BRITISH STANDARD

BS EN 10332:2003

Magnetic materials — Permanent magnet (magnetically hard) materials — Methods of measurement of magnetic properties

The European Standard EN 10332:2003 has the status of a British Standard

ICS 29.030

British Standards

National foreword

This British Standard is the official English language version of EN 10332:2003. It supersedes BS 6404-5:1995 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee ISE/NFE/5, Magnetic alloys and steels, which has the responsibility to:

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Magnetic materials - Permanent magnet (magnetically hard) materials - Methods of measurement of magnetic properties

Matériaux magnétiques - Matériaux pour aimants permanents (magnétiquement durs) - Méthodes de mesure des propriétés magnétiques

Magnetische Werkstoffe - Dauermagnet- (hartmagnetische) Werkstoffe - Verfahren zur Messung der magnetischen Eigenschaften

This European Standard was approved by CEN on 7 February 2003.

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Contents

Foreword

This document (EN 10332:2003) has been prepared by Technical Committee ECISS/TC 24, "Electrical steel sheet and strip qualities - Qualities dimensions, tolerances and specific tests", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by November 2003, and conflicting national standards shall be withdrawn at the latest by November 2003.

This document is equivalent to IEC 60404-5.

Annex A is normative.

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1 Scope

This European standard specifies the method of measurement of the magnetic flux density, magnetic polarization and the magnetic field strength and also the determination of the demagnetization curve and recoil line of permanent magnet materials, such as those specified in IEC 60404-8-1, the properties of which are presumed homogeneous throughout their volume.

The performance of a magnetic system is not only dependent on the properties of the permanent magnet material but also on the dimensions of the system, the air-gap and other elements of the magnetic circuit. The methods described in this standard refer to the measurement on the magnetic properties in a closed magnetic circuit simulating a ring.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text, and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

IEC 60050-121:1998, *International Electrotechnical Vocabulary – Part 121: Electromagnetism.*

IEC 60050-151:2001, *International Electrotechnical Vocabulary – Part 151: Electrical and magnetic devices.*

IEC 60050-221:1990, *International Electrotechnical Vocabulary) – Chapter 221: Magnetic materials and components*.

3 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in IEC 60050-121:1998, IEC 60050-151:2001 and IEC 60050-221:1990 apply.

For permanent magnet materials this standard deals with both the coercivity H_{cB} (the coercivity related to the magnetic flux density) and the intrinsic coercivity H_{cJ} (the coercivity related to the magnetic polarization).

The measurements specified in this standard are for both the magnetic flux density, B, and the magnetic polarization, J, as a function of the magnetic field strength, H. These quantities are related by the following equation :

$$B = \mu_0 H + J \qquad (1)$$

where

B is the magnetic flux density, in teslas ;

μ_0 is the magnetic constant = $4\pi\ 10^{-7}$, in henry per metre ;

H is the magnetic field strength, in amperes per metre ;

J is the magnetic polarization, in teslas.

Using this relationship H_{cJ} values can be obtained from the $B(H)$ hysteresis loop and H_{cB} values can be obtained from the $J(H)$. The point at which the modulus of the product BH has a maximum value is called the working point for $(BH)_{max}$ (see Figure 2).

4 Electromagnet and conditions for magnetization

4.1 General

The measurements are carried out in a closed magnetic circuit consisting of an electromagnet made of soft magnetic material and the test specimen. The construction of the yokes shall be symmetrical ; at least one of the poles shall be movable to minimize the air-gap between the test specimen and the pole pieces (see Figure 1). The end faces of both pole pieces shall be ground as nearly as possible parallel to each other and as nearly as possible perpendicular to the pole axis to minimize the air-gap (see Figure A.1).

NOTE For certain measurements, the yoke and the poles can be laminated to decrease eddy currents. The coercivity of the material should normally be not more than 100 A/m.

To obtain a sufficiently uniform magnetizing field in the space occupied by the test specimen, the following conditions shall be fulfilled simultaneously :

4.2 Geometrical conditions

$$d_1 \geq d_2 + 1{,}2\, l' \tag{2}$$

$$d_1 \geq 2{,}0\, l' \tag{3}$$

where

d_1 is the diameter of a circular pole piece or the dimension of the smallest side of a rectangular pole piece, in millimetres ;

l' is the distance between the pole pieces, in millimetres ;

d_2 is the maximum diameter of the cylindrical volume with a homogeneous field, in millimetres.

With reference to the magnetic field strength at the centre of the air-gap, condition (2) ensures that the maximum field decrease at a radial distance of $d_2/2$ and condition (3) ensures that the maximum field increase along the axis of the electromagnet at the pole faces is 1 %.

4.3 Electromagnetic conditions

During the measurement of the demagnetization curve, the flux density in the pole pieces shall be kept substantially lower than the saturation magnetic polarization so that the pole faces shall be brought as near as possible to be equipotential. In practice, the magnetic flux density shall be less than 1 T in iron and less than 1,2 T in iron alloy containing 35 % to 50 % cobalt.

The yoke is excited by magnetizing coils which are arranged symmetrically as near as possible to the test specimen (see Figure 1). The axis of the test specimen shall be coincident with the axis of the magnetizing coils.

Before measurement, the test specimen shall be magnetized in a magnetic field $H_{\max}$ intended to bring the test specimen close to saturation (see the following note). The determination of the demagnetization curve shall then be made in a magnetic field in the direction opposite to that used for the initial magnetization.

If it is not possible to magnetize the test specimen to near saturation within the yoke (for instance if the conditions in the following note cannot be met) the test specimen shall be magnetized outside the electromagnet in a superconducting coil or pulse magnetizer.

NOTE Where the product standard or the manufacturer does not specify the value of the magnetizing field strength $H_{\max}$, it is recommended that before the measurement of the demagnetization curve, the test specimen should be magnetized to saturation. The test specimen is considered to be saturated if the following relationships hold for two values of magnetic field strength H_1 and H_2 :

$$P_2 \leq P_1\, e^{0{,}024\,54 \ln\left(H_2/H_1\right)} \tag{4}$$

or

$$P_2 \leq P_1\, 10^{0{,}024\,54 \log\left(H_2/H_1\right)} \tag{5}$$

and $H_2 \geq 1{,}2\, H_1$ (6)

where

P_2 is the maximum attainable value of $(BH)_{\text{max}}$, in joules per cubic metre, or of coercivity H_{cB} in amperes per metre ;

P_1 is the lower value of $(BH)_{\text{max}}$, in joules per cubic metre, or of coercivity H_{cB} in amperes per metre ;

H_2 is the magnetic field strength corresponding to P_2, in amperes per metre ;

H_1 is the magnetic field strength corresponding to P_1, in amperes per metre.

In the special case of H_2/H_1 = 1,5, relationships (4) et (5) become $P_2 \leq 1{,}01\, P_1$.

In any cases, the magnetization process shall not cause the test specimen to be heated excessively.

5 Test specimen

The test specimen shall have a simple shape (for example a right cylinder or parallelepiped). The length l of the test specimen shall be not less than 5 mm and its other dimensions shall be a minimum of 5 mm and shall be such that the test specimen and the sensing devices shall be within the diameter d_2 as defined in clause 3.

The end faces of the test specimen shall be made as nearly as possible parallel to each other and perpendicular to the test specimen axis to reduce the air-gap (see Annex A).

The cross-sectional area of the test specimen shall be as uniform as possible throughout its length ; any variation shall be less than 1 % of its minimum cross-sectional area. The mean cross-sectional area shall be determined to within 1 %.

The test specimen shall be marked with the direction of magnetization.

6 Determination of the magnetic flux density

The changes in magnetic flux density in the test specimen are determined by integrating the voltages induced in a search coil.

The search coil shall be wound as closely as possible to the test specimen and symmetrical with respect to the pole faces. The leads shall be tightly twisted to avoid errors caused by voltages induced in loops in the leads.

The total error of measuring the magnetic flux density shall be not greater than ± 2 %.

The variation of the apparent magnetic flux density ΔB_{ap}, uncorrected for air flux, between the two instants t_1 and t_2 is given by :

$$\Delta B_{\text{ap}} = B_2 - B_1 = \frac{1}{AN}\int_{t_1}^{t_2} U\, dt \tag{7}$$

where

B_2 is the magnetic flux density at the instant t_2, in teslas ;

B_1 is the magnetic flux density at the instant t_1, in teslas ;

A is the cross-sectional area of the test specimen, in square metres ;

N is the number of turns on the search coil ;

$\int_{t_1}^{t_2} U\,dt$ is the integrated induced voltage, in webers, for the time interval of integration ($t_2 - t_1$), in seconds.

This change in the apparent magnetic flux density ΔB_{ap} shall be corrected to take into account the air flux included in the search coil. Thus, the change in magnetic flux density ΔB in the test specimen is given by :

$$\Delta B = \Delta B_{ap} - \mu_0 \, \Delta H \frac{(A_t - A)}{A} \qquad (8)$$

where

μ_o is the magnetic constant = $4\pi \, 10^{-7}$ in henry per metre ;

ΔH is the change in the measured magnetic field strength, in amperes per metre ;

A_t is the average cross-sectional area of the search coil, in square metres.

7 Determination of the magnetic polarization

The changes in magnetic polarization in the test specimen are determined by integrating the induced voltages at the terminals of a 2-search-coil device where the test specimen is contained in only one of these coils. If each of the individual coils has the same product of cross-sectional area and the number of turns, and if both are connected electrically in opposition, the change of magnetic polarization ΔJ in the test specimen is given by :

$$\Delta J = J_2 - J_1 = \frac{1}{AN} \int_{t_1}^{t_2} U\,dt \qquad (9)$$

where

J_2 is the magnetic polarization at the instant t_2, in teslas ;

J_1 is the magnetic polarization at the instant t_1, in teslas ;

A is the cross-sectional area of the test specimen, in square metres ;

N is the number of turns on the search coil ;

$\int_{t_1}^{t_2} U\,dt$ is the integrated induced voltage, in webers, for the time interval of integration ($t_2 - t_1$) in seconds.

Thus, the output of coil 1 compensates for the output of coil 2 except for J within the test specimen.

Because no individual air flux correction is needed, test specimens having a range of cross-sectional areas may be measured with the same two-search-coil device.

The two-search-coil device shall lie totally within the homogeneous field defined by conditions (2) and (3) (see 4.2).

The total measuring error shall not be greater than ± 2 %.

8 Measurement of the magnetic field strength

The magnetic field strength at the surface of the test specimen is equal to the magnetic field strength inside the test specimen only in that part of the space where the magnetic field strength vector is parallel to the side surface of the test specimen. Therefore, a magnetic field strength sensor is placed in the homogeneous field zone as near as possible to the test specimen and symmetrical with respect to the end faces (see Figure 1).

To determine the magnetic field strength, a flat search coil, a magnetic potentiometer or a Hall probe is used together with suitable instruments. The dimensions of the magnetic field sensor and its location shall be such that it is within area limited by the diameter d_2 (see conditions (2) and (3) in 4.2).

To reduce the measurement error, the air-gap between the test specimen and the pole pieces shall be small. The influence of the air-gap is considered in annex A.

The magnetic field strength measuring system shall be calibrated. The total measuring error shall be not greater than ± 2 %.

NOTE The pole faces of the poles of the electromagnet should be magnetically equipotential surfaces (clause 4). In some permanent magnet materials with high remanence, high coercivity, or both, magnetic flux densities higher than 1,0 T or 1,2 T can occur. These can then generate unacceptably high magnetic flux densities in parts of the pole pieces adjacent to the test specimen. In such cases the pole faces are no longer equipotential surfaces and greater errors can occur.

9 Determination of the demagnetization curve

9.1 General

The demagnetization curve can be obtained or plotted as a $B(H)$ or a $J(H)$ graph. Conversion of an originally obtained B-signal into a J-signal and vice versa can be performed electrically or numerically by subtracting or adding, respectively, $\mu_0 H$ according to equation (1).

The determination of $B(H)$ curves is described in 9.2 and 9.3. In the case of $J(H)$, curves an analogous reasoning holds if the magnetic flux density B is replaced by the magnetic polarization J in the relevant formulae and curves.

The measurements shall be carried out at an ambient temperature of (23 ± 5) °C. The temperature of the test specimen shall be measured by a non-magnetic temperature sensor affixed to the pole pieces of the electromagnet. Any temperature dependence of the measuring instrument (e.g. Hall probe) shall be taken into account.

9.2 Principle of determination of the demagnetization curve, test specimen magnetized in the electromagnet

The search coil device to be used for measuring B or J is connected to a calibrated flux integrator which is adjusted to zero. The test specimen is inserted into the search coil and assembled into the electromagnet and magnetized to saturation. The magnetizing current is then reduced to a very low level, zero, or reversed if necessary, to produce zero magnetic field strength. The corresponding value of magnetic flux density or polarization is recorded.

With the current in the reverse direction to that used for magnetization, the current level is increased until the magnetic field strength has passed the coercivity H_{cB} or H_{cJ}. The speed of variation of the magnetic flux density shall be sufficiently slow to avoid the production of a phase difference between H and B or of eddy currents in the test specimen. With some materials there is a significant delay between the change in the magnetic flux density and the change in magnetic field strength. In this case, the time constant of the flux integrator shall be long enough and the zero drift sufficiently low to ensure accurate integration.

Corresponding values of H and B or H and J, on the demagnetization curve shall be obtained either from a continuous curve produced by a recorder connected to the outputs of the magnetic field strength measurement device and the magnetic flux integrator or from point-by-point measurements of the magnetic field strength and the magnetic flux density or magnetic polarization.

9.3 Principle of determination of the demagnetization curve, test specimen magnetized in a superconducting coil or pulse magnetizer

The test specimen is magnetized to saturation in either a superconducting coil or by using a pulse magnetizer in accordance with clause 4.

The search coil device to be used for measuring B or J is connected to a calibrated flux integrator which is adjusted to zero. The test specimen is inserted into the search coil and assembled into the electromagnet and magnetized towards saturation in the same direction as previously magnetized in the superconducting coil or pulse magnetizer.

The magnetizing current is then reduced to a very low level, zero or reversed if necessary, to produce zero magnetic field strength. The corresponding value of magnetic flux density or magnetic polarization is recorded.

The current in the electromagnet is then slowly increased further in the reverse direction in accordance with 9.2 until the magnetic field strength has passed the coercivity H_{cB} or H_{cJ}.

Corresponding values of H and B or H and J, on the demagnetization curve shall be obtained in accordance with 9.2.

10 Determination of the principal characteristics

10.1 Magnetic remanence

The magnetic remanence is given by the intercept of the demagnetization curve with the B or J axis.

10.2 $(BH)_{\mathrm{max}}$ product

The $(BH)_{\mathrm{max}}$ product is the maximum value of the modulus of the product of corresponding values of B and H for the demagnetization curve.

The following are examples of methods by which it can be determined :

a) evaluation by direct reading or interpolation from a family of curves of B x H = constant (see Figure 2) ;

b) calculation of the product B x H for a number of points of the demagnetization curve and ensuring that the maximum values has been covered ;

c) evaluation by multiplying B and H electronically and plotting the product as a function of H or B.

10.3 Coercivities H_{cB} and H_{cJ}

The coercivity H_{cB} is given by the intercept of the demagnetization curve with the straight line B = 0. The coercivity H_{cJ} is given by the intercept of the demagnetization curve with the line J = 0.

10.4 Determination of the recoil line and the recoil permeability

For the starting-point B_{rec}, H_{rec} of the recoil line (Figure 3), the test specimen shall be previously magnetized by a magnetic field strength H_{max}. Operating in the second quadrant of the hysteresis loop, the demagnetizing current is increased to the value corresponding to H_{rec}. Then, the magnetic field strength is reduced by a value ΔH and the corresponding change in magnetic flux density ΔB is measured. The relative recoil permeability μ_{rec} is calculated from the equation :

$$\mu_{\mathrm{rec}} = \frac{1}{\mu_0} \frac{\Delta B}{\Delta H} \qquad (10)$$

where

μ_{rec} is the recoil permeability ;

ΔB is the change in magnetic flux density corresponding to the change ΔH, in teslas ;

ΔH is the change in magnetic field strength from H_{rec}, in amperes per metre ;

μ_0 is the magnetic constant = 4 π 10^{-7}, in henry per metre.

Since the recoil permeability is not usually constant along the demagnetization curve, the values H_{rec}, B_{rec} and ΔH shall be indicated.

11 Reproducibility

The reproducibility of the measurements is characterized by a standard deviation given in the following Table 1.

Table 1 — Reproducibility of the measurement of the magnetic characteristics of permanent magnetic materials

Quantity	AlNiCo	Ferrites, RE magnets
B_r	1 %	2 %
H_{cB}	1 %	2 %
$(BH)_{max}$	1,5 %	3 %

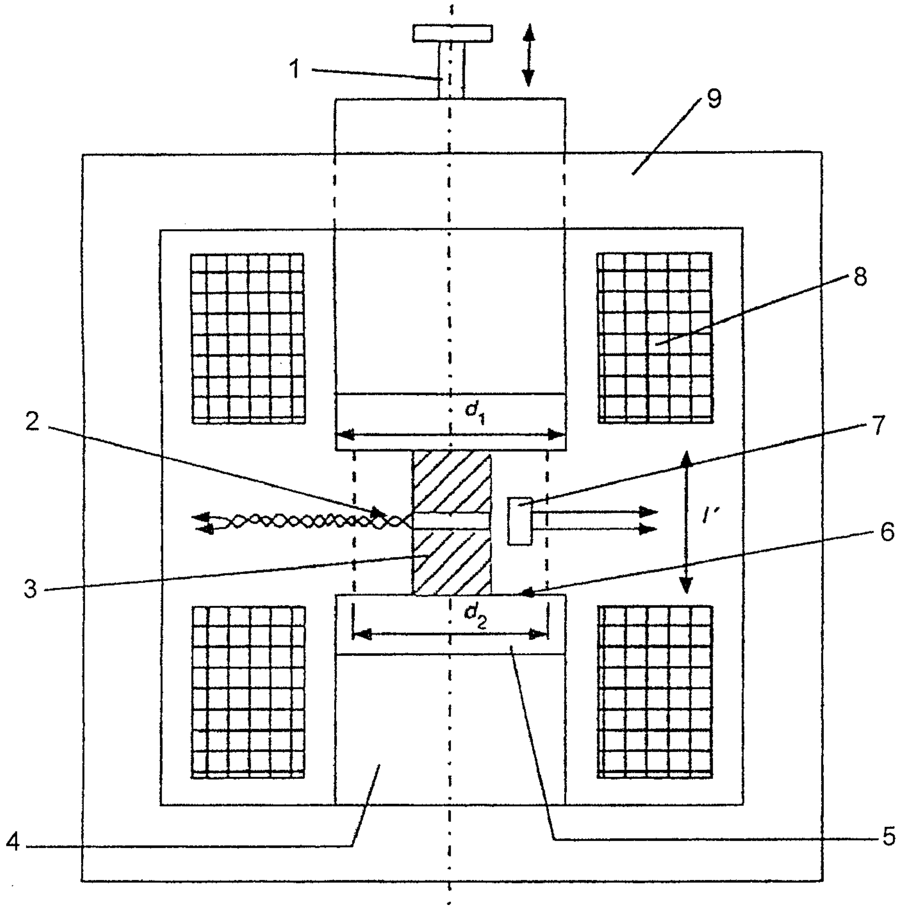
12 Test report

The test report shall contain, as applicable :

- shape and dimensions of the test specimen ;
- type of yoke used (single or double yoke) ;
- temperature of the test specimen during measurement ;
- the ambient temperature ;
- the value of the magnetizing field strength H_{max} ;
- type and identification mark of the material ;
- demagnetization curve ;
- magnetic remanence B_r or J_r ;
- coercivity H_{cB} and H_{cJ} ;
- $(BH)_{max}$ product ;
- values of B and H for $(BH)_{max}$, that is B_a and H_a (see Figure 2) ;
- recoil permeability μ_{rec} and the values B_{rec}, H_{rec} and ΔH ;
- in the case of anisotropic material : the direction of magnetization with respect to the preferred axis of the material if this angle differs from zero degrees ;

— estimated uncertainly of the measurements ;

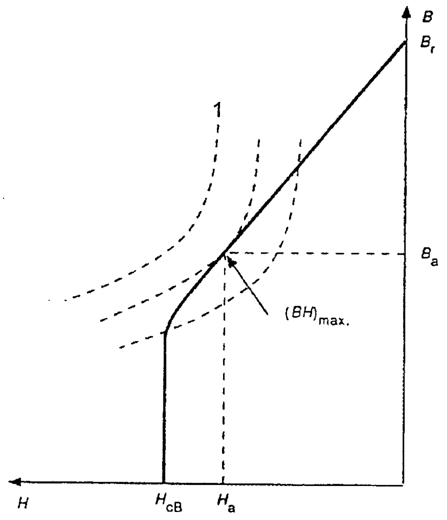
— type of H, and B or J sensor.



Key

1 device for moving the pole
2 search coil (B)
3 test specimen
4 pole of electromagnet
5 pole piece
6 pole face
7 magnetic field strength sensor
8 magnetizing winding
9 yoke

Figure 1 — Diagram of electromagnet



Key

1 *BH* = constant

Figure 2 — Demagnetization curve showing $(BH)_{max}$

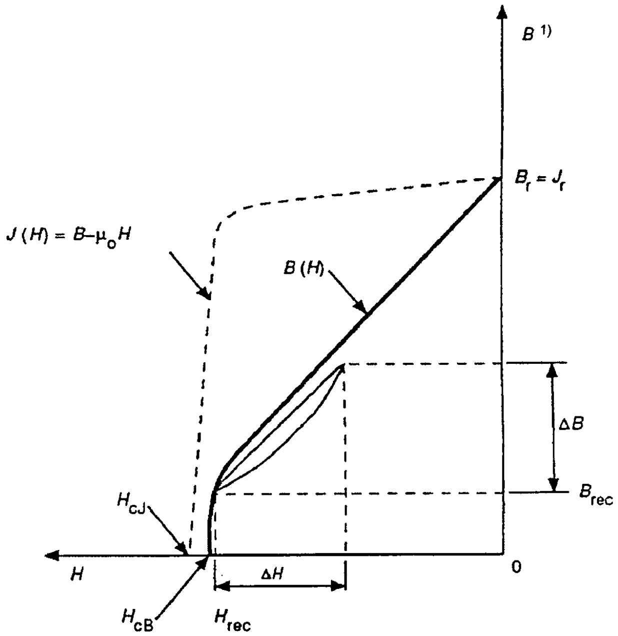


Figure 3 — Demagnetization curve and recoil loop

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[1] *B* or *J* alternatively

Annex A
(normative)

Influence of the air-gap between the test specimen and the pole pieces

The relative maximum error of the measurement of the magnetic field strength $\Delta H/H$, due to the air-gap, can be calculated approximately from the equation :

$$\frac{\Delta H}{H} = \frac{2\,d\,B}{\mu_0\,l\,H} \tag{A.1}$$

where

B, H are the values of magnetic flux density (in teslas) and magnetic field strength (in amperes per metre) at a given point on the demagnetization curve ;

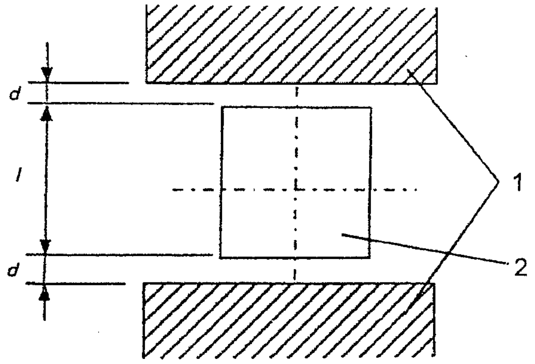
l is length of the test specimen, in metres (Figure A.1) ;

d is the length of the air-gap between the face of the test specimen and the pole piece, in metres ;

μ_0 is the magnetic constant = 4 π 10^{-7}, in henry per metre.

For example near the $(BH)_{\max}$, point, the error is 1 % for the following d/l ratios :

Material	d/l
Al Ni Co 37/5	0,000 25
Hard ferrite 25/14	0,003
RECo 120/96	0,005



Key

1 pole pieces

2 test specimen

Figure A.1 — Air gap

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