ASME B89.1.10M-2001

[Revision of ASME/ANSI B89.1.10M-1987 (R1995)]

DIAL INDICATORS (FOR LINEAR MEASUREMENTS)

AN AMERICAN NATIONAL STANDARD

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Date of Issuance: July 1, 2002

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The American Society of Mechanical Engineers
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FOREWORD

ASME Standards Committee B89 on Dimensional Metrology, under procedures approved by the American National Standards Institute (ANSI), prepares standards that encompass the inspection and the means of measuring characteristics of such various geometric parameters as diameter, length, flatness parallelism, concentricity, and squareness. Because dial indicators are widely used for the measurement and comparison of some of these features, the chair of the B89.1 Main Committee on Length authorized formation of Working Group B89.1.10 to prepare this Standard.

Most dial indicators used in the U.S. are built to inch measure specifications but International Organization for Standardization (ISO) standards do not address all the needs of U.S. industry. The inch measure portion of this Standard is strongly influence by Commercial Standard CS(E) 119-45, effective January 1, 1945, which was prepared by the American Gage Design Committee (from which the term *AGD Standard* is derived), and distributed by the Department of Commerce. It is also based in part on Commercial Item Description A-A-2348B, dated July 30, 1991, developed by the General Services Administration (GSA). It is also based on manufacturers' current practices and technologies. The metric measure portion of this Standard is based primarily on ISO efforts in support of international commerce.

Working Group B89.1.10 wishes to acknowledge the leadership of its chair, Bruce Robertson, whose untimely passing has prevented him from seeing the end result of his contributions to the work of this group.

This Standard was approved by ANSI on April 10, 2001.

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Dimensional Metrology

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Secretary, B89 Main Committee
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Proposed Revisions. Revisions are made periodically to the standard to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the standard. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this Standard. Such proposals should be as specific as possible: citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

Interpretations. Upon request, the B89 Committee will render an interpretation of any requirement of the standard. Interpretations can only be rendered in response to a written request sent to the Secretary of the B89 Main Committee.

The request for interpretation should be clear and unambiguous. It is further recommended that the inquirer submit his/her request in the following format:

Subject:	Cite the applicable paragraph number(s) and provide a concise description.
Edition:	Cite the applicable edition of the standard for which the interpretation is being requested.
Question:	Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation.

Requests that are not in this format may be rewritten in the appropriate format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

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Attending Committee Meetings. The B89 Main Committee regularly holds meetings that are open to the public. Persons wishing to attend any meeting should contact the Secretary of the B89 Main Committee.

DIAL INDICATORS (FOR LINEAR MEASUREMENTS)

1 SCOPE

This Standard is intended to provide the essential requirements for dial indicators as a basis for mutual understanding between manufacturers and consumers. Described herein are various types and groups of dial indicators used to measure a linear dimension of a variation from a reference dimension.

2 REFERENCES

CS(E) 119-45 Dial Indicators (For Linear Measurements)

Publisher: Department of Commerce, 1401 Constitution Avenue NW, Washington, DC 20230

A-A-2348B Indicator, Dial, Accessories, and Test Set

Publisher: General Services Administration, 1800 F Street NW, Washington, DC 20405

MIL-I-8422D Indicators, Dial and Accessories

Publisher: National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield VA 22161

ISO R/463 Dial Gauges Reading in 0.01 mm, 0.001 in. and 0.0001 in.

Publisher: International Organization for Standardization (ISO), 1 rue de Varembé, Case Postale 56, CH-1211, Genève, Switzerland/Suisse

3 GLOSSARY

dial indicator: a measuring instrument in which small displacements of a spindle or a lever are magnifie by suitable mechanical means to a pointer rotating in front of a circular dial having a graduated scale.

error of indication: the amount by which the displayed value on a measurement device differs from the true input.

4 CLASSIFICATION BY TYPE

(a) Type A. Dial indicators in which the spindle is parallel to the dial face (see Fig. 1).

(b) Type B. Dial indicators in which the spindle is perpendicular to the dial face (see Fig. 2).

(c) Type C. Dial indicators in which the measuring contact member is a lever. These are also known as dial test indicators (see Fig. 3).

5 CLASSIFICATION BY GROUP

Group members are assigned in accordance with nominal bezel diameter and apply only to Type A and B indicators (Table 1). For Type C indicators, which are available in a variety of sizes and designs, refer to the various manufacturers' standards. Group descriptions are as follows:

(a) Group 0. Dial indicators having nominal bezel diameters from 1 in. (25 mm) up to and including $1^3/_8$ in. (35 mm).

(b) Group 1. Dial indicators having nominal bezel diameters from above $1^3/_8$ in. (35 mm) up to and including 2 in. (50 mm).

(c) Group 2. Dial indicators having nominal bezel diameters from above 2 in. (50 mm) up to and including $2^3/_8$ in. (60 mm).

(d) Group 3. Dial indicators having nominal bezel diameters from above $2^3/_8$ in. (60 mm) up to and including 3 in. (76 mm).

(e) Group 4. Dial indicators having nominal bezel diameters from above 3 in. (76 mm) up to and including $3^3/_4$ in. (95 mm).

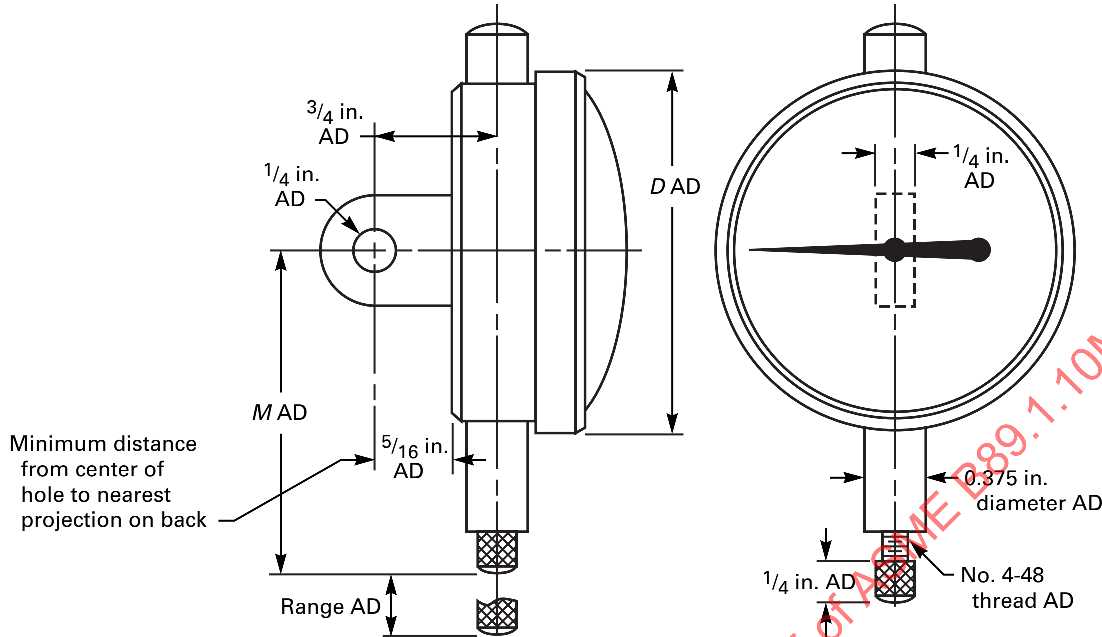
6 DIAL GRADUATION VALUES

All types of indicators shall have least graduations arranged either in four classes of inch values (i.e., 0.00005 in., 0.0001 in., 0.0005 in., and 0.001 in.) or in four classes of metric values (i.e., 0.001 mm, 0.002 mm, 0.01 mm, and 0.02 mm).

NOTE: Other values for graduations are sometimes used in industry. The supplier and the customer should agree on the determination of the maximum permissible error for dial indicators with graduations not mentioned in this Standard.

7 NOMENCLATURE

For the purposes of this Standard, the nomenclature in Figs. 1 through 6 shall apply.



GENERAL NOTES:
(a) In Type A design, the spindle is parallel to the dial face.
(b) This illustration represents the dimensions for size groups 1 through 4. For size group 0, consult the individual manufacturer's dimensional specification.
(c) For *D* and *M* dimensions, see Table 1.
(d) AD is the symbol for American Gage Design.

FIG. 1 TYPE A-AD DIAL INDICATOR

8 GENERAL REQUIREMENTS

8.1 Materials

8.1.1 Bearings. All types of indicators are furnished with either plain or jeweled bearings, or a combination of both.

8.1.2 Case. Dial indicator cases shall be of such strength and rigidity as to ensure free movement of the mechanism under normal shop condition.

8.1.3 Contact Points. Contact points shall be of hardened steel or other wear-resistant material with smooth uniform gaging surfaces. Except for Type A, Group 0, and Type C dial test indicators, all points shall have a #4–48 thread.

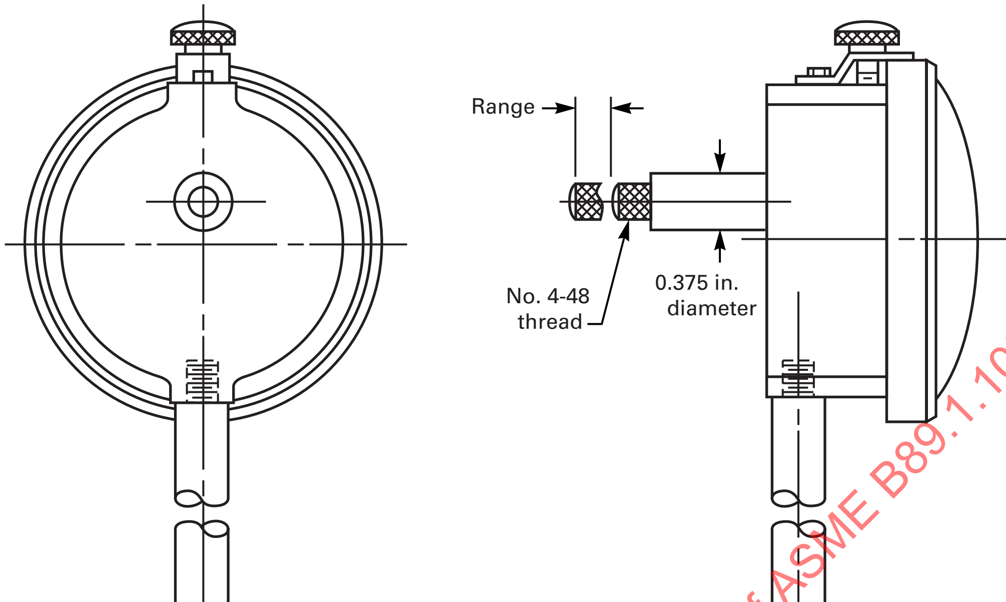
8.1.4 Crystals. The crystals shall be clear and preferably of nonshattering material.

8.2 Construction

8.2.1 Position. The zero position of the dials shall be adjustable over a range of 360 deg and the desired position fixed by a locking device or held by friction means between the case and bezel.

8.2.2 Dial Hands. The width of the tip shall be approximately the same as that of a graduation line on the dial face. Type A, $2\frac{1}{2}$-revolution indicators, shall have their hands set at approximately the nine o'clock position when the spindle is fully extended. One-revolution indicators shall have their hands set at approximately the six o'clock position at the bottom of the indicator dial. Type B indicators shall have their hands set in accordance with individual manufacturer's practice. Type C indicators will have their hands set at either the six o'clock or twelve o'clock position with the lever at rest.

8.2.3 Dial Indicator Range. For Type A indicators, the minimum range shall be $2\frac{1}{2}$ revolutions of the indicating hand unless specifically intended for use



GENERAL NOTE: In Type B design, the spindle is perpendicular to the dial face.

FIG. 2 TYPE B-AD DIAL INDICATOR

as a one-revolution indicator or unless specified for applications requiring shorter or greater travel. Types B and C shall have a minimum range of one revolution of the dial hand. Dial indicators with longer than specified range are referenced in para. 8.4.

8.2.4 Physical Dimensions. Refer to Fig. 1 for standard dimensions of Type A dial indicators. Types B and C (Figs. 2 and 3) are illustrated for general appearance. The individual manufacturer's standard practice should be consulted. Table 1 shows size group limits for nominal bezel diameters and corresponding minimum position distances along the spindle axis between contact point and center of dial for Type A indicators.

8.2.5 Dial Faces. The dial faces shall have sharp, distinct graduations and figures. Metric dials shall be yellow. One-revolution dial indicators may have a dead zone at the bottom of the dial face indicating an out-of-range condition. The dead zone may occupy no more than 20% of the circumference of the indicator. There shall be no graduations or numbering within the area occupied by the dead zone.

8.2.6 Dial Markings. Dial markings shall indicate the value of the least graduation, either inch or millimeter, and shall be in decimals [i.e. 0.001 in., not $^1/_{1000}$ in.; or 0.01 mm, not $^1/_{100}$ mm (Fig. 6)].

8.2.7 Dial Numbering. The dial numbering shall always indicate thousandths of an inch or hundredths of a millimeter, regardless of the class of dial marking.

8.3 Repeatability

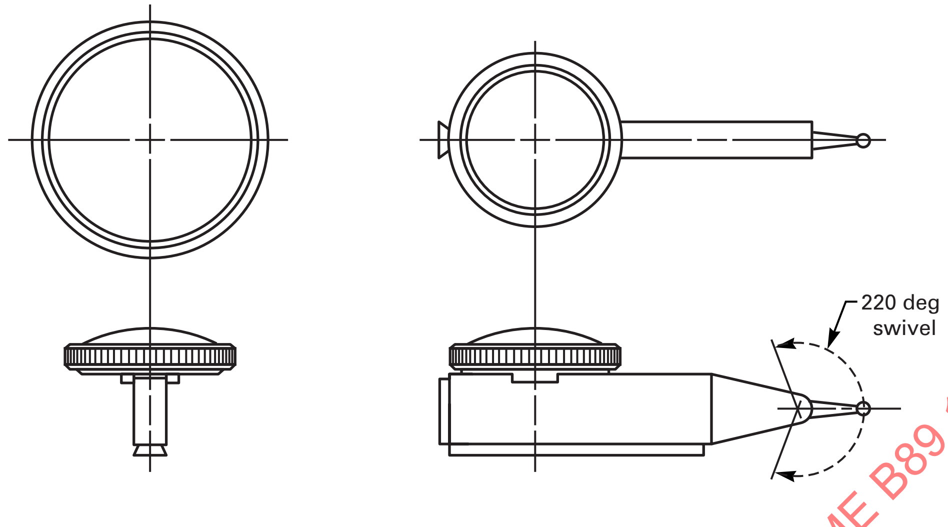
Readings at any point within the range of the indicator shall be reproducible through successive movements of the spindle or lever within $\pm ^1/_5$ least dial graduation for all types of indicators.

8.3.1 Determination of Repeatability. The following procedures are recommended for determining repeatability.

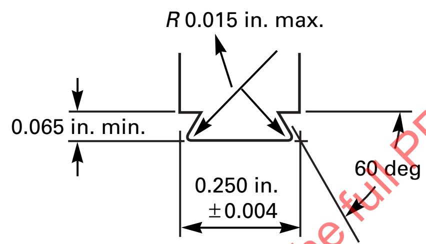
(a) Spindle Retraction. With the indicator mounted normally in a rigid system and its contact point bearing against a nondeforming stop, the spindle or lever is retracted at least five times, an amount approximately equal to $^1/_2$ revolution, and allowed to return gently against the stop. This procedure should be followed at approximately 25%, 50%, and 75% of full range.

(b) Use of Gage Blocks. With the indicator rigidly mounted normal to a flat anvil, position the indicator such that the contact point is slightly lower than the gage block length. Slide a gage block between the contact point and the anvil from four directions: front, rear, left, and right.

(c) The maximum deviation in any of the readings for (a) and (b) above shall not exceed $\pm ^1/_5$ least dial graduation.



(a) Dial Test Indicator



(b) Dovetail Typical

GENERAL NOTE: In Type C design, the measuring contact is a lever. These are also known as dial test indicators.

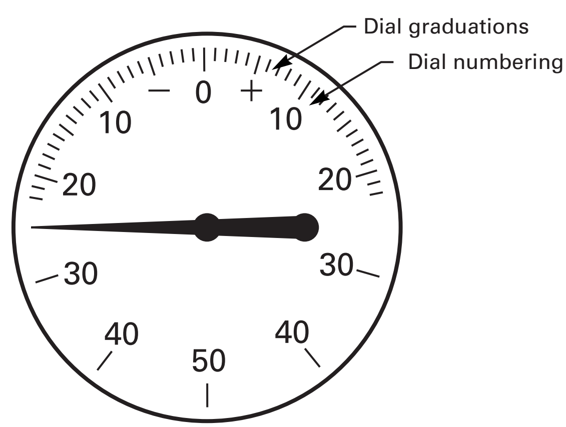
FIG. 3 TYPE C-AD DIAL INDICATORS

8.4 Accuracy

8.4.1 All types of indicators shall meet the requirements of Table 2. When determining whether an indicator meets the requirements, the measurement uncertainty of the calibration process must be taken into account.

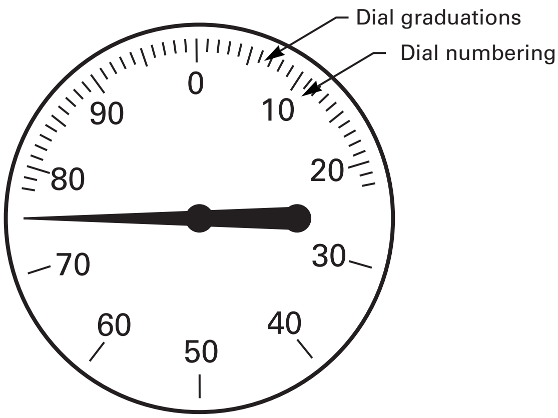
8.4.2 Determination of Error of Indication. The error of indication of a dial indicator is the degree to which the displayed values vary from known displacements of the spindle or lever. The determination of error of indication may be done with a micrometer f xture, an electronic gage, gage blocks, an interferometer, or other means. Proper techniques would require that the error of the calibrating means and its resolution be no more than 10% of the least graduation value of the indicator being checked or no more than 25% for indicators having least graduation of 0.0001 in. (0.002 mm) or smaller.

(a) Type A and B indicators are calibrated against a suitable device of known accuracy at a minimum of



GENERAL NOTE: Balanced dials will be furnished in all sizes and classes, unless continuous reading is specified.

FIG. 4 BALANCED DIAL SHOWING SPECIMEN NUMBERING



GENERAL NOTE: Continuous reading dial will be furnished in all sizes and classes, when specified.

FIG. 5 CONTINUOUS DIAL SHOWING SPECIMEN NUMBERING

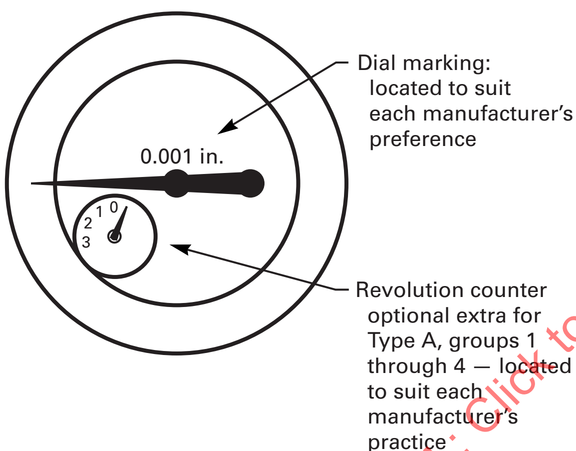


FIG. 6 DIAL SHOWING SPECIMEN DIAL MARKING AND REVOLUTION COUNTER

four equal increments per revolution over the range, starting at approximately the ten o'clock position, after setting the pointer to dial zero at the twelve o'clock position. One revolution indicators shall be started at approximately the seven o'clock position, after setting the pointer to dial zero at the twelve o'clock position.

(b) Type C indicators are calibrated against a suitable device of known accuracy through one revolution of the pointer at a minimum of four equal increments in the clockwise and counterclockwise modes after setting pointer and dial to zero just beyond the pointer rest position.

(c) Indicators of all types shall be calibrated for response to inward and outward movements of the spindle. Immediately after an inward movement is made, an outward movement shall be started without resetting the

TABLE 1 NOMINAL DESIGN DIMENSIONS FOR TYPE A INDICATORS

Size Group	Nominal Bezel Diameters, *D*				Minimum Position, *M*	
	Above		Up to and Including			
	in.	mm	in.	mm	in.	mm
0	1.0	25	1.4	35	1.3	31
1	1.4	35	2.0	50	1.6	41
2	2.0	50	2.4	60	2.0	50
3	2.4	60	3.0	70	2.2	54
4	3.0	76	3.8	95	2.6	65

GENERAL NOTE: Refer to Fig. 1 for an illustration of a Type A indicator.

indicator dial. The maximum difference between the points on the inward calibration curve and the corresponding points of the outward calibration curve, known as hysteresis, shall not exceed the limit defined in Table 3.

Figure 7 shows the charting of a sample calibration, with the inward movement, the outward movement, and hysteresis.

8.5 Gaging Force

For any indicator with a range of 10 revolutions or less, the starting force should be at least 50 g. The maximum force, when the spindle is pushed all the way in, should not exceed 180 g for dial indicators having 0.01 mm, 0.001 in., or 0.0005 in. graduations; and 250 g for dial indicators having 0.0001 in. (0.002 mm) or 0.00005 in. (0.001 mm) graduations. The difference between the starting force (spindle all the way out) and the maximum force (spindle all the way in) should be no greater than 90 g for any indicator, and there should be no points in the movement where the force goes any higher than 90 g more than the starting force.

For any indicator with a range greater than 10 revolutions, refer to the manufacturer's specifications.

8.6 Marking

Each indicator shall be marked in a plain and permanent manner with the manufacturer's name or trademark and model number for source identification. One revolution indicators shall be identified as such on the dial face.

8.7 Interchangeability

To ensure interchangeability in industrial gages and fixtures, the individual manufacturer shall indicate, in the catalogs and literature, conformance to appropriate dimensions of Type A indicators with the symbol AD (American Gage Design).

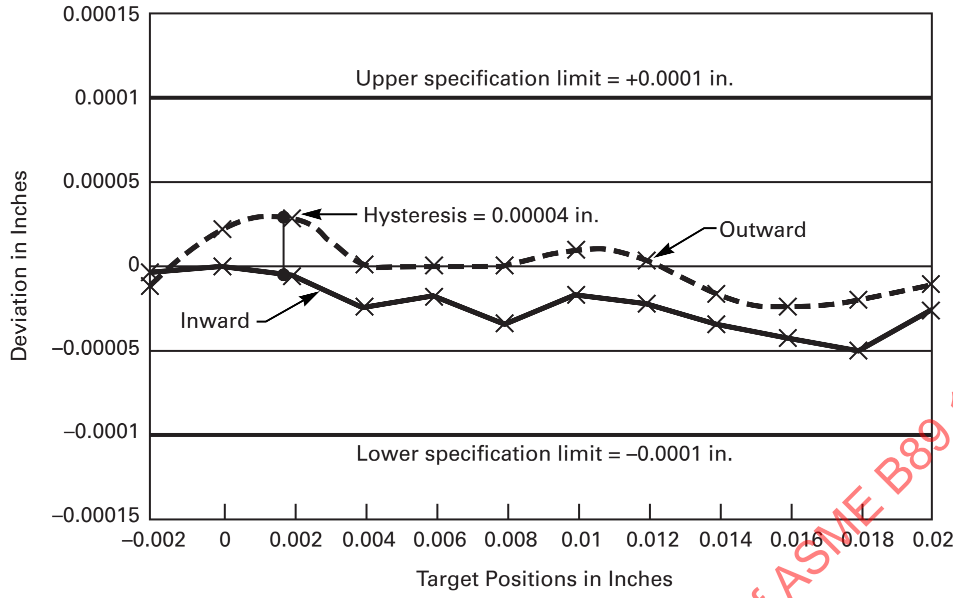


FIG. 7 CALIBRATION OF A 0.0001-in. GRADUATION INDICATOR

TABLE 2 DETERMINATION OF MAXIMUM PERMISSIBLE ERROR (MPE)

Least Graduation		Deviation in Least Graduation					
				Error of Indication			
in.	mm	Repeatability	Hysteresis	One Revolution	First $2\frac{1}{2}$ Revolutions	$>2\frac{1}{2}$ Through 10 Revolutions	>10 Through 20 Revolutions [Note (1)]
0.00005	0.001	±0.2	1.00	±1	±1	±4	. . .
0.00010	0.002	±0.2	1.00	±1	±1	±3	±4
0.00050	0.010	±0.2	0.33	±1	±1	±3	±4
0.00100	0.020	±0.2	0.33	±1	±1	±2	±4

GENERAL NOTE: For dial indicators with least graduations other than those listed above, the user and supplier should agree on the MPE.

NOTE:
(1) For more than 20 revolutions, consult the individual manufacturer for the standard practice.

NONMANDATORY APPENDIX A
TESTING, OPERATING, AND ENVIRONMENTAL CONSIDERATIONS

A1 GENERAL

This Appendix is intended to provide general guidance and awareness regarding testing, operating, and environmental considerations of indicators. Any conditions that exceed the testing, operating, and environmental recommendations and limitations of the instrument should be investigated, for the effect on the accuracy and repeatability of the indicator.

A2 PRECONDITION

A2.1 Soak Out

Allow the indicator to come to the same temperature as the test equipment. This can usually be achieved by mounting the indicator in the test fixture and then allowing it to "soak out" for at least 1 hr before beginning the test procedure.

A2.2 Visual Inspection

The indicator should be checked for damaged or missing parts. Check the dial indicator for wear points on the gaging tip ball and ensure that no flat places are worn on the ball. Ensure that the mechanical action of the gaging mechanism moves smoothly, with no evidence of sticking or binding, and makes no abnormal sounds when it is extended and retracted several times through its full range. Verify that there is no interference among the hands, dial face, and crystal and that the contact point is on tight. Ensure that the lever style indicator has the correct contact tip length, as specified by the manufacturer.

A2.3 Revolution Counter

Ensure that the revolution counter indicates $\pm\frac{1}{2}$ division of zero position of revolution counter when the indicator dial is zeroed.

A3 TESTING AND OPERATING CONSIDERATIONS

A3.1 Mounting and Fixturing the Indicator

The most common cause for inaccurate readings is unstable or flimsy mounting and fixturing equipment, as well as incorrect contact tip length. The manner and type of equipment used to mount or fixture the indicator will affect the readings. The indicator should be mounted as in as stable a configuration as possible, to ensure accurate readings.

A3.2 Direction of Movement

When readings or measurements are recorded from opposite directions of the contact movement, the readings will include the hysteresis of the indicator. More accurate readings can be obtained by approaching the surface to be measured from the same direction of contact movement.

A3.3 Alignment Error: Type C Indicators

Type C indicators typically allow the contact to be adjusted, for access to work surfaces. When the contact is adjusted to an angle other than the angle recommended by the manufacturer, the reading should be corrected to compensate for the cosine error introduced.

A4 ENVIRONMENTAL CONSIDERATIONS

A4.1 Temperature

The temperature of the indicator, fixture, and environment can effect the accuracy and repeatability of readings. Most indicators and fixtures are made of different materials, and the materials have different coefficients of expansion. When measurements are made, the temperature should be kept as near to the reference temperature of 68°F (20°C) to minimize the differences in expansion. When indicators are used, especially in production shops, working temperatures are seldom at the reference temperature. If parts made of aluminum or magnesium were checked by steel gages, an allowance for temperature differences would have to be considered, as the coeff cient of expansion for aluminum is approximately twice that of steel, while the coeff cient of expansion for magnesium is even greater.

A4.2 Humidity

The relative humidity or moisture content in the work area should preferably be kept at a level that would minimize the possibility of corrosion or inhibit smooth operation. Many applications are performed in very humid environments, and shielding or moisture proof ng the instrument may be required.

A4.3 Cleanliness

Cleanliness of indicators and equipment is an important requirement for accurate readings. Small particles of dirt or foreign material, on measuring surfaces or internally, can cause reading errors and possible premature wear of the instrument.

NONMANDATORY APPENDIX B
ELECTRONIC INDICATORS

B1 DEFINITION

An electronic indicator is a self-contained measuring instrument intended to perform the same function as a mechanical dial indicator. Displacements of a spindle or lever are detected by suitable electronic means and are displayed on a digital display, which is an integral part of the instrument.

B2 GENERAL

The use of electronic indicators and mechanical dial indicators are the same, so much of this Standard is directly applicable to either style of indicator. Some areas of this Standard, however, contain terminology and requirements that do not apply to some features and performance characteristics of electronic indicators. This Appendix will attempt to standardize a methodology for determining the accuracy of electronic indicators to facilitate mutual understanding between manufacturers and consumers.

B3 DIMENSIONAL CONSTRAINTS

To ensure interchangeability between Type A dial indicators and electronic indicators in industrial applications, individual manufacturers shall indicate, in their catalogs and literature, conformance to appropriate dimensions (see Fig. 1) with the symbol AD (American Gage Design).

B4 DISPLAYS

The numbers on the display shall have good contrast with the background, and the least-count digit shall agree with the analog reading (if present) within one digit of the least count. If the device loses count (e.g., due to a low battery condition or too quick of a spindle movement) an appropriate error indication will appear on the display.

B5 UNITS OF MEASURE AND RESOLUTION

Electronic indicators shall have minimum digital resolutions corresponding to the dial graduation classes for dial indicators as given in para. 6, or higher resolutions [e.g., 0.00001 in. (0.0002 mm) or 0.00002 in. (0.0005 mm)]. Analog-style displays or other display symbols shall be considered secondary to the digital display. Analog number markings (if present) shall correspond with paras. 8.2.6 and 8.2.7. The face of the instrument shall clearly indicate which system of units is currently being displayed.

B6 ACCURACY

In assessing the accuracy of an electronic indicator, the following factors should be considered:

(a) overall magnification and linearity

(b) accuracy of interpolation between scale elements of the indicator's encoder

(c) contribution due to the uncertainty of the least digit

(d) repeatability

(e) hysteresis

By nature of digital display systems, assuming the last digit represents a rounded-off value, the accuracy cannot be better than $\pm\frac{1}{2}$ the minimum displayed digit. The uncertainty is a uniform distribution with a width of one digit. The digitization of the data contributes an effective standard deviation of $\frac{1}{2}$ the value of the least digit divided by $\sqrt{3}$ to the evaluation of the uncertainty of measurement.

Calibration of electronic indicators should be performed by standards or instruments of known accuracy. The inaccuracies of the standards or instrumentation should preferably be less than 10% of the accuracy requirement, of the indicator under test, and should not be greater than 25% of that value.

Electronic indicators should meet the following accuracy requirements:

Repeatability:	±1 count
Hysteresis:	1 count
Overall magnification and linearity:	±3 counts

NOTE: 1 count = 1 least resolution

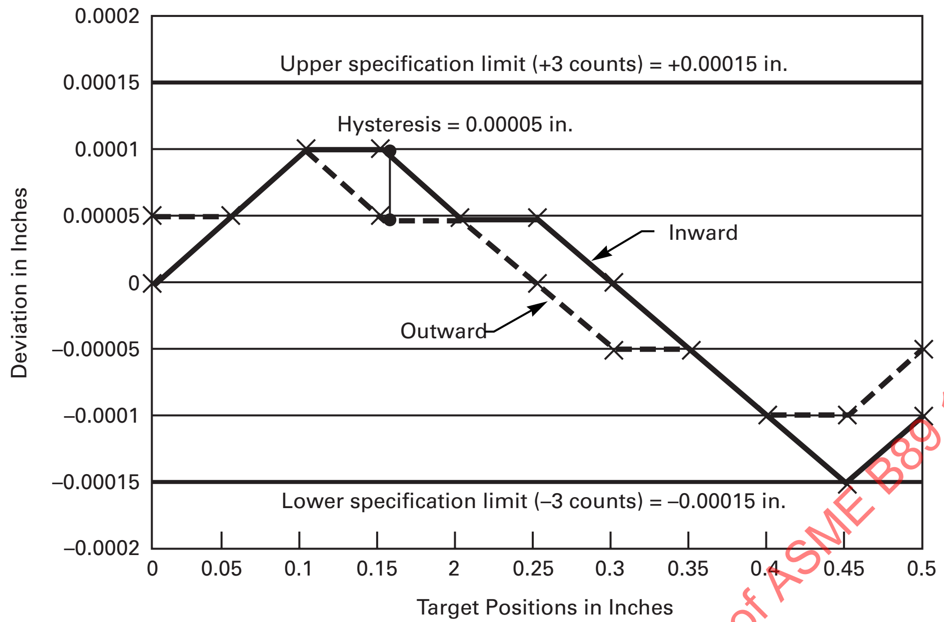


FIG. B1 OVERALL CALIBRATION OF AN ELECTRONIC INDICATOR HAVING 0.00005-in. RESOLUTION AND 0.500-in. RANGE

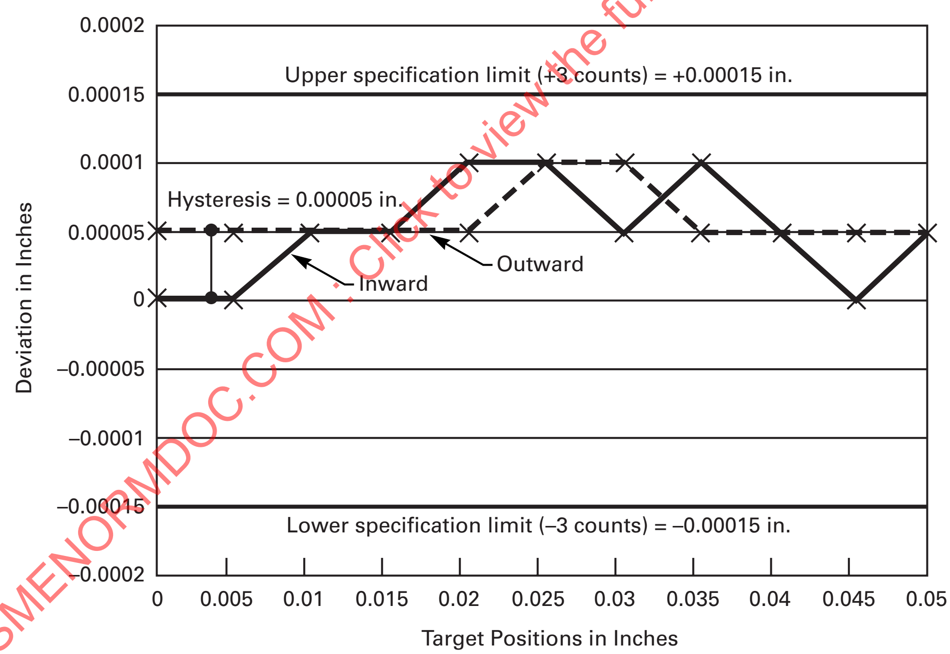


FIG. B2 MICROCALIBRATION OF AN ELECTRONIC INDICATOR HAVING 0.00005-in. RESOLUTION AND 0.500-in. RANGE

B7 DETERMINATION OF ACCURACY

(a) Electronic indicators should be checked for response in the inward and outward movement of the spindle. Evaluation of magnification and linearity should be determined from the data taken during inward movement. The evaluation of hysteresis should be determined from the maximum difference in the data taken between the inward and outward movement, at the same test point.

(b) The calibration should begin at a point within 10% of the at-rest position of the spindle and should end at a point beyond 90% of the range of the instrument. Set the starting point to zero and take at least 10 readings at equally spaced intervals covering the range. Readings should be taken with the spindle moving in and with the spindle moving out. Results of a typical calibration are shown in Fig. B1.

(c) For electronic indicators with ranges of greater than 0.200 in. (5 mm), a "microcalibration" should also be performed. To evaluate the "microcalibration" of the instrument, start from the original zero position and take 10 additional readings at intervals of 0.005 in. (0.1 mm). Results of a typical microcalibration are shown in Fig. B2.

(d) The results of the overall calibration and the microcalibration should both meet the requirements of para. B6.

B8 OUTPUT

Electronic indicators used as data generating devices directly integrated into data collection systems are equipped with data output capability. In such cases, manufacturers shall make details of the output protocol readily available, in enough detail to facilitate integration of these devices into data collection systems.

NONMANDATORY APPENDIX C
UNCERTAINTY FOR INDICATOR CALIBRATIONS

C1 SCOPE

This Appendix is intended to provide guidance in the development and application of the concept of measurement uncertainty as it applies to indicator calibration. For additional and more specif c information about measurement uncertainty, refer to the references listed in this Appendix. To assist the user, examples of uncertainty budgets are included for two different types of indicators.

C2 GLOSSARY

measurement uncertainty: parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measured (quantity being measured).

repeatability: ability of a measuring instrument to provide the same result for repeated measurements under the same conditions.

reproducibility: ability of a measuring instrument to provide the same result for repeated measurements under differing conditions.

resolution: smallest difference between indications of a displaying device that can be meaningfully distinguished.

C3 REFERENCES

ISO Guide to the Expression of Uncertainty in Measurement. 1993.

Publisher: International Organization for Standardization (ISO), 1 rue de Varembé, Case Postale 56, CH-1211, Genève, Switzerland/Suisse

Taylor, Barry N., and Chris E. Kuyatt. 1994. *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results.* NIST Technical Note 1297.

Publisher: National Technical Information Service (NTIS), 5285 Port Royal Road, Springf eld, VA 22161

C4 COMPONENTS OF UNCERTAINTY

In general, an uncertainty budget for the calibration of an indicator will consist of at least three non-negligible components.

C4.1 Uncertainty of the Master

The master may be either an instrument designed for calibrating indicators, or it may consist of a series of gage blocks. In some cases the actual value of the gage block or a correction from the calibration curve for the calibrator are used. In other cases the only information available may be that the calibration device (gage block or calibrator) is within its specif cation limits.

C4.2 Repeatability, Reproducibility, and Resolution

The greater of the repeatability or the resolution of the instrument is used in the uncertainty budget. If an uncertainty budget is being developed for a measurement process, and the process includes the use of different observers or different calibration devices, reproducibility rather than repeatability should be used in the uncertainty budget.

C4.3 Uncertainty Components Due to Thermal Effects

Components of the uncertainty budget due to temperature can be caused by

(a) uncertainty in the calibration of the thermometer

(b) uncertainty in knowing the thermal coeff cients of the materials if the temperature is not at the standard temperature of 68°F (20°C)

(c) the test item and the reference standard being at different temperatures

TABLE C1 UNCERTAINTY BUDGET FOR A MECHANICAL INDICATOR CALIBRATION

Source of Uncertainty	Value, μin.	Distribution	Divisor	Standard Uncertainty	Standard Uncertainty^2
Calibration device MPE	30	Uniform (type B)	$\sqrt{3}$	17	289
Calibration device uncertainty	20	Normal (type B)	2	10	100
Repeatability	300	Normal (type A)	1	300	90,000
Resolution	200	Uniform (type B)	$\sqrt{3}$	Not used	Not used
Thermal effects	11.5	Uniform (type B)	$\sqrt{3}$	7	49
				Combined Standard Uncertainty^2:	90,438
				Combined Standard Uncertainty:	≈ 300 μin.
				Expanded Uncertainty Expressed Using k = 2:	≈ 600 μin.

C5 CREATING AN UNCERTAINTY BUDGET AND CALCULATING UNCERTAINTY

The first step in creating an uncertainty budget is to list all possible sources of uncertainty in the measurement process. Next, the uncertainty for that component is expressed as one standard uncertainty. Finally, the standard uncertainties are combined by taking the square root of the sum of their squares.

NOTE: For Type B uncertainties, standard uncertainty is an estimate of the standard deviation. For Type A uncertainties, the standard deviation is equal to the standard uncertainty. See the references cited in para. C3 for detailed information on computing the standard uncertainty for distributions other than normal distributions. The most common case in the following examples is when the distribution is uniform over some interval. An example of this is the case where only the MPE (maximum permissible error) of a device is known, so the actual error might be anywhere within that span, with an equal probability that it is at any one particular value. Gage blocks within their grade tolerance, or calibrators within their stated specification are examples of this. In this particular case, the standard uncertainty is estimated by dividing the half-width of the distribution by the square root of three.

C5.1 Example 1: Mechanical Dial Indicator With 0.001 in. Graduations

The first example, summarized in Table C1, is an uncertainty budget for a mechanical dial indicator with 0.001 in. graduations and a working range of 1.000 in. It was calibrated using a micrometer-type calibrator. The calibration report for the instrument listed the MPE as 30 μin., and gave a measurement uncertainty for the process as 20 μin. The process was carried out in a room controlled to ±1°C.

C5.1.1 Calibration Device. The MPE of the calibration device (micrometer-based calibrator) could be up to 30 μin. It is assumed to be uniformly distributed with a half-width of 30 μin., so a divisor of $\sqrt{3}$ is used to convert this to a standard uncertainty. The stated uncertainty of the calibration (20 μin.) has a normal distribution and is the expanded uncertainty, so a divisor of 2 is used to convert this value to a standard uncertainty.

NOTE: It is assumed that this uncertainty came from a calibration certificate stating the expanded uncertainty in a form that complies with the GUM guidelines (see para. C3). It can be considered as a Type B uncertainty with a normal distribution.

C5.1.2 Repeatability, Reproducibility, and Resolution. In this example the repeatability of the indicator was determined by taking 30 separate readings at one position of the indicator. The standard deviation of this repeat test was 0.0003 in. The standard uncertainty is equal to one standard deviation from this study. This is a Type A uncertainty (see Note in para. C5).

The reproducibility was not used, because the process did not use multiple operators, calibrators, or other variables. Because there was only one set of conditions present, repeatability adequately represents the variation of the process.

For mechanical indicators having dial graduations, resolution is too complex to determine exactly. In these examples it is typically estimated to be a uniform zone with a width of ±$^1/_5$ of a graduation or less. This would make the associated standard uncertainty at Type B uncertainty, determined by taking the half-width ($^1/_5$ graduation, or 0.0002 in.) and dividing by the square root of three. This gives a value of 0.00012 in. for the standard uncertainty of the resolution, which is smaller than the value obtained for repeatability.

The value for repeatability is larger than the value for resolution so it is used in the uncertainty budget because it is the more representative value for the readability of the indicator.

C5.1.3 Thermal Effects. In this example, tests are carried out in a controlled-temperature environment. Because the temperature is close to 68°F (20°C) most of the uncertainties caused by thermal effects will be

TABLE C2 UNCERTAINTY BUDGET FOR AN ELECTRONIC INDICATOR CALIBRATION

Source of Uncertainty	Value, μin.	Distribution	Divisor	Standard Uncertainty	Standard Uncertainty[2]
Gage block tolerance	3	Uniform (type B)	$\sqrt{3}$	2	4
Gage block uncertainty	Not used	Normal (type B)	2	Not used	Not used
Repeatability	10	Normal (type A)	1	Not used	Not used
Resolution	50	Uniform (type B)	$\sqrt{3}$	29	841
Thermal effects	6.5	Uniform (type B)	$\sqrt{3}$	4	16
				Combined Standard Uncertainty[2]:	861
				Combined Standard Uncertainty:	≈ 30 μin.
				Expanded Uncertainty Expressed Using $k = 2$:	≈ 60 μin.

insignif cantly small. The only possible non-negligible source of error would be the difference in temperature between the calibrator and the indicator. Because the calibrator is handled by the operator, it was estimated that its temperature might be as much as 2°C warmer than the indicator. The change in length measured by the micrometer, due to a 2°C change in temperature is:

$$\begin{aligned} \Delta L &= \text{range} \times \Delta T \times \text{coefficient of expansion} \\ &= 1.00 \text{ in.} \times 2°\text{C} \times 11.5 \times 10^{-2}/\text{C} \\ &= 23 \ \mu\text{in.} \end{aligned}$$

Assuming a uniform distribution, with a half-width of 11.5 μin., the standard uncertainty is calculated by dividing by the square root of three, giving a value of approximately 7 μin.

C5.1.4 Expanded Uncertainty. Table C1 is the summary of the uncertainty budget for this example. The expanded uncertainty is calculated as outlined in para. C5. The results indicate that the single most significan item determining the uncertainty is the repeatability of the indicator. The value for the uncertainty of the master can be lowered by using actual values from a calibration error graph, rather than assuming that the instrument is within its specificatio limits; however, this would not improve the overall uncertainty significantly

C5.2 Example 2: Electronic Indicator With 0.0001 in. Least Significant Digit

The second example, summarized in Table C2, is an uncertainty budget for an electronic indicator with 0.0001 in. least significan digit and a working range of 0.500 in. It was calibrated using Grade 2 gage blocks. The process was carried out in a room controlled to ±1°C.

C5.2.1 Calibration Device. In this example, blocks from a Grade 2 set of blocks were used to check the indicator travel. The actual values of the blocks were not known; it was only known that they were within Grade 2 tolerances. Because the blocks could have been anywhere between the limits for Grade 2 blocks, a uniform distribution was assumed and one standard uncertainty was obtained by dividing the half-width of the distribution by the square root of three. The tolerance for Grade 2 blocks is +4/−2, so the half-width is 3 μin. If a calibrated value for the actual size of the block had been used, the standard uncertainty would have been one-half of the expanded uncertainty, reported on the block's calibration report.

C5.2.2 Repeatability, Reproducibility, and Resolution. The larger of either the repeatability or the resolution is used in the uncertainty budget. In this example the resolution is the larger of the two.

The repeatability of the indicator was determined by taking 30 separate readings at one position of the indicator. The standard deviation of this repeat test was 0.00001 in. The standard uncertainty is equal to one standard deviation from this study. This is a Type A uncertainty (see Note in para. C5).

The resolution of a digital indicator is ±1 least significan digit if the indicator truncates values beyond the least significan displayed digit and is $\pm\frac{1}{2}$ of the least significan digit if the indicator rounds off internally before displaying that digit. In this example it was determined that the indicator rounds off, so the resolution is a uniform distribution with a half-width of 0.00005 in.

C5.2.3 Thermal Effects. In this example, tests are carried out in a controlled-temperature environment. Because the temperature is close to 68°F (20°C) most of the uncertainties caused by thermal effects will be insignificantl small. The only possible non-negligible