PHILIPS

Data handbook

PHILIPS Electronic components and materials

Components and materials

Part 4b May 1975

Piezoelectric ceramics

Permanent magnet materials

COMPONENTS AND MATERIALS

Part 4b **May 1975**

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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.

ELECTRON TUBES (BLUE SERIES)

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

Part 1a Transmitting tubes for communications and Tubes for r.f. heating Types PB2/500 ÷ TBW15/125 — **April 1973**

Part 1b Transmitting tubes for communication — **August 1974**
Tubes for r.f. heating
Amplifier circuit assemblies

Part 2 Microwave products — **October 1974**

Communication magnetrons
Magnetrons for micro-wave heating
Klystrons
Traveling-wave tubes
Diodes
Triodes
T-R Switches
Microwave Semiconductor devices
Isolators Circulators

Part 3 Special Quality tubes; Miscellaneous devices — **January 1975**

Part 4 Receiving tubes — **March 1975**

Part 5a Cathode-ray tubes — **April 1975**

Part 5b Camera tubes; Image intensifier tubes — **December 1973**

Part 6 Products for nuclear technology — **January 1974**
Photodiodes

Photomultiplier tubes
Channel electron multipliers
Geiger-Mueller tubes
Neutron tubes
Photodiodes

Part 7 Gas-filled tubes — **February 1974**

Voltage stabilizing and reference tubes
Counter, selector, and indicator tubes
Trigger tubes
Switching diodes
Thyratrons
Ignitrons
Industrial rectifying tubes
High-voltage rectifying tubes

Part 8 T.V. Picture tubes — **May 1974**

SEMICONDUCTORS AND INTEGRATED CIRCUITS (RED SERIES)

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

Part 1a Rectifier diodes and thyristors — **June 1974**

Rectifier diodes
Voltage regulator diodes (> 1,5 W)
Transient suppressor diodes
Thyristors, diacs, triacs
Rectifier stacks

Part 1b Diodes — **July 1974**

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 — **July 1974**

Part 3 High frequency and switching transistors — **October 1974**

Part 4a Special semiconductors — **November 1974**

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

Part 4b Devices for opto-electronics — **December 1974**

Photosensitive diodes and transistors
Light emitting diodes
Photocouplers
Infra-red sensitive devices
Photoconductive devices

Part 5 Linear integrated circuits — **March 1975**

Part 6 Digital integrated circuits — **April 1974**

DTL (FC family)
CML (GX family)
MOS (FD family)
MOS (FE family)

COMPONENTS AND MATERIALS (GREEN SERIES)

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

Part 1 Functional units, Input/output devices, Electro-mechanical components, Peripheral devices **June 1974**

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
Electro-mechanical components
Peripheral devices

Part 2a Resistors **September 1974**

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 **November 1974**

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, aerial input assemblies
Components for black and white TV
Components for colour television
*)

Part 4a Soft ferrites **April 1975**

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

Part 4b Piezoelectric ceramics, Permanent magnet materials **May 1975**

Part 5 Ferrite core memory products **January 1974**

Ferroxcube memory cores
Matrix planes and stacks
Core memory systems

Part 6 Electric motors and accessories **March 1974**

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

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*) Deflection assemblies for camera tubes are now included in handbook series "Electron tubes", Part 5b.

Piezoelectric ceramics

INTRODUCTORY NOTES

INTRODUCTION

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. With one exception (PXE 11, which is a potassium sodium niobate), 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.

PXE6: A grade developed for applications where the mechanical quality factor, as well as temperature and time stability, must meet stringent requirements. It is, therefore, the material particularly recommended for ceramic resonators in radio and television receivers.

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 11: This material possesses a very low permittivity and a relatively high frequency constant. It also has a high shear-mode coupling coefficient and is, therefore, the recommended material for shear-mode transducers (e.g. delay lines for professional use) in the frequency range 10 MHz to 100 MHz.

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) makes 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 51: 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.

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:

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

where ε is the permittivity of the medium.

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

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

where s denotes the compliance of the medium.

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

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

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

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

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

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

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

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

Piezoelectric constants d and g

Constant	Definition	Units (SI)	Symbol
d	$\frac{\text{dielectric displacement developed}}{\text{applied mechanical stress}}$ (E = constant)	$\frac{\text{coulomb per metre}^2}{\text{pascal}}$	C/N
	$\frac{\text{strain developed}}{\text{applied field}}$ (T = constant)	$\frac{\text{metre per metre}}{\text{volts per metre}}$	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)

$$d = \varepsilon^T g \qquad (7)$$

and

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

if k is defined by

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

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.

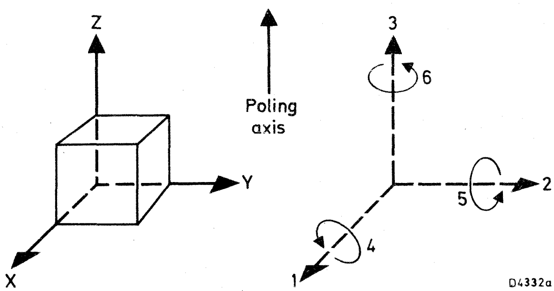


Fig. 1

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 ($k_r = k_p$).

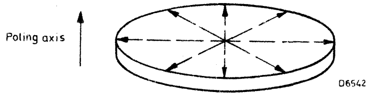


Fig. 2.

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.

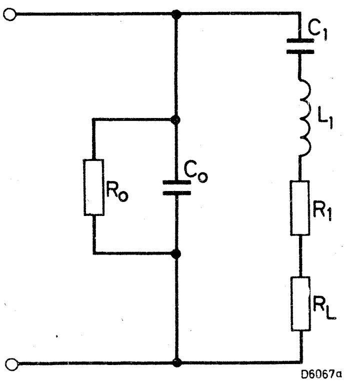


Fig. 3

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.

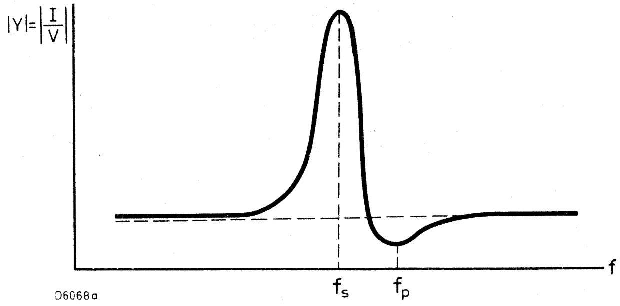


Fig. 4

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.

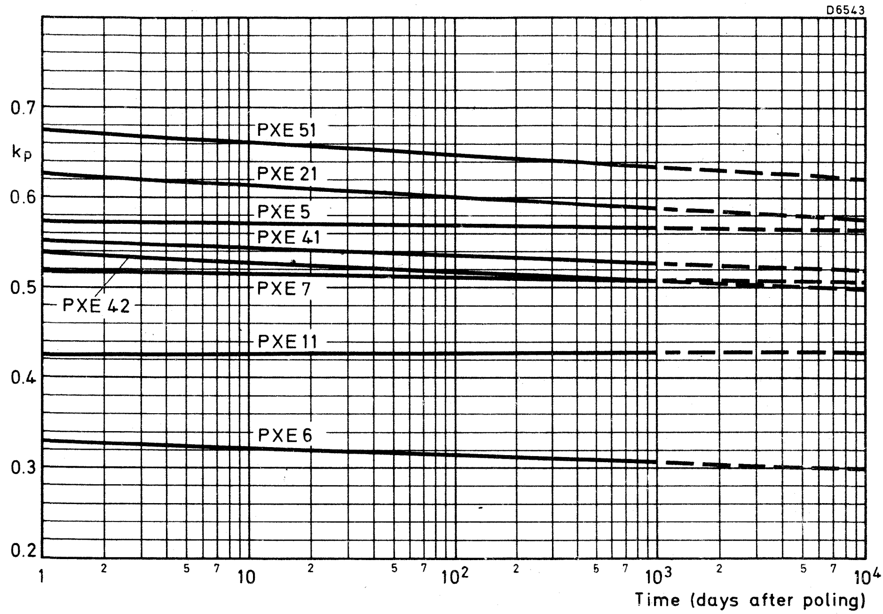


Fig. 5

PRINCIPAL PROPERTIES

Unless otherwise stated, the values are measured at 20°C ± 5°C

Property (1)	Symbol	Unit	PXE5	PXE6 (5)	PXE7	PXE11 (5)	PXE21	PXE41	PXE42	PXE51(5)(6)
THERMAL DATA										
Curie point (2)	Θ_c	°C	285	370	320	400(180) (3)	270	315	325	220
Specific heat	c	J/kg °C	420	420	420	420	420	420	420	420
Thermal conductivity	λ	W/m °C	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
MECHANICAL DATA										
Mass density	ρ_m	10^3 kg/m^3	7.60	7.70	7.75	4.50	7.75	7.90	7.80	7.70
Compliance	s_{33}^E	10^{-12}/Pa	18.9	-	15.8	9.5	18.6	14.6	15.0	17.8
	s_{11}^E		15.4	10.2	12.5	8.1	15.1	12.2	11.8	14.5
	s_{55}^E		38.5	-	35.8	24.4	-	32.0	-	-
Poisson's ratio	σ	-	≃0.3	≃0.3	≃0.3	≃0.3	≃0.3	≃0.3	≃0.3	≃0.3
Mechanical quality factor for radial mode	Q_m^E	-	≃80	≃1000	≃80	≃270	≃80	≃1000	≃750	≃50
Frequency constants	N_p^E	Hz.m or m/s	2000	2460(4)	2200	3600	2000	2200	2250	2050
	$N_3^D = \frac{1}{2} v_3^D$		1850	-	2000	2900	1900	2000	2020	1950
	$N_1^E = \frac{1}{2} v_1^E$		1460	1800	1640	2650	-	1620	-	-
	$N_5^E = \frac{1}{2} v_5^E$		930	-	970	1500	-	1020	-	-
Compressive strength	—	10^6Pa	>600	>600	>600	>600	>600	>600	>600	>600
Tensile strength	—	10^6Pa	≃80	≃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	600	700	400	1750	1200	1250	2800
	$\varepsilon_{11}^T / \varepsilon_o$	-	1800	-	1000	600	-	1130	-	-
Resistivity (25°C)	ρ_{el}	10^{12} Ωm	1	0.1	1	100	0.1	0.05	-	0.1
Time constant (25°C)	$\rho_{el} \varepsilon_{33}^T$	min.	>250	>9	>100	>6000	>25	>7	-	>40
Dielectric loss factor	tanδ	10^{-3}	16	8	20	25	16	2.5	2.5	16

Property (1)	Symbol	Unit	PXE5	PXE6 (5)	PXE7	PXE11 (5)	PXE21	PXE41	PXE42	PXE51 (5)(6)
ELECTRO-MECHANICAL DATA										
Coupling factors	k_p	-	0.58	0.32	0.52	0.43	0.62	0.56	0.55	0.66
	k_{33}	-	0.70	-	0.70	0.55	0.72	0.68	0.69	0.72
	k_{31}	-	0.34	0.19	0.31	0.25	0.37	0.33	0.32	0.39
	k_{15}	-	0.66	-	0.66	0.65	-	0.66	-	-
Piezoelectric charge constants	d_{33}	10^{-12} C/N or m/V	384	-	220	100	385	268	281	480
	d_{31}		-169	-44	-86	-47.5	-180	-119	-120	-234
	d_{15}		515	-	370	235	-	335	-	-
Piezoelectric voltage constants	g_{33}	10^{-3} Vm/N or m^2/C	24.2	-	35.4	28.2	25.0	25.2	25.4	19.3
	g_{31}		-10.7	-8.0	-14.0	-13.4	-11.6	-11.2	-10.4	-9.5
	g_{15}		32.5	-	42.0	44.0	-	33.5	-	-
TIME STABILITY										
Coupling factor	k_p	relative change per decade %	-0.5	-1.6	-0.5	-0.1	-1.5	-1.5	-2.5	-1.0
Permittivity	ε_{33}^T		-1	-0.95	-0.5	-1.6	-2	+1	-6.0	-1
Frequency constant	N_p^E		0.5	0.06	1.0	0.16	0.5	0.5	1.5	1
Quality factor	Q_m^E		-	1.5	-	-	-	10	-	-
Dielectric loss factor	tanδ		-	-	-	-	-	10	-	-

For notes (1) to (6) 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 × 10 × 0.2mm.

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

(3) In PXE 11 there is a transition from ferroelectric orthorhombic to the ferroelectric tetragonal phase at 180°C. If the material passes through this temperature in either direction, then it must be repoled.

(4) Fractional variation of N_p^E between 20°C and 65°C is less than 0.3%.

(5) Available on request.

(6) Preliminary data.

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 ($> 200\ ^{o}C$), 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

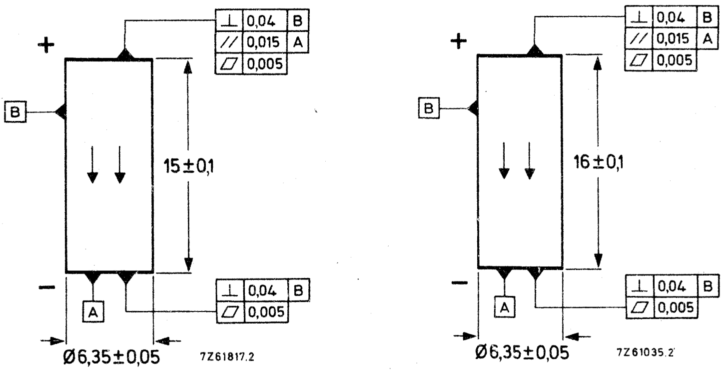
APPLICATION

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 ^{o}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 $\epsilon_{33}{}^{T}/\epsilon_{o}$	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

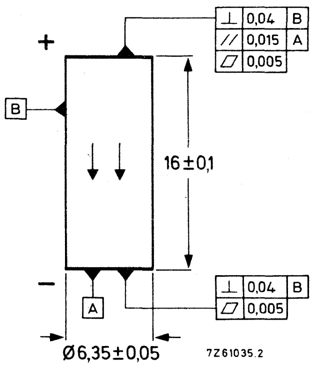
APPLICATION

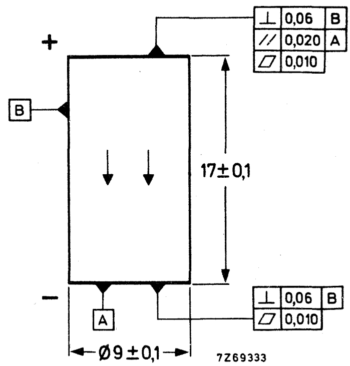
These slugs are intended for use in gas ignition mechanisms for domestic and industrial appliances.

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 IMPACT MECHANISMS

in cigarette lighters

QUICK REFERENCE DATA	
Dimensions	ϕ 3,7 mm x 5 mm
Material	PXE41
Coupling coefficient k_{33}	0,68
Capacitance	23 pF
Open output voltage, peak value (T_3 = 13000 N/cm^2)	18 kV

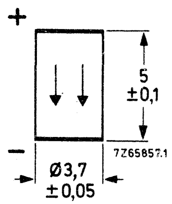
Note – The values given are nominal ones, measured at 20 ± 5 °C.

APPLICATION

This slug is intended for use in gas ignition units for cigarette lighters.

TECHNICAL DATA

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.

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, ultrasonic cleaning, and ultrasonic welding and machining.

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 directionality 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, and the well known weakness of ceramics in tension is overcome. 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 as mentioned above. 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. 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.

PIEZOELECTRIC DISCS AND RINGS
for ultrasonic cleaning and welding

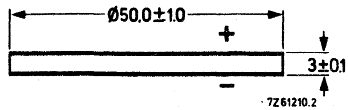
The electrodes of the discs and rings are silverplated. The electrode which has been connected to the positive terminal of the polarising apparatus, is marked. The direction of polarisation is axial.

Disc for cleaning

Material : PXE41

Nominal capacitance : 7500 pF

Catalogue number : 4322 020 05590



Dimensions in mm

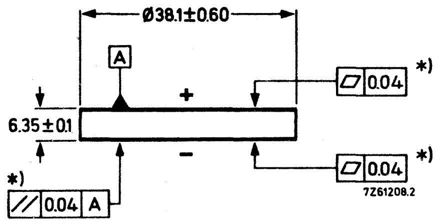
Disc for cleaning and welding

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

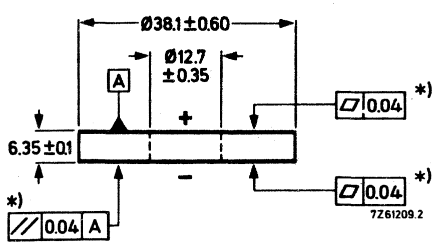
Ring for cleaning and welding

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

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

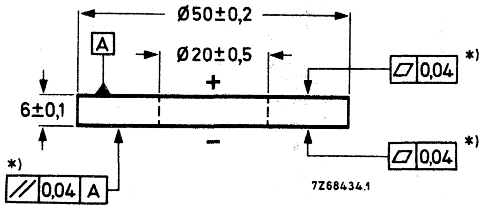
Ring for cleaning and welding

Material : PXE42

Nominal capacitance : 2800 pF

Catalogue number : 4322 020 06050

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



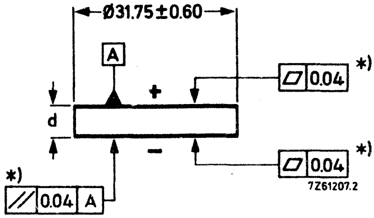
Dimensions in mm

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

PIEZOELECTRIC DISC
for echosounding probes

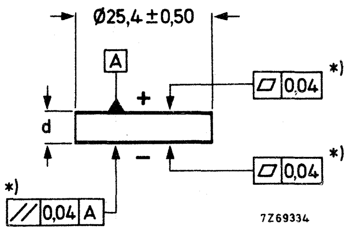
The electrodes of the discs are silverplated. The electrode which has been connected to the positive terminal of the polarising apparatus, is marked. The direction of polarisation is axial.

Material	: PXE41
Resonance frequency	: 151 ± 5 kHz (thickness mode)
Thickness (d)	: approx. 14,3 mm (adapted to resonance frequency)
Nominal capacitance	: approx. 620 pF
Catalogue number	: 4322 020 05240



Dimensions in mm

Material	: PXE41
Resonance frequency	: 200 ± 10 kHz (thickness mode)
Thickness (d)	: approx. 10,2 mm (adapted to resonance 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'.

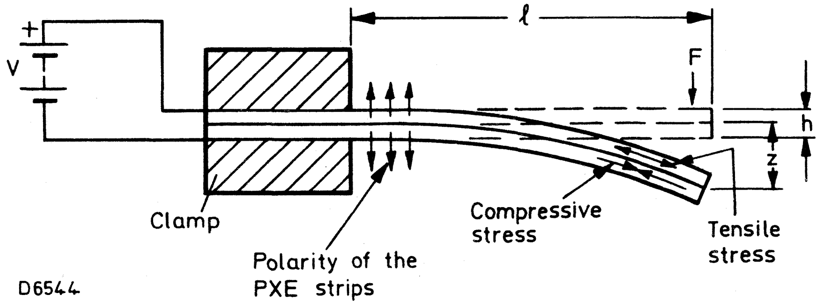


Fig. 1

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

DIMENSIONS (millimetres), MATERIAL

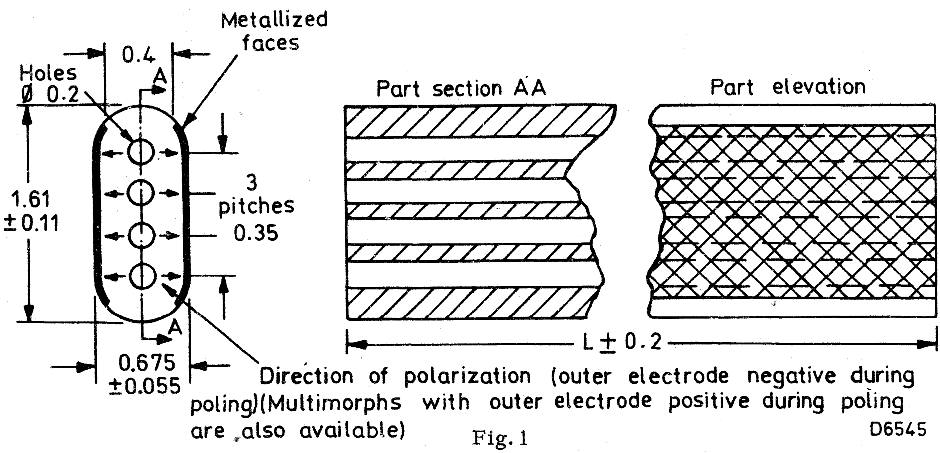


Fig. 1

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.

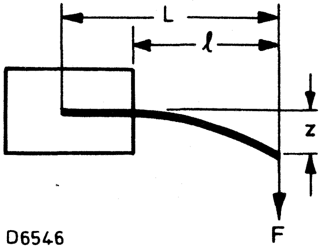


Fig. 2a

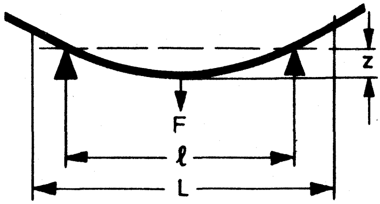


Fig. 2b

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.	52L	pF
Maximum recommended bending moment If this value is exceeded, partial depoling may result.	1.6×10^{-3}	Nm
Minimum bending moment to fracture	7.5×10^{-3}	Nm
Maximum recommended applied voltage Higher voltages may cause partial depoling.	220	V

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 above.

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 (ℓ=0.55L)	$f_o = \frac{0.9}{\ell^2} 10^6$ Hz
1st overtone	$f_1 = 6.3 f_o$	$f_1 = 2.8 f_o$ (ℓ = 0.28L)	$f_1 = 4 f_o$
2nd overtone	$f_2 = 18 f_o$	$f_2 = 5.4 f_o$ (ℓ = 0.95L)	$f_2 = 9 f_o$
3rd overtone	$f_3 = 34 f_o$	$f_3 = 8.9 f_o$ (ℓ = 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 end-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

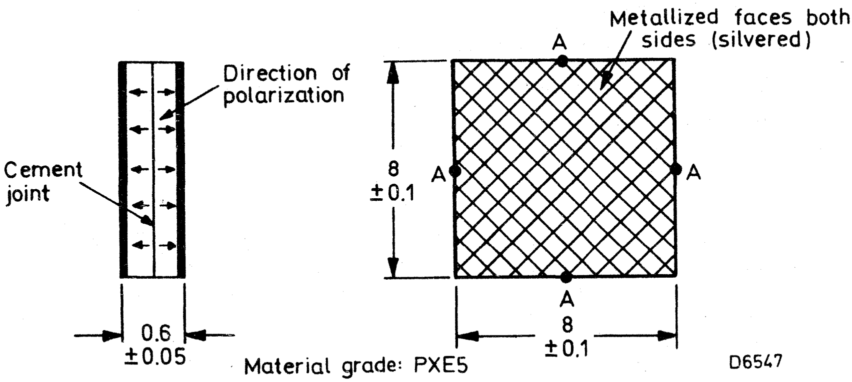
For ordering purposes please quote the 12-digit catalogue number of the multimorph.
The quantity to be ordered must be at least one box of 500 pieces or a multiple of this.

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.

DIMENSIONS (millimetres), MATERIAL



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 electro-mechanical 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 (point 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

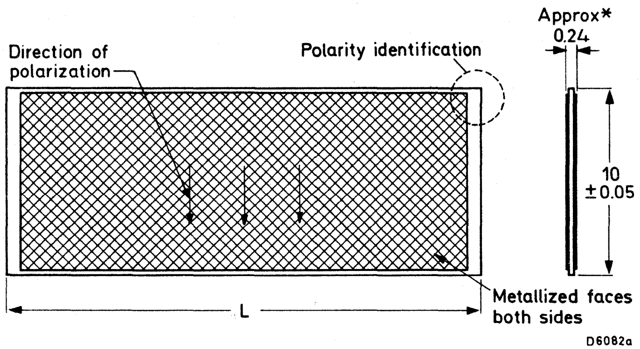
For ordering purposes please quote the 12-digit catalogue number of the bimorph. The quantity to be ordered must be at least one box of 200 pieces or a multiple of this.

DELAY LINE TRANSDUCERS

APPLICATIONS

For use in modern acoustic delay systems where an electro-mechanical 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.

DIMENSIONS (millimetres), MATERIAL



Material grade: PXE 7

Dimension L	Catalogue number
25 ± 0, 05	4322 020 12010
27 + 0, 15	4322 020 02880

*Frequency of shear vibration: 4.1 MHz ± 0.1 MHz

Information on other types is available on request.

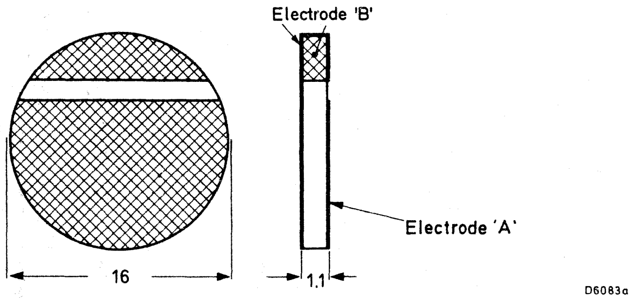
ORDERING PROCEDURE

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

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.

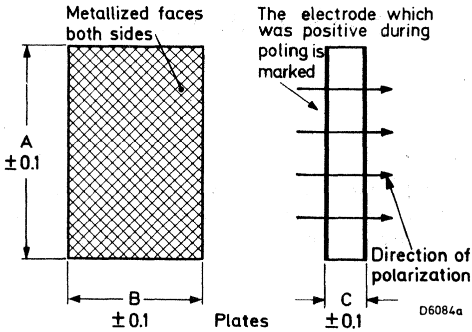


Polarity of electrode 'A' during poling: negative – 4322 020 02260
positive – 4322 020 02270

The electrode which was positive during poling is marked.

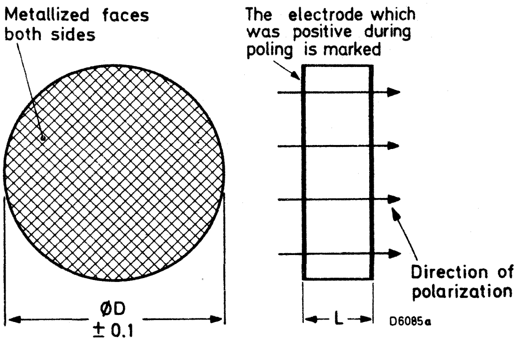
Material grade: PXE 5

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

DISCS



Dimensions (mm) ØD	L	Material grade	Catalogue number 4322 020 .....
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) ØD	L	Material grade	Catalogue number 4322 020 .....
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

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 magnetise and to demagnetise. Their magnetism is due to the electron currents in groups of similarly oriented atoms. In the unmagnetised state, these groups of atoms, known as domains, are randomly oriented, and the net polarisation of the body of the magnet is zero. When a magnetising 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 magnetising field is removed, the hard microstructure of the material prevents the domains from regaining their former disorganised arrangement and the magnet remains polarised.

In this state, the magnet has similar properties to that of an energised 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
Convertion 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

metallic alloy
ceramic material or
plastic bonded ceramic material

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

	metallic 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 characterised by high values of coercivity and resistivity while Ticonal magnets possess higher values of remanent magnetism and BH product.

Ferroxdure is therefore most suitable for applications in which demagnetising 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 (however 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.

The grades are distinguished by the addition of letters and numbers to the name of the material. The numbers are approximately relative to the nominal BH product of the grade.

* Isotropic materials can be magnetised 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 not 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 a H_{cB} well above the quoted typical value, whereas the minimum value of H_{cB} is coupled with a high value of B_r.

Designations

For plastic-bonded ferroxdure grades the letters before the numbers indicate the type of plastic material used for bonding, as follows

P = flexible thermoplastic material
SP = rigid thermoplastic material
D = rigid thermosetting material
The suffix F = flame retardant material, to 94 V-1 of UL94

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		Polarisation 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											
Ferroxdure SP5F 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)
Ferroxdure SP10;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)
Ferroxdure P30 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)
Ferroxdure P40;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)
Ferroxdure SP50 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)
Ferroxdure D55 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											
Ferroxdure SP130 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 94 V-1 of UL94.

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		Remanence		Coercivity		Polarisation coercivity		B and H at $(BH)_{max}$		Saturation field strength
	$(BH)_{max}$ kJ/m3 (MGsOe)		B_r 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.	min.
Isotropic											
Ferroxdure 100 $BaFe_{12}O_{19}$	7,6 (0,95)	7,2 (0,9)	220 (2200)	210 (2100)	135 (1700)	130 (1630)	220 (2760)				typ. 800 (typ. 10 000)
Anisotropic											
Ferroxdure 270 $SrFe_{12}O_{19}$	21,5 (2,7)	19,9 (2,5)	340 (3400)	330 (3300)	255 (3200)	247 (3100)	334 (4200)	318 (4000)	165 (1650)	131 (1650)	1114 (14 000)
Ferroxdure 280 $SrFe_{12}O_{19}$	23,0 (2,9)	21,5 (2,7)	350 (3500)	340 (3400)	239 (3000)	223 (2800)	255 (3200)	239 (3000)	180 (1800)	127 (1600)	876 (11 000)
Ferroxdure 330 $SrFe_{12}O_{19}$	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)
Ferroxdure 370 $SrFe_{12}O_{19}$	27,9 (3,5)	27,1 (3,4)	385 (3850)	380 (3800)	235 (2950)	223 (2800)	247 (3100)	231 (2900)	190 (1900)	151 (1900)	876 (11 000)
Ferroxdure 300 $BaFe_{12}O_{19}$	28,7 (3,6)	27,1 (3,4)	400 (4000)	390 (3900)	143 (1800)	127 (1600)	147 (1850)	131 (1650)	240 (2400)	119 (1500)	557 (7000)
Ferroxdure 380 $SrFe_{12}O_{19}$	27,1 (3,4)	25,5 (3,2)	380 (3800)	370 (3700)	263 (3300)	247 (3100)	279 (3500)	263 (3300)	185 (1850)	147 (1850)	955 (12 000)

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/m³ (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 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 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 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 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 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 transfer 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 transfer 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
Resonance 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
Magnetising 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
- Polarised 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

THEORY OF PERMANENT MAGNETS

Magnetic quantities are expressed in the S.I. system of units (V, A, s, m) or in the cgs system of units (Gs, Oe).

When a magnetic material is subjected to a magnetising field, the extent of the resulting magnetisation of the material will depend on the nature and immediate history of the material, and on the direction and magnitude of the magnetising field.
This dependence will be explained by describing the magnetic changes in a permanent magnet material accompanying a complete cycle of magnetisation and demagnetisation (hysteresis loop), and also the changes accompanying smaller variations in field strength (recoil line).

HYSTERESIS LOOP

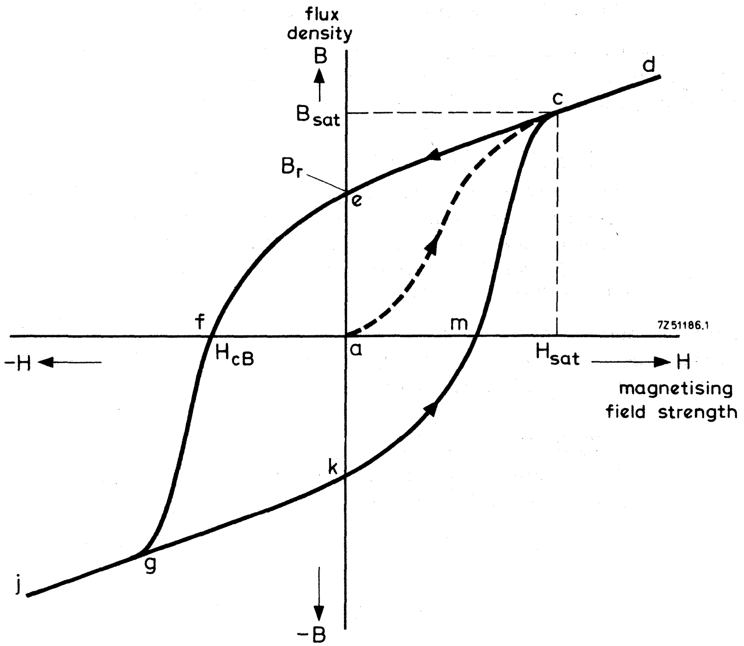


Fig. 1. Hysteresis loop, variation of flux density with applied magnetising field strength.

If the material is assumed to be completely unmagnetised before the magnetising field is applied, then the state of the material can be represented by the point a on the graph of Fig. 1, which shows the variation of flux density B in the material with magnetising field strength H applied to the material. If H is increased steadily from zero, the corresponding values of B will increase in accordance with the "initial magnetising curve" ac. If H is increased further, B will increase linearly, the slope of the straight line being constant*. Point c corresponds to the magnetic saturation of the material. The material no longer contributes to the increase in flux density, the further increase in B being attributable entirely to the relationship between the magnetising field strength and the flux density of the free space coincident with the magnetic material: $\frac{dB}{dH} = \mu_0$. The point c is defined as the point of magnetic saturation.

Saturation field strength (H_{sat})

This is the minimum field strength that has to be expended to reach the region of magnetic saturation. Here the magnetisation curve and the hysteresis loop coincide.

Saturation induction (saturation flux density) (B_{sat})

This is the value of the induction corresponding to H_{sat}.

If after saturation has been reached, H is steadily reduced, the value of B corresponds to the curve ce. When H is zero, flux density corresponding to ae resides in the material. This residual flux density is termed the remanence B_r of the material.

Remanence (B_r)

This is the induction of a magnet remaining in a closed magnetic circuit if after attaining of the saturation state the field strength returns to zero (point of intersection of the hysteresis loop with the B-axis). The units for the induction are tesla (T) or gauss (Gs).
$1\ T = 1\ Wb/m^2 = 10^4\ Gs$

When the magnetising field is reversed and is increased steadily in the opposite direction, the flux density decreases along the "demagnetisation curve" ef. At f, the flux density is zero, and the corresponding field strength is defined as the coercivity H_{cB} of the material.

Demagnetisation curve

The operating range of permanent magnets lies in the second quadrant of the hysteresis loop. This part is the demagnetisation curve.

*) In fact the slope is not yet constant at point C, but up to a certain value of H a further increase in H will cause only reversible changes in the polarisation which do not influence the course of the demagnetisation curve.

Coercivity (H_{cB})

This is the magnetic field strength at which the induction of a magnet previously magnetised up to saturation becomes zero (point of intersection of the demagnetisation curve with the H-axis).
The units for field strength are kA/m or oersted.

1 kA/m = 12,57 Oe
1 Oe = 79,58 A/m (or nearly 0,08 kA/m)

Permanent magnets have a high coercivity, i.e. broad hysteresis loops, while magnetically soft materials have a low coercivity. The difference may be greater than three powers of ten.

As the magnetising field strength is increased beyond H_{cB}, the flux density increases in the opposite direction along the curve fg. The point g is reached which corresponds to magnetic saturation in the opposite sense to that occurring at c.

Any further increase in the magnetising field gives rise to increases in B along the straight line gj. The same phenomena occur as with the part cd.

If, after saturation in the negative direction is reached, the magnetising field is reduced to zero, the flux density follows the curve gk. If the magnetising field is again reversed, the flux density follows the curve kmc, so that the loop cefgkmc is completed.

INTRINSIC HYSTERESIS LOOP

The flux density plotted in Fig. 1 is the algebraic sum of the magnetic polarisation J of the material and the flux density B_o of the space that the material occupies.

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

J is also called intrinsic flux density.
If J is plotted against H, the effect of B_o is excluded, and the resultant loop is shown in Fig. 2 together with the B/H loop.

At saturation, the polarisation hysteresis curve is horizontal. For zero applied field, the polarisation equals the flux density, and equals the remanence of the material. The magnetising field required to remove the polarisation is shown by the intersection of the curve and the horizontal axis. This field strength - the polarisation coercivity H_{cJ} - is greater than the coercivity HcB. The difference between H_{cB} and H_{cJ}, however, depends on the shape of loop: if the loop cuts the horizontal axis at a small angle, the difference will be significant; if the loop cuts at an angle approaching 90^o, it will be negligible.

Polarisation coercivity (J)

This is the magnetic field strength at which the polarisation of a magnet previously magnetised up to saturation becomes zero (point of intersection of the polarisation demagnetisation curve with the H-axis).

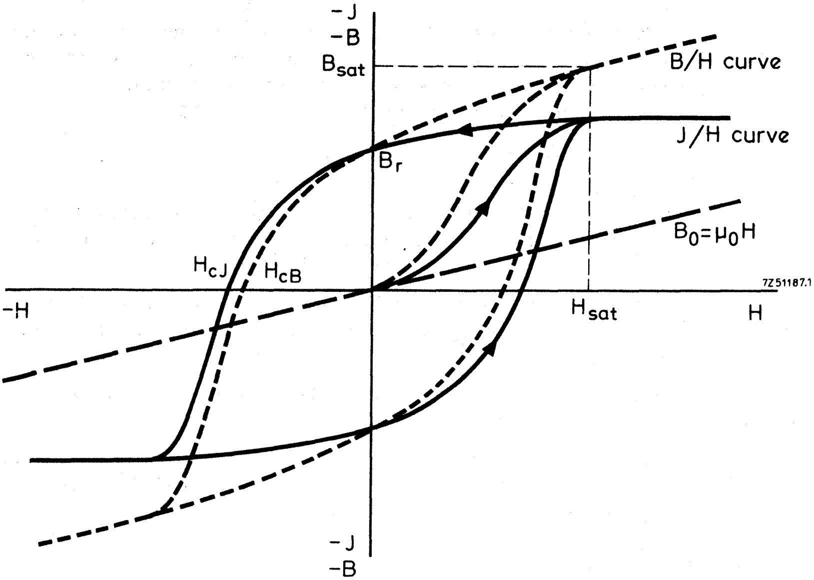


Fig. 2. Comparison of variations of flux density and polarisation with applied magnetising field strength.

DEMAGNETISATION CURVE

Complete hysteresis loops are important when considering soft magnetic materials, but with hard or permanent magnetic materials, it is the second (or fourth) quadrant that is of importance to the designer. The second quadrant shows the response of the magnetised material to demagnetising fields, and is therefore called the demagnetisation curve.

A typical normal demagnetisation curve for permanent magnetic materials is shown in Fig. 3. Also shown in Fig. 3 is a curve indicating the variation of the product BH with B. The product BH indicates the energy available in the material for a given value of B. It can be seen that a maximum value of BH-product exists, and this is designated $(BH)_{max}$. This maximum corresponds to a flux density of B_d and demagnetising field strength H_d and these, in general, represent the ideal operating point for the most efficient use of the material under static conditions.

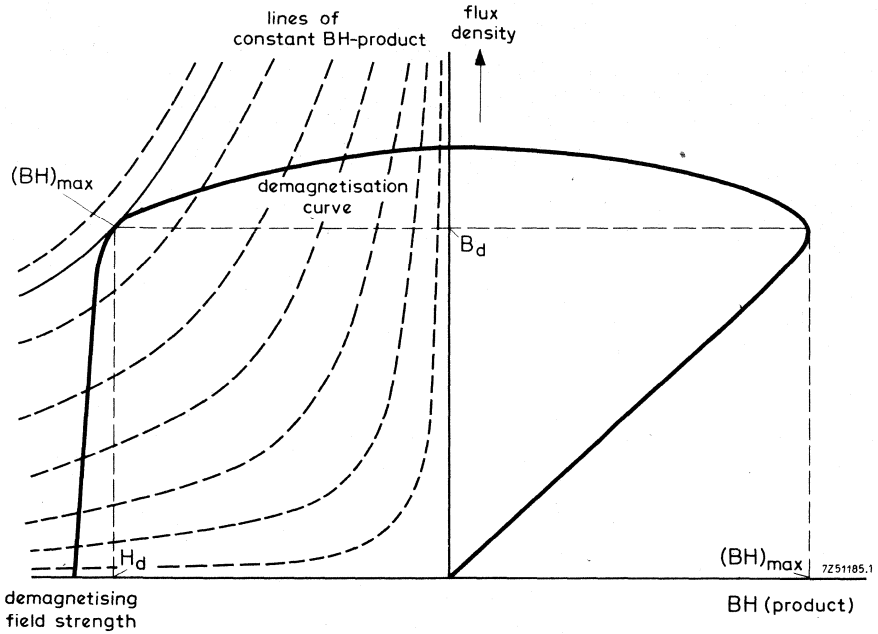


Fig. 3. Demagnetisation curve with contours of constant BH-product, and BH-product curve.

Maximum BH product $\left[(BH)_{max}\right]$

This is the maximum product of the flux density and corresponding field strength of a permanent magnet attained on the demagnetisation curve. The maximum energy in the field external to the magnetic material, per unit volume of the permanent magnet, is:

$$\frac{(BH)_{max}}{2} \text{ (S.I. units) or } \frac{(BH)_{max}}{8\pi} \text{ (c.g.s. units)}$$

The units of $(BH)_{max}$ are kilojoule/m^3 or megagauss. oersted

1 MGs. Oe = 8 kJ/m^3 = 8 mJ/cm^3 (precise factor 7,958)

(1 T.A/m = 1 Wb.A/m^3 = 1 Vs.A/m^3 = 1 Ws/m^3 = 1 J/m^3)

The values of B and H at $(BH)_{max}$ are designated B_d and H_d.

The maximum BH-product of a material occurs at the point on the demagnetisation curve where a contour line of constant BH-product of the graph would just touch it (Fig. 3).

RECOIL LINE

The demagnetisation curve of a permanent magnetic material is a smooth curve indicating the decrease in flux density with a steadily increasing demagnetising field. If a constant demagnetising field is applied to the magnetic material, the corresponding value of flux density can be obtained from the curve. However, under practical conditions, the demagnetising field will probably not be constant. Small variations can be caused by small local magnetic fields, and large variations can occur in motors and generators (which are subject to varying armature reaction and can even have their armatures removed completely). It is therefore necessary to study the effects of such variations in the demagnetising field.

If a demagnetising field of strength H_1 is applied to magnetic material which has been saturated, the flux density will fall from its remanence value B_r to some value B_1 which corresponds to the point A_1 on the demagnetisation curve of Fig. 4.

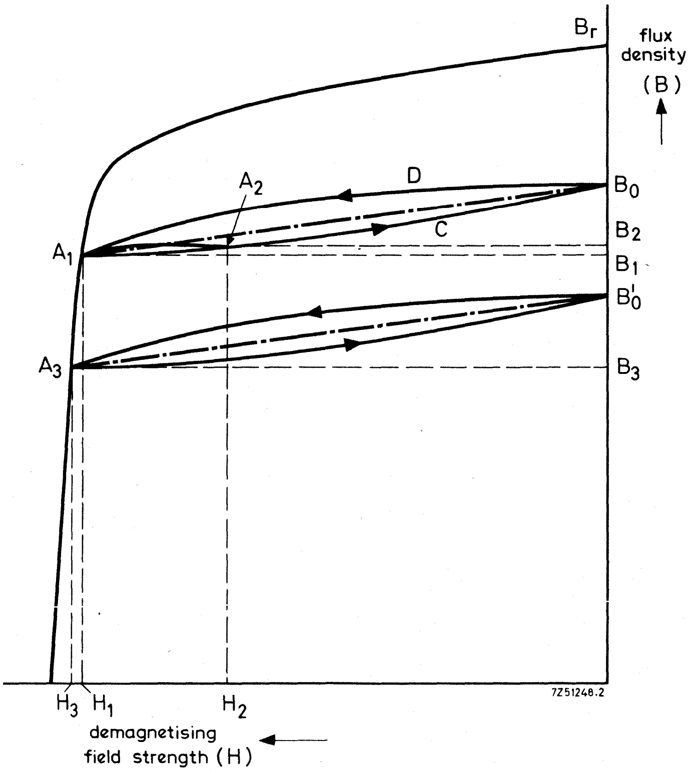


Fig. 4. Recoil lines.

If H is reduced to zero, the flux density does not follow the demagnetisation curve back to the starting point, but follows a path A_1CB_0 which leaves the demagnetisation curve abruptly. If H_1 is now restored, the flux density follows the path B_0DA_1 which ends in A_1, but which deviates from the path A_1CB_0.

The loop $A_1CB_0DA_1$ so formed constitutes a minor hysteresis loop of the material. If the demagnetisation field strength H_1 is only reduced to some value H_2 instead of being removed completely, and is then restored, another minor hysteresis loop is formed ($A_1A_2A_1$). For permanent magnetic materials, these minor hysteresis loops are very slender, and can be considered to form the straight line joining A_1 and B_0. This line is called a recoil line. The slope of the recoil line is the recoil permeability. It can be shown that the slope of a recoil line is approximately equal to the slope of the demagnetisation curve at its intersection with the vertical axis.

Recoil line

A very narrow hysteresis loop which is traversed during a limited variation of the demagnetising field strength in a permanent magnet.

Recoil permeability (μ_{rec})

The relative permeability corresponding to the slope of a recoil line.

If the demagnetising field strength H_1 is increased to some value H_3, the operating point will move along the demagnetisation curve to the point A_3 corresponding to a flux density of B_3. Reduction of the demagnetising field strength to H_1 does not restore the working point to A_1, but moves it along another recoil line $A_3B'_0$, parallel to A_1B_0. Any reduction in H_3 will only cause the working point to move along the recoil line: the point A_1 can only be regained by resaturating the material and then applying the demagnetising field strength H_1.

The effects of increases in the demagnetising field when the operating conditions of the material corresponds to a point on the demagnetisation curve are thus irreversible (except by the expedient of resaturation), so in designs where a high degree of magnetic stability is required it is usual to operate on a recoil line. A demagnetising field greater than that likely to be encountered in normaluse use is applied, and this is then reduced to the normal working value (stabilisation). Fluctuations in the demagnetising field will then only cause fluctuations of the working point along a recoil line.

TEMPERATURE COEFFICIENT

The characterise the behaviour of the material of a permanent magnet with changes in temperature the temperature coefficient of the remanence or of the coercivity is indicated in percent per ^{o}C.

$$\alpha_{Br} = \frac{1}{B_r}\frac{dBr}{dT} \times 100\,\%/^{o}C$$

$$\alpha_{HcB} = \frac{1}{H_{cB}}\frac{dH_{cB}}{dT} \times 100\,\%/^{o}C$$

CURIE TEMPERATURE AND TRANSITION TEMPERATURE

At the Curie temperature the material becomes practically non-magnetic, and the magnetism can only be restored by renewed magnetisation below this temperature. At the transition temperature the crystal structure is changed (e.g. formation of mixed crystals); this also leads to irreversible changes of the magnetisation, but these cannot be nullified by renewed magnetisation. The limit for the practical application of permanent magnet materials is in specific cases set by whichever of these temperatures is the lower.

MAGNETIC CIRCUIT DESIGN

Dimensions of magnet

The principal object of magnet circuit design is to provide efficiently a specified magnetic field in a given load (or air gap). The design of the circuit is governed by the required field strength, the dimensions of the air gap, the flux leakage from the surfaces of the magnet and the reluctance of the assembly.

In the simple circuit of Fig. 5, A_g and L_g are the area (assumed equal to that of the pole pieces) and length of the air gap respectively, and A_m and L_m are the area and length of the magnet necessary to produce the required gap field strength H_g.

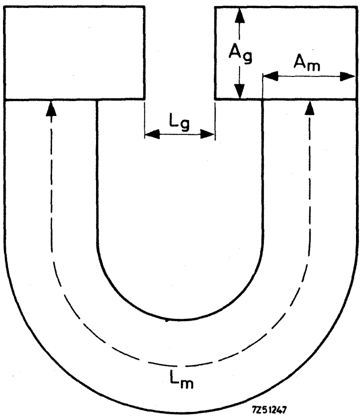


Fig. 5. Simple magnetic circuit

If, initially, flux leakage is neglected, then all lines of flux in the magnet cross the air gap. Therefore the total flux in the gap equals the total flux in the magnet. By definition, total flux equals the product of flux density and area. Thus:

$$B_m A_m = B_g A_g,$$

where B_g and B_m are the flux densities in the gap and magnet respectively. Since for an air gap, $B_g = \mu_0 H_g$, this equation can be written:

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

NOTE : When B is expressed in gausses and H in oersteds, then μ_0 = 1 gauss/oersted; when B is expressed in T and H in A/m, then $\mu_0 = 4\pi \cdot 10^{-7}$ H/m.

Magnetic flux is produced by magnetomotive force, and the ratio between m.m.f. and flux is termed the reluctance of the magnetic circuit. (This relationship is the magnetic analogy of Ohm's Law, flux, m.m.f., and reluctance corresponding to current, voltage, and resistance respectively).

In Fig. 5 the m.m.f. across the air gap is the product of the field strength H_g in the gap and the length L_g of the gap. The m.m.f. across the magnet is similarly the product of the field strength H_m in the magnet and the length L_m of the magnet. If there is no leakage from the surfaces of the magnet these values of m.m.f. are equal. Therefore:

$$H_m L_m = H_g L_g. \text{ (irrespective of sign)} \qquad (2)$$

Equations (1) and (2) give the formulas for the design of magnetic circuits, assuming no flux losses. In practice, a loss or leakage factor must be introduced into each equation. The practical design equations thus become:

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

and

$$H_m L_m = q H_g L_g \qquad (4)$$

where p and q represent the loss or leakage factors.

Leakage factor

The total flux in a magnetic circuit is made up of the useful flux and the leakage flux. A certain amount of leakage can never be avoided completely, and it becomes appreciable particularly in a magnetic circuit with small magnetic conductance of the air gap. In the calculation of a magnet the leakage is taken into account by the leakage factor

$$p = \frac{\text{total flux required}}{\text{useful flux in air gap}}$$

The leakage factor p in the equation (3) varies widely from one application to another. It will be a minimum when the magnet is as close to the working gap as possible. The precise calculation of p is extremely difficult, and an acceptable estimate must be based on experience. As a guide, some typical leakage factors are given in the following table.

Application	approximate leakage factor
Loudspeaker with Ticonal centrepole magnet, 19 mm (3/4 in) voice coil, up to 650 mT (6,5 kGs)	2
Loudspeaker with Ticonal centrepole magnet, 25 mm (1 in) voice, 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

Application	approximate leakage factor
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 semicircular magnets	2
Moving coil meter using Ticonal centrepole 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

The loss factor q in equation (4) is attributable to unwanted reluctances in series with the useful air gap. Compensation for these can generally be effected by assuming a value of q of about 1,1 (thus increasing the required length of magnet by 10%).

Equations (3) and (4) can be rewritten as:

$$A_m = \frac{p\mu_0 H_g}{B_m} \cdot A_g, \tag{5}$$

and

$$L_m = \frac{qH_g}{H_m} \cdot L_g. \tag{6}$$

The product of equations (5) and (6) gives:

$$V_m = \frac{pq\mu_0 H_g{}^2 V_g}{B_m H_m}, \tag{7}$$

where V_m and V_g are the volumes of the magnet and gap respectively.

For a given magnetic material, and therefore a given demagnetisation curve, an infinite number of combinations of length and area of magnet can be chosen for a given volume by varying the point B_mH_m on the demagnetisation curve. However, the minimum volume of material will be given when the product B_mH_m is a maximum. Thus the most efficient use of the material is obtained by operating at the design points B_d and H_d, corresponding to maximum BH-product, $(BH)_{max}$.

Thus for greatest efficiency, the design equations become;

$$A_m = \frac{p\mu_0 H_g}{B_d}.A_g, \tag{8}$$

and

$$L_m = \frac{qH_g}{H_d}.L_g, \tag{9}$$

Equations (3) and (4) can be combined to give:

$$B_m = \frac{p}{q} : \frac{A_g}{A_m} . \frac{L_m}{L_g} \cdot \mu_0 H_m, \tag{10}$$

which can be represented as the straight line OP_1 (load line), in Fig. 6, having a slope

$$\cot\alpha = \frac{B_m}{H_m} = pA_g L_m \mu_0 / qA_m L_g. \tag{11}$$

The intersection of the load line and the demagnetisation curve, P_1, is the working point which, if the design is for maximum efficiency, will be the point having the coordinates B_m, H_m = B_d, H_d.
However, operation on the demagnetisation curve does not give maximum stability: for highly stable operation the working point should lie on a recoil line.

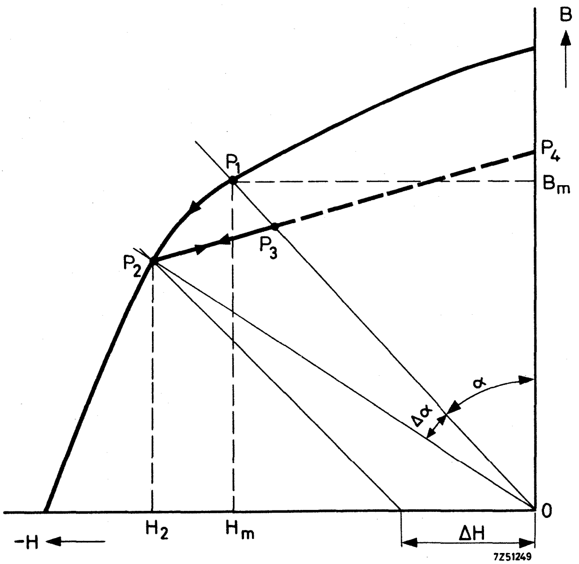


Fig. 6. Demagnetisation curve with load line and recoil line.

VARIABLE WORKING POINT AND STABILISATION

If the dimensions of a magnet and its air gap are given, the working point on the demagnetisation curve is fixed. However, when changes in the dimensions of the air gap occur, these bring about changes in the slope of the load line (see equation 11 and $\Delta\alpha$ in Fig. 6), or when an additional magnetic field occurs (ΔH in Fig. 6) the load line is shifted to a parallel position. The working point may move, by one of these events, to P_2 on the demagnetisation curve. If the change is reversed again, the working point returns along the recoil line ; the new working point then lies at P_3, the point of intersection of this line with the old load line. (The slope of the recoil line equals $\mu_0 . \mu_{rec}$.)
For adequate stabilisation, a stabilising demagnetising force should be applied to the magnet greater than the maximum demagnetising influences likely to be encountered during normal operation.

Note: As long as the change from P_1 to P_2 takes place along the straight part of the demagnetisation curve, the working point P_3 will not differ appreciable from P_1. It is therefore sometimes worth while to let the load line not pass through the point of $(BH)_{max}$ but to choose a smaller angle α , in order to remain always within the straight part of the curve. Especially with permanent magnets which will be magnetised outside their system or which may be taken out of their system it is then necessary to investigate whether, after assembly, the new working point will still lie on the straight part of the demagnetisation curve.

Changes in the induction will also take place on account of temperature changes below the Curie or transition temperatures, and are determined by the temperature coefficient. Such a change of the induction with temperature is only reversible within a certain temperature region. The irreversible changes may become particularly great if the working point on account of the temperature changes moves down beyond the knee of the demagnetisation curve. Also for this reason it is often advisable to arrange for the working point, by means of appropriate dimensioning of the system, to lie sufficiently far above the knee.

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 magnetisation

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 demagnetisation curve

J = magnetic polarisation

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} = polarisation coercivity

H_d = demagnetising field strength at $(BH)_{max}$

H_g = field strength in the air gap

H_m = demagnetising field strength in the magnet

H_{sat}, H_s = saturation field strength, field strength required for saturation

l_g (L_g) = length of the air gap parallel to the lines of flux

l_m (L_m) = effective magnetic length of magnet

N = total number of turns

Λ = permeance

R_m = reluctance

μ = permeability/normal permeability

μ_{rec} = recoil permeability

ϕ = magnetic flux/total flux

CONVERSION OF UNITS

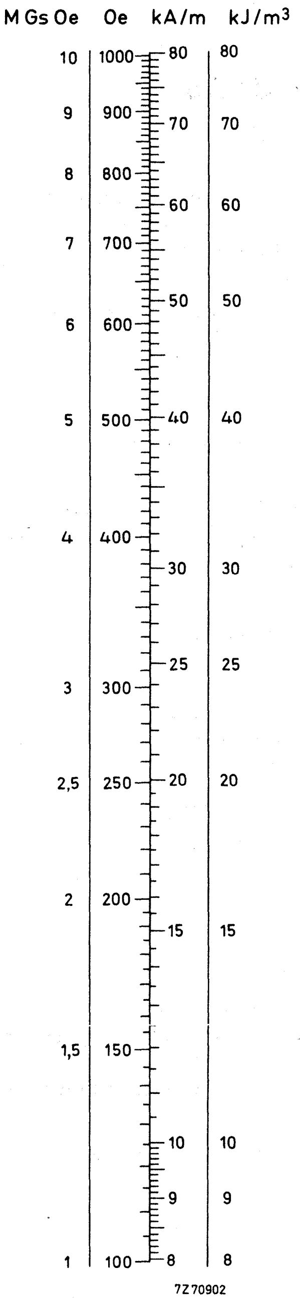
S.I. units →	c.g.s. units	
1 T (tesla) = 1 Wb/m^2 = 1 Vs/m^2	= 10^4 Gs = 10 kGs	
1 mT	= 10 Gs	
1 A/m	= 4π x 10^{-3} Oe = 0,01257 Oe	*
1 kA/m	= 4π Oe = 12,57 Oe	*
1 Wb (weber) = 1 Vs = 1 Tm^2	= 10^8 Mx	
1 μWb	= 100 Mx	
μ_0 = 4π x 10^{-7} H/m = 1,257 μH/m	μ_0 can be replaced by 1 Gs/Oe	
1 H/m = 1 Vs/Am		
1 J/m^3 = 1 TA/m	= 4π x 10 GsOe = 125,7 GsOe	*
1 kJ/m^3 = 1 mJ/cm^3	= 4π x 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 magnetisation. 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 magnetised or unmagnetised.

(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	$\pm 1^{o}$
between a ground and a cast or shell-moulded face	$\pm 3^{o}$
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.

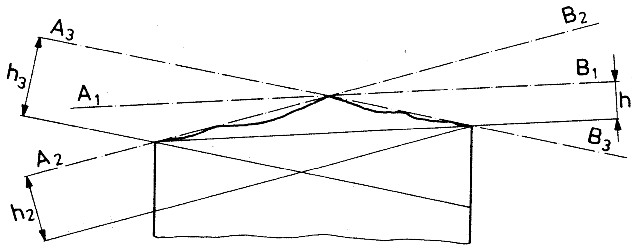


Fig. 1

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.

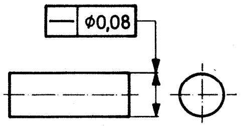
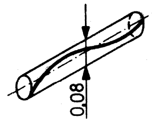
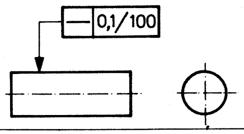
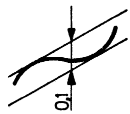
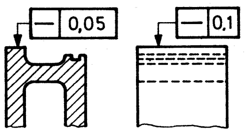
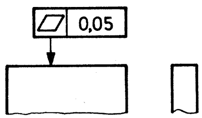
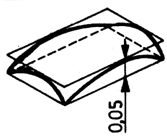
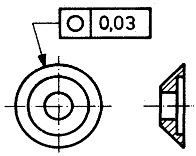
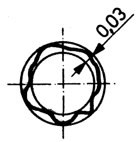
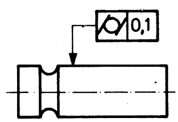
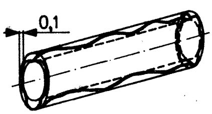
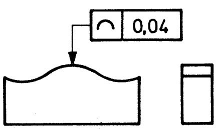
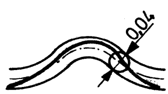
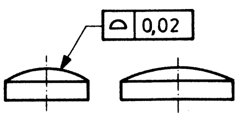
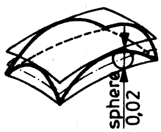
2. In some cases it may also be desirable to indicate the position of certain points which will possibly form a temporary datum feature for both manufacture and inspection.

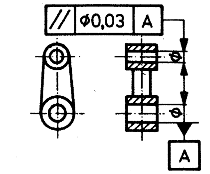
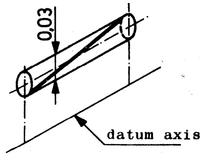
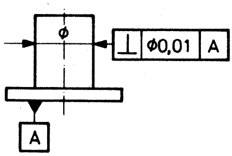
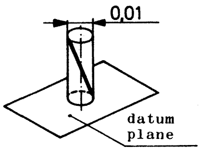
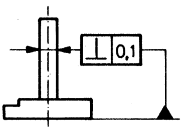
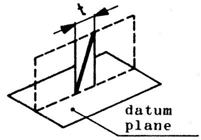
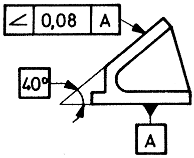
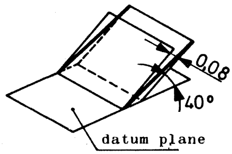
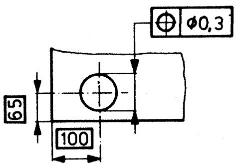
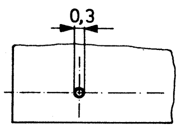
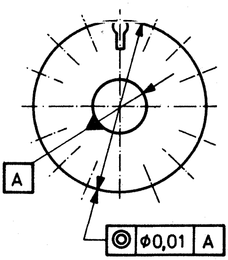
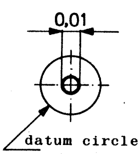
3. Symbols

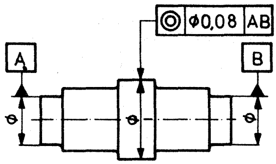
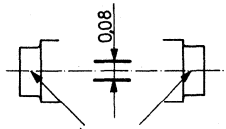
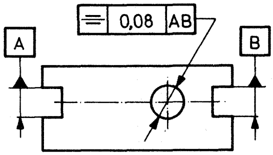
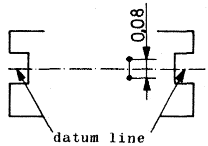
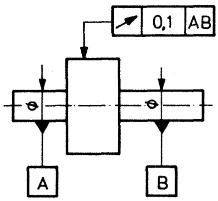
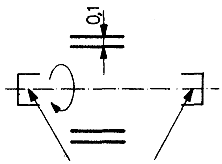
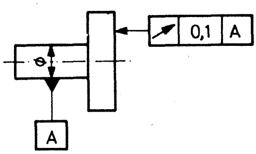
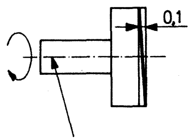
The following symbols represent the types of characteristics to be controlled by the tolerance.

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		 datum axis	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		 datum line	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 	 datum axis	During one complete revolution around the datum axis "AB" radial runout should be not more than 0,1.
	axial run-out 	 datum axis	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 MAGNETISATION

DRAWING SYMBOLS AND TERMINOLOGY

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

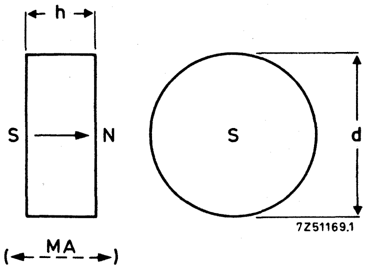
For the magnetic axis, or the preferred direction of magnetisation in unmagnetised anisotropic magnets: the symbol ←MA→.

For the direction of magnetisation in magnetised magnets: the symbol →N or S→N.

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

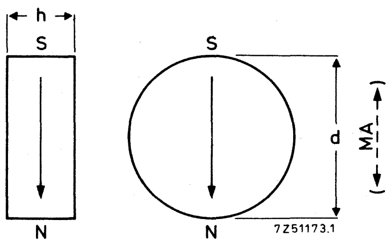
Magnetisation for isotropic and anisotropic magnets

A



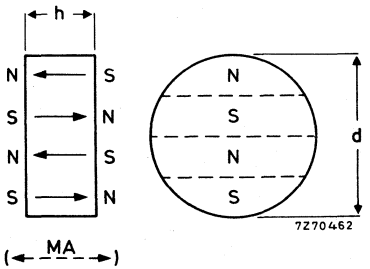
axial.

B



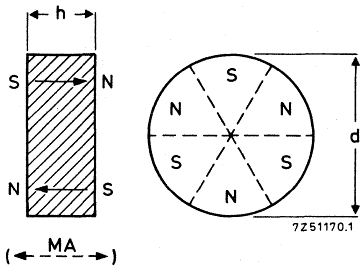
diametrical
(to be used also for rings and cylinders).

C



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

D

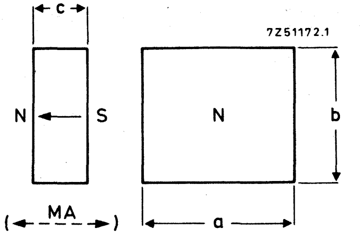


axial, n-poles,
neutral zones radial
(in the example n = 6).

NOTE: When ordering, please give the alphabetic designation and page date, e.g.: magnetisation C, January 1975, 2 poles.

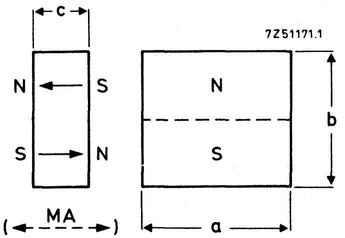
Magnetisation for isotropic and anisotropic magnets (continued)

E



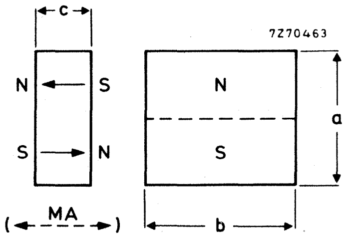
perpendicular to a x b.

F



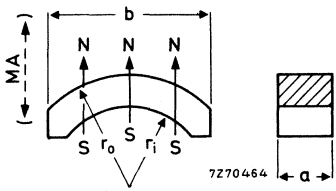
perpendicular to a x b, n poles,
neutral zone parallel to side a
(in the example n = 2).

G



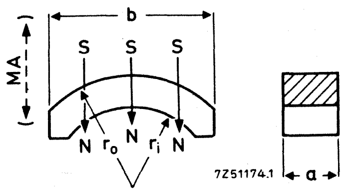
perpendicular to a x b, n poles,
neutral zone parallel to side b
(in the example n = 2).

H



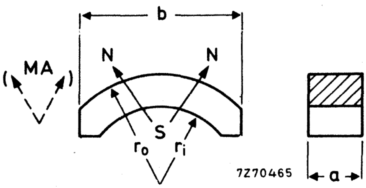
parallel (also called diametrical),
S-pole inside.

J



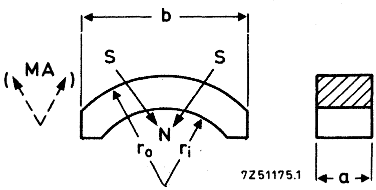
parallel (also called diametrical),
N-pole inside.

K



radial, S-pole inside.

L

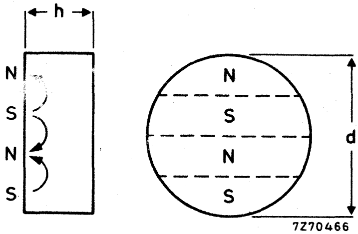


radial N-pole inside.

NOTE: When ordering, please give the alphabetic designation and page date, e.g.: magnetisation C, January 1975, 2 poles.

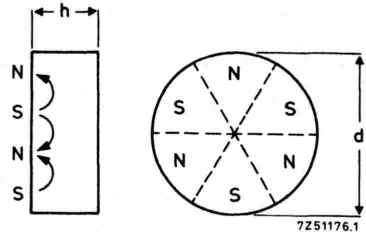
Magnetisation for isotropic magnets only

M



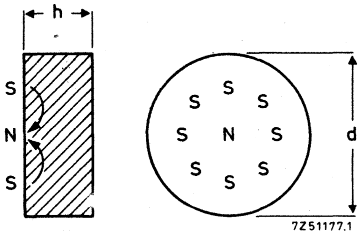
lateral, n parallel poles on one face only, (in the example n = 4).

N



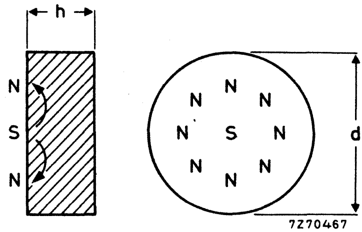
lateral, n pole sectors on one face only, (in the example n = 6).

O



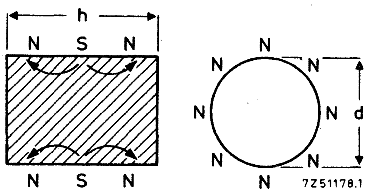
lateral, 2 poles on one face only, centred N-pole with concentric S-pole.

P



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

Q



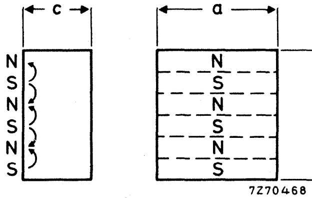
lateral, n annular poles (in the example n = 3).

NOTES

1. Magnetisations M, N, O, P, R and S can also be applied to both faces.
2. When magnetisations M, 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.: magnetisation C, January 1975, 2 poles.

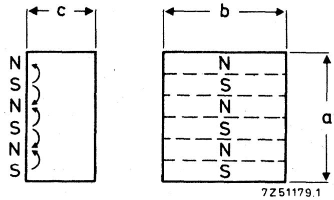
Magnetisation for isotropic magnets only (continued)

R



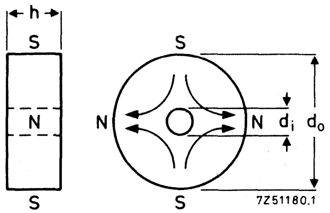
lateral, n poles on one a x b face,
poles parallel to side a
(in the example n = 6).

S



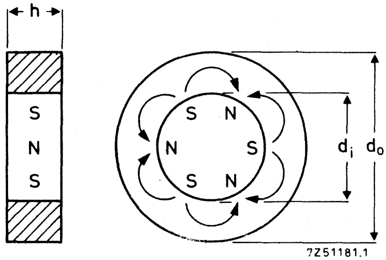
lateral, n poles on one a x b face,
poles parallel to side b
(in the example n = 6).

T



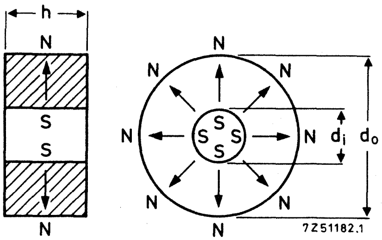
lateral, n poles on outer circumference,
neutral zones axial
(in the example n = 4).

W



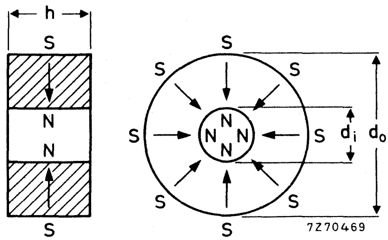
lateral, n poles on inner circumference,
neutral zones axial
(in the example n = 6).

X



radial, S-pole inside.

Y



radial, N-pole inside.

U unmagnetised magnets

NOTES

1. Magnetisations M, N, O, P, R and S can also be applied to both faces.
2. When magnetisations M, 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. magnetisation C, January 1975, 2 poles.

MARKING OF PERMANENT MAGNETS

If it is required to identify magnetised magnets of the same outline but with different directions of magnetisation, 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 MAGNETISING AND DEMAGNETISING

PRE-MAGNETISED MAGNETS

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

MAGNETISATION

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

It is essential that the field strength used for magnetising 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 magnetising equipment should be high enough to saturate the shielding circuitry also. For complicated magnetic circuits, advice should be sought.

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

DEMAGNETISATION

Partial demagnetisation of permanent magnets may be necessary for stabilisation purposes. Metal magnets not larger than 1 kg in weight can usually be demagnetised using the 50 Hz mains electricity supply. The partial demagnetisation 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 demagnetisation is often undertaken to facilitate handling and assembly. Complete demagnetisation 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 by applied to plastic-bonded Ferroxdure, where complete demagnetisation has to be effected by alternating current.

Complete demagnetisation of Ticonal is achieved in a similar way to partial demagnetisation, 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.

DEMAGNETISATION (continued)

Theoretically, alternating fields of about 15 kA/m (about 2000 Oe) peak value are sufficient to demagnetise 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 demagnetised by raising the temperature of the magnet above the Curie temperature (about 850 °C). Even raising the temperature above 600 °C will permanently destroy the magnetic performance.

Demagnetisation 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 magnetised cylinders, discs and rings	
perpendicular to M.A.	bottom limit dimensions
parallel to M.A.	mid-limit (nominal)
- Diametrically magnetised cylinders and discs	bottom limit diameter and height
- Diametrically magnetised 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-demagnetisation. The high electrical resistivity - some 10^{10} times that of iron-minimises 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.

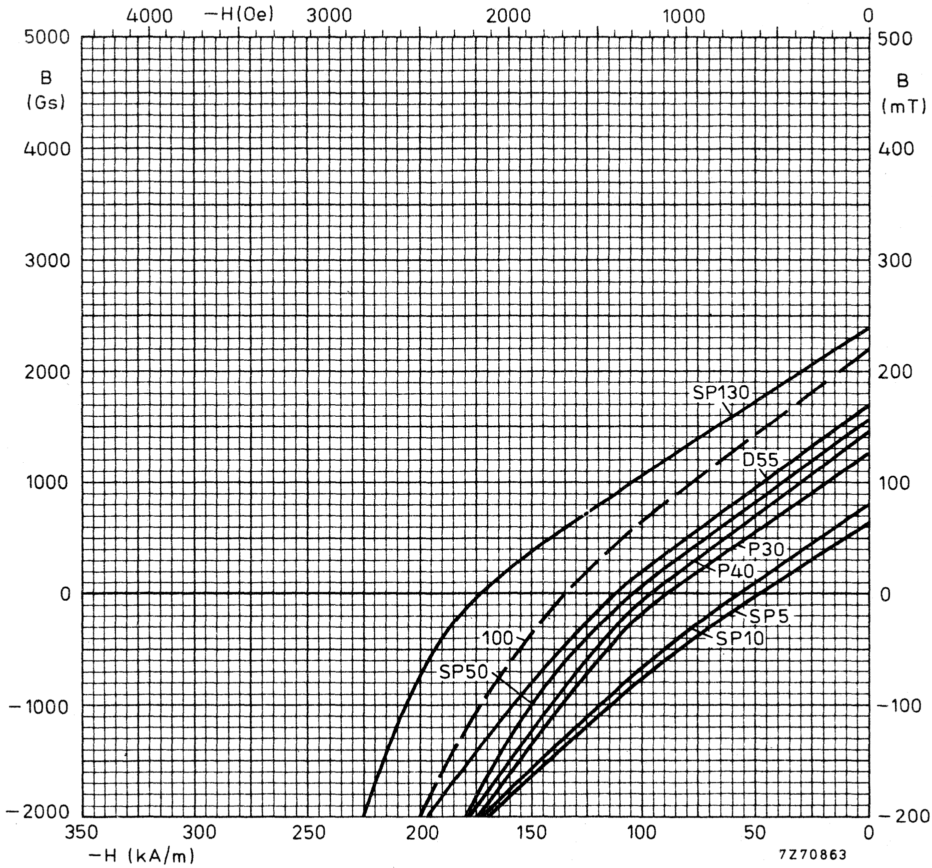
Anisotropic plastic-bonded Ferroxdure

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

Anisotropic sintered Ferroxdure

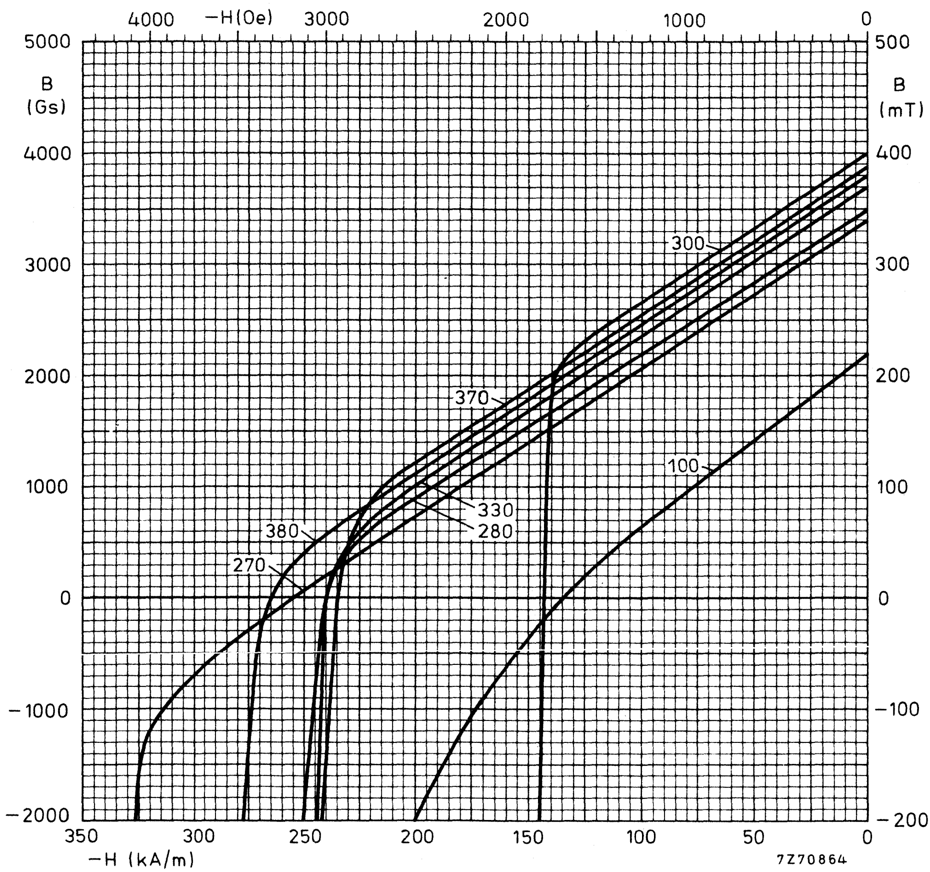
Ferroxdure 270, 280, 330, 370 and 380

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

Ferroxdure 300

This material has the highest values for $(BH)_{max}$ and B_r and is therefore especially suitable for 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 magnetised in its system.



Typical demagnetisation curves at 25 °C of sintered Ferroxdure

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

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 wavetubes
Clocks and watches.

Ferroxdure 270, 280, 330, 370 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 demagnetisation 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 %/^{o}C and a positive temperature coefficient of coercivity of about 0, 4 %/^{o}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 demagnetisation 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 demagnetisation curve. If this happens, there will be a permanent loss of flux. This is because the published demagnetisation curves are for materials at 25 ^{o}C; at other temperatures the magnetisation curves will be different, Fig. 1.

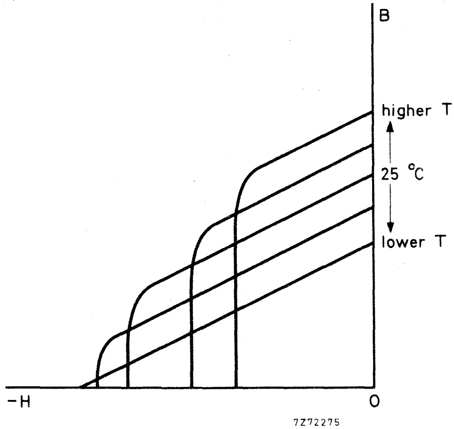


Fig. 1

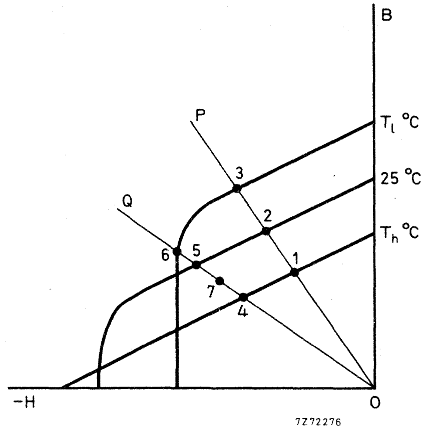


Fig. 2

The point on the demagnetisation 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 ^{o}C, 1 at some higher temperature and 3 at some lower temperature. All three points are on the upper straight line part of the demagnetisation 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 ^{o}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 ^{o}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 °C and warmed-up to 25 °C:

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

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

For high temperature operation, the working line should cut the demagnetisation 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 realised, 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
Polarisation 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 magnetised 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.	4×10^3 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 MAGNETISATION

Ferroxdure D55 is an isotropic material and may therefore be magnetised in any direction. Where magnets are to be supplied magnetised, the pole pattern must be shown on the magnet drawing.

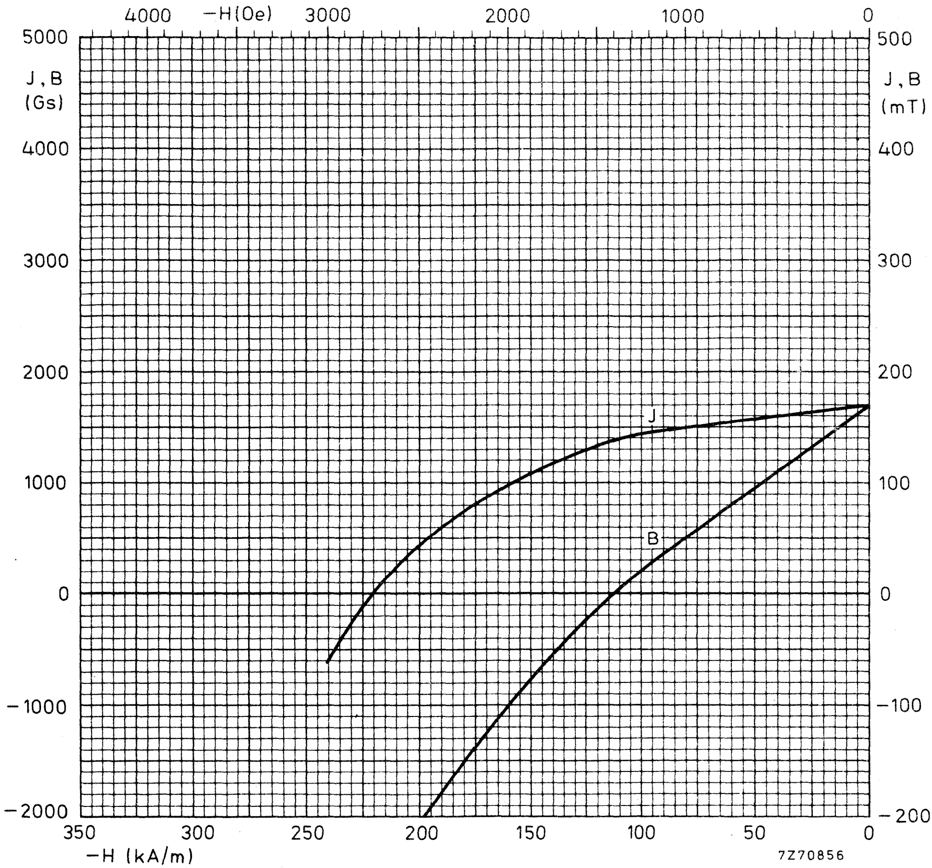
QUALITY AND FINISH

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 DEMAGNETISATION 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 realised, 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
Polarisation 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 magnetised test piece for 48 h at −30 °C and 48 h at +90 °C the changes in its magnetic properties do not exceed ± 3% of the initial values.

PHYSICAL PROPERTIES

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

PHYSICAL PROPERTIES (continued)

	Typical values at ambient temperature after 100 h storage at:			
	−50 ± 2 °C	25 ± 2 °C	70 ± 2 °C	
Shore C hardness after 10 s	55 ± 10	55 ± 10	70 ± 10	
Tensile strength at uniform speed of 50 mm/min	200	200	250	N/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 MAGNETISATION

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

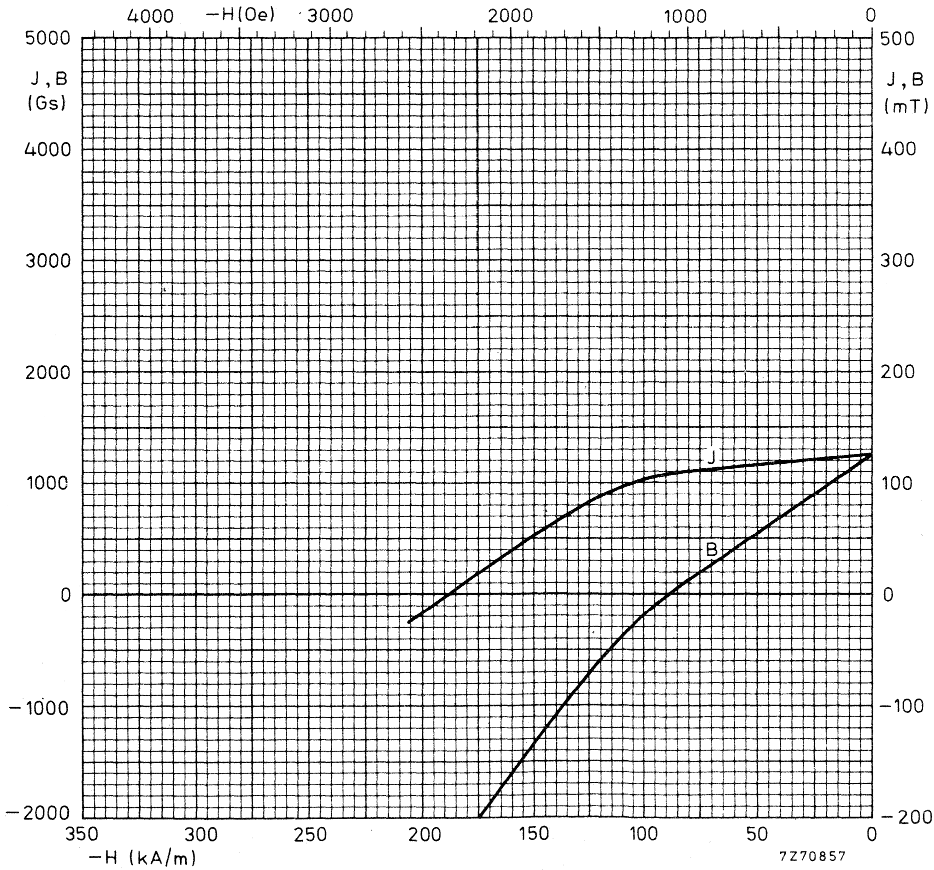
QUALITY AND FINISH

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 DEMAGNETISATION 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 realised, 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
Polarisation 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 magnetised 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/m^3 ($3,7$ g/cm^3)
Maximum temperature range (continuous)	−50 to +90 °C
Flame retardance of P40F	to 94 V-1 of UL94

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 up to 5 h	25 °C life test	70 °C up to 5 h	70 °C 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 MAGNETISATION

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

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[1]) Broad face in contact with mandrel.

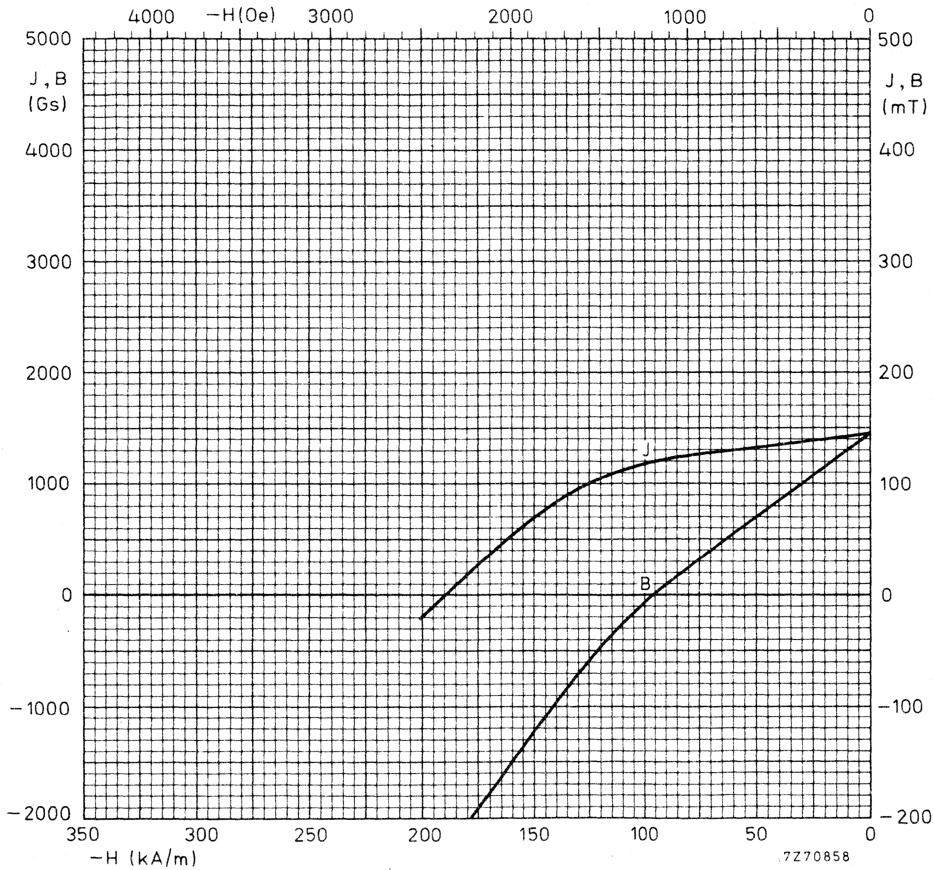
QUALITY AND FINISH

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 DEMAGNETISATION 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 electric 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 realised, 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
Polarisation 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 magnetised 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 94 V-1 of UL94		

<u>Flexural strength test</u>

- Rate of crosshead motion 50 mm/min
- Length of span 40 mm

Flexural strength after 100 h at 25 ± 3 °C	typ.	136	N/cm^2
at 100 ± 3 °C	typ.	136	N/cm^2

<u>Impact strength test</u> (pendulum type)

- Striker: 50 Ncm, length of span 40 mm

Impact strength after 100 h at 25 ± 3 °C	typ.	0,16	J/cm^2
at 100 ± 3 °C	typ.	0,14	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 (except HCl)	+	+	+	–
Concentrated HCl	–	–	–	–
Thinned lyes	+	+	+	+
Concentrated lyes	+	+	+	+
Acetic acid 10%				
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 MAGNETISATION

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

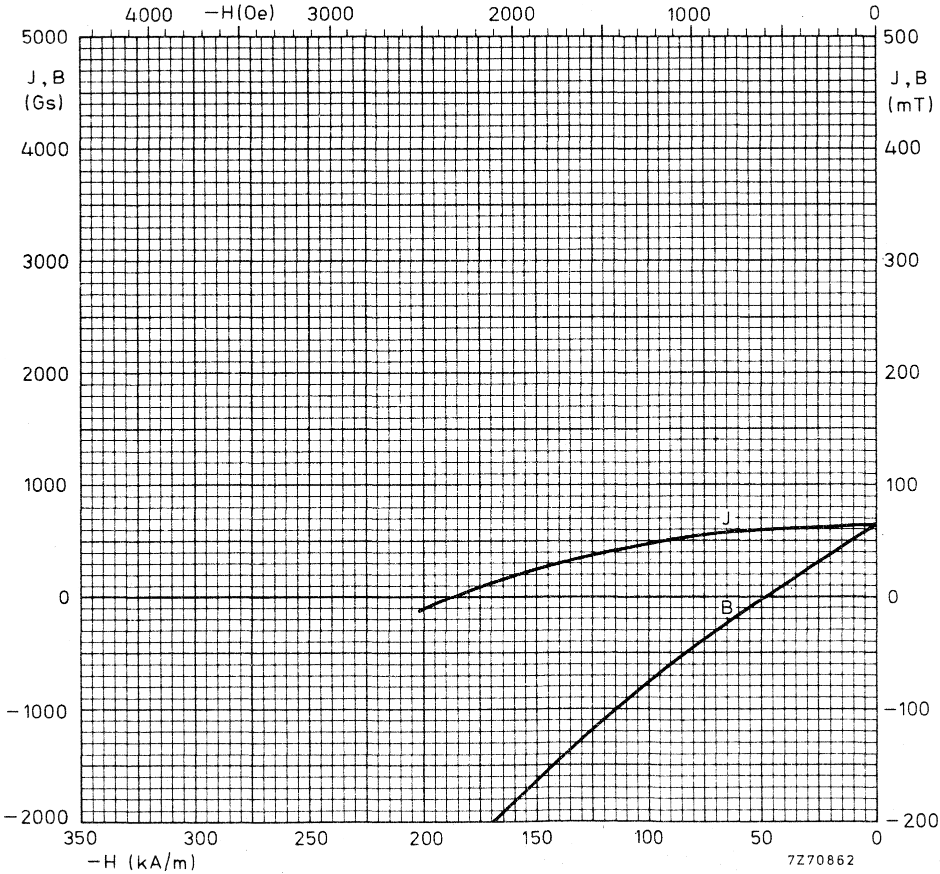
QUALITY AND FINISH

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 DEMAGNETISATION 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 electric 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 realised, 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
Polarisation 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 magnetised 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 x 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 °C	<	0,25	%
Moisture absorption during storage in water	<	0,05	% (by weight)
Flame retardance of SP10F	to 94 V-1 of UL94		

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 °C	typ.	200	150	N/cm²
at 100 ± 3 °C	typ.	200	150	N/cm²

Impact strength test (pendulum type)

- Striker: 50 Ncm, length of span 40 mm

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

CHEMICAL RESISTANCE

	25 °C		70 °C	
	up to 5 h	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 MAGNETISATION

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

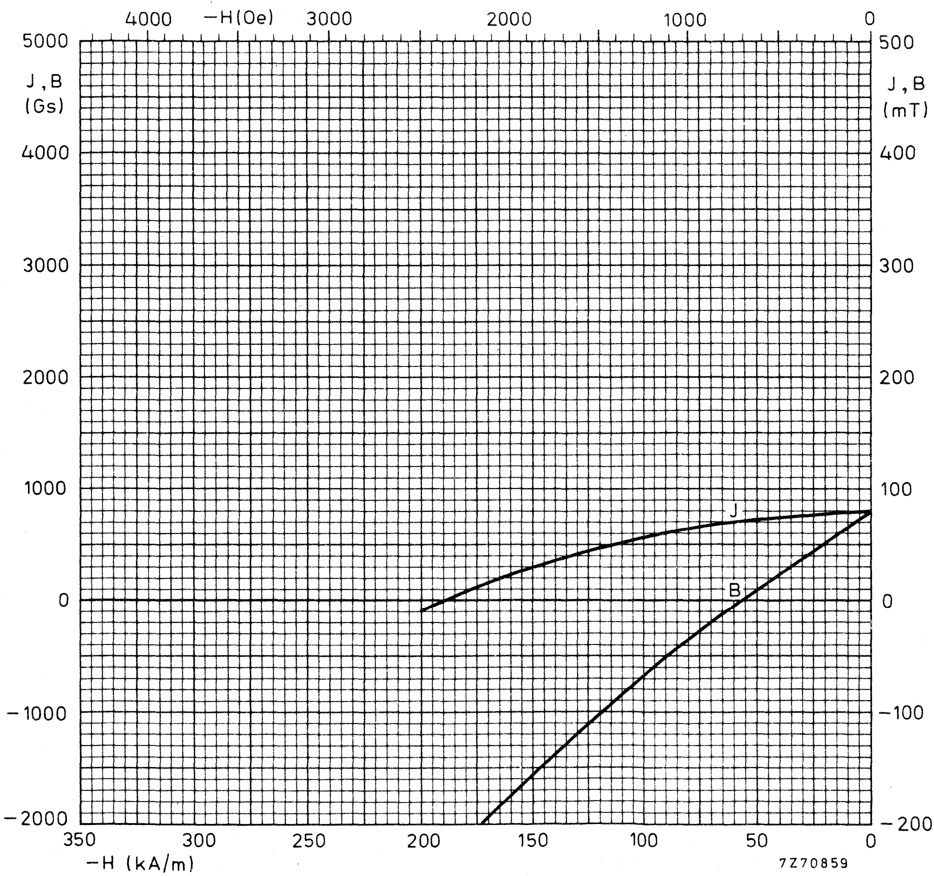
QUALITY AND FINISH

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 DEMAGNETISATION 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 electric 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 realised, 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
Polarisation 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 magnetised 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 MAGNETISATION

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

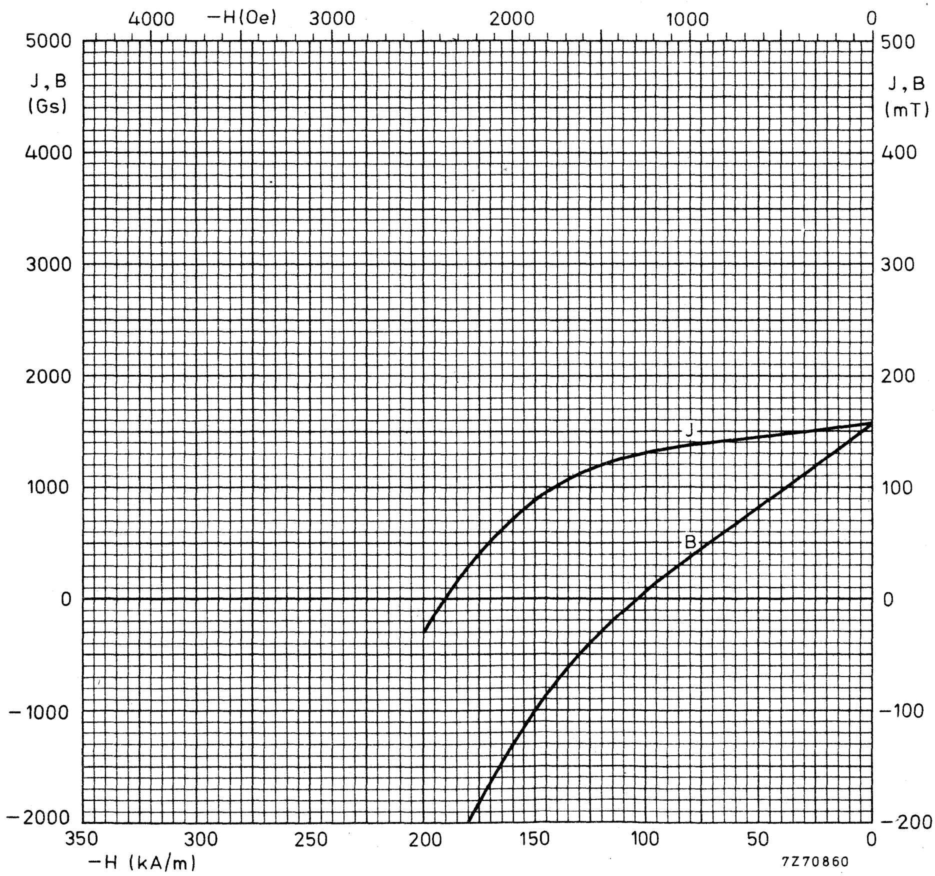
QUALITY AND FINISH

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 DEMAGNETISATION 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 electric 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 realised, 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
Polarisation 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 magnetised 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
continuously 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 MAGNETISATION

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

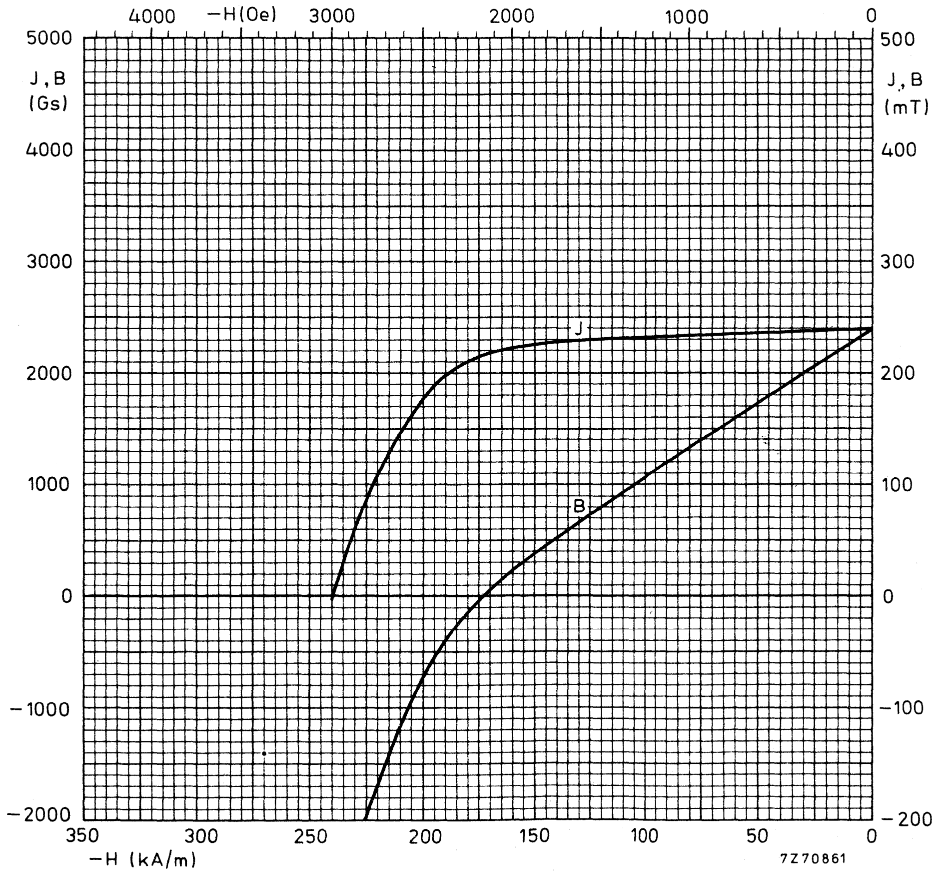
QUALITY AND FINISH

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 DEMAGNETISATION 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 realised, 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
Polarisation coercivity	H_{cJ}	220		kA/m	2760		Oe
Maximum BH product	$(BH)_{max}$	7,6	7,2	kJ/m^3	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 x 10^3 kg/m^3	(4,9 g/cm^3)
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 °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 MAGNETISATION

Ferroxdure 100 is an isotropic material, and may therefore be magnetised in any direction. Where magnets are to be supplied magnetised, 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.

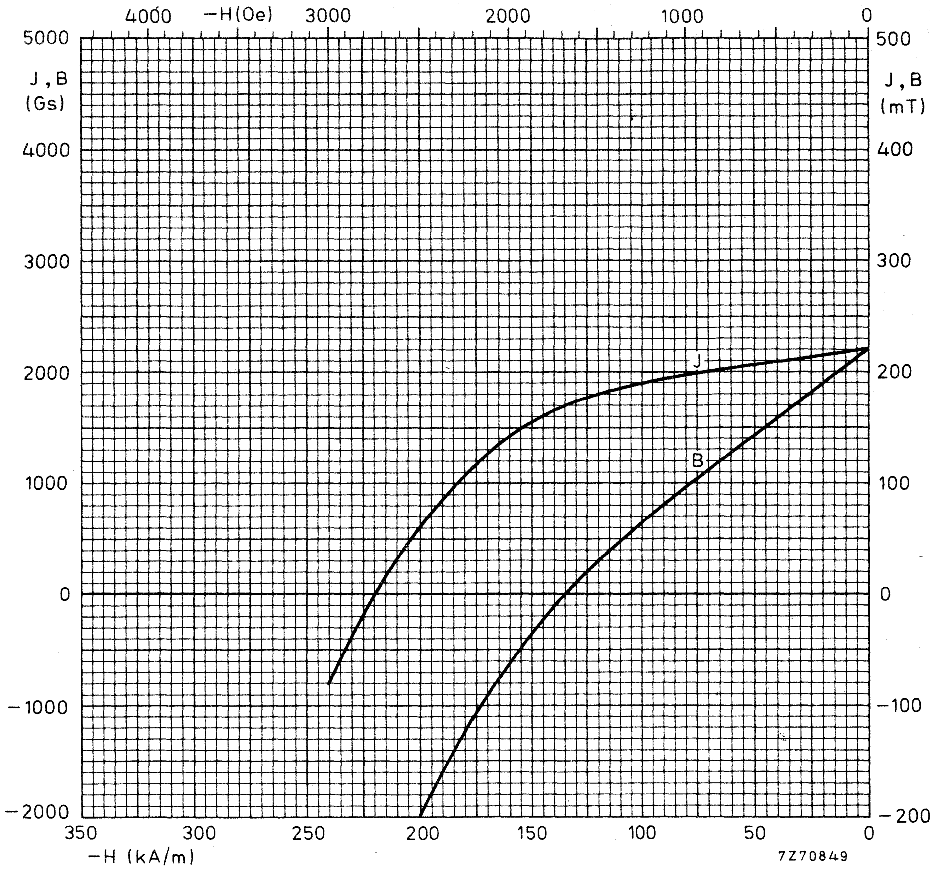
QUALITY AND FINISH

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 magnetisation is required and low prices are essential.

TYPICAL DEMAGNETISATION 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 realised, 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}	255	247	kA/m	3200	3100	Oe
Polarisation 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 MAGNETISATION

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

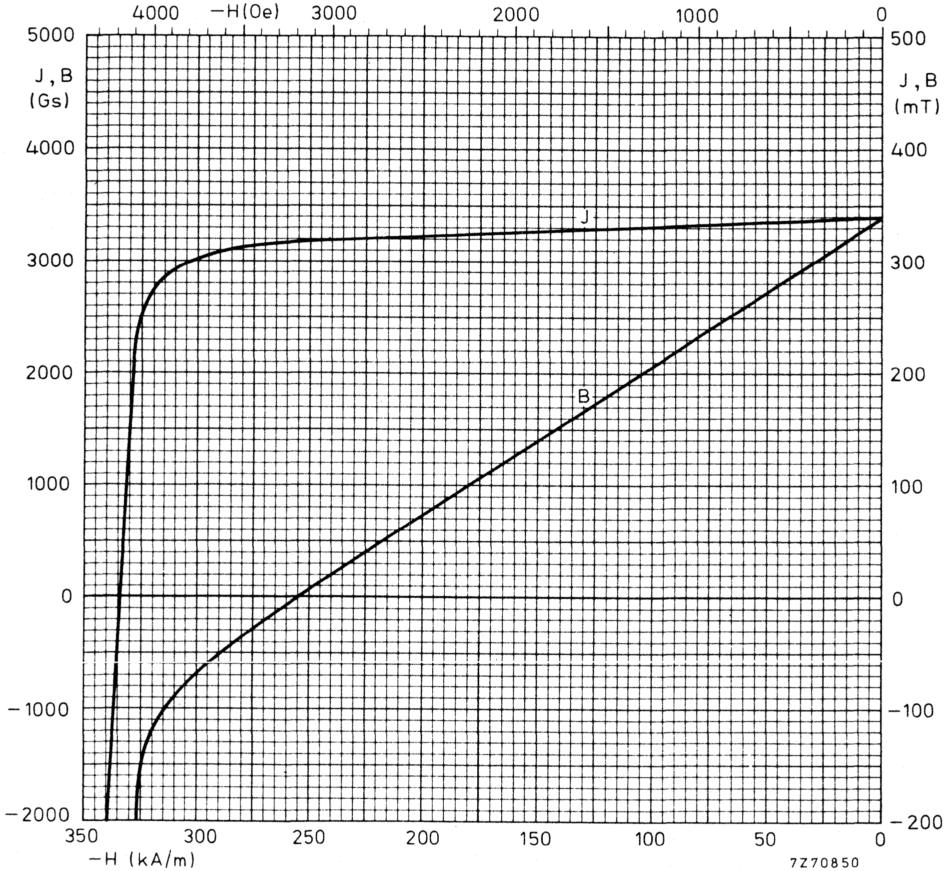
QUALITY AND FINISH

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 DEMAGNETISATION CURVE (25 °C)



FERROXDURE 280

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 realised, 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 280 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	350	340	mT	3500	3400	Gs
Coercivity	H_{cB}	239	223	kA/m	3000	2800	Oe
Polarisation coercivity	H_{cJ}	255	239	kA/m	3200	3000	Oe
Maximum BH product	$(BH)_{max}$	23	21,5	kJ/m^3	2,9	2,7	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	180		mT	1800		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	127		kA/m	1600		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		Ωm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density typ. $4,6 \times 10^3$ kg/m^3 (4,6 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 MAGNETISATION

Ferroxdure 280 is an anisotropic material, and has therefore a preferred direction of magnetisation (Magnetic Axis), which must be shown on the magnet drawing.

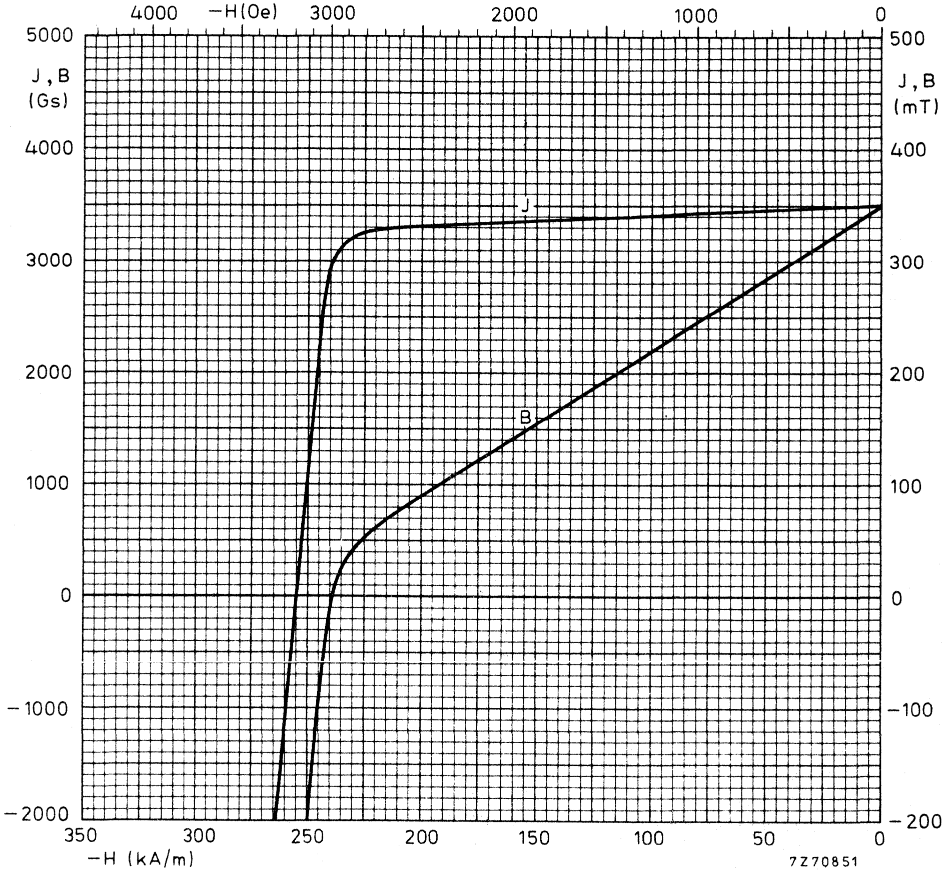
QUALITY AND FINISH

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 DEMAGNETISATION 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 realised, 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}	143	127	kA/m	1800	1600	Oe
Polarisation coercivity	H_{cJ}	147	131	kA/m	1850	1650	Oe
Maximum BH product	$(BH)_{max}$	28,7	27,1	kJ/m³	3,6	3,4	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	240		mT	2400		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	119		kA/m	1500		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 MAGNETISATION

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

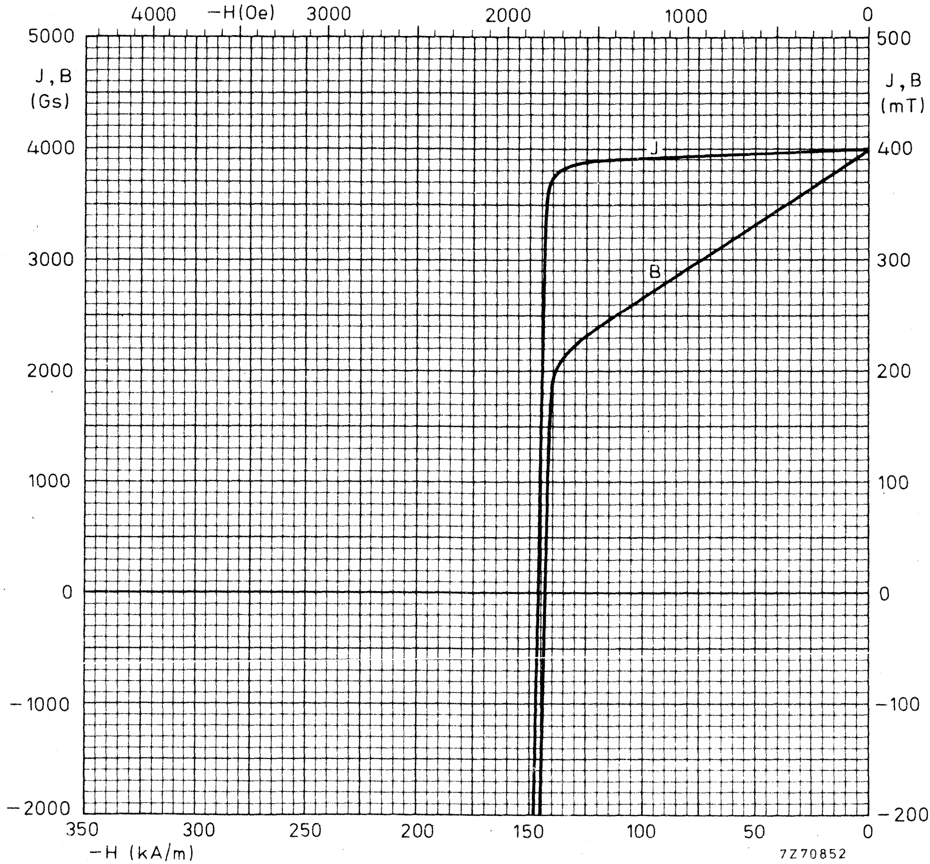
QUALITY AND FINISH

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 DEMAGNETISATION 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 realised, 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
Polarisation 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. $4,65 \times 10^3$ 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 MAGNETISATION

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

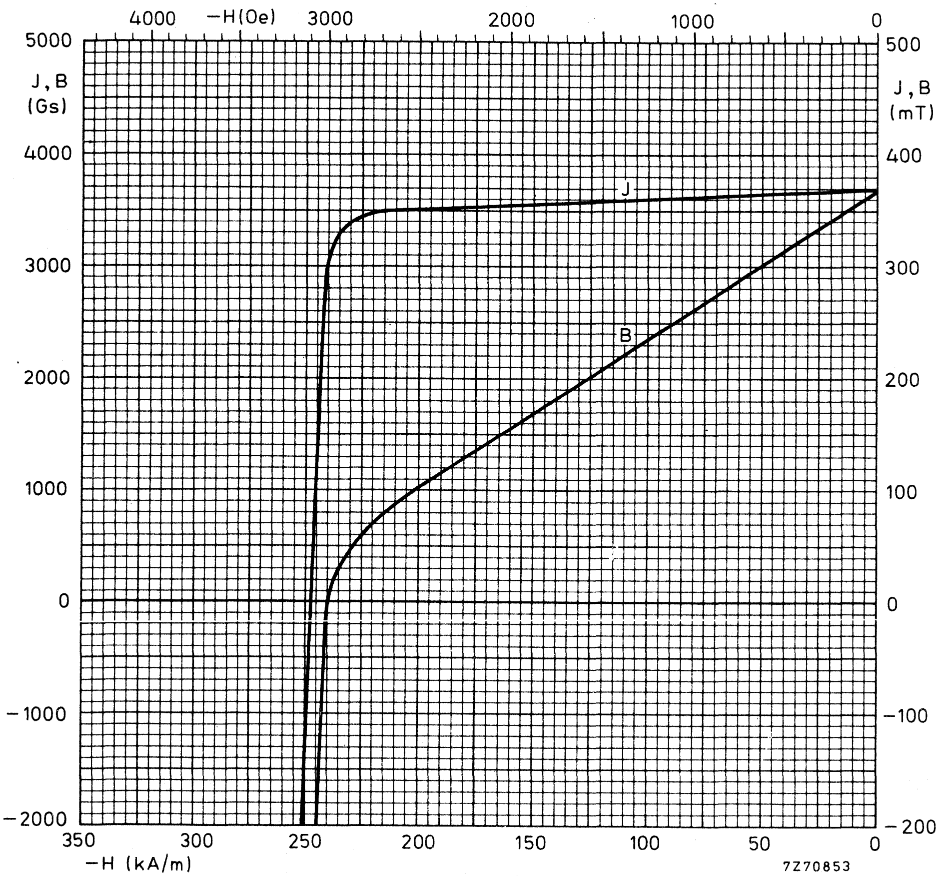
QUALITY AND FINISH

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 DEMAGNETISATION CURVE (25 °C)



FERROXDURE 370

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 realised, 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 370 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	385	380	mT	3850	3800	Gs
Coercivity	H_{cB}	235	223	kA/m	2950	2800	Oe
Polarisation coercivity	H_{cJ}	247	231	kA/m	3100	2900	Oe
Maximum BH product	$(BH)_{max}$	27,9	27,1	kJ/m^3	3,5	3,4	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	190		mT	1900		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	151		kA/m	1900		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		Ωm	10^6		Ωcm
Curie point		450		°C	450		°C

PHYSICAL PROPERTIES

Density typ. $4,75 \times 10^3$ kg/m^3 ($4,75$ 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 MAGNETISATION

Ferroxdure 370 is an anisotropic material, and has therefore a preferred direction of magnetisation (Magnetic Axis), which must be shown on the magnet drawing.

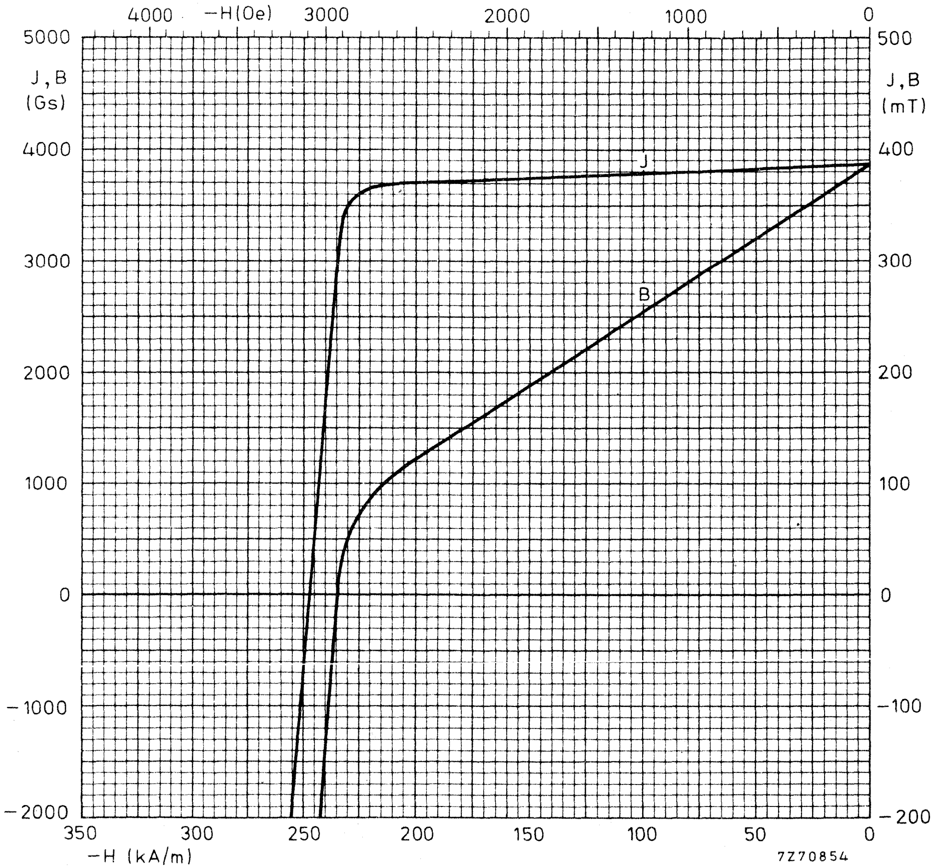
QUALITY AND FINISH

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 DEMAGNETISATION 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 realised, 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	380	370	mT	3800	3700	Gs
Coercivity	H_{cB}	263	247	kA/m	3300	3100	Oe
Polarisation coercivity	H_{cJ}	279	263	kA/m	3500	3300	Oe
Maximum BH product	$(BH)_{max}$	27,1	25,5	kJ/m³	3,4	3,2	MGsOe
Magnetic flux density corresponding to $(BH)_{max}$	B_d	185		mT	1850		Gs
Magnetic field strength corresponding to $(BH)_{max}$	H_d	147		kA/m	1850		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/m³ (4,7 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 MAGNETISATION

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

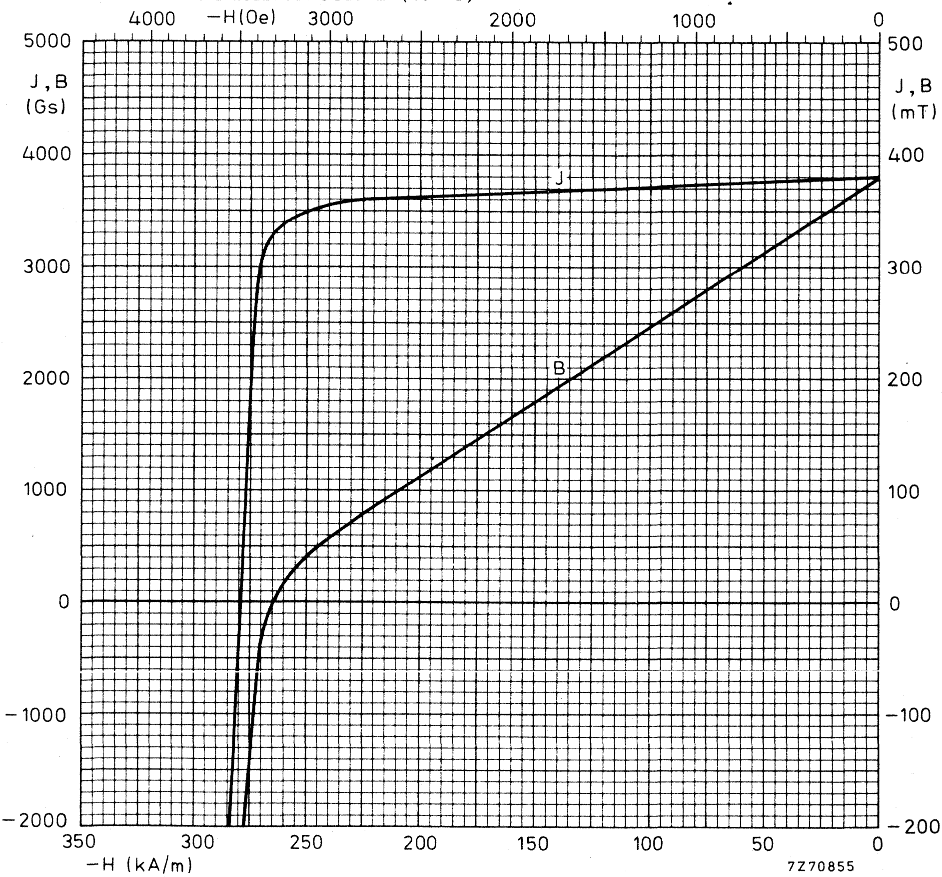
QUALITY AND FINISH

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

APPLICATION

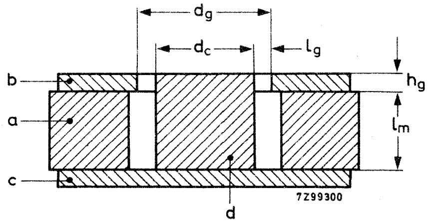
Stator magnets in motors, magnets in separators etc.

TYPICAL DEMAGNETISATION CURVE (25 °C)



FERROXDURE MAGNETS FOR LOUDSPEAKERS

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



The system consists of:

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

Loudspeaker magnet systems can be characterized by a combination of the numbers:

$$d_c/h_g/B_g - l_g$$

where: d_c = core diameter in mm
h_g = height of air gap in mm
B_g = flux density (induction) in the air gap in Gs
l_g = width of air gap = $(d_g - d_c)/2$, in mm

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, we refer to

Philips Technical Review, Vol.24, 1962/63, No.4/5, p. 150-156.

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 $H_c' = B_r/1.1\mu_0$.

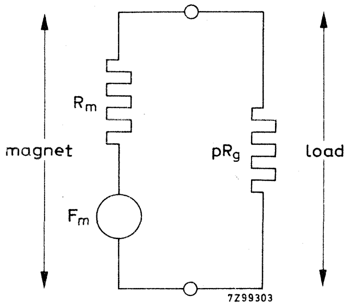


Fig.2 Equivalent magnetic circuit

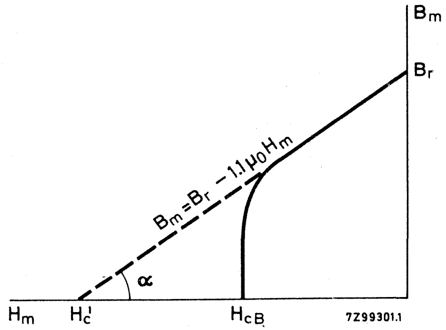


Fig.3. Demagnetization curve of ferroxdure

The flux in the air gap, usually calculated from $\phi_g = B_g A_g$, is now 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/0e

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:

$$p = 14.2\,\mu_0 l_m R_m + 1.86 = \frac{14.2}{1.1}\frac{l_m^2}{A_m} + 1.86.$$

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, which means: core diameter d_c = 16 mm,
gap height h_g = 4 mm,
gap width l_g = 0.8 mm,

has a λ_g' of 265 mm.

A ring magnet of FXD300 having the following dimensions:
external diameter d_o = 45 mm,
internal diameter d_i = 22 mm,
height $h = l_m$ = 9 mm.

can produce in the above air gap a flux Φ_g of 17 700 Mx (177 μW_b); this means a flux density B_g of 8 400 Gs (840 mT)

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

$$W_g = \frac{\Phi g^2}{2\,\mu_0 \lambda_g'} = \frac{Bg^2 Ag lg}{2\,\mu_0} = \frac{Bg^2 Vg}{2\,\mu_0}$$

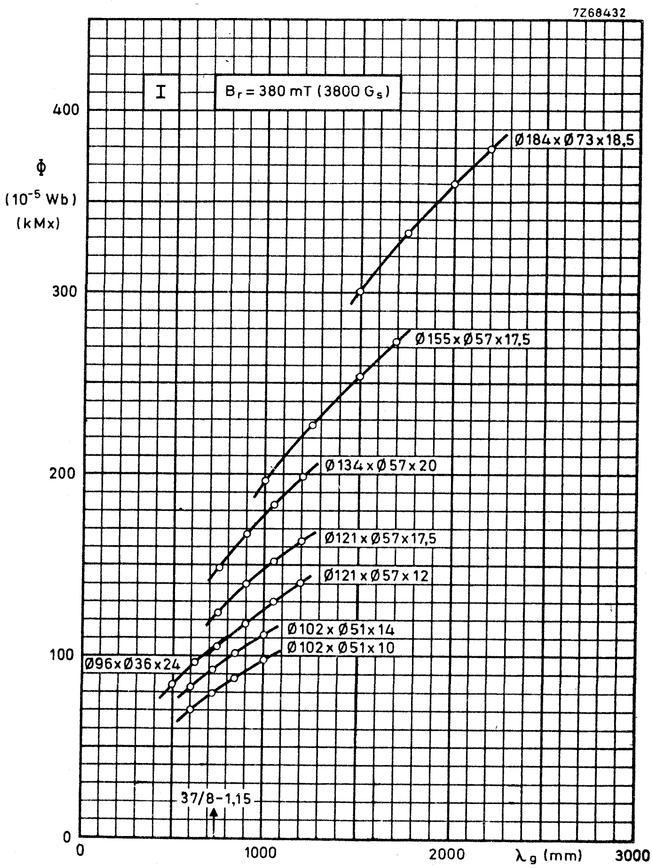
The unit of energy J (joule) is mostly to great and, therefore, W_g is expressed in mJ (mWs).

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

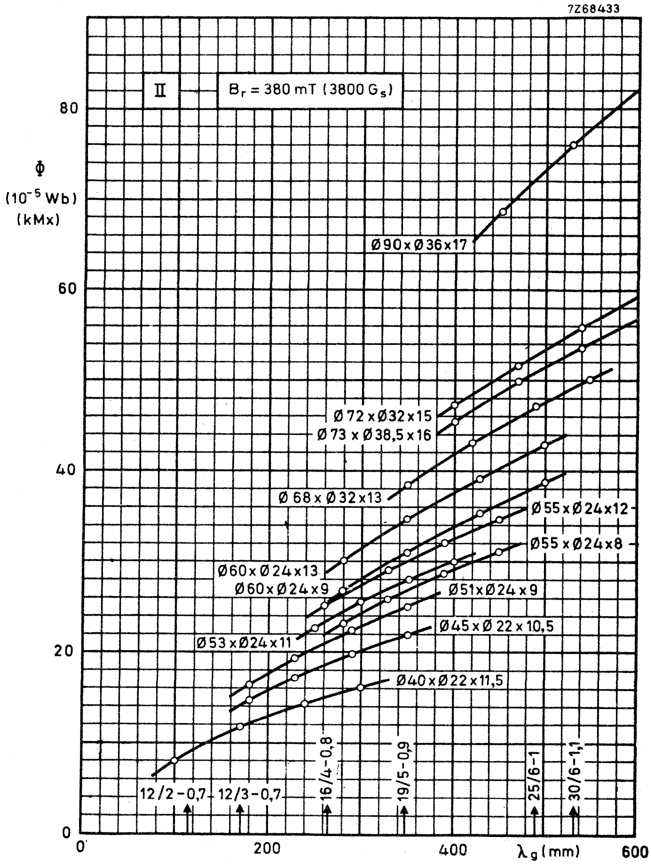
Graph III shows the energy as a function of magnet weight.

Note: For all calculations it has been assumed that FXD300 has a remanence of 3800 Gs and a density of 5 g/cm^3.

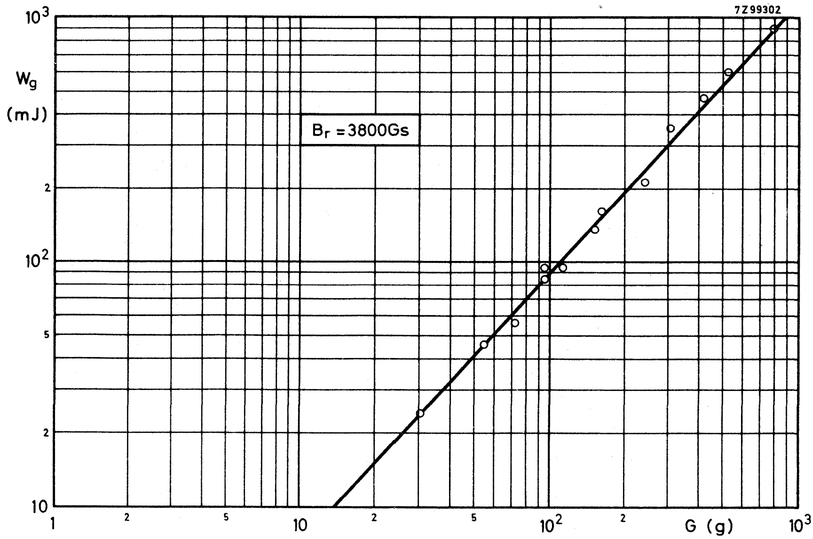
> Note: Immediately before printing, the remanence of FXD300 was uprated to a minimum of 3900 Gs from the 3800 Gs used in this Application Guide.



Graph I. Air gap flux as a function of the "relative" permeance of the air gap, calculated for a number of rings of FXD300.



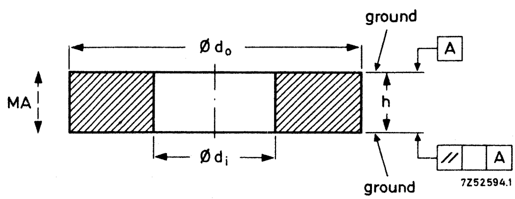
Graph II. Air gap flux as a function of the "relative" permeance of the air gap calculated for a number of rings of FXD300.



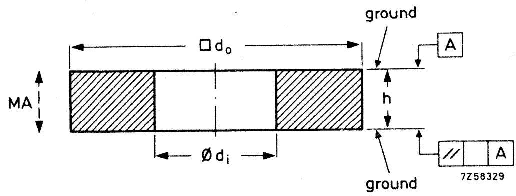
Graph III. Magnetic energy in a typical appropriate air gap as a function of the weight of the magnet

RECOMMENDED TYPES OF MAGNET

Material: FXD300
Direction of magnetic axis: axial
Supplied: unmagnetized



Ring magnet



Square magnet (rounded corners)

ring magnet						
d_o (mm)	d_i (mm)	h (mm)	//..A 1) (mm)	weight (g)	code number	system 2)
36 ± 0.8	18 ± 0.5	8 ± 0.1	0.1	30	4322 020 60070	12/3/ 8330 - 0.7
45 ± 1	22 ± 0.6	9 ± 0.1	0.1	54	60110	16/4/ 8400 - 0.8
45 ± 1	22 ± 0.6	10.5 ± 0.1	0.1	63	60120	16/4/ 8580 - 0.8
51 ± 1.2	24 ± 0.6	9 ± 0.1	0.1	71	60150	19/5/ 7800 - 0.9
53 ± 1.2	24 ± 0.5	11 ± 0.1	-	96	4304 071 80260	19/5/ 8650 - 0.9
55 ± 1.2	24 ± 0.6	12 ± 0.1	0.1	115	4322 020 60170	19/5/ 9250 - 0.9
60 ± 1.5	24 ± 0.6	8 ± 0.1	-	95	60180	19/5/ 9250 - 0.9
60 ± 1.5	24 ± 0.6	13 ± 0.1	-	154	60200	19/5/10 750 - 0.9
72 ± 1.5	32 ± 0.7	10 ± 0.1	-	163	60620	25/6/ 9360 - 1
72 ± 1.5	32 ± 0.7	15 ± 0.1	-	245	60240	25/6/10 450 - 1
90 ± 1.8	36 ± 0.9	17 ± 0.15	-	454	60280	30/6/12 700 - 1.1
102 ± 3	51 ± 1.5	10 ± 0.15	-	306	60300	37/8/ 9050 - 1.15
102 ± 3	51 ± 1.5	14 ± 0.15	-	427	60310	37/8/10 300 - 1.15
121 ± 3.6	57 ± 1.7	12 ± 0.2	-	535	60320	44/8/10 550 - 1.2
134 ± 4	57 ± 1.7	14 ± 0.2	-	805	60330	44/8/12 750 - 1.2
184 ± 5.5	73 ± 2.2	18.5 ± 0.2	-	2070	60350	63/12/14 000 - 1.3
square magnet						
30.6 ± 0.8	12.9 ± 0.4	5 ± 0.1	-	20.7	4322 020 63010	10/3/ 8500 - 0.6

Appearance: The appearance of the magnets must satisfy the requirements as illustrated in photo book KBR-11-71-43U.

1) Tolerance of parallelism.

2) 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 demagnetising 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 wobbling, 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 magnetised, their flux is compared with the flux from a standard segment.

Attention is drawn to the fact that the material for radially oriented segments has a high polarisation coercivity (H_{cJ}), which enables them to withstand high demagnetising influences.

GENERAL

Permanent magnets may be:

a. Ordered to your own design (within the limits of the materials and manufacturing techniques).

b. Selected from the MAGNET TYPE LIST, which gives initial information on the main dimensions etc. of types for which the dies and moulding plates already exist. In a lot of cases stock is available for immediate despatch to enable trials and small series production in short time.

The exact mechanical and magnetical data and the correct code number (last digit) have been laid down in the magnet specifications which exist for each type, and which are available on request.

Choice of a type from this list eliminates the need for additional tools and development work at the factory.

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 specialised 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.

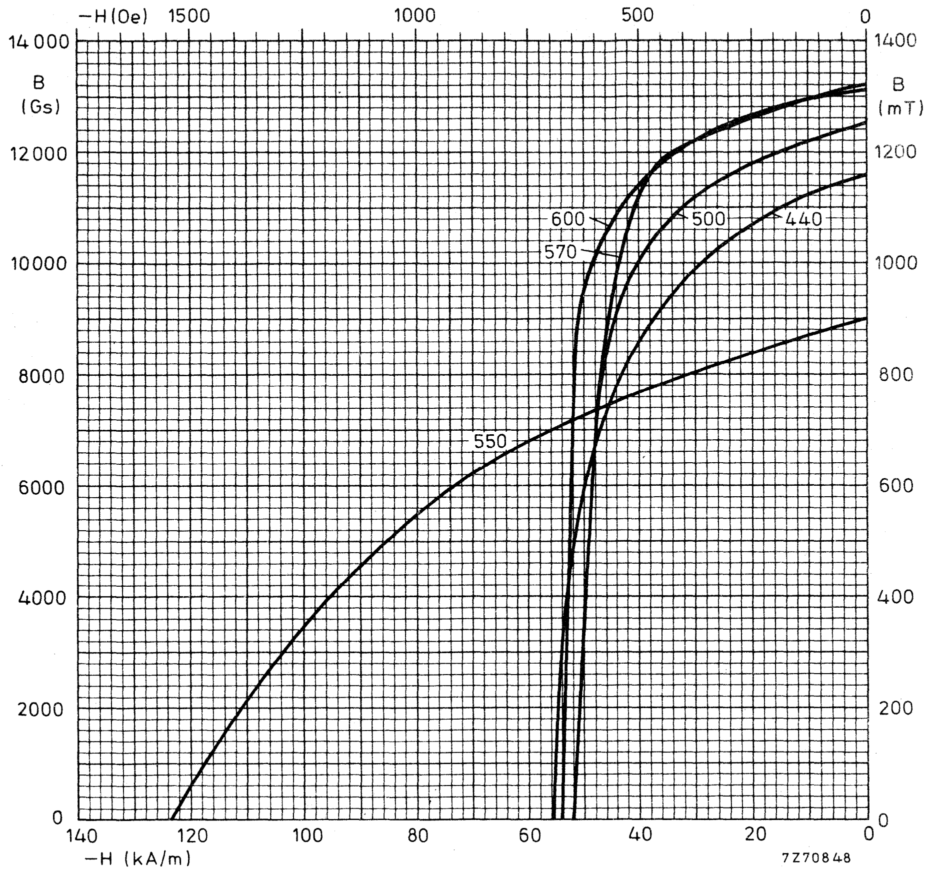
Ticonal magnets should, as far as possible, not be used as structural elements. Ticonal magnets are highly resistant to corrosion.

Ticonal permanent magnet materials are anisotropic, which means that the optimum magnetic properties are achieved only if the magnets are magnetised 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 magnetisation.

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 demagnetisation 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 metallic 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 realised, 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

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	11600	11000	Gs
Coercivity	H_{cB}	55,7	54,1	kA/m	700	680	Oe
Maximum BH product	$(BH)_{max}$	35	32,6	kJ/m^3	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	5x10^{-7}		Ωm	5x10^{-5}		Ωcm
Curie point		860		°C	860		°C

PHYSICAL PROPERTIES

Density	typ.	7,3x10^3 kg/m^3	(7,3 g/cm^3)
Coefficient of linear expansion	typ.	10,8 ppm/°C	

DIRECTION OF MAGNETISATION

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

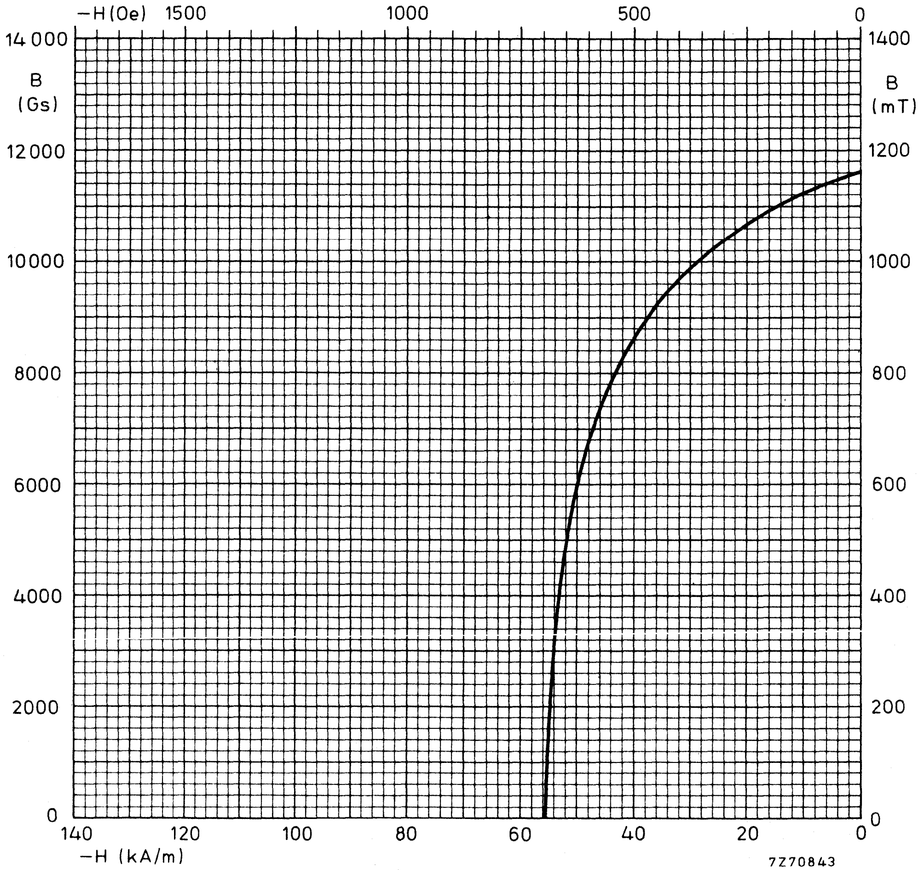
QUALITY AND FINISH

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 DEMAGNETISATION CURVE (25 °C)



TICONAL 500

anisotropic metallic 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 realised, 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	$5x10^{-7}$		Ωm	$5x10^{-5}$		Ωcm
Curie point		860		°C	860		°C

PHYSICAL PROPERTIES

Density	typ.	$7,3x10^3$ kg/m^3	(7,3 g/cm^3)
Coefficient of linear expansion	typ.	10,8 ppm/°C	

DIRECTION OF MAGNETISATION

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

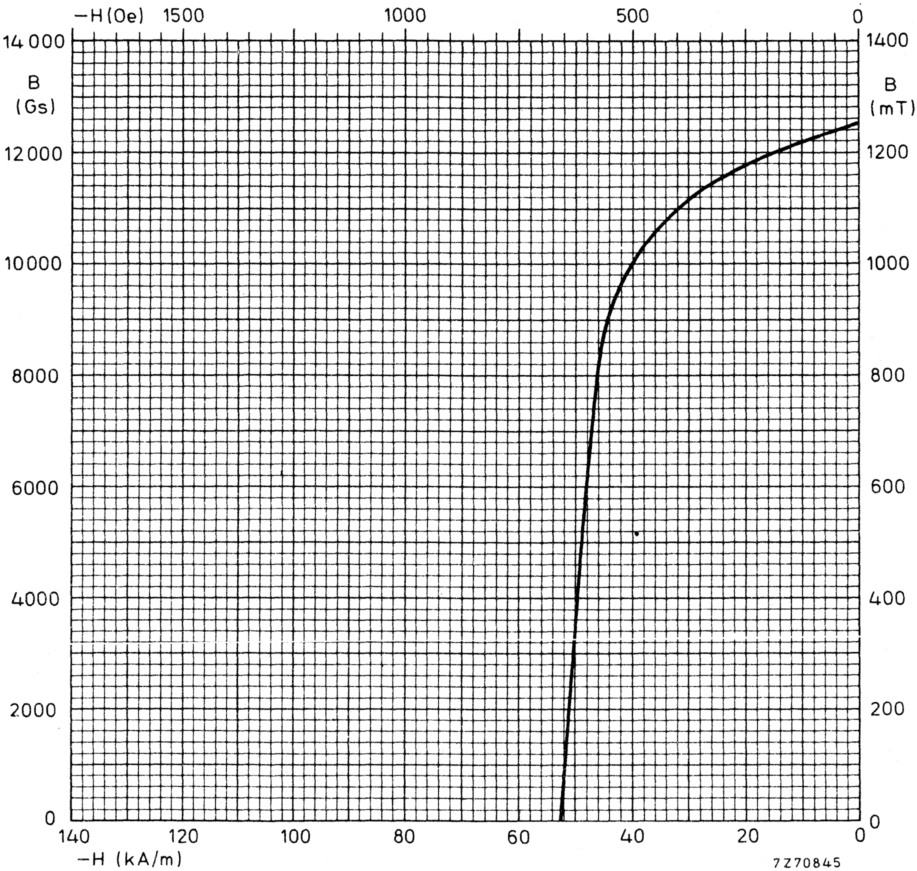
QUALITY AND FINISH

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 DEMAGNETISATION CURVE (25 °C)



TICONAL 550

anisotropic metallic 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 realised, 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	$5x10^{-7}$		Ωm	$5x10^{-5}$		Ωcm
Curie point		860		°C	860		°C

PHYSICAL PROPERTIES

Density	typ.	$7,3x10^3$ kg/m³	(7,3 g/cm³)
Coefficient of linear expansion	typ.	10,8 ppm/°C	

DIRECTION OF MAGNETISATION

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

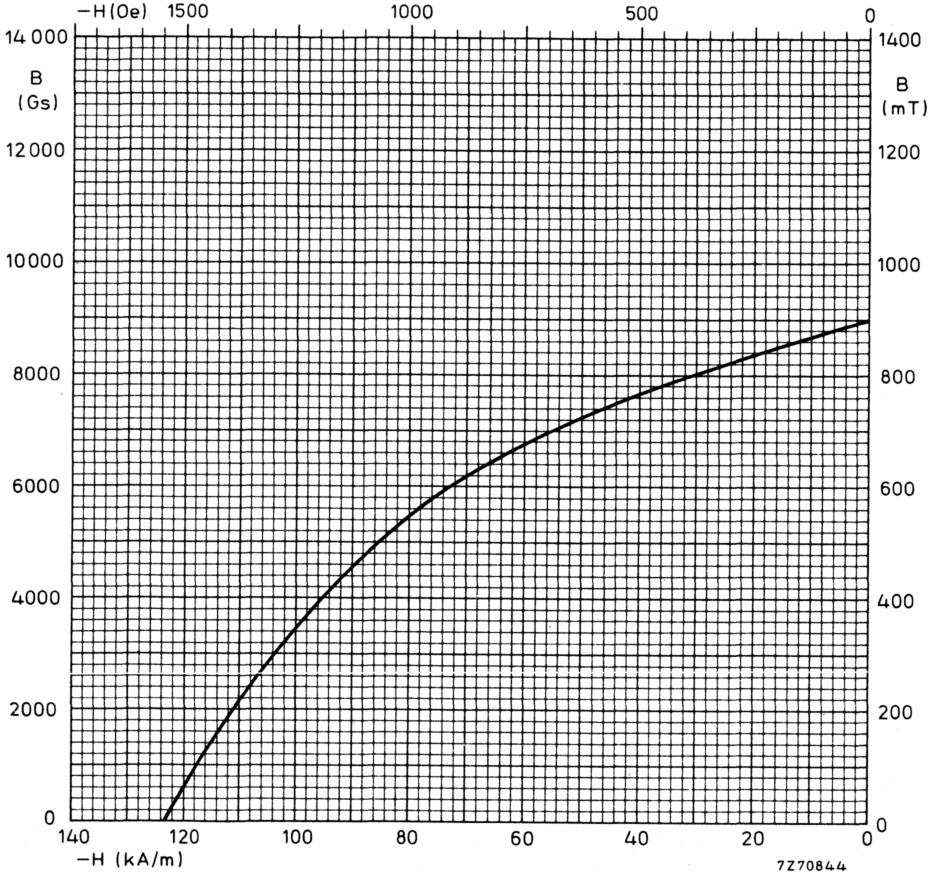
QUALITY AND FINISH

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 DEMAGNETISATION CURVE (25 °C)



TICONAL 570

anisotropic metallic 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 realised, 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/m^3	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	5x10^{-7}		Ωm	5x10^{-5}		Ωcm
Curie point		860		°C	860		°C

PHYSICAL PROPERTIES

Density	typ.	7,3x10^3 kg/m^3	(7,3 g/cm^3)
Coefficient of linear expansion	typ.	10,8 ppm/°C	

DIRECTION OF MAGNETISATION

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

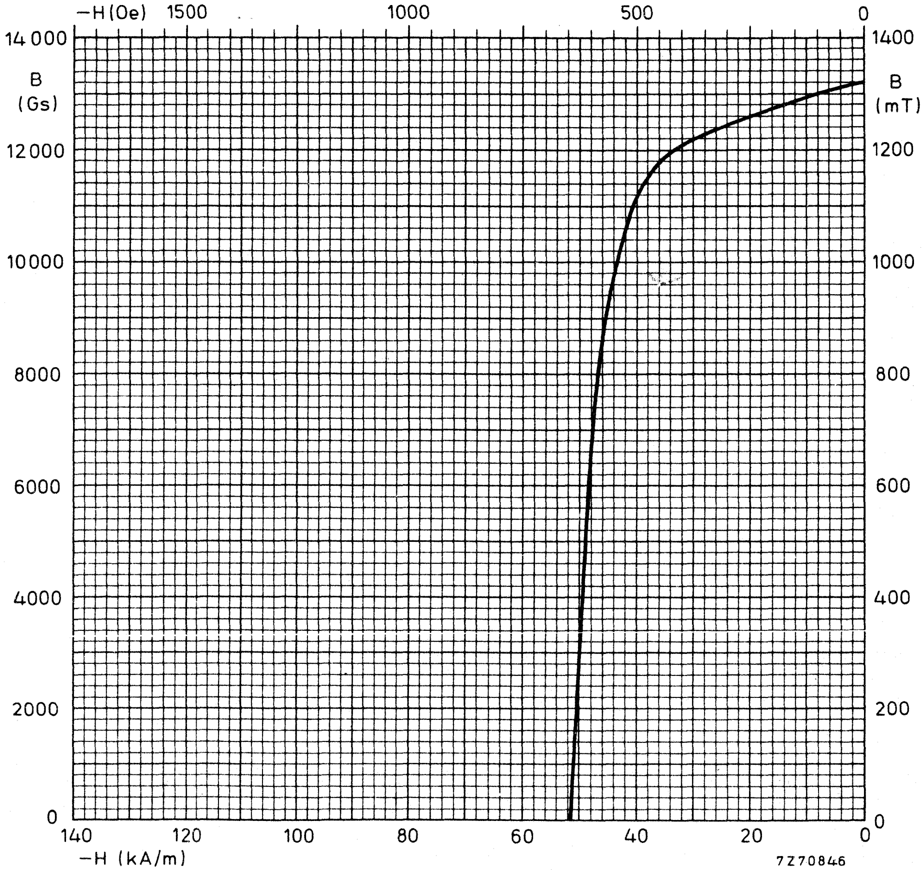
QUALITY AND FINISH

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 DEMAGNETISATION CURVE (25 °C)



TICONAL 600

anisotropic metallic 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 realised, 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	$5x10^{-7}$		Ωm	$5x10^{-5}$		Ωcm
Curie point		860		°C	860		°C

PHYSICAL PROPERTIES

Density	typ.	$7,3x10^3$ kg/m^3	(7,3 g/cm^3)
Coefficient of linear expansion	typ.	10,8 ppm/°C	

DIRECTION OF MAGNETISATION

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

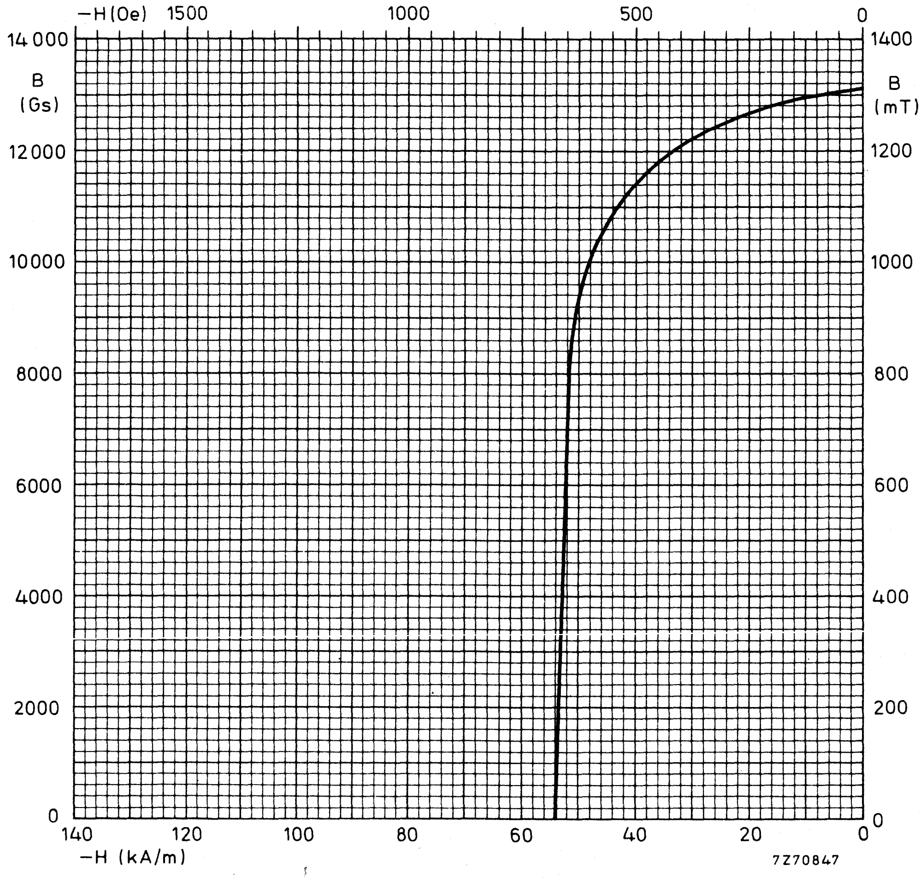
QUALITY AND FINISH

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 DEMAGNETISATION CURVE (25 °C)



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