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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 D 6782; 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 *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.*

[1] These test methods are under the jurisdiction of ASTM Committee D07 on Wood and are the direct responsibility of Subcommittee D07.01 on Fundamental Test Methods and Properties.

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2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 1990 Practice for Establishing Allowable Properties for Visually-Graded Dimension Lumber from In-Grade Tests of Full-Size Specimens
D 2395 Test Methods for Specific Gravity of Wood and Wood-Base Materials
D 2915 Practice for Evaluating Allowable Properties for Grades of Structural Lumber
D 4442 Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials
D 4444 Test Methods for Use and Calibration of Hand-Held Moisture Meters
D 4933 Guide for Moisture Conditioning of Wood and Wood-Base Materials
D 5536 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 and/or sorting 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.

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

[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*, Vol 04.10. volume information, refer to the standard's Document Summary page on the ASTM website.

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 and/or provided 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, 0, 20, 40 and 60°C (-4, 32, 68, 104 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 (Test Methods D 4442). The accuracy of the desired results must be consistent with the indicated accuracy of the specific oven-drying procedure in Test Methods D 4442. 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 (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 D 2915 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 D 5536 or Practice D 1990, 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 (Guide D 4933). 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 selected constant speed. 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 (Test Methods D 4442), specific gravity (oven-dry mass and volume) (Test Methods D 2395) and other specimen characteristics (see 5.2.1) for each specimen for comparison with the meter response. Subsequent analysis can be conducted with multi-variate 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 and/or growth sites 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 (Guide D 4933). Determine the moisture content of the pieces applying either Test Methods D 4442 or Test Methods D 4444. 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 D 4442 or D 4444. 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 D 4444 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 (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 D 4442 or by examining the specimens using the methods of Test Methods D 4444. 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 (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 D 2915 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 and/or processing variables 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 D 2915 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 D 2915 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 D 4442 and Test Methods D 4444, were replacements for the original single standard on moisture content of wood, Methods D 2016. Subsequently, a third standard, Guide D 4933, 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 D 4444) 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 D 4444 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 *Standardzation 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.

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 D 4442 and D 4444. 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.

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.

X1.6.1 Field standardization usually is conducted with standards provided by the meter manufacturer; however, the standard permits other methods.

X1.6.2 *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 D 4442 and D 4444. 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.

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.

X1.6.2.1 *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 D 4442 and D 4444 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 D 4442 and D 4444 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.

X1.6.3 *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.

X1.6.3.1 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.

X1.6.3.2 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 are displaced from one another; the signal of the sensors may be combined to simulate the “full-piece” response. Again, sampling rate may vary by design. The objectives of the evaluation obligate careful sample selection and testing; however, the choice of basis measurement is critical, as discussed in 6.3.2.

X1.6.3.3 This section provides only general guidance for mathematical analysis of the test results. Tradition has often employed regression analysis with little or no attention to variability about the mean trend. Methods of analysis other than regression may be appropriate, depending on the objectives, the number of variables for which response is desired and the anticipated application of the results. Regardless of the method used, the suggestion is made that Practice D 2915 be used as general guidance for understanding and selecting confidence levels and methods of presentation of results.

X1.6.3.4 *Conclusions*— Again, emphasis that conclusions relate to goals set for performance as well as all planning and execution of tests.

X1.6.3.5 *Report*—It is anticipated that this report may have different uses, depending upon the objectives of the test program. For example, a within-mill test may result in documentation regarding current process control; a test conducted jointly with a third-party agency may provide the basis for a formalized calibration. Consequently, the report format and content should reflect the objectives of the test. In all cases, however, this report should contain enough detail to permit re-analysis of data and substantiation of results if called upon at a future time. It is important to emphasize that different observations are likely to result from use of hand-held meters versus oven dry for the basis measurements in 6.2 because of inherent differences in the methods. Likewise, the options presented for evaluation (6.3.1 and 6.3.2) likely will yield differing results because of underlying differences in test assumptions. These differences may not be large; however, since the impact must be evaluated by the user, the report must reflect all observations, particularly as a reflection of the objectives set in 6.3.1.1 and 6.3.2.1.

X1.6.4 *Evaluating Field Response (Accept/Reject Meters)*—The reasoning behind the standard sections on accept/reject meters mirror the reasoning applied for the moisture measuring meters in X1.6.3. The major difference between the methods will be found in selection of specimens and the mathematical analysis of results. The latter (6.4.4) requires use of analyses appropriate for pass-fail type tests, sometimes termed qualitative performance, most likely employing tests of proportion accepted, and so forth.

X2. FLOW CHART FOR IN-LINE METERS STANDARDIZATION AND CALIBRATION

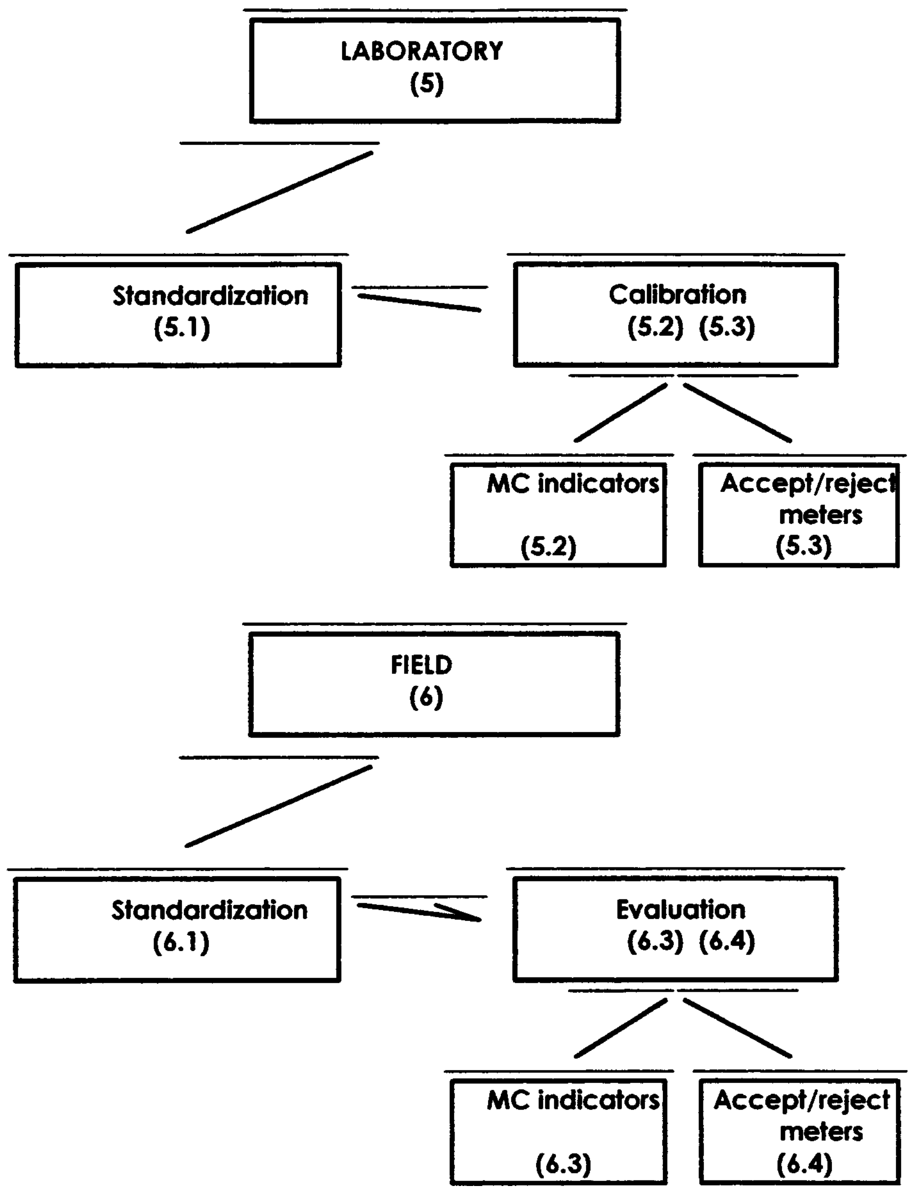

FIG. X2.1 Flow Chart for In-line Meters Standardization and Calibration

X3. SENSING PRINCIPLES

X3.1 A number of techniques can be used to estimate the moisture content of wood; the following sections provide a brief list and accompanying explanation. While some specific sections of these test methods may need adjustment to fit the operating characteristics of a particular technique, it is the intent of the standard to provide procedures and guidelines for all techniques listed.

X3.1.1 *DC-Audio Spectrum*—For these meters, the frequency is less than 30 kHz, and the system responds to the gross motion of free ions.

X3.1.2 *Radio Frequency Spectrum*—These systems operate at frequencies between 100 kHz and 50 MHz; response of the systems relates to the energy loss in polarizable molecules (primarily in water in the material).

X3.1.3 *Microwave Frequency Spectrum* —These systems operate at frequencies between 1 GHz and 50 GHz, and response relates to the nonpolarizing rotation of water molecules in the material.

X3.1.4 *Infrared Frequency Spectrum* —These systems operate with wavelengths between 1 and 20 µm. The system response relates to the interfacial interactions within water molecules in the specimens.

X3.1.5 *Nuclear Radiation*—Absorption/reflection of energy from radioactive sources. Sensitivity to moisture depends on the radiation source and radiation adsorption of the woody material. Some systems use combined neutron/gamma sensing.

X3.1.6 *Combined Techniques*—A number of the above techniques can be combined to improve discrimination and/or bias.

X4. STANDARDIZATION AND CALIBRATION

X4.1 *Standardization—*The purpose of standardization is to determine the response of the instrument to a reference material. The reference material is assumed to have constant electrical properties within the testing environment and, consequently, the response of the instrument to this material should not change over time. In other words, when the reference material is placed in the sensing field of the instrument, any changes in the instrument reading from previous reading can be assumed to be a change in the instrument, not the reference material.

X4.2 *Calibration—*Calibration is used to determine the relationship between a standardized measuring instrument and the moisture content in a desired subject material, based on a standard reference such as Test Methods D 4442 or D 4444. It is used to determine precision and bias of an instrument and accept/reject levels. Calibration is typically done by determining the functional relationship (for example, using regression technique) between the moisture content determined by a standard reference method and an observed instrument measurement.

X4.3 *Application:*

X4.3.1 *Sequence—*Standardization precedes calibration. The flow chart shown in Appendix X2 gives the sequence of testing and the relevant sections for both types of in-line meters (moisture indicators and accept/reject meters).

X4.3.2 *Standardization—* Similar laboratory and field standardization can be applied to both types of meters.

X4.3.3 *Calibration—* Separate procedures are recommended for the two types of meters. Actual wood specimens are used, having been prepared to meet criteria that specify both the wood quality and size/shape variables that represent the basis for calibration.

X4.3.3.1 *Calibration of Moisture Indicators* —These procedures are used for meters that have moisture content readings as an output. A meter calibrated by these methods may also be adapted for accept/reject operation.

X4.3.3.2 *Calibration of Accept/Reject Meters*—These procedures are used for meters that are only for accept/reject operation. A meter calibrated only by these methods is not considered acceptable for moisture content output.

X5. MOISTURE CONTENT DISTRIBUTIONS ADDRESSED WITHIN THE STANDARD

X5.1 *Uniform—*Essentially constant moisture content throughout the specimen as obtained through equilibration at specified levels of constant temperature and relative humidity. In laboratory calibration (both for moisture indicators and accept/reject meters given in Section 5), only conditioned specimens are used to establish meter accuracy without the influence of moisture variations (gradients).

X5.2 *Typical Moisture Levels and Gradients*—Moisture content distribution and variation within and between pieces result from specific processes and/or drying schedules. "Typical levels" refers to the moisture content range for which the meter is expected to produce useful data or the range in which it is expected to operate. The average moisture content of a piece is controlled by the moisture distribution through the thickness and along the length of the specimen, while the average moisture content for a sample of pieces is dependent on variation in average moisture content between specimens.

X5.2.1 When determining the moisture content of a piece, it is often assumed that whatever the gradient, the moisture content level is uniform along the piece; consequently, often only a few measurements (sometimes one) are made to characterize the moisture content of a piece. This characterization is suitable for reference to an in-line reading only under circumstances where it is clearly acknowledged that limited readings are a suitable reference.

X5.2.2 The type of moisture gradient can differ with the drying process. For material dried with conventional kiln schedules where equalizing and conditioning are not performed, the immediate gradient after drying would be expected to be parabolic, with the maximum value at the center of the piece. In contrast, material which has been equalized and/or conditioned might have a uniform moisture content or a reversed parabolic gradient. The gradient in high temperature drying (dry-bulb temperatures greater than 100°C/212°F) quite often deviates from parabolic. Whatever the case, it is important that the calibration be done on material representative of that to be processed through the meter, consistent with the definitions of the moisture content level and distribution.

X5.2.2.1 If material to be processed deviates from relatively uniform moisture content as discussed above (for example, material containing "wetwood" see Appendix X8), it is the responsibility of the person performing the meter evaluation to determine the most suitable procedure to meet the specifications for the specific product being processed. If these test methods are used to evaluate a meter under such "abnormal" conditions, the deviations must be fully documented if reference is to be made to these test methods. As an example of how such procedures can be developed, see footnote.[3]

X5.2.3 In laboratory testing, determination of the basic physical response capability of the meter is often a primary goal. Variability of moisture content both in the cross section and along the piece is not desirable as it may confound critical measurements. Consequently, wood is often equilibrated to eliminate the influence of variability. Guide D 4933 provides guidance on equilibration.

[3] Beall, F. C., Parker, R .S., and Kaluzny, S. K., "Development of a New Lumber Unstacker Moisture Meter," In: Proceedings 34th Annual Meeting–Western Dry Kiln Association, 1983, pp. 37-47.

X6. AIR GAP COMPENSATION

X6.1 It is important for manufucturers of in-line moisture detecting systems, as well as end-users, to understand the relationship between the physical location of the wood while being measured and the position of the sensor. Some sensors require direct physical contact with the wood (contact sensors), while other sensors permit the wood to be varying distances away from the sensor and still perform accurately (non-contact sensors).

X6.2 For non-contact sensors, the range of the wood locations where correct measurements will be recorded is called the "air gap compensated area". In order to determine the air gap compensated area, a person shall take pieces of wood and physically move the wood to different locations next to the sensor and record the readings. The reading of the wood in the air gap compensated area shall not change more than $\pm$x %. This exercise shall be carried out on the wettest and the driest wood the sensor is specified to work on, as well as wood in the middle of the moisture range. This test shall be repeated for the thickest, the thinnest, the widest and the narrowest pieces of wood. Also, the wood may be able to be tipped (for example, one end closer to the sensor than the other end) in any direction as long as the wood remains in the air gap compensated area. This test shall be repeated for combination of all sizes of wood and moisture contents mentioned above.

X6.3 Special attention shall also be given to the readings that the sensor produces as the wood is entering and leaving the sensing area. If extremely high or low readings (obviously incorrect) are produced, the instrument may have a means of suppressing the incorrect information, via software, or some other method. These tests shall be run for all combination of wood mentioned above in all regions of the air gap compensated area.

X6.4 Grounded feed and take off rollers may have a major effect on sensor readings and air gap compensation for some sensor designs. As the wood moves along the conveyor system the bouncing effect may cause readings to become erratic. Test each sensor design for grounding of rolls on the in-feed and out-feed. Simulated rolls may be moved closer and closer to the sensor with the roll grounded and ungrounded until a change of x % is recorded. This process identifies the allowable distance between the roll and the sensor. It is important to repeat these tests with all combinations of wood mentioned in the section above.

X7. ANALYSIS OF IN-LINE MOISTURE METER PERFORMANCE UNDER DYNAMIC CONDITIONS

X7.1 *Introduction*—This procedure applies to empirical laboratory and field testing where there is relative movement between the lumber and the sensing system, thus requiring the meter system to respond dynamically. The purpose of dynamic testing is to determine the change in system response (sensors, processor, and software algorithms) to dynamic conditions, using static measurements as the basis for comparison. Dynamic laboratory tests are designed to evaluate response without the influence of processing variables such as moisture gradients, defects within the material, fluctuation of ambient conditions (temperature and relative humidity), and so forth. A common purpose of dynamic field testing is to develop sensitivity information under specific, limited operational conditions in order to establish operational decisions regarding product performance requirements. These operational decisions may include the influence of processing variables excluded from the laboratory tests. This Appendix is a guideline because of the empirical nature of the tests and a wide variety of possible applications. It is hoped that the user of these test methods, cognizant of this empiricism, will use this Appendix as a guide to formulate an appropriate test system specific to anticipated meter use.

X7.2 *Dynamic Laboratory Evaluation:*

X7.2.1 *Establish Objectives*—Establish the objectives of the testing, including specimen criteria (for example, uniformity of moisture content, size, density, species, and so forth.), range of operating speed, and environmental conditions. The nature of the system (whether the application is a moisture content indicating system or an Accept/Reject moisture sensing system, and whether the meter will be used in longitudinal or transverse applications) may influence the objectives.

X7.2.2 *Standardization and Calibration* —Although the purpose of the process may be a dynamic evaluation, it is recommended that this be carried out only after the system has been standardized and calibrated using static methods described in 5.1 and 5.2.

X7.2.3 *Environmental Conditions*—To the degree possible and consistent with X7.2.1, environmental conditions such as temperature, sun vs. shade, air movement, humidity, and so forth, should be held constant. Alternatively, these variables, if measured and controlled, can be treated as variables in the analysis because they commonly are an operations issue in the industrial environment. Deviations from the objectives chosen should be recorded for use in analysis and reporting of test data.

X7.2.4 *Specimen Positioning*:

X7.2.4.1 *Longitudinal Flow*—With the specimen lying flat, mark the top surface of the end that will be fed into the sensor first. Ensure that this orientation is used for each and every pass through the sensing system as the speed of the system is changed. Note that this is not a test of the sensitivity of the system to product orientation; for that objective, the orientation would be purposely altered.

X7.2.4.2 *Transverse Flow*— With the specimen lying flat, mark the top surface of the end that is nearest the operator (zero end). Ensure that this orientation is used for each and every pass through the sensing system as the speed of the system is changed. To ensure that the same regions of the board are measured during each pass, mark the position of the specimen with respect to the mechanical system. This can be done by using index marks on the specimen relative to some convenient reference such as the transport system (for example, chains). As noted in X7.2.4.1, orientation control precludes study of the effect of orientation.

X7.2.5 *Processing Speed*:

X7.2.5.1 *Longitudinal Flow*—Since longitudinal moisture meters are normally installed in-line with the planer, the processing speeds may vary over quite a large range (300 to 2 500 fpm). It is therefore important that the range of speeds of interest be evaluated to determine the dynamic affects on meter response. It is recommended that a minimum of three test speeds be chosen and that the incremental rates represent speeds of commercial interest. Both the minimum and the maximum speeds of interest should be among those chosen for evaluation. For meters capable of both very low and very high speeds, three incremental speeds are likely not adequate for analysis.

NOTE X7.1—Meters designed for specific speed ranges should be evaluated within these ranges.

X7.2.5.2 *Transverse Flow*— Transverse systems normally run at much slower speeds (50 to 500 fpm) than longitudinal systems. In order to measure the dynamic effects over the entire range of speeds expected, it is recommended that the slowest processing speed (perhaps 50 fpm) be used initially, with incremental increases up to the maximum speed expected in application.

X7.2.6 *Moisture Indicating System* —In this case, the system will be used to provide accurate estimates of moisture content across a range of values from dry to wet, based on the specimen criteria established in X7.2.1.

X7.2.6.1 *Specimen Selection*—Using a meter meeting the requirements of Test Methods D 4444, select sufficient specimens to fully represent the criteria established in X7.2.1, and cover the moisture content range desired to be indicated. The specimens should be uniform in moisture content along their length, and be straight and free of characteristics that affect moisture measurement (knots, rot, pitch pockets, and so forth) unless these are explicitly included in the criteria of X7.2.1. The specimen length should be such that the specimens are adequately supported during processing to maintain correct positioning relative to the sensing region (clearance, alignment), and be longer than the sensing area over which the specimen will pass. Since there are common materials variables (density, knots, and so forth) that may act together to influence the moisture content readings, it is recommended that several specimens be selected at each moisture level within the moisture content range.

NOTE X7.2—Note that the use of specimens uniform in moisture content is not intended to evaluate any operational algorithm used to "average" varying moisture content along the length of the piece. Also, meter system sensitivity to peak moisture content against "average" background moisture levels (such as wet-spots) is not evaluated. Variations in these procedures can be made to evaluate these and other operational variables; however, also see Appendix X8.

X7.2.6.2 *Recording Static Response* —A moisture content reading is taken under static conditions as the comparative base against which the dynamic reading will be compared. If the meter has a data-recording device such as a computer or data logger, record the moisture content with the specimen located in accordance with X7.2.4.1 or X7.2.4.2. If there is no recording device, determine the reading from the display system. For a longitudinal flow meter, several static readings may be required along the length of the specimen in order to determine the moisture content with which to characterize the piece.

X7.2.6.3 *Recording Dynamic Response* —Based on the processing speeds selected in X7.2.5.1 or X7.2.5.2, adjust the speed to the initial value selected. Send the specimens through the sensing zone in the orientation chosen in X7.2.4.1 or X7.2.4.2. Record the average moisture content reading indicated by the system for each specimen. Repeat the test at each of the speed settings selected, recording the average moisture content of each specimen. For the transverse system, this is an average of the values obtained for each of the sensing heads. Continue to process the specimens at higher speeds until the critical speed is reached at which the indicated moisture content for the specimens is different from the static readings obtained in X7.2.6.2. This is designated the roll-off point, and is considered the limiting speed for the system.

NOTE X7.3—Under laboratory conditions, the moisture content of the test specimens may change if the test series is extensive. To maintain the specimens at consistent levels of moisture may take special care.

X7.2.6.4 *Presentation of Dynamic Data* —Determine the difference between the dynamic and static average moisture content for each specimen throughout the speed range measured. Average these differences at each speed, and plot specimen feed rate versus indicated moisture content difference to develop the performance curve. If the moisture measurement differences at the various speeds are also influenced by the moisture content level, develop performance curves for each of the moisture levels for which the measured differences (dynamic versus static) are not equivalent. Alternative methods of analysis include analysis of variance to determine contributions to the differences observed.

X7.2.6.5 *Action*—The dynamic response data from the laboratory tests offers information for comparison of meter performance. In addition to the speed limitations related to roll-off, the effects of specimen movement and other operational variables can provide the basis for recommended operating procedures.

X7.2.7 *Accept/Reject Meters*—In this application, the moisture measurement system is only required to determine if the material meets or exceeds the allowable moisture content programmed into the system. It is most efficient to evaluate the dynamic response of the system using material that is within a few percent of the critical moisture content normally used in operations (for example, 10 % MC (typifying lower reject levels of "dryness"), 15 % MC (American Standard Lumber), 16 % MC (laminating stock), or 19 % MC (American Standard Lumber)).

X7.2.7.1 *Specimen Selection*—Using a meter meeting the requirements of Test Methods D 4444, select sufficient specimens that are within a few percent of the critical moisture content to fully represent the criteria established in X7.2.1. The specimens should be uniform in moisture content along their length, and be straight and free of characteristics affecting moisture measurement (knots, rot, pitch pockets, and so forth) unless these are explicitly included in the criteria of X7.2.1. The specimen length should be such that the specimens are adequately supported during processing to maintain correct positioning relative to the sensing region (clearance, alignment), and be longer than the sensing area over which the specimen will pass. Since there are several variables (density, defects, and so forth) that may act together to influence the moisture content readings, it is recommended that several specimens be selected at each moisture level within the moisture content range. See Note X7.2 concerning pieces with non-uniform moisture content.

X7.2.7.2 *Recording Static Response* —A moisture content reading is taken under static conditions as the comparative base against which the dynamic reading will be compared. If the meter has a data-recording device such as a computer or data logger, record the moisture content with the specimen located in accordance with X7.2.4.1 or X7.2.4.2. If there is no moisture content recording device, determine the reading from the display system. For a longitudinal flow meter, several static readings may be required along the length of the specimen in order to determine the moisture content with which to characterize the piece. Where there is no moisture content indicator in the system, static readings (see 6.2) will necessarily be the basis for static response of the accept/reject meter.

NOTE X7.4—The concept of a static response for an accept/reject meter is valid for the meter itself only if there is a moisture content display. Meters used only as sorting devices without a display require static readings on each piece of lumber with hand-held meters to determine that the lumber is adequately selected to address the sorting capability and to provide the basis for "the moisture content" of each piece; the sorting efficiency will be based only on acceptance/rejection percentages of pieces using these hand-held meter readings.

X7.2.7.3 *Recording Dynamic Response* —Based on the processing speeds selected in X7.2.5.1 or X7.2.5.2, adjust the speed to the initial value selected.. Send the specimens through the sensing zone in the orientation chosen in X7.2.4.1 or X7.2.4.2. Record the accept/reject decision indicated by the system for each specimen. Repeat the test at each of the speed settings selected. For the transverse system, the values are obtained for each of the sensing heads. Continue to process the specimens at higher speeds until the critical speed is reached at which the accept/reject ratio changes more than an acceptable amount, compared to the accept/reject ratios from the static readings obtained in X7.2.7.2. This is designated the roll-off point, and is considered the limiting speed for the system. If it is desired to test the sensitivity of the system at different accept/reject moisture levels, rerun the specimens through the system resetting the trigger level appropriately. A set of specimens with a lower or higher distribution of moisture content may be required as the trigger levels are readjusted.

NOTE X7.5—The moisture content of the test specimens may change if the test series is extensive. Maintaining the specimens at consistent levels of moisture may take special care.

X7.2.7.4 *Presentation of Dynamic Data* —Determine the difference between the dynamic and static accept/reject ratios for the sample throughout the appropriate speed range. This difference is a measure of the bias of the system, accepting the static values as the basis for judgment. One way to visualize the performance is to plot feed speed versus the accept/reject ratio to develop a performance curve. Examine the performance of individual sensing heads in transverse systems before averaging across sensing heads to gauge overall system performance. Statistical analysis of accept/reject data requires use of methods appropriate to qualitative (enumerative) data (pass/fail, hit or miss, percent defective, and so forth).

X7.2.7.5 *Action*—The dynamic response data from the laboratory tests offers information for efficiency of the meter system performance and the speed limitations related to roll-off. Additionally, the effects of specimen movement and other operational variables can provide the basis for recommended operating procedures.

X7.3 *Dynamic Field Evaluation:*

X7.3.1 *Establish Objectives*—Establish the objectives of the testing, including specimen criteria (for example, uniformity of moisture content, size, density, species, and so forth), range of operating speed, and environmental conditions. Specimen criteria may also include concepts of grade and machining quality, therefore separate test series may be required to address all the mill variables. A decision as to whether the application is a moisture content indicating system or an accept/reject moisture content system, and whether the meter will be used in a longitudinal or transverse application will influence the process.

X7.3.2 *Standardization and Calibration* —The dynamic test should only be run after the system has been standardized and calibrated using static methods described in 6.1 and 6.2.

X7.3.3 *Environmental Conditions*—To the degree possible and consistent with X7.3.1, environmental conditions such as temperature, sun vs. shade, air movement, humidity, and so forth, should be held constant. Deviations should be recorded for use in analysis and reporting of test data.

NOTE X7.6—An example of one exception to the constant conditions of X7.3.3 would occur if the objective was to evaluate a shift in environmental conditions that commonly occur during operation, such as a normal mill temperature change in the sensor location between 5:30 AM and 3 PM. Note that such an evaluation requires careful monitoring of the actual condition of interest and addressing standardization changes. The laboratory evaluations of Section 5 may more directly address some of these issues.

X7.3.4 *Specimen Positioning*:

X7.3.4.1 *Longitudinal Flow*—With the specimen lying flat, mark the top surface of the end that will be fed into the sensor first. Ensure that this orientation is used for each and every pass through the sensing system as the speed of the system is changed.

X7.3.4.2 *Transverse Flow*— With the specimen lying flat, mark the top surface of the end that is nearest the operator (zero end). Ensure that this orientation is used for each pass through the sensing system as the speed of the system is changed. To ensure that the same regions of the board are measured, mark the position of the specimen with respect to the mechanical system. This can be done by using index marks on the specimen relative to some convenient reference such as the transport system (for example, chains).

X7.3.5 *Processing Speeds*:

X7.3.5.1 *Longitudinal Flow*—Since longitudinal moisture meters are normally installed in-line with the planer, the processing speeds may vary over quite a large range (300 to 2000 fpm). It is therefore important that performance be evaluated over the entire range of speeds of interest. If more than one operating speed is anticipated, it is recommended that the system be evaluated at the lowest processing speed initially; then the processing speed increased in increments of 300 fpm up to the maximum expected in the application.

X7.3.5.2 *Transverse Flow*— Transverse systems normally run at much slower speeds (60 to 300 fpm) than longitudinal systems. In order to measure the dynamic effects over the entire range of speeds expected, it is recommended the evaluation start initially with the lowest anticipated speed, with incremental increases of 50 fpm up to the maximum speed expected in the application.

X7.3.6 *Moisture Indicating System* —In this case, the system will be used to provide accurate estimates of moisture content across a range of values, based on the specimen moisture criteria established in X7.3.1. The target moisture output value from the system may be the average of each piece or an extreme value (for example, the highest or lowest value) along the piece (or a combination).

X7.3.6.1 *Specimen Selection*—Using a meter meeting the requirements of Test Methods D 4444, select sufficient specimens to fully represent the criteria established in X7.3.1, and cover the moisture content range desired to be indicated. The specimens should be straight and free of characteristics affecting moisture measurement (knots, rot, pitch pockets, and so forth) unless these are explicitly included in the criteria of X7.3.1. Moisture uniformity must be addressed in selecting the specimens; that is, if uniformity is expected this must be a carefully considered criteria. The specimen length should be such that the specimens are adequately supported during processing to maintain correct positioning relative to the sensing region (clearance, alignment), and be longer than the sensing area over which the specimen will pass. Since some wood variables (for example, density) influence some of the physical measurements made to estimate moisture content, either these variables must be controlled (selected for) in the experimental design or the sample size be sufficiently large to attempt to include these variables in a proportion related to that found in production.

X7.3.6.2 *Recording Static Response* —A moisture content reading is taken under static conditions as the comparative base against which the dynamic reading will be compared. See 6.2-6.4 of the standard. If the meter has a data-recording device such as a computer or data logger, record the moisture content with the specimen located in accordance with X7.3.4.1 or X7.3.4.2. If there is no recording device, determine the peak reading from the display system.

X7.3.6.3 *Recording Dynamic Response* —Based on the processing speeds selected in X7.3.5.1 or X7.3.5.2, adjust the speed to the initial value selected. Send the specimens through the sensing zone in the orientation chosen in X7.3.4.1 or X7.3.4.2. Record the target value (for example, the average, maximum or minimum moisture content reading) indicated by the system for each specimen. Repeat the test at each of the speed settings selected, recording the target moisture content of each specimen. For the transverse system, this is an average of the target values obtained for each of the sensing heads. Continue to process the specimens at higher speeds until the critical speed is reached at which the indicated moisture content for the specimens is different from the static readings obtained in X7.3.6.2. This is designated the roll-off point, and is considered the limiting speed for the system.

NOTE X7.7—The roll-off point of a meter may be different for a meter system designed to output the estimated average of a piece than for a meter designed or adjusted to output only the peak (highest) moisture content of a piece. Thus, to assure that X7.3.6.3 follows the objectives set in X7.3.1, use of the relevant target moisture content is critical. Multiple tests may be required to fully evaluate a system, especially one that offers more than one moisture content output.

X7.3.6.4 *Presentation of Dynamic Data* —Determine the difference between the dynamic and static target moisture content for each specimen throughout the speed range measured. Average these differences at each speed, and plot specimen feed rate versus indicated moisture content difference to develop a performance curve. If the moisture measurement differences at the various speeds are also influenced by the moisture content level, develop performance curves for each of the moisture levels for which the measured differences (dynamic vs. static) are not equivalent. Other statistical methods may be more appropriate, especially if corrections are desired for observed deviations from desired relationships. If one of the objectives is to determine the sensitivity to ″wet-spots″ of variable size, shape and moisture level above the desired specification, all of the parameters of the test should be examined. The presentation of data should clearly indicate the limitations of the tests.

X7.3.6.5 *Action*—The dynamic response data offers information for comparison of meter performance and for evaluation against product performance criteria. In addition to the speed limitations related to roll-off, the effects of specimen movement and other operational variables can form the basis for decision making regarding product characteristics and operating procedures.

X7.3.7 *Accept/Reject Meters*—In this application, the moisture measurement system is required to determine if a piece meets a moisture content target requirement programmed into the system. This target requirement may be one of several moisture levels and may relate to a mean or an extreme value along the piece, or both. It is therefore most efficient to select and evaluate the dynamic response of the system using material that is within a few percent of the critical moisture target level and to also select specimens that represent the stated objectives with respect to variation along the piece. Peak value analysis of meter performance is a special challenge; see X7.3.6.4 and Appendix X8 for more discussion.

X7.3.7.1 *Specimen Selection*—Using a meter meeting the requirements of Test Methods D 4444, select sufficient specimens that are within a few percent of the critical moisture content to fully represent the criteria established in X7.3.1. The specimens should be straight and free of characteristics affecting moisture measurement (knots, rot, pitch pockets, and so forth) unless these are explicitly included in the criteria of X7.3.1. Moisture uniformity must be addressed in selecting the specimens; that is, if uniformity is expected this must be a carefully considered criteria. The specimen length should be such that the specimens are adequately supported during processing to maintain correct positioning relative to the sensing region (clearance, alignment), and be longer than the sensing area over which the specimen will pass. Since some wood variables (density is an example) influence some of the physical measurements made to estimate moisture content, either these variables must be controlled (selected for) in the experimental design or the sample size be sufficiently large to attempt to include these variables in a proportion related to that found in production.

NOTE X7.8—Selecting many specimens very close to the accept/reject decision point is designed to yield a sensitive assessment of the ability of the meter to make the accept/reject decisions. It does not provide a measure of the production yield error anticipated where the location of the accept/reject target point is often at the margin; for example, at the "upper 5th percentile" of the overall moisture distribution. That assessment requires different specimen selection and analysis.

X7.3.7.2 *Recording Static Response* —A moisture content reading is taken under static conditions as the comparative base against which the dynamic reading will be compared. See 6.2-6.4 of this standard. If the meter has a data-recording device such as a computer or data logger, record the moisture content with the specimen located in accordance with X7.3.4.1 or X7.3.4.2. If there is no recording device, determine the peak reading from the display system. If there is no display system, static hand-held meter readings (see 6.2) will necessarily be the basis for performance evaluation.

X7.3.7.3 *Recording Dynamic Response* —Based on the processing speeds selected in X7.3.5.1 or X7.3.5.2, adjust the speed to the initial value selected. Send the specimens through the sensing zone in the orientation chosen in X7.3.4.1 or X7.3.4.2. Record the accept/reject decision indicated by the system for each specimen. Repeat the test at each of the speed settings selected. For the transverse system, the values are obtained for each of the sensing heads. Continue to process the specimens at higher speeds until the critical speed is reached at which the accept/reject ratio changes more than an acceptable amount, compared to the accept/reject ratios from the static readings obtained in X7.3.7.2. This is designated the roll-off point, and is considered the limiting speed for the system. If it is desired to test the sensitivity of the system at different accept/reject moisture levels, rerun the specimens through the system resetting the trigger level appropriately. A set of specimens with a lower or higher distribution of moisture content may be required as the trigger levels are readjusted (see Note X7.4).

X7.3.7.4 *Presentation of Dynamic Data* —Determine the difference between the dynamic and static accept/reject ratios for the sample throughout the appropriate speed range. This difference is a measure of the bias of the system, accepting the static values as the basis for judgment. One way to visualize the performance is to plot feed speed versus the accept/reject ratio to develop a performance curve. Examine the performance of individual sensing heads in transverse systems before averaging across sensing heads to gauge overall system performance. Statistical analysis of accept/reject data requires use of methods appropriate to qualitative (enumerative) data (pass/fail, hit or miss, percent defective, and so forth).

X7.3.7.5 *Action*—The dynamic response data offers information for comparison of meter performance and for evaluation against product performance criteria. In addition to the speed limitations related to roll-off, the effects of specimen movement and other operational variables can form the basis for decision-making regarding product characteristics and operating procedures.

X7.4 *Analysis*—Analysis methods applied depend upon the adequacy of the data presentation, and upon the objectives of the test, keeping in mind that the recorded observations are qualitative data and require mathematical treatment designed for that type of data. Care should be taken to (*1*) assess the variability from multiple pass tests to determine the test stability and to clearly identify equipment capability, and (*2*) to limit the analysis methods and conclusions to the range of test data (no extrapolations).

X7.5 *Report—*The report on the test should indicate wood specimen data (size, species, moisture content(s)), operating test variables (environment, test speeds, and so forth) and concluding statistics. The conclusions reached and advisory comments (for example, procedures, equipment, and specimen limitations identified in the test) should be reported. Particular care should be taken to express the experimental and analytical limits of the test. Due to the empirical nature of the tests, the results and analysis may not parallel laboratory evaluated variables nor represent all of the events that can occur in dynamic mill operation.

X8. THE CHARACTERISTICS, MEASUREMENT AND ACCEPTANCE OF WET-SPOTS

X8.1 *Introduction*—In developing these test methods for in-line moisture meters, the Committee recognized that the specification of both a rigorous and comprehensive method to deal with wet-spots was beyond the current state of knowledge. For example, the concentration, location, and distribution of wet-spots is too variable to be simulated with any degree of accuracy for general, "representative" conditions. The Committee is aware that artificial means can be used to simulate wet-spots, such as embedding materials containing moisture, injecting water into cavities, and adding electrically-conductive materials, where the type of artificial material to be used is dependent on the principle of operation of the meter. However, neither the sensitivity and response of meters to wet-spots nor the use of "calibrated" artificial wet-spots has been documented in the literature.

X8.1.1 In many end uses, wet-spots have little effect; however, there are more critical applications, such as laminating and end jointing processes that will be subjected to radio frequency adhesive curing, where wet-spots can interfere with the process. Because of end-use sensitivity to wet-spots, it is important to have moisture meters that react to the presence of wet-spots against the background of the average moisture level, but that can be adjusted to discriminate so as to not reject acceptable material.

X8.1.2 Wet-spots occur for three basic reasons, wetwood, wood characteristics and obstructions in the drying process. This Appendix briefly outlines the reasons for these wet-spots and comments on in-line moisture meter concerns.

X8.2 *Wet-Spots Resulting from Wetwood*—For purposes of description of these test methods, wetwood is an area of high moisture content that is associated with bacterial attack that has resulted in an infected portion of a standing tree. This bacterial infection leads to localized areas, wet spots, of low permeability to water. When subjected to a conventional drying regime, this low permeability wood retains a high level of moisture while adjacent, non-infected wood loses moisture at programmed rates. Wet-spots caused by wetwood can be very localized, present in longitudinal streaks, or intermediate in distributional patterns. The size of the wetwood areas depends on the area infected and the drying time. Wetwood in some species is very persistent, often remaining after several redrying cycles.

X8.3 *Wet-Spots Resulting from Drying Practice*—There are also non-wetwood areas of higher moisture content caused by the dry kiln process. One of the causes of these wet-spots is the contact point of stickers where, because of no air contact during drying, the localized moisture content may appear like a wet spot from wetwood. Other sources of areas of higher moisture content occur when adjacent pieces in the kiln load warp sufficiently to block the air passage between pieces and where inaccurate trimming or stickering results in one end of pieces not supported on the kiln stickers.

X8.3.1 Wet spots may also result from fast kiln schedules, where localized areas of lower permeability have a reduced drying rate relative to the balance of the load, leading to higher residual moisture contents for these areas. This condition can even happen with species that are normally considered very permeable, such as southern pine. A version of this occurs with areas of rapidly changing density within a piece, as in a butt cut from a log. If the drying time in the kiln is based on ″average″ material and there is an insufficient equalizing period, the localized high-density area may have a significantly higher moisture content than adjacent wood.

X8.3.2 One characteristic that distinguishes these drying process related wet-spots from wetwood is the rate of diffusion of moisture. The wet-spots that originate for mechanical reasons or for normally occurring differences in permeability will usually equalize with the adjacent wood more rapidly than occurs with wetwood. Consequently, depending on the holding time after drying, these may have a less severe effect on in-line meter performance.

X8.4 *Consumer Acceptance*—One of the more perplexing aspects of in-line meter response to wet-spots is the general lack of specifications against which meter performance may be measured. Species that have reputation of wetwood problems, such as Hem-Fir, attract special attention in the buyer-seller relationship if wet-spots are a problem in secondary manufacture. An example is in the production of glued laminated beams where radio-frequency gluing may be used for both end-joint and face bonding. Wet-spots will disrupt bonding by adsorbing abnormal amounts of energy and may cause destruction of the laminated beam by steam expansion ("blows"). A manufacturer of wet-spot-prone laminating stock likely will set an in-line meter to make significant rejections on the basis of individual wet-spot moisture content, while striving to meet average moisture content requirements. This will reduce grade yield if wet-spots are present but will maintain the moisture quality needed by the customer.

X8.4.1 Lacking specifications on wet-spot acceptance, acceptance of a product that is susceptible to wet-spots becomes one of producer-consumer agreement. Often this is semi-technical at best, relying on acceptable performance of the product for the customer when the wet-spot detection criteria have been set by the producer using trial and error.

X8.5 *Wet-Spot Detection*—Wet-spots have a variety of sizes and shapes, from long and narrow to short and wide; from deep to shallow; from very "rectangular" (from stickers) to irregular (sometimes from wetwood or poor air flow). In order for a meter to detect wet spots in a discriminatory manner, it must have a rapid response to localized wet areas. To be effective for the user, it must have a threshold adjustment for controlling the sensitivity so that it can be adjusted to allow the producer to meet customer criteria. The threshold adjustment must not affect the precision of the meter in determining the moisture content of the lumber; however, this wet-spot sensitivity may be compromised by the average moisture content of the piece and speed of operation. In some cases, wet spots can trigger rejection of material as "wets" by the reaction of a single head within a multiple head in-line moisture meter system. Some meters have algorithms that permit averaging or weighting of abnormal single head readings. However, these algorithms must be used advisably, since the acceptability of wet spots is highly dependent on the subsequent processing.

X8.5.1 The characteristics of wet-spots, the lack of general specifications, and need for customer acceptance emphasizes the need for close communication between in-line meter manufacturers and their meter customers so that needs are correctly anticipated and procedures are correctly followed.

X8.6 *Recommendation*—These test methods provide no prescriptive procedures for standardization or calibration of in-line moisture meters for wet-spot detection. Yet, much of industry relies on the wet-spot detection capability of commercial meters in daily production. A very desirable, even if limited, addition to these test methods would be a requirement for a demonstration of the dynamic response of in-line meters to the "step-change" in moisture content that can occur with wet-spots. The demonstration could simulate a wet-spot passing through a sensing head. It would be important to emphasize that very few actual wet-spots could be simulated and, even with those, a simulated event is only a benchmark. Existence of such a benchmark would, however, provide some comparative information on machine response.

X8.6.1 If, in addition to establishing a benchmark response, a calibration material or system was developed to allow testing the sensitivity of detection at production speed, users would have a way of assessing the continued viability of wet-spot sensitivity of their in-line systems.

X9. SELECTION OF SPECIMENS AND EVALUATION OF ACCEPT/REJECT METERS

X9.1 Accept/reject meters are expected to sort lumber into two classes, one above a target moisture content; the other below the target moisture content. The process of specimen selection for these meters and the accompanying analysis of their performance is different from meters that estimate moisture content.

X9.2 Carefully review the objective of calibration to ensure that specimen selection criteria are consistent with intended end-use inferences. With the awareness that the instrument is not directly measuring MC but the effect of MC on physical variables, select specimens that provide the material properties desired.

X9.3 The specimens used for calibration should represent moisture content levels that vary uniformly about and are within several percentage points of moisture content from the desired target moisture content. In accordance with the objectives of the calibration, select specimens using a hand moisture meter meeting the requirements of Test Methods D 4444. Select a sufficiently large sample to accommodate the variability of moisture content and physical characteristics within the individual pieces that may affect moisture measurement. This is largely a judgment influenced by both the type of product, the product specifications and the processing history. A preliminary test may be required to examine the issue of sample size.

X9.3.1 Continue the sampling process until the distribution of moisture content (as represented by specimens) is relatively uniform around the target moisture content.

X9.3.2 Calculate the standard deviation(s) of the moisture content of the sample (as represented by the moisture content of the specimens). If s > 2 % MC, increase the number of specimens or discard "outliers" to reduce to less than 2 %.

X9.3.3 For a specimen that has a moisture content at or very slightly above the desired moisture content target, adjust the accept/reject to "trigger" rejection. This should also represent the mean of the moisture distribution of the specimens (the sample), see X9.3 and X9.3.1.

X9.3.4 As an example, see Table X9.1. Assume a target rejection moisture content of 19 %. The initial sample (n=20, designated by "a") has a mean (μ) of 16.4 % and a standard deviation of 1.8 %. The difference between the set point (19 %) and the mean (16.4 %) is 2.6 %. This difference is greater than the maximum suggested difference; therefore the sample was adjusted with more specimens at a higher moisture content to a new sample set "b" (see Table X9.1). The number of specimens (n) is now 35, and μ and s are 17.6 % and 2.2 %, respectively. The difference between the mean moisture content of the sample and the target moisture content for rejection is now judged adequate (1.4 %), however s is still somewhat above the suggested limit of 2 %, therefore the specimen size is increased again by adding 15 more specimens. The new combined sample set is designated "c". Considering all the specimens (n=50) gives a mean of 18 % and an s of 2.0 %, both now judged adequate to complete the evaluation of the meter in the region of the ultimate 19 % production target; however, for the test, the target for accept/reject will be moved to 18 %, so the sample will be balanced about the target and no further sample adjustment is needed.

X9.4 *Acquiring Accept/Reject Data*—For each specimen in the sample that passes the sensing area of the in-line meter, record

TABLE X9.1 Specimen Data Set Demonstrating One Way to Adjust the Moisture Content Mean and Standard Deviation

NOTE—Samples designated "a", "b", and "c" were added, in sequence, in order to modify the distribution for a slightly higher mean and lower standard deviation. Based on the combined set mean of 18 %, the target for the accept/reject test was set at 18 %.

Set "a"	Sets "a" and "b"	Sets "a", "b", and "c"
n = 20	n = 35	n = 50
μ = 16.4	μ = 17.6	μ = 18.0
s = 1.8	s = 2.2	s = 2.0

where:
μ = mean moisture content of the sample,
s = standard deviation of the moisture content of the sample, and
n = number of specimens.

the accept/reject decision of the meter system. An example of this, continuing the example from X9.3.3, is shown in Table X9.2. Those specimens tallied in the ″correct″ column were correctly identified by the in-line meter (that is, dry if dry and wet if wet, relative to the 18 % set point), and those tallied in the ″error″ column were incorrectly identified.

X9.5 There are several ways to tabulate the performance of the meter. The effort taken will depend on the intended use and the evidence of bias or other influence on the meter performance.

X9.5.1 The simplest method of assessing the meter performance is to tally the accept/reject percentage of the specimens based on the hand-held meter readings taken on each piece and then compare this ratio with the ratio determined from the in-line meter. This error should be small but the acceptable level will be a choice influenced by end use of the product and the effect on product yield.

X9.5.2 The following method can be used to determine any bias toward one side or the other of the moisture content mean in the meter error.

X9.5.2.1 Above the target moisture level (also the sample mean). Determine the average moisture content of specimens in the "error-high" category (MC_{EH}) above the target (MC_T). These are specimens that were rejected erroneously as being too high in moisture when, in fact, they were in the acceptable category by the hand-held meter measurement. Calculate the error by:

$$\frac{MC_{EH} - MC_T}{MC_T} \times 100 = \text{percentage error high}$$

Below the target moisture level (also the sample mean). Determine the average moisture content of specimens in the "error-low" category (MC_{EL}) below the target (MC_T). These specimens were accepted but should have been rejected; they were too high in moisture content by the original selection criteria but were not rejected by the in-line meter. Calculate the error by:

$$\frac{MC_T - MC_{EL}}{MC_T} \times 100 = \text{percentage error low}$$

Comparison of the two errors provides information about meter bias as influenced by moisture level.

X9.5.3 An analysis can be made of the example of Table X9.2 following the general concept of X9.5.1. The moisture content of all specimens is known from the initial selection process, using the hand-held meter as the basis. In Table X9.2, the specimens accepted in error as dry by the in-line meter (5) were actually above 18 % by the hand-held, that is, too wet (MC_{EL}); no specimens were accepted in error as too wet by the in-line (MC_{EH}), that is, this error is zero. The data shows that the meter is not sorting on 18 % moisture but on a value above 18 %, thus the meter response is biased. The calculations of X9.5.2 may also be used to estimate the amount of adjustment needed to balance the in-line error if that is desired.

X9.5.4 Data from an analysis of accept/reject meter performance should be used with caution. In actual practice, an accept/reject meter seldom is used where a balanced moisture distribution is present. Most often it is used at the margins of a moisture distribution where the goal is to reject an upper or lower tail, a significantly smaller proportion of material may exist on one side of the target value than on the other. Further, the histogram of moisture content may show severe skewness in this region. Consequently, an equal error on both sides of the target in the above example may be of limited relevance in practice.

X9.5.4.1 Other wood variables are often not uniformly distributed within a production line of product. A typical example is density. Dense wood dries more slowly than less dense; in a moisture distribution of product, more moisture may be aligned with

TABLE X9.2 Results of "Accept/Reject" Testing—Shown for One Run Only

Run No.	Total Specimens	Specimens Accented		Specimens Rejected	
1	50	30		20	
		Correct	Error (MC_{EL})	Correct	Error (MC_{EH})
		25	5	20	0

more density. However, when the meter is applied at the margin of the moisture distribution and if the meter is also influenced by the density (or other wood variable), the result is a need to consider the practical consequences of production application of the accept/reject meter when applying the results of this Appendix.

X9.5.4.2 The tally and analysis above are based on accuracy measurement and not on operating strategy. The operating strategy (percentages of "defective" deemed acceptable) depends on prevailing grading standards and/or customer requirements including whether a direct MC measurement (Test Methods D 4442) or an inferred MC (Test Methods D 4444) is the measurement basis and the quality system in effect.

NOTE X9.1—The above example is only for illustration of accept/reject meter sample selection and analysis. Other analyses may be chosen to meet specific objectives. Similar analyses may be carried out for meters to be judged on peak moisture measurement; however, the selection of specimens will be more difficult, and reference to Appendix X8 is recommended.