PHILIPS

Data handbook

PHILIPS

Electronic components and materials

Components and materials

Part 4b December 1976

Piezoelectric ceramics

Permanent magnet materials

COMPONENTS AND MATERIALS

Part 4b **December 1976**

Piezoelectric ceramics

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Contents

DATA HANDBOOK SYSTEM

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

ELECTRON TUBES	**BLUE**
SEMICONDUCTORS AND INTEGRATED CIRCUITS	**RED**
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.

December 1972

ELECTRON TUBES (BLUE SERIES)

This series consists of the following parts, issued on the dates indicated.

Part 1a	**Transmitting tubes for communication** **and Tubes for r.f. heating Types PE05/25 – TBW15/125**	**December 1975**
Part 1b	**Transmitting tubes for communication** **Tubes for r.f. heating** **Amplifier circuit assemblies**	**January 1976**
Part 2	**Microwave products** Communication magnetrons Magnetrons for microwave heating Klystrons Travelling-wave tubes Diodes Triodes T-R Switches Microwave semiconductor devices Isolators – circulators	**May 1976**
Part 3	**Special Quality tubes;** **Miscellaneous devices**	**January 1975**
Part 4	**Receiving tubes**	**March 1975**
Part 5a	**Cathode-ray tubes**	**August 1975**
Part 5b	**Camera tubes; Image intensifier tubes**	**May 1975**
Part 6	**Products for nuclear technology** Channel electron multipliers Geiger-Mueller tubes Neutron tubes	**July 1975**
Part 7	**Gas-filled tubes** Voltage stabilizing and reference tubes Counter, selector, and indicator tubes Trigger tubes Switching diodes Thyratrons Ignitrons Industrial rectifying tubes High-voltage rectifying tubes	**August 1975**
Part 8	**TV Picture tubes**	**October 1975**
Part 9	**Photomultiplier tubes** **Phototubes (diodes)**	**June 1976**

SEMICONDUCTORS AND INTEGRATED CIRCUITS (RED SERIES)

This series consists of the following parts, issued on the dates indicated.

Part 1a **Rectifier diodes, thyristors, triacs** **March 1976**

- Rectifier diodes
- Voltage regulator diodes (> 1,5 W)
- Transient suppressor diodes
- Rectifier stacks
- Thyristors
- Triacs

Part 1b **Diodes** **October 1975**

- Small signal germanium diodes
- Small signal silicon diodes
- Special diodes
- Voltage regulator diodes (< 1,5 W)
- Voltage reference diodes
- Tuner diodes

Part 2 **Low-frequency transistors** **December 1975**

Part 3 **High-frequency and switching transistors** **April 1976**

Part 4a **Special semiconductors** **June 1976**

- Transmitting transistors
- Microwave devices
- Field-effect transistors
- Dual transistors
- Microminiature devices for thick- and thin-film circuits

Part 4b **Devices for optoelectronics** **July 1976**

- Photosensitive diodes and transistors
- Light emitting diodes
- Displays
- Photocouplers
- Infrared sensitive devices
- Photoconductive devices

Part 5a **Professional analogue integrated circuits** **November 1976**

N.B. Consumer circuits will be issued in part 5b

Part 6 **Digital integrated circuits** **May 1976**

LOCMOS HE family
GZ family

COMPONENTS AND MATERIALS (GREEN SERIES)

This series consists of the following parts, issued on the dates indicated.

Part 1 **Functional units, Input/output devices, Peripheral devices** — **November 1975**

High noise immunity logic FZ/30-Series
Circuit blocks 40-Series and CSA70
Counter modules 50-Series
NORbits 60-Series, 61-Series
Circuit blocks 90-Series
Input/output devices
Hybrid integrated circuits
Peripheral devices

Part 2a **Resistors** — **February 1976**

Fixed resistors
Variable resistors
Voltage dependent resistors (VDR)
Light dependent resistors (LDR)
Negative temperature coefficient thermistors (NTC)
Positive temperature coefficient thermistors (PTC)
Test switches

Part 2b **Capacitors** — **April 1976**

Electrolytic and solid capacitors
Paper capacitors and film capacitors
Ceramic capacitors
Variable capacitors

Part 3 **Radio, Audio, Television** — **February 1975**

FM tuners
Loudspeakers
Television tuners and aerial input assemblies
Components for black and white television
Components for colour television

Part 4a **Soft ferrites** — **October 1976**

Ferrites for radio, audio and television
Beads and chokes
Ferroxcube potcores and square cores
Ferroxcube transformer cores

Part 4b **Piezoelectric ceramics, Permanent magnet materials** — **December 1976**

Part 5 **Ferrite core memory products** — **July 1975**

Ferroxcube memory cores
Matrix planes and stacks
Core memory systems

Part 6 **Electric motors and accessories** — **September 1975**

Small synchronous motors
Stepper motors
Miniature direct current motors

Part 7 **Circuit blocks** — **September 1971**

Circuit blocks 100 kHz-Series
Circuit blocks 1-Series
Circuit blocks 10-Series
Circuit blocks for ferrite core memory drive

Part 8 **Variable mains transformers** — **July 1975**

Part 9 **Piezoelectric quartz devices** — **March 1976**

Part 10 **Connectors** — **November 1975**

Piezoelectric ceramics

INTRODUCTORY NOTES

PXE (piezoelectric ceramic) materials are suitable for many applications where electro-mechanical 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. PXE5 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.

PXE51: 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 detector applications and for fine movement control.

→ PXE 6(00) range: In this range some material grades are available for resonator and filter applications in the entertainment and in the professional field. They are characterized by excellent temperature and time stability and high mechanical quality factor.

APPLICATIONS

High voltage generators (for ignition purposes):	gas appliances, cigarette lighters, fuzes for explosives, flash bulbs, small petrol motors.
High power ultrasonic generators:	ultrasonic cleaning for industrial and domestic appliances. sonar, echo sounding, underwater telephony, ultrasonic welding of plastics and metals, ultrasonic drilling and machining of brittle materials, ultrasonic soldering, atomization, pulverization.
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, musical instruments.
Resonators and filters:	radio, television, remote control, telecommunications.
Delay lines:	colour television, electronic computers.
Push buttons and keyboards:	teleprinters, desk calculators and electronic computers, slot machines, telephones.
Miscellaneous:	h.t. transformers, small motors, analogue memories, fine movement control, flow meters and flaw 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:

$$D = \varepsilon E \quad \ldots\ldots (1)$$

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:

$$S = sT \quad \ldots\ldots (2)$$

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:

$$S = s^{E}T + dE \quad \ldots\ldots (3)$$

$$D = dT + \varepsilon^{T}E \quad \ldots\ldots (4)$$

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:

$$E = -gT + \frac{D}{\varepsilon^{T}} \quad \ldots\ldots (5)$$

$$S = s^{D}T + gD \quad \ldots\ldots (6)$$

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)	$\frac{\text{metre per metre}}{\text{volts per metre}}$	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.

Note: 1 Pa (pascal) = 1 N/m^2 (newton per metre^2)

$$d = \varepsilon^T g \quad \text{.......}(7)$$

and

$$s^D = (1 - k^2)s^E \quad \text{.......}(8)$$

if k is defined by

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

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 Table 1, 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 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 properley 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.

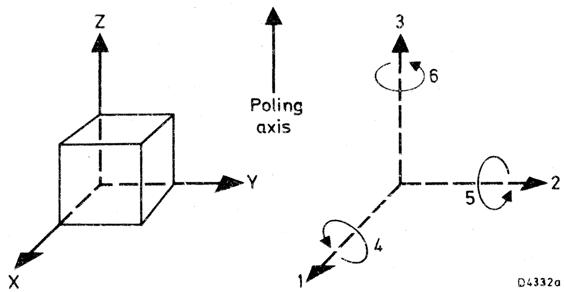


Fig. 1

Permittivity ε

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

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

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

The table below gives values for the relative permittivity $\varepsilon/\varepsilon_0$, i.e. the ratio of the absolute permittivity ε to the permittivity of vacuum ε_0, the latter being 8.85×10^{-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 ($k_r = k_p$).

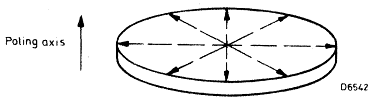


Fig. 2.

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.

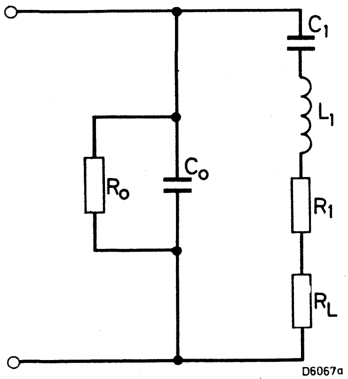


Fig. 3

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

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

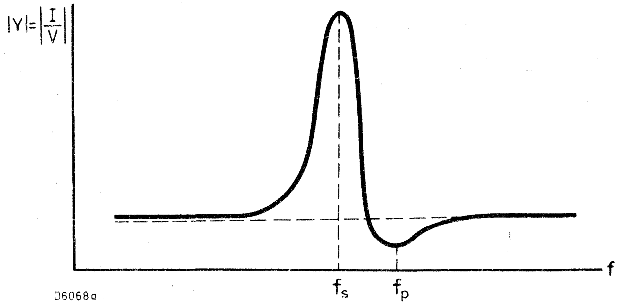


Fig. 4

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, tanδ.

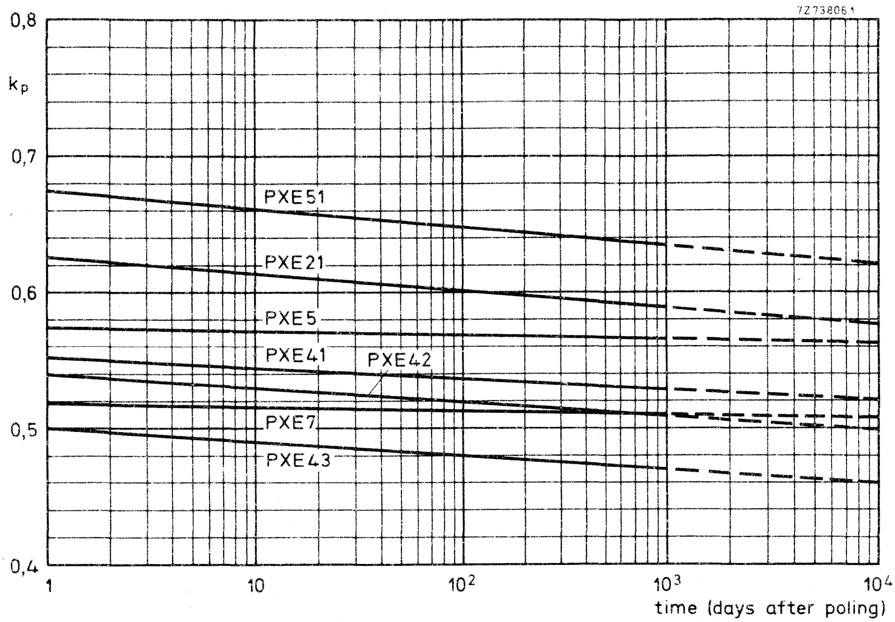


Fig. 5

PRINCIPAL PROPERTIES

Unless otherwise stated, the values are measured at 20 ± 5 °C, 24 h after poling.

Property (1)	Symbol	Unit	PXE5	PXE7	PXE21	PXE41	PXE42	PXE43	PXE51(3)(4)
THERMAL DATA									
Curie point (2)	Θ_c	°C	285	320	270	315	325	300	220
Specific heat	c	J/kg °C	420	420	420	420	420	-	420
Thermal conductivity	λ	W/m °C	1,2	1,2	1,2	1,2	1,2	-	1,2
MECHANICAL DATA									
Mass density	ρ_m	10^3 kg/m^3	7,65	7,75	7,75	7,90	7,70	7,70	7,70
Compliance	s_{33}^E	10^{-12}/Pa	17,2	15,8	18,6	14,6	15,3	12,6	17,8
	s_{11}^E		15,3	12,5	15,1	12,2	12,7	11,3	14,5
	s_{55}^E		38,5	33,2	-	37,0	-	-	-
Poisson's ratio	σ	-	≃0,3	≃0,3	≃0,3	≃0,3	≃0,3		≃0,3
Mechanical quality factor for radial mode	Q_m^E	-	≃80	≃80	≃80	≃1000	≃750	≃1000	≃50
Frequency constants	N_p^E	Hz.m or m/s	2000	2200	2000	2200	2200	2350	2050
	$N_3^D = \frac{1}{2} v_3^D$		1900	2000	1900	2000	2015	2050	1950
	$N_1^E = \frac{1}{2} v_1^E$		1460	1640	-	1620	-	-	-
	$N_5^E = \frac{1}{2} v_5^E$		930	1025	-	950	-	-	-
Compressive strength	—	10^6Pa	>600	>600	>600	>600	>600	>600	>600
Tensile strength	—	10^6Pa	≃80	≃80	≃80	≃80	≃80	≃80	≃80
ELECTRICAL DATA									
Relative permittivity ($\varepsilon_o = 8,85 \times 10^{-12}$F/m)	$\varepsilon_{33}^T/\varepsilon_o$	-	1800	820	1750	1200	1300	1000	2800
	$\varepsilon_{11}^T/\varepsilon_o$	-	1800	1200	-	1400	-	-	-
Resistivity (25 °C)	ρ_{el}	10^{12} Ωm	1	1	0,1	0,05	-	-	0,1
Time constant (25 °C)	$\rho_{el}\varepsilon_{33}^T$	min	>250	>100	>25	>7	-	-	>40
Dielectric loss factor	tanδ	10^{-3}	20	20	18	2,5	2,5	2	16

Property (1)	Symbol	Unit	PXE5	PXE7	PXE21	PXE41	PXE42	PXE43	PXE51(3)(4)
ELECTROMECHANICAL DATA									
Coupling factors	k_p	-	0,60	0,56	0,62	0,58	0,58	0,50	0,66
	k_{33}	-	0,69	0,70	0,72	0,68	0,68	0,63	0,72
	k_{31}	-	0,35	0,32	0,37	0,34	0,34	0,30	0,39
	k_{15}	-	0,66	0,64	-	0,70	-	-	-
Piezoelectric charge constants	d_{33}	10^{-12}C/N or m/V	362	220	385	268	285	210	480
	d_{31}		−175	−99	−180	−119	−130	−95	−234
	d_{15}		515	405	-	480	-	-	-
Piezoelectric voltage constants	g_{33}	10^{-3}Vm/N or m^2/C	22,7	35,7	25,0	25,2	25,0	25,0	19,3
	g_{31}		−11,0	−13,5	−11,6	−11,6	−11,0	−10,7	−9,5
	g_{15}		32,5	38,0	-	38,5	-	-	-
TIME STABILITY									
Coupling factor	k_p	relative change per time decade %	−0,5	−0,5	−1,5	−1,5	−2,5	−2	−1,0
Permittivity	ε_{33}^T		−1	−0,5	−2	1	−6,0	−4,5	−1
Frequency constant	N_p^E		0,5	1,0	0,5	0,5	1,5	1	1
Quality factor	Q_m^E		-	-	-	10	-	-	-
Dielectric loss factor	tanδ		-	-	-	−10	-	-	-

For notes (1) to (4) see next page.

NOTES:

(1) The properties of components, manufactured from PXE, are dependent on the dimensions and method of manufacture of the product, and on the measuring level. Guaranteed component properties are shown, for some components, on the data sheets; otherwise, when required, they may be obtained upon request. Properties in the planar mode are measured on discs of Ø 16mm and 1mm thick. Properties in the 33-mode are measured on cylinders Ø 6,4mm and 16mm long. Properties in the 15-mode are measured on plates 12 x 10 x 0,2mm.

(2) Temperature at which the ϵ_{33}^{T} is maximum.

→ (3) Available on request.

(4) Preliminary data.

→ (5) Preliminary data for specific applications on properties and stability characteristics of the different grades of the PXE 6(00) range are available on request.

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.E.E.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.

GENERAL

APPLICATION

PXE ceramics may be used for high voltage generation for spark ignition in gas appliances, for example in gas cookers, cigarette lighters, and camping gas equipment. They combine an almost infinite life with foolproof ignition.

PXE CYLINDERS IN IGNITION UNITS

The high voltage required for ignition is generated in one or two cylinders. The following parameters are of importance:

(1) Dimensions and linear tolerances of the cylinders.

(2) Parallelism, squareness, flatness and roughness (geometric tolerances) of the cylinder end faces.

(3) Material grade, coupling coefficient, and permittivity.

(4) Mechanical strength.

(5) Resistance to depolarization.

INSULATION

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

HOUSING

For the assembly of the complete unit, the use of polypropylene is recommended. When using polypropylene with a high moulding temperature (> 200 °C), the housing must be moulded into its final form prior to insertion of the PXE cylinder in order to prevent depoling of the PXE material. Alternatively, a polyethylene material with lower moulding temperature must be used.

MATERIAL GRADES AND PROPERTIES

The material grades suitable for gas ignition are PXE 21 and PXE 41. When an axially poled PXE cylinder is subjected to a stress T_3, a voltage V_3 will be produced between electrodes on its end faces: $V_3 = -g_{33}T_3\ell$, 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 cylinder.

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

$W_{tot} = 1/2\ CV_b^2$, 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: $w_{tot} = 1/2\ \varepsilon_{33}^T . g_{33}^2 . T_3^2$.

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 (e.g. pocket lighters), PXE 41 is the recommended material (maximum dynamic stress 130 MPa).

Note:

1 Pa (pascal) = 1 N/m^2

10^6 Pa = 1 MPa.

PIEZOELECTRIC SLUGS FOR SQUEEZING MECHANISMS
in domestic appliances

QUICK REFERENCE DATA		
	4322 020 05630	4322 020 05640
Dimensions (mm)	ϕ 6, 35 x 15	ϕ 6, 35 x 16
Material	PXE41	PXE41
Coupling coefficient k_{33}	0, 68	0, 68
Capacitance (pF)	24	23
Open output voltage, peak value (kV) (T_3 = 7500 N/cm^2)	30	32

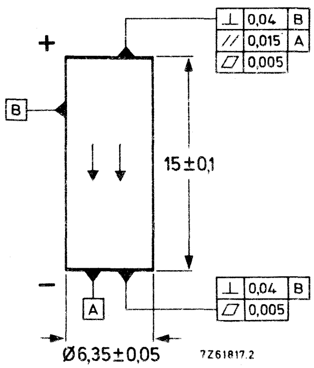
APPLICATION

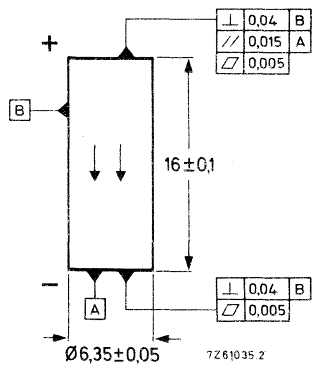
These slugs are intended for use in hand operated gas ignition mechanisms for household appliances.

TECHNICAL DATA

Unless otherwise specified the values given are nominal ones, measured at 20 ± 5 °C

Dimensions in mm





The direction of polarisation is axial.
The electrode which has been connected to the positive pole during poling is marked.
The end faces are metallised.

	4322 020 05630	4322 020 05640
Material	PXE41	PXE41
Capacitance [1])	24 pF	23 pF
Dielectric dissipation factor [1])	$2,5 \times 10^{-3}$	$2,5 \times 10^{-3}$
Piezoelectric voltage constant g_{33}	$25,2 \times 10^{-3}$ Vm/N	$25,2 \times 10^{-3}$ Vm/N
Coupling coefficient k_{33}	0,68	0,68
Relative permittivity $\epsilon_{33}^T / \epsilon_0$	1200	1200
Open output voltage, peak value (T_3 = 7500 N/cm^2)	30 kV	32 kV

ORDERING PROCEDURE

For ordering purposes please quote the 12-digit catalogue number of the slug.
The quantity to be ordered must be at least one box of 500 pieces or a multiple of this.

[1]) Measured at 1 kHz

PIEZOELECTRIC SLUGS FOR IMPACT MECHANISMS
in domestic and industrial appliances

QUICK REFERENCE DATA		
	4322 020 05070	4322 020 05650
Dimensions (mm)	ϕ 6, 35 x 16	ϕ 9 x 17
Material	PXE21	PXE21
Coupling coefficient k_{33}	0, 72	0, 72
Capacitance (pF)	33	63
Open output voltage, peak value (kV) (T_3 = 5000 N/cm^2)	20	21

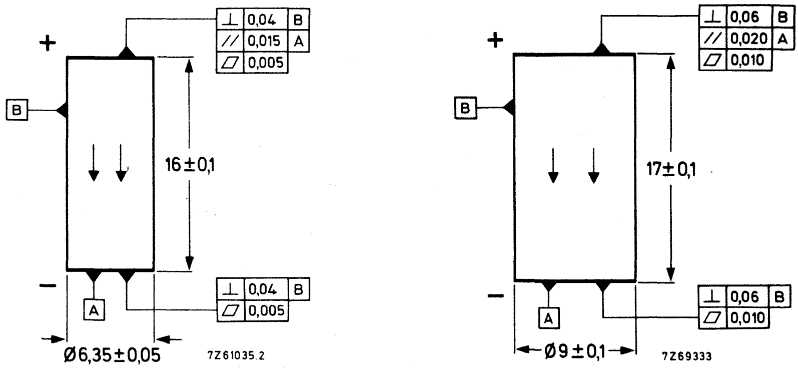
APPLICATION

These slugs are intended for use in gas ignition mechanisms for domestic and industrial appliances.

TECHNICAL DATA

Unless otherwise specified the values given are nominal onces, measured at 20± 5 °C.

Dimensions in mm



The direction of polarisation is axial.
The electrode which has been connected to the positive pole during poling is marked.
The end faces are metallised.

	4322 020 05070	4322 020 05650
Material	PXE21	PXE21
Capacitance [1])	33 pF	63 pF
Dielectric dissipation factor [1])	16×10^{-3}	16×10^{-3}
Piezoelectric voltage constant g_{33}	25×10^{-3} Vm/N	25×10^{-3} Vm/N
Coupling coefficient k_{33}	0,72	0,72
Relative permittivity $\epsilon_{33}{}^{T}/\epsilon_{o}$	1750	1750
Open output voltage, peak value (T_3 = 5000 N/cm^2)	20 kV	21 kV

ORDERING PROCEDURE

For ordering purposes please quote the 12-digit catalogue number of the slug.
The quantity to be ordered must be at least one box of 500 pieces or a multiple of this.

[1]) Measured at 1 kHz.

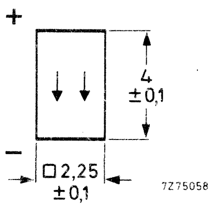
PIEZOELECTRIC SLUG FOR FLASH-BULB IGNITION

QUICK REFERENCE DATA	
Dimensions	2,25 mm x 2,25 mm x 4 mm[1])
Material	PXE 21
Coupling coefficient k_{33}	≥0,68
Charge constant d_{33}	$\geq 350.10^{-12}$ C/N
Voltage constant g_{33}	$\geq 22.10^{-3}$ Vm/N
Capacitance	19 pF

Note: The values given are nominal ones, measured at 20 ± 5 °C.

TECHNICAL DATA

Dimensions in mm



The direction of polarization is axial.
The electrode which has been connected to the positive pole during poling is identified.
The end faces are metallized.

[1]) Slugs with other dimensions are available on request.

GENERAL

INTRODUCTION

PXE ceramics, 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 ceramic 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.

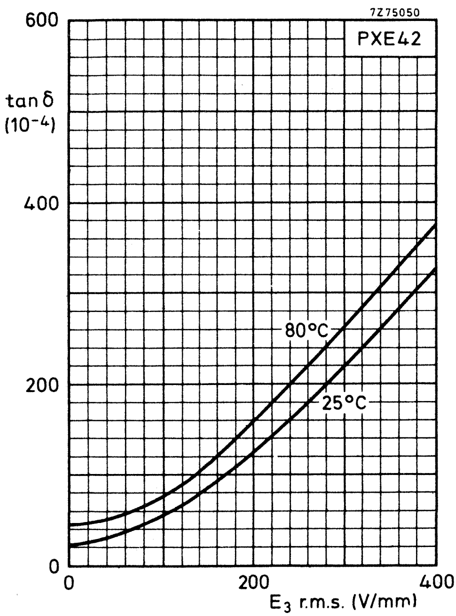
In sandwich transducers, matching with liquids may also be assisted by forming the radiating metal block from a metal of low acoustic impedance, such as aluminium or magnesium alloy.

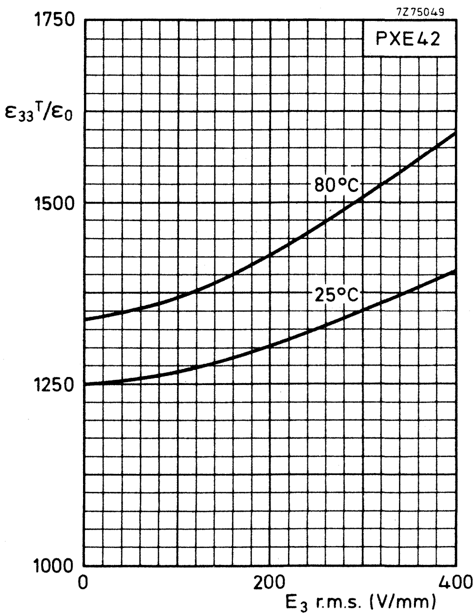
DYNAMIC BEHAVIOUR OF THE TRANSDUCER

High intensity transducers are normally driven at resonance, and the equivalent circuit is as in Fig. 3 [1]). 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.

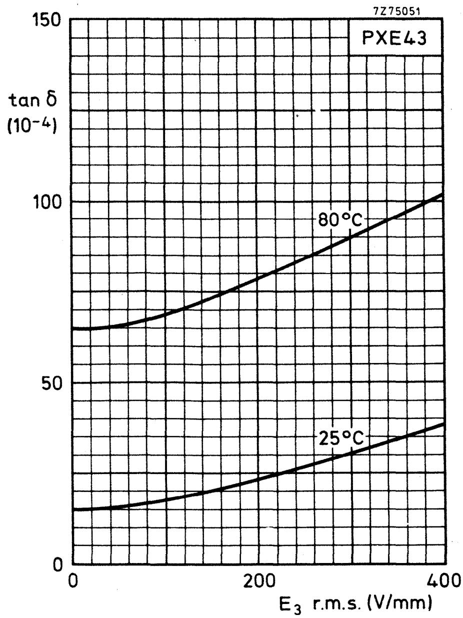
→ LARGE-SIGNAL PROPERTIES OF PXE 42 AND PXE 43

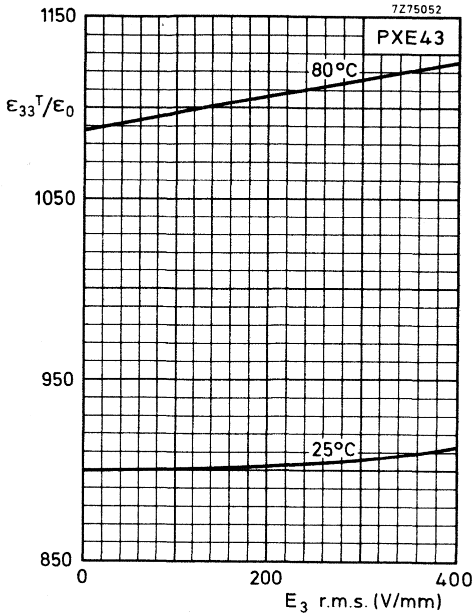
Behaviour of tan δ and relative permittivity $E_{33}{}^T/\epsilon_o$ under large driving fields.





1) Introductory notes.


7Z75051
PXE43
tan δ
(10⁻⁴)
150
100
50
0
80°C
25°C
0
200
400
E3 r.m.s. (V/mm)


7Z75052
PXE43
ε33T/ε0
1150
1050
950
850
80°C
25°C
0
200
400
E3 r.m.s. (V/mm)

PIEZOELECTRIC DISCS AND RINGS
for ultrasonic cleaning

The electrodes of the discs and 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.

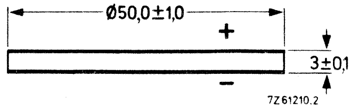
Disc for cleaning

Material : PXE41

Nominal capacitance : 7500 pF

Catalogue number : 4322 020 05590

Ordering : at least one box of 5 pieces or a multiple of this



Dimensions in mm

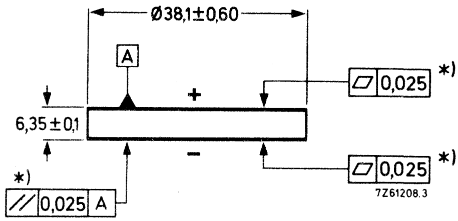
Disc for cleaning

Material : PXE42

Nominal capacitance : 1750 pF

Catalogue number : 4322 020 05660

Ordering : at least one box of 2 pieces or a multiple of this



Dimensions in mm

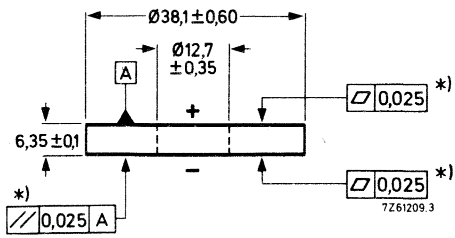
Ring for cleaning

Material : PXE42

Nominal capacitance : 1600 pF

Catalogue number : 4322 020 06040

Ordering : at least one box of 2 pieces or a multiple of this

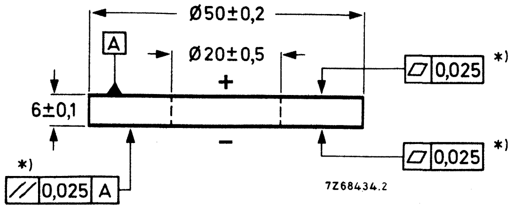


Dimensions in mm

*) For the non-silvered product the tolerance is 0,012 mm.

Ring for cleaning

Material	: PXE42
Nominal capacitance	: 2800 pF
→ Catalogue number	: 4322 020 06050
Ordering	: at least one box of 2 pieces or a multiple of this



Dimensions in mm

*) For the non-silvered product the tolerance is 0,012 mm.

PIEZOELECTRIC RING

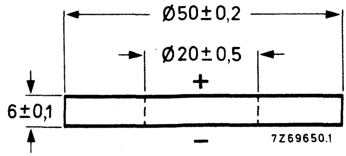
for welding

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 43

Nominal capacitance : 2000 pF

Catalogue number : 8222 293 21150



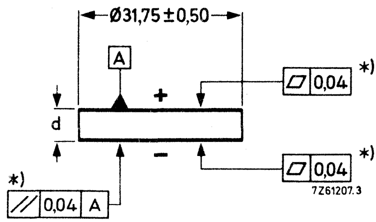
Dimensions in mm

Note: Flat-ground, non-silvered rings can be supplied on request.

PIEZOELECTRIC DISCS
for echo sounding probes

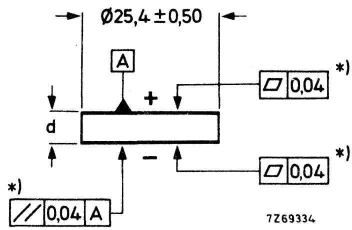
The electrodes of the discs are silver plated. The electrode that has been connected to the positive terminal of the polarizing apparatus, is identified. The direction of polarization is axial.

Material	: PXE41
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	: PXE41
Resonant frequency	: 200 ± 10 kHz (thickness mode)
Thickness (d)	: approx. 10, 2 mm (adapted to resonant frequency)
Nominal capacitance	: approx. 720 pF
Catalogue number	: 4322 020 05750



Dimensions in mm

*) For the non-silvered product the tolerance is 0, 012 mm.

GENERAL

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'.

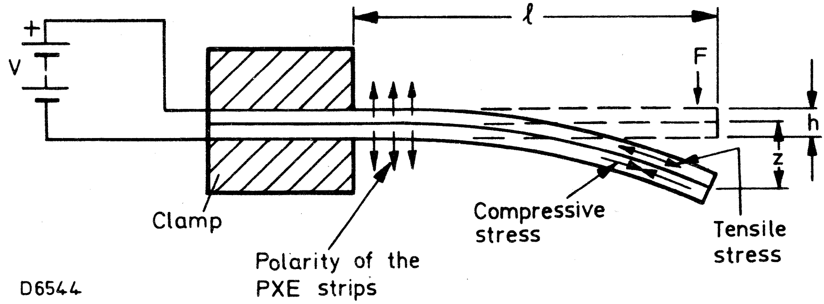


Fig. 1

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,
bell clappers,
microphones,
ultrasonic air transducers for intruder alarms, remote control, etc.
small vibratory motors,
liquid level sensors,
fine movement control,
optical scanners and choppers,
push button for keyboards.

Both multimorphs and bimorphs are described in the data sheets following this introduction.

MULTIMORPHS

APPLICATIONS

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^o to each other, and at 45^o to the record surface. Multimorphs may also be used as electro-mechanical transducers to achieve small deflections at low forces.

DIMENSIONS (millimetres), MATERIAL

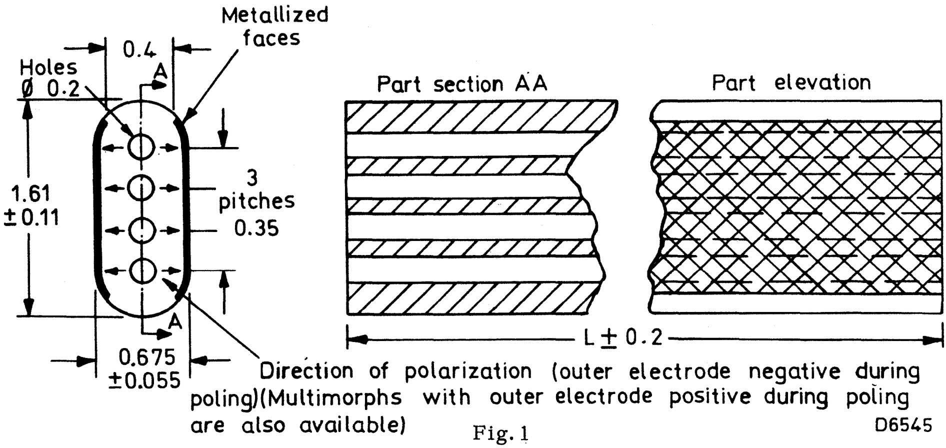


Fig. 1

Dimension 'L'	PXE grade	catalogue number	
		outer electrode negative	outer electrode positive
9,6	5	4322 020 04760	4322 020 04750
12,7	5	4322 020 02480	4322 020 02460
15,5	5	4322 020 02490	4322 020 02470
70,0	5	4322 020 04830	

ELECTRICAL AND MECHANICAL DATA

Sensitivity

There are two methods to support multimorphs serving most requirements; these are shown in figures 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 ℓ.

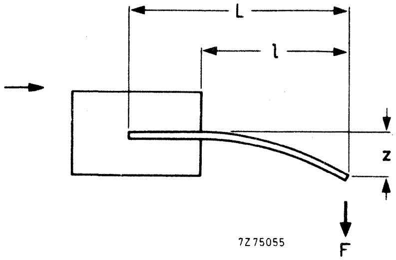


Fig. 2a

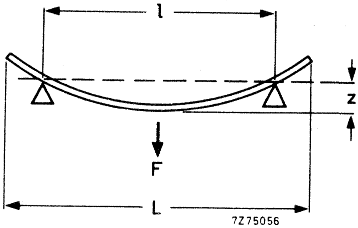


Fig. 2b

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	$0,74 \times 10^{-3} \ell^2$	$0,18 \times 10^{-3} \ell^2$
	Electric charge output versus deflection **z**	μC/mm	$5,7/\ell$	$23/\ell$
Electro-mechanical	Deflection z versus applied voltage (force F = 0)	mm/V	$7,3 \times 10^{-7} \ell^2$	$1,8 \times 10^{-7} \ell^2$
	Force F versus applied voltage (deflection z = 0)	N/V	$5 \times 10^{-3}/\ell$	$2 \times 10^{-2}/\ell$

ℓ = active (bent) length of element in millimetres.

Notes:

1. These sensitivities are accurate at low levels, 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 somwhat 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 millimetres	52 L	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	600	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 opposite.

Resonance frequencies

Mode	Cantilever support	Nodal support	Ends-pinned support $\ell \simeq L$
Fundamental	$f_o = \frac{0,32}{\ell^2} 10^6$ Hz	$f_o = \frac{2,1}{\ell^2} 10^6$ Hz ($\ell = 0.55L$)	$f_o = \frac{0,9}{\ell^2} 10^6$ Hz
1st overtone	$f_1 = 6.3 f_o$	$f_1 = 2,8 f_o$ ($\ell = 0.28L$)	$f_1 = 4 f_o$
2nd overtone	$f_2 = 18 f_o$	$f_2 = 5,4 f_o$ ($\ell = 0.95L$)	$f_2 = 9 f_o$
3rd overtone	$f_3 = 34 f_o$	$f_3 = 8,9 f_o$ ($\ell = 0.67L$)	$f_3 = 16 f_o$

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

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

L = total length in millimetres.

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

ORDERING PROCEDURE

For ordering purposes please quote the 12-digit catalogue number of the multimorph. The quantity to be ordered must be at least one box of 500 pieces or a multiple of this.

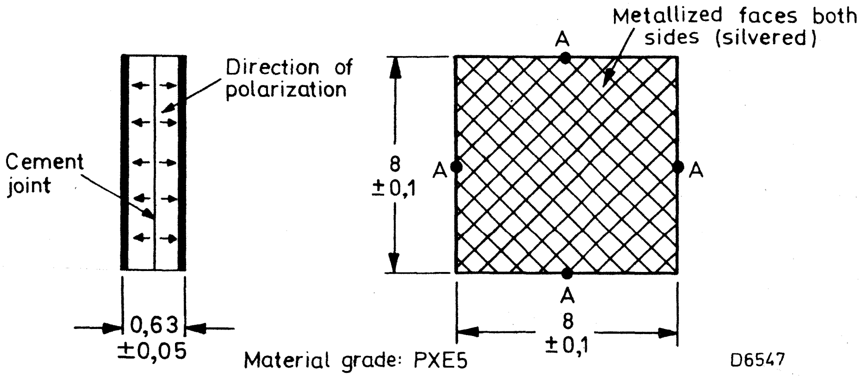
BIMORPH
ultrasonic air transducer

APPLICATION

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 t.v. receivers), and intruder alarms.

MATERIAL

Dimensions in mm



ELECTRICAL SPECIFICATION (for the PXE plate)

Resonance frequency f_s 34, 5 ± 3, 0 kHz

Capacitance at 1 kHz 1450 ± 290 pF

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
Sensitivity as a receiver (R_i = 10 Ω) (note 1)	4	μA/Pa (note 2)
Sound output (note 3) as a transmitter (when driven at 3 V r.m.s.)	0.37	Pa (note 2)

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) (note 1)	21	mV/Pa
Sound output (note 3) 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).

Notes:

1. R_i = input resistance of amplifier.
2. 1 Pa (Pascal) = 1 N/m^2 = 10 μbar.
3. Sound pressure (r.m.s.) measured at a distance 1 m in front of device.

ORDERING PROCEDURE

For ordering purposes please quote the 12-digit catalogue number of the bimorph. The quantity to be ordered must be at least one box of 200 pieces or a multiple of this.

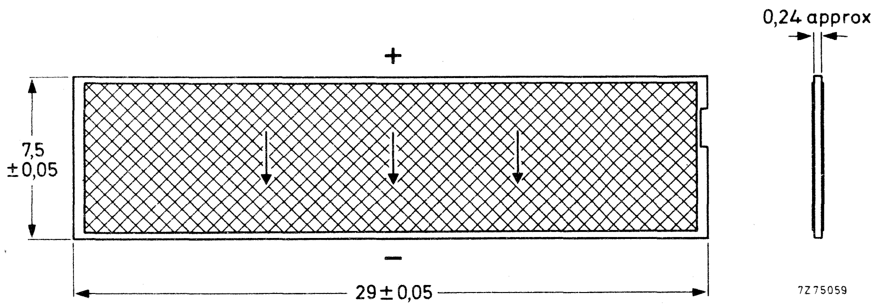
DELAY LINE TRANSDUCER

APPLICATIONS

For use in modern acoustic delay systems where an electromechanical transducer is used, 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.

MATERIAL

Dimensions in mm



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

Information on other types is available on request.

ORDERING PROCEDURE

For ordering purposes please quote the 12-digit catalogue number of the delay line transducer.
The quantity to be ordered must be at least one box of 200 pieces or a multiple of this.

DISCS AND PLATES

SOLDERING

Electrical contacts may be made to all our discs and plates by soldering to the electrodes, which are usually made of silver. A strong joint between the silver and the ceramic body is made by firing a silver paste on to the ceramic surface. The thickness of 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. Suggested soldering prescription:

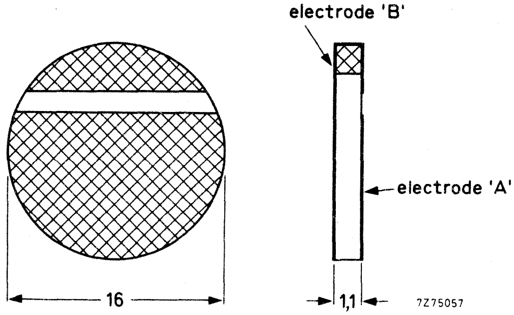
- soldering iron: Oryx type 6A, with non-coated copper tip;
- soldering iron temperature: 250 to 300 ^{o}C;
- solder: Sn/Pb 60/40;
- soldering time: 3 $\pm$ 2 s;
- flux: 502 (750 g of resin, 250 g of isopropylalcohol and 2,5 g of DMA as an activator);
- standard wire diameter: 0,2 mm.

All flux remnants should be carefully removed.

The soldering time should be kept as short as possible; otherwise the solder will dissolve the silver layer (to an extent depending on temperature and time), and polarization might be partly destroyed. Dissolving of the silver layer can be avoided by using a silver-saturated solder, but a higher soldering temperature is then required.

FEEDBACK DISCS

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.

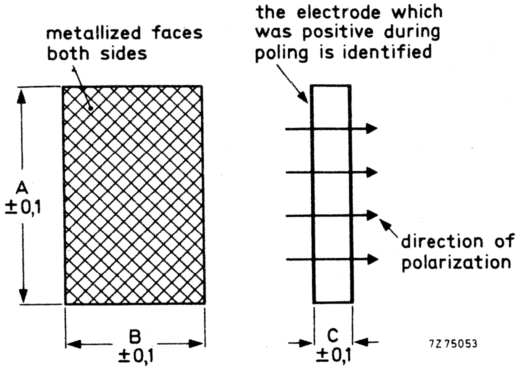


Polarity of electrode 'A' during poling: negative – 4322 020 02260
positive – 4322 020 02270

The electrode which was positive during poling is identified.

Material grade : PXE 5
Effective coupling factor k_{eff} : ≥0, 30

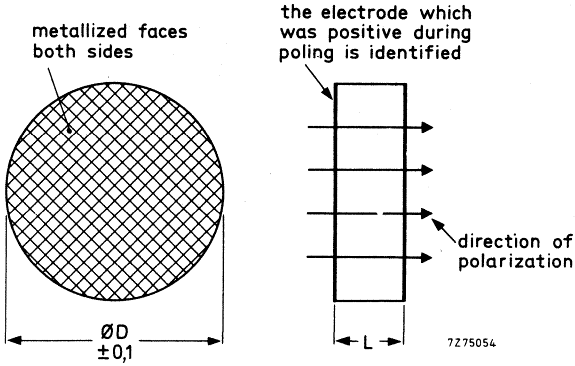
PLATES



Dimensions (millimetres)			Material grade	Catalogue number
A	B	C		
6,0	4,0	0,5	PXE5	4322 020 07150
12,0	6,0	0,5	PXE5	4322 020 07050
12,0	6,0	1,0	PXE5	4322 020 07060
16,0	12,0	1,0	PXE5	4322 020 02310

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

DISCS



Dimensions (mm)		Material grade	Catalogue number 4322 020 .....
ØD	L		
3,0	0,50±0,05	PXE 5	05250
5,0	0,20±0,05	PXE 5	05260
5,0	0,30±0,05	PXE 5	05270
5,0	0,50±0,05	PXE 5	05280
5,0	1,0±0,1	PXE 5	05300
5,0	2,0±0,1	PXE 5	05310
10,0	0,20±0,05	PXE 5	05320
10,0	0,30±0,05	PXE 5	05330
10,0	0,50±0,05	PXE 5	05340
10,0	1,0±0,1	PXE 5	02330
10,0	2,0±0,1	PXE 5	05350

Dimensions (mm)		Material grade	Catalogue number 4322 020 .....
ØD	L		
10,0	3,0±0,1	PXE 5	05360
10,0	5,0±0,1	PXE 5	05370
16,0	0,20±0,05	PXE 5	05390
16,0	0,30±0,05	PXE 5	05400
16,0	0,50±0,05	PXE 5	05410
16,0	1,1±0,1	PXE 5	02250
16,0	2,0±0,1	PXE 5	05420
16,0	3,0±0,1	PXE 5	02300
25,4	0,50±0,05	PXE 5	05430
25,4	1,0±0,1	PXE 5	05440
25,4	2,0±0,1	PXE 5	05450

→ Planar coupling factor k_p : ≥0, 55

Permanent magnet materials

FOREWORD

Modern permanent magnets are both versatile and long-lived. Properly used, their strength will remain practically unchanged, indefinitely. Among the most advanced magnets in quantity production today are those made from Ticonal alloys and Ferroxdure ceramics. They are found in nearly every home in one or more of the following applications:

loudspeakers	watt-hour meters
telephones	refrigerators
TV receivers	electric clocks
thermostats	Hi-Fi units (pick-ups)
small motors	locks and catches

In many automobiles in:

windscreen wiper motors	speedometers
fan-motors	ammeters

And for bicycles and motor bicycles in:

dynamos and magnetos.

In industry, permanent magnets are used in applications requiring the utmost reliability in severe environments:

moving-coil meters	precision motors
ore separators	cranes
chucks and clamps	relays and contactors.

Ticonal and Ferroxdure are both types of hard magnetic materials, and it is their specially developed properties which make modern magnets so useful. Hard magnetic materials are those whose magnetic state is difficult to change: they are both hard to magnetize and to demagnetize. Their magnetism is due to the electron currents in groups of similarly oriented atoms. In the unmagnetized state, these groups of atoms, known as domains, are randomly oriented, and the net polarization of the body of the magnet is zero. When a magnetizing field is applied some domains become oriented with the applied field and grow at the expense of the non-oriented domains, until the whole body of the magnet is wholly oriented or saturated. When the magnetizing field is removed, the hard microstructure of the material prevents the domains from regaining their former disorganized arrangement and the magnet remains polarized.

In this state, the magnet has similar properties to that of an energized electromagnet wound on an iron core. The sum of the effects of the electron-currents in the atoms being similar to the action of the current flowing in an electromagnet. Energy is stored in the magnet, up to half of which can be made available in the space surrounding the magnet, or concentrated by pole pieces into a specific air gap.

The field in which this external energy is stored can be used in a variety of ways. These ways can be classified according to the type of use. When the magnet is fixed, it can exert forces on other magnets or soft magnetic materials, and on moving electrical charges. The magnet itself can, in turn, be subjected to a force from another magnetic field, as in the compass. Magnet applications are grouped in four categories in the following table.

Function	Applications
Conversion between electrical and mechanical energy	Electric motors, dynamos, loudspeakers, microphones, eddy-current brakes, magnetos, moving-coil meters, speedometers.
Exertion of a force on a magnetic material	Relays, couplings, bearings, clutches, magnetic chucks and clamps, magnetic separators, door catches and seals, magnetic displays and charts.
Alignment of the magnet in an external field	Compasses, moving-magnet meters (some ammeters), positioning mechanisms (some stepper motors).
Exertion of a force on moving electric charges	Magnetrons, travelling-wave tubes, some cathode ray tubes, some power klystrons, Hall effect devices, some image intensifiers.

In addition to these applications, permanent magnets are also used to bias soft ferrites to secure gyromagnetic effects in isolators and circulators for microwave applications.

Thus a permanent magnet is essentially a device in which energy can be stored, without the continuous resistive power losses which are inescapable with normal electromagnets. The use of a permanent magnet represents a saving of energy, power dissipation, which aspect is of growing importance at the present time. The use of switchable permanent magnets in cranes and other lifting devices reduces power consumption while adding built-in, fail-safe security.

INTRODUCTION

Permanent magnets - either isotropic* or anisotropic* - can be classified as being basically either

metal alloy
ceramic material or
plastic-bonded ceramic material.

The table shows the class to which each of our materials belongs.

	metal alloys	ceramic materials	plastic-bonded ceramic materials
isotropic*		Ferroxdure	Ferroxdure
anisotropic*	Ticonal	Ferroxdure	Ferroxdure

The most obvious differences between the groups are that the Ferroxdure magnets are characterized by high values of coercivity and resistivity while Ticonal magnets possess higher values of remanence and BH product.

Ferroxdure is therefore most suitable for applications in which demagnetizing influences (either from external sources or resulting from the use of short magnets) are large, and in high frequency applications.

Ticonal is particularly suitable for applications in which a high magnetic energy is required.

The isotropic materials in general are inferior in magnetic properties to the anisotropic ones but are particularly suitable for applications in which multipole magnets are to be used or where less expensive magnets are necessary giving a reasonable performance.

The plastic-bonded Ferroxdure magnets combine the characteristic magnetic properties of ceramic Ferroxdure (on a lower level) with the mechanical properties of the plastic material used. These magnets have opened a new field of applications, especially where the price is of prime importance.

Each of the permanent magnet materials is manufactured in a variety of grades possessing different properties that result from differences in composition and treatment.

* Isotropic materials can be magnetized equally well in any direction. Anisotropic materials have optimal magnetic properties in one direction only.

SURVEY OF PERMANENT MAGNET MATERIALS

GENERAL NOTES

Units

The quantities are expressed in SI units with c. g. s. units in brackets.

Typical values

The term typical values ("typ.") denotes a value which frequently occurs. Typical values enable the 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:

1. The name of the material: Ferroxdure (FXD) or Ticonal.
2. A block of one to three figures which relate approximately to the BH_{max} value of the grade. With plastic-bonded Ferroxdure the block starts with a letter indicating the plastic material used for bonding, as follows:

   P = flexible thermoplastic material
   SP = rigid thermoplastic material
   D = rigid thermosetting material

   Where applicable, the block has a suffix F indicating that it is a flame retardant material, to UL94V-1.
3. Two pairs of figures divided by a stroke, indicating the typical values of B_r and H_{cJ} respectively.
   (These are a recent addition which eventually will replace the first set of figures.)

PLASTIC - BONDED FERROXDURE - Magnets from SP5, SP10, SP50 and SP130 are produced by injection moulding, from P30 and P40 by extruding and from D55 by pressing and hardening.

Material designation and approximate chemical composition	Max. BH product		Remanence		Coercivity		Polarization coercivity		B and H at $(BH)_{max}$		Saturation field strength
	$(BH)_{max}$ kJ/m³ (MGsOe)		Br mT (Gs)		H_{cB} kA/m (Oe)		H_{cJ} kA/m (Oe)		B_d mT (Gs)	H_d kA/m (Oe)	H_{sat} kA/m (Oe)
	typ.	min.	typ.	min.	typ.	min.	typ.	min.	typ.	typ.	typ.
Isotropic											
FXD SP5F-6, 5/19 75% $BaFe_{12}O_{19}$ 25% thermoplastic	0,7 (0,088)		65 (max.) (650 max.)	60 (600)	50 (628)	45 (565)	190 (2390)				800 (10 000)
FXD SP10-8/19; SP10F 75% $BaFe_{12}O_{19}$ 25% thermoplastic	0,9 (0,11)	0,8 (0,1)	80 (800)	75 (750)	58 (729)	54 (679)	190 (2390)				800 (10 000)
FXD P30-13/19 85% $BaFe_{12}O_{19}$ 15% thermoplastic	2,8 (0,35)	2,4 (0,30)	125 (1250)	115 (1150)	88 (1110)	84 (1050)	190 (2390)				800 (10 000)
FXD P40-15/19; P40F 90% $BaFe_{12}O_{19}$ 10% thermoplastic	3,6 (0,45)	3,2 (0,4)	145 (1450)	135 (1350)	96 (1210)	88 (1110)	190 (2390)				800 (10 000)
FXD SP50-16/19 93% $BaFe_{12}O_{19}$ 7% thermoplastic	4,4 (0,55)	4 (0,5)	155 (1550)	150 (1500)	104 (1310)	100 (1260)	190 (2390)				800 (10 000)
FXD D55-17/22 95% $BaFe_{12}O_{19}$ 5% thermosetting	4,8 (0,6)	4,4 (0,55)	170 (1700)	165 (1650)	112 (1410)	104 (1310)	220 (2760)				800 (10 000)
Anisotropic											
FXD SP130-24/24 90% $BaFe_{12}O_{19}$ 10% thermoplastic	11 (1,4)	10 (1,3)	240 (2400)	230 (2300)	175 (2200)	167 (2100)	240 (3020)				800 (10 000)

The suffix 'F' after a material designation denotes flame retardant material to UL94 V-1.

FERROXDURE (ferrite) - Magnets are pressed and sintered, and may be ground. Ferroxdure 100 can also be extruded.

Material designation and approximate chemical composition	Max. BH product $(BH)_{max}$ kJ/m³ (MGsOe) typ.	Max. BH product $(BH)_{max}$ kJ/m³ (MGsOe) min.	Remanence B_r mT (Gs) typ.	Remanence B_r mT (Gs) min.	Coercivity H_{cB} kA/m (Oe) typ.	Coercivity H_{cB} kA/m (Oe) min.	Polarization coercivity H_{cJ} kA/m (Oe) typ.	Polarization coercivity H_{cJ} kA/m (Oe) min.	B and H at $(BH)_{max}$: B_d mT (Gs) typ.	B and H at $(BH)_{max}$: H_d kA/m (Oe) typ.	Saturation field strength H_{sat} kA/m (Oe) min.
Isotropic											
FXD 100-22/22 $BaFe_{12}O_{19}$	7,6 (0,95)	7,2 (0,9)	220 (2200)	210 (2100)	135 (1700)	130 (1630)	220 (2760)				typ. 800 (typ. 10 000)
Anisotropic											←
FXD 270-34/33 $SrFe_{12}O_{19}$	21,5 (2,7)	19,9 (2,5)	340 (3400)	330 (3300)	263 (3300)	247 (3100)	334 (4200)	318 (4000)	165 (1650)	131 (1650)	1114 (14 000)
FXD 330-37/25 $SrFe_{12}O_{19}$	25,5 (3,2)	23,9 (3,0)	370 (3700)	360 (3600)	239 (3000)	223 (2800)	247 (3100)	231 (2900)	180 (1800)	143 (1800)	876 (11 000)
FXD 360-39/21 $SrFe_{12}O_{19}$	28,7 (3,6)	27,1 (3,4)	390 (3900)	380 (3800)	199 (2500)	183 (2300)	207 (2600)	191 (2400)	200 (2000)	143 (1800)	716 (9000)
FXD 380-39/28 $SrFe_{12}O_{19}$	27,8 (3,5)	26,2 (3,3)	390 (3900)	380 (3800)	263 (3300)	247 (3100)	279 (3500)	263 (3300)	188 (1875)	148 (1875)	955 (12 000)
FXD 300-40/16 $BaFe_{12}O_{19}$	29,5 (3,7)	27,8 (3,5)	400 (4000)	390 (3900)	159 (2000)	143 (1800)	163 (2050)	147 (1850)	240 (2400)	123 (1550)	557 (7000)

Other grades can be produced on special request.

TICONAL (anisotropic alloy) - Magnets are cast, and may be ground.

Material designation and approximate chemical composition	Max. BH product		Remanence		Coercivity		B and H at $(BH)_{max}$		Saturation field strength
	$(BH)_{max}$ kJ/m^3 (MGsOe)		Br mT (Gs)		H_{cB} kA/m (Oe)		B_d mT (Gs)	H_d kA/m (Oe)	H_{sat} kA/m (Oe)
	typ.	min.	typ.	min.	typ.	min.	typ.	typ.	min.
Ticonal **440-116/5,6** 24% Co, 15% Ni, 7,9% Al, 3% Cu, 1% Nb, rest Fe	35,0 (4,4)	32,6 (4,1)	1160 (11 600)	1100 (11 000)	55,7 (700)	54,1 (680)	800 (8000)	43,8 (550)	239 (3000)
Ticonal **500-125/5,3** 24% Co, 13,8% Ni, 7,6% Al, 3% Cu, 0,45% Nb, rest Fe	40,6 (5,1)	37,4 (4,7)	1250 (12 500)	1200 (12 000)	52,5 (660)	50,1 (630)	1000 (10 000)	40,6 (510)	239 (3000)
Ticonal **550-90/13** 34% Co, 15% Ni, 7,5% Al, 2,5% Cu, 5,5% Nb+Ta+Ti, rest Fe	43,8 (5,5)	39,8 (5,0)	900 (9000)	850 (8500)	123 (1550)	115 (1450)	550 (5500)	79,6 (1000)	478 (6000)
Ticonal **570-132/5,2** 24% Co, 13,8% Ni, 7,6% Al, 3% Cu, 0,45% Nb, rest Fe	45,4 (5,7)	42,2 (5,3)	1320 (13 200)	1260 (12 600)	51,7 (650)	49,4 (620)	1070 (10 700)	42,2 (530)	239 (3000)
Ticonal **600-131/5,4** 26% Co, 13,8% Ni, 7,8% Al, 3% Cu, 0,3% Nb, rest Fe	47,8 (6,0)	43,8 (5,5)	1310 (13 100)	1260 (12 600)	54,1 (680)	51,7 (650)	1090 (10 900)	43,8 (550)	239 (3000)

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.

Magnets 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.

A fifth group of magnets accomplish special effects such as the Hall effect, magnetic resistance and nuclear magnetic resonance.

EXAMPLES OF INDUSTRIAL USE

There is practically no industrial sector in which some means equipped with permanent magnets is not used. A few examples:

The ceramics industry	- separators.
Shipbuilding	- welding terminals.
Navigation	- attachment of rust-preventing anodes.
Typography	- magnetic cylinders for iron/rubber blocks.
Mining	- separators; non-skid cable wheels.
Rolling mills	- conveyors; plate lifters.
Office machines	- paper guides and holders.
Cattle raising	- garbage separation.
Foods and allied products	- separators.
Oil industry	- filling machines.
Machining	- chucks.
Miscellaneous	- clocks and watches.

SURVEY OF APPLICATIONS

Electrotechnical

Measurement and control

Galvanometers
Ammeters
Voltmeters
Fluxmeters
Photometers
Tachometers
Speedometers
Kilowatt-hour meters
Recording instruments
Vibrographs
Oscillographs
Cardiographs
Seismographs
Pressure gauges

Switchgear

Arc suppression

Motors and generators

Alternators
Magnets for IC engines
Cycle dynamos
Hand dynamos
Hysteresis motors
Synchronous motors
Clock motors
D.C. shunt motors
Screenwiper motors
Fan motors
Toy motors
Aeronautic motors and generators
Gyroscopes
Electrodynamic tachometers
Pulse generators

Electro-acoustics and communications

Tone generators
Telephones
Hearing aids
Cutting heads
Pick ups
Stringed instruments
Tape recorders
Dictaphones
Magnetrons
UHF directional isolators

Radio and TV

Loudspeakers
Transformers
Vibratory convertors
Picture tubes
Focusing units

Applied physics

Scientific

Magnetostrictive devices
Résonance measurements
Resistance modification

Industrial

Compass compensation
Material selection
Hardness testing
Film-thickness measurement
Crack detection
Polarity indicators
Water softening

General

Compasses
Coin check in vending machines
Replacement of springs
Magnetizing yokes

SURVEY OF APPLICATIONS (continued)

Mechanical

Measurement and control

Flow meters
Level indicators
Maximum thermometers
Thermocouples
Eddy-current brakes
Valves

Consumer goods

Visual demonstration
Calendars
Card-index systems
Guides of many kinds
Lamp holders
Inspection lamps

Switchgear and connectors

Switches
Microscopy
Buttons
Couplings
Pumps
Calorimeters
Mixers
Drives through a wall
Frictionless drives
Centrifugal couplings
Polarized contacts

Industrial

Holding devices
Plate lifters
Conveyors
Drain plugs
Filters
Separators
Floor cleaners
Indicating boards
Frictional brakes
Hammers
Screwdrivers
Refrigerators

Miscellaneous

Accessories

Cigarette holders
Name plates
Parking plates
Soap holders
Tin openers

Medical

Extraction of steel splinters
Blood testing
Prothesis

Toys

Toys of all kinds
Draughtsmen
Chessmen

Sundries

Magnetic drags
Veterinary uses

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, the older c.g.s. unit system is still in common use with magnet engineers. In common with the rest of the section, 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

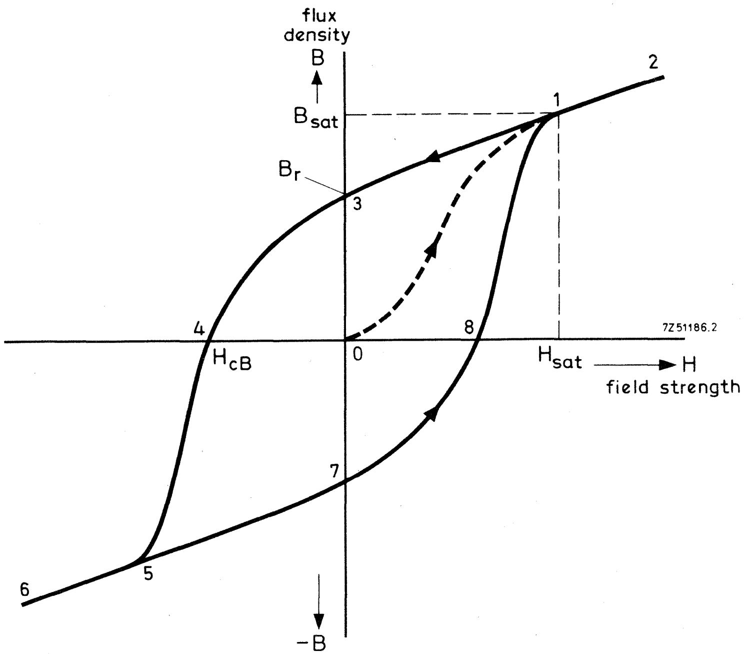


Fig. 1. Saturation hysteresis loop, variation of flux density with applied magnetic field strength H.

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 of that of 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, which is identical in its properties to the second.

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.

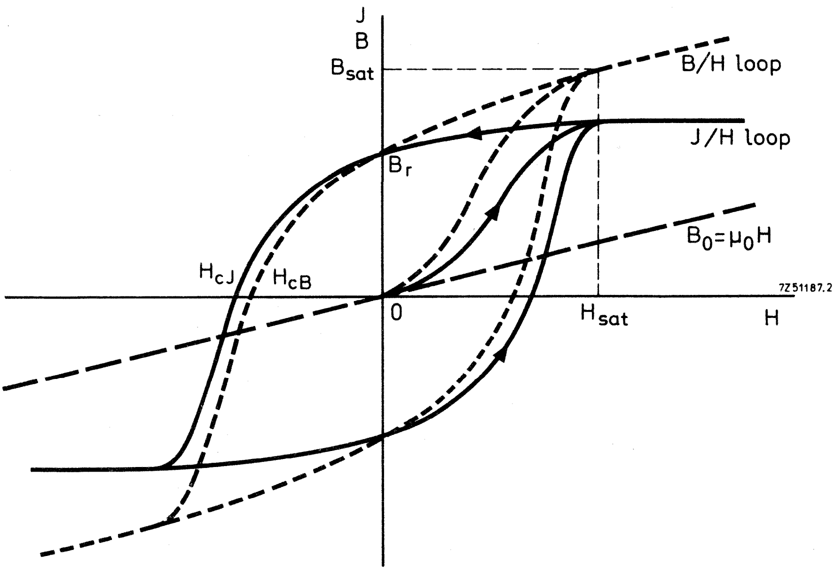


Fig. 2. Comparison of variations of flux density and polarization with applied field strength.

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, therefore, an important criterion 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.).

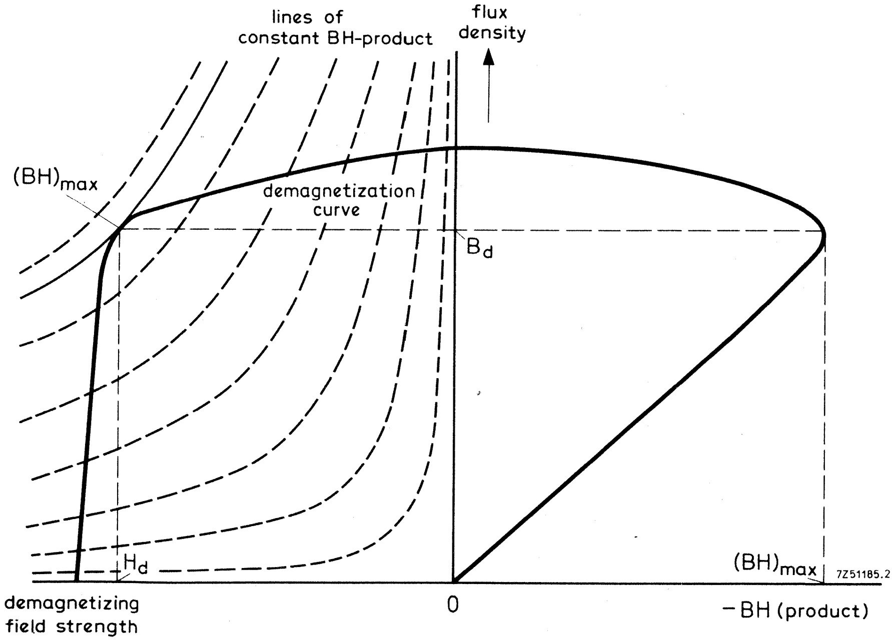


Fig. 3. Demagnetization curve with contours of constant BH-product, and BH-product curve.

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.

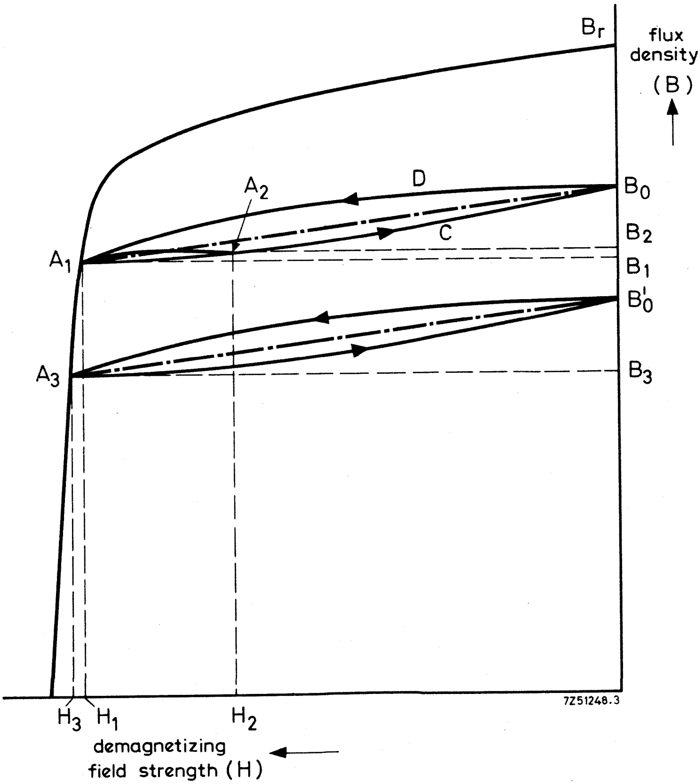


Fig. 4. Recoil lines.

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.

Recoil operation of this kind is found in applications involving varying applied fields - electric motors and generators in particular. Moreover, magnet assemblies that are required to be particularly stable, or which may be exposed to reverse fields during operation, are operated on recoil lines. Such assemblies are, after saturation, exposed to a demagnetizing field slightly greater than the maximum to be experienced in use. The magnet will then work somewhere on a recoil line and external fields will not cause additional demagnetization; the working point will move along that recoil line only.

TEMPERATURE COEFFICIENT

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

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

$$\alpha_{HcB} = \frac{1}{H_{cB}} \times \frac{dH_{cB}}{dT} \times 100\ \%/^oC.$$

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 magnet 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 minimum when the magnet is operated at its $(BH)_{max}$ point. At this point, the energy available from the magnet is maximum. Of this energy, only a fraction, usually less than half, can be concentrated in the useful air gap. The 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.

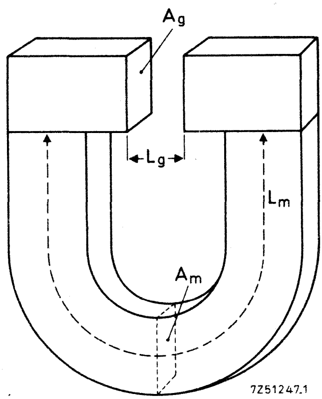


Fig. 5. Simple magnetic circuit.

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

$$H_m L_m = qH_g L_g. \qquad (2)$$

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. The table is a guide to leakage factors of typical systems.

Application	approximate leakage factor
Loudspeaker with Ticonal centre-pole magnet, 19 mm (3/4 in) voice coil, up to 650 mT (6,5 kGs)	2
Loudspeaker with Ticonal centre-pole magnet, 25 mm (1 in) voice coil, up to 800 mT (8 kGs)	2
Loudspeaker with Ferroxdure ring magnet, 36 mm ($1\frac{1}{2}$ in) voice coil, up to 1,5 T (15 kGs)	2
Loudspeaker with Ferroxdure ring magnet, 61 mm ($2\frac{1}{2}$ in) voice coil, up to 1,45 T (14,5 kGs)	2
Loudspeaker with Ticonal ring magnet, 25 mm (1 in) voice coil, up to 1,2 T (12 kGs)	3
Loudspeaker with Ticonal ring magnet, 25 mm (1 in) voice coil, up to 1,6 T (16 kGs)	6
Loudspeaker with Ticonal ring magnet, 36 mm ($1\frac{1}{2}$ in) voice coil, up to 1,6 T (16 kGs)	5
Moving-coil meter using Ticonal rectangular magnets	3
Moving-coil meter using Ticonal semi-circular magnets	2
Moving-coil meter using Ticonal centre-pole magnet	1,5
Motors using Ferroxdure segments	1,1
Motors and generators, Ticonal two-pole type	2
Motors and generators, Ticonal four-pole type	4

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

$$A_mL_m = V_m = \frac{pq\mu_0 H_g^2\, gV_g}{B_mH_m} \tag{5}$$

where V_m and V_g are the magnet and gap volumes respectively. The term B_mH_m is the energy product of the material. It can be seen from eq. (7) 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

$$B_m = \frac{pA_gL_m}{qA_mL_g}\,\mu_0 H_m. \tag{6}$$

For 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.

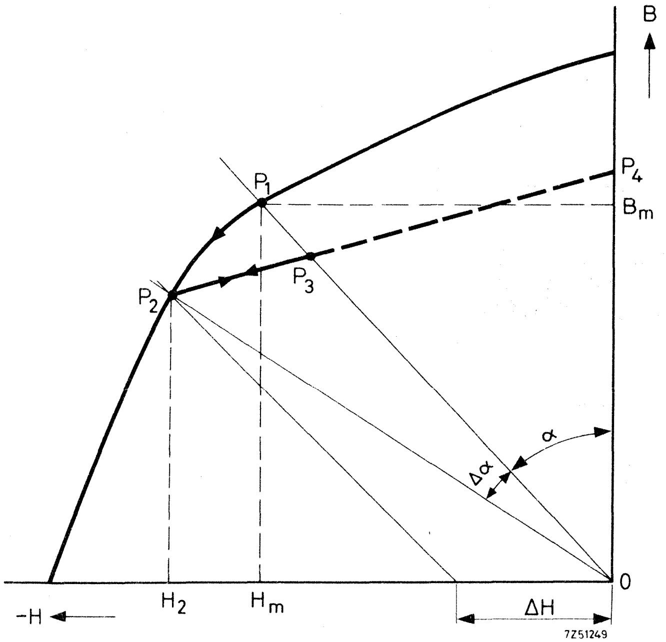


Fig. 6. Demagnetization curve with load line and recoil line.

Recoil operation and stabilization

Operation on the demagnetization curve itself does not ensure stability in the presence of external magnetic fields, varying temperatures and changing air gaps. Where particularly stable operation is required, the magnet should be operated on a recoil line.

An increase of air gap implies an increase of reluctance and thus a decrease of permeance $\Delta\alpha$. If the permeance reduces by $\Delta\alpha$, the working point of the magnet will change from P_1 to P_2. Similarly, if a reverse field ΔH is applied, the load line will be moved to a parallel position, also to intersect the demagnetization curve at P_2, as shown in Fig. 6. Removal of the demagnetizing influence (larger air gap or ΔH) will cause the working point to move up the recoil line to point P_3.

The changes due to temperature result from a change in the shape of the demagnetizing curve itself corresponding to the change in B_r and H_{cB}. The effect is similar to that of a change in air gap.

Where a particularly stable field is required, it is normal to arrange for the magnet to work above the knee of the demagnetization curve. As explained earlier, the slope of recoil lines is about the same as the slope of the demagnetization curve at B_r. In fact, the slope between B_r and the knee is usually fairly constant, and recoil lines originating above the knee coincide with or run close to the main demagnetization curve. Thus, until the demagnetizing influence becomes large enough to force the working point below the knee, the flux losses will be minimized.

SYMBOLS

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	=	permeabilitv/normal permeability
μ_{rec}	=	recoil permeability
ϕ	=	magnetic flux/total flux

CONVERSION OF UNITS

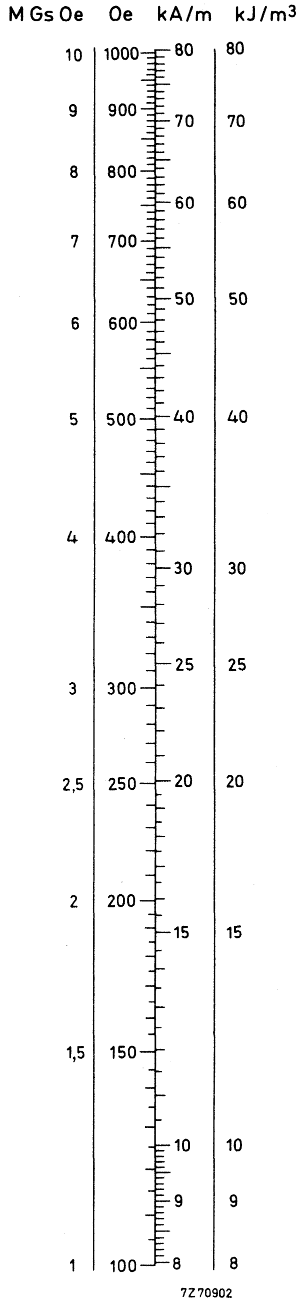
S.I. units →	c.g.s. units	
1 T (tesla) = 1 Wb/m^2 = 1 Vs/m^2	= 10^4 Gs = 10 kGs	
1 mT	= 10 Gs	
1 A/m	= $4\pi \times 10^{-3}$ Oe = 0,01257 Oe	*
1 kA/m	= 4π Oe = 12,57 Oe	*
1 Wb (weber) = 1 Vs = 1 Tm^2	= 10^8 Mx	
1 μWb	= 100 Mx	
$\mu_0 = 4\pi \times 10^{-7}$ H/m = 1,257 μH/m	μ_0 can be replaced by 1 Gs/Oe	
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 (joule) = 1 Ws = 1 Nm	= 10^7 erg	
1 N (newton) = 1 kgm/s^2 = = 0, 1019 kilogramme-force	= 10^5 dynes	

S.I. 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:

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

*) For CONVERSION SCALE turn page.



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

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.

SIZE AND SHAPE TOLERANCES

GENERAL

In the interest of rational and economical manufacture, tolerances should be as wide as possible to avoid additional machining. Tolerances shown in this data sheet 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

Sintered Ferroxdure 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	± 2,5 %
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

Plastic-bonded Ferroxdure 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

SP and D grade magnets	
below 10 mm	± 0,05 to 0,1 mm
10 mm to 30 mm	± 0,1 to 0,2 mm
above 30 mm up to 60 mm	± 0,2 to 0,3 mm
above 60 mm	± 0,5%

PLASTIC-BONDED FERROXDURE (continued)

P grade magnets	
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: P grade 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	$\pm 1^{\circ}$
between a ground and a cast or shell-moulded face	$\pm 3^{\circ}$
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 R 1101-1969 "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.

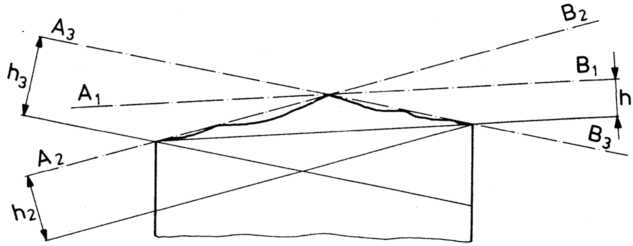


Fig. 1

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.

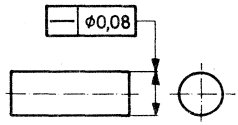
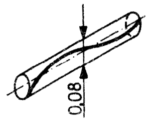
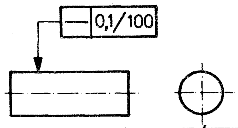
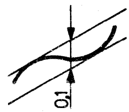
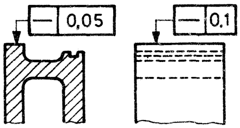
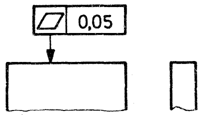
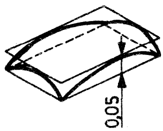
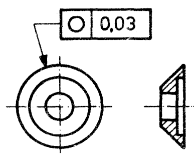
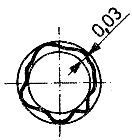
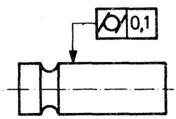
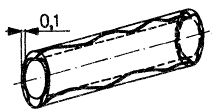
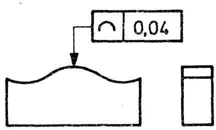
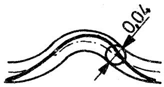
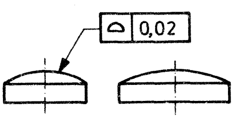
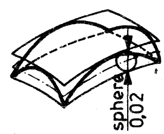
2. In some cases it may also be desirable to indicate the position of certain points which will possibly form a temporary datum feature for both manufacture and inspection.

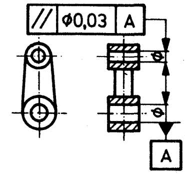
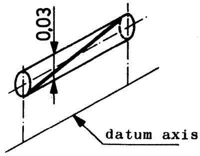
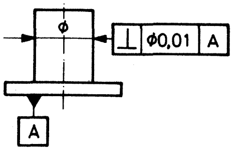
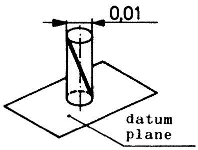
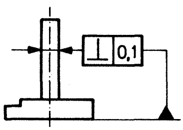
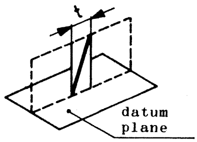
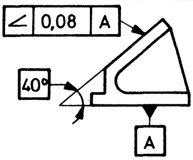
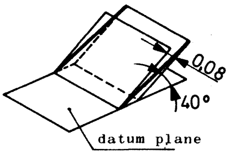
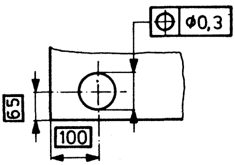
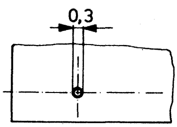
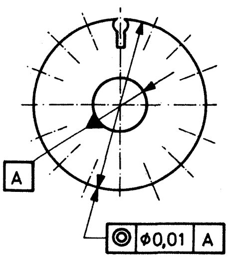
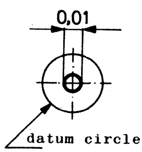
3. Symbols

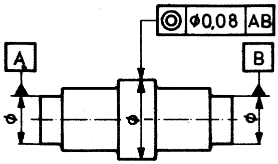
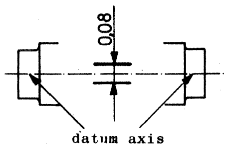
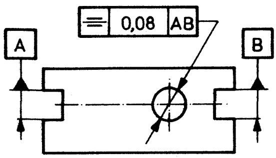
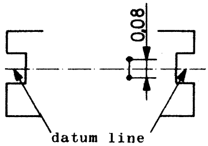
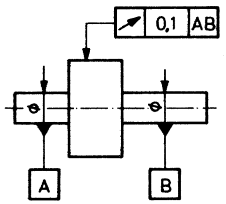
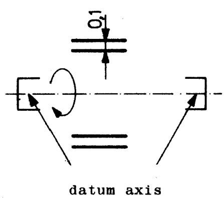
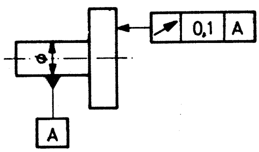
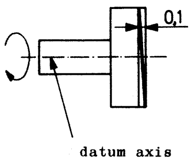
The following symbols represent the types of characteristics to be controlled by the tolerance.

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 toler-anced	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 toleranced	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 :

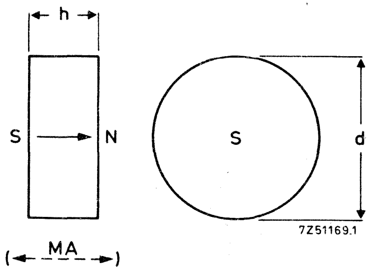
For the magnetic axis, or the preferred direction of magnetization in unmagnetized anisotropic magnets : the symbol ←-MA-→.

For the direction of magnetization in magnetized magnets : the symbol → N or S → N.

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

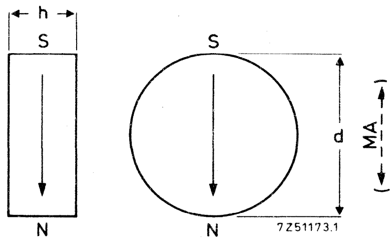
Magnetization for isotropic and anisotropic magnets

A



axial.

B



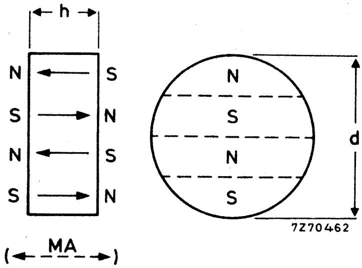
diametrical
(also to be used for rings and cylinders).

NOTE

When ordering, please give the alphabetic designation and page date, e.g.: magnetization B, August 1976. Orientation of unmagnetized anisotropic magnets can be indicated by the prefix U, e.g.: orientation UB, August 1976. (Unmagnetized isotropic magnets : letter U.)

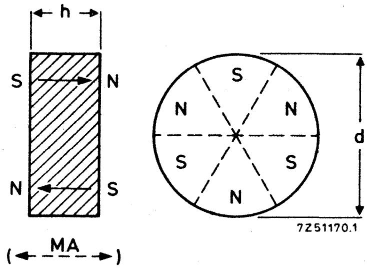
Magnetization for isotropic and anisotropic magnets (continued)

C



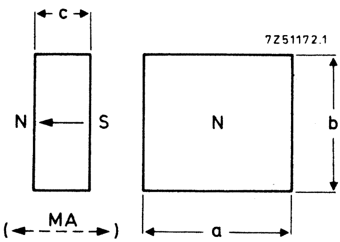
axial, n-poles,
neutral zones in parallel
(in the example n = 4).

D



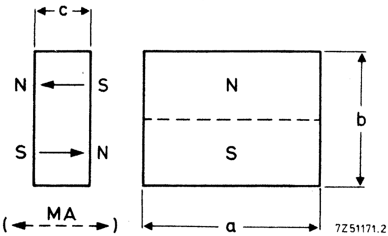
axial, n-poles,
neutral zones radial
(in the example n = 6).

E



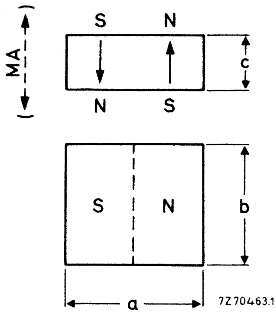
perpendicular to a x b.

F



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

G

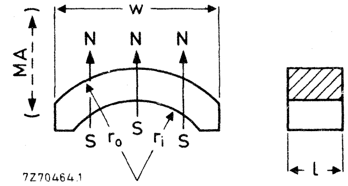


perpendicular to a x b, n poles,
neutral zone parallel to **side b**
(in the example n = 2).

NOTE

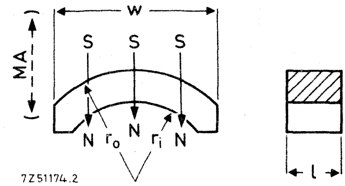
When ordering, please give the alphabetic designation and page date, e.g.: magnetization C, August 1976, 2 poles. Orientation of unmagnetized magnets can be indicated by the prefix U, e.g.: orientation UC, August 1976, 2 poles. (Unmagnetized isotropic magnets: letter U.)

H



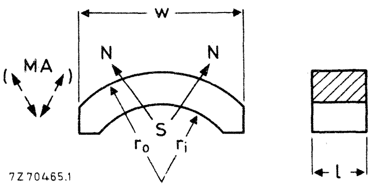
parallel (also called diametrical),
S-pole inside.

J



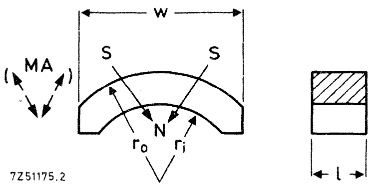
parallel (also called diametrical),
N-pole inside.

K



radial, S-pole inside.

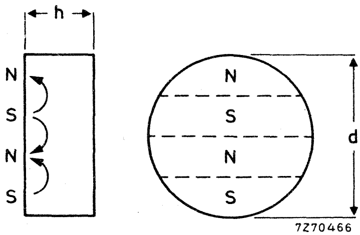
L



radial N-pole inside.

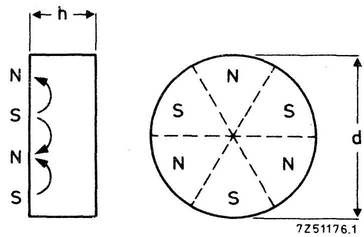
Magnetization for isotropic magnets only

M



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

N



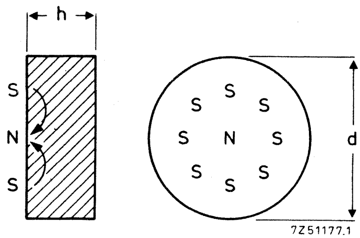
lateral, n pole sectors on one face only,
(in the example n = 6).

NOTES

1. Magnetizations M and N can also be applied to both faces.
2. 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").
3. When ordering, please give the alphabetic designation and page date, e.g. magnetization M, August 1976, 4 poles. Orientation of unmagnetized anisotropic magnets can be indicated by the prefix U, e.g.: orientation UH, August 1976. (Unmagnetized isotropic magnets: letter U.)

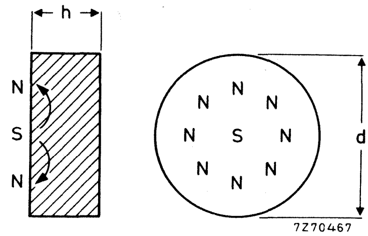
Magnetization for isotropic magnets only (continued)

O



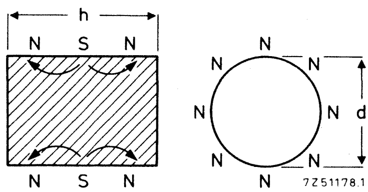
lateral, 2 poles on one face only, centred N-pole with concentric S-pole.

P



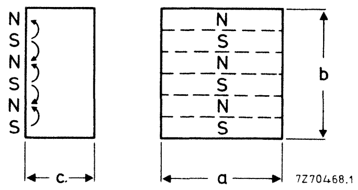
lateral, 2 poles on one face only, centred S-pole with concentric N-pole.

Q



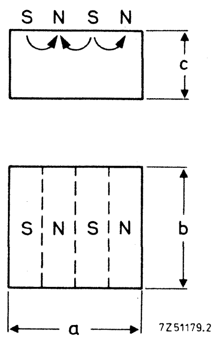
lateral, n annular poles (in the example n = 3).

R



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

S

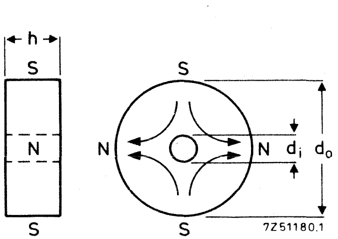


lateral, n poles on one a x b face, poles parallel to **side b** (in the example n = 4).

NOTES

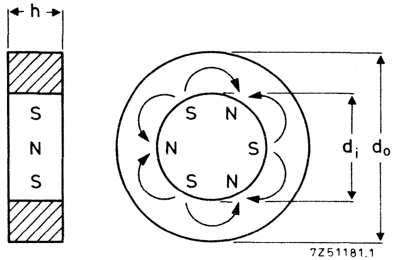
1. Magnetizations O, P, R and S can also be applied to both faces.
2. When magnetizations Q, R or S are required with an odd number of poles the polarity of the centre pole should be specified (e.g. N, S, or "don't care").
3. When ordering, please give the alphabetic designation and page date, e.g.: magnetization R, August 1976, 4 poles. (Unmagnetized isotropic magnets : letter U.)

T



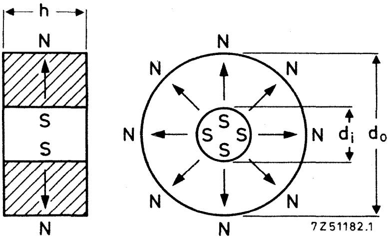
lateral, n poles on outer circumference,
neutral zones axial
(in the example n = 4).

W



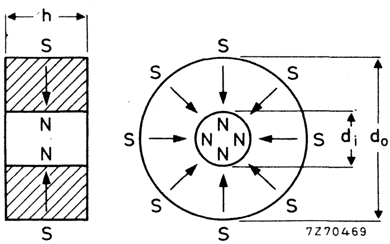
lateral, n poles on inner circumference,
neutral zones axial
(in the example n = 6).

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 MAGNETIZING AND DEMAGNETIZING

PRE-MAGNETIZED MAGNETS

The demagnetization curves of Ferroxdure materials (with the exception of FXD300 and FXD360) have a long straight section. Magnets made from these materials can therefore be subjected to strong demagnetization, in some cases until $B = 0$, and yet recoil to nearly their original flux density after the demagnetizing influence is removed.

MAGNETIZATION

Permanent magnets made from materials other than Ferroxdure (see above) should generally be magnetized only after being built into their magnetic circuit, since their demagnetization curves permit little self-demagnetization. Furthermore, magnetization after assembly considerably simplifies handling and the removal of magnetic particles from the magnet.

It is essential that the field strength used for magnetizing the magnet is not less than the specified field strength (H_{sat}), otherwise the maximum performance of the material will not be achieved.

Note: A saturation field strength of h kA/m corresponds with 10h ampere-turns per cm length of magnet.

If the magnet is assembled in a circuit which shields the magnet, then the number of ampere-turns of the magnetizing equipment should be high enough also to saturate the shielding circuitry. For complicated magnetic circuits, advice should be sought.

The required magnetizing current can be obtained from rectifiers, half-cycle pulse magnetizers, storage accumulators, capacitor discharge magnetizers or motor generators. To obtain the maximum effect from the magnetizing current, the magnetic circuit should be adapted to the magnetizing equipment. For instance, for pulse magnetization a heavy laminated iron yoke is required to minimize eddy currents.

DEMAGNETIZATION

Partial demagnetization of permanent magnets may be necessary for stabilization purposes. Metal magnets not larger than 1 kg in weight can usually be demagnetized using the 50 Hz mains electricity supply. The partial demagnetization is achieved by a controlled alternating field; the magnet is placed in an open coil in which the alternating current is controlled by means of a variable transformer.

Complete demagnetization is often undertaken to facilitate handling and assembly. Complete demagnetization of sintered Ferroxdure magnets is best produced by raising the temperature of the magnet beyond its Curie temperature (about 450 ^{o}C). This heating process will not in any way affect the magnetic properties of the ceramic material, but, naturally, cannot be applied to plastic-bonded Ferroxdure, where complete demagnetization has to be effected by alternating current.

Complete demagnetization of Ticonal is achieved in a similar way to partial demagnetization, although considerably more power is required. It is generally more convenient to connect the supply directly to the coil and to move the magnet slowly through the coil.

DEMAGNETIZATION (continued)

Theoretically, alternating fields of about 15 kA/m (about 2000 Oe) peak value are sufficient to demagnetize Ticonal magnets, but the effectiveness of the field is considerably reduced by the screening by associated iron circuits. The exact extent of this screening is difficult to calculate and, in practice, the quickest method of finding the actual field and current requirements is by experiment.

Under no circumstances should Ticonal be demagnetized by raising the temperature of the magnet above the Curie temperature (about 850 ^{o}C). Even raising the temperature above 600 ^{o}C will permanently destroy the magnetic performance.

Demagnetization of very large magnets is a special problem, and advice should be sought in each case.

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 the working conditions for which the magnet is intended. For this reason the inspection of any type of magnet should be laid down in concert 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 of which photographs 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 is 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 standards may either have
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.

FERROXDURE

INTRODUCTION

The largest volume production of industrial permanent magnet materials is in the ferromagnetic 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 more than 320 kA/m (4000 Oe) - and such high electrical resistivity that it may be considered to be 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.
The relatively low induction values require larger cross-sections than for conventional permanent magnets.

These properties have led to new applications and new designs for existing 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.

Ferroxdure has a low specific gravity which gives it a weight advantage over other permanent magnet materials.

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

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 pressing 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 from which the pieces emerge with a ceramic structure and a black colour.

INTRODUCTION (continued)

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 about 15% of the dimensions of the pressed form.

Plastic-bonded Ferroxdure, isotropic and anisotropic permanent magnets are manufactured starting 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 narrow size tolerances without being machined (SP and D-grades);
- 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 and D-grades).

Thus plastic-bonded Ferroxdure magnets can be useful where permanent magnets have been unsuitable till now for either 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.
Ferroxdure D55	Hard and rigid; shaped by pressing and hardening.

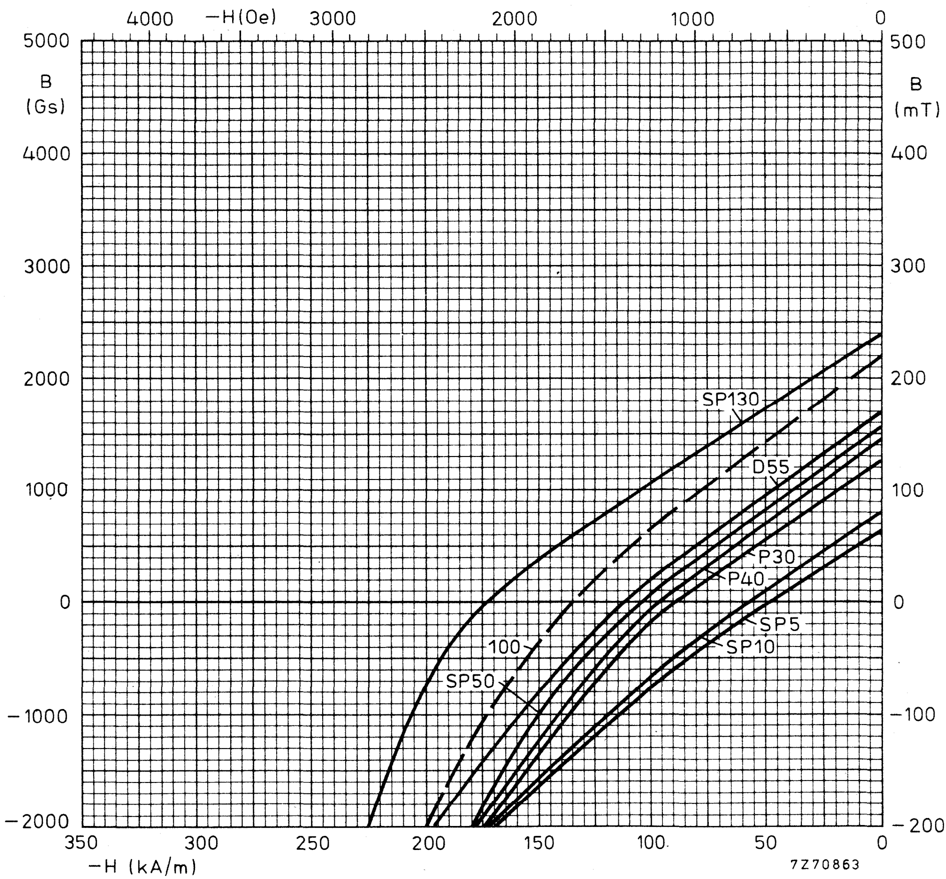
Anisotropic plastic-bonded Ferroxdure

Ferroxdure SP130	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 either for applications where high magnetic values are not essential or where isotropic properties are required.



Typical demagnetization curves at 25 °C of plastic-bonded Ferroxdure
(and of Ferroxdure 100 for comparison)

Anisotropic sintered Ferroxdure

→ Ferroxdure 270, 330 and 380

The materials have high values of coercivity and are therefore ideal for dynamic applications where strong demagnetizing influences are encountered, such as radially oriented segments for use in d.c. motors.

Ferroxdure 300

This material has the highest value for B_r and is therefore especially suitable for static applications such as in loudspeaker magnet systems.

If dismounting requirements and/or highest flux requirements are imposed, it is recommended (due to the lower coercivity) that the magnet be magnetized in its system.

→ Ferroxdure 360

The magnetic properties of this material are between those of Ferroxdure 330 and Ferroxdure 300, and it is therefore suitable for use in fly-wheel magnetos and flat loudspeaker magnet systems.

CHEMICAL RESISTANCE

Sintered Ferroxdure is not attacked by:
- a 30% solution of sodium chloride,
- a 50% solution of benzol and trichlorethylene,
- petrol,
- nitric acid,
- a 50% solution of nitric acid,
- acetic acid,
- cresol,
- phenolic solutions,
- sodium-sulphate solution.

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

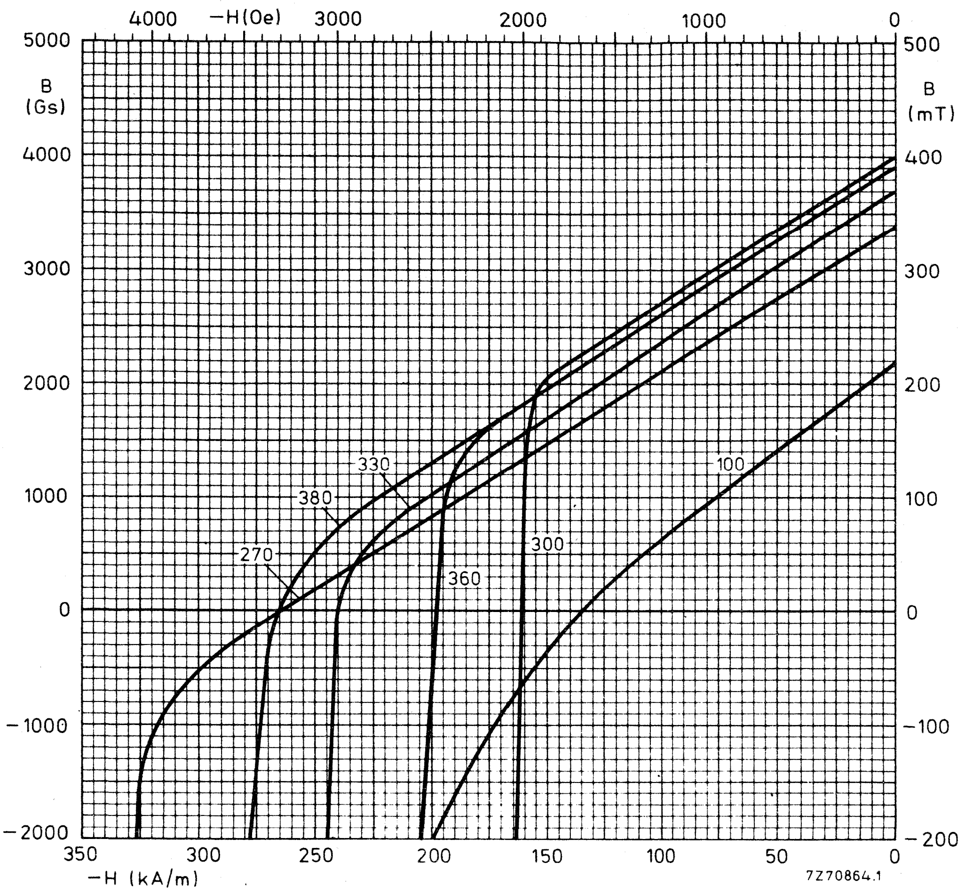
It is attacked by concentrated hydrochloric acid.

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 of most metals:

Sintered Ferroxdure	8 to 15 ppm/^{o}C
Steel	11 to 20 ppm/^{o}C
Brass	18 ppm/^{o}C



Typical demagnetization curves at 25 °C of sintered Ferroxdure

APPLICATIONS

Some applications in which Ferroxdure permanent magnets are commonly used today are:

- Loudspeakers
- Bicycle dynamos
- Generators and magnetos
- Synchronous and d.c. motors
- Separators, filters and chucks
- Couplings and sticking devices
- Deflection units and biasing magnets in soft magnetic circuits
- Travelling wave tubes
- Clocks and watches.

Ferroxdure 270, 330 and 380 will, no doubt, further stimulate the use of radially orientated segments in fractional horse power motors:

a) for the automobile industry such as starter motors, screen wiper motors, ventilator motors, screen washer motors and all other motor-equipped devices which make driving more comfortable.

b) in household appliances such as mixers, coffee mills, knives, electric tooth brushes, small vacuum cleaners, washing machines, polishers, etc.

All grades with almost straight demagnetization curves are used in sandwich type devices and professional applications such as travelling wave tubes, watches, magnetos, alternators, generators, synchronous motors, filters and separators.

MAGNETIC TEMPERATURE COEFFICIENTS

All grades of Ferroxdure have a negative temperature coefficient of remanence of about 0, 2 %/°C and a positive temperature coefficient of coercivity of about 0, 4 %/°C. For isotropic Ferroxdure, the effect of temperature on magnetic performance is practically reversible, i.e. after heating or cooling, the magnet will return to the point on the BH curve at which it started. Permanent demagnetization occurs only on heating a magnet to a temperature above the Curie point.

Where anisotropic Ferroxdure magnets are to be 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.

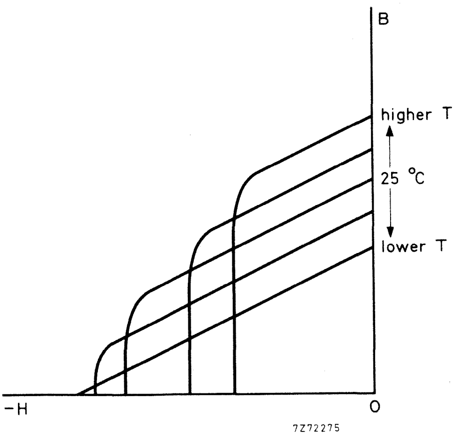


Fig. 1

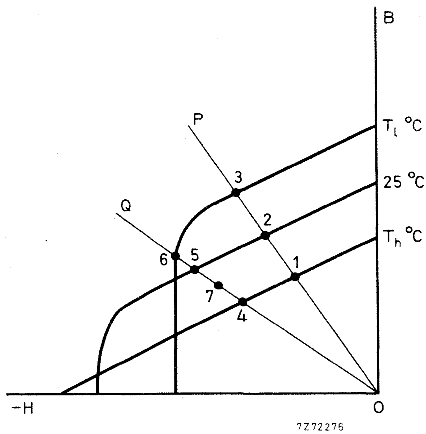


Fig. 2

The point on the demagnetization curve at which a magnet works 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 magnet will work at 2 at 25 °C, 1 at some higher temperature and 3 at some lower temperature. All three points are on the upper straight line part of the demagnetization curve, and so 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 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 enables the flux (B_{25}) remaining in the magnet to be calculated after the magnet has been cooled to T_ℓ ^oC and warmed-up to 25 ^oC:

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

where B_ℓ is the flux density at a temperature of T_ℓ ^oC. To find B_ℓ it will be necessary to plot the demagnetization curve of the material for a temperature of T_ℓ ^oC, and draw the working line for the magnet. Note: in plotting the demagnetization curves for temperatures other than 25 ^oC, 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 ^oC curve until they intersect. The point of intersection will indicate the position of the new knee.

For high temperature operation, the working line should cut the demagnetization line above the knee at room temperature; thus, as it will continue to do so at rising temperature, flux changes (due to temperature cycling) will 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 D55

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 has dimensions of approximately ϕ30 mm x 20 mm, if a disc, and ϕ30 mm x ϕ22 mm x 12 mm, if a ring.

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

Ferroxdure D55 is a barium ferrite, the main constituent being $BaFe_{12}O_{19}$ with 5% (by weight) of thermosetting material added.

MAGNETIC AND ELECTRICAL PROPERTIES OF THE TEST PIECE [1)]

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

		typ.	min.		typ.	min.	
Remanence	B_r	170	165	mT	1700	1650	Gs
Coercivity	H_{cB}	112	104	kA/m	1410	1310	Oe
Polarization coercivity	H_{cJ}	220		kA/m	2760		Oe
Maximum BH product	$(BH)_{max}$	4,8	4,4	kJ/m³	0,60	0,55	MGsOe
Temperature coefficient of B_r (−20 to + 100 °C)		−0,2		%/°C	−0,2		%/°C
Temperature coefficient of H_{cJ} (−20 to + 100 °C)				%/°C			%/°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 +100 °C the changes in its magnetic properties do not exceed ± 3% of the initial values.

PHYSICAL PROPERTIES

Density	typ.	4 x 10^3 kg/m³	(4 g/cm³)
Coefficient of linear expansion (20 to 90 °C)	typ.	140 ppm/°C	
Maximum permissible temperature (continuous)		150 °C	

1) Measured parallel to the pressing direction.

PHYSICAL PROPERTIES (continued)

Linear shrinkage after 100 h at 150 °C	<	0,1 %
Moisture absorption during storage in water	<	3 % (by weight)

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 ± 5%.
Life test = 177 hours immersed.

MANUFACTURE OF MAGNETS

Magnets can be produced by pressing combined with or succeeded by a thermal hardening process. Turning and milling with special (steel) tools is possible; for grinding diamond tools are necessary, Vibro-Finishing can also be used.

DIRECTION OF MAGNETIZATION

Ferroxdure D55 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.

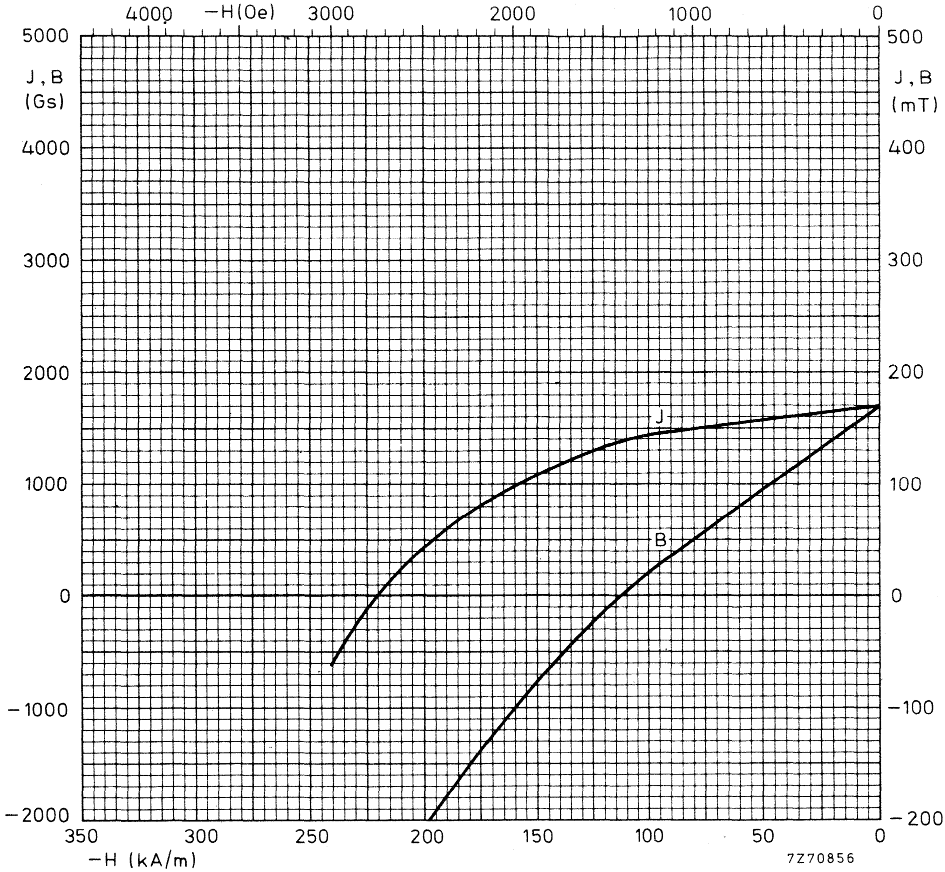
QUALITY AND FINISH

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

APPLICATION

Where permanent magnets having close mechanical tolerances are required and low prices are essential.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



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 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

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/m^3	0,35	0,3	MGsOe
Temperature coefficient of B_r (−20 to +90 °C)		−0,2		%/°C	−0,2		%/°C
Temperature coefficient of H_{cJ} (−20 to +90 °C)				%/°C			%/°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/m^3 (3,1 g/cm^3)

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/cm^2
Diameter of mandrel around which the test piece can be bent without cracking or breaking 1)	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.

1) Broad face in contact with mandrel.

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.

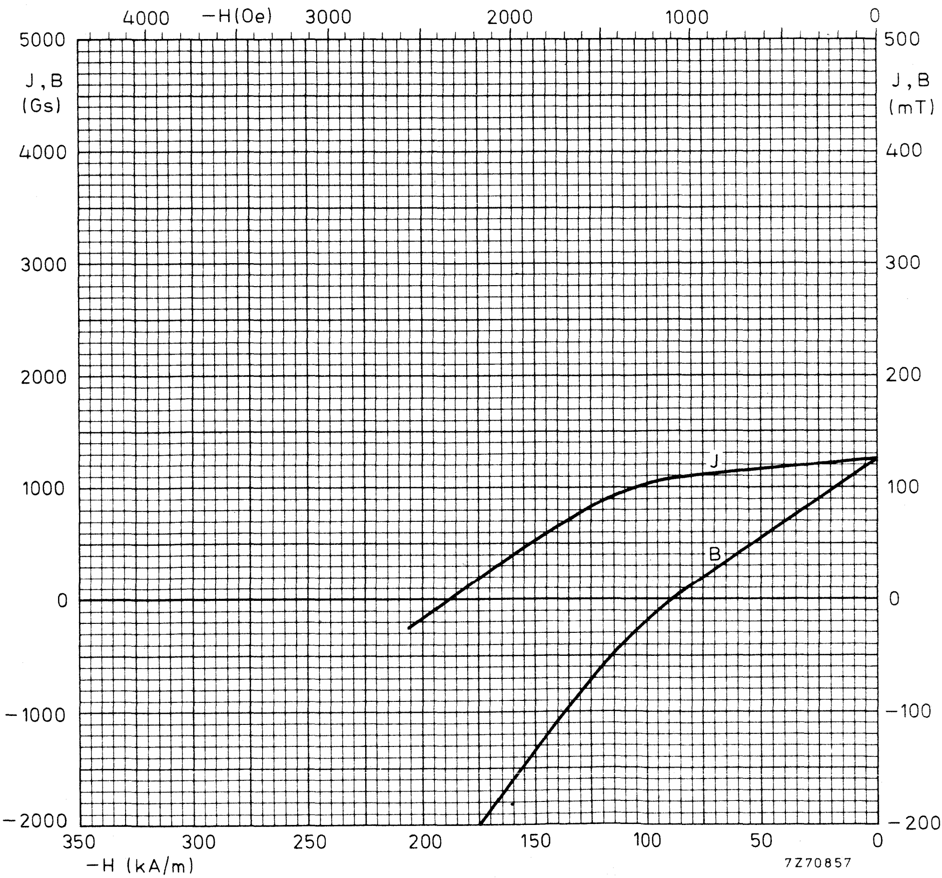
QUALITY AND FINISH

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

APPLICATION

Where flexible and/or elastic magnets are required.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE P40 AND P40F

isotropic plastic-bonded ceramic materials (P40F= 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 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

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/m^3	0,45	0,4	MGsOe
Temperature coefficient of B_r (−20 to +90 °C)		−0,2		%/°C	−0,2		%/°C
Temperature coefficient of H_{cJ} (−20 to +90 °C)				%/°C			%/°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 [1]	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.

[1]) Broad face in contact with mandrel.

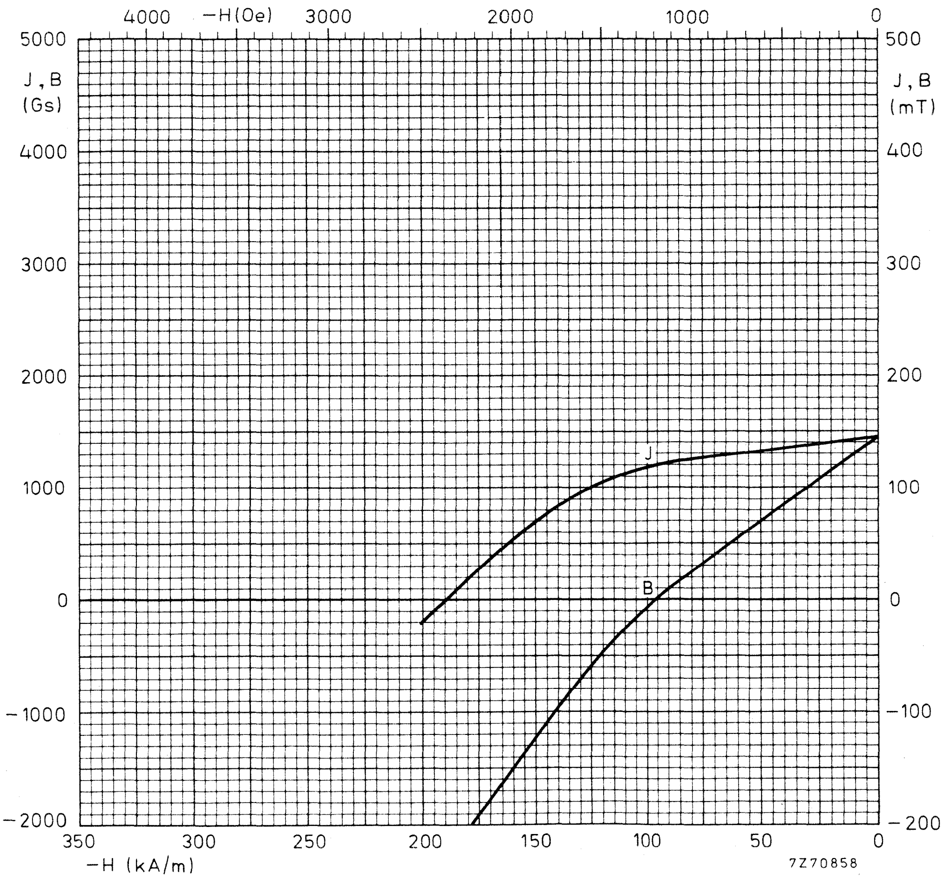
QUALITY AND FINISH

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

APPLICATION

Where flexible and/or elastic magnets are required.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE SP5F

isotropic , flame retardant, 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 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

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	max. 65	60	mT	max. 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/m^3	0,088		MGsOe
Temperature coefficient of B_r (−20 to + 100 °C)		−0,2		%/°C	−0,2		%/°C
Temperature coefficient of H_{cJ} (−20 to + 100 °C)				%/°C			%/°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/m^3 (2,8 g/cm^3)
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.

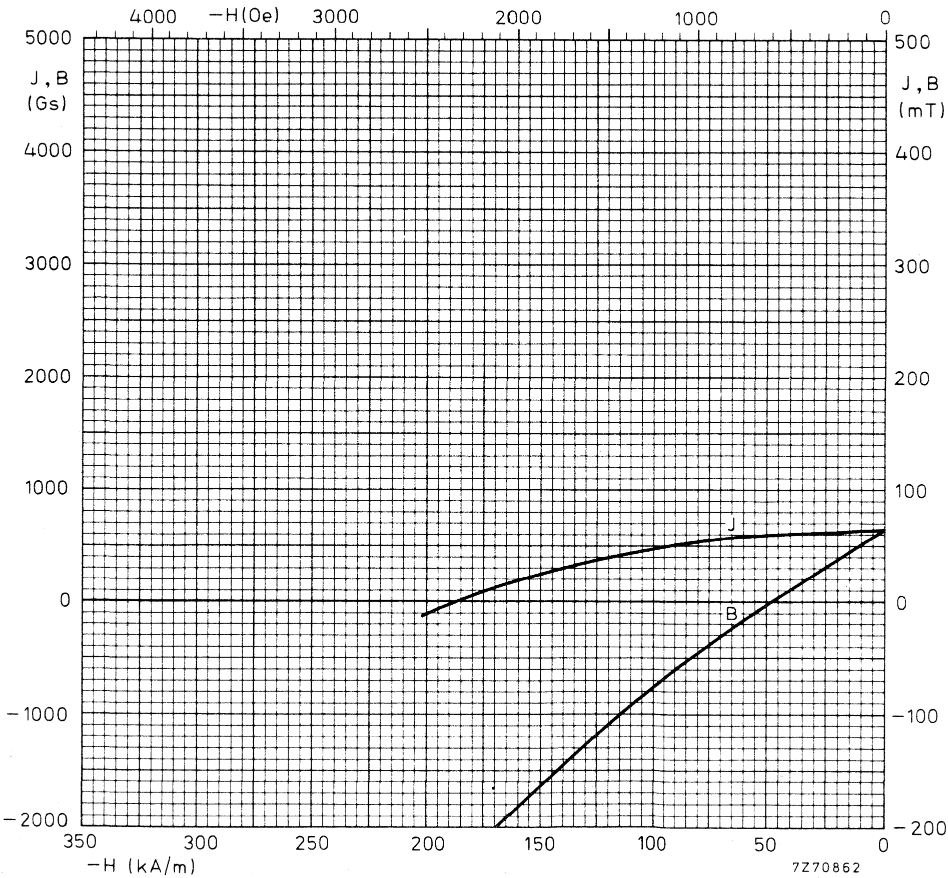
QUALITY AND FINISH

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

APPLICATION

Permanent magnets for use where low saturation field strength is acceptable, close mechanical tolerances are required and low prices are essential.

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 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

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 °C unless otherwise specified.

		typ.	min.		typ.	min.	
Remanence	B_r	80	75		800	750	Gs
Coercivity	H_{cB}	58	54		729	679	Oe
Polarization coercivity	H_{cJ}	190		kA/m	2390		Oe
Maximum BH product	$(BH)_{max}$	0,9	0,8	kJ/m³	0,11	0,1	MGsOe
Temperature coefficient of B_r (−20 to + 100 °C)		−0,2		%/°C	−0,2		%/°C
Temperature coefficient of H_{cJ} (−20 to + 100 °C)				%/°C			%/°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.	$2,5 \times 10^3$ kg/m³	(2,5 g/cm³)
Coefficient of linear expansion (20 to 90 °C)	typ.	5 ppm/°C	
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 ^{o}C	<	0,25	%
Moisture absorption during storage in water	<	0,05	% (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

		SP10	SP10F	
Flexural strength after 100 h at 25 ± 3 ^{o}C	typ.	200	150	N/cm^2
at 100 ± 3 ^{o}C	typ.	200	150	N/cm^2

Impact strength test (pendulum type)

- Striker: 50 Ncm, length of span 40 mm

		SP10	SP10F	
Impact strength after 100 h at 25 ± 3 ^{o}C	typ.	0,4	0,35	J/cm^2
at 100 ± 3 ^{o}C	typ.	0,4	0,3	J/cm^2

CHEMICAL RESISTANCE

	25 ^{o}C		70 ^{o}C	
	up to 5 h	life test	up to 5 h	life test
	SP10/SP10F	SP10/SP10F	SP10/SP10F	SP10/SP10F
Water	+	+	+	+
Thinned acids	+	–/+	–/+	–
Concentrated acids (except 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.

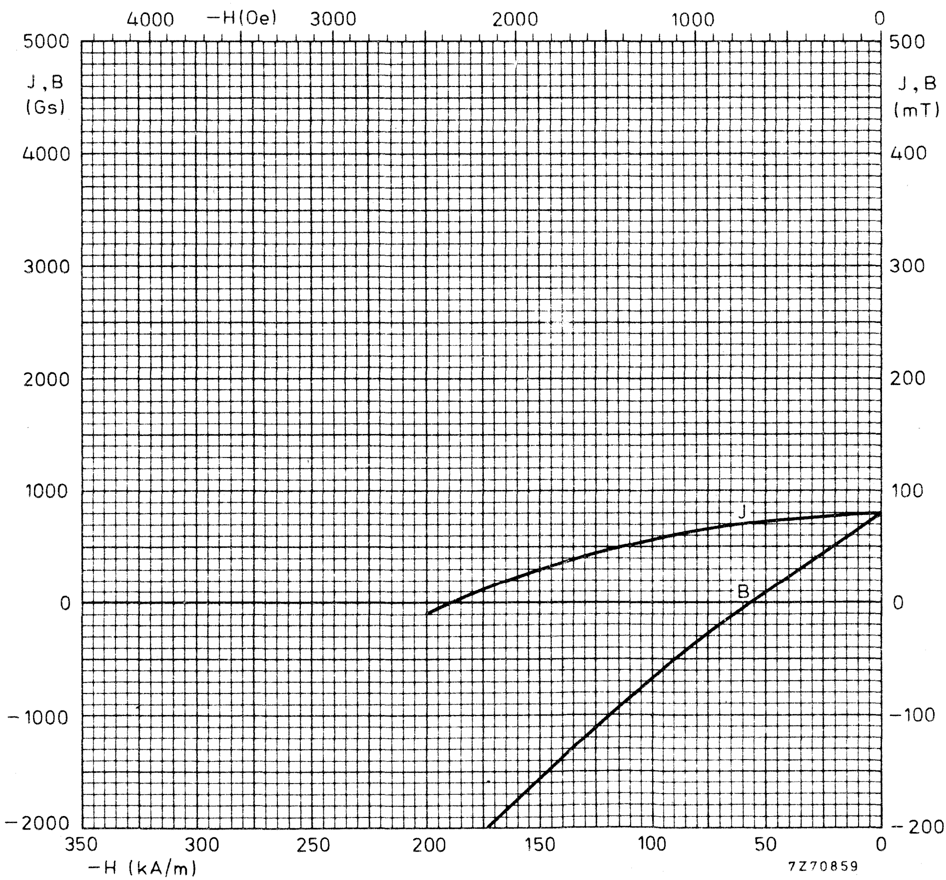
QUALITY AND FINISH

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

APPLICATION

Where permanent magnets having close mechanical tolerances are required and low prices are essential.

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 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

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/m^3	0,55	0,5	MGsOe
Temperature coefficient of B_r (−20 to + 100 °C)		−0,2		%/°C	−0,2		%/°C
Temperature coefficient of H_{cJ} (−20 to + 100 °C)				%/°C			%/°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/m^3	($3,9$ g/cm^3)
Coefficient of linear expansion (20 to 90 °C)	typ.	24 ppm/°C	
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/cm^2
at 100 ± 3 °C	typ.	100	N/cm^2

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/cm^2
at 100 ± 3 °C	typ.	0,1	J/cm^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 ± 1%.
Life test = 150 hours 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.

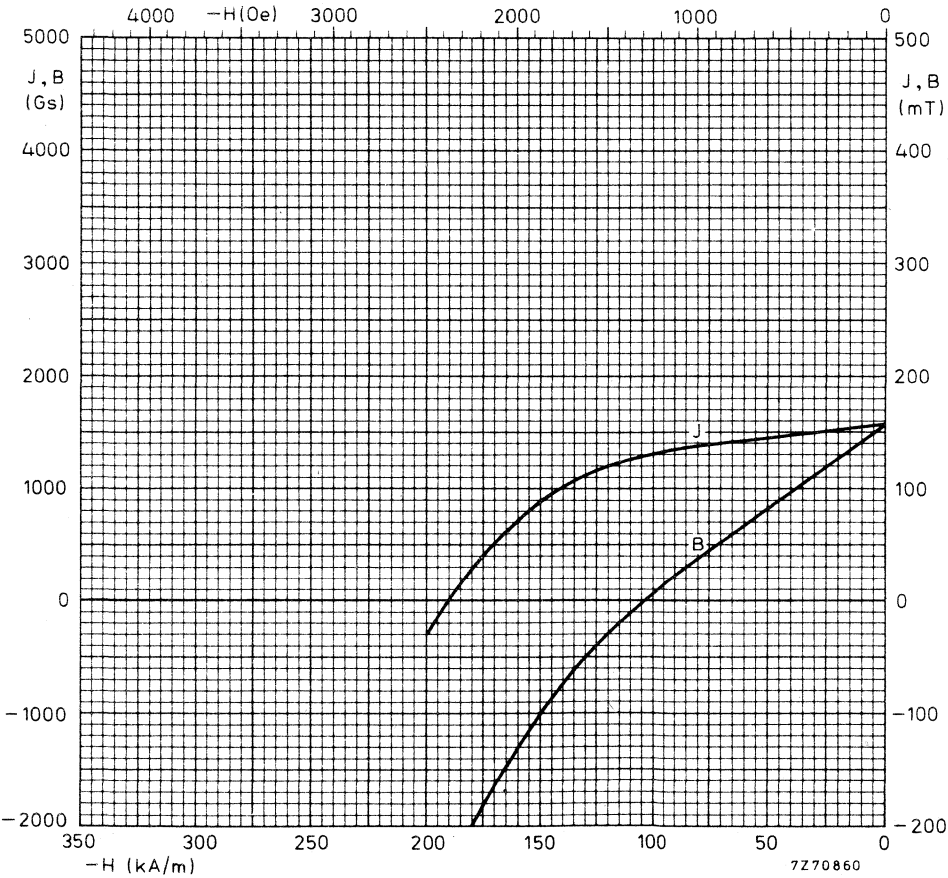
QUALITY AND FINISH

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

APPLICATION

Where permanent magnets having close mechanical tolerances are required and low prices are essential.

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 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

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		%/°C	−0,2		%/°C
Temperature coefficient of H_{cJ} (−20 to + 100 °C)				%/°C			%/°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 ppm/°C	
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/cm^2
at 100 ± 3 °C	typ.	60	N/cm^2

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/cm^2
at 100 ± 3 °C	typ.	0,1	J/cm^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 ± 1%.
Life test = 170 hours 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.

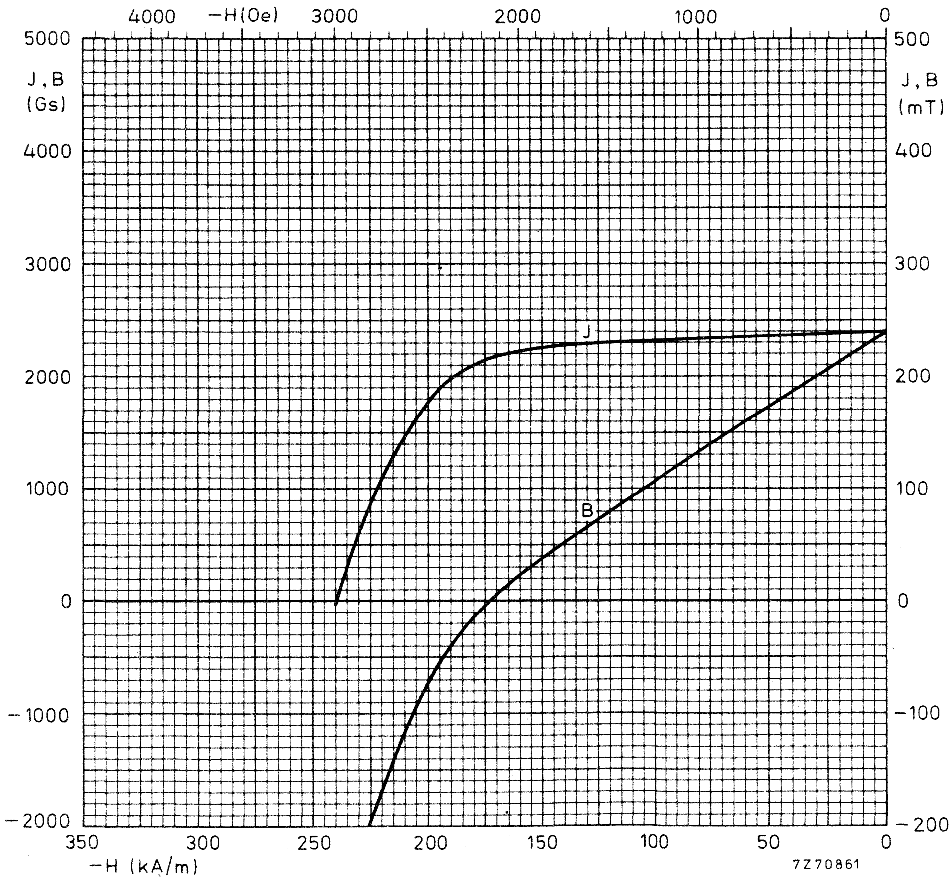
QUALITY AND FINISH

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

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 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

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		%/°C	−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		+0,4		%/°C	+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.	$4,9 \times 10^3$ kg/m³	(4,9 g/cm³)
Coefficient of linear expansion (20 to 300 °C)	typ.	10 ppm/°C	
Hardness (Moh's scale)	typ.	7	

PHYSICAL PROPERTIES (continued)

Young's modulus	typ.	150	kN/mm^2
Tensile strength	typ.	50	N/mm^2
Compressive strength	typ.	700	N/mm^2
Thermal conductivity	typ.	5,5	W/m ^{o}C

MANUFACTURE OF MAGNETS

Magnets are produced by a dry-pressing process or by extrusion. They may be machined only by grinding with diamond tools.

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.

On special request any poles can be marked by spots of paint or some other identification mark, as follows:

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

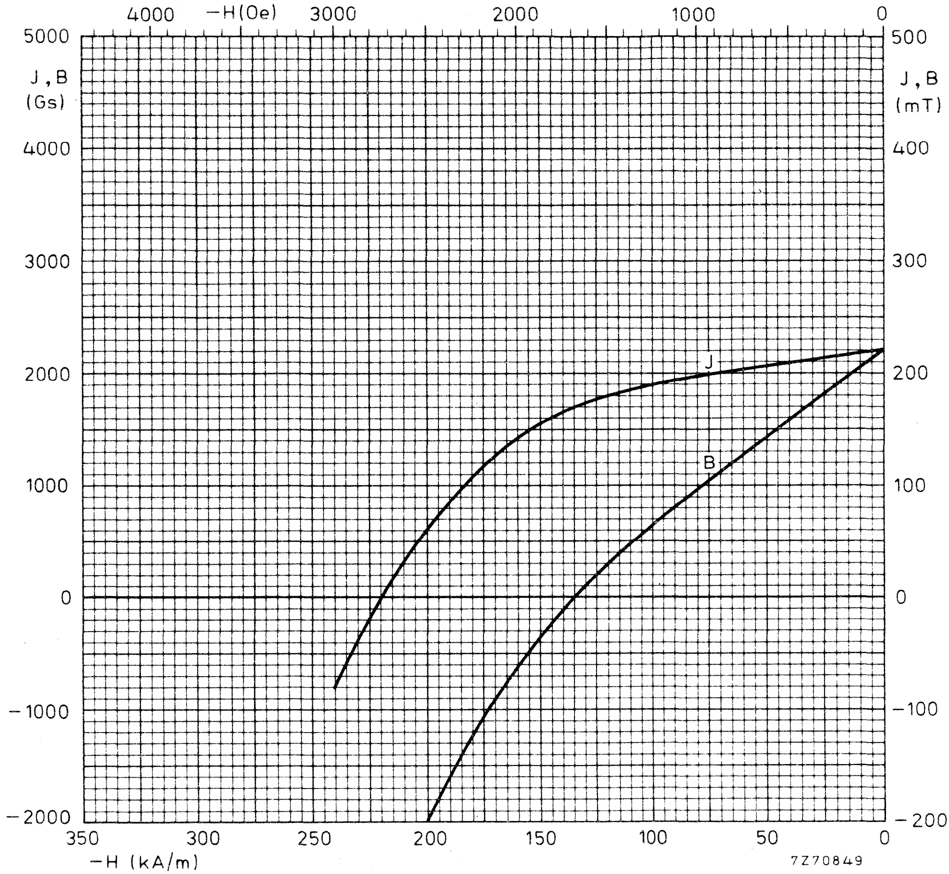
QUALITY AND FINISH

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 where a high coercivity or multi-polar magnetization is required and low prices are essential.

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 ϕ35 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

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}	263	247	kA/m	3300	3100	Oe ←
Polarization coercivity	H_{cJ}	334	318	kA/m	4200	4000	Oe
Maximum BH product	$(BH)_{max}$	21,5	19,9	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			−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		+0,45			+0,45		%/°C
Saturation field strength	H_{sat}		1114	kA/m		14 000	Oe
Resistivity	ρ	10^4		Ωm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density typ. $4,6 \times 10^3$ kg/m³ (4,6 g/cm³)

Coefficient of linear expansion (20 to 300 °C) ⊥M.A. 8 and // M.A. 13 ppm/°C

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.

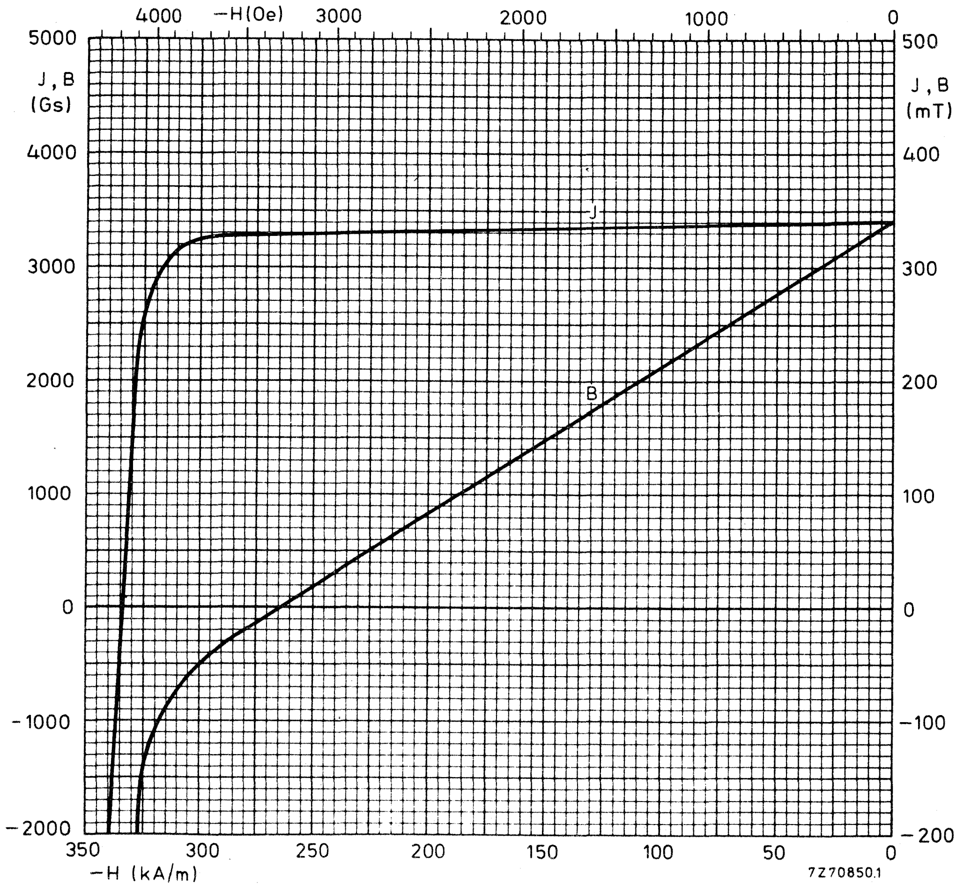
QUALITY AND FINISH

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

APPLICATION

Stator magnets in motors.

→ 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 ϕ35 mm x 12 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

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}	159	143	kA/m	2000	1800	Oe
Polarization coercivity	H_{cJ}	163	147	kA/m	2050	1850	Oe
Maximum BH product	$(BH)_{max}$	29,5	27,8	kJ/m³	3,6	3,5	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	240		mT	2400		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	123		kA/m	1550		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Temperature coefficient of B_r (−40 to +200 °C)		−0,2			−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		+0,45			+0,45		%/°C
Saturation field strength	H_{sat}		557	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) ⊥ M.A. 8 and // M.A. 13 ppm/°C

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.

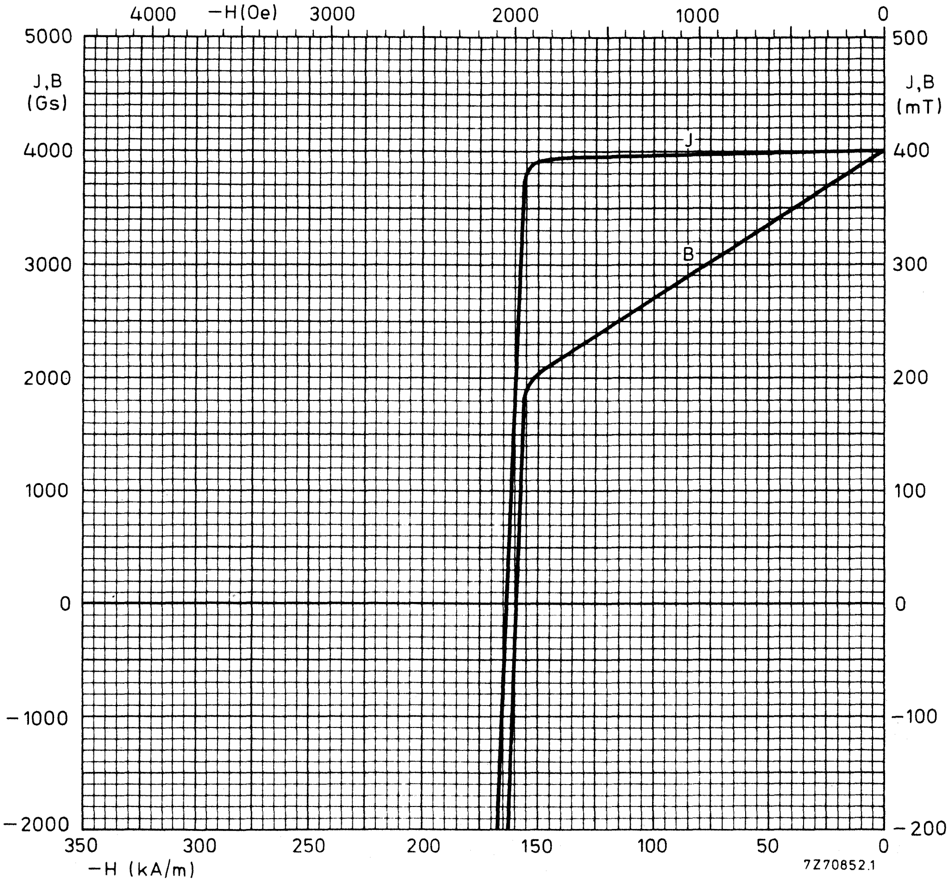
QUALITY AND FINISH

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

APPLICATION

Permanent magnets in loudspeakers.

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 ϕ35 mm x 12 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 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}	239	223	kA/m	3000	2800	Oe
Polarization coercivity	H_{cJ}	247	231	kA/m	3100	2900	Oe
Maximum BH product	$(BH)_{max}$	25,5	23,9	kJ/m^3	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	143		kA/m	1800		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Temperature coefficient of B_r (−40 to +200 °C)		−0,2			−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		+0,45			+0,45		%/°C
Saturation field strength	H_{sat}		876	kA/m		11000	Oe
Resistivity	ρ	10^4		Ωcm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density typ. 4,65 x 10^3 kg/m^3 (4,65 g/cm^3)

Coefficient of linear expansion (20 to 300 °C) ⊥ M.A. 8 and // M.A. 13 ppm/°C

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.

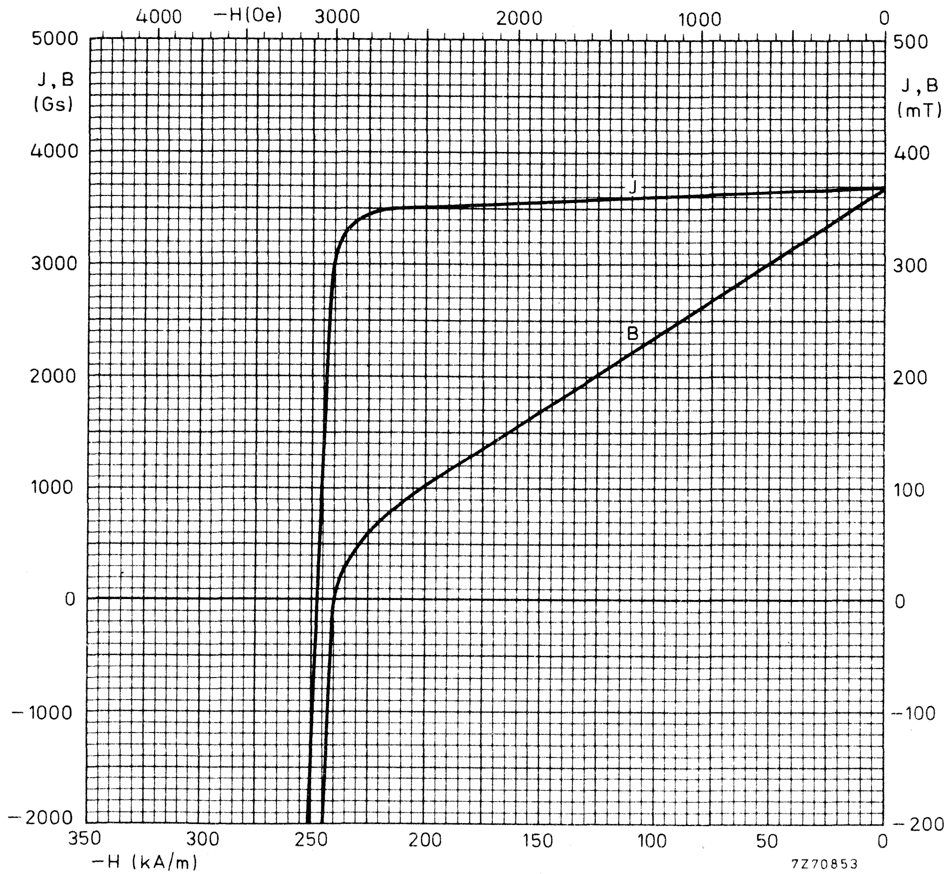
QUALITY AND FINISH

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

APPLICATION

Stator magnets in motors, magnets in separators, filters, chucks, clocks, watches, couplings, etc.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE 360

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 ϕ35 mm x 12 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

Ferroxdure 360 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}	199	183	kA/m	2500	2300	Oe
Polarization coercivity	H_{cJ}	207	191	kA/m	2600	2400	Oe
Maximum BH product	$(BH)_{max}$	28,7	27,1	kJ/m^3	3,6	3,4	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	200		mT	2000		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	143		kA/m	1800		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Temperature coefficient of B_r (−40 to +200 °C)		−0,2			−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		+0,45			+0,45		%/°C
Saturation field strength	H_{sat}		716	kA/m		9000	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/m^3 ($4,9$ g/cm^3)

Coefficient of linear expansion (20 to 300 °C) ⊥M.A. 8 and // M.A. 13 ppm/°C

Hardness (Moh's scale) typ. 6,5

DIRECTION OF MAGNETIZATION

Ferroxdure 360 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

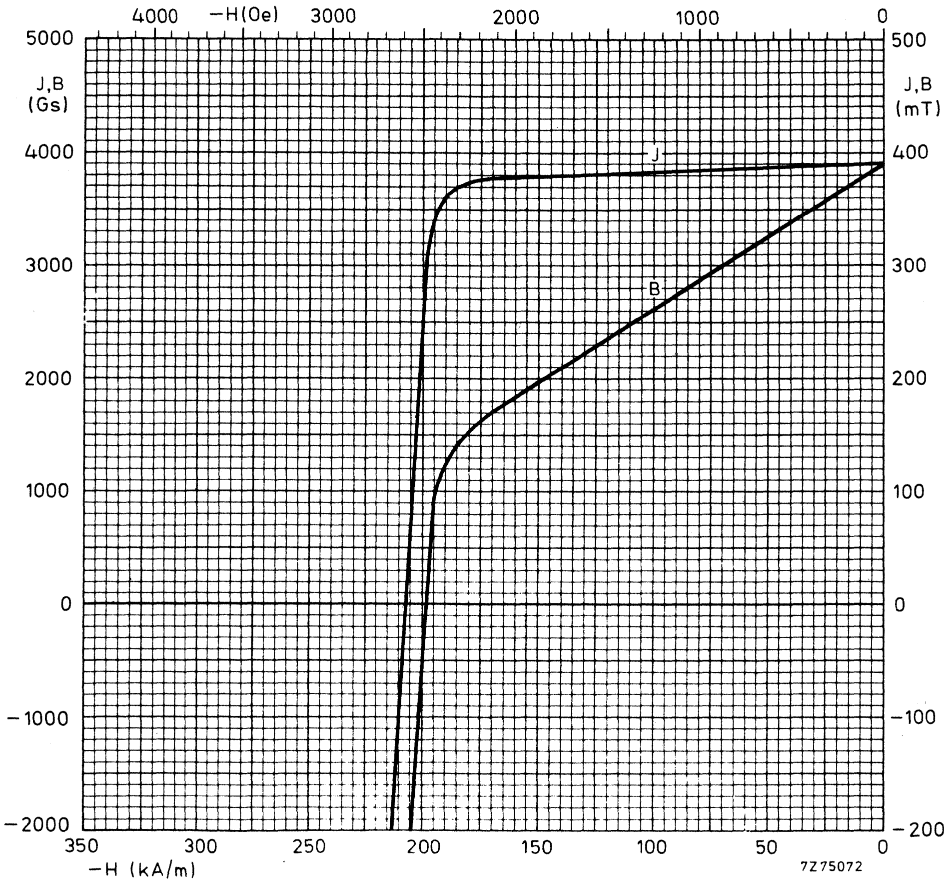
QUALITY AND FINISH

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

APPLICATION

Loudspeaker magnets and flywheel magnetos.

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 ϕ35 mm x 12 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

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}	263	247	kA/m	3300	3100	Oe
Polarization coercivity	H_{cJ}	279	263	kA/m	3500	3300	Oe
Maximum BH product	$(BH)_{max}$	27,8	26,2	kJ/m^3	3,5	3,3	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	188		mT	1875		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	148		kA/m	1875		Oe
Recoil permeability	μ_{rec}	1,1			1,1		
Temperature coefficient of B_r (−40 to +200 °C)		−0,2			−0,2		%/°C
Temperature coefficient of H_{cJ} (−40 to +200 °C)		+0,45			+0,45		%/°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. $4,7 \times 10^3$ kg/m^3 (4,7 g/cm^3)

Coefficient of linear expansion (20 to 300 °C) ⊥M.A. 8 and // M.A. 13 ppm/°C

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.

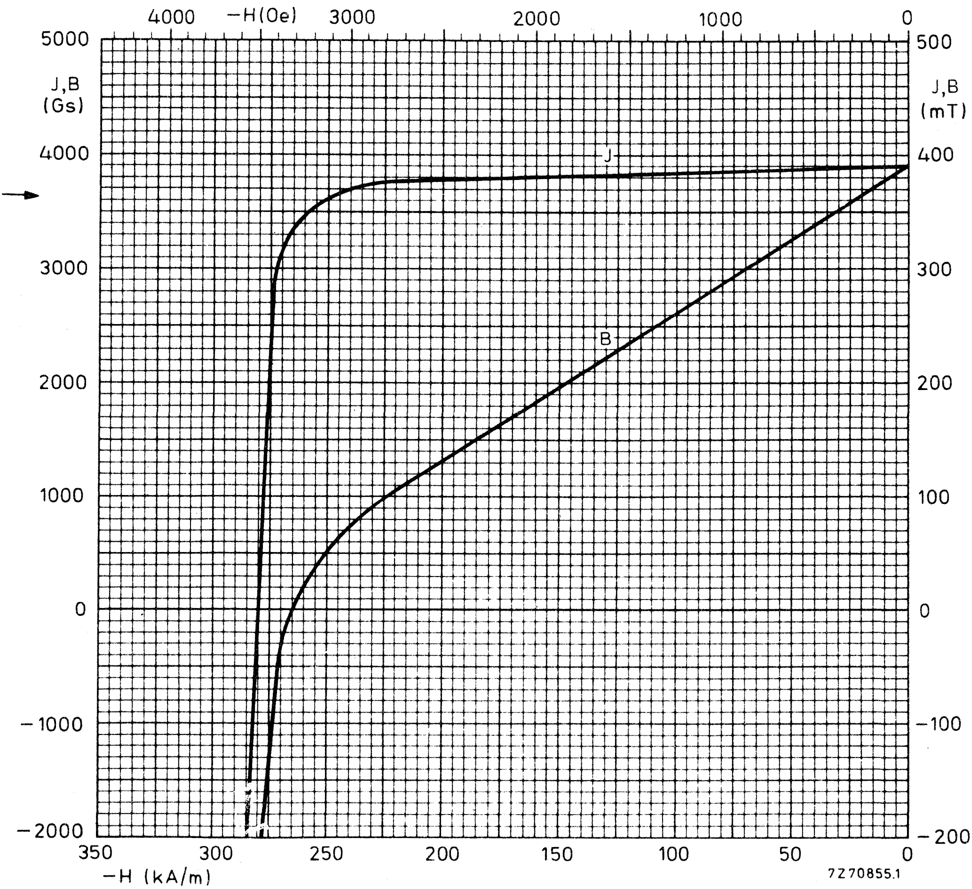
QUALITY AND FINISH

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

APPLICATION

Stator magnets in motors, magnets in separators etc.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



FERROXDURE MAGNETS FOR LOUDSPEAKERS

A loudspeaker magnet system equipped with a ring magnet of Ferroxdure is illustrated in Fig. 1.

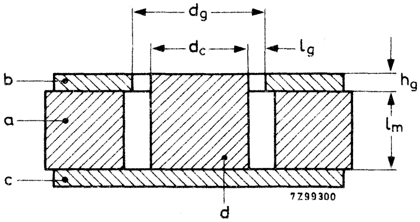


Fig. 1

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.
See the table of recommended magnet types.

SYSTEM DESIGN

For the calculation of the flux density in a given loudspeaker magnet system, and for the determination of the dimensions of the Ferroxdure ring to produce a given flux density in the air gap, refer to Philips Technical Review, Vol. 24, 1962/63, No. 4/5, p. 150-156. Also ask for information on computer-aided design of loudspeaker magnet systems.

The article gives a design method which introduces an internal magnetic resistance (internal magnetic reluctance) R_m lying in series with the magnetomotive force F_m, see equivalent magnetic circuit Fig. 2.
The design is also based on a straight demagnetization line extrapolated to the point H_c' on the –H-axis, see Fig. 3, so that $F_m = H_c' l_m$. The tangent of the angle α is $1,1\ \mu_0$, so that $H_c' = B_r/1,1\ \mu_0$. (1, 1 represents the recoil permeability of Ferroxdure 300 and 330.)

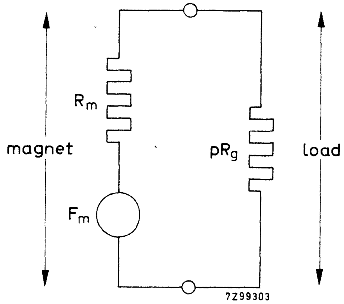


Fig. 2. Equivalent magnetic circuit

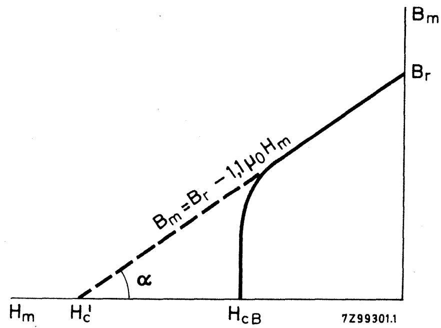


Fig. 3. Demagnetization curve of Ferroxdure

The flux in the air gap is calculated from an equation derived from Fig. 2:

$$\phi_g = \frac{F_m}{pR_g + R_m} = \frac{H_c' l_m}{pR_g + R_m}$$

R_m = internal magnetic resistance (reluctance) of magnet = $\dfrac{l_m}{1,1\ \mu_0 A_m}$

R_g = magnetic resistance (reluctance) of air gap = $\dfrac{l_g}{\mu_0 A_g}$

A_m = cross-sectional area of magnet

A_g = area of air gap = $\pi\ (d_c + l_g)\ h_g = \frac{1}{2}\ \pi\ (d_c + d_g)\ h_g$

μ_0 = permeability of vacuum = $4\pi . 10^{-7}$ H/m or 1 Gs/Oe

The term pR_g represents the load of the magnet including the leakage losses of the whole magnet system. The leakage factor p has been empirically found to be dependent on the system's dimensions:

$$p = 14,2\ \mu_0 l_m R_m + 1,86 = \frac{14,2\ l_m^2}{1,1\ A_m} + 1,86.$$

The above equations have been used for a number of standardized rings of Ferroxdure 300. As a result graphs I and II give the flux in the air gap as a function of its "relative" permeance (Λ') with the magnets as parameter.

$$\Lambda g' = \frac{\Lambda g}{\mu_0} = \frac{1}{\mu_0 R_g} = \frac{A g}{l_g}$$

(In the c.g.s. system of units Λ_g' is identical to Λ_g.)

Example: A magnet system 16/4 - 0,8: core diameter d_c = 16 mm, air gap height h_g = 4 mm, air gap width l_g = 0,8 mm,

has a Λ_g' of 264 mm.

A ring magnet of Ferroxdure 300 having the following dimensions:

external diameter d_o = 45 mm,
internal diameter d_i = 22 mm,
height $h = l_m$ = 9 mm,

can produce a flux ϕ_g of 186 µWb (18,6 kMx) in the above air gap; this means a flux density B_g of 880 mT (8,8 kGs).

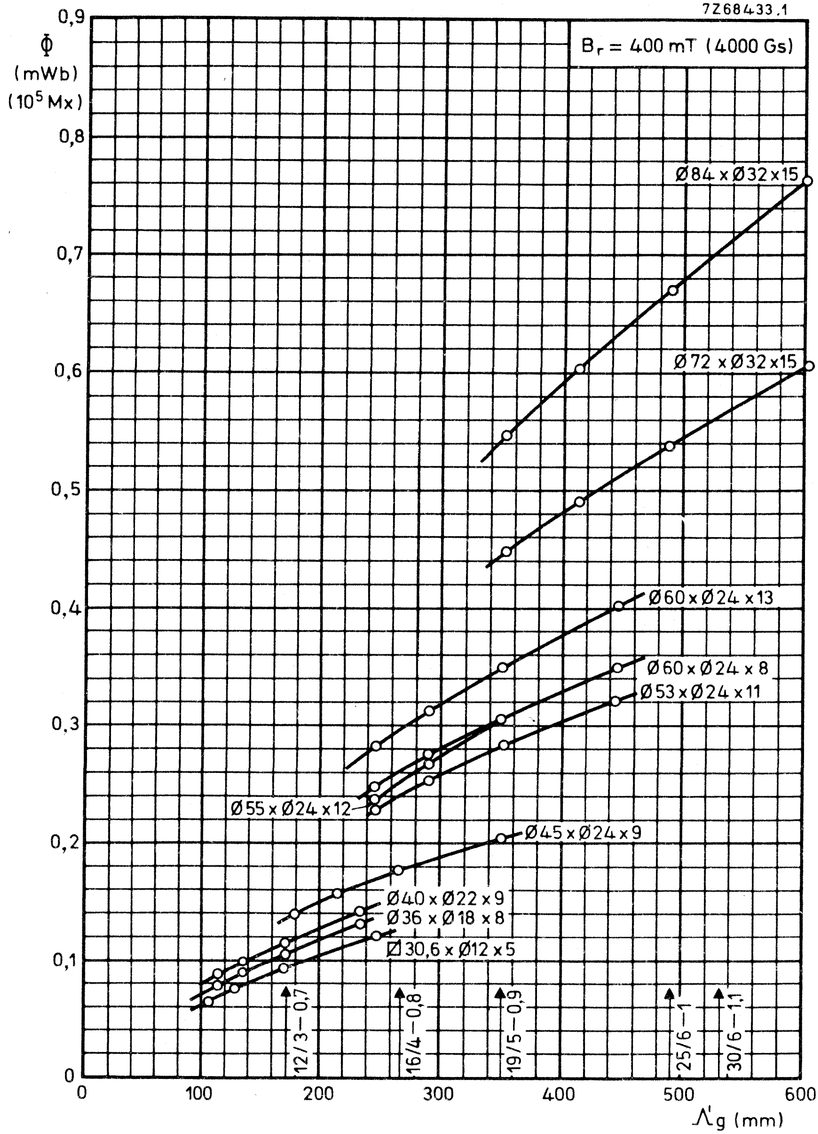
Another quantity which is often used in the design of loudspeaker magnet systems is the magnetic energy in the air gap:

$$W_g = \frac{\phi g^2}{2\mu_0 \Lambda g'} = \frac{Bg^2 A g l g}{2\mu_0} = \frac{Bg^2 V g}{2\mu_0}.$$

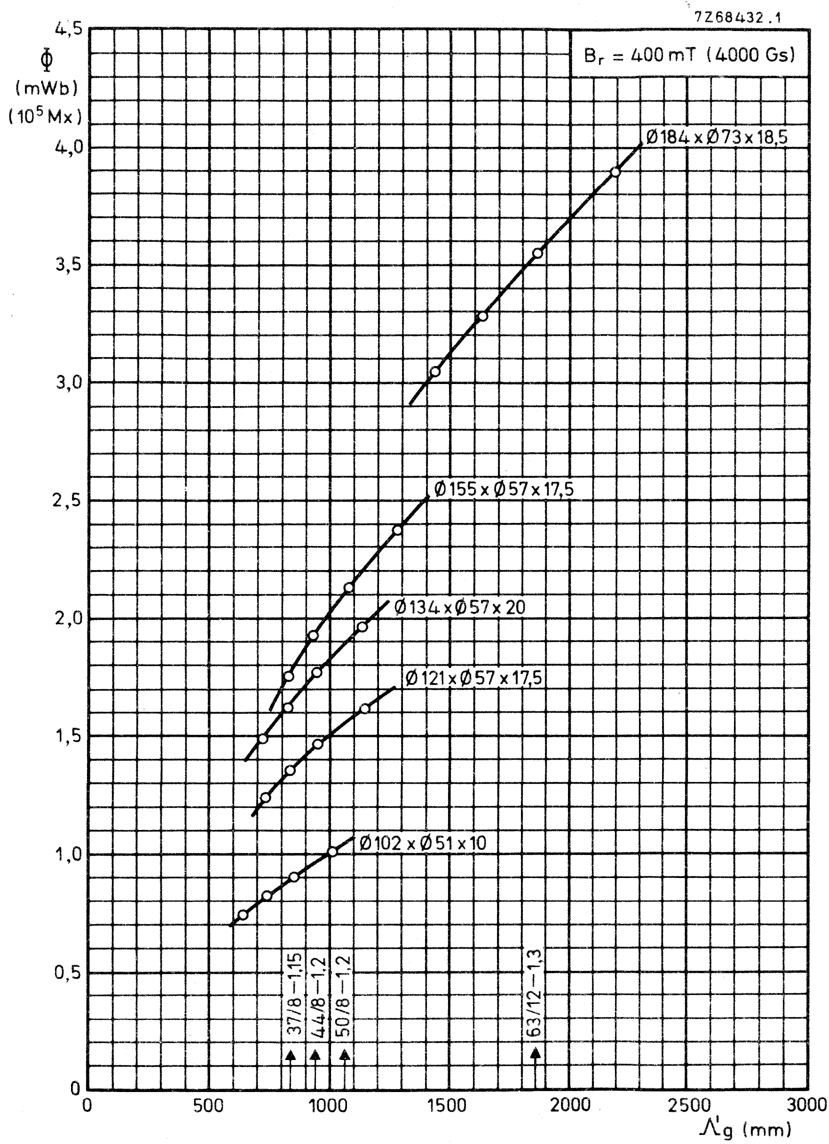
The unit of energy J (joule) is usually too great and, therefore, W_g is expressed in mJ (mWs).

When ϕ_g is expressed in Mx and Λ_g' in cm, then W_g follows in ergs; 1 erg = 10^{-4} mJ.

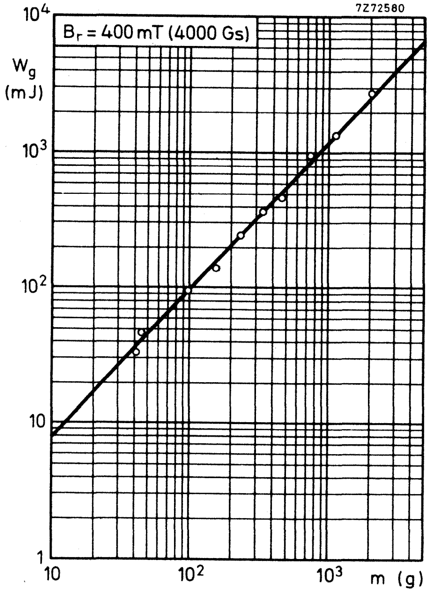
Graph III shows the energy as a function of magnet mass.



Graph I. Air gap flux as a function of "relative" permeance of air gap, calculated for a number of rings of Ferroxdure 300.



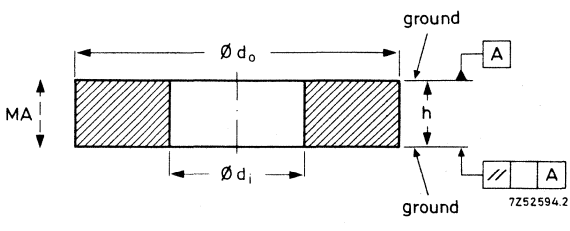
Graph II. Air gap flux as a function of "relative" permeance of air gap calculated for a number of rings of Ferroxdure 300.



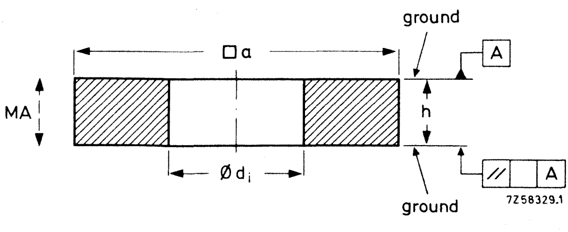
Graph III. Magnetic energy in air gap as a function of magnet mass (typical-design values)

RECOMMENDED TYPES OF MAGNET

Material: Ferroxdure 300
Direction of magnetic axis: axial
Supplied: unmagnetized



Ring magnet



Square magnet (rounded corners)

	ring magnet					
d_o (mm)	d_i (mm)	h (mm)	//..A (mm)	mass (g)	code number	system [1]
36 ± 0,8	18 ± 0,5	8 ± 0,1	0,1	30	4322 020 60070	12/3/ 8800-0,7
40 +1,3 −0,7	22 ± 0,5	9 ± 0,1	0,1	39	4311 021 30030	12/3/ 9730-0,7
45 ± 1	24 ± 0,6	9 ± 0,1	-	50	4322 020 60130	16/4/ 8460-0,8
53 ± 1,2	24 ± 0,5	11 ± 0,1	-	95	4304 071 80260	19/5/ 9080-0,9
55 ± 1,2	24 ± 0,6	12 ± 0,1	0,1	113	4322 020 60170	19/5/ 9770-0,9
60 ± 1,5	24 ± 0,6	8 ± 0,1	-	93	60180	19/5/ 9720-0,9
60 ± 1,5	24 ± 0,6	13 ± 0,1	-	151	60200	19/5/ 11 300-0,9
72 ± 1,5	32 ± 0,7	15 ± 0,1	-	240	60240	25/6/ 11 000-1
84 ± 1,8	32 ± 0,9	15 ± 0,1	-	348	60270	25/6/ 13 700-1
90 ± 1,8	36 ± 0,9	17 ± 0,1	-	445	60280	30/6/ 13 300-1,1
102 ± 3	51 ± 1,5	10 ± 0,15	-	300	60300	37/8/ 9400-1,15
121 ± 3,6	57 ± 1,7	17,5 ± 0,2	-	767	60570	44/8/ 13 000-1,2
134 ± 4	57 ± 1,7	20 ± 0,2	-	1132	60020	44/8/ 15 600-1,2
155 ± 4,5	57 ± 1,7	17,5 ± 0,2	-	1400	60010	50/8/ 16 600-1,2
184 ± 5,5	73 ± 2,2	18,5 ± 0,2	-	2032	60350	63/12/14700-1,3
	square magnet					
30,6 ± 0,8	12,9 ± 0,4	5 ± 0,1	0,1	19,3	4322 020 63010	10/3/ 9400-0,6

These magnets are represented in graphs I and II.

For complete list of types refer to:
FERROXDURE MAGNET TYPE LIST - Anisotropic sintered Ferroxdure (section 2).

[1]) System which for example can be realized with this ring.

ANISOTROPIC FERROXDURE SEGMENTS

Segment magnets are made with both radial and diametrical magnetic orientation. They are used in a variety of applications, including d.c. motors and fly-wheel magnetos, in which the magnetic circuit comprises a wound soft-iron armature, with the segment magnets mounted on the inside of a soft-iron or mild-steel ring.

The following data are essential for both the circuit engineer and the manufacturer of the magnets.

A. The internal radius of the ring.
B. The external radius of the armature.
C. The minimum acceptable air gap between rotor and magnet.
D. The angle of the segment.
E. The orientation of the segment: radial or diametrical.
F. The required flux.
G. The maximum demagnetizing field strength to be experienced by the segment, and the minimum temperature to which it is to be exposed.

On enquiry, please give at least these data complete with tolerances. A check list is also available on request.

The radii of the segments should slightly exceed the radii of the ring and of the armature + minimum acceptable air gap. In this way, the segments will touch the ring at two points, avoiding rocking, and will not touch the armature at maximum thickness of the segment. It is apparent that two-point contact can be achieved by a number of segment profiles which are not pure radii.

The shape of the segment is checked by means of a special gauge as approved by customer. Width, length, height and thickness are checked in the usual way.

Normally, the magnetic flux is checked in a static system where a segment is enclosed by a soft-iron ring and surrounds a soft-iron cylinder which carries a longitudinal measuring coil or in which a Hall probe has been placed. After the segments have been so magnetized, their flux is compared with the flux from a standard segment.

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.

From PREFERRED TYPES (indicated by an asterisk) easier delivery of samples can be expected. In some cases stock is available for immediate despatch for short run production.

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 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 listed.

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

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 - see the section "Design advisory service".

MAGNET TYPE LIST

available separately
on request

TICONAL

INTRODUCTION

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. The earliest materials of this composition, the isotropic reco alloys, are no longer included in our range.

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 correct choice from this range enables magnetic circuits to be designed having efficiencies hitherto unattainable. The reduction in the size of magnets and the associated circuits usually results in a significant reduction in costs.

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 (12 MGsOe).

The following alloys are in normal mass production:

Ticonal 440 and 500:
These Ticonal grades are made by applying a magnetic field during cooling, resulting in anisotropic 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 750 and 900, improved grades with ultra-high performance, are now used only in small quantities and are no longer included in our standard range.

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 and 600 holes have to be avoided and inserts cannot be used otherwise the crystal orientation will be impaired during casting.

Ticonal magnets can be fixed be 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.

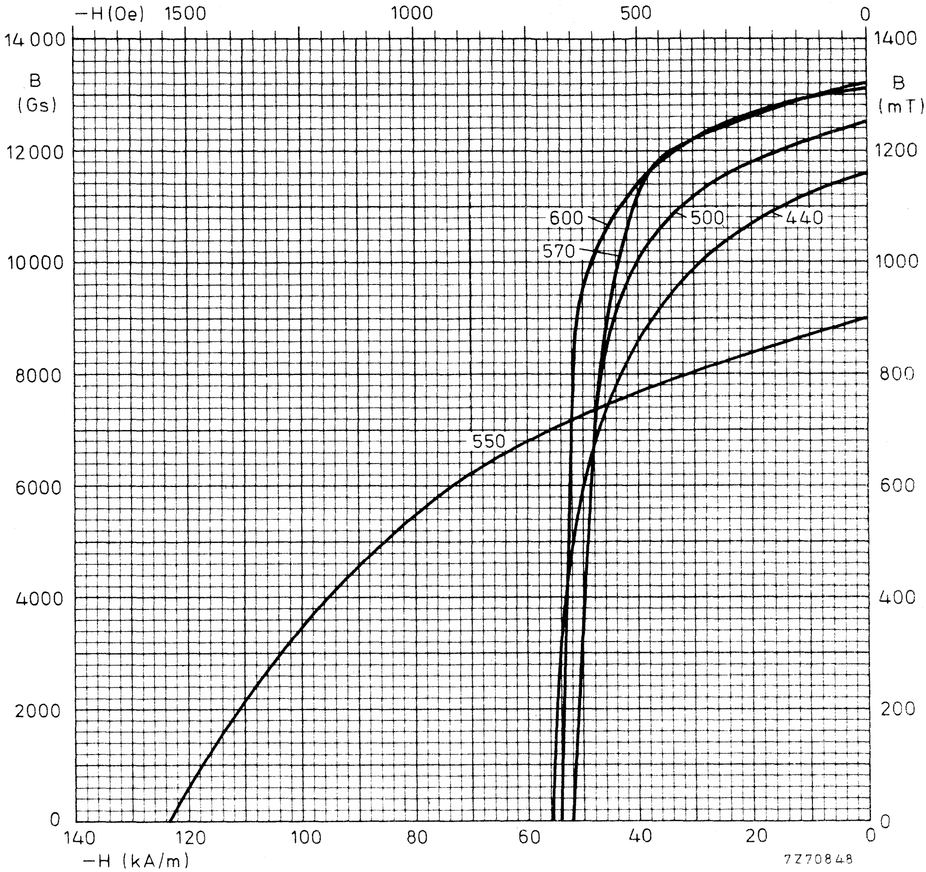
Ticonal magnets should, as far as possible, not be used as structural elements. Ticonal magnets are highly resistant to corrosion.

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.



Typical demagnetization curves at 25 °C

APPLICATIONS

Ticonal magnets, having high remanence values, are used in those applications requiring superior performance per unit volume, stability and small dimensions such as in:

watches,
loudspeakers,
microphones and telephones,
meters,
magnetos,
motors.

TICONAL 440

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 ϕ34 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 440 is an alloy comprising approximately 24% Co, 15% Ni, 7,9% Al, 3% Cu, 1% 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	1160	1100	mT	11 600	11 000	Gs
Coercivity	H_{cB}	55,7	54,1	kA/m	700	680	Oe
Maximum BH product	$(BH)_{max}$	35	32,6	kJ/m³	4,4	4,1	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	800		mT	8000		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	43,8		kA/m	550		Oe
Recoil permeability	μ_{rec}	4,5			4,5		
Temperature coefficient of B_r (−40 to +200 °C)		−0,02		%/°C	−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 ppm/°C	

DIRECTION OF MAGNETIZATION

Ticonal 440 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

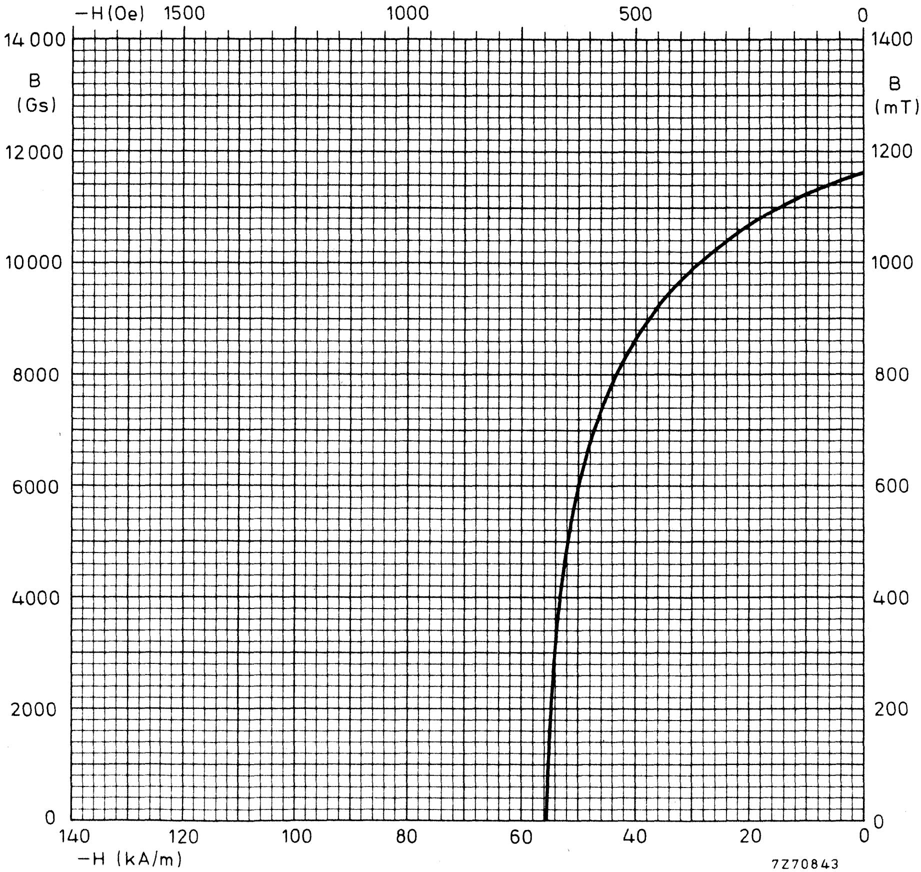
QUALITY AND FINISH

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, small motors and generators, etc.

TYPICAL DEMAGNETIZATION CURVE (25 °C)



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 ϕ34 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, 13,8% Ni, 7,6% 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_{cB}	52,5	50,1	kA/m	660	630	Oe
Maximum BH product	$(BH)_{max}$	40,6	37,4	kJ/m^3	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		%/°C	−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/m^3	(7,3 g/cm^3)
Coefficient of linear expansion	typ.	10,8 ppm/°C	

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.

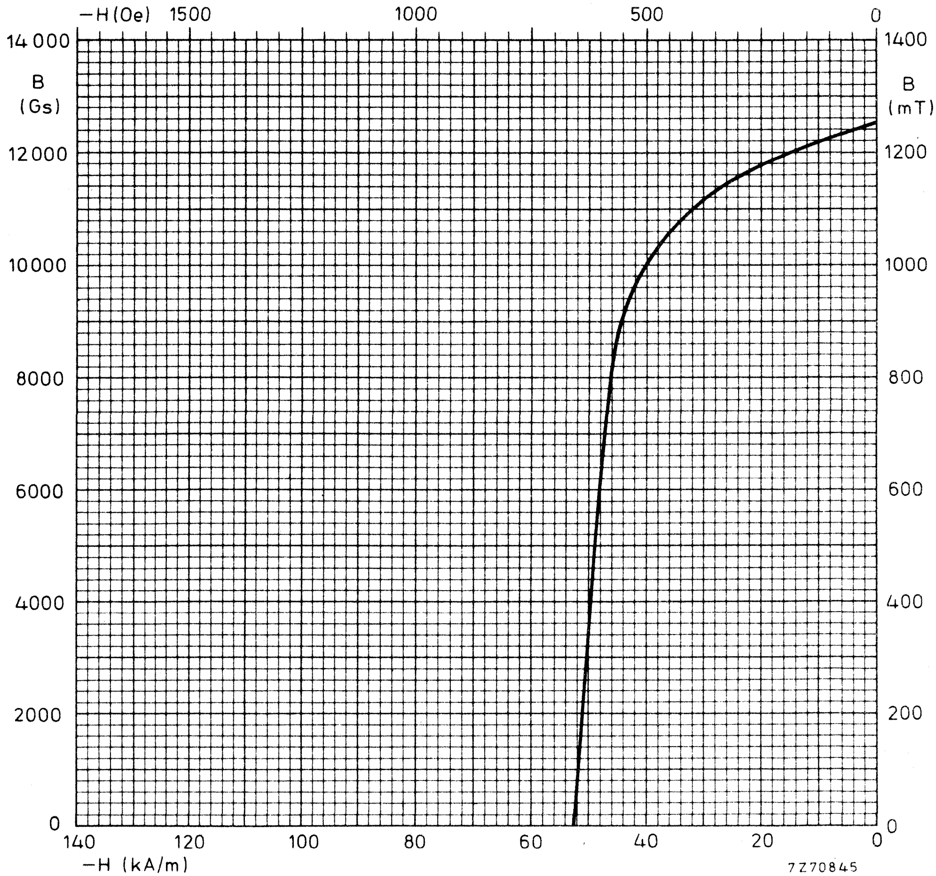
QUALITY AND FINISH

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 ϕ34 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_{cB}	123	115	kA/m	1550	1450	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		%/°C	−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 ppm/°C	

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.

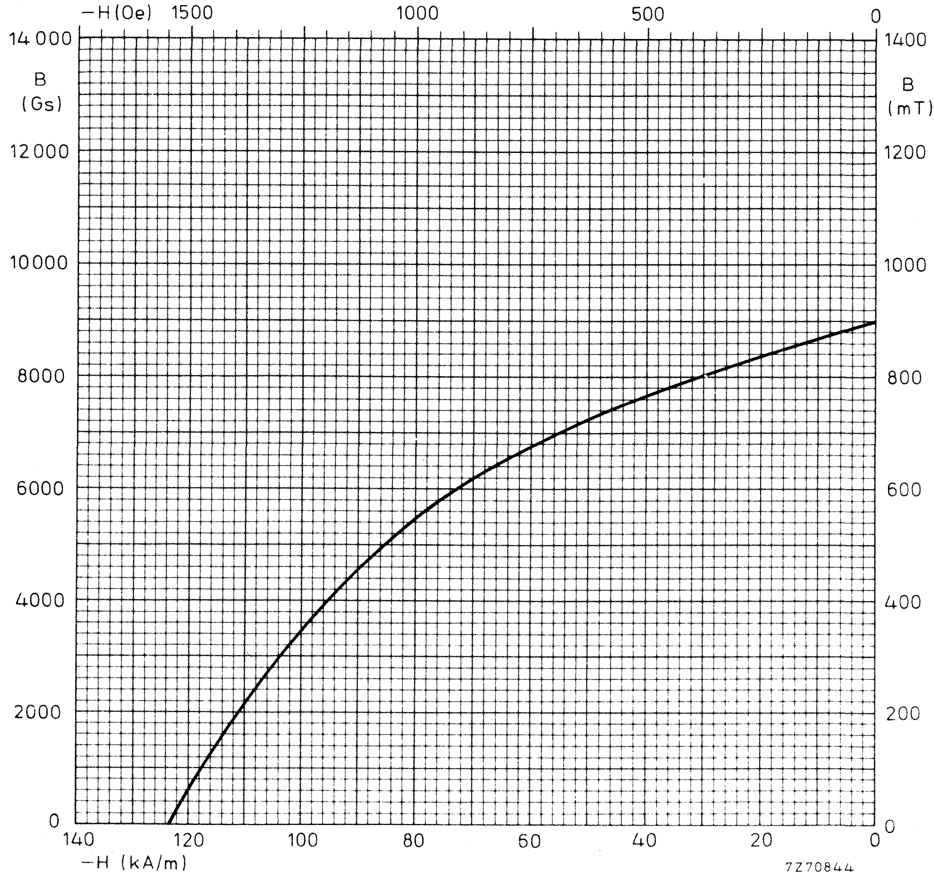
QUALITY AND FINISH

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 ^{o}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 ϕ18 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, 13,8% Ni, 7,6% 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_{cB}	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		%/°C	−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 ppm/°C	

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.

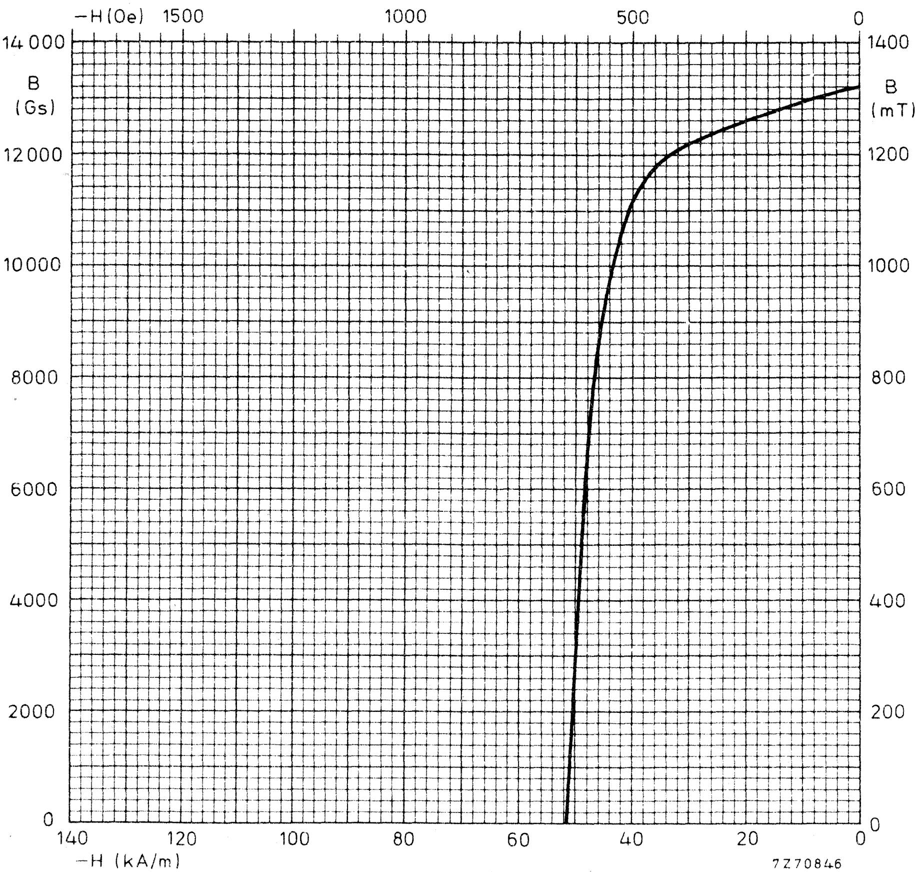
QUALITY AND FINISH

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 ϕ18 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, 13,8% Ni. 7.8% 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_{cB}	54,1	51,7	kA/m	680	650	Oe
Maximum BH product	$(BH)_{max}$	47,8	43,8	kJ/m^3	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		%/°C	−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/m^3	(7,3 g/cm^3)
Coefficient of linear expansion	typ.	10,8 ppm/°C	

DIRECTION OF MAGNETIZATION

Ticonal 600 is an anisotropic material, and has therefore a preferred direction of magnetization (Magnetic Axis), which must be shown on the magnet drawing.

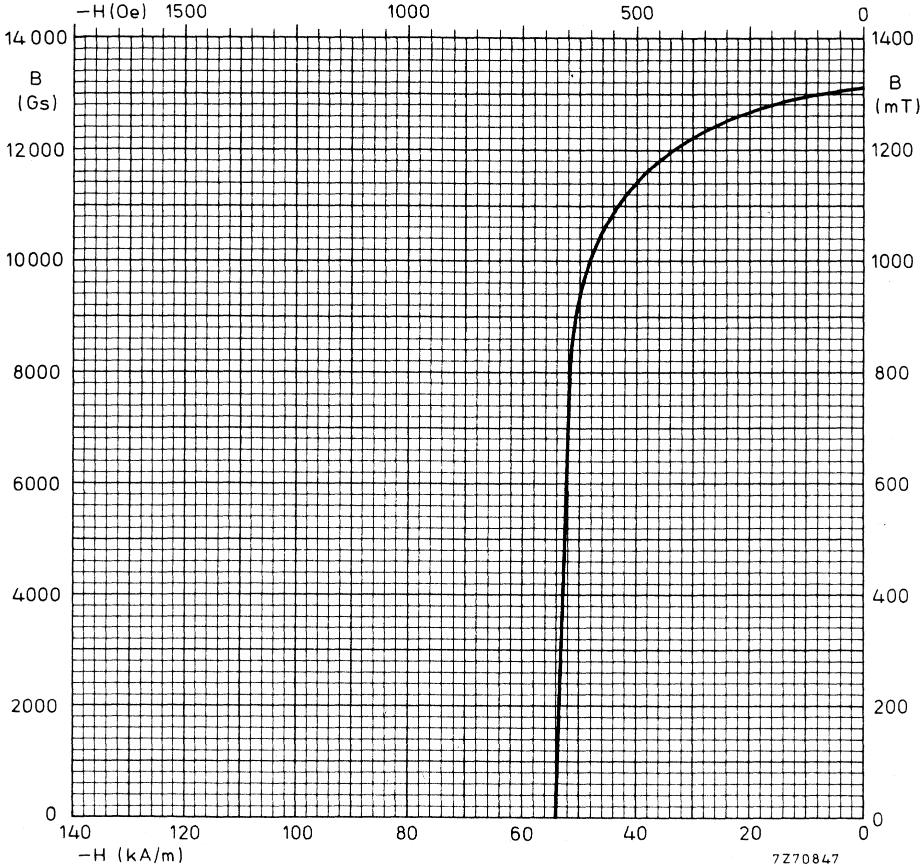
QUALITY AND FINISH

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)



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