

Measurement Uncertainty Factors in the Calibration of Screw Thread Gages

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The American Society of
Mechanical Engineers

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**The American Society of
Mechanical Engineers**

Two Park Avenue • New York, NY • 10016 USA

Date of Issuance: May 24, 2019

The next edition of this Standard is scheduled for publication in 2024. This Standard will become effective 1 year after the Date of Issuance.

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Two Park Avenue, New York, NY 10016-5990

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FOREWORD

The increasing demand for regular calibration of equipment used to ensure dimensional conformity in manufacturing has created corresponding growth in the number of calibration facilities to meet it. This in turn has brought more stringent requirements for those doing such work, including a requirement for a statement of measurement uncertainty applicable for each measurement reported.

Publications such as the ASME B1 Technical Report Measurement Uncertainty for 60 deg. Screw Thread Gage Element Measurement were produced to assist in evaluating the impact of uncertainty for gage calibration. Unfortunately, the values shown in ASME B1 were often adopted as generic in nature even though equipment and procedures being used did not match those on which the indicated values were based. This led to wide variations in reported uncertainties and disagreements over measurements. This Standard replaces the B1 Technical Report by providing a generic base that can be used for uncertainty calculations.

While the calculations used to produce uncertainty values are well documented, the elements that have to be considered require knowledge of metrology in keeping with the specialized nature of precision gage calibrations and the standards to which precision gage calibration devices are made. This is particularly critical with respect to the calibration of thread gages. This Standard has been prepared to assist in the calculation of related uncertainty values by noting unique details of the calibration procedures and the various elements that have to be considered.

Following the approvals of the ASME B1 Standards Committee and ASME, approval for this edition was granted by ANSI on March 15, 2019.

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Screw Threads

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MEASUREMENT UNCERTAINTY FACTORS IN THE CALIBRATION OF SCREW THREAD GAGES

1 INTRODUCTION

Every measurement contains an element of uncertainty with respect to the values obtained compared to the true value of the measured feature. This Standard has been prepared as a guide to the factors that contribute to uncertainty in the calibration of screw thread gaging devices. The reference section at the end of this Standard provides sources on how to compute uncertainty values.

This Standard is intended to provide the following:

- (a) an explanation of measurement uncertainty and the factors that contribute to it
- (b) characteristics of the equipment required for thread gage calibration
- (c) guidance in the application of measurement uncertainty
- (d) methods to resolve measurement disputes

NOTE: The metric values shown in parentheses are not conversions. They represent the closest typical metric values for the inch values shown.

2 SCOPE

(a) This Standard notes technical factors that can explain measurement differences between two parties calibrating the same gage. It is directed to the metrology involved, not acceptance rules or other quality considerations.

(b) While measurement uncertainty applies to the calibration of gages to any standard, this Standard focuses on gages made to ASME standards only. The calibration of gages necessitates a thorough understanding of the standards they were made to because the standards often include required conditions for and corrections to the calibration.

(c) Users of this Standard should be aware that while a number of elements for each gage type are listed, independent calibration laboratories may not include them all in their reports. Agreement should be reached with outside calibration providers as to what elements are included in their various levels of calibration.

3 DEFINITIONS

3.1 General Definitions

measurement uncertainty: the amount that a measurement of size may differ from the true value of that feature. Every measurement contains an element of uncertainty expressed as plus or minus from the reading of a size obtained. Uncertainty values determined by this Standard

indicate the true measurement is included within the uncertainty band with 95% confidence. With an expansion of the uncertainty value, the confidence of the true measurement being included could be raised to 99%.

It is important to understand that there is no generic uncertainty for a given process. Two laboratories having identical principal equipment will have different uncertainties due to variations in the factors noted in [section 5](#).

Often several laboratories report the same or similar values for uncertainty due to rounding of the actual values to the nearest convenient value. For example, 12 μin . may be rounded to 15 μin . in a conservative budget.

uncertainty budget: a listing of all of the factors affecting a particular measurement and the mathematical method used to process each one to arrive at a total expanded uncertainty. Each factor is processed to show its common dimensional effect even though it may not be of dimensional origins, such as temperature or measurement force. Also called uncertainty statement.

3.2 Dimensional Calibration Definitions

The following terminology is commonly used in dimensional calibration; however, some terms may refer to thread gages and related devices only:

accuracy: an indication of the performance of an instrument, the dimensional state of a master, or the outcome of a process when compared to specified values. Per JCGM 200:2012, "accuracy" is not a quantity and is not given a numerical quantity value.

comparison: a dimensional measurement process in which the unknown size of a gage is compared to the known size of a master, such as a gage-block build-up. Some instruments, usually referred to as comparators, are designed for this type of short-range measurement only. Other devices with a long measurement range may be set up in a similar manner for improved precision. The performance of all devices used in this manner is limited by the uncertainty in the calibration of the dimensional master(s) used.

cosine error: an error that results when the feature being measured, such as a diameter, is not normal (square) to the axis of measurement. This error may be encountered when plug gages rest on a worktable that cannot be adjusted to offset it. It may also appear in the direct measurement of solid thread ring gages. In both cases, it occurs because either the face or table the gage is

resting on is not square to the axis. It can also be found in devices that mount the gage on centers that are not aligned properly.

functional size: a size, such as a diameter, that contains all elements it is comprised of such that it could be larger on an external thread or smaller on an internal thread than indicated by discrete measurement for the dimension (e.g., diameter) alone (see ASME B1.7).

lead: the axial distance a thread gage will travel over one revolution in a mating thread. When single start threads are involved, the lead will be equal to the linear pitch of the thread.

NOTE: A thread with no lead or pitch variation could still contain considerable helical path error.

linearity: a measuring instrument characteristic comparable to accuracy. An instrument is said to be “linear” when, for every unit of input, it displays an equal unit of measured value. A simple example of this is a dial or digital indicator. For every 0.0001 in. (0.001 mm) the contact point is moved, the display reading will show a change of the same amount.

National Institute of Standards and Technology (NIST): the national legal authority for measurements in the United States through which measurements may be linked to international standards for length, such as SI, etc. Formerly called the National Bureau of Standards (NBS).

pitch, linear: the distance between corresponding points on adjacent thread forms in the same axial plane on the same side of the thread axis. It is often incorrectly referred to as “lead.”

reading: a measuring device’s display of a measured value or its variation from a master.

repeatability: the range within which a device will repeat a given measured value over a short period of time. While an important characteristic of the measurement process, repeatability on its own should not be confused with accuracy or uncertainty.

resolution: the smallest measured value an instrument can display. While a critical feature of any instrument, it is not necessarily an indication of that instrument’s performance.

simple pitch diameter: on a parallel thread, the imaginary cylinder or diameter that passes through the thread form in such a way that the widths of the thread ridge and groove are equal. This diameter is equidistant from the top and bottom of a perfect unrelieved thread form. Also known as thread groove diameter.

thread form: a thread’s profile in an axial plane for a length of one pitch of the thread.

thread form, half angle: the angle of one flank of a thread form. A 60-deg symmetric thread form is defined by two 30-deg half angles.

true value: the precise value of a measured feature that is, in practice, unknowable. The difference between this value and that obtained through calibration is the measurement uncertainty for the process.

4 CALIBRATION EQUIPMENT CONSIDERATIONS

While handheld portable instruments and thread-measuring wires may be used for measuring product pitch diameter and other dimensions, the level of precision of these methods is inadequate for the calibration of gages. This would be shown by an uncertainty budget for such a process compared to one using suitable equipment.

In this section, the minimum requirements for equipment are shown to assist users in evaluating the suitability of their equipment for calibration work. In all cases, it is assumed that the instruments, thread-measuring wires, and masters being used are in a known state of calibration.

4.1 Bench Micrometers and Similar Devices

Bench micrometers and similar precision-measuring devices function much in the same way as outside micrometers; the axis of the gage may be vertically oriented, or the gage may be horizontally mounted on the centers for measurement of pitch diameter, etc. Devices similar to bench micrometers include micrometer-like devices with adjustable tailstocks, floating carriage-measuring machines designed specifically for calibration work, and universal length-measuring machines (ULMs). Of these devices, ULMs offer the highest order of precision.

The basic requirements for bench micrometers and similar devices are as follows:

- (a) changeable measuring forces that comply with the requirements of the thread standard
- (b) 0.00001-in. (0.0002-mm) resolution or finer
- (c) measuring faces that are flat and parallel within 20 $\mu\text{in.}$ (0.5 μm)
- (d) retractable, adjustable measuring face(s) to facilitate insertion of thread wires

4.2 High-Resolution Comparators

High-resolution comparators incorporate a high-resolution indicator system that is set to a nominal size using a gage block buildup with the axis of the gage horizontal. The measuring head is adjusted vertically to accommodate various gage sizes. During measurement of pitch diameter, the gage is located on two thread-measuring wires on the comparator worktable.

The basic requirements for high-resolution comparators are as follows:

- (a) the same measurement forces as noted for bench micrometers [see para. 4.1(a)], although these are not usually obtainable due to the design of the equipment. In many situations, this deviation from the proper measuring forces can become a major contributor to uncertainty.

- (b) 0.00001-in. (0.0002-mm) resolution or finer.
- (c) sensitive contact measuring face, and the face of the lower anvil should be flat and parallel within 20 μin (0.5 μm).

4.3 Thread-Measuring Wires

The dimensional requirements for thread-measuring wires are noted in detail in the standard to which they are made for calibration of thread gages to North American standards. The following basic requirements are from ASME B89.1.17:

- (a) Wires shall be within 0.000020 in. (0.00050 mm) of "best" wire size and calibrated to 0.000010 in. (0.000250 mm). Other size wires may be used, but the corrections and calculations involved are simplified or eliminated if the wires used comply with those of ASME B89.1.17.
- (b) Each of the three wires in a set shall be within 0.000010 in. (0.000250 mm) of each other for size, roundness, and taper.
- (c) Wires shall be round within 0.000010 in. (0.000250 mm).
- (d) The taper over the central 1 in. (25.4 mm) of the wire length must be within 0.000010 in. (0.000250 mm).

Standards require that the diameter of thread wires be calibrated using specified measuring forces and that a value for the "constant" of the set be calculated from the calibration results. The method outlined in the applicable thread standard must be used for calculating the constants.

NOTE: Nominal "constant" values from charts or container labels should not be used as they may not be the correct constant values based on actual wire size. Constants vary with the form and type of thread involved. Always consult the standard applicable to the particular thread.

In most applications following ASME standards, it is assumed that three wires are used for pitch diameter measurement of parallel threads.

4.4 Thread-Measuring Balls/Probes

Thread-measuring balls or the probes containing them are made to specified "best" sizes as used for the thread-measuring wires (see ASME B89.1.17). Since one, two, or three balls may be used for an application, single balls are supplied rather than sets of three as is done with thread-measuring wires.

The basic requirements for thread-measuring balls are as follows:

- (a) Ball diameter must be within 0.000020 in. (0.00050 mm) of "best" size the standard shows for a given pitch and calibrated to 0.000010 in. (0.000250 mm). Different sizes can be used, but calculations and corrections are required to produce accurate results.
- (b) The diameters of the balls or spherical probe tips must be within 0.000010 in. (0.000250 mm) of each other.

- (c) Sphericity of such contacts must be within 0.000010 in. (0.000250 mm) of each other.

NOTE: Calculations for constants, measurements over or under a ball, probe offsets, and/or master configurations require actual calibrated values for accuracy. Always consult the standard applicable to the specific thread being measured.

4.5 Optical Comparators

Optical comparators project a magnified image of the thread form on a rotating glass screen, enabling the user to measure the thread form using either on-screen calibrated angular values or, if provided, an integrated digital measuring system. Magnifications used vary with the pitch of the thread being measured. For inch threads coarser than 14 threads per inch (TPI), use 20X magnification; for 14 TPI to 40 TPI, use 50X magnification; and for finer than 40 TPI, use 100X magnification. For metric threads coarser than 1.75-mm pitch, use 20X magnification; for 1.7-mm to 0.6-mm pitch, use 50X magnification; and for finer than 0.6-mm pitch, use 100X magnification.

The basic requirements for optical requirements are as follows:

- (a) interchangeable lenses to provide 20X, 50X, and 100X magnification per the standard
- (b) magnification accuracy precision of approximately 0.05%
- (c) adjustment to align the thread helix to the optical path for form measurement
- (d) linear measurement resolution of 0.0001 in. (0.002 mm) or better
- (e) angle-measuring system with 0-deg, 1-min resolution

While overlay charts with tolerance lines on them are used with optical comparators to inspect thread form on products, they are not accurate enough for thread gages.

4.6 Toolmakers' Microscopes

Toolmakers' microscopes function in much the same way as an optical comparator except that the image of the thread form is viewed through an eyepiece. Some toolmakers' microscopes have an accessory that provides a small screen for viewing the image in lieu of the eyepiece. The basic requirements are the same as for optical comparators.

4.7 Linear Pitch-Measuring Devices

Several devices specifically designed to measure linear pitch of gages are available, but their designs and capabilities vary considerably. The basic criteria for these devices are as follows; other criteria may be included based on individual design:

- (a) overall precision accuracy of 0.00004 in. (0.001 mm) or better
- (b) resolution of 0.00002 in. (0.0005 mm) or better

Optical comparators and similar devices may have specially designed accessories for measuring linear pitch, but their overall performance is limited compared to that of instruments designed for such work.

5 FACTORS TO BE INCLUDED IN UNCERTAINTY BUDGETS

Every factor that could affect a particular measurement should be included in the uncertainty budget or statement for the measurement. It is recommended that even a factor of little significance be included because its inclusion will assure anyone reviewing the uncertainty budget that all factors have been considered.

Similarly, multiple readings for each measurement help to quantify the effects of some of the factors. From a commercial point of view, however, this ideal is rarely realized due to the costs involved. A typical commercial laboratory takes only a single reading for each measurement location on a gage, whereas a NIST laboratory or another National Measurement Institute facility takes multiple measurements and generates statistically significant values for a factor. The lab values therefore have a lower level uncertainty than do the commercial laboratory's values. The factors noted in this section assume that a single reading for each measurement will be treated mathematically using statistically derived divisors or multipliers with that situation in mind.

5.1 Common Factors

5.1.1 Temperature. All dimensional measurement results are considered valid at the standard reference temperature of 68°F (20°C). Measurements taken at other temperatures are acceptable if they are corrected for the deviation from the standard reference temperature. Alternatively, the uncertainty budget could include a factor for large variations from the standard temperature. A footnote to the uncertainty statement should indicate that if the alternative is chosen, that fact should be noted in the budget.

An uncertainty budget must include known temperature variations and errors in the thermometry used to determine them. Typically, the finer the resolution of the measurement or the larger the item being measured, the greater the effects of the temperature variations.

5.1.2 Repeatability and Resolution. The typical uncertainty budget includes either the repeatability or the resolution of the measurement process, whichever of these elements has the higher variation. Usually, resolution is much finer than repeatability, and so repeatability is the element that appears in the uncertainty budget.

It should be noted that repeatability refers to the repeatability of the overall process and not just to that of the measuring device. While the overall repeatability may be estimated, tests of 30 readings or more can be processed statistically for a more reliable indication of

its effects, which can vary significantly due to the thread wires used.

5.1.3 Gage Geometry and Surface Texture. Roundness and surface texture are factors that shall be considered when thread gages are calibrated, particularly used gages that have dings or chips and/or show signs of excessive rust, corrosion, or abuse. Similarly, the finish on turned rather than ground gages can present significant problems. When rusting is severe, some laboratories will not attempt to calibrate them and will advise the gage user about the situation. Others will estimate the effects on uncertainty and get customer approval before proceeding. Some will calibrate the gages if possible but include a note in their report to indicate the state of the gages and the fact that the uncertainty shown does not include the effects of their condition.

5.2 Uncertainty Factors for Pitch (Groove) Diameter Calibration

5.2.1 Thread Plug Gages

- (a) temperature
- (b) uncertainty from calibration of gage blocks used as a setting master
- (c) uncertainty in the calibration of thread wire size¹
- (d) variations in measuring force from specified values
- (e) uncertainty in the calibration of the measuring instrument
- (f) variations in thread wire roundness/taper¹
- (g) cosine error

5.2.2 Setting and Checking Plug Gages for Thread Ring Gages

- (a) all of the factors in [para. 5.1.3](#).
- (b) overall linear pitch, variations that have a 1.732:1 effect on the functional size of 60-deg threads, 1.781:1 on 45-deg × 7-deg or 7-deg × 45-deg buttress threads, and 3.867:1 on 29-deg Acme threads. Effects will vary with other forms.

5.2.3 Thread Ring Gages

(a) *Adjustable Type.* This type of gage is calibrated for its functional size in accordance with ASME B1 standards. Final settings are subjective in nature, but variations can be reduced if the following factors are addressed:

- (1) uncertainty of calibration of the setting plug used.
- (2) temperature. The temperature-setting process generates heat through friction, so acceptance of the final setting should not be made until this heat has dissipated.

¹ These variations have a 3.00:1 effect on measured pitch diameter for 60-deg threads. On 29-deg Acme threads, the ratio is 4.993929:1, while on 45-deg × 7-deg or 7-deg × 45-deg buttress threads, the ratio is 3.156891:1. These ratios hold true for threads with a lead angle not exceeding 5 deg. Effects will vary with other thread forms.

(3) calibrated size for the setting plug used. This value shall be listed in the report showing the calibrated size.

(b) *Solid Type Using Check Plugs*

(1) uncertainty of the calibration of parallel plugs used

(2) temperature from friction

(c) *Solid Type Using Direct Measurement.* This is a partial calibration since it does not include the effects of variations in pitch, angle, or roundness, etc. Measurements will always be larger than functional calibration. The following elements should be included:

(1) uncertainty of the measuring instrument calibration

(2) linear pitch error positioning the probe

(3) ball contact diameter calibration uncertainty

(4) variation of thread-measuring forces

(5) errors due to the use of different types of setting masters for the equipment, such as plain rings, gage blocks, or vee-grooved masters, etc.

(6) cosine error

5.2.4 Variable Thread Comparators

(a) uncertainty of the indicating unit calibration

(b) parallelism of rolls/segments

(c) temperature

(d) pitch errors in multi-rib gaging rolls/segments

(e) uncertainty of calibration of masters used

(f) pitch misalignment of rolls/segments

NOTE: It is assumed that the frame, indicator, and rolls/segments of a variable thread comparator are calibrated as a unit.

5.3 Uncertainty Factors for Major and Minor Diameter Calibrations

5.3.1 Thread Plug Gages

(a) *Major Diameter*

(1) temperature

(2) uncertainty of the measuring instrument used

(3) calibration uncertainty of setting master calibration (if used)

(4) measuring force variation

NOTE: Forces noted in the standard for the measurement of pitch diameter are used for major diameter calibration.

(5) flatness/parallelism of measuring faces

(b) *Minor Diameter Clearance*

(1) factors in [para. 5.2.1](#)

(2) calibration uncertainty of prisms if used to contact the minor diameter

(3) uncertainty of optical comparator measurement system if used

5.3.2 Thread Ring Gages: Minor Diameter

(a) uncertainty of calibrated plain plug gages if used

(b) factors in [para. 5.3.1](#) if direct measurement is used

(c) roundness variations, if two- or three-point measuring device is used

5.3.3 Plain Ring Gages

(a) uncertainty of instrument calibration

(b) uncertainty of master(s) calibration

(c) contact tip geometry

(d) cosine errors from tip misalignment

(e) cosine errors due to out-of-square datum faces on ring

(f) centralizing errors

5.3.4 Plain Plug Gages

(a) errors in parallelism of contact faces

(b) errors introduced by comparator tables that are not flat

(c) uncertainty of instrument calibration

(d) uncertainty of master(s) calibration

NOTE: The factors shown for plain ring (see ASME B89.1.6) and plug gages (see ASME B89.1.5) apply when they are used for the calibration of gages referred to in this Standard only.

5.4 Uncertainty Factors for Angle Calibration

5.4.1 External Flank Angle. Uncertainty factors for the external flank angle include those in the optical comparator protractor screen calibration or the edge-detection and computing system, whichever is used.

NOTE: See the applicable ASME B1 Standard for recommended magnifications.

5.4.2 Internal Flank Angle. Uncertainty factors for calibration of the internal flank angle include the following:

(a) uncertainty in optical comparator protractor screen calibration or edge detection and computing system, if used

(b) distortion in casting medium

5.5 Uncertainty Factors for Linear Pitch Calibration

(a) temperature

(b) calibration uncertainty of instrument used

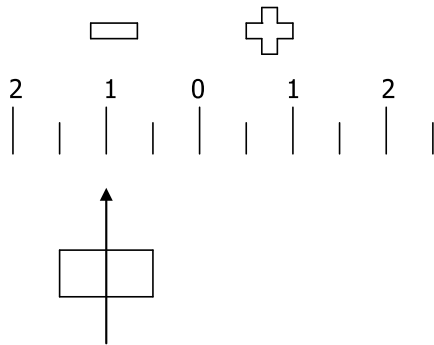
(c) uncertainty of setting master calibration (if used)

(d) factors unique to the type of instrument used, such as cosine error from misaligned centers

5.6 Uncertainty Factors for Functional Lead Calibration

The uncertainty factors noted in [para 5.5](#) are applicable to functional lead calibration.

Figure 6-1 One Measurement Showing Its Associated Range of Uncertainty



Functional lead calibration requires the use of a master mating part to evaluate the gage as defined in some standards. The following factors unique to that process shall be considered:

- (a) uncertainty in the calibration of the master mating thread
- (b) pitch and helical path variation of master mating thread
- (c) squareness of gage end face
- (d) effects of variations caused by inaccurate rotation of gage

6 MEASUREMENT UNCERTAINTY EXAMPLES

This section assumes that the uncertainty values have been developed in accordance with recognized standards and include all factors related to the equipment and processes involved.

Figure 6-1 shows an instrument reading of $+1$. The box shown on the pointer represents the uncertainty for that particular measurement of ± 0.5 units. In this case, the true

value for the measurement could be anywhere from -0.5 units to $+1.5$ units.

If this range is not close enough for a particular application, there are two ways of changing it. The first is to review the uncertainty budget to determine which factor is the greatest contributor to the uncertainty. A change in the process or equipment used for this factor could be all that is required to reduce the overall uncertainty to a more acceptable level. Conversely, while the largest factor cannot be conveniently changed, several smaller factors could be combined to achieve the goal.

Reviews of this type may indicate that the equipment, masters, or environment is inadequate for the given needs. Consequently, the calibration work may require different equipment or the use of a better-equipped outside laboratory.

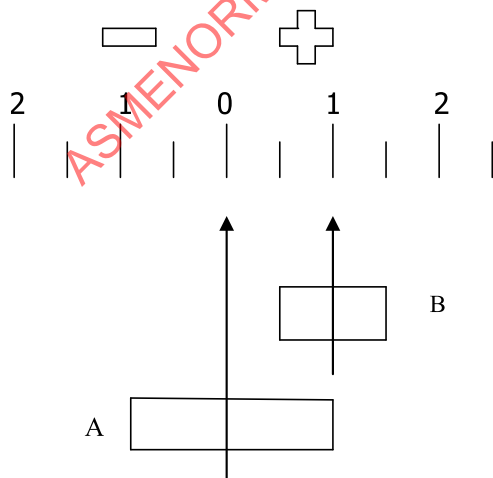
Figure 6-2 illustrates a common measurement situation where two laboratories are providing different readings. Laboratory B's reading of $+1$ has an uncertainty of ± 0.5 while laboratory A's reading of 0 has an uncertainty of ± 1 .

In this example, the uncertainty bands overlap from $+0.5$ to $+1$, within which the true value is likely to be. This could be confirmed by using a different method or having measurements taken by a third party.

Figure 6-3 shows a more desirable situation where the readings from two sources are the same; only their uncertainties are different. In this case, the assumption that the smaller uncertainty band is where the true value would be found for both laboratories is probably true.

Figure 6-4 shows a common situation where the readings are significantly different and the uncertainties are as well. It might be assumed that the laboratory with the lowest uncertainty has produced the most reliable reading, but that may not be the case as noted in section 7.

Figure 6-2 Two Measurements With Differing Uncertainties



7 DISPUTE RESOLUTION

Disputes will arise, and as in the preparation of an uncertainty budget, if matters are reviewed in an organized way, all parties should be able to reach a consensus as to what the true value is likely to be for the measurement. In many cases, the difference between readings is such that it is of little consequence and not worth pursuing.

7.1 Human Factors

Many disputes over measurements are due to lack of skill or knowledge on the part of one or more participants in the process. The most accurate devices available for a given measurement can be rendered ineffective by inspectors who lack the skills and experience required for such work.