutting wheels.

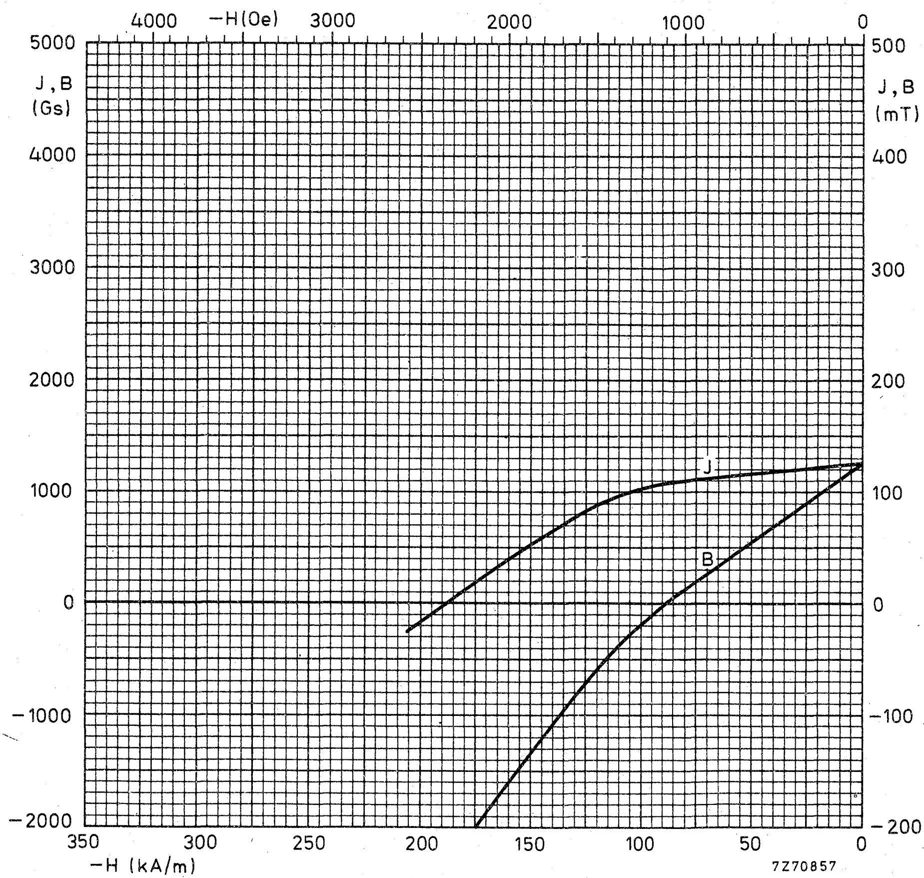
DIRECTION OF MAGNETIZATION

Ferroxdure P30 is an isotropic material and may therefore be magnetized in any direction. Where magnets are to be supplied magnetized, the pole pattern must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish, and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE P40 AND P40F

isotropic plastic-bonded ceramic materials (P40 = flame retardant)

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece is an extruded strip with a cross-section of approximately 11 mm x 3 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure P40 and P40F are barium ferrites, the main constituent being $BaFe_{12}O_{19}$ with 10% (by weight) of thermoplastic material added. Flame retarders are added to P40F.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	145	135	mT	1450	1350	Gs
Coercivity	H_{cB}	96	88	kA/m	1210	1110	Oe
Polarization coercivity	H_{cJ}	190		kA/m	2390		Oe
Maximum BH product	$(BH)_{max}$	3,6	3,2	kJ/m³	0,45	0,4	MGsOe
Temperature coefficient of B_r (−20 to +90 °C)		−0,2		%/K	−0,2		%/°C
Saturation field strength	H_{sat}	800		kA/m	10 000		Oe
Resistivity	ρ		10^6	Ωm		10^8	Ωcm

After storage of the magnetized test piece for 48 h at −30 °C and 48 h at +90 °C the changes in its magnetic properties do not exceed ± 3% of the initial values.

PHYSICAL PROPERTIES

Density	typ.	$3,7 \times 10^3$ kg/m³ (3,7 g/cm³)
Maximum temperature range (continuous)		−50 to +90 °C
Flame retardance of P40F		to UL94 V-1

PHYSICAL PROPERTIES (continued)

Typical values at ambient temperature after 100 h storage at:

		−50 ± 2 °C	25 ± 2 °C	70 ± 2 °C	
Shore C hardness after 10 s	P40	80 ± 10	80 ± 10	90 ± 10	
	P40F	90 ± 10	90 ± 10	90 ± 10	
Tensile strength at uniform speed of 50 mm/min	P40	400	350	500	N/cm^2
	P40F	800	800	950	N/cm^2
Diameter of mandrel around which the test piece can be bent without cracking or breaking; broad face in contact with mandrel	P40	15	15	25	mm
	P40F	20	20	25	mm
Linear shrinkage		0,25	0,25	2	%

CHEMICAL RESISTANCE

	25 °C		70 °C	
	up to 5 h	life test	up to 5 h	life test
Water	+	+	+	+
Thinned acids	+	−	+	−
Concentrated acids	−	−	−	−
Thinned lyes	+	+	+	−
Concentrated lyes	+	−	+	−
Acetic acid 10%	+	−	−	−
Mineral oil	+	−	−	−
Light petrol	−	−	−	−
Ethyl alcohol	+	+	+	+
Acetone	+	−	−	−
Butyl acetate	−	−	−	−
Toluol	−	−	−	−
Carbon tetrachloride	−	−	−	−

A "+" means that in the chemical resistance test the test pieces showed no change in appearance and no weight change exceeding ±3%.

MANUFACTURE OF MAGNETS

Magnets can be produced by rolling, calendering, transfer-moulding or extrusion, after which the magnets may be further processed by cutting tools, die-cutting machines, shears and high-speed diamond cutting wheels.

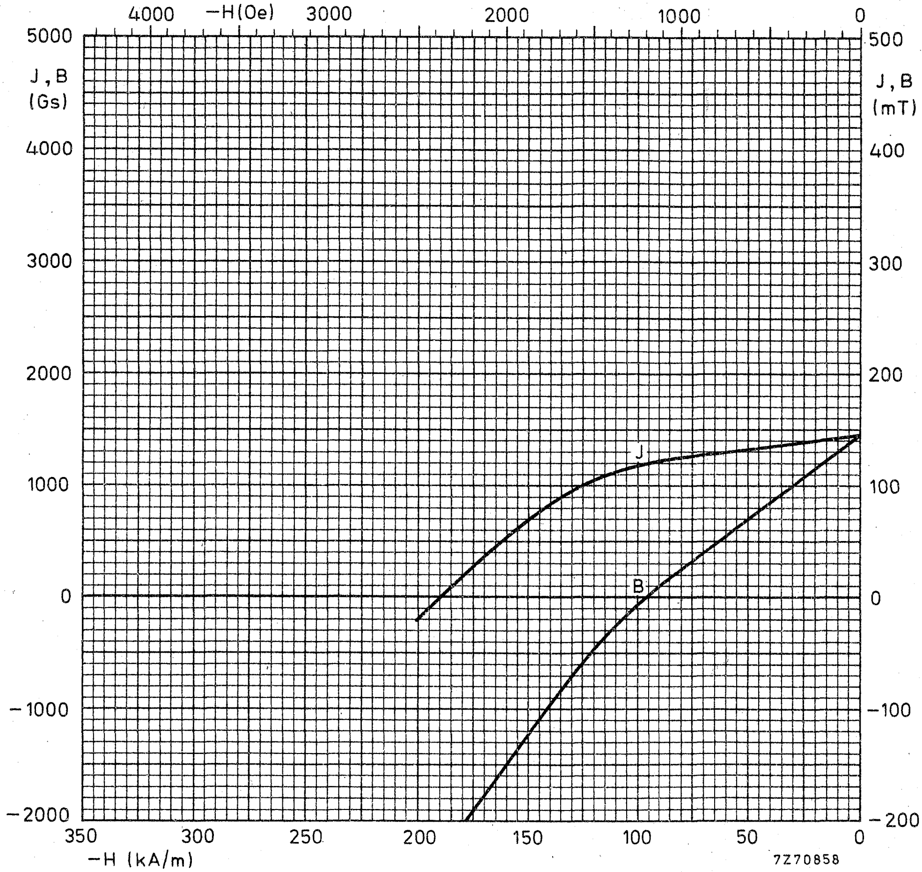
DIRECTION OF MAGNETIZATION

Ferroxdure P40 and P40F are isotropic materials and may therefore be magnetized in any direction. Where magnets are to be supplied magnetized, the pole pattern must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish, and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 ^{o}C)



FERROXDURE SP5F

isotropic, flame retardent, plastic-bonded ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately 2 mm x 10 mm x 80 mm for magnetic and electrical tests and 6 mm x 4 mm x 50 mm for mechanical and thermal tests.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure SP5F is a barium ferrite, the main constituent being $BaFe_{12}O_{19}$ with 25% (by weight) of thermoplastic material and flame retarders added.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	65	60	mT	650	600	Gs
Coercivity	H_{cB}	50	45	kA/m	628	565	Oe
Polarization coercivity	H_{cJ}	190		kA/m	2390		Oe
Maximum BH product	$(BH)_{max}$	0,7		kJ/m³	0,088		MGsOe
Temperature coefficient of B_r (−20 to + 100 °C)		−0,2		%/K	−0,2		%/°C
Saturation field strength	H_{sat}	800		kA/m	10 000		Oe
Resistivity	ρ		10^8	Ωm		10^{10}	Ωcm

After storage of the magnetized test piece for 48 h at −30 °C and 48 h at +80 °C the changes in its magnetic properties do not exceed ± 3% of the initial values.

PHYSICAL PROPERTIES

Density	typ.	$2{,}8 \times 10^3$ kg/m³ (2,8 g/cm³)
Maximum permissible temperature		
continuous		100 °C
short periods		120 °C

PHYSICAL PROPERTIES (continued)

Test piece 6 mm x 4 mm x 50 mm produced by plunger-type extruder

Linear shrinkage after 100 h at 90 °C	<	0,25 %
Moisture absorption during storage in water	<	0,06 % (by weight)
Flame retardance		to UL94 V-1

Flexural strength test

Rate of crosshead motion		50 mm/min
Length of span		40 mm
Flexural strength after 100 h		
at 25 ± 3 °C	typ.	136 N/cm²
at 100 ± 3 °C	typ.	136 N/cm²

Impact strength test (pendulum type)

Striker: 50 Ncm, length of span 40 mm

Impact strength after 100 h		
at 25 ± 3 °C	typ.	0,16 J/cm²
at 100 ± 3 °C	typ.	0,14 J/cm²

CHEMICAL RESISTANCE

	25 °C		70 °C	
	up to 5 h	life test	up to 5 h	life test
Water	+	+	+	+
Thinned acids	+	+	+	–
Concentrated acids (except HCl)	+	+	+	–
Concentrated HCl	–	–	–	–
Thinned lyes	+	+	+	+
Concentrated lyes	+	+	+	+
Mineral oil	+	+	+	+
Petrol	+	+	+	–
Ethyl glycol	+	+	+	+
Acetone	+	+	+	–
Butyl acetate	+	+	+	–
Toluol	+	+	+	–
Carbon tetrachloride	+	–	–	–

A "+" means that in the chemical resistance test the test pieces showed no change in appearance and no weight change exceeding ± 1%.

MANUFACTURE OF MAGNETS

Magnets can be produced by injection moulding, followed by cutting to the required shape. Turning and milling with special (steel) tools is possible.

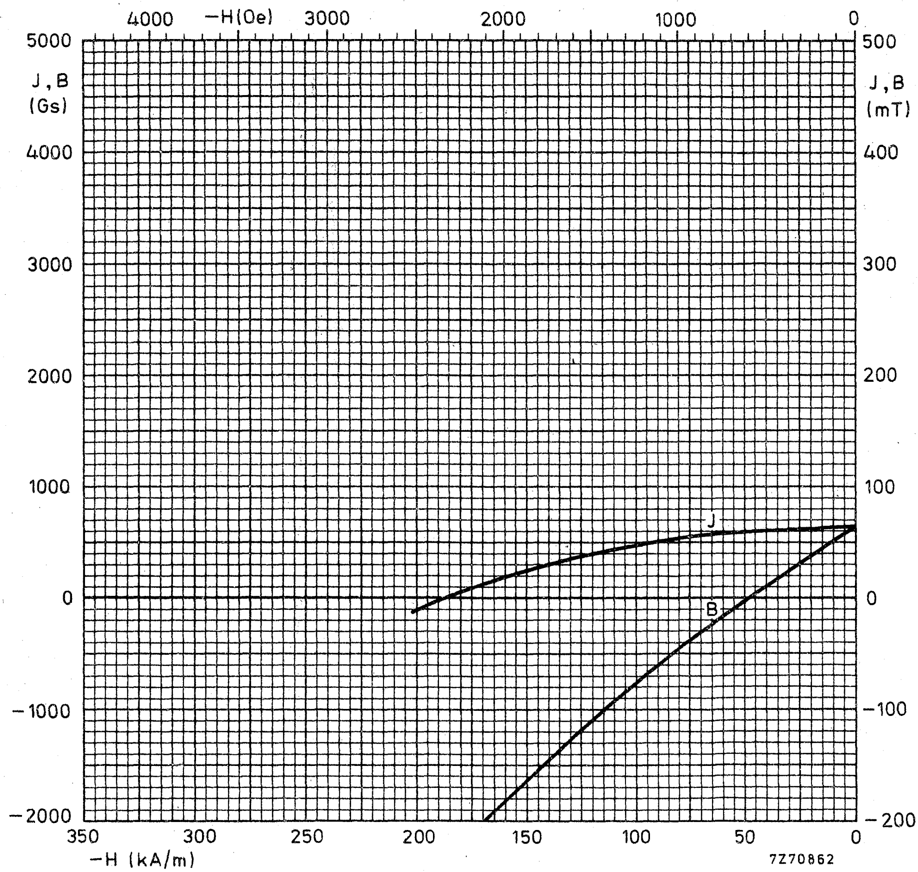
DIRECTION OF MAGNETIZATION

Ferroxdure SP5F is an isotropic material and may therefore be magnetized in any direction. Where magnets are to be supplied magnetized, the pole pattern must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish, and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE SP10 AND SP10F

isotropic plastic-bonded ceramic materials (SP10F = flame retardant)

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately 2 mm x 10 mm x 80 mm for magnetic and electrical tests and 6 mm x 4 mm x 50 mm for mechanical and thermal tests.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure SP10 and SP10F barium ferrites, the main constituent being $BaFe_{12}O_{19}$ with 25% (by weight) of thermoplastic material added. Flame retarders are added to SP10F.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 ^{o}C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	80	75	mT	800	750	Gs
Coercivity	H_{cB}	58	54	kA/m	729	679	Oe
Polarization coercivity	H_{cJ}	190		kA/m	2390		Oe
Maximum BH product	$(BH)_{max}$	0,9	0,8	kJ/m^3	0,11	0,1	MGsOe
Temperature coefficient of B_r (−20 to +100 ^{o}C)		−0,2		%/K	−0,2		%/^{o}C
Saturation field strength	H_{sat}	800		kA/m	10 000		Oe
Resistivity	ρ		10^8	Ωm		10^{10}	Ωcm

After storage of the magnetized test piece for 48 h at −30 ^{o}C and 48 h at +80 ^{o}C the changes in its magnetic properties do not exceed ±3% of the initial values.

PHYSICAL PROPERTIES

Density	typ.	2,5 x 10^3 kg/m^3 (2,5 g/m^3)
Coefficient of linear expansion (20 to 90 ^{o}C)	typ.	5 · 10^{-6}/K
Maximum permissible temperature		
continuous		100 ^{o}C
short periods		120 ^{o}C

PHYSICAL PROPERTIES (continued)

Test piece 6 mm x 4 mm x 50 mm produced by plunger-type extruder

Linear shrinkage after 100 h at 90 °C	<	0,25 %
Moisture absorption during storage in water	<	0,25 % (by weight)
Flame retardance of SP10F		to UL94 V-1

Flexural strength test

Rate of crosshead motion			50 mm/min
Length of span			40 mm
Flexural strength after 100 h		SP10	SP10F
at 25 ± 3 °C	typ.	200	150 N/cm²
at 100 ± 3 °C	typ.	200	150 N/cm²

Impact strength test (pendulum type)

Striker: 50 Ncm, length of span 40 mm

Impact strength after 100 h		SP10	SP10F
at 25 ± 3 °C	typ.	0,4	0,35 J/cm²
at 100 ± 3 °C	typ.	0,4	0,3 J/cm²

CHEMICAL RESISTANCE

	25 °C		70 °C	
	up to 5 h SP10/SP10F	life test SP10/SP10F	up to 5 h SP10/SP10F	life test SP10/SP10F
Water	+	+	+	+
Thinned acids	+	–/+	–/+	–
Concentrated acids (excepte HCl)	–/+	–/+	–/+	–
Concentrated HCl	–	–	–	–
Thinned lyes	+	+	+	–/+
Concentrated lyes	+	+	+	–/+
Acetic acid 10%	+/.	+/.	+/.	+/.
Mineral oil	+	+	+	–
Petrol	+	–/+	–/+	–
Ethyl alcohol	+/.	+/.	+/.	–/.
Ethyl glycol	./+	./+	./+	./+
Acetone	+	–/+	–/+	–
Butyl acetate	+	–/+	–/+	–
Toluol	+	–/+	–/+	–
Carbon tetrachloride	–/+	–	–	–

A "+" means that in the chemical resistance test the test pieces showed no change in appearance and no weight change exceeding ± 1%. A "." means not tested.

MANUFACTURE OF MAGNETS

Magnets are produced by injection moulding, followed by cutting to the required shape. Turning and milling with special (steel) tools is possible.

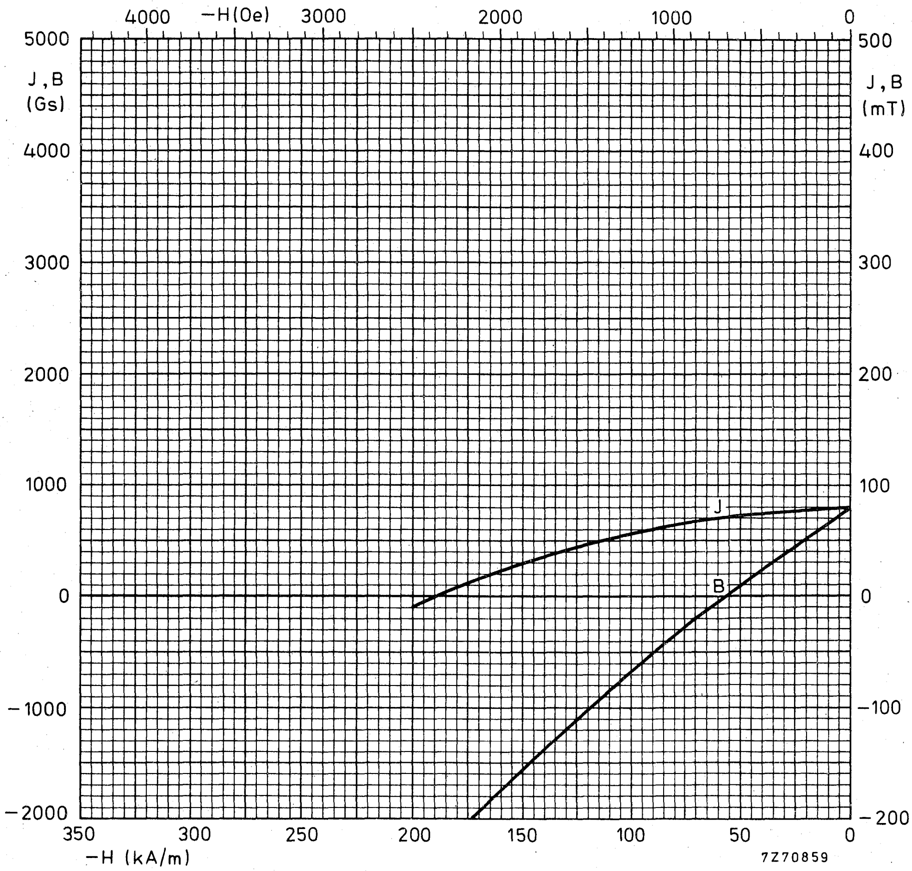
DIRECTION OF MAGNETIZATION

Ferroxdure SP10 and SP10F are isotropic materials and may therefore be magnetized in any direction. Where magnets are to be supplied magnetized, the pole pattern must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish, and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE SP50

isotropic plastic-bonded ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece is an injection moulded strip with a cross-section of approximately 11 mm x 3 mm for magnetic and electrical tests and 6 mm x 4 mm (length 50 mm) for mechanical and thermal tests.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure SP50 is a barium ferrite, the main constituent being $BaFe_{12}O_{19}$ with 7% (by weight) of thermoplastic material added.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	155	150	mT	1550	1500	Gs
Coercivity	H_{cB}	104	100	kA/m	1310	1260	Oe
Polarization coercivity	H_{cJ}	190		kA/m	2390		Oe
Maximum BH product	$(BH)_{max}$	4,4	4	kJ/m³	0,55	0,5	MGsOe
Temperature coefficient of B_r (−20 to +100 °C)		−0,2		%/K	−0,2		%/°C
Saturation field strength	H_{sat}	800		kA/m	10 000		Oe
Resistivity	ρ		10^4	Ωm		10^6	Ωcm

After storage of the magnetized test piece for 48 h at −30 °C and 48 h at +80 °C the changes in its magnetic properties do not exceed ± 3% of the initial values.

PHYSICAL PROPERTIES

Density	typ.	$3{,}9 \times 10^3$ kg/m³ (3,9 g/cm³)
Coefficient of linear expansion (20 to 90 °C)	typ.	$24 \cdot 10^{-6}$/K
Maximum permissible temperature		
continuous		100 °C
short periods		120 °C

PHYSICAL PROPERTIES (continued)

Test piece 6 mm x 4 mm x 50 mm produced by plunger-type extruder

Linear shrinkage after 100 h at 80 °C	<	0,3 %
Moisture absorption during storage in water	<	1 % (by weight)

Flexural strength test

Rate of crosshead motion		50 mm/min
Length of span		40 mm
Flexural strength after 100 h		
at 25 ± 3 °C	typ.	100 N/cm²
at 100 ± 3 °C	typ.	100 N/cm²

Impact strength test (pendulum type)

Striker: 50 Ncm, length of span 40 mm

Impact strength after 100 h		
at 25 ± 3 °C	typ.	0,1 J/cm²
at 100 ± 3 °C	typ.	0,1 J/cm²

CHEMICAL RESISTANCE

	25 °C		70 °C	
	up to 5 h	life test	up to 5 h	life test
Water	+	+	+	+
Thinned acids	+	–	–	–
Concentrated acids	–	–	–	–
Thinned lyes	+	+	+	+
Concentrated lyes	+	+	+	–
Acetic acid 10%	+	–	+	–
Mineral oil	+	+	–	–
Light petrol	+	–	–	–
Ethyl alcohol	+	+	+	–
Acetone	–	–	–	–
Butyl acetate	–	–	–	–
Toluol	–	–	–	–
Carbon tetrachloride	–	–	–	–

A "+" means that in the chemical resistance test the test pieces showed no change in appearance and no weight change exceeding ± 1%.
Life test = 150 h immersed.

MANUFACTURE OF MAGNETS

Magnets are produced by injection moulding, followed by cutting to the required shape. Turning and milling with special (steel) tools is possible.

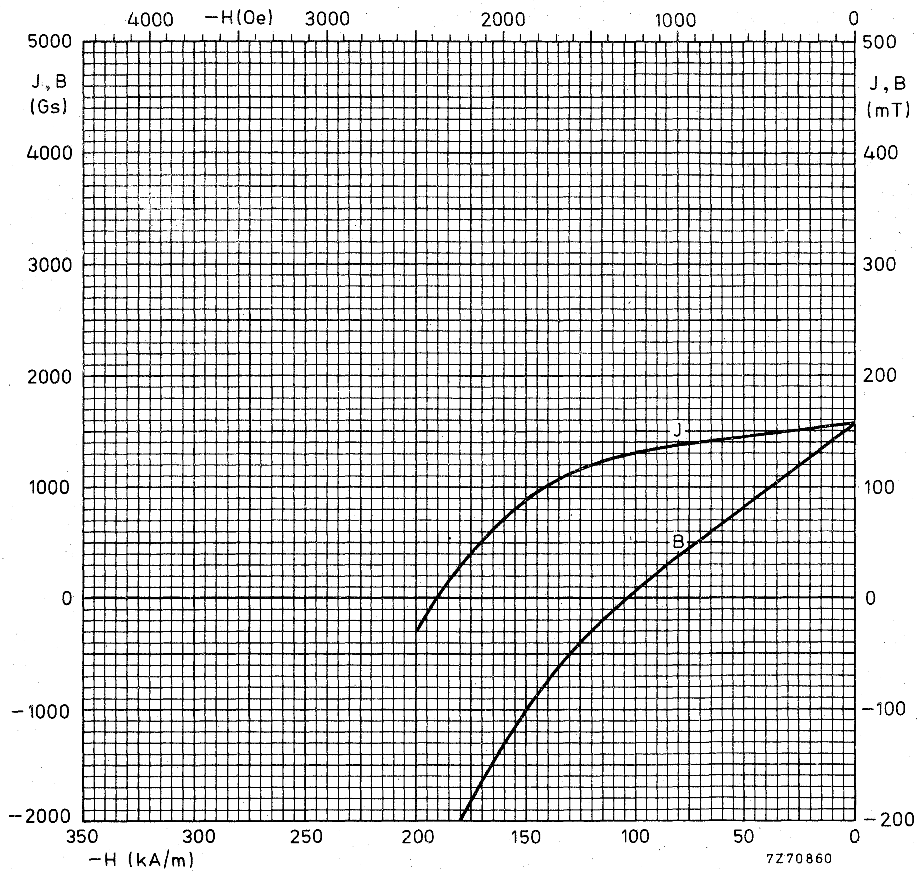
DIRECTION OF MAGNETIZATION

Ferroxdure SP50 is an isotropic material and may therefore be magnetized in any direction. Where magnets are to be supplied magnetized, the pole pattern must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish, and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE SP130

anisotropic plastic-bonded ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece is an injection moulded strip with a cross-section of approximately 11 mm x 3 mm for magnetic and electrical tests and 6 mm x 4 mm (length 50 mm) for mechanical and thermal tests.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be test used as a basis for performance guarantees.

COMPOSITION

Ferroxdure SP130 is a barium ferrite, the main constituent being $BaFe_{12}O_{19}$ with 10% (by weight) of thermoplastic material added.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	240	230	mT	2400	2300	Gs
Coercivity	H_{cB}	175	167	kA/m	2200	2100	Oe
Polarization coercivity	H_{cJ}	240		kA/m	3020		Oe
Maximum BH product	$(BH)_{max}$	11	10	kJ/m³	1,4	1,3	MGsOe
Temperature coefficient of B_r (−20 to +100 °C)		−0,2		%/K	−0,2		%/°C
Saturation field strength	H_{sat}	800		kA/m	10 000		Oe
Resistivity	ρ		10^5	Ωm		10^7	Ωcm

After storage of the magnetized test piece for 48 h at −30 °C and 48 h at +90 °C the changes in its magnetic properties do not exceed ± 5% of the initial values.

PHYSICAL PROPERTIES

Density	typ.	$3,5 \times 10^3$ kg/m³ (3,5 g/cm³)
Coefficient of linear expansion (20 to 90 °C)	typ.	$5 \cdot 10^{-6}$/K
Maximum permissible temperature		
continuous		100 °C
short periods		120 °C

PHYSICAL PROPERTIES (continued)

Test piece 6 mm x 4 mm x 50 mm produced by plunger-type extruder

Linear shrinkage after 24 h at 125 °C	$<$	0,1 %
Moisture absorption during storage in water	$<$	0,05 % (by weight)

Flexural strength test

Rate of crosshead motion		50 mm/min
Length of span		40 mm
Flexural strength after 100 h		
at 25 ± 3 °C	typ.	60 N/cm²
at 100 ± 3 °C	typ.	60 N/cm²

Impact strength test (pendulum type)

Striker: 50 Ncm, length of span 40 mm

Impact strength after 100 h		
at 25 ± 3 °C	typ.	0,1 J/cm²
at 100 ± 3 °C	typ.	0,1 J/cm²

CHEMICAL RESISTANCE

	25 °C		70 °C	
	up to 5 h	life test	up to 5 h	life test
Water	+	+	+	+
Thinned acids	+	–	–	–
Concentrated acids	–	–	–	–
Thinned lyes	+	+	+	–
Concentrated lyes	+	+	+	–
Acetic acid 10%	+	+	+	+
Mineral oil	+	+	+	–
Light petrol	+	–	–	–
Ethyl alcohol	+	+	+	–
Acetone	+	–	–	–
Butyl acetate	+	–	–	–
Toluol	+	–	–	–
Carbon tetrachloride	+	–	–	–

A "+" means that in the chemical resistance test the test pieces showed no change in appearance and no weight change exceeding ± 1%.
Life test = 170 h immersed.

MANUFACTURE OF MAGNETS

Magnets are produced by injection moulding, afterwards the products may be machined by turning and milling with special (steel) tools, by grinding using diamond tools and also by vibro-finishing.

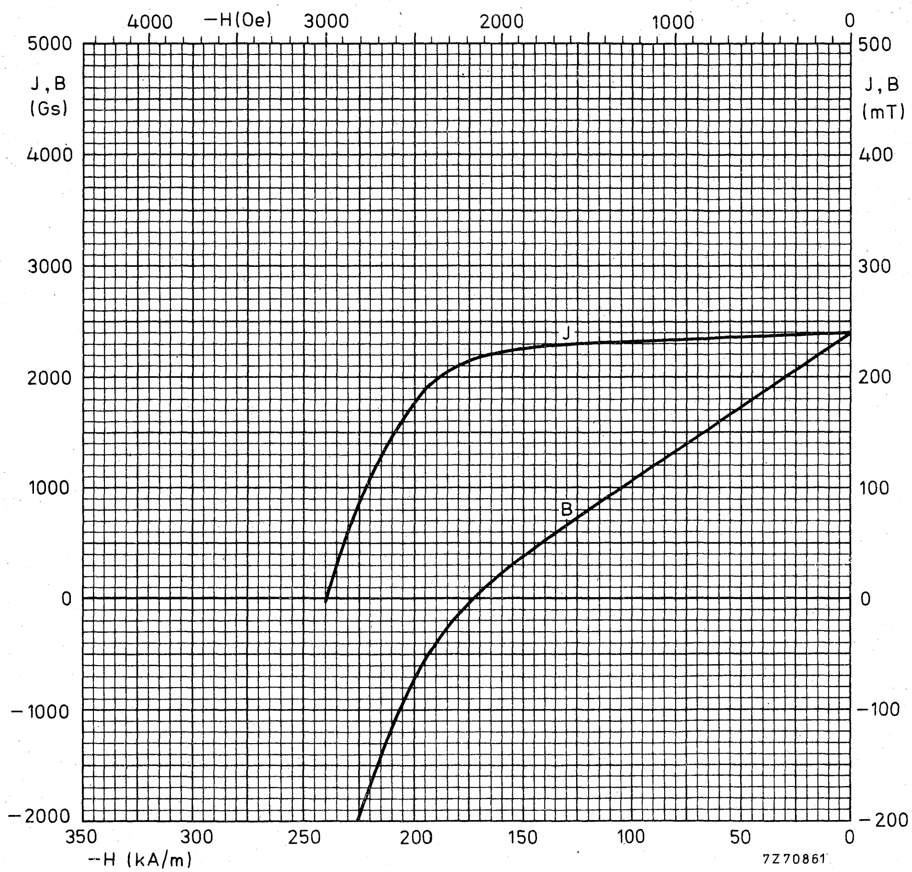
DIRECTION OF MAGNETIZATION

Ferroxdure SP130 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE SP170

anisotropic plastic-bonded ceramic material

GENERAL

This specification relates to tests performed on test pieces which are processed together with each batch in normal production. The test piece is an injection moulded strip with dimensions: 20 ± 0,5 x 12 ± 0,5 x 6 ± 0,5 mm. Preferred direction of magnetization parallel to the 6 mm dimension.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure SP170 is a mixture of barium and strontium ferrite, with 6% (by weight) of thermoplastic material added.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	270	260	mT	2700	2600	Gs
Coercivity	H_{cB}	196	188	kA/m	2460	2360	Oe
Polarization coercivity	H_{cJ}	260		kA/m	3270		Oe
Maximum BH product	$(BH)_{max}$	14	13	kJ/m³	1,75	1,6	MGsOe
Temperature coefficient of B_r (−20 to + 100 °C)		−0,2		%/K	−0,2		%/°C
Temperature coefficient of H_{cJ} (−20 to + 100 °C)				%/K			%/°C
Saturation field strength	H_{sat}	800		kA/m	10 000		Oe
Resistivity	ρ		10^5	Ωm		10^7	Ωcm

After storage of the magnetized test piece for 48 h at −30 °C and 48 h at + 90 °C the changes in its magnetic properties do not exceed ± 5% of the initial values.

PHYSICAL PROPERTIES

Density	typ.	$3,9 \times 10^3$ kg/m³	(3,9 g/cm³)
Coefficient of linear expansion (20 to 90 °C)	typ.	$5 \cdot 10^{-6}$/K	
Maximum permissible temperature			
continuous		100 °C	
short periods		120 °C	

PHYSICAL PROPERTIES (continued)

Test piece 6 mm x 4 mm x 56 mm produced by plunger-type extruder

Linear shrinkage after 24 h at 125 °X	<	0,1 %
Moisture absorption during storage in water	<	0,05 % (by weight)

Flexural strength test

Rate of crosshead motion 20 mm/min
Length of span 40 mm

Flexural strength after 100 h		
at 25 ± 3 °C	typ.	30 C/cm²
at 100 ± 3 °C	typ.	40 N/cm²

Impact strength test (pendulum type)

Striker: 50 Ncm, length of span 40 mm

Impact strength after 100 h		
at 25 ± 3 °C	typ.	0,08 J/cm²
at 100 ± 3 °C	typ.	0,08 J/cm²

CHEMICAL RESISTANCE

	25 °C		70 °C	
	up to 5 H	life test	up to 5 h	life test
Water	+	+	+	+
Thinned acids	+	–	–	–
Concentrated acids	–	–	–	–
Thinned lyes	+	+	+	–
Concentrated lyes	+	+	+	–
Acetic acid 10%	+	+	+	+
Mineral oil	+	+	+	–
Light petrol	+	–	–	–
Ethyl alcohol	+	+	+	–
Acetone	+	–	–	–
Butyl acetate	+	–	–	–
Toluol	+	–	–	–
Carbon tetrachloride	+	–	–	–

A "+" means that in the chemical resistance test the test pieces showed no change in appearance and no mass change exceeding ± 1%.
Life test = 170 h immersed.

MANUFACTURE OF MAGNETS

Magnets are produced by injection moulding. After complete demagnetization the products may be machined by turning and milling with special (steel) tools or by grinding using diamond tools.

DIRECTION OF MAGNETIZATION

Ferroxdure SP170 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

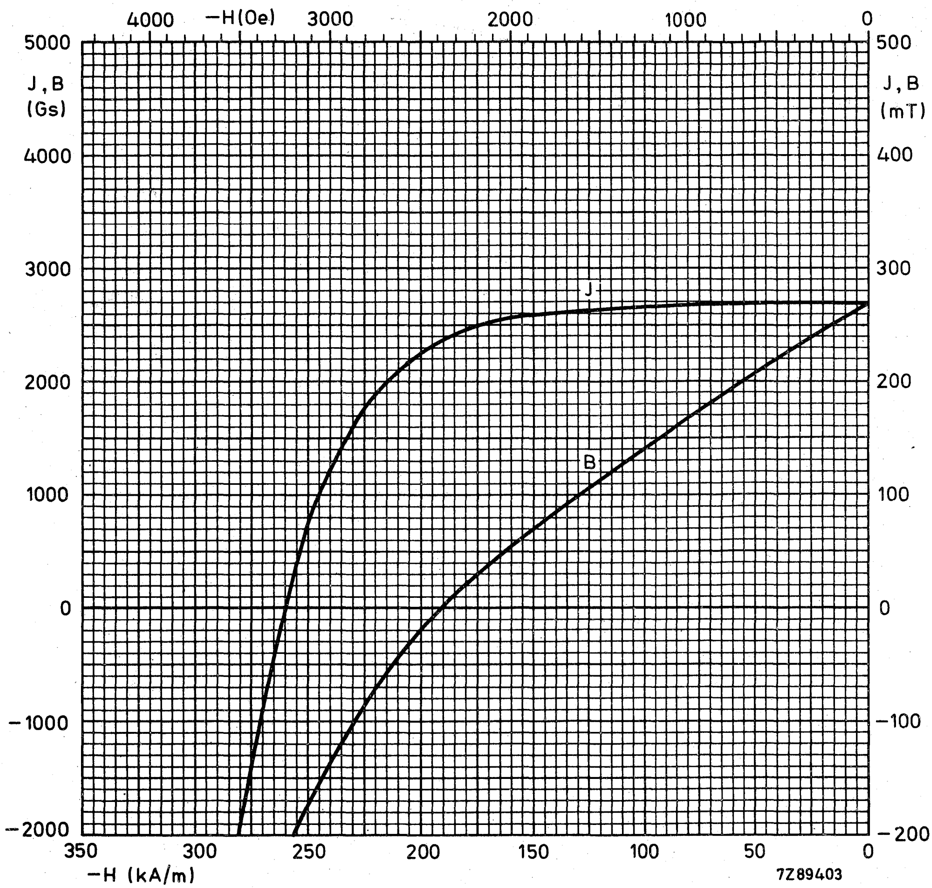
QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

APPLICATION

Where high-coercivity permanent magnets are required.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE 100

isotropic ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ32 mm x 12 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure 100 is a barium ferrite, the main constituent being $BaFe_{12}O_{19}$.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	220	210	mT	2200	2100	Gs
Coercivity	H_{cB}	135	130	kA/m	1700	1630	Oe
Polarization coercivity	H_{cJ}	220		kA/m	2760		Oe
Maximum BH product	$(BH)_{max}$	7,6	7,2	kJ/m³	0,95	0,9	MGsOe
Temperature coefficient of B_r (−40 to +200 °C)		−0,2		%/K	−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		+0,4		%/K	+0,4		%/°C
Saturation field strength	H_{sat}	800		kA/m	10 000		Oe
Resistivity	ρ		10^4	Ωm		10^6	Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density	typ.	4,9 x 10³ kg/m³	(4,9 g/cm³)
Coefficient of linear expansion (20 to 300 °C)	typ.		$10 \cdot 10^{-6}$/K
Hardless (Moh's scale)	typ.		7
Young's modulus	typ.		150 kN/mm²
Tensile strength	typ.		50 N/mm²
Compressive strength	typ.		700 N/mm²
Thermal conductivity	typ.		5,5 W/m °C

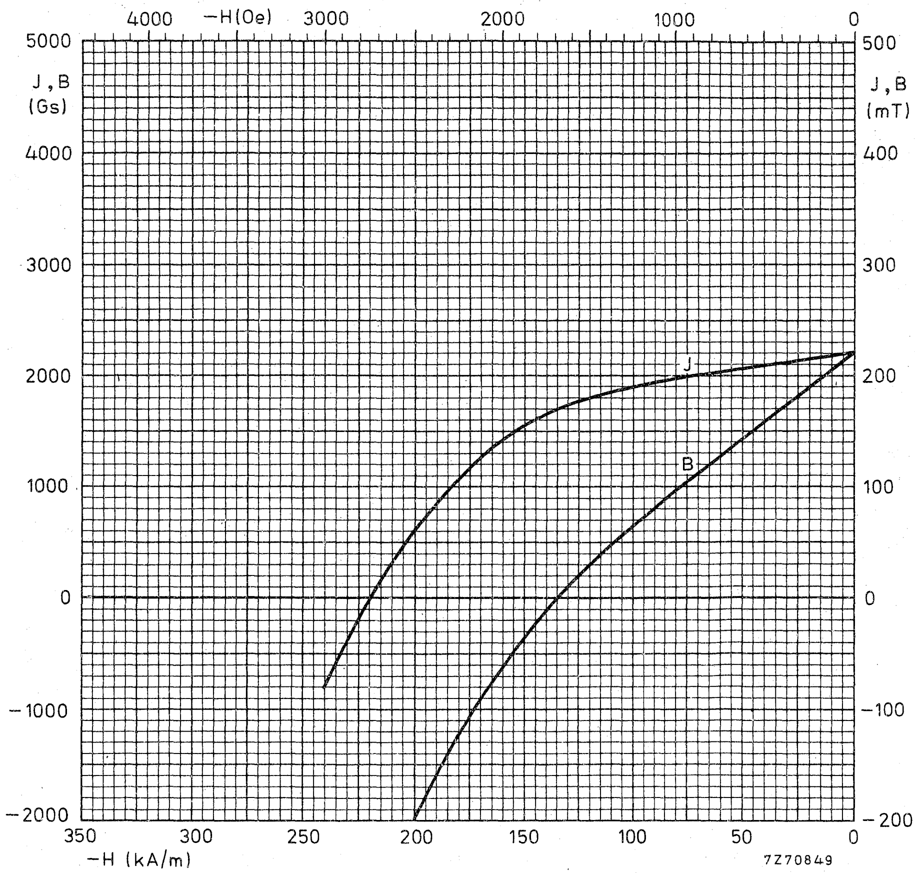
DIRECTION OF MAGNETIZATION

Ferroxdure 100 is an isotropic material, and may therefore be magnetized in any direction. Where magnets are to be supplied magnetized, the pole pattern must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish, and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE 270

anisotropic ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 35 mm x 15 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be test used as a basis for performance guarantees.

COMPOSITION

Ferroxdure 270 is a strontium ferrite, the main constituent being $SrFe_{12}O_{19}$.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	340	330	mT	3400	3300	Gs
Coercivity	H_{cB}	265	250	kA/m	3300	3100	Oe
Polarization coercivity	H_{cJ}	335	320	kA/m	4200	4000	Oe
Maximum BH product	$(BH)_{max}$	21,5	20,0	kJ/m³	2,7	2,5	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	165		mT	1650		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	131		kA/m	1650		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Temperature coefficient of B_r (−40 to +200 °C)		−0,2		%/K	−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		≈ 0,95		kA/m/K	≈ 12		Oe/°C
Saturation field strength	H_{sat}		1115	kA/m		14 000	Oe
Resistivity	ρ	10^4		Ωm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density	typ.	4,6 x 10³ kg/m³	(4,6 g/cm³)
Coefficient of linear expansion (20 to 300 °C)		⊥ MA 8 and // MA 13	· 10^{-6}/K
Hardness(Moh's scale)	typ.	6,5	

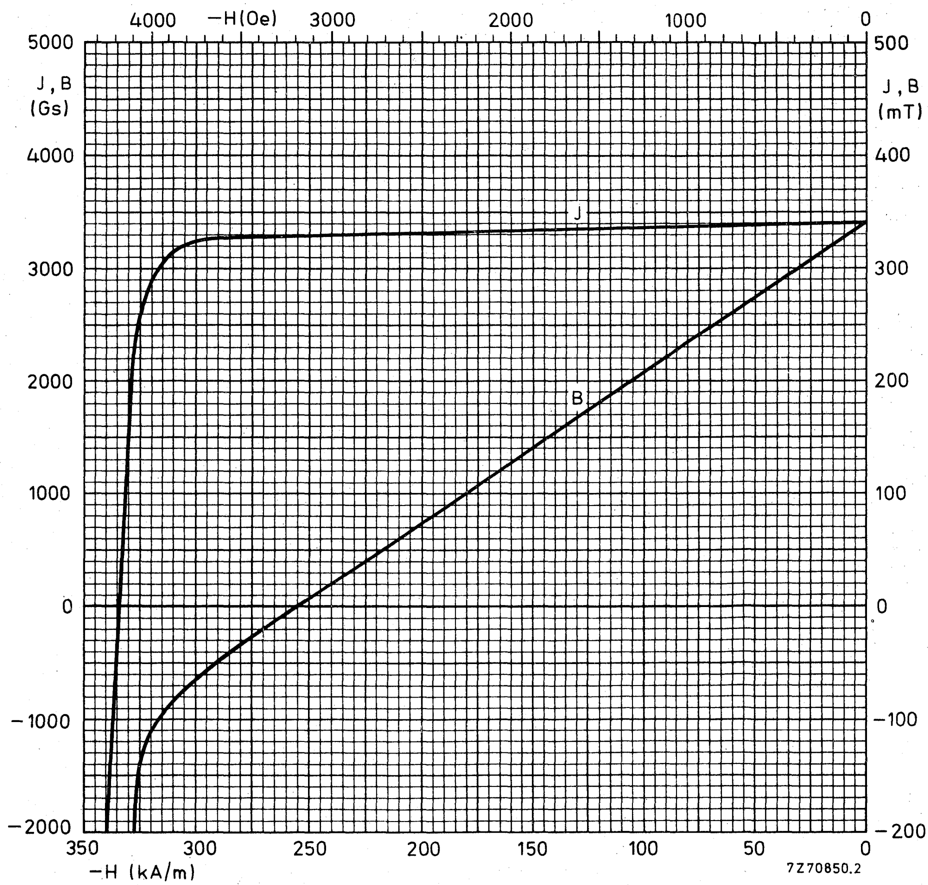
DIRECTION OF MAGNETIZATION

Ferroxdure 270 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE 300

anisotropic ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 35 mm x 12 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure 300 is a barium ferrite, the main constituent being $BaFe_{12}O_{19}$.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	400	390	mT	4000	3900	Gs
Coercivity	H_{cB}	160	145	kA/m	2000	1800	Oe
Polarization coercivity	H_{cJ}	165	150	kA/m	2050	1850	Oe
Maximum BH product	$(BH)_{max}$	29,5	28,0	kJ/m³	3,7	3,5	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	220		mT	2200		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	135		kA/m	1700		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Temperature coefficient of B_r (−40 to +200 °C)		−0,2		%/K	−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		~ 0,8		kA/m/K	~ 10		Oe/°C
Saturation field strength	H_{sat}		560	kA/m	7000		Oe
Resistivity	ρ	10^4		Ωm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density	typ.	$4,9 \times 10^3$ kg/m³	(4,9 g/cm³)
Coefficient of linear expansion (20 to 300 °C)		⊥ MA 8 and // MA 13	$\cdot 10^{-6}$/K
Hardness (Moh's scale)	typ.	6,5	

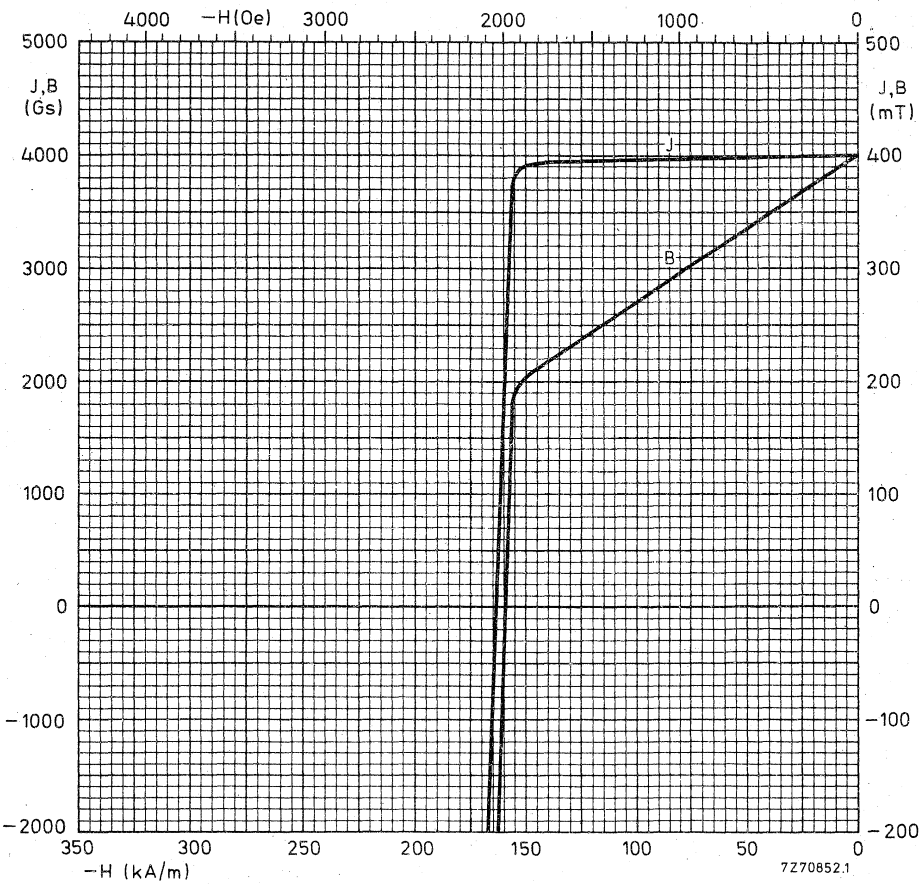
DIRECTION OF MAGNETIZATION

Ferroxdure 300 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE 330

anisotropic ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 35 x 12 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure 330 is a strontium ferrite, the main constituent being $SrFe_{12}O_{19}$.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	370	360	mT	3700	3600	Gs
Coercivity	H_{cB}	240	225	kA/m	3000	2800	Oe
Polarization coercivity	H_{cJ}	245	230	kA/m	3100	2900	Oe
Maximum BH product	$(BH)_{max}$	25,5	24,0	kJ/m³	3,2	3,0	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	180		mT	1800		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	145		kA/m	1800		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Remperature coefficient of B_r (–40 to +200 °C)		–0,2		%/K	–0,2		%/°C
Temperature coefficient of H_{cJ} (–40 to +200 °C)		≈ 0,95		kA/m/°C	≈ 12		Oe/°C
Saturation field strength	H_{sat}		875	kA/m		11 000	Oe
Resistivity	ρ	10^4		Ωm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density	typ.	4,65 x 10³ kg/m³	(4,65 g/cm³)
Coefficient of linear expansion (20 to 300 °C)	⊥ MA 8 and // MA 13		· 10^{-6}/K
Hardness (Moh's scale)	typ.	6,5	

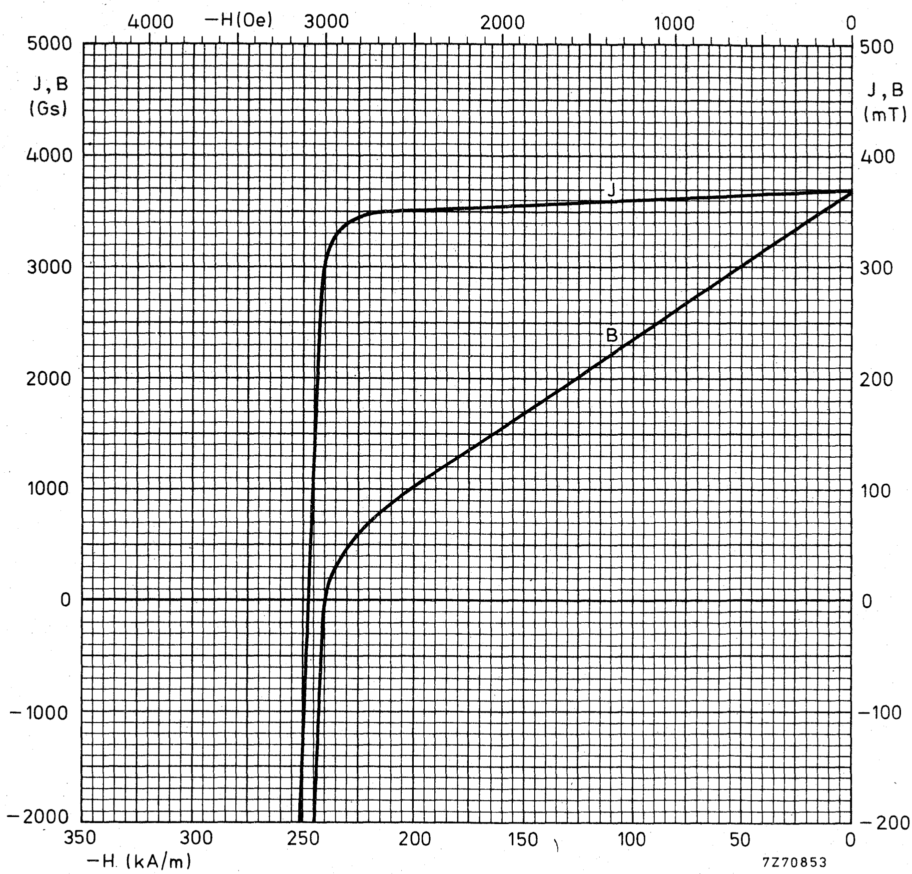
DIRECTION OF MAGNETIZATION

Ferroxdure 330 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE 375

anisotropic ceramic material

GENERAL

This specification relates tp tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately of ϕ 35 x 12 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure 375 is a strontium ferrite, the main constituent being $SrFe_{12}O_{19}$.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	380	370	mT	3800	3700	Gs
Coercivity	H_{cB}	265	250	kA/m	3300	3100	Oe
Polarization coercivity	H_{cJ}	275	260	kA/m	3500	3300	Oe
Maximum BH product	$(BH)_{max}$	27,0	25,5	kJ/m³	3,4	3,2	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	185		mT	1850		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	145		kA/m	1800		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Temperature coefficient of B_r (−40 to +200 °C)		−0,2		%/K	−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C		~ 0,95		kA/m/K	~ 12		Oe/°C
Saturation field strength	H_{sat}		995	kA/m		12 000	Oe
Resistivity	ρ	10^4		Ωm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density	typ.	4,7 x 10³ kg/m³	(4,7 g/cm³)
Coefficient of linear expansion (20 to 300 °C)	⊥ MA 8 and // MA 13		$\cdot 10^{-6}$/K
Hardness (Moh's scale)	typ.	6,5	

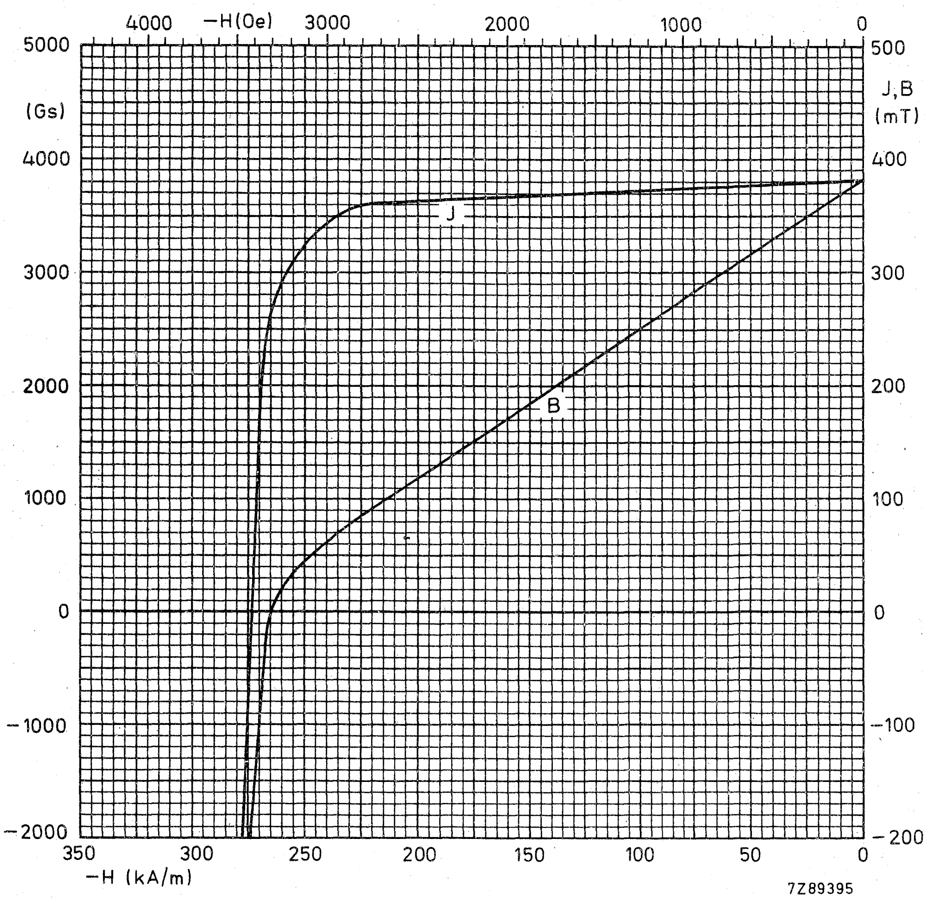
DIRECTION OF MAGNETIZATION

Ferroxdure 375 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE 380

anisotropic ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 35 mm x 12 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure 380 is a strontium ferrite, the main constituent being $SrFe_{12}O_{19}$.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	390	380	mT	3900	3800	Gs
Coercivity	H_{cB}	265	250	kA/m	3300	3100	Oe
Polarization coercivity	H_{cJ}	275	260	kA/m	3500	3300	Oe
Maximum BH product	$(BH)_{max}$	28,5	27,0	kJ/m³	3,6	3,4	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	190		mT	1900		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	150		kA/m	1900		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Temperature coefficient of B_r (−40 to +200 °C)		−0,2		%/K	−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		~0,95		kA/m/K	~12		Oe/°C
Saturation field strength	H_{sat}		955	kA/m		12 000	Oe
Resistivity	ρ	10^4		Ωm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density	typ.	4,75 x 10³ kg/m³	(4,75 g/cm³)
Coefficient of linear expansion (20 to 300 °C)	⊥ MA 8 and // MA 13		· 10^{-6}/K
Hardness (Moh's scale)	typ.	6,5	

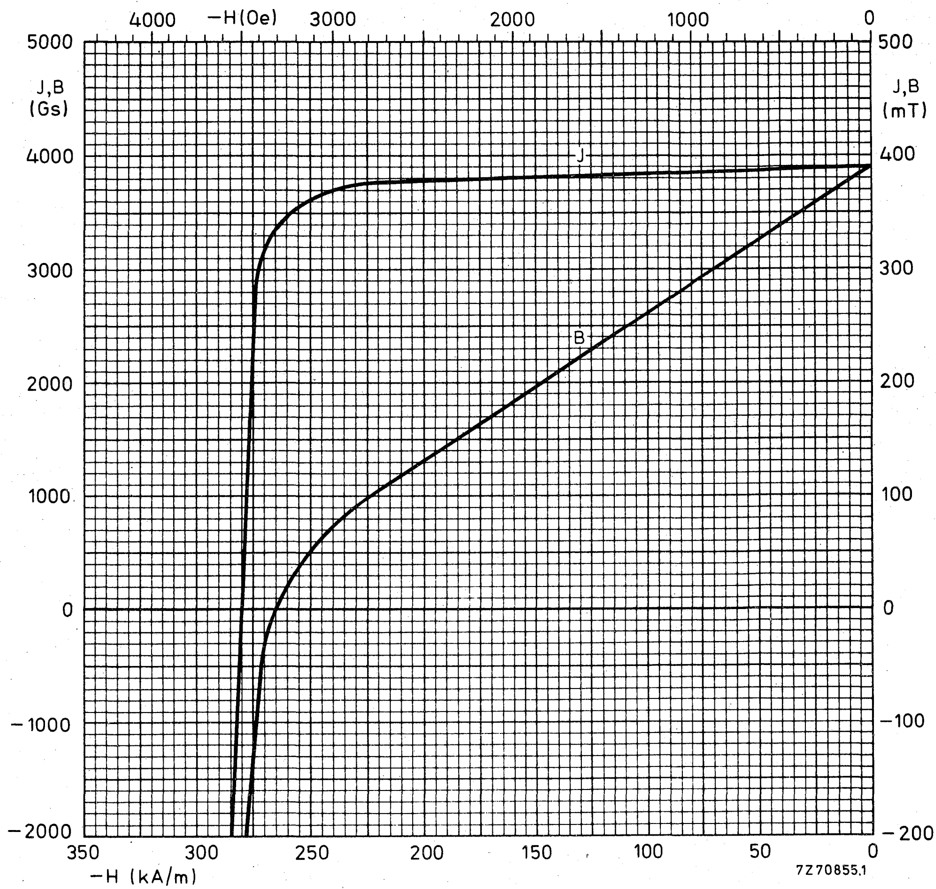
DIRECTION OF MAGNETIZATION

Ferroxdure 380 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE 390

anisotropic ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 35 mm x 12 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure 390 is a strontium ferrite, the main constituent being $SrFe_{12}O_{19}$.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	400	390	mT	4000	3900	Gs
Coercivity	H_{cB}	265	250	kA/m	3300	3100	Oe
Polarization coercivity	H_{cJ}	275	260	kA/m	3500	3300	Oe
Maximum BH product	$(BH)_{max}$	30,0	28,5	kJ/m³	3,6	3,8	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	195		mT	1950		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	155		kA/m	1950		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Temperature coefficient of B_r (−40 to +200 °C)		−0,2		%/K	−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		0,95		kA/m/K	≈ 12		Oe/°C
Saturation field strength	H_{sat}		955	kA/m		12 000	Oe
Resistivity	ρ	10^4		Ωm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density	typ.	4,75 x 10³ kg/m³	(4,75 g/cm³)
Coefficient of linear expansion (20 to 300 °C)		⊥ MA 8 and // MA 13	· 10^{-6}/K
Hardness (Moh's scale)	typ.	6,5	

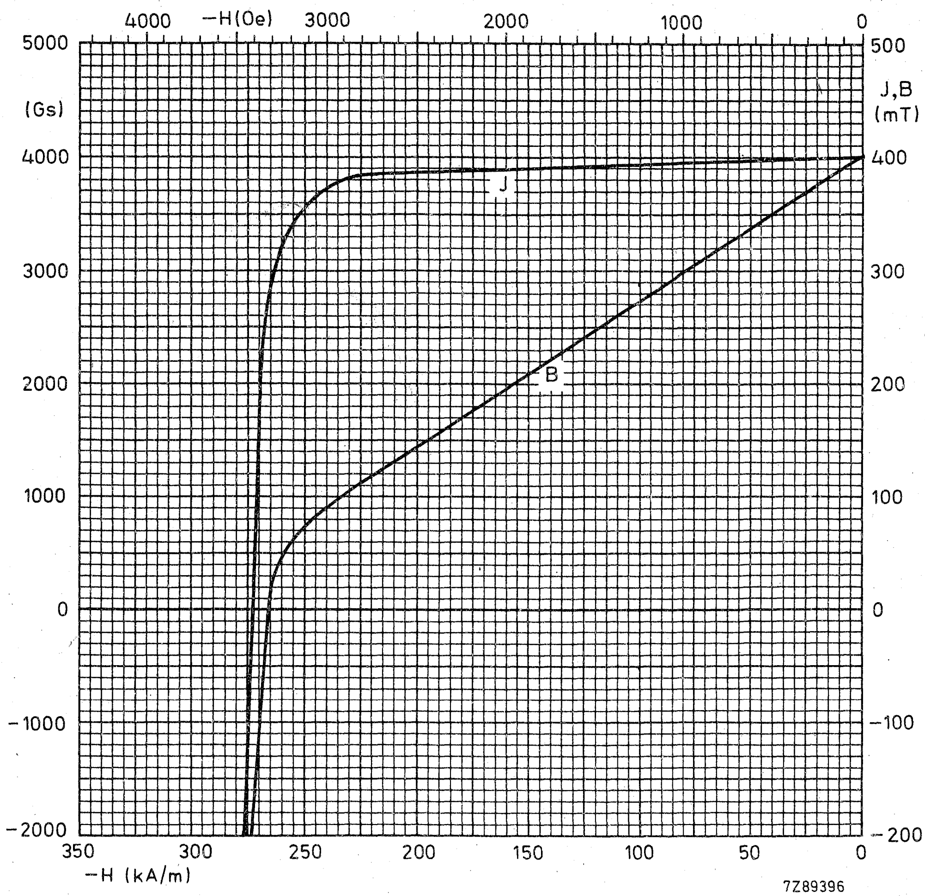
DIRECTION OF MAGNETIZATION

Ferroxdure 390 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE 400

anisotropic ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 35 mm x 12 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure 400 is a strontium ferrite, the main constituent being $SrFe_{12}O_{19}$.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	410	400	mT	4100	4000	Gs
Coercivity	H_{cB}	265	250	kA/m	3300	3100	Oe
Polarization coercivity	H_{cJ}	275	260	kA/m	3500	3300	Oe
Maximum BH product	$(BH)_{max}$	31,5	30,0	kJ/m³	4,0	3,8	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	200		mT	2000		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	160		kA/m	2000		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Temperature coefficient of B_r (–40 to +200 °C)		–0,2		%/K	–0,2		%/°C
Temperature coefficient of H_{cJ} (–40 to +200 °C)		≈ 0,95		kA/m/K	≈ 12		Oe/°C
Saturation field strength	H_{sat}		955	kA/m		12 000	Oe
Resistivity	ρ	10^4		Ωm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density	typ.	$4,8 \times 10^3$ kg/m³	(4,8 g/cm³)
Coefficient of linear expansion (20 to 300 °C)	⊥ MA 8 and // MA 13		$\cdot 10^{-6}$/K
Hardness (Moh's scale)	typ.	6,5	

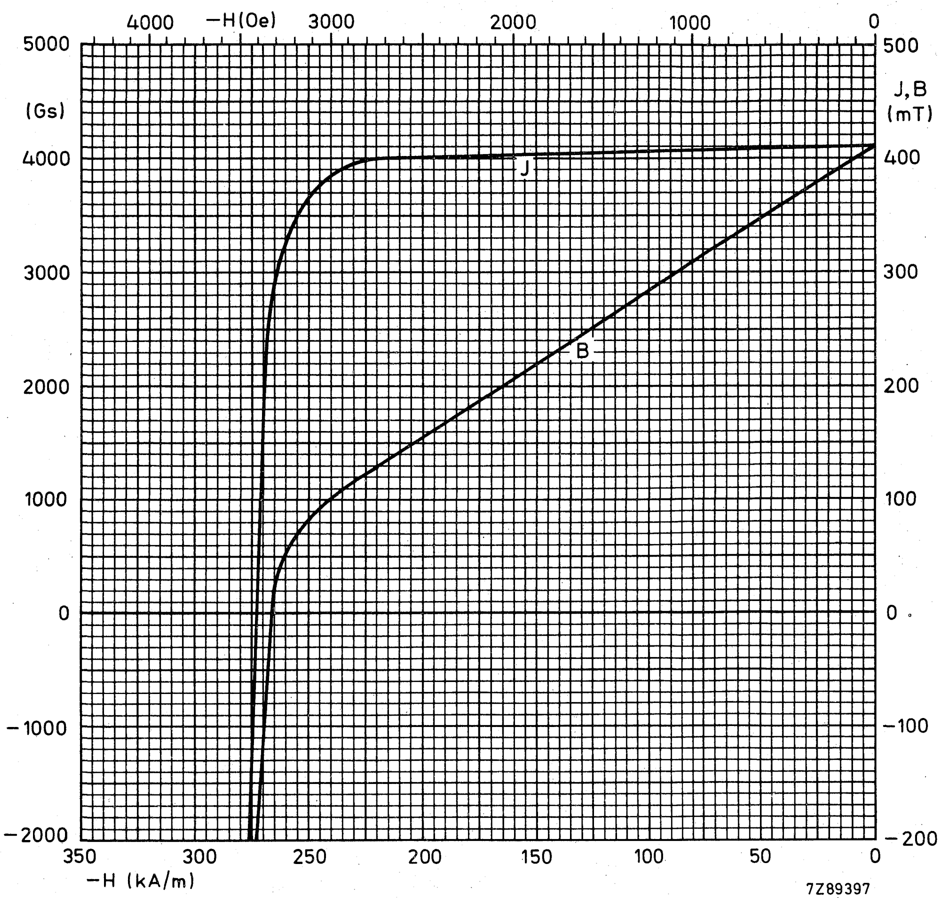
DIRECTION OF MAGNETIZATION

Ferroxdure 400 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE 405

anisotropic ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 35 mm x 12 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure 405 is a strontium ferrite, the main constituent being $SrFe_{12}O_{19}$.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	360	350	mT	3600	3500	Gs
Coercivity	H_{cB}	270	255	kA/m	3400	3200	Oe
Polarization coercivity	H_{cJ}	340	325	kA/m	4300	4100	Oe
Maximum BH product	$(BH)_{max}$	24,0	22,5	kJ/m³	3,0	2,8	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	175		mT	1750		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	140		kA/m	1750		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Temperature coefficient of B_r (−40 to +200 °C)		−0,2		%/K	−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		≈ 0,95		kA/m/K	≈ 12		Oe/°C
Saturation field strength	H_{sat}		1115	kA/m		14 000	Oe
Resistivity	ρ	10^4		Ωm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density	typ.	$4,5 \times 10^3$ kg/m³	(4,5 g/cm³)
Coefficient of linear expansion (20 to 300 °C)	⊥ MA 8 and // MA 13		$\cdot 10^{-6}$/K
Hardness (Moh's scale)	typ.	6,5	

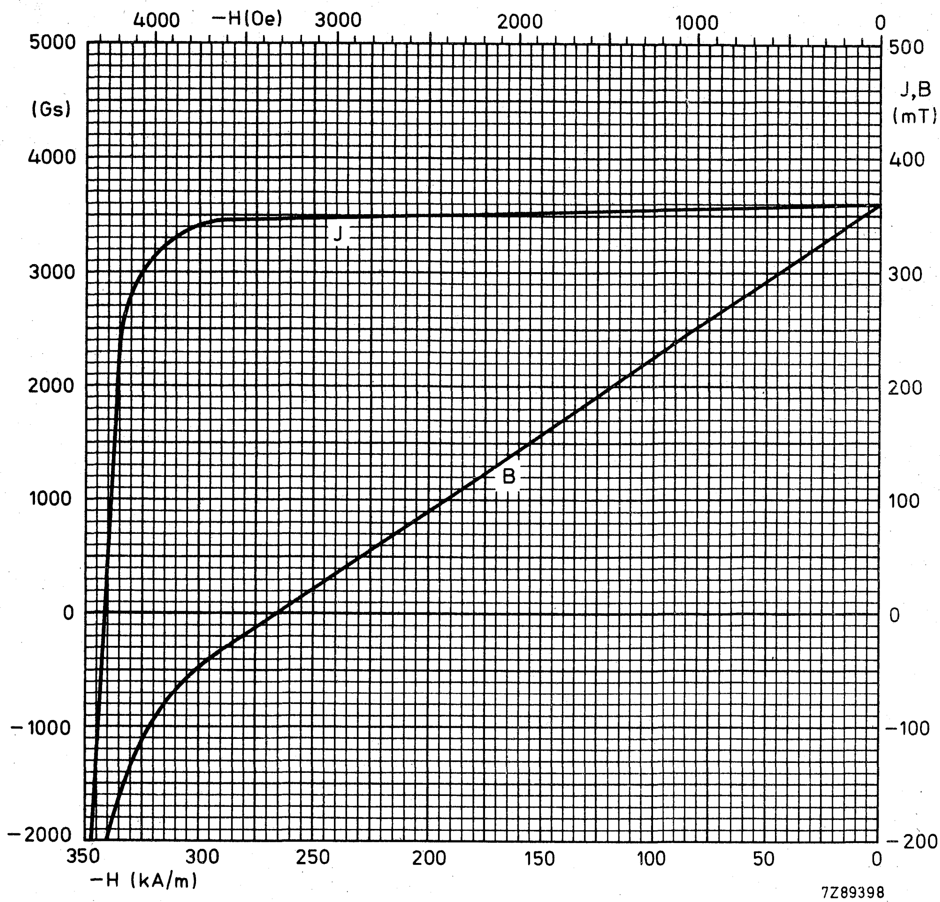
DIRECTION OF MAGNETIZATION

Ferroxdure 405 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE 410

anisotropic ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 35 mm x 12 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure 410 is a strontium ferrite, the main constituent being $SrFe_{12}O_{19}$.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	380	370	mT	3800	3700	Gs
Coercivity	H_{cB}	280	270	kA/m	3500	3400	Oe
Polarization coercivity	H_{cJ}	320	305	kA/m	4000	3800	Oe
Maximum BH product	$(BH)_{max}$	27,0	25,5	kJ/m³	3,4	3,2	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	190		mT	1900		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	145		kA/m	1800		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Temperature coefficient of B_r (−40 to +200 °C)		−0,2		%/K	−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		≈ 0,95		kA/m/K	≈ 12		Oe/°C
Saturation field strength	H_{sat}		1115	kA/m		14 000	Oe
Resistivity	ρ	10^4		Ωm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density	typ.	4,7 x 10³ kg/m³	(4,7 g/cm³)
Coefficient of linear expansion (20 to 300 °C)	⊥ MA 8 and // MA 13		· 10^{-6}/K
Hardness (Moh's scale)	typ.	6,5	

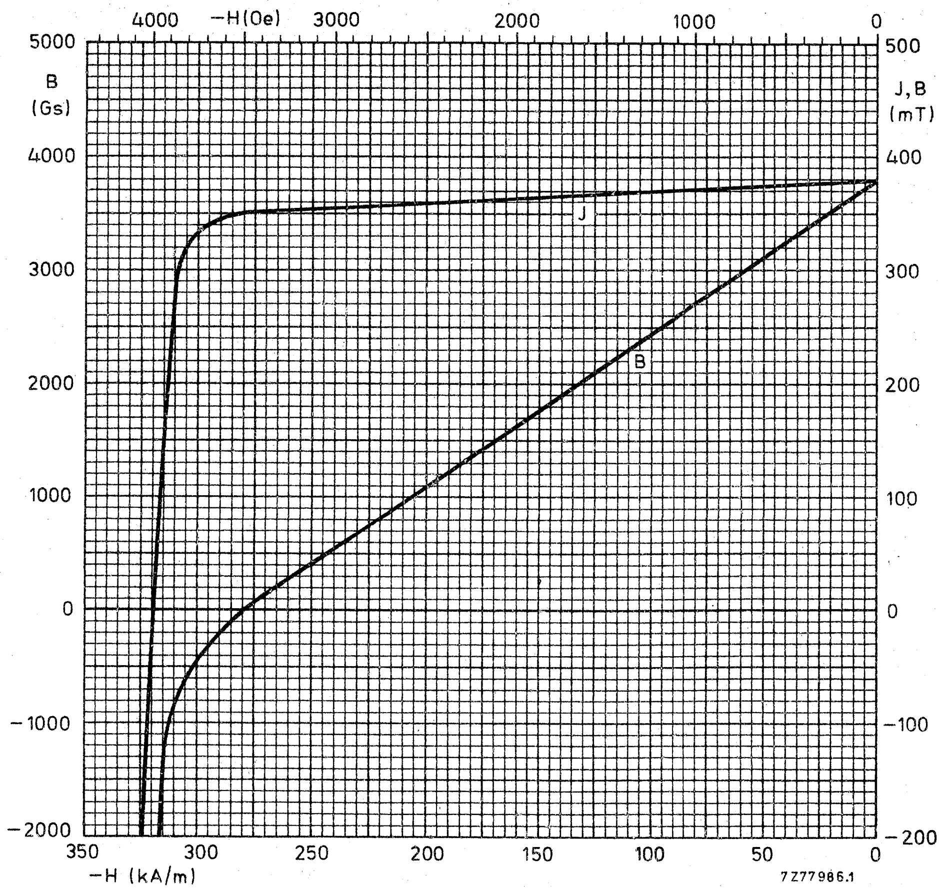
DIRECTION OF MAGNETIZATION

Ferroxdure 410 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE 425

anisotropic ceramic material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 35 mm x 12 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

COMPOSITION

Ferroxdure 425 is a strontium ferrite, the main constituent being $SrFe_{12}O_{19}$.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	420	410	mT	4200	4100	Gs
Coercivity	H_{cB}	225	215	kA/m	2800	2700	Oe
Polarization coercivity	H_{cJ}	240	225	kA/m	3000	2800	Oe
Maximum BH product	$(BH)_{max}$	33,0	31,5	kJ/m³	4,2	4,0	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	200		mT	2000		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	160		kA/m	2000		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Temperature coefficient of B_r (−40 to +200 °C)		−0,2		%/K	−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		≈ 0,95		kA/m/K	≈ 12		Oe/°C
Saturation field strength	H_{sat}		875	kA/m		11 000	Oe
Resistivity	ρ	10^4		Ωm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density	typ. 4,8 x 10³ kg/m³	(4,8 g/cm³)
Coefficient of linear expansion (20 to 300 °C)	⊥ MA 8 and // MA 13	· 10^{-6}/K
Hardness (Moh's scale)	typ. 6,5	

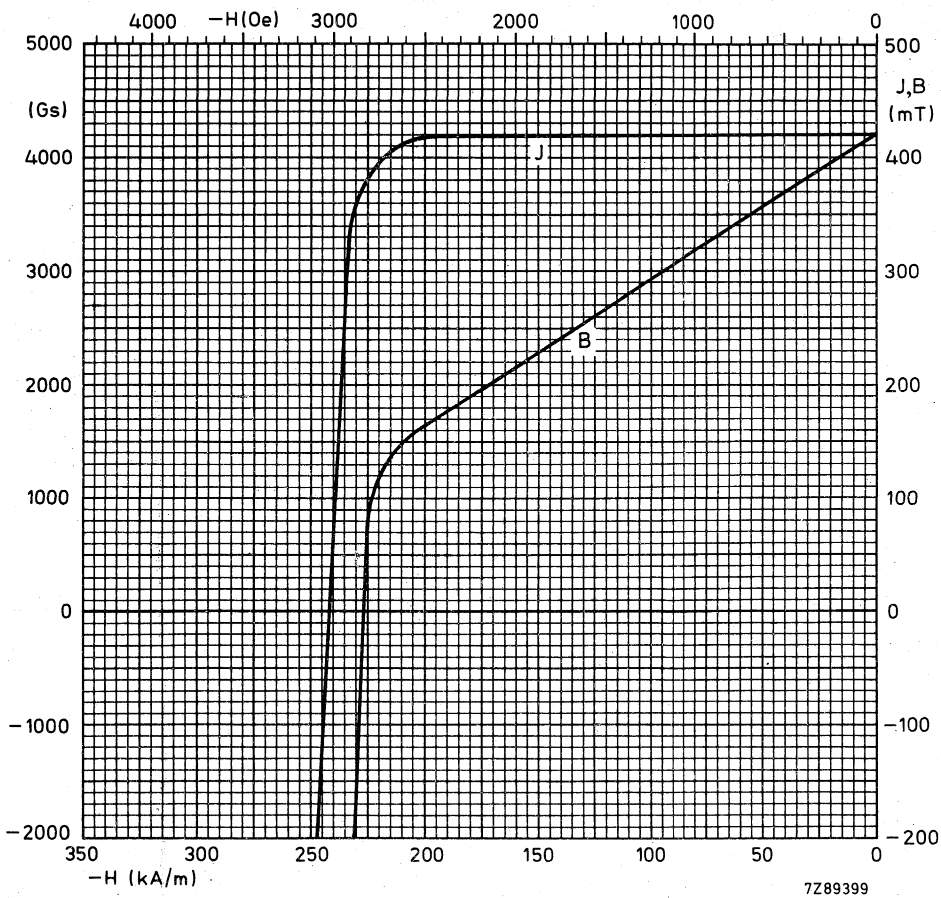
DIRECTION OF MAGNETIZATION

Ferroxdure 425 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



GENERAL

The MAGNET TYPE LIST gives initial information on the main dimensions etc. of types for which tooling already exists. Choice of a type from this list eliminates the need for new tools and consequent delay in delivery. It is important to check with the supplier if the data are still valid. Frequent additions, eliminations or changes may render the survey in this Data Handbook outdated. In that case, an updated list should be consulted.

The exact mechanical and magnetic data and the correct code number (last digit) have been laid down in the MAGNET SPECIFICATIONS, which exist for each type, and which will be sent on request.

For anisotropic sintered Ferroxdure, all shapes can be supplied in ANOTHER MATERIAL GRADE than that listed, however, due to different shrinkage properties, some differences in dimensions may be expected.

For isotropic sintered and plastic-bonded Ferroxdure all shapes can be supplied with DIFFERENT POLE PATTERNS than those listed.

For optimum results, supply of pre-magnetized magnets is not always advisable because self-demagnetization may occur due to unfavourable combinations of grade, the ratio of magnetic area to magnetic length and temperature variation.

Permanent magnets can also be ordered to your OWN DESIGN (within the limits of the material and manufacturing techniques). Our TECHNICAL ASSISTANCE on the design and application of permanent magnets is always at your disposal.

The MAGNET TYPE LIST of Ferroxdure products is divided in 7 sections:

For anisotropic sintered Ferroxdure

- Δ section 1 - blocks
- Δ section 2 - discs and rods (axially oriented)
- Δ section 3 - cylinders (diametrically oriented)
- Δ section 4 - rings (axially oriented)
- Δ section 5 - segments

For isotropic sintered Ferroxdure

- Δ section 6 - discs, rods, rings and blocks

For isotropic plastic bonded Ferroxdure

- Δ section 7 - various shapes

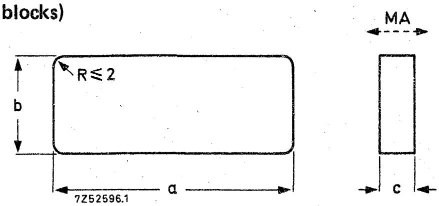
ANISOTROPIC SINTERED FERROXDURE

(section 1 - blocks)

BLOCKS

Orientation: perpendicular to a x b

Where more than one catalogue number is mentioned in the table, the first is of an unmagnetized product, the second is of a magnetized product.



a mm	b mm	c mm	FXD	mass g	catalogue no.
2,6 ± 0,1	2,6 ± 0,1	4 ± 0,1	330	0,13	— 8222 413 14280
4 ± 0,05	4 ± 0,2	3 − 0,1	330	0,23	4311 021 30270 4311 021 31460
4 ± 0,1	4 ± 0,1	4,7 ± 0,1	330	0,37	— 8222 413 14180
4,8 ± 0,2	4,8 ± 0,2	3,9 ± 0,1	330	0,44	— 4322 020 62390
5 ± 0,15	2,7 ± 0,15	5 ± 0,1	330	0,31	3122 134 91200 —
5 ± 0,2	4 ± 0,2	4 − 0,2	330	0,38	4322 020 62400 —
5 ± 0,2	5 ± 0,2	3,9 ± 0,1	330	0,48	4322 020 62380 4322 020 62020
5,1 + 0,1 − 0,15	5,1 + 0,1 − 0,15	2 ± 0,1	330	0,24	— 3522 200 51340
5,1 ± 0,15	5,1 ± 0,1	3 − 0,2	330	0,35	— 3522 200 65440
5,1 ± 0,1	5,1 ± 0,1	3,9 ± 0,1	330	0,47	— 4322 020 62370
6 − 0,05 − 0,11	4,75 − 0,05 − 0,45	2,5 ± 0,5	330	0,34	— 4311 021 31050
7 ± 0,05	4 ± 0,1	2 ± 0,05	330	0,27	4311 021 31210 —
7 ± 0,1	4 ± 0,1	7 ± 0,1	330	0,99	— 4322 020 62410
7 ± 0,3	7 ± 0,3	4,2 ± 0,05	330	1	— 4322 020 62000
8 ± 0,3	2 ± 0,3	4 ± 0,3	330	0,30	— 4311 021 33410

BLOCKS (continued)

a mm	b mm	c mm	FXD	mass g	catalogue no.
8 ± 0,15	8 ± 0,15	3,5 ± 0,15	330	1	— 4322 020 62360
8 ± 0,15	8 ± 0,15	5 ± 0,15	330	1,49	4322 020 62350 —
8,2 ± 0,1	7 ± 0,1	6,5 ± 0,1	300	2	— 4311 021 32730
9 ± 0,1	4 ± 0,1	8,4 ± 0,05		1,4	4322 020 67240 —
12 + 0,1 − 0,5	8 ± 0,3	7 + 0,3 − 0	330	3,2	— 4311 021 31220
12 + 0,1 − 0,5	11 + 0 − 0,6	5 ± 0,1	330	3,3	— 4311 021 31090
12 + 0,1 − 0,5	11 + 0 − 0,6	7 ± 0,1	330	4,6	— 4311 021 30150
13 ± 0,3	10 ± 0,3	3 ± 0,2	330	1,85	— 4311 021 31410
13 ± 0,3	10 ± 0,3	4 ± 0,05	330	2,4	4311 021 32790 —
13 ± 0,3	10 ± 0,3	5 ± 0,4	330	3,1	— 4311 021 32680
15 ± 0,3	9 ± 0,5	5 ± 0,25	330	3	— 3122 104 92700
15 ± 0,3	12 − 0,6	5 ± 0,1	330	4,4	— 4311 021 31100
15 − 0,3	15 − 0,3	4 ± 0,05	330	4,2	— 4322 020 62420
15 − 0,3	15 − 0,3	5 ± 0,05	330	5,5	— 4322 020 62430
15	15	5 ± 0,3	330	5,5	4322 020 67230 4322 020 67220
16,65 ± 0,4	5,8 ± 0,3	4,8 ± 0,4	330	2,3	— 4311 021 31070
17 ± 0,4	10 ± 0,3	5 ± 0,4	330	4,3	— 4311 021 30980
18 − 0,9	15 − 0,7	9 − 0,1	330	10,8	— 4311 021 31920
18 − 0,9	15 − 0,7	9 − 0,2	330	10,8	— 8211 071 24360
18,6 − 0,05	13 ± 0,2	4 ± 0,05	330	4,73	8211 071 21770 —

BLOCKS (continued)

a mm	b mm	c mm	FXD	mass g	catalogue no.
19 ± 0,5	5 ± 0,3	4,9 ± 0,25	330	2,2	— 4322 020 62440
19 ± 0,5	8 ± 0,3	4 ± 0,1	330	2,9	— 8211 071 23340
19 ± 0,5	9 ± 0,5	4,9 ± 0,1	330	4	— 4322 020 62250
19 ± 0,5	13,5 ± 0,4	5,2 ± 0,5	330	6,5	8211 071 33910 —
19 ± 0,5	16 ± 0,5	4 ± 0,05	330	6	— 4322 020 62450
19 ± 0,5	24 ± 0,5	5 ± 0,1	330	10,5	4322 020 62460 —
20 ± 0,5	10 ± 0,3	5 ± 0,4	330	4,6	— 4311 021 30720
20 ± 0,6	10 ± 0,4	5 ± 0,3	330	4,6	— 4311 021 31160
22 ± 0,5	9 ± 0,3	4 ± 0,1	330	3,75	— 8211 071 23350
24,8 ± 0,5	5,1 ± 0,1	9 ± 0,1	330	5,6	4222 017 20000 —
25 ± 0,5	11 ± 0,3	6 ± 0,5	330	7,7	— 4311 021 30810
28 ± 0,7	10 ± 0,3	4 ± 0,1	330	5,3	— 8211 071 23360
40 ± 1	21 ± 0,5	10 ± 0,5	330	41	— 4311 021 33400
40 ± 1	21 ± 0,5	10 ± 0,5	370*	41	— 8211 071 15470
40 ± 1	25 ± 0,75	10 ± 1	330	46	4322 020 62300 4322 020 62180
42,5 + 1,6	25,2 + 1,2	6 ± 0,05	300	32	4311 021 33670 —
42,5 + 1,6	25,2 + 1,2	7,4 ± 0,5	300	38,8	4311 021 33680 —
42,5 + 1,6	25,2 + 1,2	8,8 ± 0,05	300	48	4311 021 32690 —
42,5 + 1,6	25,2 + 1,2	9,9 ± 0,4	300	54	4311 021 32340 4311 021 33460
43,3 ± 1,1	25,8 ± 0,65	6 – 0,1	330	31,5	— 8211 071 23730

* Modified FXD 375 with B_r = 380 mT. H_{cB} = 225 kA/m and H_{cJ} = 230 kA/m.

BLOCKS (continued)

a mm	b mm	c mm	FXD	mass g	catalogue no
43,3 ± 1,1	25,8 ± 0,65	8 – 0,1	330	42	– 4311 071 33580
49,2 ± 1,2	49,2 ± 1,2	2 – 0,06	330	23,5	4311 021 31910 –
49,2 ± 1,2	49,2 ± 1,2	3 – 0,05	330	35,2	4311 021 31740 –
49,2 ± 1,2	49,2 ± 1,2	4 ± 0,05	330	47,5	8211 071 20710 –
49,2 ± 1,2	49,2 ± 1,2	4 ± 0,1	330	47,5	8211 071 23330 –
49,2 ± 1,2	49,2 ± 1,2	4,5 ± 0,5	330	53,5	4311 021 33630 –
49,2 ± 1,2	49,2 ± 1,2	6 – 0,05	330	89	4311 021 32700 –
50 ± 1,3	19 ± 0,5	4,9 – 0,25	330	21	4322 020 62220 4322 020 62270
50 ± 1,3	19 ± 0,5	6,1 ± 1	330	26	4322 020 62190 4322 020 62210
51,5 + 3	51,5 + 3	8,4 ± 0,05	334*	109	4322 020 67330 –
51,5 + 3	51,5 + 3	10 ± 0,1	334*	123	4322 020 67340 –
72,5 ± 0,5	39 ± 0,5	25,4 ± 0,2	330	340	8211 071 17810 –
72,5 ± 0,5	59,5 ± 2,5	25,4 ± 0,2	330	514	8211 071 17820 –
75 ± 2	50 ± 1,5	19,9 ± 0,1	330	353	4322 020 62310 4322 020 62320
100 ± 2,5	50 ± 1,25	25,4 ± 0,2	330	605	4311 021 32320 4311 021 32900
100 ± 2,5	63,5 ± 1,50	15,87 ± 0,15	370**	478	8211 071 20880 –
100 ± 2,5	75 ± 1,9	25,4 ± 0,2	330	900	4311 021 32330 4311 021 32910
100 ± 2,5	75 ± 1,9	50,8 ± 0,4	330	1800	– 8211 071 24030
131 ± 3	51 ± 1,5	15 ± 0,2	330	460	4322 020 62470 –
131 ± 3	51 ± 1,5	17,5 ± 0,2	330	550	4322 020 62140 4322 020 62480

* Modified FXD 330 with B_r = 370 mT; H_{cB} = 210 kA/m and H_{cJ} = 215 kA/m.
** Modified FXD 370 with B_r = 380 mT; H_{cB} = 225 kA/m and H_{cJ} = 230 kA/m.

BLOCKS (continued)

a mm	b mm	c mm	FXD	mass g	catalogue no.
150 ± 3,7	100 ± 2,5	25,4 ± 0,2	330	1800	4322 020 62330 4322 020 62340
150 ± 3,7	100 ± 2,5	25,4 ± 0,2	370*	1800	4311 021 33050 4311 021 33150
150 ± 3,7	100 ± 2,5	27,5 ± 1,5	370*	1950	8211 071 14610 —
150 ± 3,7	100 ± 2,5	50,8 ± 0,4	330	3600	— 8211 071 33990

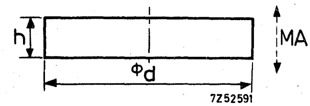
* Modified FXD 375 with B_r = 380 mT; H_{cB} = 225 kA/m and H_{cJ} = 230 kA/m.

ANISOTROPIC SINTERED FERROXDURE

(section 2, discs and rods)

DISCS

Orientation: axial
Where more than one catalogue number is mentioned, the first is of an unmagnetized product, the second is of a magnetized one.

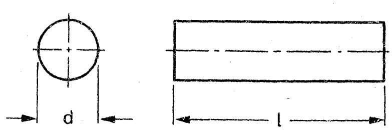


d mm	h mm	FXD	mass g	catalogue number
4,5 ± 0,1	2 ± 0,05	330	0,15	— 4322 020 62790
4,5 – 0,1	2,3 – 0,05	330	0,2	4322 020 62660 —
5,5 ± 0,05	1,8 ± 0,03	330	0,2	4322 020 62590 4322 020 62800
5,5 ± 0,06	5,2 ± 0,1	330	0,6	4322 020 62780 —
6 ± 0,05	1,8 ± 0,03	330	0,3	— 4322 020 62760
6 – 0,06	2,2 ± 0,03	330	0,28	4322 020 62680 4322 020 62770
6,4 ± 0,1	5,1 ± 0,1	330	0,8	4322 020 62750 —
6,5 – 0,06	2,3 – 0,06	330	0,35	4322 020 62740 4322 020 62730
8,9 – 0,1	5 ± 0,1	330	1,4	4322 020 62720 4322 020 62710
10 ± 0,2	2 ± 0,05	330	0,8	4322 020 62500 4322 020 62700
10 ± 0,5	4,6 ± 0,1	330	1,7	4322 020 62580 8222 413 05210
10 ± 0,3	7 – 0,2	330	2,3	— 4322 020 62640
11,9 ± 0,3	6 ± 0,4	330	2,75	— 4311 021 31040
12 ± 0,3	6 ± 0,25	300	3,5	— 4322 020 62540
12,1 ± 0,3	6 ± 0,4	330	3,3	— 4311 021 33690

d mm	h mm	FXD	mass g	catalogue number
22,8 −0,3	15 −0,5	300	–	4322 020 62570 —
29,25 ± 0,75	7,2 + 0,2	330	22,6	4311 021 30240 4311 021 31390
29,25 ± 0,75	10,5 ± 0,5	330	33	— 4311 021 32570
37,5 ± 0,2	6,5 ± 0,1	330	–	3312 060 23600 —
39 ± 1	7 ± 0,1	330	39,5	8211 071 32890 —
40,6 ± 1	9 ± 0,1		54,2	4322 020 62550 —
45 ± 1	9 ± 0,1	330	67,7	4322 020 62560 —
49 ± 0,5	12 −0,3	330	–	4322 020 62630 —
53 ± 1,3	9 ± 0,1	330	94	8211 071 22690 —
68 −0,4	18 ± 0,1	330	–	4322 020 62600 —
72,7 ± 1,8	15 ± 0,1	310		— 4322 020 62520

RODS

Orientation: axial
Where more than one catalogue number is mentioned, the first is of an unmagnetized product, the second is of a magnetized one.



d mm	l mm	FXD	mass g	catalogue number
2,9 ± 0,05	~ 14	330	0,5	4322 020 61050 —
2,9 ± 0,05	ca 14	330	0,5	4322 020 61050 —
4 ± 0,05	5 ± 0,1	330	0,3	— 4322 020 61070
4,1 ± 0,05	~ 14	330	0,9	4322 020 61040 —
6 ± 0,03	15 ± 1	330	2	4322 020 61110 —
10 ± 0,2	~ 15	330	5,5	4322 020 63710 —

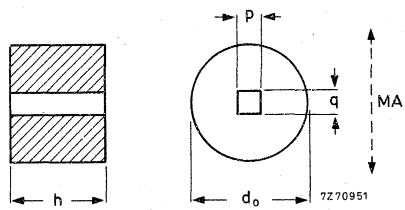
d mm	l mm	FXD	mass g	catalogue number
10 ± 0,5	10 ± 0,2	330	3,8	– 4322 020 61020
10 ± 0,5	12 ± 0,2	330	4,8	– 4322 020 61010
10 ± 0,5	15 ± 0,2	330	5,5	– 4322 020 61000

ANISOTROPIC SINTERED FERROXDURE

(section 3, cylinders)

CYLINDERS

Orientation: diametrical
Where more than one catalogue number is mentioned, the first is of an unmagnetized product, the second is of a magnetized one.



d_o mm	p x q mm	h mm	FXD	mass g	catalogue number
14,7 ± 0,03	4,2 ± 0,2 x 3,5 ± 0,2	25,5 ± 0,1	250*	20	4203 014 80120 –
18,3 ± 0,03	5,5 ± 0,2 x 4,8 ± 0,2	30 ± 0,1	250*		8203 400 12670 –

* Modified FXD330 with B_r = 330 mT. H_{cB} = 200 kA/m and H_{cJ} = 210 kA/m.

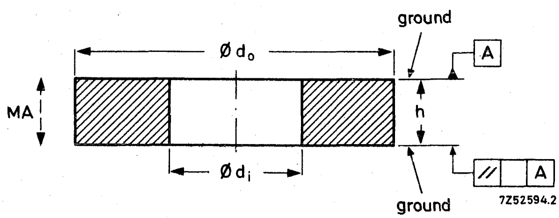
ANISOTROPIC SINTERED FERROXDURE
(section 4)

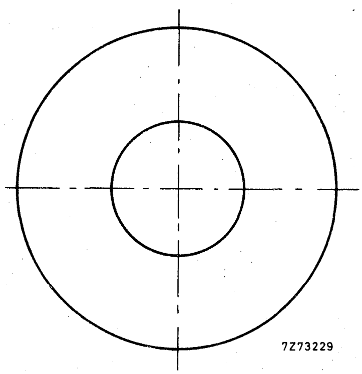
Rings in this section have axial magnetic orientation. These products are usually supplied with only pole faces ground; see also list of rings with special mechanical tolerances.

FXD300 RINGS

These are especially suitable for loudspeaker applications.

Unmagnetized versions only are listed, magnetized products from this range are also available. Some loss of performance can be expected when using pre-magnetized rings. The extent of this is dependent on dimensions and storage conditions. Please ask for details.





FXD300 RINGS (FOR LOUDSPEAKERS)

d_o mm	d_i mm	h mm	// . . A mm	mass g	catalogue number
20 ± 0,5	12,8 ± 0,4	5 ± 0,05	0,1	4,1	3922 232 00050
30 ± 0,75	16 ± 0,4	5 ± 0,1	0,1	12,4	8211 071 24330
36 ± 0,8	18 ± 0,5	6 ± 0,1	0,1	23	4311 021 33260
36 ± 0,8	18 ± 0,5	8 ± 0,1	0,1	30	4322 020 60070
$40^{+1,3}_{-0,7}$	15 ± 0,4	7 ± 0,1	0,1	37	4304 071 80130
$40^{+1,3}_{-0,7}$	22 ± 0,5	4,5 ± 0,1	0,1	20	4322 020 60610
$40^{+1,3}_{-0,7}$	22 ± 0,5	9 ± 0,1	0,1	39	4311 021 30030
$40^{+1,3}_{-0,7}$	22 ± 0,5	11,5 ± 0,1	0,1	49	4311 021 31300
45 ± 1	22 ± 0,6	8 ± 0,1	0,1	47	4322 020 60100
45 ± 1	22 ± 0,6	9 ± 0,1	0,1	53	4322 020 60110
45 ± 1	22 ± 0,6	10,5 ± 0,1	0,1	62	4322 020 60120
45 ± 1	24 ± 0,6	9 ± 0,1	0,1	50	4322 020 60130
51 ± 1,2	24 ± 0,6	6 ± 0,1	0,1	46	4311 021 32850
51 ± 1,2	24 ± 0,6	9 ± 0,1	0,1	70	4322 020 60150
53 ± 1,2	24 ± 0,6	8 ± 0,1	0,1	69	8211 071 24910
53 ± 1,2	24 ± 0,6	11 ± 0,1	0,1	95	4304 071 80260
53 ± 1,2	24 ± 0,6	15 ± 0,1	0,1	130	8222 290 12500
55 ± 1,2	24 ± 0,6	6 ± 0,1	0,1	57	3103 201 10080
55 ± 1,2	24 ± 0,6	7 ± 0,1	0,1	66	4311 021 30100
55 ± 1,2	24 ± 0,6	8 ± 0,1	0,1	75	4322 020 60160
55 ± 1,2	24 ± 0,6	10 ± 0,1	0,1	94	4322 020 60560
55 ± 1,2	24 ± 0,6	12 ± 0,1	0,1	113	4322 020 60170
$55,5^{+1,5}_{-0}$	24 ± 0,6	10 ± 0,1	0,1	97	4322 020 60550
$55,5^{+1,5}_{-0}$	24 ± 0,6	12 ± 0,1	0,1	116	4322 020 60540
60 ± 1,5	24 ± 0,6	7 ± 0,1	0,1	81,5	8211 071 32030
60 ± 1,5	24 ± 0,6	8 ± 0,1	0,1	93	4322 020 60180
60 ± 1,5	24 ± 0,6	9 ± 0,1	0,1	105	4311 021 31180
60 ± 1,5	24 ± 0,6	10 ± 0,1	0,1	116	4311 021 32860
60 ± 1,5	24 ± 0,6	12 ± 0,1	0,1	139	4322 020 60190
60 ± 1,5	24 ± 0,6	13 ± 0,1	0,1	151	4322 020 60200
60 ± 1,5	30 ± 0,7	8 ± 0,1	0,1	83	8211 071 20870

FXD300 RINGS (FOR LOUDSPEAKERS) (continued)

d_o mm	d_i mm	h mm	// . . A mm	mass g	catalogue number
60 ± 1,5	30 ± 0,7	10 ± 0,1	0,1	104	4322 020 60210
60 ± 1,5	30 ± 0,7	12 ± 0,1	0,1	125	8211 071 33870
60 ± 1,5	30 ± 0,7	13 ± 0,1	0,1	136	4311 021 32580
61,5 ± 1,5	24 ± 0,6	7 ± 0,1	0,1	86	8211 071 32080
61,5 ± 1,5	24 ± 0,6	13 ± 0,1	0,1	160	4311 021 33270
68 ± 1,5	32 ± 0,7	13 ± 0,1	0,1	180	4322 020 60230
72 ± 1,5	32 ± 0,7	8 ± 0,1	0,1	128	4311 021 34410
72 ± 1,5	32 ± 0,7	10 ± 0,1	0,1	160	4322 020 60620
72 ± 1,5	32 ± 0,7	12,7 ± 0,1	0,1	203	8211 071 32420
72 ± 1,5	32 ± 0,7	15 ± 0,1	0,1	240	4322 020 60240
72 ± 1,5	32 ± 0,7	18 ± 0,1	0,1	288	4311 021 32880
72 ± 1,5	32 ± 0,7	20 ± 0,1	0,1	320	8211 071 31500
72 ± 1,5	36 ± 0,9	18 ± 0,1	0,1	270	8211 071 33501
72 ± 1,5	40,5 ± 1	13,5 ± 0,1	0,1	184	3922 250 00040
73 ± 1,5	38,5 ± 1,5	16 ± 0,1	0,1	237	4311 021 30000
84 ± 2,1	32 ± 0,8	10 ± 0,1	0,1	232	4322 020 60830
84 ± 1,8	32 ± 0,8	14 ± 0,1	0,1	325	4322 020 64500
84 ± 2,1	32 ± 0,8	15 ± 0,1	0,1	348	4322 020 60270
84 ± 2,1	32,8 ± 0,9	15 ± 0,1	0,1	345	4311 021 33660
84 ± 2,1	42 ± 1,1	12 ± 0,1	0,1	244	8211 071 39090
84 ± 2,1	42 ± 1,1	15 ± 0,1	0,1	306	4322 020 60980
84 ± 2,1	42 ± 1,1	16 ± 0,1	0,1	326	8211 071 39070
84 ± 2,1	42 ± 1,1	18 ± 0,1	0,1	367	4322 020 60910
90 ± 1,8	36 ± 0,9	17 ± 0,15	0,15	445	4322 020 60280
90 ± 1,8	42 ± 1,1	17 ± 0,15	0,15	415	4322 020 60750
90 ± 1,8	42 ± 1,1	21 ± 0,15	0,15	520	4322 020 60880
96 ± 2,4	40 ± 1	10 ± 0,15	0,15	290	8211 071 24710
96 ± 2,4	40 ± 1	24 ± 0,15	0,15	703	4311 021 31060
96 ± 2,4	40 ± 1	25 ± 0,15	0,15	733	4322 020 60290
102 ± 3	40 ± 1	12 ± 0,15	0,15	407	4322 020 60810
102 ± 3	42 ± 1,1	17 ± 0,15	0,15	565	8211 071 39060
102 ± 3	42 ± 1,1	24 ± 0,2	0,2	798	8211 071 23120
102 ± 3	51 ± 1,5	10 ± 0,15	0,15	300	4322 020 60300
102 ± 3	51 ± 1,5	14 ± 0,15	0,15	420	4322 020 60310
102 ± 3	51 ± 1,5	17 ± 0,15	0,15	513	4322 020 60950
102 ± 3	51 ± 1,5	18 ± 0,15	0,15	540	4311 021 33900

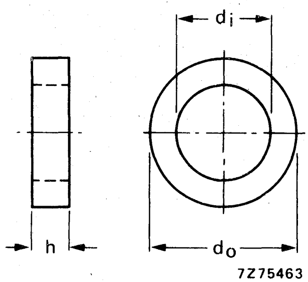
FXD300 RINGS (FOR LOUDSPEAKERS) (continued)

d_o mm	d_i mm	h mm	// . . A mm	mass g	catalogue number
102 ± 3	51 ± 1,5	20 ± 0,15	0,15	600	8211 071 32100
102 ± 3	57 ± 1,5	12 ± 0,15	0,15	330	4322 020 60790
102 ± 3	57 ± 1,5	15 ± 0,15	0,15	415	4322 020 60960
102 ± 3	57 ± 1,5	17 ± 0,15	0,15	470	4322 020 60930
110 ± 3,3	45 ± 1,1	18 ± 0,15	0,15	698	8211 071 39230
110 ± 3,3	57 ± 1,7	20 ± 0,15	0,15	681	8211 071 17090
121 ± 3,6	57 ± 1,7	12 ± 0,2	0,20	526	4322 020 60320
121 ± 3,6	57 ± 1,7	17,5 ± 0,2	0,20	767	4322 020 60570
121 ± 3,6	57 ± 1,7	20 ± 0,2	0,20	876	8211 071 17080
121 ± 3,6	57 ± 1,7	24 ± 0,2	0,20	1050	8222 290 13900
121 ± 3,6	64 ± 1,7	20 ± 0,2	0,20	811	4322 020 60900
121 ± 3,6	64 ± 1,7	24 ± 0,2	0,20	973	8222 290 13930
130 ± 3,3	57 ± 1,7▲	20 ± 0,2	0,20	1031	4322 020 60760
134 ± 4	57 ± 1,7	14 ± 0,2	0,20	792	4322 020 60330
134 ± 4	57 ± 1,7	20 ± 0,2	0,20	1132	4322 020 60020
155 ± 4,5	57 ± 1,7	17,5 ± 0,15	0,15	1400	4322 020 60010
184 ± 5,5	73 ± 2,2	18,5 ± 0,2	0,20	2032	4322 020 60350
184 ± 5,5	81,3 ± 2	18,5 ± 0,2	0,20	1941	4322 020 60000
224 ± 5	122 ± 3	23 ± 0,2	0,20	3124	8211 071 23090
224 ± 5	122 ± 3	25,3 ± 0,2	0,20	3434	8211 071 39041

▲ This type has 3 axial slots on the inner circumference.

FERROXDURE RINGS (other than in FXD300)

Listed are rings in material grades other than FXD300, either with or without special mechanical tolerances. Rings are usually available in any specified Ferroxdure grade.



A = Magnetized axially.

d_o mm	d_i mm	h mm		FXD	mass g	catalogue number
22 ± 0,5	12,5 ± 0,5	4 ± 0,1		330	5	4322 020 60740
26,5 ± 0,65	12,7 ± 0,5	3,8 ± 0,1		330	7,5	8211 071 39320
30 ± 0,75	16 ± 0,4	5 ± 0,1		330	12	8211 071 39290
51 ± 1,2	25 ± 0,6	9 ± 0,1		330	68	4311 021 32080
51 ± 1,2	24 ± 0,6	9 ± 0,1		370*	68	8211 071 24940
55 ± 1,2	24 ± 0,6	8 ± 0,1	A	330	75	4311 021 31230
72 ± 1,5	32 ± 0,7	10,2 ± 0,1		330	158	4311 021 32940
102 ± 3	57 ± 1,5	12 ± 0,15		370*	320	8211 071 33470

* Modified FXD375 with B_r = 380 mT, H_{cB} = 225 kA/m, H_{cJ} = 230 kA/m.

FERROXDURE RINGS (other than in FXD300) (continued)

Rings with special tolerances

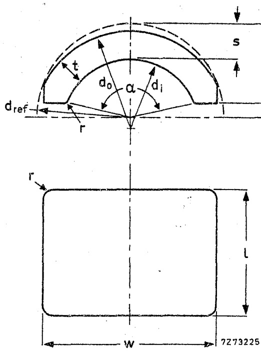
d_o mm	d_i mm	h mm		FXD	mass g	catalogue number
8 $^{+1}_{-0}$	4 $^{+0,5}_{-0}$	4 ± 0,5	A	330	0,8	8211 071 24000
24 $^{+0,08}_{-0}$	10,2 ± 0,3	3,96 ± 0,12		330	7	8222 290 13990
26,2 $^{+0}_{-0,3}$	12,7 ± 0,5	3,8 ± 0,05		330	7,3	8211 071 39160
30 $^{+0,6}_{-0,8}$	12,7 ± 0,5	6,35 ± 0,05		330	17	8222 290 13980
36 ± 0,8	18 ± 0,5	8 $^{+0}_{-1,2}$		330	26	8211 071 24780
45 ± 0,25	22 ± 0,6	9 ± 0,1	A	300	53	4311 021 32140

ANISOTROPIC SINTERED FERROXDURE

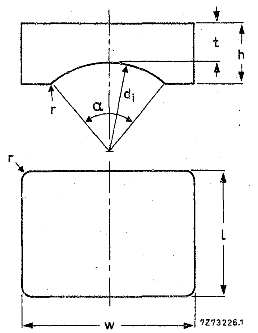
(section 5-segments)

SEGMENTS FOR MOTORS

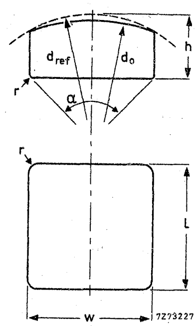
Basic shapes



A
Concave-convex



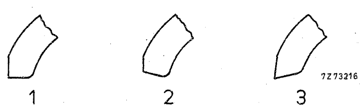
B
Flat-concave



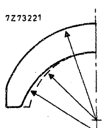
C
Flat-convex

Note: The diameter d_{ref} corresponds with the maximum internal diameter of the stator housing. Most segments have an outer diameter $\geqslant d_{ref}$. In this way, two-point contact with the stator housing is obtained, avoiding rocking of the segment.

Variants on the feet of shapes A and B

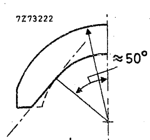


Variants on the inner radii of shapes A and B



a

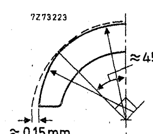
"Divergence"



b

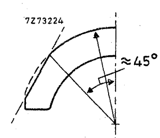
Tangential flats inside

Variants on the outer radii of shapes A and C



c

Contact points within 90°

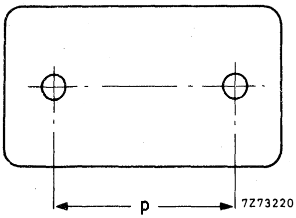


d

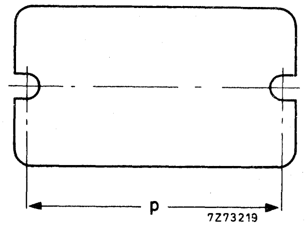
Outside flats

Addition of holes or slots

In principle, all basic shapes can be provided with holes (o) or slots (u).



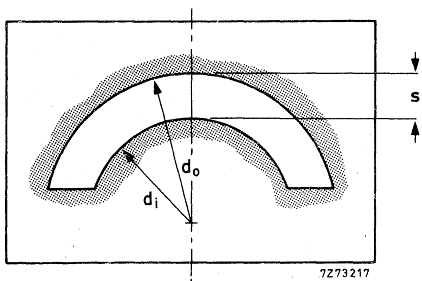
o



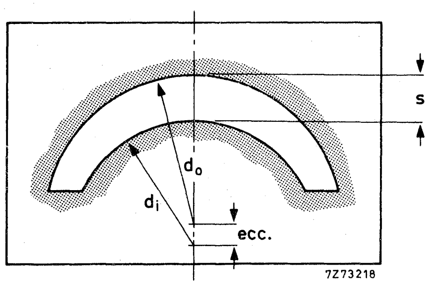
u

Gauge

All motor segments produced have to pass through a gauge which defines the maximum space that the segment may occupy (left figure) and in which d_o corresponds with minimum stator diameter and d_i with maximum rotor diameter + 2x minimum air gap. The main dimensions of the gauges are given in the tables. Where the centre point of the inner gauge diameter is below that of the outer gauge diameter (see right figure), the "ecc." column gives the (negative) value for this eccentricity, which corresponds with variant "a" on the previous page.



"Go" gauge



"Go" gauge for variant "a"

Legend

or. = orientation
p = parallel orientation
r = radial orientation
m = mass

Note

In the catalogue number column, the first catalogue number is for an unmagnetized segment; the second is for a magnetized segment, S-pole inside; the third is for a magnetized segment, N-pole inside.

Concave-convex segments

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
20,73	13,26	–	3,73	⩾ 20,73	⩾ 13,26	14,99 –0,74	13,11 + 0,2	5,92 ± 0,31	3,73 –0,38	100	A1	r	330	3,9	8222 413 03220 8222 413 03240 8222 413 03250
			same data as 8222 413 03220 except										370*	4,0	8222 413 02820 – –
23,6	17,6	–0,1	3,1	⩾ 23,8	⩾ 17,6	15 ± 0,4	19,5 –0,7	7 ± 0,3	3 –0,4	115	A2c	r	330	4,3	8211 071 23160 – –
26,04	–	–	4,2	⩾ 26,1	⩾ 17,8	20 ± 0,5	21,3 ± 0,5	9 ± 0,4	4,1 –0,3	135	A2c	r	380	9,1	4311 021 33710 – –
28,0	20,2	–	3,9	⩾ 28,0	⩾ 20,2	24 +0,4 –0,6	24 ± 0,5	10,5 ± 0,3	3,8 –0,4	140	A2c	r	330	11,7	4311 021 33500 – –
30,0	21,8	–	4,1	30 + 0,3	⩾ 21,8	18 ± 0,5	25,85 ± 0,65	9,1 ± 0,4	–	120	A2c	r	330	9,1	4311 021 32050 8211 071 21970 8211 071 21980
31,9	23,8	–	4,05	⩾ 31,9	⩾ 24	24 +0,6 –0,4	27,5 ± 0,5	11,6 ± 0,3	3,9 –0,4	140	A2c	r	330	14,5	4311 021 33490 – –
31,9	23,8	–	4,05	⩾ 31,9	⩾ 24	20 ± 0,5	29 ± 0,5	11,6 ± 0,3	3,9 –0,4	140	A2c	r	330	11,9	8211 071 31900 – –
36,84	–	–	5,42	36,84	26	30 ± 1	32 ± 0,8	12 ± 0,3	5,3 –0,4	120	A1c	r	330	26	8211 071 34590 – –

* Modified FXD 375 with B_r = 380 mT. H_{cB} = 225 kA/m and H_{cJ} = 230 kA/m.

Concave-convex segments (continued)

gauge			segment												
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h▪ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
37,0	27,0	+ 0,1	4,9	⩾ 37	⩾ 27	30 ± 0,7	30 ± 0,5	11,8 ± 0,4	4,8 −0,4	125	A2c	r	330	22,5	4311 021 33510 — —
			same dimensions as 4311 021 33510 except										380	22,5	8211 071 31340 — —
38,1	28,8	—	4,65	⩾ 38,1	⩾ 28,8	25 ± 0,6	34 ± 0,5	13,4 ± 0,5	4,55 −0,4	135	A1b	r	375	22	8222 413 12690 — —
			same dimensions as 8222 413 12690 except										380	22	4322 020 66270 — —
38,1	—	—	4,65	⩾ 38,1	⩾ 28,8	28 ± 0,75	29 ± 0,75	9,9 ± 0,4	4,55 −0,4	105	A1c	r	330	18,2	8211 071 24380 — —
38,1	28,8	—	4,65	⩾ 38,1	⩾ 28,8	$30^{+0,5}_{-1}$	34 ± 0,85	13,4 ± 0,5	4,55 −0,4	135	A3c	r	330	25	8211 071 33740 — —
38,1	28,8	—	4,65	⩾ 38,1	⩾ 28,8	40,6 −2	34 ± 0,85	13,4 ± 0,5	4,55 −0,4	135	A3c	r	330	32	4311 021 32500 — —
			same dimensions as 4311 021 32500 except										375	32	8211 071 23710 — —
			same dimensions as 4311 021 32500 except										400	32	8211 071 34490 — —
42,6	27,8	—	7,4	⩾ 42,6	⩾ 27,8	25 ± 0.6	37 ± 0.9	16,3 ± 0.5	7,3 −0.6	140	A3bc	r	330	36	8211 071 13130 — —

gauge d_o mm	gauge d_i mm	ecc. mm	s mm	segment d_o mm	segment d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
42,8	32,8	−0,2	5,2	≥ 42,8	≥ 32,8	32 ±0,8	39 ±0,6	16 −1	4,9 −0,4	140	A1bc	r	330	35	4311 021 32150 – –
44,2	32,6	–	5,8	44,2 +0,3	32,6 +0,8	28,7 ±0,7	38 ±0,5	16,1 ±0,5	5,7 −0,5	140	A2c	r	330	33,5	4311 021 32460 – –
46,1	34,2	–	5,95	≥ 46,0	≥ 34,2	19,7 ±0,5	38 ±1	–	–	120	A2b	r	330	19	4322 020 66160 – –
46,07	38,8	−2,8	6,44	≥ 46,2	≥ 38,8	45 −1,8	33 ±0,65	11,2 ±0,35	6,4 −0,46	90	A2c	r	380	44	8211 071 32440 – –
46,1	34,2	−0,05	6,0	≥ 46,1	≥ 34,2	29,4 ±0,75	40 ±0,6	15,8 ±0,4	5,9 −0,4	130	A1b	r	330	38	4322 020 61940 8222 413 03630 8222 413 03640
46,1	34,2	−0,05	6,0	≥ 46,1	≥ 34,2	29,75 ±0,75	40 ±0,6	15,8 ±0,4	5,9 −0,4	130	A1b	r	330	38	4311 021 31510 – –
46,1	34,2	−0,05	6,0	≥ 46,1	≥ 34,2	30 ±0,8	43,8 ±1	18 ±0,6	5,9 −0,4	150	A1b	r	330	44	8222 413 01120 – –
46,1	34,2	+0,15	5,8	≥ 46,1	≥ 34,2	36 −1,6	40 ±0,6	15,8 ±0,4	5,8 −0,5	130	A1b	r	330	46,5	4311 021 32970 – –
46,1	34,1	–	6,0	≥ 46,1	≥ 34,2	45 −2,2	40 ±0,6	15,8 ±0,4	5,9 −0,4	130	A1b	r	330	57,5	4311 021 33520 – –

Concave-convex segments (continued)

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
46,1	34,5	–	5,8	46,3 + 0,8	⩾ 34,5	$35^{+0,6}_{-1}$	40 ± 0,6	16 ± 0,4	5,7 –0,4	130	A1c rum-bled	r	330	43	4311 021 32980 – –
46,26	33,28	–	6,49	≈ 46,1	⩾ 33,68	19,05 ± 0,89	39,68 ± 1,04	8,0■ ± 0,64	⩾ 5,81	125	A1	r	330	24	4313 020 72400 – –
46,26	33,28	–	6,49	≈ 46,1	⩾ 33,68	31,75 ± 0,95	39,68 ± 1,04	8,0■ ± 0,64	⩾ 5,81	125	A1	r	330	40	4313 020 72660 – –
46,3	34,3	–	6	⩾ 46,4	⩾ 34,3	$35^{-1}_{+0,6}$	40 ± 0,6	16 ± 0,4	5,9 –0,4	130	A1c rum-bled	r	380	45	4311 021 33700 – –
47,0	33,4	–	6,8	⩾ 47,0	⩾ 33,4	45 ± 1,1	33,8 ± 0,6	13 ± 0,5	6,6 –0,38	105	A1	r	330	51	8211 071 23570 – –
			same dimensions as 8211 071 23570 except										380	51	8211 071 31820 – –
47,27	34,34	–	6,46	⩾ 47,27	≈ 35	50,8 ± 1	⩾ 41,40	–	⩾ 5,9	130	A2bc	r	270	–	4313 020 72710 – –
49	35,8	–	6,6	⩾ 49	⩾ 35,8	22 ± 1	36 ± 1	13,5 ± 0,5	6,5 –0,4	105	A3	r	330	26,5	4311 021 33280 8211 071 33340 8211 071 33350

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
49	35,8	–	6,6	⩾ 49	⩾ 35,8	38,5 ± 1	36 ± 1	13,5 ± 0,5	6,5 –0,4	105	A3	r	330	45	4311 021 32510 8211 071 22340 8211 071 22350
49	35,8	–	6,6	⩾ 49	⩾ 35,8	45 ± 1	36 ± 1	13,5 ± 0,5	6,5 –0,4	105	A3	r	330	54	4311 021 33530 – –
50,02	33,42	–	8,30	50,2	33,42	49,25 ± 1	33,75 ± 0,63	14,53 ± 0,3	8,18 –0,5	105	A1	r	330	71	8211 071 23290 – –
53	41	–	6	53,1 + 0,8	41,1 + 0,6	$35^{+0,6}_{-1}$	46 ± 0,6	16,3 ± 0,4	5,90 –0,4	120	A1c	r	330	49	4311 021 33540 – –
53,2	41,6	–0,15	5,9	53,2 + 1,2	41,6 + 2	45 –2,2	48,8 ± 1,2	19,2 ± 0,5	5,8 –0,4	140	A1bd	r	380	66	4311 021 33470 8211 071 34380 8211 071 34390
			same data as 4311 021 33470 except										370*	66	8211 071 33380 – –
53,15	41	0,08	6	⩾ 53,2	⩾ 41	$35^{+0,6}_{-1}$	46 ± 0,9	16,3 ± 0,4	5,9 –0,4	120	A1c	r	380	49	4311 021 33570 – –
53,30	40,84	–	6,23	⩾ 53,40	⩾ 41,24	45 ± 1	46 ± 1	9,03 ± 0,5	6,17 –0,4	120	A1c	r	330	–	4313 020 72670 – –
54,61	40,84	–	6,88	≈ 54,61	⩾ 41,24	22 + 1,3	46,5 + 3	9,53 –1	6,88 –0,58	130	A1c	r	330	–	4313 020 72560 – –

* Modified FXD 375 with B_r = 380 mT. H_{cB} = 225 kA/m and H_{cJ} = 230 kA/m.

Concave-convex segments (continued)

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
55	40,6	–	7,2	⩾ 55	40,6 +0,6	19,8 ±0,5	42 ±1	16 ±0,5	–	110	A1	r	330	31	4311 021 33970 4311 021 33980 4311 021 33990
55	41	–	7,0	⩾ 55,2	⩾ 41	19 ±0,5	45 ±0,4	14,94 ±0,5	6,65 −0,4	120	A2b	r	330	29,5	4311 021 33140 – –
55	41	–	7,0	⩾ 55,2	⩾ 41	30 ±0,75	45 ±0,4	14,94 ±0,5	6,65 −0,4	120	A2b	r	330	48	8211 071 30500 – –
55	41	–	7,0	⩾ 55,12	⩾ 41	37 ±1	$51^{+1,5}_{-1}$	20,4 ±0,6	6,8 −0,4	135	A3bc	r	330	70	4311 021 32030 – –
			same data as 4311 021 32030 except								A3bc rum-bled	r	330	70	4311 021 33550 – –
			same data as 4311 021 32030 except										380	70	– 8211 071 31620 8211 071 31630
55,1	44	−1,55	7,1	55,12	44 +1	37 ±1	51 ±1	20,4 ±0,6	7 −0,6	135	A3bc	r	375	69	8211 071 34640 – –
55,3	43,5	–	5,9	⩾ 55,3	⩾ 43,6	40 ±1	49 ±1,2	18,6 ±0,5	5,8 −0,4	130	A1c	r	380	61	8211 071 33330 8211 071 34750 8211 071 34760

gauge				segment											
d_α mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
			same dimensions as 8211 071 33330 except										375	61	8211 071 34300 – –
55,35	43,72	–	5,81	55,66 + 0,3	44,12 + 0,6	38,1 ± 0,95	⩾ 50	–	5,70 –0,4	135 ± 2	A2c	r	270	57,5	8211 071 34350 – –
			same dimensions as 8211 071 34350 except										405	57,5	8211 071 34660 – –
56,06	43,4	–	6,33	⩾ 56,18	⩾ 43,6	27,5 ± 0,8	48 ± 1,5	19 ± 0,5	6,2 –0,6	130	A1	r	330	46	4313 020 72480 – –
56,06	43,6	–0,1	6,33	⩾ 56,18	⩾ 43,6	28 ± 0,8	48 ± 1,5	19 ± 0,5	6,2 –0,6	130	A1	r	330	46	4311 021 34010 – –
56,06	43,6	–0,1	6,33	⩾ 56,18	⩾ 43,6	31,8 ± 0,8	48 ± 1,5	19 ± 0,5	⩽ 6,2	130	A1	r	330	52	8211 071 24160 – –
56,06	43,6	–0,1	6,33	⩾ 56,18	⩾ 43,6	35 ± 0,7	48 ± 1,5	19 ± 0,5	⩽ 6,2	130	A1	r	330	58	4311 021 31880 – –
			same data as 4311 021 31880 except										380	58	8211 071 30920 – –
56,06	43,6	–0,1	6,33	⩾ 56,18	⩾ 43,6	35 ± 0,7	48 ± 1,5	19 ± 0,5	6,2 –0,4	130	A1	r	330	59	4311 021 33200 – –

Concave-convex segments (continued)

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
56,06	43,6	–	6,23	⩾ 56,18	⩾ 43,6	39 ± 1	48 ± 1,5	9,03■ ± 0,5	6,1 –0,5	130	A1	r	330	–	4313 020 72440 – –
56,06	43,6	–0,1	6,33	⩾ 56,18	⩾ 43,6	39 ± 1	48 ± 1,5	19 ± 0,5	6,2 –0,4	130	A1	r	380	64	4322 020 66200 – –
			same data as 4322 020 66200 except										400	64	8222 413 13090 – –
56,06	43,6	–0,1	6,33	⩾ 56,18	⩾ 43,6	42 ± 1	48 ± 1,5	19 ± 0,5	6,2 –0,4	130	A1	r	330	–	4313 020 72650 – –
56,06	43,6	–0,1	6,33	⩾ 56,18	⩾ 43,6	45 ± 1,1	48 ± 1,5	19 ± 0,5	6,2 –0,6	130	A1	r	330	75	4311 021 32520 – –
56,16	42,56	–	6,8	⩾ 56,16	⩾ 42,8	30 ± 0,7	45 ± 0,7	17 ± 0,6	6,7 –0,4	120	A1	r	330	48	4311 021 31310 – –
56,2	38,2	–	9	57 + 0,6	40,6 + 0,6	21 ± 0,5	44 ± 1	16 ± 0,5	8,6 –0,6	105	A1d	r	330	37	– 4311 021 31950 4311 021 31960
57,1	44	–1,45	8,0	⩾ 57,2	⩾ 44	55 + 1,1	53 ± 1	21,5 ± 0,4	7,9 –0,6	140	A1c	r	330	120	4311 021 33720 – –

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
57,9	40,4	–	8,75	⩾ 58	⩾ 40,4	20 ± 0,5	51 ± 1	⩽ 20,3	–	125	A1bc	r	330	45	4311 021 32280 4311 021 31270 4311 021 31280
57,9	40,4	–	8,75	⩾ 58	⩾ 40,4	20 ± 0,5	52 ± 1	⩽ 20,3	–	125	A1bc	r	330	45	– 4311 021 32300 4311 021 32310
57,9	40,4	–	8,75	⩾ 58	⩾ 40,4	30 ± 0,75	51 ± 1	20,3 –1	–	125	A1bc	r	330	68	4311 021 34080 4311 021 31480 4311 021 21490
57,9	40,4	–	8,75	58 + 0,6	40,4 + 2	35 ± 0,9	51 ± 1	20,3 –1	–	125	A1bc	r	330	79	4311 021 33640 4311 021 32430 4311 021 32440
57,9	40,4	–	8,75	⩾ 58	⩾ 40,4	40 ± 1	51 ± 1	20,3 –1	–	125	A1bd	r	330	90	– 4311 021 33060 4311 021 33070
58	40,6	–	8,7	⩾ 58	⩾ 40,6	19,8 ± 0,5	42 ± 1	16 ± 0,3	–	100	A1	p	330	34	4311 021 31240 4311 021 30470 4311 021 30480
58	40,6	–	8,7	⩾ 58	40,6 + 0,6	21 ± 0,5	44 ± 1	16 ± 0,5	8,6 –0,6	100	A1	r	330	37	4311 021 33880 4311 021 33590 4311 021 33600
58	40,4	–	8,8	⩾ 58	40,6 + 0,6	41 ± 1	42 ± 1	16 ± 0,5	8,6 –0,95	100	A1	r	330	74	– 4311 021 33210 4311 021 33220
58	44,8	–	6,6	58 + 0,6	⩾ 45	30 ± 0,75	$52^{+1}_{-1,3}$	20,3 –1	6,5 –0,4	130	A1c	r	330	55	– 4311 021 33830 4311 021 33840

Concave-convex segments (continued)

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
58,4	42,12	–	8,14	⩾ 58,52	⩾ 42,6	$20^{+1}_{-0,6}$	51,6 ± 1,1	21,5 ± 0,7	7,9 –0,4	140	A3	r	330	41	8211 071 15070 4311 021 32360 4311 021 32370
58,4	42,12	–	8,14	⩾ 58,52	⩾ 42,6	$30^{+1}_{-0,6}$	51,6 ± 1,2	21,5 ± 0,7	7,9 –0,4	140	A3	r	330	61	4311 021 32120 4311 021 33780 4311 021 33790
58,4	42,12	–	8,14	⩾ 58,52	⩾ 42,6	$36^{+1}_{-0,6}$	51,6 ± 1,2	21,5 ± 0,7	7,9 –0,4	140	A3	r	330	73	4311 021 31320 4311 021 32630 4311 021 32640
58,4	43,3	–	7,55	⩾ 58,4	⩾ 43,3	20 ± 0,5	51,6 ± 1,2	21,5 ± 0,4	7,35 –0,4	140	A1c	r	330	42	8211 071 32170 4311 021 33910 4311 021 33920
58,4	43,3	–	7,55	⩾ 58,4	⩾ 43,3	$30^{+1}_{-0,6}$	51,6 ± 1,2	21,5 ± 0,7	7,35 –0,4	140	A1c	r	330	64	4311 021 33620 – –
63,5	50,6	–	6,45	⩾ 63,5	⩾ 51	28 ± 0,8	57 ± 0,5	21,5 ± 0,5	–	130	A1	r	330	53	4322 020 61630 4311 021 31610 4311 021 31620
		same data as 4322 020 61630 except											380	60	8211 071 21620 – –
63,5	50,62	–	6,44	⩾ 63,5	⩾ 51	31 ± 1	57 ± 0,5	21,5 ± 0,5	6,25	130	A1	r	380	60	4311 021 33560 – –
66,75	52,89	–	6,93	67,02 + 0,38	⩾ 52,94	25,4 ± 0,76	57,4 + 3,04	10,41■ ± 0,76	–	135	A1	r	330	–	4313 020 72180 – –

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
66,75	52,89	–	6,93	67,02 + 0,38	⩾ 52,94	38,6 ± 0,8	⩾ 57,4	10,41■ ± 0,76	–	135	A1	r	330	–	4313 020 72170 4313 020 72700 –
66,86	51,98	–	7,51	⩾ 67	≈ 53,44	38,6 ± 0,8	⩾ 57,4	10,41■ ± 0,76	–	135	A1	r	330	–	4313 020 72280 – –
67	51,6	–0,6	8,3	⩾ 67	⩾ 50,7	40 ± 1	60 ± 2,5	21 +0,5 –1	7,7 + 0,3	120	A1	r	330	95	4322 020 61930 4322 020 66040 4322 020 66050
			same data as 4322 020 61930 except										410	95	8222 413 13180 – –
67	51,6	–0,6	8,3	⩾ 67	⩾ 51,7	55 ± 1,4	60 ± 2,5	21 +0,5 –1	7,6 + 0,4	120	A1	r	330	135	4311 021 33890 – –
67,8	54,8	–	6,5	67,8 + 0,4	⩾ 54,8	24 ± 0,6	61 ± 1	22 ± 0,5	6,25 –0,4	130	A1c	r	330	54	8211 071 13320 – –
67,8	54,8	–	6,5	67,8 + 0,4	⩾ 54,8	26 ± 0,8	61 ± 1	22 ± 0,5	6,25 –0,4	130	A1c	r	330	58	4311 021 33440 – –
			same data as 4311 021 33440 except										370*	59	4311 021 33120 – –
67,8	54,8	–	6,5	67,8 + 0,4	⩾ 54,8	52 ± 1,05	61 ± 1	22 ± 0,5	6,25 –0,4	130	A1c	r	330	116	8211 071 31200 – –

* Modified FXD 375 with B_r = 380 mT. H_{cB} = 225 kA/m and H_{cJ} = 230 kA/m.

Concave-convex segments (continued)

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
68,2	52,2	–	8	⩾ 68,2	⩾ 52,6	41 ± 1	54 ± 1	21 ± 0,6	7,9 –0,5	120	A1	r	330	95	4311 021 31470 – –
70,06	53,7	–	8,18	⩾ 70,18	⩾ 53,7	29,8 ± 0,8	60 ± 1,5	24 ± 0,7	8,05 –0,6	130	A1	r	330	75	4311 021 32830 4311 021 32210 4311 021 32220
70,06	53,7	–	8,18	⩾ 70,18	⩾ 53,7	34,2 ± 0,8	60 ± 1,5	24 ± 0,7	8,05 –1,15	130	A1	r	330	82	8211 071 24170 – –
70,06	53,7	–	8,18	⩾ 70,18	⩾ 53,7	35 ± 0,8	60 ± 1,5	24 ± 0,7	8,05 –0,6	130	A1c	r	384*	92	4311 021 33960 – –
70,06	53,7	–	8,18	⩾ 70,18	⩾ 53,7	40 ± 1	60 ± 1,5	24 ± 0,7	8,05 –1,15	130	A1	r	330	100	4311 021 32060 8211 071 33560 8211 071 33570
			same data as 4311 021 32060 except										370**	100	4311 021 33240 – –
70,06	53,7	–	8,18	⩾ 70,18	⩾ 53,7	40 ± 1	60 ± 1,5	24 ± 0,7	8,05 –0,6	130	A1	r	330	100	4311 021 32070 8211 071 22360 8211 071 22370
70,06	53,7	–	8,18	⩾ 70,18	⩾ 53,7	40 ± 1	60 ± 1,5	24 ± 0,7	8,05 –0,6	130	A1c	r	330	100	8211 071 32630 – –
70,06	53,7	–	8,18	⩾ 70,18	⩾ 53,7	50 ± 1	60 ± 1,5	24 ± 0,7	8,05 –0,6	130	A1	r	330	125	4311 021 31940 – –

* Modified FXD 380 with B_r = 390 mT. H_{cB} = 210 kA/m and H_{cJ} = 215 kA/m.

** Modified FXD 375 with B_r = 380 mT. H_{cB} = 225 kA/m and H_{cJ} = 230 kA/m.

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
70,06	53,7	–	8,18	⩾ 70,18	⩾ 53,7	50 ± 1	60 ± 1,2	24 ± 0,7	8,05 −0,6	130	A1bc	r	330	131	4311 021 33740 – –
70,10	55,04	–	7,53	⩾ 70,10	≈ 55,6	50,8 ± 1	63,6 ± 1,3	11,84■ ± 0,45	⩾ 6,9	120	A1c	r	330	–	4313 020 72720 – –
70,26	57,14	–	6,56	⩾ 70,26	⩾ 57,14	26,7 ± 0,76	$64,37^{+3}_{-0}$	25,23 ± 0,6	⩽ 6,56	140	A1c	r	330	64	4311 021 33030 8211 071 31700 8211 071 31710
70,26	57,15	–	6,56	≈ 70,1	≈ 57,4	26,67 ± 0,76	62,5 + 2,5	9,65■ ± 0,63	⩾ 6,18	140	A1	r	330	–	4313 020 72520 4313 020 72330 4313 020 72320
70,26	57,15	–	6,56	≈ 70,1	≈ 57,4	31,5 ± 1	62,48 ± 2,8	9,65■ ± 0,63	⩾ 6,04	140	A1	r	330	–	4313 020 72590 – –
70,26	57,16	–	6,56	≈ 70,1	≈ 57,4	33 ± 1	⩾ 62,50	9,65■ ± 0,63	⩾ 6,18	140	A1	r	330	–	4313 020 72500 – –
70,26	57,16	–	6,55	⩾ 70,1	≈ 57,4	41,65 ± 1,05	⩾ 62,50	25,4 ± 0,63	⩾ 5,95	140	A1	r	330	99	4311 021 33480 – –
70,26	57,16	–	6,55	≈ 70,1	≈ 57,4	41,65 ± 1,05	⩾ 64	10,0■ + 0,8	⩾ 6,17	140	A1	r	330	–	4313 020 72620 – –
70,25	57,15	–	6,55	≈ 70,1	≈ 57,4	41,66 ± 1,02	62,48 + 2,8	9,80■ ± 0,5	⩾ 6,04	140	A1	r	330	–	4313 020 72340 4313 020 72600 4313 020 72610

Concave-convex segments (continued)

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
70,66	55,88	–	7,39	⩾ 70,8	55,88 + 1	16,31 + 1,39	55,2 + 4,4	16,89■ –0,88	6,99 + 0,4	110	A1	r	330	–	4313 020 72410 – –
70,66	55,88	–	7,39	⩾ 70,8	55,88 + 1	17 ± 0,7	57,4 ± 0,44	18,88 ± 0,44	7,39 –0,4	110	A1	r	330	36,5	4313 021 32660 – –
70,66	55,88	–	7,39	⩾ 70,8	55,88	25,4 + 1,27	60,8 + 4,2	13,85■ + 0,88	6,99 + 0,4	120	A1	r	330	–	4313 020 72380 – –
70,66	55,88	–	7,39	⩾ 70,82	⩾ 55,88	26,04 ± 0,63	62,85 ± 2,15	20,98 ± 0,51	7,19 ± 0,2	120	A1	r	330	–	4302 020 66190 – –
70,66	55,88	–	7,39	⩾ 70,82	55,88 + 1	36 ± 0,9	60,8 + 4,2	13,85■ + 0,88	6,99 + 0,4	120	A1	r	330	–	4313 020 72580 – –
71,10	57,2	–	6,95	71 + 0,3	57,4 + 2	25 +2 –0,6	61 ± 1	22 –1	–	120	A1bd	r	330	51	– 4311 021 31430 4311 021 31440
70,95	57	–0,37	7,35	⩾ 71,1	⩾ 57	30 ± 0,8	60,3 + 3	21,4 –1,2	6,95 –0,4	120	A3b	r	330	63	– 8222 413 12830 8222 413 12840
70,95	57	–0,37	7,35	⩾ 71,1	⩾ 57	39,4 ± 1	60,3 + 3	21,4 –1,2	6,95 –0,4	120	A3b	r	330	85	4311 021 32590 4311 021 32600 4311 021 32610
71,1	57	–0,3		⩾ 71,1	⩾ 57	49,4 ± 1	60,3 + 3	21,4 –1,2	6,95 –0,4	120	A3b	r	330	108	4322 020 66170 4322 020 66060 4322 020 66070

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
			same data as 4322 020 66170 except										380	115	4322 020 66110 – –
71,1	55,8	–	7,65	⩾ 71,1	⩾ 55,7	49,4 ± 1	61,8 ± 1,5	22 ± 0,6	7,55 –0,4	120	A1c	r	375	121	8211 071 33490 – –
71,2	61	–1,9	7,00	⩾ 71,2	⩾ 61	38 ± 0,9	66 ± 1,6	25 ± 0,6	6,9 –0,5	135	A1ac	r	380	101	4322 020 66100 – –
			same dimensions as 4322 020 66100 except										400	101	8222 413 13210 – –
71,2	56	–	7,6	⩾ 71,2	⩾ 56	38 ± 0,9	66 ± 1,6	25 ± 0,6	7,5 –0,4	135	A1c	r	410	105	8222 413 11080 – –
			same dimensions as 8222 413 11080 except Two-grades segment - ratio ≈ 3 : 1										380/270	135	8222 413 12710 – –
72	57,2	–	7,40	72 + 0,6	⩾ 57,2	27 ± 1	62 ± 1,75	22,5 –1	–	120	A1bd	r	330	57	8211 071 21550 4311 021 32250 4311 021 32260
72	57,2	–	7,40	72 + 0,6	57,8 + 1	30 ± 0,9	62 ± 1,75	22,5 –1	–	120	A1bd	r	330	67	– 4311 021 33750 4311 021 33760
72	57,2	–	7,40	72 + 0,6	⩾ 57,2	35 ± 0,9	62 ± 1,75	22,5 –1	–	125	A1bd	r	330	74,5	– 8211 071 20840 8211 071 20850

Concave-convex segments (continued)

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
72	57,2	–	7,40	72 + 0,6	⩾ 57,2	40 ± 1	62 ± 1,75	22,5 −1	–	120	A1bd	r	330	85	8211 071 32160 4311 021 33090 4311 021 33100
72,08	57,36	–	7,36	⩾ 72,14	⩾ 57,92	27,25 ± 0,65	⩾ 62,71	21,79 ± 0,38	–	120	A1	r	330	66	4311 021 32390 – –
72,08	57,34	–	7,37	≈ 72,12	≈ 57,90	27,25 ± 0,64	⩾ 62,71	21,79 ± 0,38	⩾ 6,86	120	A1	r	330	–	4313 020 72250 – –
72,08	57,34	–	7,37	≈ 72,12	≈ 57,90	36 ± 0,74	⩾ 62,71	21,79 ± 0,32	⩾ 6,86	120	A1	r	330	–	4313 020 72570 – –
72,8	57,4	–	7,7	⩾ 72,8	⩾ 57,4	50,8 ± 1,02	72 ± 1	32 ± 1,6	7,6 −0,4	163	A1	r	270	167	8222 413 02450 – –
82,16	68	−0,36	7,4	⩾ 82,16	⩾ 68	55,25 ± 1,2	71,5 + 1,5	$24,3^{+0,6}_{-1}$	7,4	120	A3b	r	330	137	8211 071 22330 8222 413 02640 8222 413 02650
			same dimensions as 8211 071 22330 except										270	137	8211 071 34620 – –
			same dimensions as 8211 071 22330 except										410	148	8211 071 34690 – –
86,07	69,7	–	8,19	⩾ 86,22	⩾ 69,7	40 ± 1	78,5 ± 1,5	30 ± 0,8	8 −0,6	135	A1b	r	330	134	8222 413 13070 8222 413 13420 8222 413 13430

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
			same data as 8222 413 13070 except										380	134	8222 413 11120 – –
86,07	69,7	–	8,19	⩾ 86,21	⩾ 69,7	60 ± 1,5	78 ± 1,5	30 ± 0,8	8 –0,6	135	A1b	r	330	219	8222 413 11220 8222 413 12660 8222 413 12670
95	81,2	–	6,9	95 + 0,3	81,2 + 2	25 ± 0,6	52 ± 1	13 ± 0,5	–	65	A1b	r	330	42	– 4311 021 33000 4311 021 33010
95	77,4	–	8,80	95 + 0,6	⩾ 77,4	55 ± 1,35	85 ± 1,7	32,2 ± 0,7	8,6 –0,6	135	A1	r	330	223	4311 021 33650 – –
95	77	–	9	95 –0,25	77 + 1,4	72 + 3,6	85 + 1	33 –1,6	8,8 –0,6	135	A1b	r	330	300	8211 071 20570 8211 071 19620 8211 071 19600
			same dimensions as 8211 071 20570 except										270	300	8211 071 33190 – –
95	82	–	6,5	95 –0,25	82 + 0,25	72 + 3,6	85 ± 1	33 –1,6	6,3 –0,5	135	A1	r	370*	203	8211 071 15800 – –
–	–	–	–	98 ± 4	85 ± 0,2	22 ± 0,55	36 ± 0,9		6,5 ± 0,1	45	A1	r	330	25	4311 021 33730 – –
102,2	82	+ 0,1	10	⩾ 102,2	⩾ 82	66 + 2,6	60 ± 1	18,0 ± 0,6	9,9 –0,4	70	A1	r	270	187	8222 413 12140 – –
			same data as 8222 413 12140 except										330	187	8222 413 13040 – –

* Modified FXD375 with B_r = 380 mT. H_{cB} = 225 kA/m and H_{cJ} = 230 kA/m.

Concave-convex segments (continued)

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
102,2	82	–	10,1	102,2 + 0,6	82	75 ± 1,9	53,2 ± 1,25	15,5 ± 0,5	10 –0,6	60	A1	r	330	188	– 8211 071 24500 8211 071 24510
102,2	83	+ 0,1	9,5	⩾ 102,2	⩾ 83	66 + 2,6	60 ± 1	17,5 ± 0,5	9,4 –0,4	70	A1	r	330	178	8222 413 01780 8222 413 13110 8222 413 13120
			same data as 8222 413 01780 except										270	178	8222 413 11970 8222 413 11980 8222 413 11990
			same data as 8222 413 01780 except										375	178	8222 413 12680 – –
103,36	88,78	–	7,29	⩾ 103,36	⩾ 88,78	25,2 ± 0,8	54,36 + 3,04	38,78■ ± 0,38	⩾ 6,89	65	A1	r	330	–	4313 020 72420 4313 020 72640 4313 020 72630
104,6	78	–	13,3	104 + 0,6	⩾ 78	55 ± 1,5	46 ± 1	17 ± 0,5	⩽ 13	55	A1	r	330	155	– 8211 071 22550 8211 071 22560
107,6	93,3	–	7,15	⩾ 107,6	⩾ 93,3	26,5 ± 0,7	85 –3	24 ± 0,6	7 –0,6	100	A1	r	330	78	4311 021 33130 – –
107,6	93,6	–	7,00	107,6 + 5		26 + 1,3	39 ± 0,5	7,8	7 –0,4	40	A2	p	330	30	4311 021 34020 8211 071 24180 8211 071 24190
109,2	94	–	7,6	108,6 + 0,3	⩾ 94	27 ± 0,7	59 ± 0,8	14 ± 0,5	7,8	61	A1	r	330	56	– 4311 021 33850 4311 021 33860

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
113	83	–	15	⩾ 113	⩾ 83	66 + 2,6	60 ± 1	23 ± 0,6	14,9 –0,5	70	A1	r	330	276	8222 413 12130 – –
116	91	–	12,5	116 + 0,6	⩾ 91	40 ± 1	43 ± 1	15,75 ± 0,5	12,4 –0,5	45	A1	p	330	102	8211 071 23190 8211 071 12600 8211 071 12610
–	–	–	–	118 + 4	104 ± 0,1	20 ± 0,5	29,15 ± 0,6	–	7 ± 0,1	30	A1	r	330	20	4311 021 33380 – –
130	110	–	10	⩾ 130	⩾ 110	150 ± 3	65 ± 1,6	19 ± 1	9,9 –0,5	65	A2	r	380	380	8222 413 13240 – –
130	96	–	17	⩾ 130	⩾ 96	150 ± 3	65 ± 1,6	25 ± 1	16,9 –0,6	65	A2	r	380	840	8222 413 13250 – –
130,2	99,8	–	17,2	⩾ 130,2	⩾ 99,8	65 ± 1,3	61 ± 1,5	22,2 ± 1,2	17,1 –0,75	60	A1	r	384*	300	8222 413 11400 – –
130,2	99,8	–	17,2	⩾ 130,2	⩾ 99,8	100 ± 2	61 ± 1,5	22,2 ± 1,2	17,1 –0,75	60	A1	r	384*	462	8222 413 11390 8222 413 12800 8222 413 12810
130,2	99,8	–	17,2	⩾ 130,2	⩾ 99,8	127 ± 3,1	61 ± 1,5	22,2 ± 1,2	17,1 –0,75	60	A1	r	384*	586	8222 413 11380 – –
133,35	112,73	–	10,31	⩽ 133,35	⩾ 112,73	60,96 ± 1,52	80 ± 1	20 ± 1	10,21 –0,6	65	A1	r	270	234	8222 413 01610 – –

* Modified FXD 380 with B_r = 390 mT. H_{cB} = 210 kA/m and H_{cJ} = 215 kA/m.

Concave-convex segments (continued)

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
				same data as 8222 413 01610 except									330	234	8222 413 12150 8222 413 12560 8222 413 12570
133,6	126,74	17,14	20,57	133,6 −0,50	126,74 + 0,50	127 ± 3,175	61 ± 1,5	24,0 ± 1,0	20,57 −1,0	50	A2	r	370	560	8222 413 03500 — —
161,04	135,38	—	12,83	⩾ 161,04	⩾ 135,38	71,63 ± 0,51	101,8 ± 1	28 ± 0,89	12,62 −0,38	85	A2	r	330	450	8222 413 01950 — —
				same data as 8222 413 01950 except									270	450	8222 413 10690 — —
				same data as 8222 413 01950 except									370*	450	8222 413 02870 — —
				same data as 8222 413 01950 except									380	450	8222 413 13320 8222 413 13330 8222 413 13340
224	204	—	10	⩾ 224	⩾ 204	100 + 4	87 + 4	20 ± 1	9,9 −0,5	50	A2	r	380	440	8222 413 13260 — —
224	184	—	20	⩾ 224	⩾ 184	100 + 4	87 + 4	28 ± 1	19,9 −0,7	50	A2	r	380	380	8222 413 13270 — —
224	177	−2,4	31,1	224 −4	178,5 + 2	100 + 4	76 + 4	37 ± 0,8	31 −0,7	50	A1	r	380	1211	8222 413 11280 8222 413 12310 8222 413 12320

* Modified FXD375 with B_r = 380 mT. H_{cB} = 225 kA/m and H_{cJ} = 230 kA/m.

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	m g	catalogue no.
228,4	186	–	21,2	⩾ 228,4	⩾ 186	120 + 5	100 + 4,4	–	21,2 −1,7	55	A2	r	370*	–	4313 020 72470 – –

* Modified FXD375 with B_r = 380 mT. H_{cB} = 225 kA/m and H_{cJ} = 230 kA/m.

Concave-convex segments with holes or slots

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	catalogue no. (see note page 2)	m g
110,2	94,7	−0,2	7,95	110,2 + 0,8	⩾ 94,7	27 ± 0,65	54 ± 0,8	14,45 ± 0,4	7,65 −0,5	60	A1u (note 1)	r*	330	4311 021 33040 8211 071 22410 8211 071 22420	51
			same dimensions as 4311 021 33040 except										270	– 8211 071 34430 8211 071 34440	51
138	117	–	10,5	⩾ 138	⩾ 117	29 ± 0,6	70 ± 1,5	19 ± 0,6	10,4 −0,6	65	A1o (note 2)	p	330	8222 413 00770 – –	88
–	–	–	–	≈ 156,36	≈ 135,42	23,1 ± 0,15	27,56 ± 0,55	–	10,46 −0,15	23	A1u (note 3)	p	330	4311 021 33350 – –	31

Notes: 1. p = 45,6. 2. p = 46,6 ± 0,7. 3. Slots in length direction.

Flat-concave segments

–	–	–	–	–	31 + 0,6	54 ± 1,5	29 ± 0,8	10,5 ± 0,5	6,8 –0,3	80	B1	p	330	4311 021 32740 4311 021 32090 4311 021 32100	64,5
–	–	–	–	–	31 ± 2	54 ± 1,5	29 ± 0,8	11,2 ± 0,7	7,7 ± 0,7	80	B1	p	330	4311 021 33430 – –	74
–	37	–	8,0	–	37 + 0,4	55 +1,5 –1,3	28 + 1,4	10,7 ± 0,3	7,2 –0,4	60	B1	p	330	4311 021 32350 – –	69
			same data as 4311 021 32350 except										370*	4311 021 33160 – –	70

* Modified FXD 375 with B_r = 380 mT. H_{cB} = 225 kA/m and H_{cJ} = 230 kA/m.

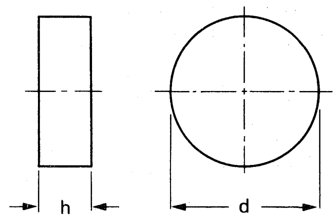
Flat-convex segments

gauge				segment											
d_o mm	d_i mm	ecc. mm	s mm	d_o mm	d_i mm	l mm	w mm	h,h■ mm	t mm	α deg	shape	or.	FXD	catalogue no. (see note page 2)	m g
–	–	–	–	114 ± 2	–	25 ± 0,5	39,5 ± 0,8	9,5 ± 0,2	–	40	C	p	330	4311 021 30130 – –	39,5
–	–	–	–	148 ± 4	–	27 ± 0,65	40,5 ± 1	15 ± 0,2	–	30	C	p	330	– 8211 071 14690 8211 071 14700	87,5
–	–	–	–	⩾ 157,6	–	46,5 ± 1,2	22 ± 0,6	13,6 ± 0,2	–	20	C	p	270	– 8211 071 12640 8211 071 12650	64

ISOTROPIC SINTERED FERROXDURE
(section 6)

DISCS

A = Magnetized axially
B = Magnetized diametrically
M_n = Magnetized laterally,
n parallel poles on one face only
Ne at pole marking = Neutral zone



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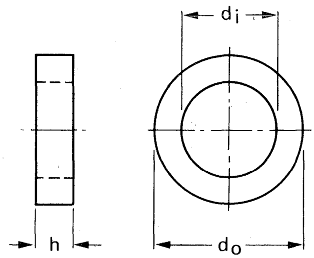
d mm	h mm		FXD		pole marking	sticking force N	catalogue number
10 ± 0,5	5 ± 0,3		100	A	S : yellow	0,45 (Δ = 0)	4312 020 65940
12,5 ± 0,3	6 ± 0,3		100	B			4312 020 65520
14 ± 0,5	5 ± 0,3		100	A		0,55 (Δ = 0,5)	4312 020 65890
25 ± 0,5	5 ± 0,4		100	M6	Ne : white	7,5 (Δ = 0)	4312 020 65780
30 +0,2 −0,7	5 ± 0,3		100	M6		6 (Δ = 0,5)	4312 020 65740

RINGS

A = Magnetized axially
B = Magnetized diametrically
Mn = Magnetized laterally, n parallel poles on one face only
Nn = Magnetized laterally, n pole sectors on one face only
Tn = Magnetized laterally, n poles on outer circumference, neutral zones axial
Wn = Magnetized laterally, n poles on inner circumference, neutral zones axial
X = Magnetized radially, S-pole inside
Y = Magnetized radially, N-pole inside
U = Unmagnetized
Ne at pole marking = Neutral zone



7Z75463

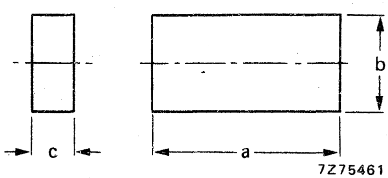
d_o mm	d_i mm	h mm	FXD		pole marking	sticking force N	catalogue number
8 −0,03	4 +0,4	2,8 ± 0,05	100	U			4304 170 00000
8,05 + 0,2	5 ± 0,2	3,5 ± 0,2	100	M2	Ne : white		4312 020 63270
11 + 0,43	5,18 ± 0,1	11 ± 0,32	100	U			4313 020 64110
11 + 0,43	5,18 ± 0,1	5,34 + 0,32	100	U			4313 020 63850
11,13 + 0,65	7,96 + 0,5	6,35 + 0,5	100	U			4313 020 63960
12 + 0,5	□3,2 ± 0,3	12 ± 0,5	100	B			3122 104 92690
12 −0,03	4 + 0,6	5 ± 0,05	100	U			3104 101 80950
12,2 ± 0,2	4,2 + 0,2	8 ± 0,3	100	X			4312 020 63180
12,25 ± 0,25	□3,2 ± 0,3	10 ± 0,3	100	B			4312 020 62110
13 ± 0,2	5,3 ± 0,2	8 ± 0,2	100	Y			3122 104 92670
13 ± 0,2	5,3 ± 0,2	8 ± 0,2	100	X			4312 020 63420
13 ± 0,2	5,3 ± 0,2	8 ± 0,2	100	X	N : red		3122 104 92660
13 ± 0,2	5,3 ± 0,2	10 ± 0,3	100	X			3122 134 91410
14 ± 0,5	4 ± 0,25	4 ± 0,25	100	M2	Ne : white	0,8 (Δ = 0,5)	4312 020 62980
14 ± 0,02	8 −0,5	13 ± 0,05	100	U			3122 104 90010
14 ± 0,02	9 ± 0,5	3,5 −0,1	100	U			3122 104 90070
15 ± 0,05	6,25 +0,1 −0,3	3 +0,1 −0,05	100	N4	Ne : white		4312 020 63370
18 ± 0,45	5 ± 0,2	5 ± 0,3	100	A		1 (Δ = 0)	4312 020 62140
19 + 0,04	11,6 + 1/7 + 1,2	18 + 0,05	100	U			4304 170 01660
19,7 + 0,04	11,6 + 1/7 + 1,2	18 + 0,05	100	U			4304 170 01650
19,75 + 0,05	17,75 + 0,5	4,8 + 0,4	100	T8			4313 020 75080
→ 19,8 + 0,05	9 ± 0,5	5 ± 0,05	100	U			3122 104 90030
19,8 −0,03	4 + 0,6	5,95 ± 0,05	100	U			3104 101 80960
→ 21 ± 0,1	10 ± 0,5	24 + 0,7	100	T8			4312 020 63160
24,5 ± 0,3	10 ± 0,3	3,5 ± 0,1	100	N6	Ne : white		4312 020 62600
25,4 ± 0,5	6,35 ± 0,25	4,45 ± 0,25	100	M4			4313 020 63820
25,4 ± 0,5	3,4 ± 0,2/6 ± 0,5	5 ± 0,3	100	N6			4312 020 63430
28 −0,05	21 ± 0,3	16,5 ± 0,05	100	U			4304 170 00540
30 −0,05	16 ± 0,3	33,9 ± 0,1	100	U			3122 104 94910
30 −0,1	> 22,8	9,9 ± 0,3	100	U			4312 020 63350

RINGS (continued)

d_o mm	d_i mm	h mm	FXD		pole marking	sticking force N	catalogue number
30 −0,1	> 22,8	> 11,2	100	U			4322 010 68040
30 −0,1	> 22,8	17 ± 0,4	100	U			4312 020 63440
30 −0,1	> 23,2	> 11,2	100	U			4322 010 85690
30,4 ± 0,4	19,9 ± 0,2	10,9 ± 0,3	100	U			4322 010 69800
37,95 + 0,05	31 ± 0,7	7 −0,3	100	U			3122 104 90040
48 ± 0,05	30 ± 0,05	12 ± 0,1	100	T14			4312 020 62750
78 ± 0,2	26 −0,25	25 ± 0,2	100	T6			4312 020 63080 ←
104,8 + 0,1	86 ± 0,2	25 ± 0,2	100	W6			4312 020 63090

BLOCKS

E = Magnetized perpendicular to a x b
Rn = Magnetized laterally, n poles on one face a x b, poles parallel to side a
Sn = Magnetized laterally, n poles on one face a x b, poles parallel to side b
Ne at pole marking = Neutral zone

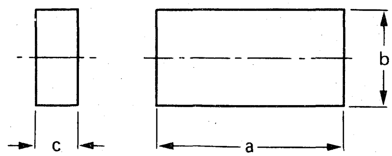


a mm	b mm	c mm	FXD		pole marking	sticking force N	catalogue number
2,2 −0,2	2,2 −0,2	3,2 + 0,2	100	E			3103 201 10150
8 ± 0,2	5 ± 0,2	8 ± 0,2	100	E	S : yellow		4312 020 66880
15 ± 0,5	15 ± 0,5	5 ± 0,3	100	E	S : yellow	0,5 (Δ = 0,1)	4312 020 66950
62 ± 0,6	8 ± 0,3	6,5 ± 0,15	100	A			3122 134 91750

ISOTROPIC PLASTIC BONDED FERROXDURE
(section 7)

BLOCKS, STRIPS, ROLLS

E = Magnetized perpendicular to a x b
Rn = Magnetized laterally, n poles on one a x b face, poles parallel to side a



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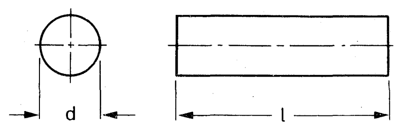
a mm	b mm	c mm	FXD		pole marking	sticking force N	catalogue number
8 ± 0,3	6 ± 0,3	2,5 ± 0,15	P40B	E			3103 134 90040
150 m	9 ± 0,3	3 ± 0,1	P40B	R2		0,25 (Δ = 0,5)	4312 020 70020
40 ± 0,6	10 ± 0,2	6 ± 0,15	P40F				3122 134 91890

RODS, ROTORS

A = Magnetized axially
B = Magnetized diametrically
U = Unmagnetized

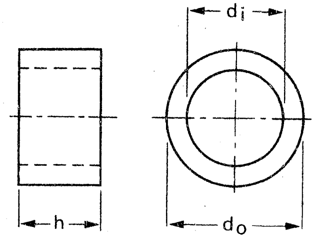


7Z75462

a mm	l mm		FXD		pole marking		catalogue number
5 ± 0,2	30 − 1		P40	A	yes		3122 104 94980
5 ± 0,2	40 − 1		P40B	A	yes		3122 104 90360
13,7 − 0,08	3 ± 0,1		SP50	U			3122 107 67410

RINGS

B = Magnetized diametrically
Wn = Magnetized laterally, n poles on inner circumference, neutral zones axial
Y = Magnetized radially, N-pole inside
U = Unmagnetized

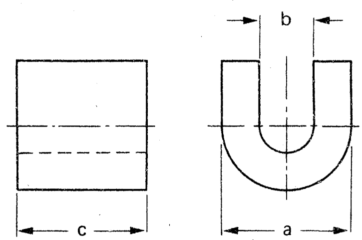


7Z75466

d$_o$ mm	d$_i$ mm	h mm	FXD			catalogue number
12,4 −0,4		7 +0,5	P40B	Y		3122 104 93530
22,5 −0,15	17,55 + 0,08	22,4 ± 0,15	SP130	W2		4222 017 20220
24,9 −0,15	19,55 + 0,25	14,5 ± 0,2	SP130	W2		4322 010 83600
28 ± 0,1	23 ± 0,2	25,5 ± 0,2	SP130	W2		4304 099 10060

U-SHAPED SEGMENT

X = Magnetized radially, S-pole inside

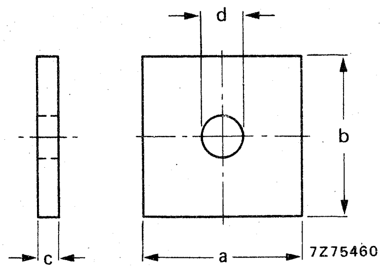


7Z75465

a mm	b mm	c mm	FXD			catalogue number
12 + 0,6	5,2 ± 0,1	12 ± 0,3	P40B	X		3122 104 93770
12 + 0,6	5,2 ± 0,1	12 ± 0,3	100	X		3122 134 91400

PLATES with hole

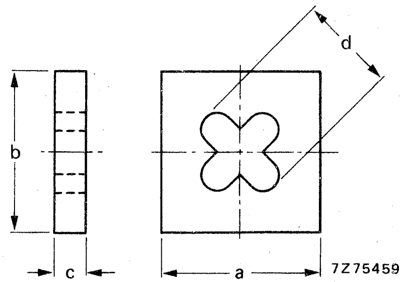
E = Magnetized perpendicular to a x c
Rn = Magnetized laterally, n poles on one a x b face, poles parallel to side a



a mm	b mm	c mm	d mm	FXD			catalogue number
13 + 0,6	13 + 0,6	3 ± 0,15	3 – 0,3	P30	E		4312 020 76990
13 + 0,6	40 – 1	3 ± 0,15	3 – 1	P40F	E	hole not in centre	3122 104 95000

PLATES with slot

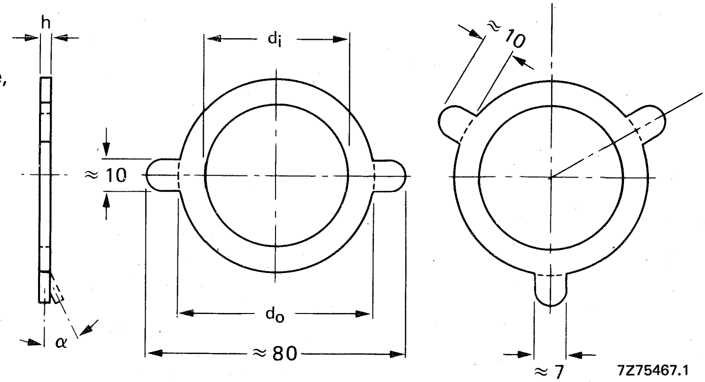
E = Magnetized perpendicular to a x c



a mm	b mm	c mm	d mm	FXD			catalogue number
8,4 – 0,6	8,4 – 0,6	1,5 ± 0,3	5,8 + 0,5	P30	E		4312 020 76900
8,4 – 0,6	8,4 – 0,6	3 ± 0,15	5,8 + 0,5	P30	E		3122 104 94120
10,6 – 0,6	10,6 – 0,6	3 ± 0,15	9	P30	E		3122 104 93540
11 + 0,6	11 + 0,6	3 ± 0,15	6,5 + 0,5	P30	E		3122 104 02720

RINGS with notches

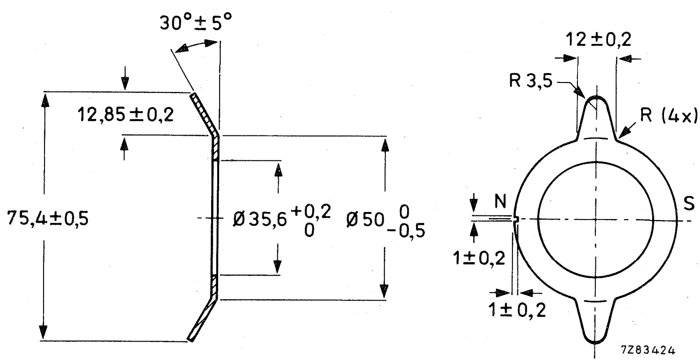
W2 = Magnetized laterally, 2 poles on inner circumference, neutral zones axial



d_o mm	d_i mm	d mm	FXD		number of notches	α	catalogue number
39 + 0,5	27 + 0,4	1,5 ± 0,1	SP10F	W2	3	30°	3122 134 91290
50 – 0,5	35,6 + 0,2	1,7 + 0,2	SP10	W2	1	0°	4312 020 72110
50 – 0,5	35,6 + 0,2	1,7 + 0,2	SP10F	W2	2	30°	3122 104 93980
90 ± 0,3	65,1 + 0,4	2 ± 0,15	SP10F	W2	3	35°	3122 104 94210

RING with wings

B = Magnetized diametrically



d_o mm	d_i mm	h mm	FXD				catalogue number
50	35,6	1,7 $^{+0,2}_{-0,0}$	SP10F	B			3122 134 91870

INTRODUCTORY NOTES

The invention of Ticonal was responsible for rapid growth in the use of permanent magnets. Today, Ticonal alloys are still in widespread use, particularly where small, highly stable magnets are required. They consist of Fe, Ni, Co and Al, some grades having additions of Cu and Ti.

Ticonal alloys owe their properties to the techniques of precipitation hardening, they are made by modern foundry techniques and specialized heat treatment. The available range of these high-efficiency metallic permanent magnet materials gives a wide coverage of performance and characteristics. The material is especially useful in applications requiring a high remanent flux density and/or extremely low temperature coefficients.

Ticonal permanent magnets are cast from alloys of pure elements. All stages of the processing are controlled by advanced metallurgical techniques to ensure high and uniform performance.

There have been marked advances in the manufacture of these alloys since their introduction: our laboratories have developed alloys having maximum BH products of over 9,5 kJ/m^3.

The following alloys are currently available.

Ticonal 500

This Ticonal grade is made by applying a magnetic field during cooling, resulting in anisotrophic properties.

Ticonal 570 and 600

The improved Ticonal grades which are achieved by orienting the crystals in combination with a heat treatment in a magnetic field. The orientation is accomplished by casting the molten metal against steel plates, which chill the metal and cause rapid cooling and growth of long crystals in the desired preferred direction, resulting in a higher value of the BH product. This technique can only be followed for straight sections and solid magnets.

Ticonal 550

This Ticonal grade has a high coercivity obtained by special composition and heat treatment.

Ticonal 900 is an improved version of Ticonal 550.

MATERIAL PROPERTIES

Ticonal magnets are very hard and brittle and cannot therefore be machined except by grinding. "As cast" tolerances can generally be kept to fairly close limits and only the surfaces through which the magnetic flux is passing need further machining.

Holes should be avoided, but can be produced by means of a core from sand in the casting and should allow a generous clearance. Accurate holes can be obtained by filling oversize cored holes with a low melting point alloy or by casting around a mild-steel insert and subsequently drilling to size.

In magnets from Ticonal 570, 600 and 900 holes have to be avoided and inserts cannot be used otherwise the crystal orientation will be impaired during casting.

Ticonal magnets can be fixed by means of screws (if the magnet can be manufactured with a hole or insert), adhesive or soft soldering. Hard-soldering temperatures may lead to deterioration in magnetic properties. Screws through holes in the preferred direction should be non-magnetic.

Ticonal magnets should, as far as possible, only be subjected to compressive stresses.

Ticonal magnets are highly resistant to corrosion.

Ticonal permanent magnet materials are anisotropic, which means that the optimum magnetic properties are achieved only if the magnets are magnetized in the preferred direction.

With the technique of heat treatment in a magnetic field an axial preferred direction is most easily obtained. For optimum magnetic properties, the magnets should therefore have a straight axis coincident with the preferred direction of magnetization.

Due to the treatment the Ticonal grades have a structure which is metallurgically very stable.

The magnet designer should take into account the influence of temperature, stray fields and vibration.

APPLICATIONS

Ticonal magnets are characterised by their excellent temperature stability and high remanence. They are particularly useful in near static applications because of their high initial $(BH)_{max}$ value. Typical applications in:

loudspeakers,
microphones,
pick-up cartridges,
magnetos,
ironless motors,
measuring equipment.

TICONAL 500

anisotropic metal alloy

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 34 mm x 15 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux or similar test can be described in each magnet specification, and this test used as a basis for performance guarantees.

COMPOSITION

Ticonal 500 is an alloy comprising approximately 24% Co, 14,0% Ni, 8,0% Al, 3% Cu, 0,45% Nb and the remainder Fe.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	1250	1200	mT	12 500	12 000	Gs
Coercivity	H_{cJ}	52,5	50,1	kA/m	660	630	Oe
Maximum BH product	$(BH)_{max}$	40,6	37,4	kJ/m³	5,1	4,7	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	1000		mT	10 000		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	40,6		kA/m	510		Oe
Recoil permeability	μ_{rec}	4,5			4,5		
Temperature coefficient of B_r (−40 to + 200 °C)		−0,02		%/K	−0,02		%/°C
Saturation field strength	H_{sat}		239	kA/m		3000	Oe
Resistivity	ρ	5×10^{-7}		Ωm	5×10^{-5}		Ωcm
Curie point		860		°C	860		°C

PHYSICAL PROPERTIES

Density	typ.	$7{,}3 \times 10^3$ kg/m³	(7,3 g/cm³)
Coefficient of linear expansion	typ.	$10{,}8 \cdot 10^{-6}$/K	

DIRECTION OF MAGNETIZATION

Ticonal 500 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

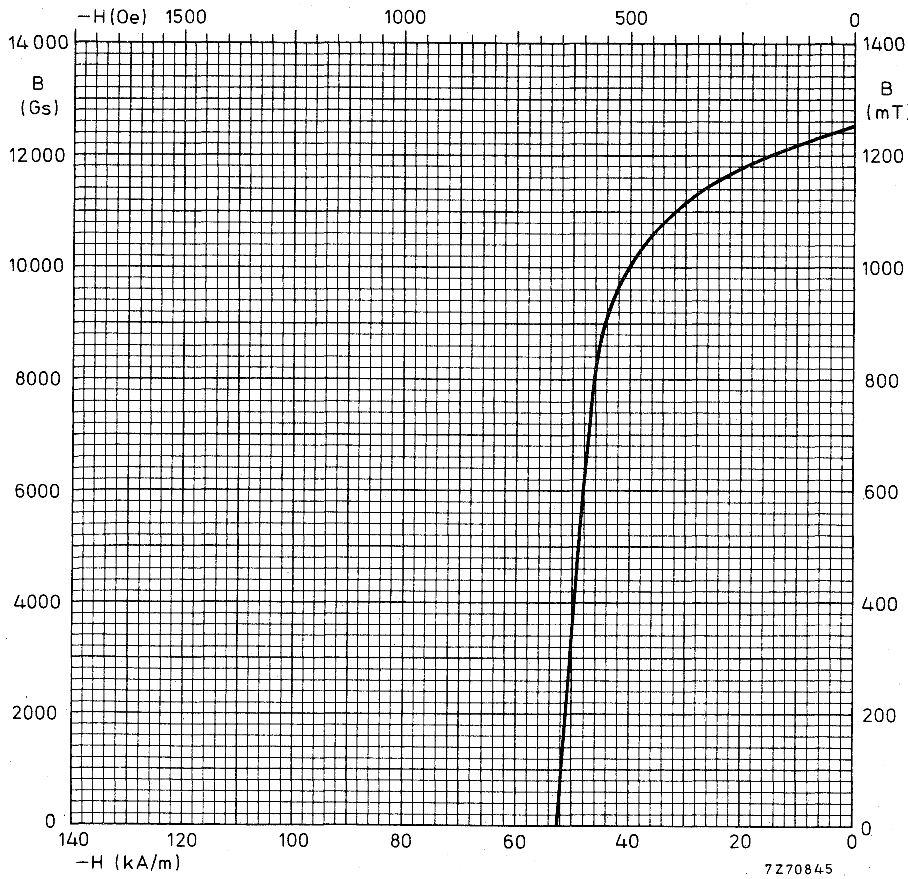
QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

APPLICATION

Permanent magnets for use in magnetrons, moving-coil instruments, loudspeakers, microphones, isolators, pen recorders, eddy-current brakes, etc.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



TICONAL 550

anisotropic metal alloy

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 34 mm x 15 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux or similar test can be described in each magnet specification, and this test used as a basis for performance guarantees.

COMPOSITION

Ticonal 550 is an alloy comprising approximately 34% Co, 15% Ni, 7,5% Al, 2,5% Cu, 5,5% Nb+Ta+Ti and the remainder Fe.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	900	850	mT	9000	8500	Gs
Coercivity	H_{cJ}	119	111	kA/m	1500	1400	Oe
Maximum BH product	$(BH)_{max}$	43,8	39,8	kJ/m³	5,5	5,0	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	550		mT	5500		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	79,6		kA/m	1000		Oe
Recoil permeability	μ_{rec}	2,8			2,8		
Temperature coefficient of B_r (−40 to + 200 °C)		−0,02		%/K	−0,02		%/°C
Saturation field strength	H_{sat}		478	kA/m		6000	Oe
Resistivity	ρ	5×10^{-7}		Ωm	5×10^{-5}		Ωcm
Curie point		860		°C	860		°C

PHYSICAL PROPERTIES

Density	typ.	$7,3 \times 10^3$ kg/m³	(7,3 g/cm³)
Coefficient of linear expansion	typ.	$10,8 \cdot 10^{-6}$/K	

DIRECTION OF MAGNETIZATION

Ticonal 550 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

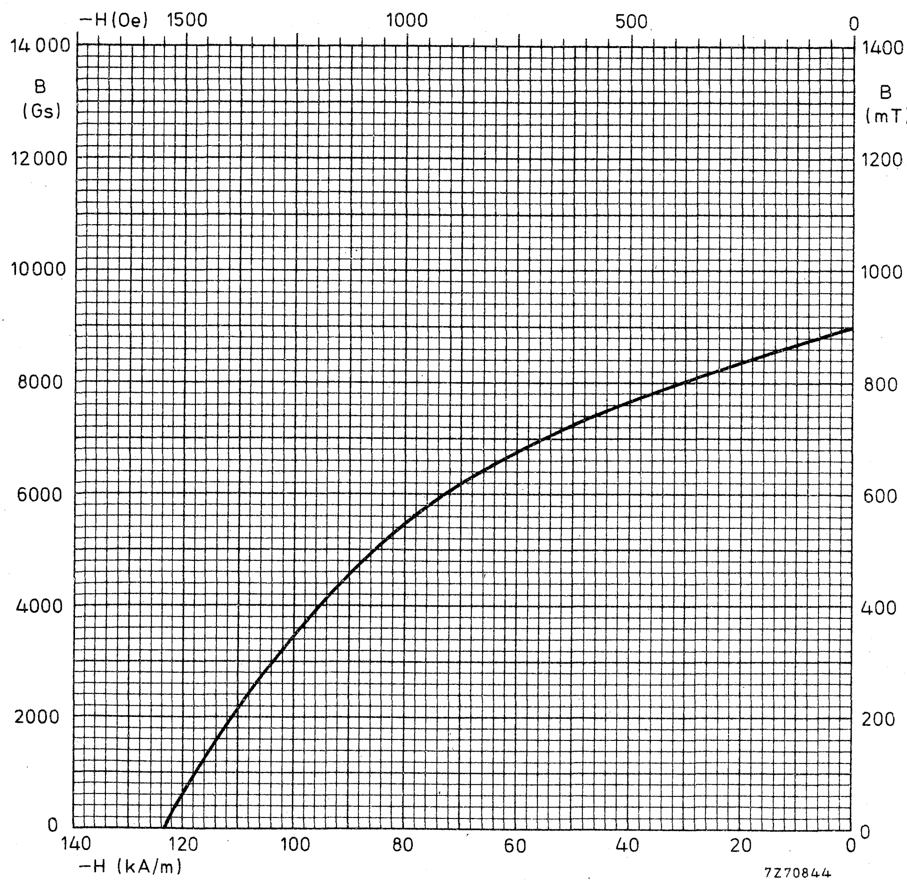
QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

APPLICATION

Permanent magnets for use in moving-coil instruments, small motors etc.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



TICONAL 570

anisotropic metal alloy

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 18 mm x 15 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux or similar test can be described in each magnet specification, and this test used as a basis for performance guarantees.

COMPOSITION

Ticonal 570 is an alloy comprising approximately 24% Co, 14,0% Ni, 8,0% Al, 3% Cu, 0,45% Nb and the remainder Fe.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	1320	1260	mT	13 200	12 600	Gs
Coercivity	H_{cJ}	51,7	49,4	kA/m	650	620	Oe
Maximum BH product	$(BH)_{max}$	45,4	42,2	kJ/m³	5,7	5,3	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	1070		mT	10 700		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	42,2		kA/m	530		Oe
Recoil permeability	μ_{rec}	4			4		
Temperature coefficient of B_r (−40 to + 200 °C)		−0,02		%/K	−0,02		%/°C
Saturation field strength	H_{sat}		239	kA/m		3000	Oe
Resistivity	ρ	5×10^{-7}		Ωm	5×10^{-5}		Ωcm
Curie point		860		°C	860		°C

PHYSICAL PROPERTIES

Density	typ.	$7,3 \times 10^3$ kg/m³	(7,3 g/cm³)
Coefficient of linear expansion	typ.	$10,8 \cdot 10^{-6}$/K	

DIRECTION OF MAGNETIZATION

Ticonal 570 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

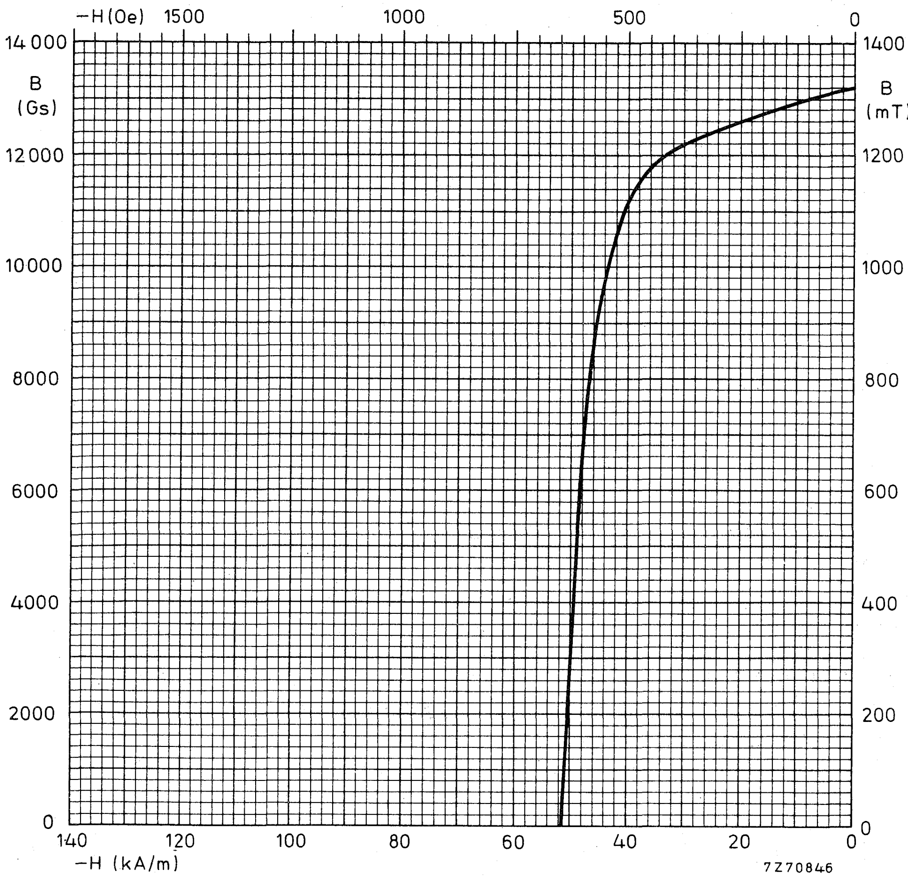
QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

APPLICATION

Permanent magnets for loudspeakers, moving-coil instruments, microphones, eddy-current brakes, etc. (Only simple cylinders and blocks can be produced from Ticonal 570.)

TYPICAL DEMAGNETIZATION CURVE (25 °C)



TICONAL 600

anisotropic metal alloy

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 18 mm x 15 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux or similar test can be described in each magnet specification, and this test used as a basis for performance guarantees.

COMPOSITION

Ticonal 600 is an alloy comprising approximately 26% Co, 14,0% Ni, 8,0% Al, 3% Cu, 0,3% Nb and the remainder Fe.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	1310	1260	mT	13 100	12 600	Gs
Coercivity	H_{cJ}	54,1	51,7	kA/m	680	650	Oe
Maximum BH product	$(BH)_{max}$	47,8	43,8	kJ/m³	6,0	5,5	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	1090		mT	10 900		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	43,8		kA/m	550		Oe
Recoil permeability	μ_{rec}	3,5			3,5		
Temperature coefficient of B_r (−40 to + 200 °C)		−0,02		%/K	−0,02		%/°C
Saturation field strength	H_{sat}		239	kA/m		3000	Oe
Resistivity	ρ	5×10^{-7}		Ωm	5×10^{-5}		Ωcm
Curie point		860		°C	860		°C

PHYSICAL PROPERTIES

Density	typ.	$7,3 \times 10^3$ kg/m³	(7,3 g/cm³)
Coefficient of linear expansion	typ.	$10,8 \cdot 10^{-6}$/K	

DIRECTION OF MAGNETIZATION

Ticoanl 600 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

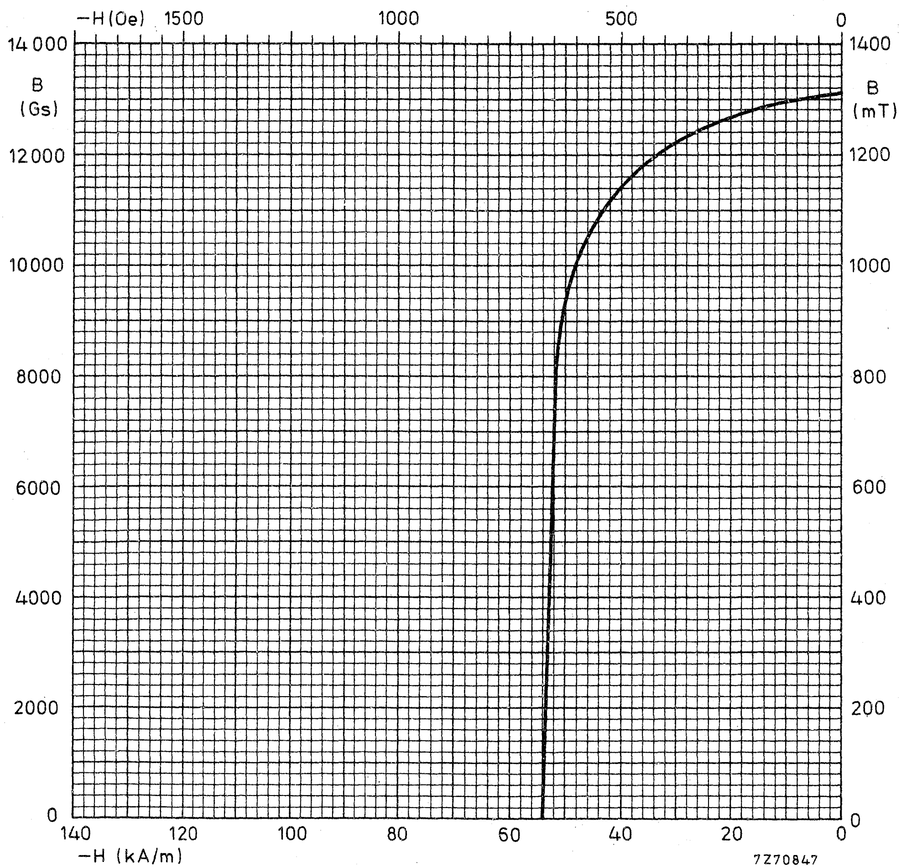
QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

APPLICATION

Permanent magnets for loudspeakers, moving-coil instruments, microphones, eddy-current brakes, etc. (Only simple cylinders and blocks can be produced from Ticonal 600).

TYPICAL DEMAGNETIZATION CURVE (25 °C)



TICONAL 900

anisotropic metal alloy

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production. The test piece has dimensions of approximately ϕ 28 mm x 15 mm.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux or similar test can be described in each magnet specification, and this test used as a basis for performance guarantees.

COMPOSITION

Ticonal 900 is an alloy comprising approximately 34% Co, 15% Ni, 7,5% Al, 2,5% Cu, 5,5% Nb + Ta + Ti and the remainder Fe.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	1100	1000	mT	11 000	10 000	Gs
Coercivity	H_{cB}	115	111	kA/m	1450	1400	Oe
Maximum BH product	$(BH)_{max}$	79,6	67,7	kJ/m³	10,0	8,5	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	900		mT	9000		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	79,6		kA/m	1000		Oe
Recoil permeability	μ_{rec}	2,3			2,3		
Temperature coefficient of B_r (−40 to + 200 °C)		−0,02		%/K	−0,02		%/°C
Saturation field strength	H_{sat}		478	kA/m		6000	Oe
Resistivity	ρ	5×10^{-7}		Ωm	5×10^{-5}		Ωcm
Curie point		860		°C	860		°C

PHYSICAL PROPERTIES

Density	typ.	$7,3 \times 10^3$ kg/m³	(7,3 g/cm³)
Coefficient of linear expansion	typ.	$10,8 \cdot 10^{-6}$/K	

DIRECTION OF MAGNETIZATION

Ticonal 900 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

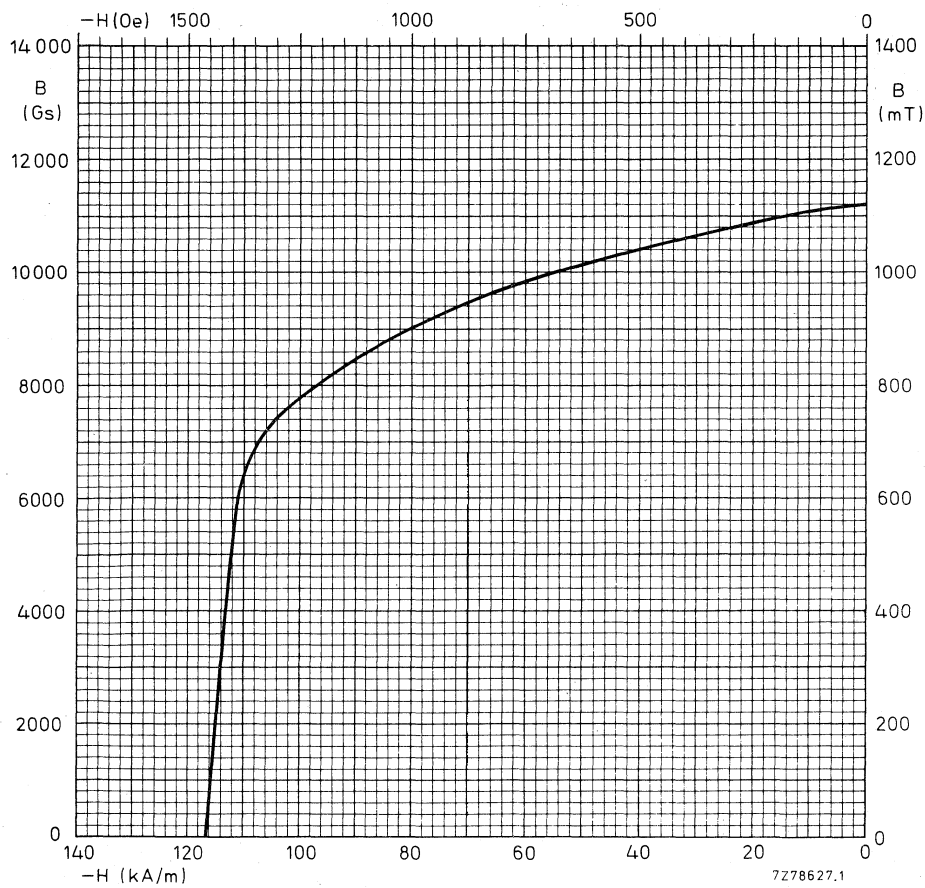
QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

APPLICATION

Permanent magnets for use in magnetrons, watches, pick-up cartridges, etc.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



RARE-EARTH COBALT MAGNETS

INTRODUCTION

Rare-earth cobalt magnets are capable of providing higher magnetic energy than any other available material. They combine this quality with low temperature coefficient (of remanence and coercivity) and an almost ideal BH characteristic.

Their development represents a significant advance over other magnetic materials, and since their introduction they have expanded the range of permanent magnet applications considerably, by providing solutions to problems formerly considered difficult. In addition their use can considerably reduce the volume of a magnetic system. Their high resistance to demagnetization permits the use of very short magnetic lengths and their high remanence often obviates the necessity to use steel poles to concentrate flux, resulting in low flux leakage designs.

RES RARE-EARTH MAGNETS

RES magnets are intermetallic compounds of cobalt and the rare-earth samarium.

RES160 and RES190 are sintered materials with a similar manufacturing method as Ferroxdure. A prepared powder is compacted in a suitable dimensioned die. During this stage an enhanced magnetization direction is imparted to the products by aligning particles with an external magnetic field. This is possible along one axis only. The material is then sintered in a furnace with suitably controlled temperature and atmosphere. This is followed by heat treatment to improve its magnetic properties.

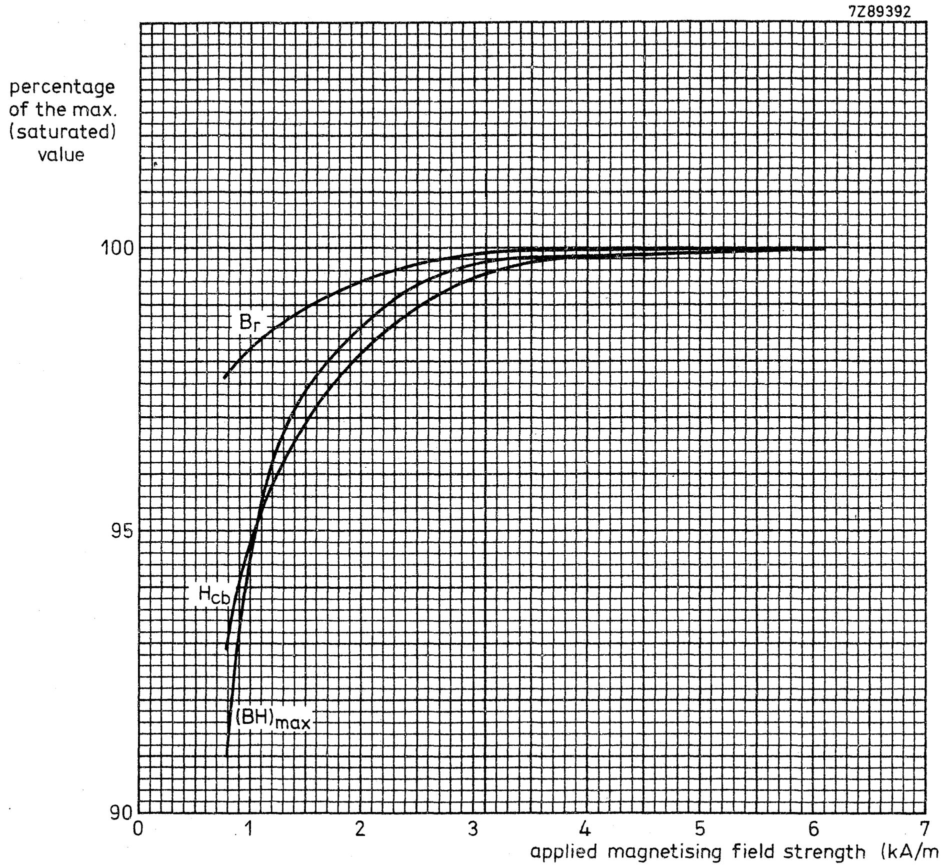
During sintering, the magnet shrinks. The amount of shrinkage depends upon production factors and upon the magnet's final shape and size. This results in some variation in magnet dimensions, so for closer tolerances the surfaces must be machined. Because it is hard, the material is usually ground or cut with diamond coated wheels. Please refer to tolerance guide for more details.

Magnetization

RES magnets can be supplied magnetized or unmagnetized. They do not self-demagnetize, but they may suffer mechanically if handled in a magnetized state; so wherever possible, the magnets should be magnetized after assembly.

The figures quoted for minimum magnetizing field strength relate to magnets that have not been magnetized since the final production heat treatment. Subsequent magnetizing operations require much stronger fields than used in the initial magnetization (up to three times as strong). The graph (see next page) shows the effect of an increasing magnetic field on the properties of a magnet. Note the marked effect on coercivity.

The magnets can be demagnetized by applying a sufficiently high reverse field. However, such action should be avoided if at all possible in view of the material's high coercivity and the consequent strong magnetic field then required to remagnetize it. Heating the magnet above its Curie point will also demagnetize it, but this should not be attempted without special precautions since otherwise the magnet's subsequent properties will suffer.



B_r, H_{cB} and $(BH)_{max}$ as a percentage of the maximum obtained (saturated) value as a function of magnetizing field strength. Values are typical for an RES magnet not previously magnetized.

Effect of temperature on electrical properties

The working point induction of a magnet falls with increasing temperature. The losses that occur with rising temperature fall into two categories: reversible and irreversible.

Reversible losses, caused by the effect of temperature on the saturation polarization are expressed in terms of the *temperature coefficient of remanence,* which for RES magnets is very low indeed (compared with Ferroxdure).

Irreversible losses can be divided into those that are recoverable by remagnetization and those that are not. In most instances this distinction is academic since remagnetization is rarely practical.

Irreversible losses recoverable by remagnetization are caused by elemental parts of the magnet becoming demagnetized by thermal agitation. The extent to which this occurs depends upon the magnetic working point (the demagnetizing field strength) and upon temperature; so the data given in this handbook relates to losses at a specified working point.

Irreversible losses that cannot be recovered by remagnetization are caused by metallurgical changes within the magnet (such as oxidation). Improvements is production technology have reduced this problem significantly for normal working conditions. The maximum recommended operating temperature should, however, not be exceeded.

To provide the superior temperature stability needed in some applications, the magnets can undergo an ageing operation. This involves heating the magnets (at the relevant working point) for several hours at a temperature somewhat in excess of the expected maximum operating temperature.

REM RARE-EARTH MAGNETS

REM (rare-earth matrix) magnets are manufactured by an injection moulding process, using a powdered alloy of samarium, cerium, cobalt, copper and iron, mixed with a plastic binder. During moulding, external magnetic fields impart preferred magnetization directions to the material by aligning the powder grains parallel to the magnetic field gradient.

Injection moulded products are quite rigid and, other than by machining (which is fairly easy with these products), do not allow further shaping after manufacture. However, the tolerances obtained after moulding are usually acceptable without machining.

Injection moulding possesses the advantage of allowing relatively complicated magnets with complex magnetic patterns and good mechanical properties to be produced fairly easily. The magnetic properties are good, although still modest in comparison with sintered rare-earth materials. The stored magnetic energy is strongly influenced by the density of magnetic material in a magnet.

High temperatures reduce the strength of the matrix binder, allowing some mechanical deformation of the magnet. We therefore quote two temperature limits: a lower limit for continuous operation, and a higher absolute limit.

Specifications for two REM materials: REM50 and REM60, are given in this publication. REM50 is useful for applications requiring complex magnetization configurations. Usually these products are supplied magnetized. For applications requiring a somewhat higher temperature limit, an alternative bonding material is available. This does, however, reduce the magnetic energy (by an amount that depends upon the final product). We advise you to consult us when deciding which material to use for your application.

REM50

- Anisotropic plastic-bonded cobalt rare earth material of the copper precipitation type

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.	
Remanence	B_r	490	470	mT
Coercivity	H_{cB}	355	345	kA/m
Polarization coercivity	H_{cJ}		1100	kA/m
Maximum BH product	$(BH)_{max}$	46	42	kJ/m^3
Maximum permissible temperature				
continuous			70	°C
short periods			85	°C
Recommended magnetizing field (initial)		> 2400		kA/m
Recoil permeability	μ_{rec}	1,05		
Temperature coefficient of B_r		–0,08		%/K
Resistivity	ρ	$4,3 \times 10^{-3}$		Ωm

PHYSICAL PROPERTIES

Density typ. $5,7 \times 10^3$ kg/m^3 ($5,7$ g/cm^3)

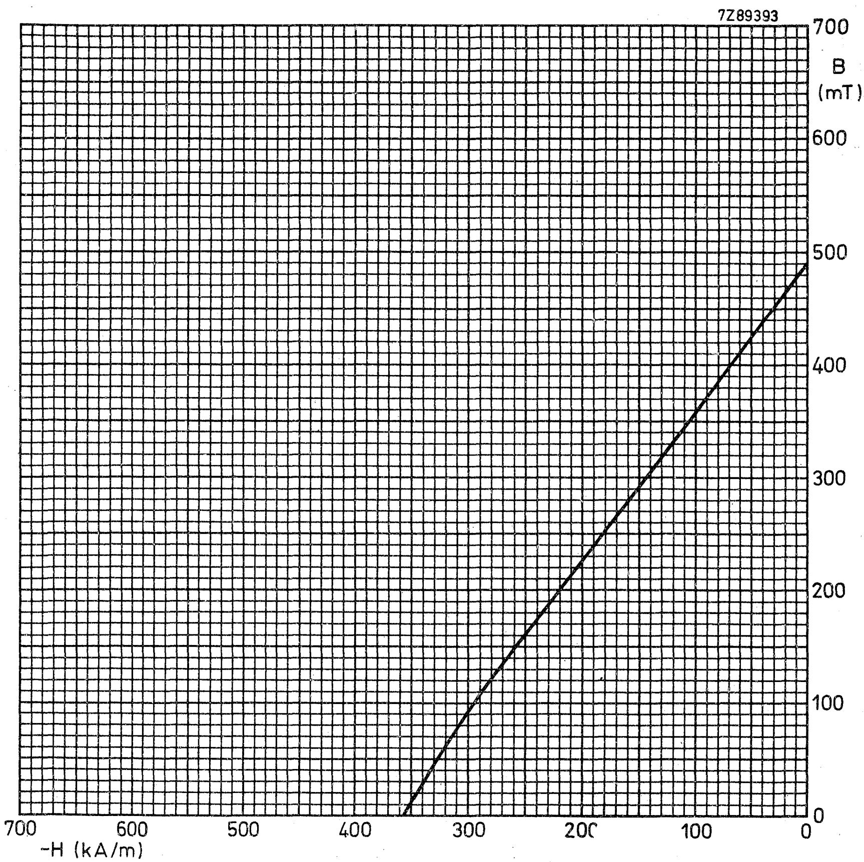
DIRECTION OF MAGNETIZATION

REM50 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



REM60

- Anisotropic plastic-bonded cobalt rare earth material of the copper precipitation type

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.	
Remanence	B_r	540	510	mT
Coercivity	H_{cB}	335	325	kA/m
Polarization coercivity	H_{cJ}	540	520	kA/m
Maximum BH product	$(BH)_{max}$	53	48	kJ/m³
Maximum permissible temperature				
continuous			70	°C
short periods			85	°C
Recommended magnetizing field (initial)		> 1200		kA/m
Recoil permeability	μ_{rec}		1,06	
Temperature coefficient of B_r		–0,08		%/K
Resistivity	ρ	$4,3 \times 10^{-3}$		Ωm

PHYSICAL PROPERTIES

Density typ. $5,7 \times 10^3$ kg/m³ (5,7 g/cm³)

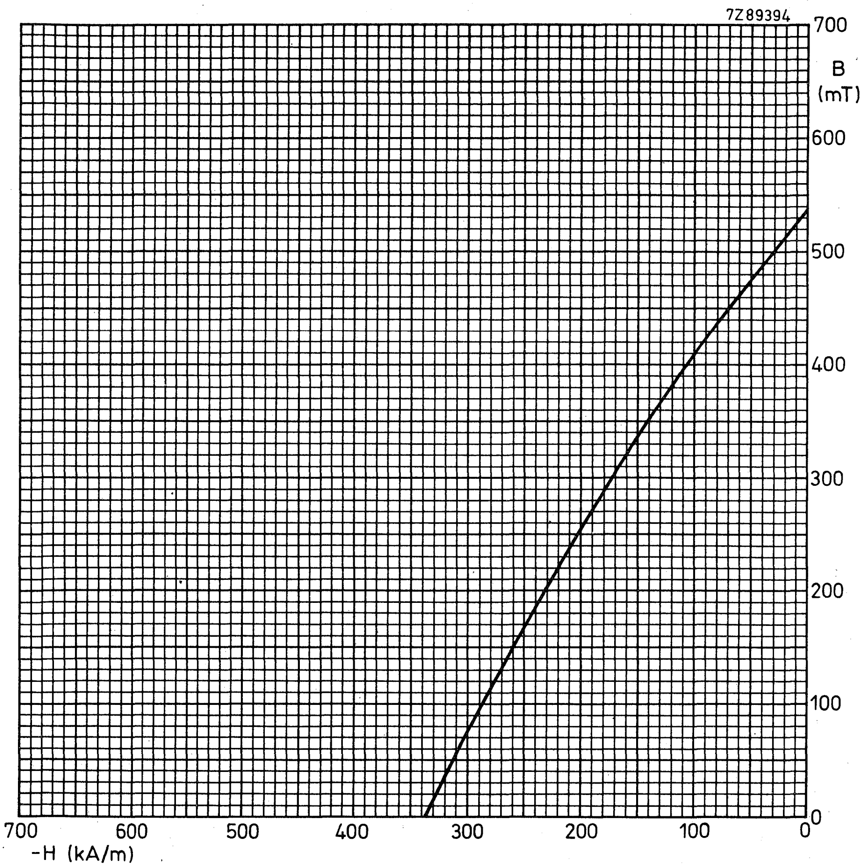
DIRECTION OF MAGNETIZATION

REM60 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



RES160

- Anisotropic cobalt samarium material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.	
Remanence	B_r	810	790	mT
Coercivity	H_{cB}	600	560	kA/m
Polarization coercivity	H_{cJ}		1100	kA/m
Maximum BH product	$(BH)_{max}$	128	120	kJ/m^3
Maximum continuous operating temperature		250		°C
Recommended initial magnetizing field		> 1800		kA/m
Recoil permeability	μ_{rec}	1,05		
Temperature coefficient of Br		–0,05		%/K
Irreversible flux loss*		< 4		%
Resistivity	ρ	$0,5 \cdot 10^{-6}$		Ωm
Curie point		720		°C

PHYSICAL PROPERTIES

Density	typ.	$8,3 \times 10^3$ kg/m^3	($8,3$ g/cm^3)	
Hardness (Vickers)			500	
Young's modulus			$1,5 \cdot 10^{11}$	N/m^2

* Measured after heating to 150 °C and with $\frac{B}{\mu_0 H} = -1$.

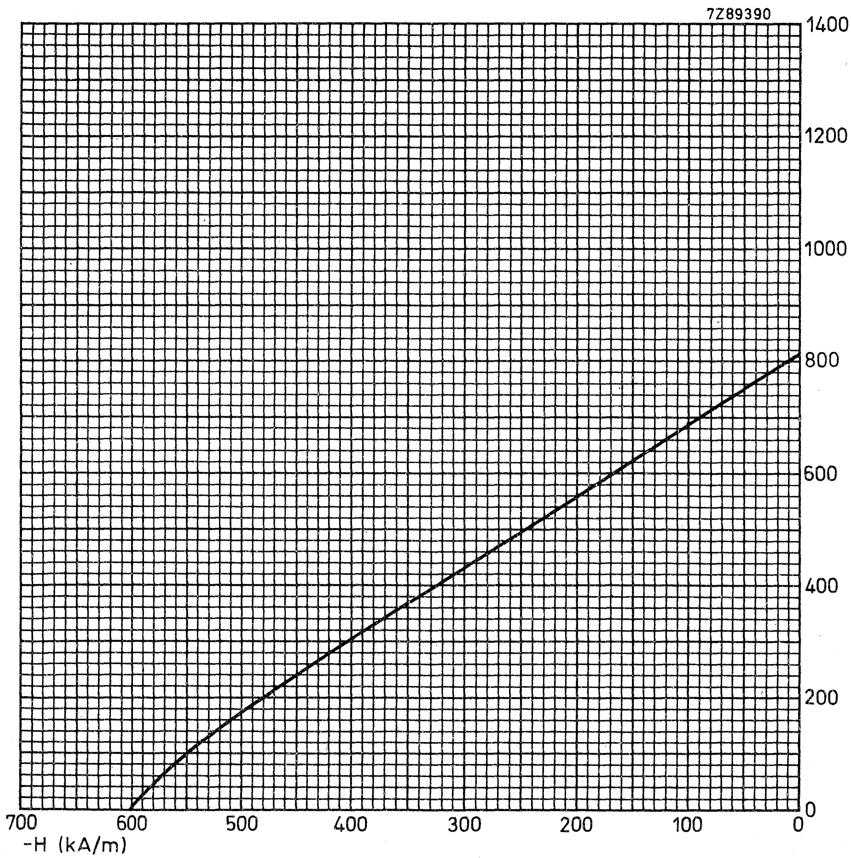
DIRECTION OF MAGNETIZATION

RES160 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



RES190

- Anisotropic cobalt samarium material

GENERAL

This specification relates to tests carried out on test pieces made from each batch of material taken from normal production.

Magnets manufactured from this material conform generally to this specification but, owing to the method of manufacture and to the variation in size and shape, some limits cannot always be realized, or indeed checked by measurement on the magnet. However, a minimum-flux test or similar test described in each magnet specification, can be used as a basis for performance guarantees.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE

Temperature of the test piece is 25 ± 2 °C unless otherwise specified.

		typ.	min.	
Remanence	B_r	890	870	mT
Coercivity	H_{cB}	670	620	kA/m
Polarization coercivity	H_{cJ}		1100	kA/m
Maximum BH product	$(BH)_{max}$	154	144	kJ/m³
Maximum continuous operating temperature		250		°C
Recommended initial magnetizing field		> 1800		kA/m
Recoil permeability	μ_{rec}	1,05		
Temperature coefficient of B_r		−0,05		%/K
Irreversible flux loss*		< 4		%
Resistivity	ρ	$0,5 \cdot 10^{-6}$		Ωm
Curie point		720		°C

PHYSICAL PROPERTIES

Density	typ.	$8,3 \times 10^3$ kg/m³	(8,3 g/cm³)
Hardness (Vickers)		500	
Young's modulus		$1,5 \cdot 10^{11}$	N/m²

* Measured after heating to 150 °C and with $\frac{B}{\mu_0 H} = -1$.

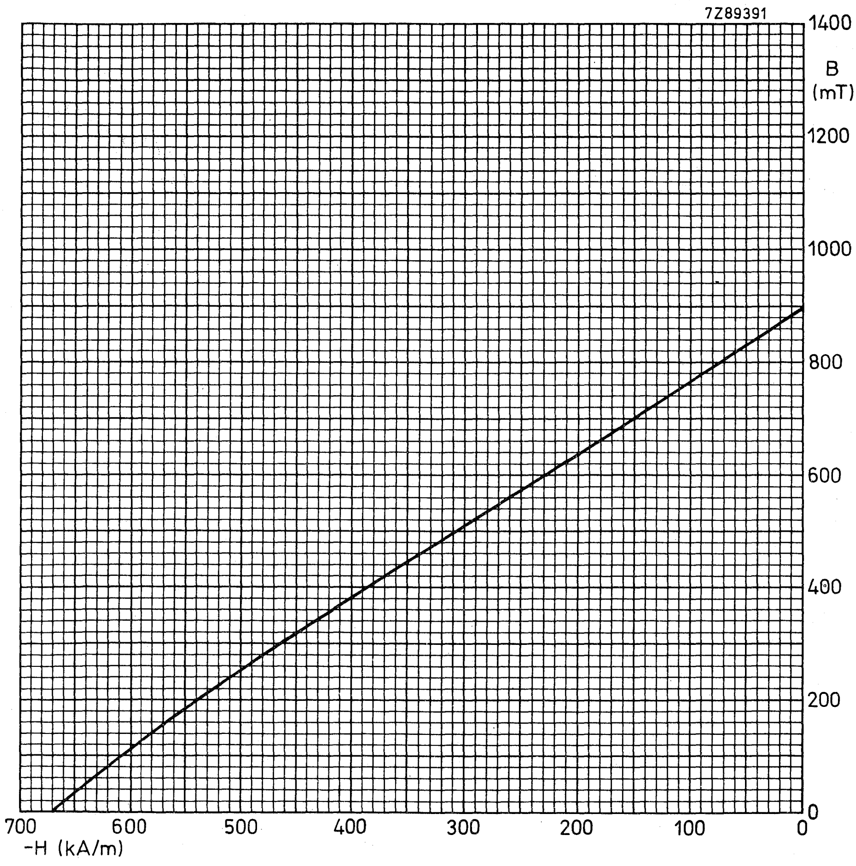
DIRECTION OF MAGNETIZATION

RES190 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

QUALITY AND FINISH

The material allows magnets to be produced having a good, clean finish and appearance according to the appropriate visual limit samples.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



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PIEZOELECTRIC CERAMICS and PERMANENT MAGNET MATERIALS

A PIEZOELECTRIC CERAMICS

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