Designation:A 773/A 773M–96

An American National Standard Designation: A 773/A 773M – 01 (Reapproved 2009)

Standard Test Method for dc Magnetic Properties of Materials Using Ring and Permeameter Procedures with dc Electronic Hysteresigraphs[1]

This standard is issued under the fixed designation A 773/A 773M; 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 reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method provides dc hysteresigraph procedures (*B-H* loop methods) for the determination of basic magnetic properties of materials in the form of ring, toroidal, link, double-lapped Epstein cores, or other standard shapes that may be cut, stamped, machined, or ground from cast, compacted, sintered, forged, or rolled materials. It includes tests for normal induction and hysteresis taken under conditions of continuous sweep magnetization. Rate of sweep may be varied, either manually or automatically at different portions of the curves during tracing. Total elapsed time for tracing a hysteresis loop is commonly 10 to 120 s per loop.

1.2The values stated in either customary (cgs-emu and inch-pound) units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the systems may result in nonconformance with this test method.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. 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 non-conformance with the standard.

1.3 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A 34/A 34M Practice for Sampling and Procurement Testing of Magnetic MaterialsMaterials

A 341/A 341M Test Method for Direct- Current Magnetic Properties of Materials Using dcD-C Permeameters and the Ballistic Test Methods[2]Methods

A 343/A 343M Test Method for Alternating-Current Magnetic Properties of Materials at Power Frequencies Using the Wattmeter-Ammeter-Voltmeter Method and 25-cm Epstein Frame[2]Test Frame

A 596/A 596M Test Method for Direct-Current Magnetic Properties of Materials Using the Ballistic Method and Ring Specimens[2]Specimens

2.2 *Other:*

IEC Publication 404-4: Magnetic Materials—Part 4: Methods of Measurement of dc Magnetic Properties of Iron and Steel (1995)[3]

3. Summary of Test Method

3.1 As in making most magnetic measurements, a specimen is wound with an exciting winding (the primary) and a search coil (the secondary) for measuring the change in flux. When an exciting current, *I*, is applied to the primary winding, a magnetic field, *H*, is produced in the coil, and this in turn produces magnetic flux ϕ in the specimen. In uniform specimens that do not contain

[1] This test method is under the jurisdiction of ASTM Committee A-6 A06 on Magnetic Properties and is the direct responsibility of Subcommittee A06.01 on Test Methods.

Current edition approved Dec. 10, 1996. Published March 1997. Originally published as A773–80. Last previous edition A773–91.

Current edition approved May 1, 2009. Published August 2009. Originally approved in 1980. Last previous edition approved in 2001 as A 773/A 773M–01.

[2] Annual Book of ASTM Standards, Vol 03.04.

[2] 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.

[3] Available from American National Standards Institute, 1125 W. 42nd43rd St., 13th4th Floor, New York, NY 10036.

air gaps, such as ring samples, all of the exciting current is used to magnetize the specimen, and H is proportional to I in accordance with the following equation:

$$H = KI \tag{1}$$

where:

H = magnetic field strength, Oe ~~[A/m],~~ [A/m];
I = current in the exciting coil ~~A,~~A; and
K = constant determined by the number of primary turns the magnetic path length of the specimen and system of units.

3.1.1 The magnetic flux may be determined by integration of the instantaneous electromotive force that is induced in the secondary coil when the flux is increased or decreased by a varying H. The instantaneous voltage, e, is equal to:

$$e = -NK_1 \frac{d\phi}{dt} \tag{2}$$

or

$$\phi = \frac{1}{K_1 N} \int edt$$

where:

dt = time differential,
N = number of turns, and
K_1 = 10^{-8} for cgs-emu system, or $K_1 = 1$ for SI system.

The flux ϕ can be obtained if ~~lMi~~ $\int edt$ can be determined. This can be accomplished by several means, as described in *ASTM STP 526*. (**1**)[4] The most common method ~~utilizes~~uses an electronic integrator consisting of a high-gain dc amplifier with resistive-capacitive feedback. The relationship to ~~lMi~~ $\int edt$ is:

$$E = \frac{1}{RC} \int edt \tag{3}$$

where:

E = output voltage, V~~,~~;
R = input resistance of the integrator in the secondary circuit, ~~Ω,~~Ω; and
C = the feedback capacitance, F.

By combining the two equations:

$$\phi = \frac{ERC}{K_1 N} \text{ or } E = \frac{\phi N K_1}{RC} \tag{4}$$

$$\phi = \frac{ERC}{K_1 N} \text{ or } E = \frac{\phi N K_1}{RC} \tag{4}$$

If the voltage, E, is applied to the Y axis of an X-Y recorder, the Y deflection of the pen is proportional to the flux, ϕ.

3.1.2 Measurements of magnetic field strength and flux by the hysteresigraph method is illustrated in the block diagram of Fig. 1. The system consists of a magnetizing power source, an exciting current controller, an electronic flux integrator, and a data recorder. As exciting current is applied to the coil, a voltage proportional to I is produced across the shunt resistor which is connected in series with the primary coil. This voltage determines the value of H.

3.1.3 In the testing of hard magnetic materials, or soft magnetic materials in the form of wire, bars or rods, it is usually necessary to use a permeameter. This is shown in the block diagram of Fig. 2. When using permeameters, the value of H in the gap is generally not proportional to I that flows through the exciting coil of the yoke. In these cases, the value of H is determined by integration of the electromotive force that is induced in an H ~~-coil~~coil (or Chattock potentiometer) or from the signal developed by a Hall probe which is placed near the specimen. When using an H ~~-coil,~~coil, the determination of H is accomplished with an H integrator in exactly the same manner as that used to determine flux with the B integrator described in 3.1. When using a Hall sensor, the H values are determined from the voltage output which is proportional to H. In some cases, the H versus I relationship

[4] The boldface numbers in parentheses refer to ~~the~~a list of references at the end of this ~~test method.~~standard.

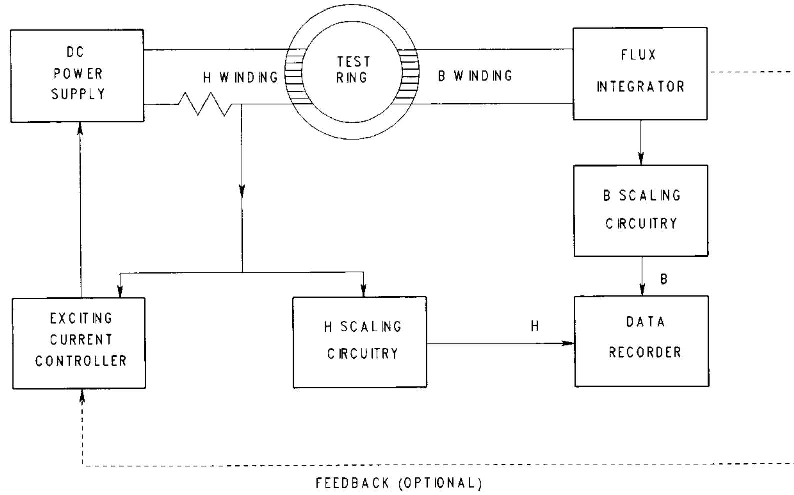

FIG. 1 Block Diagram of Ring Test Apparatus

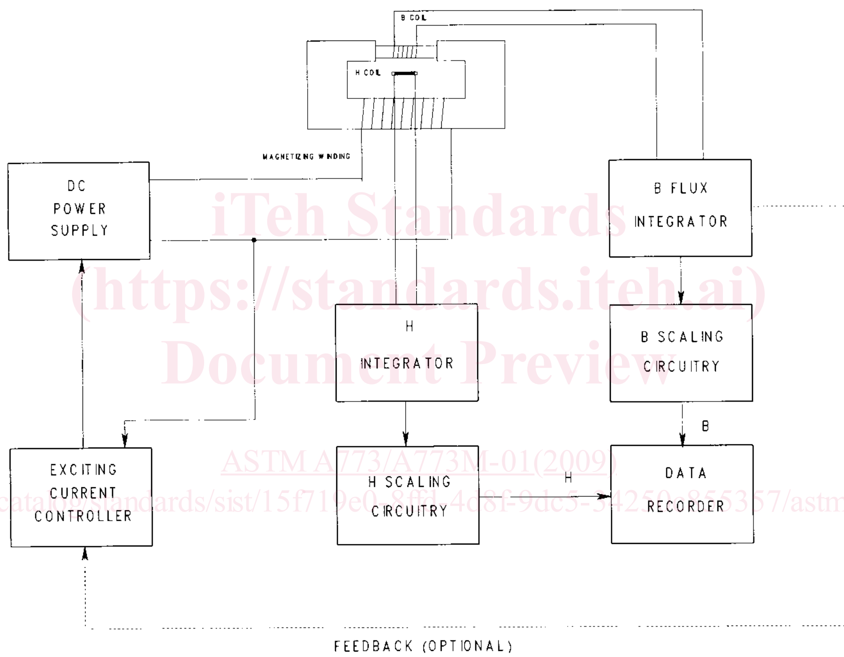

FIG. 2 Block Diagram of Permeator Test Apparatus

may be sufficiently linear from 0 to the coercive field strength (H_c) of the material under test. In such cases, it is acceptable to determine the second quadrant of the hysteresis loop by determining H from the value of I in the exciting winding.

4. Significance and Use

4.1 Hysteresigraph testing permits more rapid and efficient collection of dc hysteresis (B-H loop) data as compared to the point by point ballistic Test Methods ~~A341 and A596~~A 341/A 341M and A 596/A 596M. The accuracy and precision of testing is comparable to the ballistic methods. Hysteresigraphs are particularly desirable for testing of ~~semi-hard~~semihard and hard magnetic materials where either the entire second quadrant (demagnetization curve) or entire hysteresis loop is of primary concern.

4.2 Provided the test specimen is representative of the bulk sample or lot, this test method is well suited for design, specification acceptance, service evaluation and research and development.

5. Interferences

5.1 Test methods using suitable ring-type specimens are the preferred methods for determining the basic magnetic properties of a material. However, this test method has several important requirements. Unless adequate inside diameter to outside diameter ratios are maintained in the test specimens, the magnetic field strength will be excessively nonuniform throughout the test material and the measured parameters cannot be represented as material properties. The basic quality of materials having directional sensitive properties cannot be tested satisfactorily with punched rings or laminations. With them it is necessary to use Epstein specimens cut with their lengths in the direction of specific interest or use long link-shaped or spirally wound core test specimens whose long dimensions are similarly oriented. The acceptable minimum width of strip used in such test specimens is also sensitive to the material under test. At present, it is believed the silicon steels should have a strip width of at least 3 cm [30 mm]. Unless ring specimens are large, it is difficult to provide sufficient magnetizing turns or current-carrying capacity to reach high magnetic field strengths. In general, magnetic materials tend to have nonuniform properties throughout the body of the test specimens; for this reason, uniformly distributed test windings and uniform specimen cross-sectional area are highly desirable to average nonuniform behavior to a tolerable degree.

5.2 When conducting permeameter tests on bars, rods, and other appropriate specimens, this test method covers a range of magnetic field strengths from about 0.05 Oe [4 A/m] up to about 20 000 Oe [1600 kA/m] or more, depending on the specimen geometry and the particular permeameter that is ~~employed.~~used. In general, the lower limit of magnetic field strength is determined by the area-turns of the *H* coil (or the sensitivity of the Hall probe if it is used), the sensitivity of the integrator, and the sensitivities of the measuring and recording components. The upper limitation in magnetic field strength is determined by the type of permeameter appropriate for the specimen, the power supply, and the heat generated in the yoke windings. Recommendations of the useful range of magnetic field strength for the various permeameters are shown in Table 1. Other types may be used with appropriate precautions.

5.2.1 In general, permeameters do not maintain a uniform magnetic field in either the axial or radial directions around the test specimen. The field gradients in both of these directions will differ in the various permeameters. Also the *H*-sensing and *B*-sensing coils of the different permeameters are not identical in area, in turns, or in length or identically located. Although test specimens are prepared to have uniform physical cross section, they may have undetected nonuniform magnetic properties radially or axially along the specimen length adjacent to the *H* or *B* coils. Some permeameters may also introduce clamping strains into the test specimen. For these reasons test results obtained on a test specimen with one type of permeameter may not compare closely with those obtained on the same specimen from another type permeameter, and both may differ from more precise testing methods.

5.2.2 The limitation in the *B* measurement by this test method is determined by the number of turns on the specimen, the cross-sectional area, the permeability, and the sensitivities of the *B* integrator and *X-Y* recorder. In general, normal induction and hysteresis data may be determined from a flux linkage corresponding to 1000 Maxwell~~-~~ turns [10^{-5} Weber turns] to an upper induction that corresponds to the intrinsic saturation for most materials.

5.2.3 Some permeameters ~~utilize~~use compensation coils and require continual adjustment of the current flowing through these coils. This may not be compatible with commercially available hysteresigraphs and can be a source of significant error.

5.2.4 The magnetic test results, particularly for high permeability alloys, may not exactly agree with test results obtained by the ballistic methods, Test Methods ~~A341 and A596~~A 341/A 341M and A 596/A 596M. This is due to the influence of eddy currents and the different nature of the magnetizing waveform between hysteresigraph and ballistic testing.

6. Apparatus

6.1 The apparatus shall consist of as many of the components described in ~~6.2 through 6.6~~ 6.2-6.6 as required to perform the tests.

6.1.1 All apparatus used in this test method shall be calibrated against known standards to ensure the accuracy limits given below.

6.2 *Balance or Scales*:

6.2.1 The balance or scales used to weigh the test specimen shall be capable of weighing to an accuracy of 0.2 %.

TABLE 1 Permeameters Recommended for Use With Hysteresigraphs

NOTE ~~1~~—Other permeameters may be suitable for use with dc hysteresigraphs where appropriate modifications are made. Refer to Test Method A 341/A 341M for other permeameters.

Permeameter	Magnetic Field Strength Range		*H* Measurement Device
	Oe	kA/m	
~~Babbit **(2, 3)**~~	~~40/100~~	~~3.2/8~~	~~current, *H* coil~~
Babbit **(2, 3)**	40/100	3.2/8	current, *H* coil
~~Fahy Simplex **(4,5,6)**~~	~~0.1/300~~	~~0.008/24~~	~~*H* coil~~
Fahy Simplex **(4-6)**	0.1/300	0.008/24	*H* coil
~~Fahy Simplex Super H Adapter **(6)**~~	~~100/2500~~	~~8/200~~	~~*H* coil~~
Fahy Simplex Super H Adapter **(6)**	100/2500	8/200	*H* coil
~~IEC Type A~~	~~12/2500~~	~~1/200~~	~~*H* coil, Hall probe~~
IEC Type A	12/2500	1/200	*H* coil, Hall probe
~~IEC Type B~~	~~12/620~~	~~1/50~~	~~*H* coil~~
IEC Type B	12/620	1/50	*H* coil
~~Isthmus **(6, 7)**~~	~~100/20 000 +~~	~~8/1600 +~~	~~*H* coil, Hall probe~~
Isthmus **(6, 7)**	100/20 000 +	8/1600 +	*H* coil, Hall probe

6.2.2 The micrometer or dimensional measuring scales used to determine specimen dimensions for calculation of cross-sectional area shall be capable of measuring to an accuracy of at least 0.1 %.

6.3 *Magnetizing Power Source*—The power source may range from simple batteries to sophisticated regulated, low-ripple, protected, programmable types. It shall have sufficient capacity to produce the maximum currents required for magnetization of the specimen under test.

6.4 *Exciting Current Controller*—Instantaneous value of magnetizing current, and its rate of change, may be controlled entirely manually by means of rheostats, potentiometers, shunts, reversing switches, ~~etc.;~~ and so forth; semiautomatically by means of variable-speed motors or sweep generators, ~~etc.;~~ and so forth; or entirely automatic by means of rate sensors, ~~etc.~~and so forth. In all cases, components shall be capable of carrying the required currents without overheating, and controls shall be of such design that magnetizing current may be increased or decreased in a uniform manner so that smooth traces are plotted on the *X-Y* recorder.

6.5 *B or H Integrator*—The flux integrator(s) may be any of the types described in ASTM *STP 526* (or other) and should have sufficient sensitivity, stability, linearity, and freedom from drift to ensure an accuracy of at least 0.5 % of full scale.

6.6 *Data Recorder*—The *B* and *H* values can be recorded and displayed by either analog or digital *X-Y* chart recorders, dataloggers, or computers. The recording device shall be capable of resolving *B* or *H* values of 1 % of the full-scale value. For analog to digital converters, ~~12-bit~~twelve-bit resolution is desirable.

7. Test Specimens for Ring-Type Measurements

7.1 The specifications in ~~7.2 to 7.8~~ 7.2-7.8 cover the general case for specimens in which magnetic field strength is proportional to the exciting current, that is, $H = kI$.

7.2 When the test specimen represents a test lot of material, its selection shall conform to the requirements of Practice A 34/A 34M or of an individual specification.

7.3 To qualify as a test specimen suitable for evaluation of material properties, the effective ratio of mean diameter to radial width shall be not less than 10 to 1 (or an inside diameter to outside diameter ratio not less than 0.82). When the test specimen has smaller ratios than the above requirements, the test data should not be represented as material properties but should be called core properties because of nonuniform flux distribution.

7.4 When link, oval-shaped, or rectangular test- specimen forms are used, the requirements of 7.3 apply to the end or corner sections where flux crowding occurs. When straight-sided test specimens are very long relative to the length of the corner or end sections, they are suitable for basic material properties evaluation with relatively unoriented materials, provided the uncertainty in determination of true-path (effective) length is less than 1 % of the total path length. When this uncertainty in path length (shortest or longest relative to the mean-path length) exceeds 1 %, the test values should be reported as core properties and not basic material properties.

7.5 The test specimen may be constructed of solid, laminated, or strip materials and in any of the shapes described in 1.1.

7.6 Test- specimen cores made from strip may be laminated, machined, spirally wound, or Epstein specimens (the method of selection for Epstein specimens is described in Annex A3 of Test Method A 343/A 343M). When the material is to be tested half transverse and half longitudinal, the material shall be cut into Epstein strips or square laminations of adequate dimensional ratio.

7.7 Test specimens used for basic material evaluation shall be cut, machined, ground, slit, or otherwise formed to have a cross section that remains sufficiently uniform that its nonuniformity will not materially affect the accuracy of establishing and measuring induction, *B*, or magnetic field strength, *H*, in the test specimen.

~~7.8When~~7.8 When required for material- properties development, the test specimen shall have received a stress relief or other anneal after preparation. This anneal is subject to agreement between manufacturer and purchaser.

8. Test Specimens for Permeameter Measurements

8.1 The specifications in ~~8.2 to 8.11~~ 8.2-8.11 cover the general case for specimens in which the magnetizing force is not proportional to exciting current and the specimen must be tested in conjunction with a suitable permeameter.

8.2 Where possible, test specimen cross-sectional area shall be directly measured using calipers or micrometers. If not possible ~~due to~~because of cross-sectional shape or surface roughness, then the cross-sectional area shall be determined from the mass, length, and assumed density of the test specimen.

8.3 Test specimens in bar form may be of round, square, or rectangular cross-sectional shape. In some permeameters, the bar specimen may be a half round or any shape having a uniform cross-sectional area. Permeameters must have a good magnetic joint between the ends of the test specimen and the permeameter yoke or pole faces. Generally, to achieve a good magnetic joint, the test specimen must be of square or rectangular cross section and must be machined or ground to have straight and parallel surfaces. For permeameters using specimens butted to the pole tips, the specimen ends must be smooth and parallel.

8.4 When the material is in flat-rolled form and is to be evaluated as half transverse-half longitudinal, the test sample shall be sheared to have strip specimens in multiples of four in accordance with Table 2. When flat-rolled material is to be evaluated in only one direction, the test specimen shall conform to Table 2 or to the requirements for best test quality for the particular permeameter being used. For flat-rolled materials of thickness 0.0100 in. [0.254 mm] or thinner, the test specimen cross-sectional area shall be not less than 0.310 in.^{2} [200 mm^2] and not more than 0.620 in.^{2} [400 mm^2].

8.5 When the test specimen for strip materials is to be half transverse and half longitudinal, the strips shall be positioned to be

TABLE 2 Number of Test Strips

Nominal Thickness		Electrical Sheet Gage Number	Number of Strips
in.	mm		
0.0100 to 0.0250	0.254 to 0.635	32 to 24	12
0.0280 to 0.0435	0.711 to 1.105	23 to 19	8
0.0500 and over	1.270 and over	18 and thicker	4

composed of alternately transverse and longitudinal throughout the specimen and a transverse strip shall be placed adjacent to the permeameters yoke or pole face.

8.6 For full testing accuracy, the length and size of the test specimen must meet the requirements of the permeameter being used. Generally for most permeameters, a test specimen length of 10 in. [254 mm] or more is required. Shorter specimens with some permeameters require the use of pole-piece extensions~~,~~ and may cause a reduction in testing accuracy. Other permeameters are designed for short specimens without loss of testing accuracy.

8.7 When the test specimen is short and is to butt endwise directly against the pole piece or pole piece extensions, it shall have ends with flat, smooth, and parallel surfaces.

8.8 All test specimen forms shall be cut, machined, or ground to have a uniform cross-sectional area along the active length of the test specimen. The cross-sectional area shall be sufficiently uniform so that its nonuniformity does not materially affect the accuracy of establishing and measuring induction in the test specimen.

8.9 When required for development of material properties, the test specimen shall receive a stress relief or other anneal after preparation. This anneal is subject to agreement between manufacturer and purchaser.

8.10 Specimens of permanent-magnet material shall be processed previous to testing in accordance with a procedure acceptable to both the manufacturer and the purchaser.

~~8.11The~~8.11 The test specimen shall conform to the requirements of Practice A 34/A 34M.

9. Calibration of Integrator(s)

9.1 The integrator(s) may be calibrated by any convenient means that will ensure an integration accuracy of at least 0.5 %. Calibration may be accomplished by means of a certified Maxwell-turns generator, or volt-seconds generator, or mutual inductor, or by verification of input resistors and feed-back capacitors in operational amplifier-type integrators.

10. Calibration of Magnetizing Circuit

10.1 In cases ~~where~~ in which the magnetic field strength is proportional to current, such as in ring specimens, long solenoids, special permeameters, ~~etc.,~~and so forth, the shunt resistor(s) through which the magnetizing current flows shall be verified to at least 0.1 %, at rated current.

11. Calibration of Data Recorder

11.1 The various scales of the data recorder shall be calibrated by means of a verified voltage source to at least the quoted accuracy of the recorder in use.

12. Procedure

12.1 The following test procedure is based on a hysteresigraph which features both manual and automatic control of magnetizing current, operational amplifier-type integrators, and an analog *X-Y* recorder. The use of other hysteresigraphs, including fully computerized units, is permissible and detailed operating steps will vary. However, the general test procedure is similar in all units. The following procedure covers manual current sweeping, automatic current sweeping, and automatic current sweeping with symmetrical tracing.

12.2 ~~*Set Up*~~Setup—The procedures of ~~12.2.1 through 12.2.6~~ 12.2.1-12.2.6 should be observed for all methods of current sweep.

12.2.1 Before beginning a test, allow a minimum warmup period of 10 min for all apparatus and instrumentation.

12.2.2 Connect the specimen, observing polarity so that the pen of the recorder moves in the first quadrant on initial application of exciting current. (It is imperative that proper polarity be established ~~prior to~~before demagnetization of the test specimen.)

12.2.3 Before test, demagnetize the specimen through the coils by ac or dc techniques by establishing a magnetic field strength sufficiently large to reach a point well above the knee of the magnetization curve. Then, while continuously cycling the magnetization, slowly reduce the magnetizing current to zero. (In the demagnetization process, down-switching of voltage taps to reduce current may result in current surges. It is advisable to select voltage sources and controls that have the ability to reduce current to a low value without switching taps, preferably to a current level that does not exceed a value of 0.1 times the coercivity of the material.)

12.2.4 For the *B* measurement, set the *B* integrator range and scaling potentiometer so that B is read directly on the *Y* ~~-axis~~axis of the recorder.

12.2.5 For the *H* measurement, select the appropriate shunt resistor (current range) and set the scaling potentiometer so that *H* is read directly on the *X* ~~-axis.~~ axis.