



Standard Test Methods for Permeability of Weakly Magnetic Materials¹

This standard is issued under the fixed designation A342/A342M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 These test methods cover four procedures for determination of the permeability [relative permeability]² of materials having a relative permeability not exceeding 6.0.

1.2 The test methods covered are as follows:

1.2.1 *Test Method 1—Fluxmetric Method* is suitable for materials with relative permeabilities between 1.0 and 4.0. This method permits the user to select the magnetic field strength at which the permeability is to be measured.

1.2.2 *Test Method 2—Permeability of Paramagnetic Materials* has been eliminated as an acceptable method of test.

1.2.3 *Test Method 3—Low Mu Permeability Indicator* is suitable for measuring the permeability of a material as “less than” or “greater than” that of calibrated standard inserts with relative permeabilities between 1.01 and 6.0, as designated for use in a Low-Mu Permeability Indicator.³ In this method, a small volume of specimen is subjected to a local magnetic field that varies in magnitude and direction, so it is not possible to specify the magnetic field strength at which the measurement is made.

1.2.4 *Test Method 4—Flux Distortion* is suitable for materials with relative permeabilities between 1.0 and 2.0. In this method, a small volume of specimen is subjected to a local magnetic field that varies in magnitude and direction, so it is

not possible to specify the magnetic field strength at which the measurement is made.⁴

1.2.5 *Test Method 5—Vibrating Sample Magnetometry* is suitable for materials with relative permeabilities between 1.0 and 4.0. This test method permits the user to select the magnetic field strength at which the permeability is to be measured.

1.3 Materials typically tested by these methods such as austenitic stainless steels may be weakly ferromagnetic. That is, the magnetic permeability is dependent on the magnetic field strength. As a consequence, the results obtained using the different methods may not closely agree with each other. When using Methods 1 and 5, it is imperative to specify the magnetic field strength or range of magnetic field strengths at which the permeabilities have been determined.

1.4 The values and equations stated in customary (cgs-emu and inch-pound) or SI units are to be regarded separately as standard. Within this standard, SI units are shown in brackets except for the sections concerning calculations where there are separate sections for the respective unit systems. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

¹ These test methods are under the jurisdiction of ASTM Committee A06 on Magnetic Properties and are the direct responsibility of Subcommittee A06.01 on Test Methods.

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² Test Methods 1 and 5 actually measure magnetic susceptibility. The permeability (μ) [relative permeability (μ_r)] is related to the susceptibility (κ) by the equations:

$$\begin{aligned}\mu &= 1 + 4\pi\kappa \text{ (cgs-emu)} \\ \mu_r &= 1 + \kappa \text{ (SI)}\end{aligned}$$

The term permeability has been retained in these test methods because of its widespread commercial and technological usage.

³ The sole source of supply of the apparatus known to the committee at this time is Low-Mu Permeability Indicator, manufactured by Severn Engineering Co., Inc., 555 Stage Rd., Suite 1A, Auburn, AL 36830, <http://www.severnengineering.com>. (Indicators can be returned for recalibration.) If the user of this test method is aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,¹ which you may attend.

⁴ The sole source of supply of the apparatus known to the Committee at this time is the Magnetoscop manufactured by INSTITUT DR. POERSTER GmbH & Co. KG. in Laisen 70, 72766, Reutlingen, Germany. (Probes can be returned for calibration.) If the user of this test method is aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,¹ which you may attend.

2. Referenced Documents

2.1 *ASTM Standards*:⁵

[A34/A34M Practice for Sampling and Procurement Testing of Magnetic Materials](#)

[A341/A341M Test Method for Direct Current Magnetic Properties of Soft Magnetic Materials Using D-C Permeameters and the Point by Point \(Ballistic\) Test Methods](#)

TEST METHOD 1, FLUXMETRIC METHOD

3. Significance and Use of Test Method 1

3.1 This test method is suitable for specification acceptance, design purposes, service evaluation, regulatory statutes, manufacturing control, and research and development.

3.2 Because of the restrictions on the specimen shape and size, this test method is most often used to evaluate semifinished product before fabrication of parts.

4. Apparatus

4.1 *Power Supply*—A source of dc current for the electrical circuit shown in Fig. 1. Electronic power supplies are preferable although the use of storage batteries is permitted.

4.2 *Test Fixture*—A test fixture consisting of a magnetizing solenoid with a pair of test coils, one for measuring B in the specimen and one for measuring air flux, plus a variable resistor for precisely canceling the air flux, and a fluxmeter and associated circuitry conforming to the following requirements:

4.2.1 *Magnetizing Solenoid, C₁*, having a minimum length of 30 cm [300 mm] and a ratio of length to equivalent diameter of four or more. The magnetizing winding shall be uniformly

wound and be capable of producing a uniform field of at least 300 Oe [24 kA/m] over the length of the test specimen for a short time (approximately 10 seconds) without overheating.

4.2.2 *Test Coil, B₁*, used for measuring magnetic flux density, shall have a cross-sectional area not greater than ten times that of the test specimen. The test coil should have sufficient turns (>1000) to provide adequate resolution and should be no longer than 20 % of the test specimen length.

4.2.3 *Compensating Coil, B'₁*, of the same length, cross-sectional area, and number of turns as coil B₁ and connected to it in series opposition.

4.2.4 *Air Flux Compensating Resistor, R'_B*—This resistor is used in conjunction with coil B'₁ of Fig. 1 to adjust for exact compensation for the air flux enclosed by coil B₁ in order that the intrinsic flux density may be measured directly.

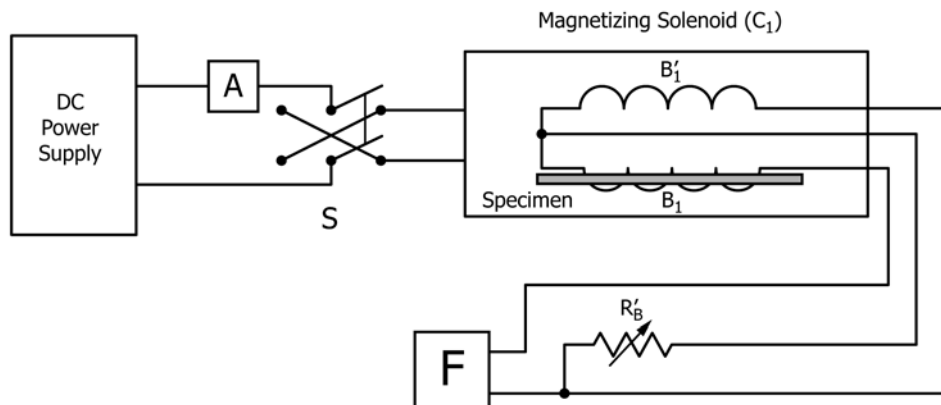
4.2.5 *Electronic Fluxmeter, F*—used to measure magnetic flux density. Alternatively, the magnetizing fixture may be connected to a dc hysteresigraph. The combined resistance of the two test coils and the air flux compensating resistor form part of the input resistance of the fluxmeter. The fluxmeter shall be appropriately adjusted to compensate.

5. Test Specimens

5.1 The test specimens shall consist of straight bars, rods, wires, or strips of uniform cross section. Multiple pieces of the same test lot may be used to increase the specimen cross-sectional area when needed. The cross-sectional area shall be not less than 0.2 cm² [20 mm²]. The length shall be not less than 10 cm [100 mm] and the ratio of length to diameter or equivalent diameter (that is, the diameter of a circle having an area equal to the cross-sectional area of the specimen) shall be as follows:

Relative Permeability	Dimensional Ratio
Under 1.5	10 or greater
1.5 to 2.0, incl.	15 or greater
2.0 to 4.0	30 or greater

⁵ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



- S - Current Reversing Switch
- A - Ammeter and Current Range Network
- F - Electronic Fluxmeter
- C₁ - Magnetizing Solenoid
- B₁ - Test Coil
- B'₁ - Compensating Coil
- R'_B - Air Flux Compensating Resistor

FIG. 1 Circuit Diagram for Method No. 1

5.2 This test method can be used with smaller dimension-ratio test specimens when used for comparing to similar specimens for quality control purposes.

6. Procedure

6.1 Measure the thickness and width or diameter of the test specimens and calculate the cross-sectional area in square centimetres [square millimetres].

6.2 Before inserting the test specimen in the solenoid, obtain an exact balance to nullify the effect of air flux in coil B_1 by reversing the highest magnetizing current to be used in the test and adjusting the compensating resistor to obtain the minimum output from the flux sensing coils.

6.3 Place the test specimen in position in coil B_1 , adjust the magnetic field strength to the desired test value, then reverse the magnetizing current (from $+H_m$ to $-H_m$) and record the fluxmeter reading. Optionally, the B versus H curve can be recorded on a hysteresisgraph.

7. Calculation (Customary Units)

7.1 Convert the fluxmeter reading to intrinsic flux density B_i and calculate the permeability as follows:

$$\mu = 1 + \frac{B_i}{H} \tag{1}$$

where:

- μ = permeability of the test specimen;
- B_i = intrinsic flux density of the test specimen, G; and
- H = magnetic field strength, Oe.

8. Calculation (SI Units)

8.1 The output from the fluxmeter is the magnetic polarization J . The relative permeability is calculated as follows:

$$\mu_r = 1 + \frac{J}{\mu_0 H} \tag{2}$$

where:

- μ_r = relative permeability of the test specimen;
- J = magnetic polarization, T;
- μ_0 = magnetic constant = $4\pi \times 10^{-7}$ H/m; and
- H = magnetic field strength, A/m.

9. Precision and Bias of Test Method 1

9.1 The precision and bias of this test method have not been established by interlaboratory study.

9.2 The measured permeability will be less than the true value due to the demagnetizing field, which depends on the specimen dimensional ratio. This leads not only to an overestimation of the magnetic field strength but also reduces the flux linkages in the B -coil. Provided the specimen and coil dimensional ratios are as specified in 4.2.2 and 5.1, the largest negative error in $\mu - 1$ as a result of demagnetizing effects^{6,7} will be -3% for $\mu - 1 < 0.5$.

TEST METHOD 3, LOW-MU PERMEABILITY INDICATOR METHOD OF TEST

10. Significance and Use of Test Method 3

10.1 The Low-Mu Permeability Indicator, schematically shown in Fig. 2, is suitable for determining if the permeability of low permeability materials (relative permeability of 6.0 or less) is greater than or less than that of the standard insert employed at the time of the test.

10.2 The instrument is portable and suitable for use in the shop, field, and laboratory.

10.3 The instrument is suitable to test all forms and shapes including parts, provided a suitable flat surface is available on the specimen. The material under test is that which is at the surface and is against or is in immediate proximity to the permanent bar magnet.

10.4 This test method provides test values (generally stated as “permeability is less than”) suitable for specification purposes. It was originally created to comply with now obsolete Specification MIL – I – 17214B.

11. Apparatus

11.1 *Permanent Bar Magnet*—The center of the permanent bar magnet is attached to one end of a movable arm having a

⁶ Chen, D.-X., and Li, B.-Z., “On the Error of Measurement of Feebly Magnetic Material in Regard to Demagnetizing Field,” *Acta Metall. Sinica*, Vol. 19, pp. 217–224, Oct. 1983 (in Chinese).

⁷ Chen, D.-X., Brug, J. A., and Goldfarb, R. B., “Demagnetizing Factors for Cylinders,” *IEEE Trans. Magn.*, Vol. 27, 1991, pp. 3601–3619.

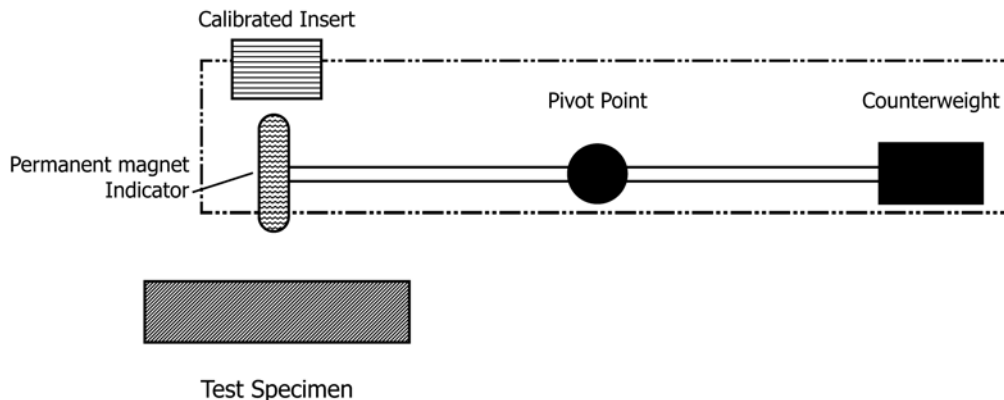


FIG. 2 Schematic Illustration of Low Permeability Indicator

fulcrum in the center and a counterbalance at the opposite end, thus permitting the permanent magnet to move in one plane in both directions.

11.2 *Inserts*—The standard inserts are weakly magnetic materials of known permeability values as calibrated by the manufacturer of the indicator against their established standards. They are available with relative permeability ranging from 1.01 to 6.0.

11.3 *Interferences*—Bringing another magnet in contact with the indicator permanent bar magnet will disturb the calibration of the indicator to such an extent that it must be returned to the manufacturer for recalibration. Avoid contacting the indicator with strongly magnetic materials such as steel, cast iron, ferritic, or martensitic stainless steels.

12. Test Specimen

12.1 The test specimen or material to be tested is recommended to have a minimum area of 1 cm² [100 mm²] and a minimum thickness of 0.3 cm [3 mm] (the specimen may be laminated). Test specimens having a volume in excess of the minimum value implied above may be in any form, shape, or condition (for example, castings, forgings, bars, weld beads, and so forth). The indicator may be placed on any location on the specimen to be tested provided that the surface is suitably flat and in full contact with the permanent bar magnet. The indicator is capable of detecting surface permeability differences, if present, of large objects.

13. Procedure

13.1 Screw into the top of the case a calibrated insert of known permeability. The permanent magnet is attached to the insert by a force dependent upon the insert's designated permeability value. Place the end of the permanent magnet projecting from the hole in the bottom of the indicator in contact with the material being tested. Move the indicator away in a direction normal to the contact surface. If the material being tested has a permeability higher than that of the insert, the permanent magnet will break contact first with the insert as the indicator is moved away. However, if the permeability of the material being tested is lower than that of the insert, the permanent magnet will break contact first with the test material as the indicator is moved away. By interchanging inserts, it is possible to bracket the permeability of the material under test.

14. Precision and Bias of Test Method 3

14.1 The precision and bias of this test method have not been established by interlaboratory study.

14.2 The manufacturer of the Low-Mu Permeability Indicator determines the permeability of the calibrated inserts. The standards used in calibrating the inserts were measured by the National Institute of Standards and Technology using Test Method A341/A341M. No significant changes were observed between 1952 and 1976. Measurements were made in a magnetic field strength of 100 Oe [8 kA/m] at 25°C.

14.3 Calibrated inserts are claimed by the manufacturer to have a bias of ± 1 % or less at the low range and within ± 5 % at the high range relative to the standards.

TEST METHOD 4, FLUX DISTORTION METHOD OF TEST

15. Significance and Use of Test Method 4

15.1 The Flux Distortion Method of Test, schematically shown in Fig. 3, is suitable for determining the permeability of low permeability materials (relative permeability between 1.0 and 2.0) with resolution up to 0.00001. When the instrument with probe is calibrated against standards with known permeability values as determined by the manufacturer of the indicator against their established standards or national standards, the measured values of permeability can be made traceable to national standards.

15.2 The commercially available electronic instruments for performing this test are portable and suitable for use in the shop, field, and laboratory.

15.3 This test method is suitable to test all forms and shapes including finished parts, provided a suitable flat or nearly flat surface is available on the specimen. The material under test is that which is at the surface and is against, or is in immediate proximity to, the probe.

15.4 This test method is suitable for specification acceptance, design purposes, service evaluation, regulatory statutes, manufacturing control, and research and development. Relative test values allow for comparison of permeability between parts of the same physical geometry.

16. Apparatus

16.1 *Electronic Measuring Instrument*—An electronic instrument contains the hardware and software required to measure the distortion of magnetic flux around a permanent magnet within the permeability probe, caused by the presence of the specimen under test. Such instruments are available from commercial manufacturers.

16.2 *Permeability Probe*—A suitable probe, matched to the particular brand of instrument being used, is required. There is a variety of probes to cover the various ranges of permeability and magnetic field strength. Suitable probes are available from commercial manufacturers.

16.3 *Interferences*—Exposure of the probe to strong magnetic fields will permanently change its characteristics. The measurement is sensitive to temperature and nearby magnetic influences such as the stray field of a permanent magnet, of an electromagnetic device, or proximity to a ferromagnetic object. Significant magnetic field gradients near the test location will affect the measurement accuracy.

17. Test Specimen

17.1 The size and shape of the test specimen or material to be tested is critical, and for absolute measurements the specimen size and shape must be as specified by the instrument manufacturer. Generally, materials to be measured with permeability probes should be >0.3 in. [>8 mm] thick, the flat test area where the probe will be placed should have diameter >0.8 in. [>20 mm] and curved surfaces should have radius of curvature >1.6 in. [>40 mm]. When testing specimens with

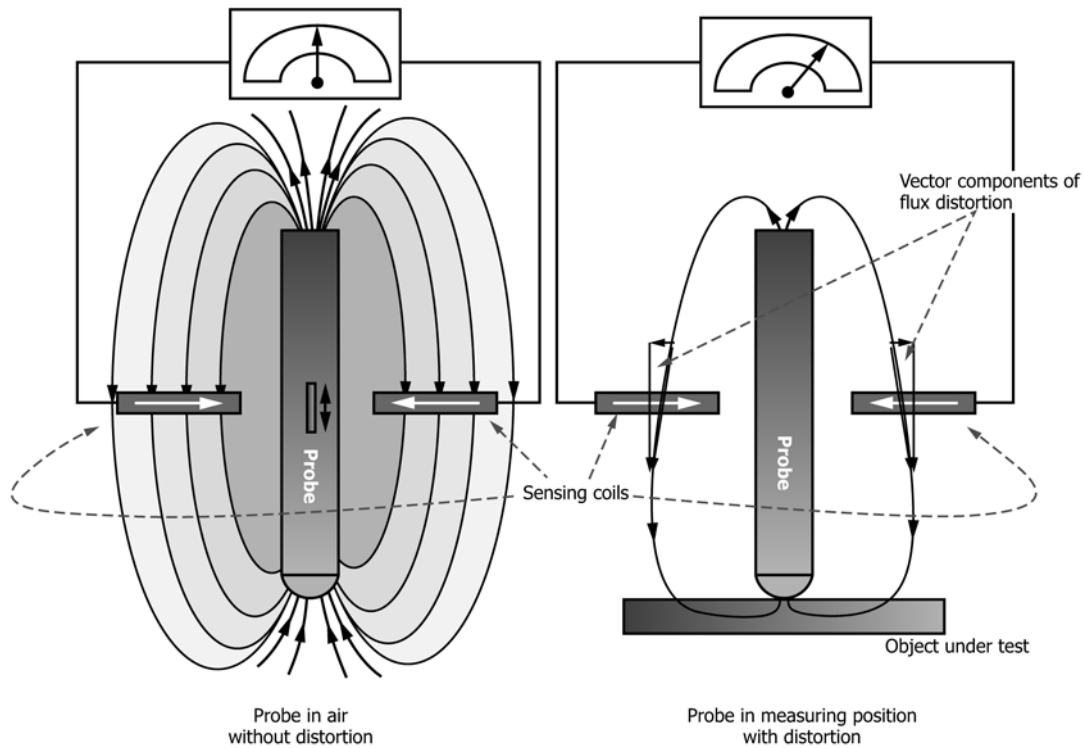


FIG. 3 Schematic Illustration of Flux Distortion Method

dimensions smaller than these approximate limits, the instrument will indicate permeability different than the actual value.

18. Procedure

18.1 Best results are obtained when the probe is in a fixed location and the specimen is moved into contact with the probe.

18.2 *Absolute Measurements:*

18.2.1 Identify a location on the test piece which meets the dimensional requirements stated by the instrument manufacturer.

18.2.2 Connect a suitable probe to the instrument, as recommended by the instrument manufacturer.

18.2.3 Calibrate the instrument/probe against a calibration standard per manufacturer recommendations.

18.2.4 Place the test piece in contact with the probe and record the display reading.

18.3 *Comparative Measurements:*

18.3.1 Identify a location on the test piece.

18.3.2 Calibrate the instrument/probe against the reference object to which the comparison will be made.

18.3.3 Place the test piece in contact with the probe and record the display reading.

19. Precision and Bias

19.1 The precision and bias of this test method have not been established by interlaboratory study.

19.2 The manufacturer of the instrument determines the permeability of the calibration standards. Standards with permeability traceable back to national standards are available.

19.3 One manufacturer states an absolute accuracy of permeability measurement of better than $\pm 5\%$ of the actual value.

TEST METHOD 5, VIBRATING SAMPLE MAGNETOMETER METHOD OF TEST

20. Significance and Use of Test Method 5

20.1 The vibrating sample magnetometer (VSM), schematically shown in Fig. 4, is well suited for determining the properties of weakly magnetic materials. It is sensitive enough to measure the magnetization of a paramagnet, and can apply fields over a large enough range to separate and measure paramagnetism and weak ferromagnetism when they co-exist.

20.2 This method is suitable for any material that can be prepared in the form of a small disk or cube of known volume. The values of constant (field independent) permeability as low as 1.001 may be determined with an uncertainty of ± 0.0001 . There is no theoretical upper limit to the measurable permeability, but in practice ferromagnetic behavior quickly masks paramagnetic behavior.

20.3 Because specimens for vibrating sample magnetometry are typically small disks less than 1 cm [0.01 m] in diameter and require fabrication into a specific shape, due care in specimen preparation is necessary to prevent the preparation procedures from affecting the test results.

20.4 This test method is suitable for specification acceptance, design purposes, service evaluation, regulatory statutes, manufacturing control, and research and development.