# Standard Practices for Verification of Displacement Measuring Systems and Devices Used in Material Testing Machines[1]

This standard is issued under the fixed designation E2309/E2309M; 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 practices cover procedures and requirements for the calibration and verification of displacement measuring systems by means of standard calibration devices for static and quasi-static testing machines. This practice is not intended to be complete purchase specifications for testing machines or displacement measuring systems. Displacement measuring systems are not intended to be used for the determination of strain. See Practice E83.

1.2 These procedures apply to the verification of the displacement measuring systems associated with the testing machine, such as a scale, dial, marked or unmarked recorder chart, digital display, etc. *In all cases the buyer/owner/user must designate the displacement-measuring system(s) to be verified.*

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 Displacement values indicated on displays/printouts of testing machine data systems—be they instantaneous, delayed, stored, or retransmitted—which are within the Classification criteria listed in Table 1, comply with Practices E2309/E2309M.

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

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

E83 Practice for Verification and Classification of Extensometer Systems

## 3. Terminology

3.1 *Definitions:*

3.1.1 *accuracy, n*—degree of conformity of a measure to a standard.

3.1.2 *error, n*—the amount of deviation from a standard.

3.1.2.1 *Discussion*—The word "error" shall be used with numerical values, for example, "At a displacement of +1.00 in., the error of the displacement measuring system was +0.001 in."

3.1.3 *tolerance, n*—the allowable deviation from a standard.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *calibration, n*—in the case of displacement measuring systems used with testing machines, the process of comparing the displacement indication of the machine or system under test to that of a standard, making adjustments as needed to meet error requirements.

3.2.2 *capacity range, n*—in the case of testing machines, the range of displacement for which it is designed. Some testing machines have more than one capacity range, that is, multiple ranges.

3.2.3 *correction, n*—in the case of a testing machine, the difference obtained by subtracting the measured displacement from the correct value of the applied displacement.

3.2.4 *displacement, n*—a movement or measurement of length expressed in terms of millimeters, inches, etc.

3.2.5 *displacement measuring system, n*—a device or set of devices comprised of a displacement transducer and associated instrumentation.

[1] These practices are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.01 on Calibration of Mechanical Testing Machines and Apparatus.

Current edition approved Jan. 1, 2016. Published February 2016. Originally published in 2005. Last previous edition approved in 2011 as E2309/E2309M-05(2011)$^{\varepsilon1}$. DOI: 10.1520/E2309_E2309M-16

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

***A Summary of Changes section appears at the end of this standard**

TABLE 1 Classification of Displacement Measuring Systems

| Classification | Resolution not to Exceed the Greater of: | | Error not to Exceed the Greater of: | |
|---|---|---|---|---|
| | Fixed Error, mm [in.] | % of Reading | Fixed Error, mm [in.] | Relative Error (% of Displacement) |
| Class A | 0.013 [0.0005] | ±0.25 | ±0.025 [0.001] | ±0.5 |
| Class B | 0.038 [0.0015] | ±0.5 | ±0.075 [0.003] | ±1.0 |
| Class C | 0.064 [0.0025] | ±1.0 | ±0.125 [0.005] | ±2.0 |
| Class D | 0.13 [0.005] | ±1.5 | ±0.25 [0.010] | ±3.0 |

3.2.6 *lower limit of verification range, n*—the lowest value of displacement at which a displacement measuring system can be verified.

3.2.7 *percent error, n*—in the case of a displacement measuring system, the ratio, expressed as a percent, of the error to the correct value of the applied displacement.

3.2.7.1 *Discussion*—The measured displacement, as measured by the testing machine, and the applied displacement, as computed from the readings of the verification device, shall be recorded at each verification displacement data point. The error, and the percent error, shall be calculated from this data as follows:

$$\text{Error} = A - B$$
$$\text{Percent Error} = \left[(A - B)/B\right] \times 100$$

where:

$A$ = displacement measured by the machine being verified, mm [in.], and

$B$ = correct value of the applied displacement, mm [in.], as determined by the calibration device.

3.2.8 *reference standard, n*—a standard used to measure displacement applied by the testing machine and measured by the displacement measuring system to be verified.

3.2.9 *resolution of the displacement indicator, n*—smallest change of displacement that can be estimated or ascertained on the displacement measuring apparatus of the testing machine or system, at any applied displacement. Appendix X1 describes a method for determining resolution.

3.2.10 *resolution of analog type displacement indicators (scales, dials, recorders, etc.), n*—the resolution is the smallest change in displacement indicated by a displacement of a pointer, or pen line. The resolution is calculated by multiplying the displacement corresponding to one graduation by the ratio of the width of the pointer or pen line to the center to center distance between two adjacent graduation marks.

3.2.11 *resolution of digital type displacement indicators (numeric, displays, printouts, etc.), n*—the resolution is the smallest change in displacement that can be displayed on the displacement indicator, at any applied displacement. Appendix X1 describes a method for determining resolution.

3.2.11.1 *Discussion*—If the displacement indication, for either type of displacement indicator, fluctuates by more than twice the resolution, as described in 3.2.9 or 3.2.10, the resolution, expressed as displacement, shall be equal to one-half the range of the fluctuation.

3.2.12 *relative repeatability, n*—the closeness of the agreement between the results of successive measurements from the same applied displacement, carried out under the same conditions of measurement. It is expressed as percentage of the mean indicated output for the same applied displacement on two successive calibrations for the given displacement.

3.2.13 *relative reversibility, n*—the difference between the mean measured displacement obtained for a given applied displacement applied in an increasing mode and the mean indicated displacement obtained for the same given displacement applied in a decreasing mode.

3.2.14 *testing machine, n*—a mechanical device for applying force and displacement to a specimen.

3.2.14.1 *Discussion*—The instrumentation may be either an electrical or a mechanical device, that is, a scale or pointer system.

3.2.15 *verification, n*—in the case of displacement measuring systems used with testing machines, the process of comparing the displacement indication of the machine or system under test to that of a standard and reporting results, without making adjustments.

3.2.16 *verification displacement, n*—a displacement with traceability derived from national standards of length with a specific uncertainty of measurement, which can be applied to displacement measuring systems.

3.2.17 *verified range of displacement, n*—in the case of testing machines, the range of measured displacement for which the testing machine gives results within the permissible variations specified.

## 4. Significance and Use

4.1 Testing machines that apply and measure displacement are used in many industries. They may be used in research laboratories to determine material properties, and in production lines to qualify products for shipment. The displacement measuring devices integral to the testing machines may be used for measurement of crosshead or actuator displacement over a defined range of operation. The accuracy of the displacement value shall be traceable to the National Institute of Standards and Technology (NIST) or another recognized National Laboratory. Practices E2309 provides a procedure to verify these machines and systems, in order that the measured displacement values may be traceable. A key element to having traceability is that the devices used in the verification produce known displacement characteristics, and have been calibrated in accordance with adequate calibration standards.

## 5. Calibration Devices

5.1 Reference standards used for calibration and or verification of displacement measuring systems shall have estimated measurement uncertainties. The reported uncertainty of reference standards must be equal to or less than ⅓ the allowable error for the measuring system Classification as shown in Table 1. The estimated measurement uncertainty of the reference standard should have a confidence level of 95 % ($k$ = 2).

## 6. System Verification

6.1 Displacement measuring systems shall be verified as a system with the displacement sensing and measuring devices (see 1.2 and 1.4) in place and operating as in actual use.

6.2 System verification is invalid if the displacement sensing devices are removed and checked independently of the testing machine.

6.3 A Practices E2309 verification consists of at least two verification runs of displacement contained in the displacement range(s) selected. See 8.1 and 8.2.

6.3.1 If the initial verification run produces values within the Practices E2309 requirements of Section 15, the data may be used "as found" for run one of the two required for the new verification report.

6.3.2 If the initial verification run produces any values which are outside of the Practices E2309 requirements, the "as found" data may be reported and may be used in accordance with applicable quality control programs.

6.3.3 Calibration adjustments may be made to improve the accuracy of the system. They shall be followed by the two required verification runs, and issuance of a new verification report.

## 7. Application of Displacement

7.1 In the verification of the displacement measuring system, approach the displacement test value by applying the test displacement from a lower value of displacement. To reduce the error in displacement measurement due to internal backlash of the testing machine, associated fixtures and or apparatus, make sure to approach the starting zero position of the testing machine from a point less than zero and in the direction for which the resultant verification data will be acquired. This procedure shall be followed when acquiring descending verification data as well. When acquiring descending verification data apply a displacement greater than the starting point and adjust the testing machine to re-establish a starting zero position in the direction for which verification data is to be acquired.

7.2 Displacement measuring systems that are used to acquire test data in both ascending and descending directions, shall be verified in both directions.

## 8. Selection of Verification Displacement Values

8.1 For any displacement range, verify the displacement measuring system by applying at least five test displacement values, at least two times, with the difference between any two successive displacement value applications being no larger than one-third the difference between the selected maximum and minimum test displacement values. Applied displacement values on the second run are to be approximately the same as those on the first run. Report all values.

8.2 The low limit of displacement measurement must be equal to or greater than:

400 times the resolution for Class A
200 times the resolution for Class B
100 times the resolution for Class C
67 times the resolution for Class D

8.2.1 Where the resolution of the displacement measuring system is sufficient to allow for verification below 10 % of displacement capacity or range, verify the displacement range by applying at least two successive series of displacement values, arranged in overlapping decade groups, such that the maximum displacement value in one decade is the minimum displacement value in the next higher decade. Starting with the selected minimal displacement value in each decade, there are to be at least five displacement applications, in an approximate ratio of 1:1, 2.5:1, 5:1, 7.5:1, and 10:1, unless the maximum displacement value is reached prior to completing all displacement application ratios. Report all displacement values and their percent errors.

NOTE 1—Example: If full scale is 200 mm [8 in.] and the minimal resolution is 0.025 mm [0.001 mm], the minimum verified displacement would be 5 mm (0.025 × 200). Two decades of 20 and 200 mm could be selected to cover the displacement application range. Suitable verification test displacement values would then be approximately 5, 10, 15, 20, 50, 100, 150, 200 mm. The largest reported error of the two sets of the test runs is the maximum error for the displacement range.

## 9. Preliminary Procedure

9.1 *Alignment:*

9.1.1 When fixturing the calibration device, it is important to minimize any misalignment. Significant errors can be induced due to misalignment. Gauge blocks or a square may be used to ensure that the calibration device operates parallel to the actuator in hydraulic testing machines or perpendicular to the crosshead in electro-mechanical testing machines.

9.2 *Temperature Considerations:*

9.2.1 Where the displacement measuring systems are electrical, connect the displacement transducer, indicator, interface, etc. using the appropriate cabling used in the actual machine setup. Turn on power and allow the components to warm up for a period of time recommended by the manufacturer. In the absence of any recommendations, allow at least 15 min for the components to be energized.

9.2.2 Position a temperature measuring device in close proximity to the machine being verified. Allow the displacement measuring device and all relevant parts of the verification equipment to reach thermal stability.

9.2.3 Include any bias due to temperature effects in the expanded uncertainty statement associated with the verification displacement values if required.

## 10. Procedure

10.1 *General:*

10.1.1 After completing the preliminary procedure given in Section 9 and before commencing with the verification procedure, adjust the testing machine to the maximum verification displacement to ensure that the maximum displacement can be achieved, and the machine has adequate space for the calibration device.

NOTE 2—Care should be given to the way a testing machine is used in determining the appropriate procedure for verifying a given machine. If a testing machine used to measure both positive and negative displacement values during normal testing, the system must be verified through zero, and both positive and negative verification values must be obtained.

10.1.2 During the verification, measure the ambient temperature by placing a calibrated thermometer as close to the calibration device as possible. The calibrated thermometer should have an accuracy of ±1°C or better.

10.2 *Procedure:*

10.2.1 Place the calibration device in the testing machine so that its center line coincides as closely as feasible with the center line of the testing machine's application of force.

10.2.2 There are two methods for using displacement calibration devices:

10.2.2.1 *Follow-the-Displacement Method*—The displacement reading on the calibration device is followed until the testing machine reaches a nominal graduation on the displacement-readout scale of the displacement measuring system. Record the displacement from the calibration device.

10.2.2.2 *Set-the-Displacement Method*—The nominal displacement is preset by adjusting the testing machine to the reading displayed by the calibration device, and the displacement measuring system readout is recorded when the nominal displacement displayed by the calibration device is achieved.

10.2.3 After selecting suitable displacement increments, obtain zero readings for both the machine and the calibration device, and adjust the testing machine slowly and smoothly for all verification measurements (see 7.1).

10.2.4 Ensure that the use of the maximum displacement indicators, recorders, or other accessory devices do not cause errors which exceed the Classification criteria listed in Table 1.

10.2.5 Record the measured displacement of the displacement measuring system and the applied displacement from the calibration device, as well as the error and percentage of error calculated from the readings.

## 11. Basis of Verification

11.1 The percent error for displacement values within the verified range of the displacement measuring system shall not exceed the required Classification criteria as listed in Table 1. The algebraic difference between errors of two applications of same displacement (repeatability) shall not exceed the required Classification criteria listed in Table 1 (see 8.1 and 8.2).

NOTE 3—This means that the report of the verification of a displacement measuring system will state within what verified range of displacement values it may be used, rather than reporting a blanket acceptance or rejection of the machine. In testing machines that possess multiple-capacity ranges, the verified range of displacement values of each range must be stated.

11.2 In establishing the lower limit of a verified displacement application range, the algebraic difference between the highest and lowest percent error at displacement test values shall not exceed the required Classification criteria listed in Table 1.

NOTE 4—This means that to establish the lower limit of a verified displacement range to Class B, the errors of the readings taken at each test displacement shall not only not exceed the greater of ±1.0 % of reading or ±0.025 mm [0.001 in.], but also shall not differ by more than the greater of ±1.0 % of reading or ±0.025 mm [0.001 in.]. For example, for test readings that would fall under the % of Reading error criteria for Class B, if the minimum error is −1.0 %, the maximum error cannot exceed 0.0 %. If the minimum error is 0.0 %, the maximum error cannot exceed +1.0 %.

11.3 In no case shall the verified displacement range be stated as including displacement values below the values listed in 8.2.

11.4 Displacement measuring systems may be more or less accurate or repeatable than the allowable Classification criteria listed in Table 1, which is the Practices E2309 verification basis. Buyers/owners/users or product specification groups may require or allow larger or smaller error systems. Systems with accuracy and repeatability errors larger than the allowable criteria for Class D as listed in Table 1, do not comply with Practices E2309.

## 12. Corrections

12.1 The measured displacement of a testing machine that exceeds the tolerance shall not be corrected either by calculation or by the use of a calibration diagram in order to obtain displacement values within the required permissible variation.

## 13. Time Interval Between Verifications

13.1 Calibration intervals should be discussed and agreed upon with the client/customer. It is recommended that displacement measuring systems be verified annually or more frequently if required.

13.2 Displacement measuring systems shall be verified immediately after repairs (this includes new or replacement parts, or mechanical or electrical adjustments) that may in any way affect the operation of the displacement measuring systems, or the values displayed.

13.2.1 Examples of new or replacement parts which may not effect the proper operation of a displacement measuring systems include: printers, computer monitors, keyboards, and modems.

13.3 Verification is required whenever there is a reason to doubt the accuracy of the displacement measuring system, regardless of the time interval since the last verification.

## 14. Accuracy Assurance Between Verifications

14.1 Some product-testing procedures may require daily, weekly, or monthly intermediate checks to ascertain that a displacement measuring system is capable of producing accurate displacement values between the testing machine verifications specified in Section 13.

14.2 Intermediate checks may be performed on ranges of interest or at displacement levels of interest utilizing suitable calibration devices specified in Section 5.

14.3 Make intermediate checks at approximately 20 % and 80 % of a range unless otherwise agreed upon or stipulated by the material supplier/user.

14.4 Displacement testing machine error shall not exceed the Classification criteria for the required class of device, as listed in Table 1 for the intermediate check applied displacement values. Should errors be greater than the required

Classification criteria at any of the intermediate check displacement values, a complete verification of the displacement measuring system is required (see 13.3).

14.5 Maintain a record of the intermediate check tests which shall include the name, serial number, verification date, verification agency, and the serial number or asset control number for the calibration device, also include the name of person making the intermediate checks.

14.6 The displacement measuring system shall be considered verified up to the date of the last successful intermediate check verification (see 14.4), provided that the displacement measuring system is verified in accordance with Section 13 on a regular schedule. Otherwise intermediate checks are not permitted.

14.7 When intermediate checks are made, a clear, concise record shall be maintained as agreed upon between the supplier and the user. The record must also contain documentation of the regular verification data and schedule.

## 15. Report

15.1 Prepare a clear and complete report of each verification of a displacement measuring system including the following:

15.1.1 Name of the calibrating agency,

15.1.2 Date of verification,

15.1.3 Testing machine description, serial number, and location,

15.1.4 Method of verification used,

15.1.5 Serial number and manufacturer of all devices used for verification,

15.1.6 Serial number and manufacturer of the displacement measuring system being verified,

15.1.7 Temperature during calibration,

15.1.8 The displacement measuring system error and percent error for each displacement measuring system at each displacement value and the maximum algebraic error difference (repeatability) for each displacement range and measuring system verified,

15.1.9 Class of the displacement measuring system. If separate classifications are established for various ranges, report the range and displacement values associated with each classification,

15.1.10 A specification of the uncertainty of the verified displacement values, if required,

15.1.11 Verified range of displacement for each measuring system of the testing machine,

15.1.12 Statement that verification has been performed in accordance with Practices E2309. It is recommended that verification be performed in accordance with the latest published issue of Practices E2309, and

15.1.13 Names of calibration personnel and witnesses (if required).

## 16. Keywords

16.1 calibration; displacement range; resolution; verification

# APPENDIXES

**(Nonmandatory Information)**

## X1. DETERMINING RESOLUTION OF THE DISPLACEMENT INDICATOR

X1.1 The resolution of a displacement measuring system in general is a complex function of many variables including applied displacement, displacement range, electrical and mechanical components, electrical and mechanical noise, and application software.

X1.2 A variety of methods may be used to check the resolution of the system. Some suggested procedures are as follows.

X1.3 *Procedure for Analog Type Displacement Indicators*:

X1.3.1 Typically these systems are not auto-ranging. The resolution should be checked at the lowest verified displacement in each range of interest.

X1.3.2 Divide the pointer width by the distance between two adjacent graduation marks at the displacement where the resolution is to be ascertained to determine the pointer to graduation ratio. If the distance between the two adjacent graduation marks is less than 2.5 mm [0.10 in.] and the ratio is less than 1:5, use 1:5 for the ratio. If the distance between the two adjacent graduation marks is greater than or equal to 2.5 mm [0.10 in.] and the ratio is less than 1:10, use 1:10 for the ratio. If the ratio is greater than those given in these exceptions, use the ratio determined. Typical ratios in common usage are 1:1, 1:2, 1:5, and 1:10.

X1.3.3 Multiply the ratio determined above by the displacement represented by one graduation to determine the resolution.

X1.3.4 Apply as constant a displacement as possible where the resolution is to be ascertained to minimize the fluctuation of the displacement indicator. It is recommended that the fluctuation be no more than twice the resolution determined in the previous step.

X1.4 *Procedure for Non-Auto-Ranging Digital Type Displacement Indicators*:

X1.4.1 The resolution should be checked at the lowest verified displacement in each range of interest.

X1.4.2 Adjust the testing machine for a displacement approximately equal to that at which the resolution is to be ascertained, and slowly change the applied displacement. Record the smallest change in displacement that can be ascertained as the resolution.

X1.4.3 Next adjust the testing machine for a constant displacement at the displacement value where the resolution is to be ascertained to ensure that the displacement indicator does not fluctuate by more than twice the resolution determined in the previous step. If the indicator fluctuates by more than twice the resolution, the resolution shall be equal to one-half the range of the fluctuation.

X1.5 *Procedure for Auto-Ranging Digital Type Displacement Indicators*:

X1.5.1 This procedure is the same as that for non-autoranging digital displacement indicators except that the resolution is checked at the lowest verified displacement in each operating portion of the range. The indicator resolution must meet the requirements listed in 8.2.

X1.5.1.1 Adjust the testing machine over the complete range of displacement taking note of the approximate displacement values that cause the display to automatically change the indicated resolution.

X1.5.1.2 Adjust the testing machine to approximately the lowest displacement in each operating section of the range just prior to the change in display resolution. Determine the resolution per sections X1.4.2 and X1.4.3 for each operating portion of the range.

## X2. IDENTIFYING AND DETERMINING MEASUREMENT UNCERTAINTY COMPONENTS DURING AN ASTM E2309/E2309M VERIFICATION

X2.1 The measurement uncertainty determined using this appendix is the measurement uncertainty of the errors reported during a verification of displacement of a testing machine's displacement measuring systems or devices. It is not the measurement uncertainty of the testing machine's displacement measuring systems or devices or the measurement uncertainty of test results determined using the testing machine's displacement measuring systems or devices.

X2.2 Under normal conditions, the measurement uncertainty of the reported errors of a testing machine's displacement measuring systems or devices determined during a verification using Practices E2309/E2309M is a combination of three major components: the measurement uncertainty of the calibration laboratory performing the verification, the uncertainty due to the non-repeatability of the testing machine's displacement measuring systems or devices during verification, and possibly the uncertainty component of the resolution of the displacement indicator of the testing machine's displacement measuring systems or devices at the displacement the error is being determined and at zero displacement.

X2.2.1 The measurement uncertainty of the calibration laboratory performing the verification is a combination of factors such as, but not limited to:

X2.2.1.1 The measurement uncertainty of the laboratory's displacement standard,

X2.2.1.2 Environmental effects such as temperature variations,

X2.2.1.3 Drift in the displacement standard,

X2.2.1.4 Measurement uncertainty of the verification of the displacement standard, and

X2.2.1.5 Repeatability and reproducibility of the displacement standard in actual use.

NOTE X2.1—A laboratory's measurement uncertainty should be based on the maximum uncertainty of the displacement standards used and the worst environmental conditions allowed. It may be advantageous to evaluate the measurement uncertainty of the actual displacement standard used at the actual displacement for which the measurement uncertainty of the error of the testing machine's displacement measuring systems or devices is being determined.

NOTE X2.2—If there are circumstances in which verification is performed under conditions outside of the laboratory's normal operating parameters, additional components may need to be considered. For example, a laboratory may permit a 5°C temperature variation to occur during verification and has factored this into their measurement uncertainty. When greater temperature variations occur, the uncertainty due to this increased temperature variation should be included in the determination of measurement uncertainty.

NOTE X2.3—A calibration laboratory's measurement uncertainty is usually expressed as an expanded uncertainty using a coverage factor of two. If this is the case, prior to combining it with the other uncertainty components, divide it by two.

X2.2.2 A way of assessing the uncertainty due to repeatability during the verification process is to evaluate the differences between the two runs of data (the repeatability).

X2.2.2.1 For each displacement verification point, find the sum of the squares of the differences in error between the first run and the second run of that verification point and the four verification points closest to that verification point. Divide that sum by ten and take the square root of the result to obtain an estimate of the uncertainty due to repeatability during the verification process.

NOTE X2.4—The sum is divided by ten because there are five pairs of readings used, and the variance of each pair is equal to the difference divided by two.

X2.2.2.2 Usually this type of assessment of uncertainty due to repeatability will include the uncertainty due to the resolution of the testing machine's displacement measuring systems or devices; however, it is possible to repeat runs without seeing the effects of the resolution. At each displacement, test to see that the uncertainty due to repeatability is greater than the uncertainty due to the resolution of the testing machine's displacement measuring systems or devices . If, at a given verification displacement, the uncertainty due to repeatability is not greater than or nominally equal to the uncertainty due to the resolution of the testing machine's displacement measuring systems or devices, for that verification displacement, include the components of uncertainty due to the resolution of the testing machine's displacement measuring systems or devices at that displacement and at zero displacement.

X2.2.2.3 The uncertainty due to the resolution of the testing machine's displacement measuring systems or devices at each verified displacement is the square root of the sum-of-the-squares of the following two components.

*(1)* The uncertainty component due to the resolution of the displacement indicator of the testing machine's displacement measuring systems or devices being verified can be determined by dividing the resolution of the displacement indicator at the displacement where uncertainty is being evaluated by the quantity of two times the square root of three.

*(2)* The uncertainty component due to the resolution of the displacement indicator of the testing machine's displacement measuring systems or devices at zero displacement can be determined by dividing the resolution of the displacement indicator at zero displacement by the quantity of two times the square root of three.

X2.3 The two major components (or three if necessary) can be combined by squaring each component, adding them together, and then taking the square root of the sum to determine the combined measurement uncertainty of the error determined for the testing machine's displacement measuring systems or devices.

X2.4 The expanded measurement uncertainty may then be determined by multiplying the combined uncertainty by two, for a confidence level of approximately 95%.

NOTE X2.5—Example: The measurement uncertainty of the reported error of a testing machine's displacement measuring systems or devices is to be determined at 50 mm. The calibration laboratory's measurement uncertainty expanded using a factor of 2 is 0.1% of applied displacement. The testing machine's displacement measuring systems or device's resolution at 50 mm is 0.001 mm. The resolution of the testing machine's displacement measuring system or devices at 0 mm displacement is 0.001 mm.

X2.5 The following are the calculations of measurement uncertainty for the 50 mm data point and two calibration runs:

The uncertainty component due to the calibration laboratory's measurement uncertainty, $u_{CL}$ is:

$$u_{CL} = \frac{0.001 \times 50}{2} = 0.025 \quad \text{(X2.1)}$$

The uncertainty component due to repeatability at 50 mm, $u_r$ is calculated as follows:

The repeatability at 50mm and the four closest displacements to 50 mm are 0.47% of 10 mm, 0.43% of 25 mm, 0.42% of 50 mm, 0.21% of 75 mm, and 0.15% of 100 mm which respectively are 0.047, 0.11, 0.21, 0.158, and 0.15 mm. Therefore:

$$u_r = \sqrt{\frac{0.047^2+0.11^2+0.21^2+0.158^2+0.15^2}{10}} = 0.103 \text{ mm} \quad \text{(X2.2)}$$

The component due to the testing machine's displacement measuring systems or devices resolution at 50 mm, $u_{R50}$ is:

$$u_{R50} = \frac{0.001}{2\sqrt{3}} = 0.0003 \text{ mm} \quad \text{(X2.3)}$$

The component due to the testing machine's displacement measuring systems or devices resolution at zero displacement, $u_{RZ}$ is:

$$u_{RZ} = \frac{0.001}{2\sqrt{3}} = 0.0003 \text{ mm} \quad \text{(X2.4)}$$

The total component due to resolution at 50 mm is:

$$\sqrt{0.0003^2+0.0003^2} = 0.0004 \text{ mm} \quad \text{(X2.5)}$$

Since the uncertainty due to non-repeatability is greater than that due to resolution, the component due to resolution is not included.

The combined measurement uncertainty of the error determined at 50 mm, $u$ is:

$$u = \sqrt{0.025^2+0.103^2} = 0.106 \text{ mm} \quad \text{(X2.6)}$$

The expanded measurement uncertainty of the error determined at 50 mm, $U$ using a coverage factor of two is:

$$U = 2 \times 0.106 = 0.212 \text{ mm} \quad \text{(X2.7)}$$

0.212 mm is 0.42% of 50 mm.

**TABLE X2.1 Verification Data**

| Machine Reading1 (mm) | Verification Apparatus Reading1 (mm) | % Error 1 | Machine Reading 2 (mm) | Verification Apparatus Reading 2 (mm) | % Error 2 | % Repeatability |
|---|---|---|---|---|---|---|
| 10 | 9.985 | 0.15% | 10 | 10.032 | -0.32% | 0.47% |
| 25 | 24.952 | 0.19% | 25 | 25.061 | -0.24% | 0.43% |
| 50 | 49.835 | 0.33% | 50 | 50.045 | -0.09% | 0.42% |
| 75 | 74.812 | 0.25% | 75 | 74.973 | 0.04% | 0.21% |
| 100 | 99.834 | 0.17% | 100 | 99.982 | 0.02% | 0.15% |

## SUMMARY OF CHANGES

Committee E28 has identified the location of selected changes to this standard since the last issue (E2309/E2309M-05(2011)$^{\varepsilon 1}$) that may impact the use of this standard.

*(1)* Appendix X2 was added.