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An American National Standard

Standard Test Methods for Thickness of Solid Electrical Insulation[1]

This standard is issued under the fixed designation D 374; 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.

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

1. Scope

1.1 These test methods cover the determination of the thickness of several types of solid electrical insulating materials employing recommended techniques. Use these methods except as otherwise required by a material specification.

1.2 The values stated in inch-pound units are 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:*

D 1711 Terminology Relating to Electrical Insulation[2]

D 6054 Practice for Conditioning Electrical Insulating Materials for Testing[3]

E 252 Test Method for Thickness of Thin Foil and Film by Weighing[4]

3. Terminology

3.1 Refer to Terminology D 1711 for definitions pertinent to this standard.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *1 mil, n*—a dimension equivalent to 0.0010 in.

3.2.2 *absolute uncertainty (of a measurement), n*—the smallest division that may be read directly on the instrument used for measurement.

3.2.3 *micrometer, n*—an instrument for measuring any dimension with absolute uncertainty of 1 mil or smaller.

4. Summary of Test Methods

4.1 This standard provides eight different test methods for the measurement of thickness of solid electrical insulation materials. The test methods (identified as Methods A through H) employ different micrometers that exert various pressures for varying times upon specimens of different geometries. Table 1 and Table 2 display basic differences of each test method and identify methods applicable for use on various categories of materials.

5. Significance and Use

5.1 Some electrical properties, such as dielectric strength, vary with the thickness of the material. Determination of certain properties, such as relative permittivity (dielectric constant) and volume resistivity, usually require a knowledge of the thickness. Design and construction of electrical machinery require that the thickness of insulation be known.

6. Apparatus

6.1 *Apparatus A— Machinist's Micrometer Caliper*[5] *with Calibrated Ratchet or Friction Thimble:*

6.1.1 Apparatus A is a micrometer caliper without a locking device but is equipped with either a calibrated ratchet or a friction thimble. By use of a proper manipulative procedure and a calibrated spring (see Annex A1), the pressure exerted on the specimen is controllable.

6.1.2 Use an instrument constructed with a vernier capable of measurement to the nearest 0.1 mil.

6.1.3 Use an instrument with the diameter of the anvil and spindle surfaces (which contact the specimen) of 250 ± 1 mil.

6.1.4 Use an instrument conforming to the requirements of 7.1, 7.2, 7.5, 7.6.1, and 7.6.2.

6.1.5 Periodically, test the micrometer for conformance to the requirements of 6.1.4.

6.2 *Apparatus B—Machinist's Micrometer Without a Ratchet*:

6.2.1 Apparatus B is a micrometer caliper without a locking device.

6.2.2 Use an instrument constructed with a vernier capable of measurement to the nearest 0.1 mil.

6.2.3 Use an instrument with the diameter of the anvil and spindle surfaces (which contact the specimen) 250 ± 1 mil.

6.2.4 Use an instrument conforming to the requirements of 7.1, 7.2, 7.5.1, 7.5.2, 7.5.3, 7.6.1, and 7.6.3.

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[1] These test methods are under the jurisdiction of ASTM Committee D-9 on Electrical and Electronic Insulating Materials and are the direct responsibility of Subcommittee D09.12 on Electrical Tests.

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[2] *Annual Book of ASTM Standards*, Vol 10.01

[3] *Annual Book of ASTM Standards*, Vol 10.02.

[4] *Annual Book of ASTM Standards*, Vol 02.02.

[5] Hereinafter referred to as a machinist's micrometer.

TABLE 1 Methods Suitable for Specific Materials

Material	Method
Plastic sheet and film	A B C or D
Paper (all thicknesses)	E
Paper (over 2 mils thickness)	F or G
Rubber and other elastomers	H

TABLE 2 Method Parameter Differences

Method	Apparatus	Diameter of Presser Foot or Spindle, mils	Pressure on Specimen, approximate, PSI
A	Machinist micrometer with calibrated ratchet or thimble	250	not specified
B	Machinist micrometer without ratchet/thimble	250	unknown
C	Dead-weight dial type bench micrometer—Manual	125 to 500	0.5 to 130
D	Dead-weight dial type bench micrometer—Motor operated	125 to 500	0.5 to 130
E	Dead-weight dial type bench micrometer—Motor operated	250	25
F	Dead-weight dial type bench micrometer—Manual	250	25
G	Machinist micrometer with calibrated ratchet or thimble	250	25
H	Dead-weight dial type bench micrometer—Manual	250	4

6.2.5 Periodically, examine and test the micrometer for conformance to the requirements of 6.2.4.

6.3 *Apparatus C— Manually-Operated, Dead-Weight, Dial Type Thickness Gage*:[6]

6.3.1 Use a dead-weight dial-type gage in accordance with the requirements of 7.1, 7.3, 7.4, 7.6.1, 7.6.4, that has:

6.3.1.1 A presser foot that moves in an axis perpendicular to the anvil face,

6.3.1.2 The surfaces of the presser foot and the anvil (which contact the specimen) parallel to within 0.1 mil (see 7.3),

6.3.1.3 A vertical dial spindle,

6.3.1.4 A dial indicator essentially friction-free and capable of repeatable readings within ±0.05 mil at zero setting, or on a steel gage block,

6.3.1.5 A frame, housing the indicator, of such rigidity that a load of 3 lbf applied to the dial housing, out of contact with the presser foot spindle (or any weight attached thereto) will produce a deflection of the frame not greater than the smallest scale division on the indicator dial, and,

6.3.1.6 A dial diameter at least 2 in. and graduated continuously to read directly to the nearest 0.1 mil. If necessary, equip the dial with a revolution counter that displays the number of complete revolutions of the large hand.

6.3.1.7 An electronic instrument having a digital readout in place of the dial indicator is permitted if that instrument meets the other requirements of 6.3.

[6] Herein referred to as a dial gage.

6.3.2 The preferred design and construction of manually operated dead-weight dial-type micrometers calls for a limit on the force applied to the presser foot. The limit is related to the compressive characteristics of the material being measured.

6.3.2.1 The force applied to the presser foot spindle and the weight necessary to move the pointer upward from the zero position shall be less than the force that will cause permanent deformation of the specimen. The force applied to the presser foot spindle and the weight necessary to just prevent movement of the pointer from a higher to a lower reading shall be more than the minimum permissible force specified for a specimen.

6.4 *Apparatus D—Motor-Operated Dead-Weight Dial Gage*:

6.4.1 Except as additionally defined in this section, use an instrument that conforms to the requirements of 6.3. An electronic instrument having a digital readout in place of the dial indicator is permitted if that instrument meets the other requirements of 6.3 and 6.4.

6.4.2 Use a motor operated instrument having a presser foot spindle that is lifted and lowered by a constant speed motor through a mechanical linkage such that the rate of descent (for a specified range of distances between the presser foot surface and the anvil) and the dwell time on the specimen are within the limits specified for the material being measured. Design the mechanical linkage so that the only downward force upon the presser foot spindle is that of gravity upon the weighted spindle assembly without any additional force exerted by the lifting/lowering mechanism.

6.4.2.1 The preferred design and construction of motor operated dead-weight dial-type micrometers calls for a limit on the force applied to the presser foot. The limit is related to the compressive characteristics of the material being measured.

6.4.2.2 The force applied to the presser foot spindle and the weight necessary to move the pointer upward from the zero position shall be less than the force that will cause permanent deformation of the specimen. The force applied to the presser foot spindle and the weight necessary to just prevent movement of the pointer from a higher to a lower reading must be more than the minimum permissible force specified for a specimen.

7. Calibration (General Considerations for Care and Use of Each of the Various Pieces of Apparatus for Thickness Measurements)

7.1 Good testing practices require clean anvil and presser foot surfaces for any micrometer instrument. Prior to calibration or thickness measurements, clean such surfaces by inserting a piece of smooth, clean bond paper between the anvil and the presser foot and slowly moving the bond paper between the surfaces. During measurements, check the zero setting frequently. Failure to repeat the zero setting may be evidence of dirt on the surfaces.

NOTE 1—Avoid pulling any edge of the bond paper between the surfaces to reduce the probability of depositing any lint particles on the surfaces.

7.2 The parallelism requirements for machinist's micrometers demand that observed differences of readings on a pair of screw-thread-pitch wires or a pair of standard 250-mil nominal diameter plug gages be not greater than 0.1 mil. Spring-wire stock or music-wire of known diameter are suitable substitutes. The wire (or the plug gage) has a diameter dimension that is known to be within ±0.05 mil. Diameter dimensions may vary by an amount approximately equal to the axial movement of the spindle when the wire (or the plug gage) is rotated through 180°.

7.2.1 Lacking a detailed procedure supplied by the instrument manufacturer, confirm the parallelism requirements of machinist's micrometers using the following procedure:

7.2.1.1 Close the micrometer on the screw-thread-pitch wire or the plug gage in accordance with the calibration procedure of 7.6.2 or 7.6.3 as appropriate.

7.2.1.2 Observe and record the thickness indicated.

7.2.1.3 Move the screw-thread-pitch wire or the plug gage to a different position between the presser foot and the anvil and repeat 7.2.1.1 and 7.2.1.2.

7.2.1.4 If the difference between any pair of readings is greater than 0.1 mil, the surfaces are NOT parallel.

7.3 Lacking a detailed procedure supplied by the instrument manufacturer, confirm the requirements for parallelism of dial-type micrometers given in 6.3.1.2 by placing a hardened steel ball (such as is used in a ball bearing) of suitable diameter between the presser foot and the anvil. Mount the ball in a fork-shaped holder to allow the ball to be conveniently moved from one location to another between the presser foot and the anvil. The balls used commercially in ball bearings are almost perfect spheres having diameters constant within a few microinches.

NOTE 2—Exercise care with this procedure. Calculations using the equations in X1.3.2 show that the use of a 24-oz weight on a ball between the hardened surfaces of presser foot and anvil can result in dimples in the anvil or presser foot surfaces caused by exceeding the yield stress of the surfaces.

7.3.1 Observe and record the diameter as measured by the micrometer at one location.

7.3.2 Move the ball to another location and repeat the measurement.

7.3.3 If the difference between any pair of readings is greater than 0.1 mil, the surfaces are NOT parallel.

7.4 Lacking a detailed procedure supplied by the instrument manufacturer, confirm the flatness of the anvil and the spindle surface of a micrometer or dial gage by use of an optical flat which has clean surfaces. Surfaces shall be flat within 0.05 mil.

7.4.1 After cleaning the micrometer surfaces (see 7.1), place the optical flat on the anvil and close the presser foot as described in 7.6.2 or 7.6.3 or 7.6.4 or 7.6.5 as appropriate.

7.4.2 When illuminated by diffused daylight, interference bands are formed between the surfaces of the flat and the surfaces of the micrometer. The shape, location, and number of these bands indicate the deviation from flatness in increments of half the average wavelengths of white light, which is taken as 0.01 mil.

7.4.2.1 A flat surface forms straight parallel fringes at equal intervals.

7.4.2.2 A grooved surface forms straight parallel fringes at unequal intervals.

7.4.2.3 A symmetrical concave or convex surface forms concentric circular fringes. Their number is a measure of deviation from flatness.

7.4.2.4 An unsymmetrical concave or convex surface forms a series of curved fringes that cut the periphery of the micrometer surface. The number of fringes cut by a straight line connecting the terminals of any fringes is a measure of the deviation from flatness.

7.5 *Machinist's Micrometer Requirements*:

7.5.1 The requirements for zero reading of machinist's micrometers are met when ten closings of the spindle onto the anvil, in accordance with 7.6.2.3 or 7.6.3.3 as appropriate, result in ten zero readings. The condition of zero reading is satisfied when examinations with a low-power magnifying glass show that at least 66 % of the width of the zero graduation mark on the barrel coincides with at least 66 % of the width of the reference mark.

7.5.2 Proper maintenance of a machinist's micrometer may require adjusting the instrument for wear of the micrometer screw so that the spindle has no perceptible lateral or longitudinal looseness yet rotates with a torque load of less than 0.25 ozf–in. If this is not achievable after disassembly, cleaning, and lubrication, replace the instrument.

7.5.3 After the zero reading has been checked, use the calibration procedure of 7.6.2 or 7.6.3 (as appropriate for the machinist's micrometer under examination) to check for maximum acceptable error in the machinist's micrometer screw.

7.5.3.1 Use selected feeler-gage blades with known thicknesses to within ±0.02 mil to check micrometers calibrated in English units at approximately 2, 5, and 10-mil points. Use standard gage blocks at points greater than 10 mil.

7.5.3.2 At each point checked, take ten readings. Calculate the arithmetic mean of these ten readings.

7.5.3.3 The machinist's micrometer screw error is within requirements if the difference between the mean value of 7.5.3.2 and the gage block (or feeler-gage blade) thickness is not more than 0.1 mil.

7.5.4 *Calibration of Spindle Pressure in Machinist's Micrometer with Ratchet or Friction Thimble*:

7.5.4.1 See Annex A1, which details the apparatus and procedure required for this calibration.

7.6 *Calibration of Micrometers*:

7.6.1 Calibrate all micrometers in a standard laboratory atmosphere maintained at 50 % relative humidity and 23°C or some other standard condition as mutually agreed upon between the seller and the purchaser. Use standard gage blocks or other metallic objects of known thickness. The known thickness accuracy of such blocks shall be within ±10 % of the smallest scale division of the micrometer dial or scale. Thus, if an instrument's smallest scale division is 0.1 mil, the standard gage block thickness shall be known to within ±0.01 mil. Perform calibration procedures only after the instrument has been checked and found to meet the requirements of the pertinent preceding paragraphs of this standard. Perform calibration procedures at least once every 30 days.

7.6.2 *Calibration Procedure for Apparatus A, Machinist's Micrometer with Ratchet or Friction Thimble*:

7.6.2.1 Calibrate the ratchet spring or friction thimble in accordance with Annex A1.

7.6.2.2 Rotate the spindle so as to close the micrometer on the gage block or other calibrating device. Reverse the rotation so as to open the micrometer 4 to 5 mils.

7.6.2.3 Using the ratchet knob or the friction thimble, again close the micrometer so slowly on the calibrating device that the scale divisions may be easily counted as they move past the reference mark. This rate approximates about 2 mils/s.

7.6.2.4 Continue the closing motion until the ratchet clicks three times or the friction thimble slips.

7.6.2.5 Observe and record the thickness reading.

7.6.2.6 Repeat the procedures in 7.6.2.2-7.6.2.5 using several gage blocks (or other calibration devices) of different thicknesses covering the range of thickness of electrical insulation for measurement with this micrometer.

7.6.2.7 Construct a calibration curve that will provide the corrections for application to the observed thickness of specimens tested for thickness using this calibrated micrometer.

7.6.3 *Calibration Procedure for Apparatus B, Machinist's Micrometer without Ratchet or Friction Thimble*:

7.6.3.1 Rotate the spindle so as to close the micrometer on the gage block or other calibrating device. Reverse the rotation so as to open the micrometer 4 to 5 mils.

7.6.3.2 Close the micrometer again so slowly on the calibrating device that the scale divisions may be easily counted as they move past the reference mark. This rate approximates about 2 mils/s.

7.6.3.3 Continue the closing motion until the spindle face contacts the surface of the gage block (or other calibrating device). Contact is made when frictional resistance initially develops to the movement of the calibrating device between the anvil and the spindle face.

7.6.3.4 Observe and record the thickness reading.

7.6.3.5 Repeat the procedures in 7.6.3.1-7.6.3.4 using several gage blocks (or other calibration devices) of different thicknesses covering the range of thickness of electrical insulation for measurement with this micrometer.

7.6.3.6 Construct a calibration curve that will provide the corrections for application to the observed thickness of specimens tested for thickness using this calibrated micrometer.

7.6.4 *Calibration Procedure for Apparatus C, Manually-Operated Dial-Type Micrometers*:

7.6.4.1 Using the procedures detailed in Section 9 pertinent to the material to be measured, collect calibration data from observations using several gage blocks (or other calibration devices) of different thicknesses covering the range of thickness of electrical insulation for measurement with this micrometer.

7.6.4.2 Construct a calibration curve that will provide the corrections for application to the observed thickness of specimens tested for thickness using this calibrated micrometer.

7.6.5 *Calibration Procedure for Apparatus D, Motor-Operated Dial-Type Micrometers*:

7.6.5.1 Using the procedures detailed in Section 9 pertinent to the material to be measured, collect calibration data from observations using several gage blocks (or other calibration devices) of different thicknesses covering the range of thickness of electrical insulation for measurement with this micrometer.

7.6.5.2 Construct a calibration curve that will provide the corrections for application to the observed thickness of specimens tested for thickness using this calibrated micrometer.

8. Test Specimens

8.1 Prepare and condition each specimen in equilibrium with the appropriate standard laboratory test conditions in accordance with the test method applicable to the specific material for test.

8.2 For each specimen, take precautions to prevent damage or contamination that might adversely affect the thickness measurements.

8.3 Unless otherwise specified, make all thickness measurements at the standard laboratory atmosphere in accordance with Practice D 6054.

8.4 In the procedure sections a requirement is made to avoid making measurements at locations that are less than 250 mils from any specimen edge. There may be instances, particularly when measuring very narrow strip specimens used for tensile tests, and so forth, when this requirement cannot be satisfied. In such cases, it is permissible to ignore this requirement.

9. Procedures

NOTE 3—In the remainder of this section the word *method* denotes a combination of both a specific apparatus and a procedure describing its use.

9.1 The selection of a method for measurement of thickness is influenced by the characteristics of the solid electrical insulation for measurement. Each material will differ in its response to test method parameters, which include, but may not be limited to: compressibility, rate of loading, ultimate load, dwell time, and the dimensions of the presser foot and anvil. For a specific electrical insulating material, these responses may cause measurements made using one method to differ significantly from measurements made using another method. The procedures that follow are categorized according to the materials to which each applies. See also Appendix X1.

9.2 *Test Methods Applicable to Plastic Sheet and Film*:

9.2.1 Except as otherwise specified in other applicable documents, use either Method A or Method B for plastic sheet or film specimens having nominal thickness greater than 10 mils.

9.2.2 Except as otherwise specified in other applicable documents, use either Method C or Method D for plastic sheet or film specimens having nominal thickness at least 1 mil but not greater than 10 mils.

9.2.3 Annex A3 of Test Method E 252 contains an alternative method applicable to all films of nominal thickness equal to or less than 2 mils.

9.2.4 When testing specimens by Methods A, B, C, or D, use apparatus that conforms to the requirements of appropriate parts of Sections 6 and 7 including the requirement for accuracy of zero setting. In addition, use an instrument for either Method C or Method D that has:

9.2.4.1 Presser foot diameter not less than 125 mils nor greater than 500 mils, 9.2.4.2 Diameter of the anvil surface upon which the specimen rests of at least 2 in., and

9.2.4.3 A force applied by the presser foot to the specimen not less than 0.1 lbf nor greater than 1.6 lbf.

9.2.4.4 Calculations using the dimensions of 9.2.4.1 and the forces of 9.2.4.3 show that the pressure upon a specimen can range between 0.5 and 130 psig.

NOTE 4—An electronic gage may be substituted for the dial gage in Method C if the presser foot and anvil meet the requirements of that method.

NOTE 5—**Caution:** Cleaning the presser foot and anvil surfaces as described in 7.1 can cause damage to digital electronic gages, which may then require very expensive repairs by the instrument manufacturer. To avoid these costs, obtain procedures for cleaning such electronic gages from the instrument manufacturer.

9.2.5 When testing specimens using Method D, use an instrument that has a drop rate from 45 ± 15 mils/s between 25 and 1 mil on the dial and a capacity of at least 31 mils.

9.2.6 The presence of contaminating substances on the surfaces of the test specimens, presser foot, anvil, or spindle can interfere with thickness measurements and result in erroneous readings. To help prevent this interference, select only clean specimens for testing and keep them and the thickness measuring instrument covered until ready to make measurements.

9.2.7 *Method A (applicable to plastic sheet and film having nominal thickness greater than 10 mils)*:

9.2.7.1 Using Apparatus A and specimens in conformance with Section 8, close the micrometer on an area of the specimen outside of the area for measurement. Observe this initial reading and then open the micrometer approximately 4 mils beyond the initial reading and move the specimen to the first measurement position. Avoid using measurement positions that are closer than 250 mils from any specimen edge.

9.2.7.2 Using the ratchet, or the friction thimble, close the micrometer at such a rate that the scale divisions may be counted easily as they pass the reference mark. This rate is approximately 2 mils/s.

9.2.7.3 Continue the closing motion until the ratchet clicks three times, or the friction thimble slips. Observe the indicated thickness.

9.2.7.4 Correct the observed indicated thickness using the calibration chart obtained in accordance with 7.6 and record the corrected thickness value.

9.2.7.5 Move the specimen to another measurement position and repeat 9.2.7.1-9.2.7.4.

9.2.7.6 Unless otherwise specified make and record at least three thickness measurements on each specimen. The arithmetic mean of all thickness values is the thickness of the specimen.

9.2.8 *Method B (applicable to plastic sheet and film having nominal thickness greater than 10 mils)*:

9.2.8.1 Using Apparatus B and specimens in conformance with Section 8, close the micrometer on an area of the specimen outside of the area for measurement. Observe this initial reading and then open the micrometer approximately 4 mils beyond the initial reading and move the specimen to the first measurement position. Avoid using measurement positions that are closer than 250 mils from any specimen edge.

9.2.8.2 Slowly close the micrometer at such a rate that the scale divisions may be counted easily as they pass the reference mark. This rate is approximately 2 mils/s.

9.2.8.3 Continue the closing motion until contact with the specimen surface is just made as evidenced by the initial development of frictional resistance to movement of the micrometer screw. Observe the indicated thickness.

9.2.8.4 Correct the observed indicted thickness using the calibration chart obtained in accordance with 7.6 and record the corrected thickness value.

9.2.8.5 Move the specimen to another measurement position and repeat 9.2.8.1-9.2.8.4.

9.2.8.6 Unless otherwise specified, make and record at least three thickness measurements on each specimen. The arithmetic mean of all thickness values is the thickness of the specimen.

9.2.9 *Method C (applicable to plastic sheet and film having nominal thickness equal to or greater than 1 mil but not greater than 10 mils)*:

9.2.9.1 Using Apparatus C and specimens in conformance with Section 8, place the dial gage on a solid, level, clean table or bench that is free of excessive vibration. Confirm that the anvil and presser foot surfaces are clean. Adjust the zero point.

9.2.9.2 Using Apparatus C and specimens in conformance with Section 8, close the micrometer on an area of the specimen outside of the area for measurement. Observe this initial reading and then open the micrometer approximately 4 mils beyond the initial reading and move the specimen to the first measurement position. Avoid using measurement positions that are closer than 250 mils from any specimen edge.

9.2.9.3 Raise the presser foot slightly.

9.2.9.4 Move the specimen to the first measurement location and lower the presser foot to a dial reading approximately 0.3 to 0.4 mil higher than the initial reading of 9.2.9.2.

9.2.9.5 Drop the foot onto the specimen. See also Note 7.

9.2.9.6 Observe the dial reading. After correcting the observed indicated thickness using the calibration chart obtained in accordance with 7.6, record the corrected thickness value.

9.2.9.7 Move the specimen to another measurement position and repeat 9.2.9.1-9.2.9.6.

9.2.9.8 Unless otherwise specified, make and record at least three thickness measurements on each specimen. The arithmetic mean of all thickness values is the thickness of the specimen.

9.2.9.9 Recheck the instrument zero setting after measuring each specimen. A change in the setting is usually the result of contaminating particles carried from the specimen to the contacting surfaces of the presser foot and anvil. This condition necessitates the cleaning of these surfaces (see 7.1 and Note 5).

9.2.10 *Method D (applicable to plastic sheet and film having nominal thickness equal to or greater than 1 mil but not greater than 10 mils)*:

9.2.10.1 Using Apparatus D and specimens in conformance with Section 8, place the motor operated dial gage on a solid, level, clean table or bench that is free of excessive vibration. Confirm that the anvil and presser foot surfaces are clean.

9.2.10.2 Apply power to the motor and allow the instrument to reach a thermal equilibrium with the ambient. Equilibrium is attained when the zero point adjustment becomes negligible. Do not stop the motor until all of the measurements are made. This will minimize any tendency to disturb the thermal equilibrium between the instrument and the ambient during the thickness measurements.

9.2.10.3 When the opening between the presser foot and the anvil is near its maximum, insert and position a specimen for the first measurement. Avoid using measurement positions that are less than 250 mils from any specimen edge.

9.2.10.4 While the presser foot is at rest on the specimen surface, observe the dial reading. After correcting the observed indicated thickness using the calibration chart obtained in accordance with 7.6, record the corrected thickness value.

9.2.10.5 While the presser foot is near its maximum lift, move the specimen to another measurement position and repeat 9.2.10.1-9.2.10.4.

9.2.10.6 Unless otherwise specified, make and record at least three thickness measurements on each specimen. The arithmetic mean of all thickness values is the thickness of the specimen.

9.2.10.7 Recheck the instrument zero setting after measuring each specimen. A change in the setting is usually the result of contaminating particles carried from the specimen to the contacting surfaces of the presser foot and anvil. This condition necessitates the cleaning of these surfaces (see 7.1 and Note 5).

9.3 *Methods Applicable to Papers*:

9.3.1 Each of the methods for measurement of thickness of paper requires apparatus that:

9.3.1.1 Meets the requirements of the appropriate parts of Sections 6 and 7,

9.3.1.2 Is capable of applying a pressure of 25 ± 2 psig on the paper specimen, and

9.3.1.3 Has a presser foot diameter 25 ± 1 mils.

9.3.2 Except as otherwise specified in other applicable documents, for electrical insulating paper having nominal thickness less than 2 mils, use Method E with a specimen comprised of at least eight, and preferably ten, layers of paper. Method E is also the preferred method for use with any paper of nominal thickness from 2 to 26 mils using a specimen consisting of a single sheet. Method E does not prohibit the testing of single sheet specimens of paper having nominal thickness under 2 mils.

9.3.3 Use any of the methods of 9.3 for any paper or pressboard having nominal thickness of at least 2 mils.

9.3.4 *Method E*, applicable to all electrical insulating paper and pressboard, uses a motor operated, dead-weight, dial-type micrometer described as Apparatus D and conforming to 6.4, 7.1, and 7.6 and that also uses a drop rate of 45 ± 15 mils/s from 25 to 1 mil above zero; has a capacity of at least 31 mils; has a dwell time between 2 and 4 s from 25 to 1 mil above zero; and uses a presser foot assembly having a weight of 20 ± 2 oz, which exerts the force to meet the pressure requirement of 9.3.1.2.

9.3.4.1 Using Apparatus D as described in 9.3.4 and specimens in conformance with Section 8, place the motor operated dial gage on a solid, level, clean table or bench that is free of excessive vibration. Confirm that anvil and presser foot surfaces are clean.

9.3.4.2 Apply power to the motor and allow the instrument to reach a thermal equilibrium with the ambient. Equilibrium is attained when the zero point adjustment becomes negligible. Do not stop the motor until all of the measurements are made. This will minimize any tendency to disturb the thermal equilibrium between the instrument and the ambient during the thickness measurements.

9.3.4.3 Historically, some but not all specifications for electrical insulating papers having nominal thickness under 2 mils require a thickness specimen that consists of a stack of at least eight (preferably ten) layers of paper (see Note 6). The micrometer reading of the stack, corrected from the calibration chart, is divided by the number of layers in the stack and reported as the thickness. Thickness of paper measured with a stack specimen deviates significantly from thickness of the same paper measured on a single layer specimen.

NOTE 6—Originally, the selection of stack versus single sheet specimens was based on data obtained using manually operated micrometers. Those micrometers were perceived to have greater measurement reliability at the wider micrometer openings. For very thin papers and values of n between 1 and 5, the ratio of total thickness of a stack of n sheets to n continuously decreases. The change in the ratio between $n = 6$ layers and $n = 10$ layers is approximately zero. Variations in thickness within a single layer are largely hidden in a stacked specimen which results in reduced ranges of high and low thickness observations on stack specimens versus single sheet specimens.

9.3.4.4 When the opening between the presser foot and the anvil is near its maximum, insert and position a specimen for the first measurement. Avoid using measurement positions which are closer than 250 mils from any specimen edge.

9.3.4.5 While the presser foot is at rest on the specimen surface, observe the dial reading. After correcting the observed indicated thickness using the calibration chart obtained in accordance with 7.6, record the corrected thickness value.

9.3.4.6 While the presser foot is near its maximum lift, move the specimen to another measurement position and repeat 9.3.4.4 and 9.3.4.5. Select these subsequent measurement positions so that they are approximately on a line parallel to the cross machine direction of the paper. If practicable, make ten readings.

9.3.4.7 Unless otherwise specified, make and record at least five thickness measurements on each specimen. The arithmetic mean of all thickness values is the thickness of the specimen.

9.3.5 *Method F*, applicable to all electrical insulating paper and pressboard, uses a manually operated, dead-weight, dial-type micrometer described as Apparatus C and conforming to 6.3, 7.3, 7.4, 7.6.1, 7.6.4, 9.3.1, which also has a capacity of at least 31 mils and uses a presser foot assembly having a weight of 20 ± 2 oz, which exerts the force to meet the pressure requirement of 9.3.1.2.

9.3.5.1 Using the apparatus as described in 9.3.5 and specimens in conformance with Section 8, place the manually operated dial gage on a solid, level, clean table or bench that is free of excessive vibration. Confirm that the anvil and presser foot surfaces are clean.

9.3.5.2 Historically (see Note 6 in 9.3.4.3), some but not all specifications for electrical insulating papers having nominal thickness under 2 mils require a thickness specimen that consists of a stack of at least eight (preferably ten) layers of paper. The micrometer reading of the stack, corrected from the calibration chart, is divided by the number of layers in the stack and reported as the thickness. Thickness of paper measured with a stack specimen deviates significantly from thickness of the same paper measured on a single layer specimen.

9.3.5.3 Lift the presser foot and place a specimen on the anvil so as to make an initial reading on an area outside the area for measurement. Avoid using measurement locations that are closer than 250 mils from any specimen edge. Slowly lower the presser foot onto the initial measurement location and observe the initial reading between 2 and 4 s after the presser foot contacts the specimen surface.

9.3.5.4 Raise the presser foot and move the specimen to the first measurement location. Lower the presser foot to a dial reading approximately 0.3 mil higher than the initial reading of 9.3.5.3.

9.3.5.5 Drop the presser foot onto the specimen. See also Note 7.

9.3.5.6 Between 2 and 4 s after the presser foot contacts the specimen, observe the dial reading. After correcting the observed indicated thickness using the calibration chart obtained in accordance with 7.6, record the corrected thickness value.

NOTE 7—The procedure of 9.3.5.4-9.3.5.6 minimizes small errors present when the presser foot is lowered slowly onto the specimen.

NOTE 8—When measuring the thickness of noticeably compressible electrical insulating papers, the purchaser and the supplier may wish to fix the exact dwell time, within the above limits, during which the correct pressure is applied to the specimen.

9.3.5.7 Move the specimen to another measurement position and repeat 9.3.5.4-9.3.5.6.

9.3.5.8 Unless otherwise specified, make and record at least five thickness measurements on each specimen. The arithmetic mean of all thickness values is the thickness of the specimen.

9.3.5.9 Recheck the instrument zero setting after measuring each specimen. A change in the setting is usually the result of contaminating particles carried from the specimen to the contacting surfaces of the presser foot and anvil. This condition necessitates the cleaning of these surfaces (see 7.1 and Note 5).

9.3.6 *Method G* (applicable to electrical insulating paper and pressboard having nominal thickness greater than 2 mils) uses a machinist's micrometer with a calibrated ratchet or friction thimble described as Apparatus A and conforming to 6.1, 7.1, 7.2, 7.5, 7.6.1, 7.6.2, and 9.3.1.

9.3.6.1 Using apparatus as described in 9.3.6 and specimens in conformance with Section 8, close the micrometer on an area of the specimen outside of the area for measurement. Observe this initial reading and then open the micrometer approximately 4 mils beyond the initial reading.

9.3.6.2 Move the specimen to the first measurement position. Avoid using measurement positions that are closer than 250 mils from any specimen edge.

9.3.6.3 Using the ratchet, or the friction thimble, close the micrometer at such a rate that the scale divisions may be counted easily as they pass the reference mark. This rate is approximately 2 mils/s.

9.3.6.4 Continue the closing motion until the ratchet clicks three times, or the friction thimble slips. Observe the indicated thickness.

9.3.6.5 Correct the observed indicated thickness using the calibration chart obtained in accordance with 7.6 and record the corrected thickness value.

9.3.6.6 Move the specimen to another measurement position and repeat 9.3.6.2-9.3.6.5.

9.3.6.7 Unless otherwise specified, make and record at least five thickness measurements on each specimen. The arithmetic mean of all thickness values is the thickness of the specimen.

9.4 *Methods Applicable to Rubber and Other Elastomers*:

9.4.1 Method H is applicable to rubber or other elastomeric materials that have:

9.4.1.1 Shore A durometer hardness between 30 and 80, and

9.4.1.2 Nominal thickness in the range from approximately 30 to 250 mils.

9.4.2 Method H uses a manually operated dead-weight dial type micrometer described as Apparatus C in 6.3, which conforms to the requirements in 7.1, 7.3, 7.4, 7.6.1, and 7.6.4, and has:

9.4.2.1 A presser foot diameter 250 $\pm$ 1 mils,

9.4.2.2 An anvil diameter of at least 2 in.,

9.4.2.3 A capacity of at least 300 mils, and

9.4.2.4 A design and construction capable of applying a pressure of 3.8 $\pm$ 0.6 psig on the rubber or other elastomeric material specimen. This pressure is the result of the ratio of the force on the specimen (exerted by gravity on the 3 oz weight of the presser foot assembly, out of contact with the lifting mechanism) to the specified area of the presser foot.

9.4.3 Using the apparatus as described in 9.4.2 and specimens in conformance with Section 8, place the manually operated dial gage on a solid, level, clean table or bench that is free of excessive vibration. Confirm that the anvil and presser foot surfaces are clean and that the accuracy of zero reading has been determined.

9.4.4 Method H involves two different procedures for thickness measurements of rubber or other elastomeric materials. One procedure uses the dial micrometer as a comparison gage. The other procedure uses the dial micrometer as a direct thickness reading instrument. Test results using either procedure are not significantly different.

9.4.5 Satisfactory accuracy of thickness measurements on rubber and other elastomeric materials are obtained by using the dial gage as a comparison measuring instrument. The use of this technique does not require the construction of a calibration curve. Details of the comparison procedure follow.

9.4.5.1 Do not drop the presser foot but slowly lower the presser foot onto the surface of a specimen. Make an initial reading 5 s after the presser foot has contacted the specimen surface. The initial reading estimates the specimen thickness. Avoid using measurement locations that are closer than 250 mils from any specimen edge.

9.4.5.2 Raise the presser foot and remove the specimen.

9.4.5.3 Select a gage block that most closely approximates the initial reading observed in 9.4.5.1. Place the gage block on the anvil, and slowly lower the presser foot. DO NOT DROP THE PRESSER FOOT.

9.4.5.4 After the presser foot comes to rest, adjust the zero setting of the dial micrometer so that the dial reading is exactly the thickness of the gage block.

9.4.5.5 Lift the presser foot, remove the gage block, and place the specimen on the anvil.

9.4.5.6 Slowly lower the presser foot onto the specimen and allow it to come to rest for 5 s before reading the dial.

9.4.5.7 Repeat 9.4.5.2-9.4.5.6 until at least five thickness readings are obtained. The arithmetic mean of the five readings is taken as the thickness of the specimen.

9.4.6 Method H uses the dial micrometer as a direct thickness measurement instrument using the following procedure.

9.4.6.1 Do not drop the presser foot but slowly lower the presser foot onto the surface of a specimen. Make an initial reading 5 s after the presser foot has contacted the specimen surface. The initial reading estimates the specimen thickness. Avoid using measurement locations that are closer than 250 mils from any specimen edge.

9.4.6.2 Raise the presser foot no more than 20 mils above the thickness observed in 9.4.6.1 and move the specimen to the first measurement location.

9.4.6.3 Do not drop the presser foot but gently lower the presser foot onto the specimen and allow the presser foot to rest on the specimen for 5 s before reading the indicator dial.

9.4.6.4 Observe the thickness indicated on the dial and apply any correction from the calibration curve generated in accordance with 7.6. Record the corrected thickness value.

9.4.6.5 Repeat the procedure of 9.4.6.1-9.4.6.4 on different areas of the specimen until at least five thickness measurements have been recorded. The arithmetic average of the five corrected values is the thickness of the specimen.

9.4.7 There will be some compression of low durometer hardness rubber and other elastomeric materials due to the force exerted by the presser foot. That error magnitude will increase as specimen thickness decreases.

9.4.8 For the measurements of thickness on low durometer hardness rubber, the most significant and precise values are obtained by the use of Apparatus C modified so that the presser foot simulates the total load force expected in the intended application.

9.4.9 There may be occasions when it is desirable to measure the thickness of large sheets of flexible rubber or other elastomeric material. For large specimens of such materials there may be a tendency to overhang the anvil and cause a bulging-up near the position of the presser foot. The use of a support structure, which is level and parallel to the anvil, is recommended to minimize such problems.

10. Report

10.1 Report the following information:

10.1.1 Complete identification of the material tested including type, grade, source, and lot number,

10.1.2 Date of testing, identity of the testing laboratory, and identity of the responsible personnel,

10.1.3 Test method used, details of any deviation therefrom, and the choice of any options in the standard procedure,

10.1.4 The number of specimens per sample and the number of measurements per specimen, and

10.1.5 The arithmetic mean and the range of all measurements made on a sample.

11. Precision and Bias

11.1 *Precision*—Since the test methods herein employ different pieces of apparatus, call for one of several magnitudes of forces to be exerted upon specimens of widely different geometries for varying periods of time, and are used for a wide variety of materials, it is the consensus that a precision statement in this standard is not practicable. There will be different precisions between methods and between materials. The reader is directed to seek precision statements in those other ASTM standards that deal with specific solid electrical insulation material measured by any of these methods.

11.2 *Bias*—The bias of any one of these methods is unknown. A standard specimen of known thickness of solid electrical insulation is not available for measurement of thickness by each of these methods.

12. Keywords

12.1 caliper; elastomers; electrical insulation; micrometer; paper; paperboard; plastic film; plastic sheet; polymeric film; pressboard; rubber; thickness

ANNEX

(Mandatory Information)

A1. CALIBRATION OF MACHINIST'S MICROMETER RATCHET SPRING OR SPINDLE FORCE

A1.1 Introduction

A1.1.1 This annex describes apparatus and procedures suitable for ascertaining the pressure exerted by the spindle on a machinist's micrometer equipped with a calibrated-spring actuated ratchet or friction thimble. Such a micrometer is described in Section 6 as Apparatus A.

A1.2 Apparatus for Calibration

A1.2.1 *Balance*, triple-beam, single plate, graduated to 0.1 g, having a maximum capacity of about 2.6 kg using auxiliary weights. Equip the balance with an adjustable counterbalance.

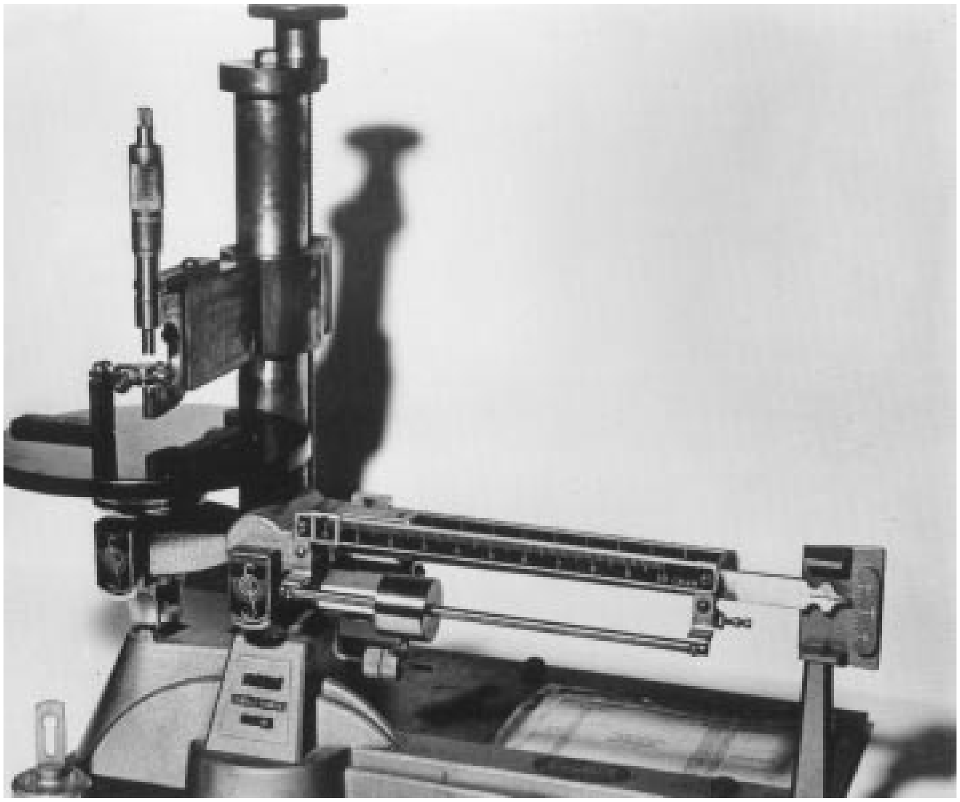

FIG. A1.1 Balance

TABLE A1.1 Applicable Weights and Pressures for 0.250 in. Diameter Spindles

Pressure, psig	Weight, g
21	470
22	490
23	510
24	530
25	560
26	580
27	600
28	620
29	650

A1.2.2 *Attachment*,[7] mounted vertically upon the plate of the balance so as to support a universal joint, one face of which is lapped flat.

A1.2.3 *Vertical Arm Support*, mounted at right angles to the balance plate that will hold the machinist's micrometer for test. Hold the micrometer by this arm in such a way that the clamping pressure of the arm support will not distort the micrometer frame.

A1.2.4 Refer to Fig. A1.1, which pictures the assembled apparatus.

A1.3 Procedure

A1.3.1 Place the micrometer in position on the supporting arm.

A1.3.2 Adjust the support arm position to allow the balance pointer free travel between ±50 mg.

A1.3.3 Lock the support arm in this position.

A1.3.4 Place a specimen, such as a 10 layer pad of capacitor paper, between the spindle foot of the micrometer and the lapped surface of the universal joint.

A1.3.5 Adjust the micrometer spindle so that the pointer of the balance reads 50 mg.

A1.3.6 Apply a weight, from among the weights shown in Table A1.1, to the balance arm. To calibrate a micrometer that will exert a pressure of 27.0 psig select a weight of 600 g. For other pressures, refer to Table A1.1.

A1.3.7 Turn the micrometer spindle until the ratchet clicks three times or until the friction thimble slips.

A1.3.8 The ratchet should click, or the thimble should slip, if a 600-g weight is selected. The ratchet or thimble should bring up the pointer easily if a 510-g weight is selected.

A1.3.9 If the pressure for a micrometer with ratchet is high, clip the spring until the proper range is observed. If the pressure is too low, discard the spring and replace with a new spring.

NOTE A1.1—Obtain a new micrometer spring from the micrometer manufacturer or make one from a coil spring wire of 18-mil nominal diameter. Make the inside diameter of the coiled wire 190 ± 3 mils with a 78 ± 2-mil spacing between coil turns. Grind the ends of the spring flat.

A1.3.10 If it is necessary to elongate a spring so as to increase pressure, the maximum permitted elongation is 25 %.

A1.3.11 Make certain the spring seats properly in the ratchet assembly and completely assemble the ratchet before making any tests.

[7] This attachment can be adapted from a Starrett Center Tester No. 65, L. S. Starret Co., Athol, MA 01331.

A1.3.12 Do not use oil in the ratchet assembly.

A1.3.13 If the pressure for a micrometer with a friction thimble is outside the permissible limits, consult the manufacturer for procedures to remedy the non-conformance.

APPENDIX

(Nonmandatory Information)

X1. ELASTICITY THEORY ADAPTED TO THICKNESS MEASUREMENT

X1.1 Introduction

X1.1.1 Theoretical dissertations pertinent to the problems involved when a rigid cylindrical die is pressed into a semi-infinite elastic solid may be found in treatises on elasticity.[8]

X1.1.2 The equations derived therein indicate that the distance of penetration of the die (analogous to the presser foot of a micrometer) into the elastic solid (analogous to a thickness specimen) is proportional to the ratio of the applied force to the diameter of the cylinder.

X1.1.3 Other mechanical properties of the materials involved also have some influence on the distance of penetration.

X1.1.4 If a plot of measured thickness versus the ratio of applied force to presser foot diameter is made for each of several materials (including rubbers and recorder tapes) a linear relationship is found.

X1.1.5 In the absence of any better theoretical model, the equations for a cylinder die and a spherical die indenting a semi-infinite solid are presented and adapted to thickness measurements in the hope that further work is stimulated based on adapting the semi-infinite model to finite size models.

X1.1.6 In thickness measurements, keeping the average pressure constant when changing the diameter of presser feet has never been satisfactory, and this old notion needs to be discarded.

X1.1.7 The theory developed in the treatises does not give any information about how to handle the effects due to time of loading. Until something better is established, the effects of time need evaluation for each material over the range of thicknesses, forces, and foot diameters expected in testing.

X1.2 Cylindrical Pressure Foot

X1.2.1 For the cylindrical presser foot the expression for penetration *d* is:

$$d = (W/D) \times [(1 - \sigma^2)/E] \quad \text{(X1.1)}$$

where:
W = force downward on the foot,
D = diameter of the face,
σ = Poisson's ratio = 0.40 to 0.45 for plastics in general, and
E = Young's modulus of the specimen.

The presser foot and anvil are regarded as infinitely rigid.

X1.2.2 As a result, the amount of penetration is determined by the ratio of force, or load, to the diameter of the presser foot. Data on rubber and recorder tape confirm this finding. Consequently, if the radius of the presser foot is reduced by a factor, reduce the load by the same factor to keep the penetration, and therefore, the apparent thickness constant. This is in contrast to previously held perceptions of the necessity for maintaining constant average pressure.

X1.2.3 The pressure, *P*, applied at any point on the specimen inside the perimeter of the foot is given by:

$$P = W/[2 \pi R(R^2 - r^2)^{0.5}] \quad \text{(X1.2)}$$

where *W* is the force and *R* is the radius and *r* is the radial distance of the point being discussed from the center of the surface. This brings out the important point that at the periphery of the foot surface (where *r* approaches *R*), *P* approaches infinity and the specimen is stressed beyond its yield point so that an imprint of the outline of the presser foot surface remains upon the specimen surface. Dressing the edge of the presser foot to have a slight radius avoids this effect.

X1.2.4 Assuming the equations apply to a relatively thin specimen, the actual thickness measured will be the no-load thickness minus the penetration and the equation for thickness becomes:

$$T = T_o - d = T_o - W/D(1 - \sigma^2)/E \quad \text{(X1.3)}$$

where:
T_o = the no-load thickness.

X1.2.5 A plot of *T* versus *W/D* results in a straight line. The intercept at $W/D = 0$ provides a value for T_o. Data for the plot may be obtained by making a series of measurements on a specimen using different weights with a fixed diameter of presser foot or a fixed weight with presser feet of differing diameter.

X1.2.6 If such a plot is made for polymeric film and the slope of the line is established from the plot or by regression analysis of the data, a number of characteristics of the film may be obtained.

X1.2.7 The plot can also be useful in estimating the effects of making thickness measurements on the material using different dimensions of the presser foot and different applied forces to the specimen.

X1.3 Hemisphere-Shaped Foot

X1.3.1 For a hemisphere pressing a semi-infinite specimen, the penetration, *d*, into the surface is given by the equation:

[8] Timoshenko, S., *Theory of Elasticity*, McGraw-Hill Book Co., New York, NY, 1934, p. 338.

$$d = 0.8255 \times (W^2/R)^{1/3} \times [(1 - \sigma^2)/E]^{2/3} \quad (X1.4)$$

where:

W = force downward on the hemisphere,
R = radius of the hemisphere which is assumed incompressible,
σ = Poisson's ratio = 0.40 to 0.45 for plastics, and
E = Young's modulus of the specimen.

Consequently, the amount of elastic displacement observed for a given material depends on the ratio W/R. If the radius of the hemisphere is reduced by 4, the load on the gage must be reduced by a factor of 2 to maintain the same penetration.

X1.3.2 Permanent indentation will occur if the elastic yield point of the specimen is exceeded. This occurs unless the loads and radius are such that:

$$Y > 0.5784 \times [E/(1 - \sigma^2)]^{2/3} \times (W/R^2)^{1/3} \quad (X1.5)$$

where Y is the yield stress of the material. In selecting loads to apply to the specimen, make a calculation to see if the resulting load and radius combination is too near the yield strength.

X1.3.3 Assuming that the equation will still hold for a finite specimen, the reading obtained for the thickness is the no-load thickness of the specimen minus the amount of penetration. An equation can be written expressing this idea using the equation for penetration written above:

$$T = T_o - [0.8255 (W^2/R)^{1/3} \times [(1 - \sigma^2)/E]^{2/3}] \quad (X1.6)$$

where T_o is the thickness read and $T_o$is the no-load thickness. A plot of T versus either $W^{2/3}$ or $(W^2/R)^{1/3}$ should result in a straight line that when extrapolated to $W = 0$ gives the no-load thickness T_o.