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# Standard Test Methods for Standardization and Calibration of In-Line Dry Lumber Moisture Meters[1]

This standard is issued under the fixed designation D6782; 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 These test methods apply to instruments designed to detect, or measure, moisture in wood which has been dried below the fiber saturation point. The purpose of these tests is to provide a unified standard against which such systems can demonstrate their suitability for their intended use (see Appendix X1).

1.2 The standard is configured to support tests by moisture meter manufacturers as well as end-users of such systems, therefore the text follows two tracks (see Appendix X2).

1.3 Test methods specified for manufacturers are generally designed for laboratory settings and are intended to provide a standard against which a manufacturer certifies calibration and general system conformance.

1.4 Test methods for end-users are generally designed for field settings and are intended as a standardized set of procedures for determining the suitability of a specific machine for a particular use.

1.5 Applications such as lumber marking or sorting systems utilizing the output of the in-line meter are not part of this standard.

1.6 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.7 *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]

D1990 Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens
D2395 Test Methods for Specific Gravity of Wood and Wood-Based Materials
D2915 Practice for Sampling and Data-Analysis for Structural Wood and Wood-Based Products
D4442 Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials
D4444 Test Method for Laboratory Standardization and Calibration of Hand-Held Moisture Meters
D4933 Guide for Moisture Conditioning of Wood and Wood-Based Materials
D5536 Practice for Sampling Forest Trees for Determination of Clear Wood Properties

## 3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *accept/reject meters, n*—meters that permit identification or sorting, or both, of pieces into moisture content classes. The simplest design has one set point or target level to separate wetter from drier pieces. Often the meters described in 3.1.5 may be operated as accept/reject meters.

3.1.2 *field, n*—an environment usually not meeting the criteria of 3.1.4. This is often a meter installation at the wood processing facility where the meter and the lumber are subject to the process environment of mill production.

3.1.3 *flow, n*—a term that describes the movement and orientation of the piece with respect to the sensing area.

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[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.

3.1.3.1 *longitudinal-flow*—in this flow arrangement, pieces pass lengthwise through the sensing area. All or some portion of the length may be sensed.

3.1.3.2 *transverse-flow*—in this flow arrangement, the pieces pass crosswise through the sensing area. Transverse meters frequently have more than one sensing area, consequently, the meter may sense more than one area of the piece even if the entire piece is not sensed.

3.1.4 *laboratory, n*—an environment under which conditions of temperature and moisture content can be controlled within stated tolerances and which permit use of carefully selected and controlled specimens.

3.1.5 *meters, n*—in-line (or in process) moisture sensors designed to respond in one pass to the moisture content of a piece passing the sensing area.

3.1.5.1 *Discussion*—Meters are typically a system consisting of one or more fixed sensing areas (termed heads) and a processing/readout console that may be remote from the region where sensing takes place. Meters may be either non-contact or contact types, and are considered nondestructive if the anticipated performance of the product is not adversely affected by the meter. The magnitude of the sensing area (sampling area) is often regarded in processing as representative of the entire piece, although the intended product requirements may require alternate sampling or analysis schemes. The term sensing region is sometimes used in lieu of sensing area to encompass the three-dimensional sensing pattern of a meter. Meters may have more than one sensing area; consequently, the meter may independently sense more than one area of the piece. Meters may be designed to indicate moisture content percentage, to operate as accept/reject instruments, or to be used for both applications.



3.1.6 *moisture content level, n*—the moisture content at which products are defined as dry, or at which accept/reject decisions are made. This level is dependent upon the specific grading rule, quality control requirements or product specification.

3.1.7 *moisture indicators, n*—meters which display or record the estimated moisture content, or both. The moisture content is estimated from a predetermined relationship between the meter output and moisture content determined by a standard method.

3.1.7.1 *Discussion*—Typical sensing principles are given in Appendix X3.

3.1.8 *Standardization and Calibration:*—

3.1.8.1 *standardization*—the determination of the response of the meter to a reference material (see Appendix X4).

3.1.8.2 *calibration*—the determination of the relationship between the response of a standardized meter and the moisture content of a reference material, determined by a standard method (see Appendix X4).

3.1.9 *test modes, n*—these terms describe the status of the piece during measurement.

3.1.9.1 *static*—the piece is stationary in the sensing area when the moisture measurement is made.

3.1.9.2 *dynamic*—the piece moves through the sensing area during measurement.

## 4. Significance and Use

4.1 In-line meters provide a rapid means of detecting moisture content of lumber or wood products in processing (that is, on a continuous production line). Two major uses are monitoring the performance of the drying process (air drying, kiln drying), and providing sorting or identification of material at predetermined levels of moisture content. These measurements are inferential in the sense that physical measurements are made and compared against calibration curves to obtain an indirect measure of moisture content. These measurements may be influenced by one or more physical properties such as actual moisture content (average and gradient; see Appendix X5), density, surface moisture, chemical composition, size, and temperature of wood. In addition, the measurements may also be influenced by environmental conditions and the design specifications of the meter. The best performance is obtained by an awareness of the effect of each parameter on the meter output and correction of readings as specified by these test methods.

4.2 The two major anticipated users of these test methods are instrument manufacturers whose primary concern is laboratory standardization and calibration, and instrument owners who may have a primary focus on field standardization and calibration. These test methods present the laboratory and the field as separate tracks (see Appendix X2).

4.2.1 *Laboratory Standardization and Calibration*—This portion of these test methods is intended for guidance of equipment manufacturers. Specific test recommendations are tailored to the capabilities of a laboratory environment.

4.2.2 *Field Standardization and Calibration*—The predominant use of in-line meters is in production in which lumber characteristics and environmental conditions reflect actual mill processes. Field standardization and calibration is essential to address or encompass much of the variability in production.

4.2.3 Applications using the output of the in-line moisture meter may modify the meter output signals or have inherent response characteristics that are not representative of the meter.

## 5. Laboratory Standardization and Calibration

This procedure is intended for testing of a specific model or version of meters.

5.1 *Laboratory Standardization*—Standardization shall be performed on the meter to test the integrity of the meter and sensing region. The meter shall be standardized using suitable reference materials to provide at least one reference point other than zero on the meter readout. In transverse feed systems, standardization shall be performed separately for each sensing region.

5.1.1 *Reference Specimens*—These references are often recommended or provided, or both, by the manufacturer of the meter. In absence of recommended reference specimens, materials shall be obtained that will provide consistent results during testing and retesting.

NOTE 1—Although the references are preferably non-hygroscopic, they maybe hygroscopic if due care is used to assure consistency during testing. For example, uniformly equalized clear wood specimens could be used if stored to maintain constant moisture content.

5.1.2 *Test Procedure*—In the following procedure, at least one reference specimen shall be used. Before each test, the meter shall be initialized by adjusting to the manufacturer's recommended initial reading with no material in the sensing region. The static and dynamic tests are to be conducted at room temperature (20-30°C/68-86°F). Any deviation from this temperature shall be documented in the report.

5.1.2.1 *Positioning*—The reference materials shall be positioned in the sensing region as recommended by the manufacturer and consistent with the constraints of the intended or recommended installation (see Appendix X6).

NOTE 2—Although the procedure specifies a single position, it may be useful to vary the position systematically to assess positional sensitivity. The variation in position may provide information on requirements for installation accuracy and effects from board misalignment, such as skewing or warping.

5.1.2.2 *Static Standardization Test*—After initializing, conduct a static standardization by placing the reference material in the sensing zone with the feed system disabled.

5.1.2.3 *Dynamic Standardization Test*—After initializing and conducting the static standardization (5.1.2), sequentially place each reference specimen (See 5.1.1 and Note 3) on a feed assembly outside the sensing zone. Energize the feed assembly to move the reference through the sensing zone at a selected constant speed. The speed selected shall be consistent with the intended installation. Record the meter reading (for example, maximum or average) as the reference standard passes through the sensing zone. Repeat the test at the selected test speeds. (The more detailed procedure of the dynamic test is described in Appendix X7).

NOTE 3—In some systems, such as longitudinal flow meters operating at high speed, it may not be possible to conduct dynamic laboratory standardization at operating speeds for practical reasons of control and safety. In these situations, the static or slow speed standardization results will necessarily be the basis for proceeding to the calibration step.

5.1.2.4 *Temperature Test*—The test shall be conducted at -20°C, 0°C, 20°C, 40°C and 60°C (-4°F, 32°F, 68°F, 104°F and 140°F) to determine the response of reference material, sensing heads, and console with temperature. At each temperature level, the system components shall be at specified thermal equilibrium, allowing sufficient time for any temperature soak effect. Record the observed temperature and meter reading at each temperature level.

(*1*) *Reference Material*— With the sensing heads and console at ambient room temperature (20-30°C/68-86°F), condition the reference material at the temperatures listed in 5.1.2.4. Quickly insert the reference material within the electrical field of one sensing head. Repeat the measurement at each temperature level and record average readings.

(*2*) *Sensing Heads*— With the console at ambient room temperature (20-30°C/68-86°F), place the sensing heads in a room to cycle to temperatures listed in 5.1.2.4. Allow the reference specimen to remain with the sensing heads. Determine the thermal drift of each sensing head by the difference of readings from those obtained in (*1*).

(*3*) *Console*—With the sensing heads and reference material at ambient room temperature (20-30°C/68-86ºF), cycle the console through the temperatures listed in 5.1.2.4. Determine the thermal drift of the console by differences in readings from those obtained in (*1*) and (*2*).

5.1.3 *Report*—The report shall include the data collected in 5.1.2 together with a detailed description of the reference materials, the method used for temperature exposure, and any variation from the specified procedure.

5.2 *Laboratory Calibration (MC Indicators)*—This method is intended for obtaining the greatest accuracy by comparison of the meter output to moisture content obtained gravimetrically using the oven-drying method (see Test Methods D4442). The accuracy of the desired results must be consistent with the indicated accuracy of the specific oven-drying procedure in Test Methods D4442. Laboratory calibration procedures are intended to provide reference data under controlled conditions of wood and ambient variables, This calibration is designed for full-scale calibration of the meter on actual wood specimens having uniform moisture content (see 5.2.2). Meters must be standardized (see 5.1) before being calibrated. In transverse feed systems, calibration shall be done separately for each sensing region. The calibration curve should neither be extrapolated below the lowest nor above the highest value tested.

5.2.1 *Calibration Objectives*—Establish the objectives of the calibration test including specimen characteristics criteria (for example, uniformity of moisture content, density, species, and so forth), operating speed, and environmental conditions.



5.2.2 *Specimen Selection and Preparation*— Specimens shall be selected to represent the characteristics identified as calibration variables in 5.2.1. Other characteristics that are to be held constant shall be identified as selection criteria. One example is the nominal thickness of the particular species for which calibration is desired. Specimen length shall exceed the dimensions of the sensing region for transverse meters and, for longitudinal meters, be a single length unless length is a variable for which calibration is desired. The selected specimens shall be free of visible irregularities such as knots, decay, reaction wood, wane, and resin concentrations. These specimens shall be carefully selected to be representative for the particular species and growth site. Specimens shall be chosen to be entirely sapwood or heartwood if possible.

5.2.2.1 If density is a variable chosen for calibration, evaluation requires data from a wide range of wood samples representing various density groups will be required. At a minimum, three density groups shall be prepared.

5.2.2.2 Where growth site is the subject of calibration, development of corrections will require specimens representing several different growth sites. Where the desired accuracy of the calibration is known and the influence of site can be estimated, Practice D2915 can be used to establish a sampling plan.

5.2.2.3 If testing of meter sensitivity to presence of wet pockets is required, it will be necessary to prepare a group of specimens with well defined wet pockets (size, position with respect to a board, MC gradients) of several typical sizes and locations (see Appendix X8). The obtained data shall be included in the report.

5.2.2.4 Species calibrations that are intended to represent an entire species, for example, to correspond to globally-determined design values assigned to structural products, shall be obtained only by conducting species-wide sampling. Committee D07 regards this species-wide sampling as meeting the principles that guide Practice D5536 or Practice D1990, or both. The species sampling suggested in these test methods is not required to be species-wide. Species representation claims based on less-than species-wide sampling shall be correspondingly limited.

5.2.3 *Specimen Conditioning*—The specimens shall be divided into four groups of at least twelve each and equilibrated (following a desorption path) to four selected equilibrium moisture content (EMC) levels for the applicable MC range (see Guide D4933). Alternately, twelve specimens shall be equilibrated (following a desorption path) at each of the EMC conditions (see Note 4).

NOTE 4—The twelve-specimen alternative lengthens the test considerably, but may be the only practical choice under certain conditions, particularly when wood variable effects are to be minimized.

5.2.4 *Test Procedure*—In the following procedure, the meter shall be initialized (5.1.2) with no specimens in the sensing region. The dynamic test shall be conducted at room temperature.

5.2.4.1 *Positioning*—The specimens shall be positioned in the sensing region recommended by the manufacturer and consistent with the constraints of the intended or recommended installation (see Appendix X6).

5.2.4.2 *Dynamic Test*—After initializing (5.1.2), obtain one set of specimens at a specific EMC level. Sequentially place each specimen on the feed assembly outside the sensing zone. Energize the feed assembly to move the specimens through the sensing zone at a series of constant speeds selected to encompass the operating range of speeds of the meter assembly. Record the meter reading (maximum or average) as the specimens pass through the sensing zone. (The more detailed procedure of the dynamic test is described in Appendix X7).

NOTE 5—Often an objective is evaluation of the dynamic response of the meter to a localized wet area. If this is desired as part of the dynamic calibration, modification of the specimen selection and preparation, positioning and response monitoring will be required. Discussion of wet spot issues is contained in Appendix X8.

5.2.4.3 *Wood Temperature Test*—Place the entire system, including the specimen material, in a room capable of variation from -20 to 60°C (-4 to 140°F) (see 5.1.2.4). With the system in equilibrium at selected temperatures between -20 and 60°C (-4 to 140°F), place each specimen statically within the sensing area to obtain meter readings with the specimens at the exposure temperatures. Apply the results of the temperature test, 5.1.2.4, for the drift and temperature effect corrections. The thermal effect of sensors, control consoles and wood samples must be tested independently. Place the sensors in the temperature-controlled room with cables running outside of the room to the console which is equalized at room temperature. Next reverse the setup with the console in the control room while keeping the sensors at room temperature. Finally, test the system with wood at different temperatures while the entire moisture detection system is equalized at room temperature. Use 5.2.4.3 to obtain data for the total (wood plus system) temperature correction. All specimens at the different EMC levels are to be used.

5.2.5 *Effect of Variables*—Determination of corrections. After completing 5.2.4, obtain oven-dry values of moisture content (see Test Methods D4442), specific gravity (oven-dry mass and volume) (see Test Methods D2395) and other specimen characteristics (see 5.2.1) for each specimen for comparison with the meter response. Subsequent analysis can be conducted with multivariate methods that address all of the chosen variables within the analysis, such as a multiple regression, or the response of the meter may be addressed one variable at a time if the covariance is not of interest. The following paragraphs list recommended procedures.

5.2.5.1 *Species*—From the data collected in the dynamic test (5.2.4.2), regress the readings obtained against the moisture contents of the specimens.

5.2.5.2 *Density and Growth Site*—From the data collected in the dynamic test (5.2.4.2), perform a multiple regression or similar analysis, incorporating moisture content density values or growth sites, or both, in the analysis regression model, to permit determination of the effect of these variables density and growth site on moisture content readings. If the multiple regression is performed using a statistical software package, the significance of the addition of density and growth site to the model will be incorporated in the printed copy of the results. If the technique used to perform the multiple regression does not determine the significance of added factors, then an analysis of variance shall be performed to determine the significance factors.

5.2.5.3 *Temperature*—From the data collected in 5.2.4.3, conduct an analysis, such as regression, to relate the moisture content readings of the meter to those obtained from oven-drying.

5.2.6 *Report*—The report shall contain a description of objectives selected in 5.2.1, the data collected in 5.2.3 and 5.2.4 together with a detailed description of the specimens and EMC levels, the corrections or adjustments determined for the target variables species, density, growth site and temperature, and any deviation from the specified procedure.

5.3 *Laboratory Calibration (Accept/Reject Meters)* —This procedure is designed for the calibration of the meter at a specific set point or set points, for operation as an accept/reject gauge. Moisture content values are not to be associated with specific boards sensed by such a meter except as below or above certain moisture content values. If such moisture content identification is desired for individual boards, the meter shall be calibrated as per 5.2. Meters shall be standardized (5.1) before being calibrated. In transverse feed systems, calibration shall be done separately for each sensing region.

5.3.1 *Calibration Objectives*—Establish the objectives of the calibration test including specimen criteria (for example, uniformity of moisture content, density, and so forth), operating speed, and environmental conditions.

5.3.2 *Specimen Selection and Preparation*— Specimens shall be selected following the criteria of 5.2.2 to represent the nominal thicknesses of the particular species for which calibration is desired. Specimen length shall exceed the dimensions of the sensing region. The selected specimens shall be free of visible irregularities such as knots, decay, reaction wood, and resin concentrations. The specimens shall be carefully selected to be representative of the particular species and growth site. Specimens shall be chosen to be entirely sapwood or heartwood.

5.3.2.1 *Specimen Conditioning*—Prepare sufficient specimens to obtain the desired degree of set point accuracy (see Note 6). Expose the specimens to controlled conditions to obtain equilibrium of individual pieces with minimal moisture gradients, centralized about the set point value (see Guide D4933). Determine the moisture content of the pieces applying either Test Methods D4442 or Test Methods D4444. Keep the specimens wrapped in a vapor retarder material to minimize variability when not being actively tested.

NOTE 6—The number of specimens required depends on the degree of success in conditioning to the set point level. See Appendix X9 for an example of selecting specimens.

5.3.3 *Test Procedure*—In the following procedure, the meter shall be initialized (5.1.2) with no specimens in the sensing region. The dynamic test is to be conducted at room temperature. This procedure is intended to both adjust and evaluate the accuracy of the set point(s).

5.3.3.1 *Positioning*—The specimens shall be positioned in the sensing region recommended by the manufacturer and consistent with the constraints of the intended or recommended installation (see Appendix X6).

5.3.3.2 *Dynamic Test*—Sequentially place each specimen from 5.3.2.1 on the feed assembly outside the sensing zone. The moisture content of the specimens shall be close to the accept/reject level and they shall be tested at different speeds. Energize the feed assembly to move the specimens through the sensing zone at selected speeds. Record the accept/reject status as specimens pass through the sensing zone (see Note 5 and Note 7). (The more detailed procedure of the dynamic test is described in Appendix X7).

NOTE 7—Longitudinal-type accept/reject meters may require special adjustments to compensate for reaction time in the readout or marker system, particularly for specimens of non-uniform moisture content.

5.3.3.3 *Temperature Test*—Place the entire system in a room capable of variation from -20 to 60ºC (-4 to 140ºF). With the system in equilibrium at selected temperatures between -20 and 60°C (-4 to 140ºF), place each specimen statically within the sensing area to obtain accept/reject readings with the specimens at the exposure temperatures. Apply the results of the temperature test, 5.1.2.4, for the drift and temperature effect corrections. Use the results reported from 5.2.6 to obtain data to report the species and temperature effect on set point performance.

5.3.4 *Report*—The report shall contain a discussion of the test objectives, a detailed description of the specimen moisture content distribution (average, variability, wet spots if appropriate, and so forth), the percentage of specimens that were below and above the respective set points, and number of specimens either below or above the set points, each relative to the total number of specimens tested; the species or species group; the effects of temperature, density and growth site on set point stability; and any deviation from the specified procedure.

## 6. Field Standardization and Evaluation

Laboratory standardization and evaluation shall have been performed on the meter or on a model with similar operational characteristics before testing to the procedures of this section. If laboratory calibration has not been carried out, this shall be acknowledged when reporting the results on Section 6 tests under 6.3.3.

6.1 *Field Standardization*—Field standardization and evaluation permit addressing mill conditions and specimen variables of practical concern with installed equipment; however, field standardization is not intended to supplant laboratory standardization because of its more limited scope and lack of environmental control. Field evaluation does not replace laboratory calibration but supplements with mill process and product-specific data.

NOTE 8—In many instances, field standardization and evaluation are performed on a species group rather than specific species, and on lumber having defects, grain deviation, and moisture gradients that are typically found in processing, and in a physical environment difficult to duplicate in laboratory testing. Consequently, laboratory and field tests may not provide identical results.



6.1.1 *Reference Specimens*—These reference specimens or procedures commonly are recommended or provided, or both, by the manufacturer of the meter. In the absence of recommended references, materials shall be obtained that will provide consistent results during testing and retesting.

NOTE 9—Although the reference materials are preferably non-hygroscopic, they may be hygroscopic if due care is used to ensure consistency during testing. For example, uniformly equalized clear wood specimens that are suitable may be used if stored to maintain constant moisture content.

6.1.2 *Test Procedure*—In the following procedure, at least one reference specimen shall be used. Before each test, the meter shall be initialized with no material in the sensing region of each sensor. The test is to be conducted at ambient temperature and at the reference temperatures of concern in field application. If the dynamic test in laboratory standardization (5.1.2.3) has demonstrated no speed effect, 6.1.2.2 may be omitted from this procedure, unless the maximum laboratory speed is well below that expected during production.

NOTE 10—If the system contains multiple sensing regions (heads) and if the data from each region is available together with the indicated average value, it is preferable to compare the average output against the individual values to determine any variations from a simple average. Likewise, if the intent is sensitivity to localized wet areas, provision to check each sensing region is important.

6.1.2.1 *Positioning*—The reference specimens shall be positioned in the sensing region recommended by the manufacturer and consistent with the constraints of the installation. The entire specimen shall always pass completely through the sensing region (see Appendix X6).

6.1.2.2 *Static Standardization*—Conduct a static standardization in accordance with the manufacturers instructions.

6.1.2.3 *Dynamic Standardization Test*—After initializing and conducting the static standardization, sequentially place each reference specimen on the feed assembly outside the sensing zone. Energize the feed assembly to move the standard through the sensing zone at a selected constant speed. Record the meter reading (maximum or average) as the standard passes through the sensing zone. If the feed system has variation in speed control, repeat the test within the range of available speeds. (The more detailed procedure of the dynamic test is described in Appendix X7).

NOTE 11—Safety is a paramount issue in dynamic systems, particularly in a complex mill environment. In some systems, such as longitudinal meters operating at high speed, it may not be possible to conduct field standardization at operating speeds for practical reasons of control and safety. In these situations, static or slow speed standardization results will necessarily be the basis for proceeding to the calibration step.

6.2 *Basis Moisture Measurement*—The moisture value against which the meter response is to be compared will depend on the objectives of the test established in 6.3.1.1 or 6.3.2.1; for example, whether an oven dry or a hand-held meter reading are regarded as the basis, and whether average piece moisture values, highest wet local reading, or readings at specified areas are to be used as basis. These static moisture readings shall be taken immediately after the meter response tests are completed, in accordance with either Test Methods D4442 or D4444. Sampling is a critical element of the basis measurement since it is unlikely that the area examined by the basis technique will be exactly the same as that scanned by the sensor, especially if methods Test Methods D4444 are used for basis. Consequently, multiple readings will be required if the entire sensor area is to be evaluated by the basis measurement. Another common option is to make a practical decision on a subset area of the sensor region to represent the moisture content. This method relates to quality monitoring procedures.

NOTE 12—While basis moisture content values may be obtained in several different ways, depending on the meter type, equipment available, and degree of accuracy desired, these measurements have variability that should be considered when calibrating an in-line meter. Total moisture values from a cross-section obtained from oven-dry measurements may require multiple sampling within the lumber portion in the sensing zone. Subset samples from single or multiple reading instruments, such as hand-held meters may be required. Multiple measurements by either means are recommended to obtain reasonable accuracy and to identify unusual variations of moisture content in the specimens.

6.2.1 *Full-piece Basis Values*—To obtain a basis moisture value for comparison to full-piece moisture scanning, particularly for longitudinal in-line meters, it may be desirable to take multiple basis readings along the length of the member and integrate these in an appropriate manner to simulate the full-piece scan of the in-line meter.

6.3 *Evaluation of Field Response (MC Indicators)* —These procedures are intended to provide a method to evaluate moisture measurement errors associated with processed lumber having typical moisture content levels, moisture gradients, and typical physical characteristics. Meters shall be standardized (see 6.1) before being evaluated. In transverse feed systems, these evaluations shall be done separately for each sensing region. The extrapolation of results beyond the range of the test data is not recommended. A method for evaluating selected portions of the piece, and dynamic options for evaluating the whole piece are presented. Each method provides a different set of information upon which field calibration, operational adjustments, product selection decisions and product moisture claims may be based. The choice of option depends upon the inferences to be made with the results.

6.3.1 *Evaluation of Selected-Portion Response*—This method emulates the response of the meter to selected portions of lumber passing through the sensors where the wood represents specific characteristics. For example, no knots, limited grain distortion, and no decay might be selected as the location criteria. Meter response readings are taken with the lumber locations meeting the criteria in the electrode position(s). Subsequently, basis moisture readings are made at these same locations. This response evaluation method may not be suitable for longitudinal flow meters in a dynamic mode.

6.3.1.1 *Objectives*—The objective of this method is to determine the response of the in-line meter where the locations of measurement are carefully controlled to be the same for both the meter and the basis measurement against which the meter will be compared. Often, these locations are regarded as clear wood or as areas which would be selected for moisture inspection in quality monitoring, or both. The character of the wood in the selected locations shall be clearly identified as part of the objectives. The uniformity and level of moisture permitted through the cross-section and in the length and width in each piece shall be part of the objectives. This method does not directly represent the response of the meter to characteristics that have been excluded from the objectives, but which may be present during moisture scanning. Among the latter may be knotholes and wane, which are often not included in the basis measurement.

6.3.1.2 *Specimen Selection and Preparation*— Lumber specimens shall be selected to represent the objectives outlined in 6.3.1.1. Test locations on each piece shall be identified and marked. Moisture conditions meeting the objectives shall be verified using sampling of matched material with the destructive methods of Test Methods D4442 or by examining the specimens using the methods of Test Methods D4444. Wood characteristic determination shall be by the grading rules governing the grades represented in the sample.

6.3.1.3 *Test Procedure*—Lumber specimens shall be placed in the meter such that only the designated test location (see 6.3.1.2) is actively monitored by the meter sensor. Meter manufacturer recommendations shall be followed regarding any overlap or area of sensitivity beyond the physical sensor geometry so that the chosen wood characteristics are maintained in these areas. Tests shall include both repetitions with the same piece and (same designated area) for repeatability and multiple pieces for between-piece variability information. Sample size shall be determined from preliminary tests run to obtain variability estimates; Practice D2915 and ASTM International standards on precision and bias provide guidance on setting sample size on the basis of the desired quality of the estimate. Lacking the above data, a minimum sample size of 20 is recommended; however, it is likely that a larger, carefully selected sample will be needed if many wood variables are to be included.

6.3.2 *Full-Piece Response*—The principle employed in this option is to record the meter response to the lumber at the speed of operation including all wood characteristics as run, and relate this response to the basis moisture content reference. The sampling of the piece by the meter system must be acknowledged; a longitudinal system will sample much of the piece along the length while a transverse system will sample designated locations on the piece. In the latter case, however, these locations are not controlled by test objectives to certain wood characteristics but only by the mill positioning equipment. Two options are offered for analysis; these are the choice of two methods of selecting the sampling for the base moisture measurement, one at the anticipated inspection site for quality monitoring; one an integration of base samples from the entire area monitored by the in-line meter. Each option offers a different insight into the practical use of the in-line meter.

6.3.2.1 *Test Objectives*—Establish the lumber or processing variables, or both, to be evaluated by the dynamic test and the basis measurement sampling. Lumber variables that may influence the meter output include lumber size, grade, and moisture content variability due to wet spots or gradients. Processing variables may include operating speed and environmental conditions.

6.3.2.2 *Specimen Selection and Preparation*— Specimens shall be selected to represent the nominal thickness of the particular species for which calibration is desired. Specimen length shall exceed the overall dimensions of the sensing regions. The specimens shall be pre-screened to obtain a sufficiently wide range of moisture content. The number of specimens shall be selected using the principles of Practice D2915 Section 3.4 which links the objectives of 6.3.2.1 with the variability anticipated in order to determine the results with sufficient precision. Consequently, the sampling of multiple head, transverse meters should be considered in specimen preparation and test procedures. If grade is a criteria, pieces shall be determined to be on grade by applicable rules.

6.3.2.3 *Test Procedure*—In the following procedure, the meter shall be initialized with no specimens in the sensing region. The dynamic test shall be conducted at ambient temperature or at the reference temperatures of concern in field application.

6.3.2.4 *Positioning*—The specimens shall be passed through the sensing region as recommended by the manufacturer, and consistent with the constraints of the installation (see Appendix X6) and the objectives of 6.3.2.1. Obtain one set of specimens at the variable range of interest (for example, moisture, grade, and so forth). Sequentially place each specimen on the feed assembly outside the sensing zone. Record the appropriate meter reading (maximum or average) as the specimens pass through the sensing zone(s). (The more detailed procedure of a dynamic test is described in Appendix X7.)

6.3.3 *Effect of Variables/Determination of Effect Of Test Variables*—The effect of the variables on meter response can be used to determine the importance of meter adjustments and to anticipate the moisture variability in the product. Species, temperature, and density corrections are some of the more common results of analyzing the effect of test variables on meter response. Regression and analysis of variance are two methods that may be used to describe meter response. Practice D2915 Section 4 provides guidance on analysis, confidence statements, and data presentation.

6.3.3.1 *Species and Site*—From the data collected, a minimum analysis would be a regression of the MC meter response readings obtained against the appropriate basis moisture contents (determined in 6.2). Since duplicating market proportions of species in a species group may be difficult, care shall be taken in representing species in this analysis (see 5.2.5.1). If site is a variable, conduct sufficient analysis to determine site effects within species.

6.3.3.2 *Density*—If density is a variable of interest, identification of this effect within species or species groups may require special attention in analysis. In some product lines, a further analysis of the effect of density within grades within a market group may also be important to calibrating the in-line meter.

6.3.4 *Conclusions*—The manner in which the results of 6.3.3 are applied shall be consistent with the objectives and conduct of the test. Those conducting the test shall set the target precision and bias goals against which the performance of the meter is to be measured in field test. These decisions may result in meter corrections, in process changes, or in product claims regarding moisture control, or combination thereof. Consequently, the conclusions reached from field calibration shall be based on the goals set for performance, the objectives established for the test, and the conduct and results of the test itself.

6.3.4.1 *Selected-Portion Conclusions*—Because the analysis conducted on selected-portion sampling is limited to specific areas defined in the test objectives, the conclusions from this test method are limited to the test areas and to the lumber characteristics defined for those areas. The results may provide useful information on the response of the in-line system to the characteristics included; it provides no information on meter response to other lumber characteristics. Further, if the testing is conducted only in static mode (as may be the case with longitudinal meters), the influence of dynamic process variables will not be included in the analysis and shall not be referenced in the conclusions.

6.3.4.2 *Full-Piece Conclusions*—The in-line meter output from this calibration method contains the meters' dynamic response to the characteristics of the lumber scanned. Consequently, the calibration conclusions are conditional upon the lumber characteristics as stated in the test objectives (including size, grade, moisture, and so forth, and the variability permitted in these characteristics) plus speed of operation and other dynamic variables. Further, the two basis measurement options applied to full-piece calibration, local area or an integrated full-piece value, present two distinct differences in conclusions. If the full-piece in-line reading is to be compared with a local area basis reading (as may be the case if the basis reading is a third-party quality assurance measurement at one location on a piece), the dynamic test and full-piece variables will not be represented in the basis measurement; correlations between the in-line and the basis will contain this discrepancy as part of the error. If the full-piece in-line reading is to be compared with an integrated basis reading (6.2.1), the comparison includes an attempt to include many of the same lumber characteristics, such as moisture gradients along the piece. The influence of lumber characteristics, such as knots, and dynamic variables, such as movement of the piece in sensing region, remain in the error to be estimated.

6.3.5 *Report*—The report shall include the data collected in 6.1, 6.3.1, and 6.3.2, together with a detailed description of the reference materials used in 6.1, the lumber characteristics including moisture content levels, the results of 6.3.3 and the conclusions of 6.3.4. Any deviations from the specified procedure shall be reported. The report shall also describe the basis moisture measurement.

6.4 *Evaluating Field Response (Accept/Reject Meters)*—These procedures are intended to provide a method to evaluate accept/reject moisture meter performance within the critical moisture decision range for processed lumber having typical moisture content levels, moisture and gradients, and growth and finishing characteristics. An accept/reject meter has a specific or preset set-point which identifies lumber with moisture contents higher or lower than a predefined target value of the set-point. Meters shall be field standardized (6.1) before being evaluated for measurement performance. In transverse feed systems, response shall be evaluated separately for each sensing region.

6.4.1 *Objectives*—An accept/reject meter can be installed to meet specific objectives, often limited to only one or two functions (for example, identifying pieces in excess of a specified moisture target). These shall be identified prior to evaluation and subsequent selection of specimens and conduct of tests shall be in accordance with these objectives.

6.4.2 *Specimen Selection and Preparation*— Specimens shall be selected to represent the nominal thicknesses of the particular species for which calibration is desired. Specimen length shall exceed the overall dimensions of the sensing regions. The specimens shall be pre-screened to obtain sufficient specimens within a critical range of moisture content. Select the number of specimens to provide the sensitivity needed. See relevant ASTM standards on sampling and Appendix X9 for methodology.

6.4.2.1 *Test Criteria*—The considerations of sampling for moisture content and evaluation that were considered in 6.1 and 6.3 are equally important for accept/reject meters. It is necessary to select either meter performance based on selected portions (parallel to 6.1) or full-piece (parallel to 6.3) for evaluation. The basis measurement shall be chosen to fit this selection. The critical difference between the accept/reject evaluation and those of 6.1 and 6.3 is that more specimens need to be selected within close proximity to the accept/reject moisture levels selected for evaluation.

6.4.2.2 *Basis Measurement*—See 6.2 for explanation of selecting the appropriate basis measurement to match the performance evaluation chosen for the meter.

6.4.3 *Test Procedure*—The meter shall be initialized with no specimens in the sensing region. The dynamic test is to be conducted at ambient temperature or at the reference temperatures of concern in field application.

6.4.3.1 *Positioning*—The specimen shall be positioned in the sensing region as recommended by the manufacturer and consistent with the constraints of the installation (see Appendix X6).

6.4.3.2 *Selected Portion Test*—Follow the general procedures of 6.3.1 for conduct of the test with the exception that data is gathered on pieces accepted and rejected at the performance level selected.

6.4.3.3 *Full Piece Test*—Follow the procedures of 6.3.2 except for data collection. Record the accept/reject decision for each specimen. The more detailed procedure of the dynamic test is described in Appendix X7. See Note 11 on safety considerations of dynamic tests.

6.4.4 *Effect of Variables/Determination of Effect of Test Variables*—The effect of the variables on meter response can be used to determine the importance of meter adjustments and to anticipate the moisture variability in the product. The design of the test shall have anticipated the need to conduct an analysis of the pass/fail performance of the meter using the appropriate methodology for confidence statements concerning percent acceptance/rejection.

6.4.5 *Report*—The report shall contain a detailed description of the moisture content distribution, the percentage of below set point failures and above set point failures, and total failures, each relative to the total number of specimens tested; the species or species group; the effects of temperature, density and growth site composition on set point stability; and any variation from the test objectives and the procedure selected. The mathematical analysis used to evaluate the performance shall be reported.



## 7. Precision and Bias

7.1 *Precision*—For an in-line meter, with samples that are free of moisture gradients and in the MC range below the fiber saturation point, readings corrected for species and temperatures typically have a coefficient of variance of 5 % or less.

7.2 *Bias*—For an in-line meter, bias is dependent on the standardization and calibration procedures in this standard. Selection of bias targets for judgments of performance adequacy are user driven, as noted in these test methods, because in-line meters are often judged against other measurement systems.

## 8. Keywords

8.1 in-line moisture meter; moisture content; moisture meters; wood

## APPENDIXES

### (Nonmandatory Information)

### X1. COMMENTARY

The numbers following the Xl prefix indicate the paragraph in these test methods to which the commentary applies.

X1.1 *Scope—The Rationale for the Test Methods for Standardization and Calibration of In-line Dry Lumber Moisture Meters*—The need for these test methods was recognized by ASTM Committee D07 on Wood in about 1975, but the development was deferred until several basic standards could be completed. Two of these standards, Test Methods D4442 and Test Methods D4444, were replacements for the original single standard on moisture content of wood, Methods D2016. Subsequently, a third standard, Guide D4933, was developed to complete the basic standards set. It was recognized that the in-line standard would have to be limited to a specific product (lumber) and a restricted moisture range (consistent with rules writing agency standards) because of the inherent complexity of writing a generic standard for all wood and wood-base materials. However, the standard was written to be generic for all sensing principles rather than restrict it (as was done in Test Methods D4444) to existing commercial practices. A major complication was recognized since in-line lumber moisture meters may be used in transverse (as in lumber un-stacker moisture meters after kiln drying) or longitudinal (as before or after planers) applications. The inherent value of both types lies in sensing area and physical arrangement. For example, most transverse meters sense a limited portion of a board whereas longitudinal meters can sense all or majority of the piece. Either sampling approach may be suitable for a particular product specification.

The subcommittee attempted to work with manufacturers of existing meters and other interested parties to assure that the standard could be used at many levels: development or improvement of meters, manufacturing standardization and calibration, within-mill testing, a reference for grading agencies, and for users to understand the limitations and variables with such moisture content measurement. The Task Group and Subcommittee also recognized that the scope of the standard (from bench testing to field evaluation) will necessitate revisions and expansion as experience is gained.

To some degree, the standard parallels Test Methods D4444 in a number of specifications. One obvious and important difference in the in-line standard is that the material is moving through a sensing area. Therefore, methods are included to test the meter under dynamic conditions to determine the effect of feed speed at typical operating conditions on the indicated moisture content. In some cases, the measured MC values can be quite different from static specimen measurements.

X1.3 *Terms*—These test methods are designed to incorporate many technologies; however, the requirements are developed based on capabilities of meter systems commercial in 2001.

X1.3.3 *Longitudinal and Transverse*—Terminology encompasses current industry technology. The generic term area of a piece in which the meter is responsive to moisture content may be described by various industrial terms but is intended to reflect the sensing patterns of any meter to which these test methods are applied.

X1.3.5 *Meters*—It is necessary to distinguish between meters that display moisture content and those that accept or reject lumber pieces based on selected trigger levels. Meter complexity, field evaluation and applications often differ for the two types of meters. Meters designed to indicate moisture content may be used as accept/reject meters if so instrumented; however, it is the intent of these test methods that both aspects of a dual purpose meter may be evaluated with these test methods.

X1.3.8 *Standardization and Calibration*— Terms that link meter performance to specific tests and to the sequence of standardization followed by calibration. See Appendix X4.

X1.4 Appendix X2 is referenced to indicate the laboratory and field tracks of the standard are distinctly different and should be identified in applying the standard. It is intended that field standardization and evaluation be applied to meters that have been previously subjected to laboratory standardization and calibration. Meters that have not been laboratory tested in accordance with these test methods may have unknown response to the environmental and process variables that are evaluated in those tests.

X1.4.1 Appendix X5 elaborates on moisture measurement. It is the intent of the standard to focus on normal moisture gradients, relatively uniform moisture content along the length of the piece, and standard lumber characteristics (that is, pieces on grade). However, the standard procedures will provide a basis for applications outside of these common applications; examples would include rain-wet lumber, lumber with wet spots, and so forth, but it is the intent in these instances that the characteristics of these applications be very carefully identified so that the sampling and analysis is suitably designed and the documentation is comprehensive.

X1.5 Laboratory standardization and calibration are critical elements of these test methods. It is the intent to prescribe basic elements that are essential with some specifics adjustable for specific meters (speed, size, species, and so forth). Appendix X7 and Appendix X8 provide more comment.

X1.5.2.1 This paragraph is important because it stipulates careful statement of test objectives in advance of the test to ensure that sampling will be adequate and the needs of the subsequent analysis are considered.

X1.5.2.2 This section specifically eliminates many common wood characteristics from a laboratory calibration in order to enhance definition of meter capability under controlled conditions. At the same time, latitude is provided where objectives so specify.

X1.5.2.2.4 This section introduces the concept of adequate global sampling when it is desired to make a claim of a species calibration. As stated in these test methods, this is consistent with ASTM practice when a value derived from a standard is claimed to represent a species. When samples of a species do not meet the global strategies recognized by ASTM Committee D07, the limitations of the sampling shall be so stated.

X1.5.3 Many industrial meters have the primary purpose of accepting or rejecting pieces of lumber on the basis of estimated moisture content. Some also indicate the moisture content, values which may be used to monitor dry kiln performance, while the primary function remains accept/reject. Sample selection and analysis are specific to the type of meter function.

X1.6 *Field Standardization and Evaluation*—This section is designed to be carried out in mill or other field-type applications where the environment is not controlled and there may be limitations on instrumentation. It also recognizes different objectives for field tests and cautions that the sampling, the testing, the analysis and the conclusions are contingent on understanding and designing the study to meet the objective. If clear wood response is desired, tests in selected portions of the piece can be used. If the response to wood containing many characteristics like knots is desired, the full-piece methodology can be applied. The moisture content used for comparison with the meter is termed the basis measurement, referencing Test Methods D4442 and D4444. However, the method of applying the basis measurement is keyed to the test objectives. For example, monitoring of dry kiln performance may require a different approach than if the desire is to replicate the results of a moisture audit of a unit of lumber.

X1.6.1 In many instances, field standardization and evaluation are performed on a species group rather than specific species, and on lumber having defects, grain orientation deviation, and moisture gradients that are typically found in processing and in a physical environment difficult to duplicate in laboratory testing. Consequently, laboratory and field tests may not provide identical results.

X1.6.2 Field standardization usually is conducted with standards provided by the meter manufacturer; however, the standard permits other methods.

X1.6.3 *Basis Moisture Measurement*—This is a critical element of these test methods because it recognizes that the moisture comparison base against which the meter will be evaluated can be established in different ways, even within the scopes of the reference standards Test Methods D4442 and D4444. If it is desired to make the comparison on a clear wood basis only, this can be so-stated in the objectives and reflected in the basis measurement. On the other hand, the basis can reflect empirical choices of location, either full-piece or portions of pieces, each of which will be evaluated against the basis method chosen.

X1.6.3.1 While basis moisture content values may be obtained in several different ways, depending on the meter type, equipment available, and degree of accuracy desired, these measurements have variability that should be considered when calibrating an in-line meter. Total moisture values from a cross-section obtained from oven-dry measurements may require multiple sampling within the lumber portion in the sensing zone. Subset samples from single or multiple reading instruments, such as hand-held meters may be required. Multiple measurements by either means are recommended to obtain reasonable accuracy and to identify unusual variations of moisture content in the specimens.

X1.6.3.2 *Full-Piece Basis Values*— The difficulty of obtaining an estimate of the full-piece moisture scan by a meter through a multiplicity of Test Methods D4442 and D4444 based readings should not be underestimated. Often a preliminary test is useful to determine the statistical variations in the localized readings so that an estimate of an integrated reading is meaningful. Samples that represent the typical moisture distribution, wood characteristics and environmental conditions are important to obtaining a useful estimate of the integrated reading. It is also understood that the typical Test Methods D4442 and D4444 moisture estimates will not include some of the material scanned by the in-line meter (such as knots, decay, and so forth). Consequently, selection of an estimate of the full-piece (integrated) moisture level for the basis must be conditional on, and reflect, the sources of error associated with this choice.

X1.6.4 *Evaluation of Field Response*—In virtually all installations of an in-line meter, an evaluation will be required at the installation site to determine its applicability. Uses vary widely and, in fact, more than one use may be made of a meter in the same installation. An example would be the need to relate the output of the meter to the audit results obtained by a third-party inspector and, with the same in-line meter output, be able to interpret results of a kiln charge for steam leaks in the kiln, adequacy of kiln sticker placement, and so forth, as well as overall drying performance. As a consequence of these many uses, the evaluation of this section emphasizes collection of data relevant to carefully designed objectives. The evaluation of the data depends on the use(s) intended, but may include actual calibration of the meter to a product, a statistical statement about the adherence of the product to a moisture standard, or regular assessment of the quality of drying. Field response testing often includes the effect of lumber characteristics other than clear wood in the in-line meter response. When the in-line meter response includes these variables, the design of the evaluation must acknowledge the sample selection parameters since these may have a significant effect on the analysis of the test data and on the conclusions of the evaluation.

X1.6.4.1 All of 6.3.1 is devoted to the objective of evaluating the response of an in-line meter to carefully selected portions of lumber passing through the sensors. Because of this focus on selected areas, the statement of objectives (6.3.1.1), the specimen selection and preparation (6.3.1.2), and the test procedure (6.3.1.3) must be carefully designed in advance and both the meter and the basis measurement.

X1.6.4.2 Section 6.3.2 focuses on evaluation of an in-line meter response to the entire piece of lumber. In some meters, this response is an integration of systematic sampling along the length of the piece by one sensor or by an array of sensors in close proximity; the frequency of sampling may vary by meter design. In other meters, multiple sensors may be employed that