Searching for Zero

A Guide for Gage and Instrument Calibration

2nd Edition

AMTMA®

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FOREWORD

The American Measuring Tool Manufacturers Association (AMTMA) was founded in 1973 to promote the interests of the manufacturers of the measuring tools, gages and instruments used for dimensional measurement. Today our membership also includes dimensional calibration laboratories, consultants and other organizations involved in this field.

We are mindful of our role as advisors to our customers on measurement techniques and technology and produce programs and materials to assist them in their work. This booklet is one example of an effort by the AMTMA to improve the level of competence in dimensional metrology. Each year we publish a directory of member companies and the products and services they provide that is a valuable reference for everyone in the dimensional metrology field.

Our members are active in helping to create published standards that all can work with to ensure consistency in the products offered for more efficient manufacturing and quality control. The organizations that issue such standards our members help produce include the American Society of Mechanical Engineers (ASME), American National Standards Institute (ANSI), the International Organization for Standardization (ISO), and the Canadian General Specifications Board (CGSB) among others.

Participation in these activities helps our membership keep up-to-date on the latest standards and aware of changes that are forthcoming. This up-to-date knowledge is one of the many benefits users of instruments and gages receive when dealing with an AMTMA manufacturer, calibration laboratory or consultant.

In addition, we conduct round-robin measurement programs so our members can compare their measurement capabilities with their peers to ensure the true "state of the art" becomes more widely known.

Our meetings provide a public forum for the open discussion of the technical problems within our industry and the field of dimensional metrology that we serve. If you would like to attend one of our semi-annual meetings, please write us for details.

AUTHORS

This publication was compiled and written under the auspices of the AMTMA by:

2nd Edition: Hilliard Cox
Terra Cotta, Ont. Canada
In cooperation with the AMTMA Technical Committee

1st Edition: Hilliard Cox
Dennis Cadieux
W. Springfield, MA

SCOPE

The member companies of the American Measuring Tool Manufacturers Association have produced this publication as a guide for our customers who, like us, are searching for certainty in a very uncertain world.

This document reflects the 'real world' of dimensional metrology in which we all work.

There is an element of uncertainty attached to every dimensional measurement made and we hope this guide to the most common sources that contribute to that uncertainty will help everyone improve their capability. The experience of our members is also offered with hints that are noted for each type of calibration we have outlined here. We are limited in that this publication is a guide to help you and can only deal with the more popular procedures employed at the commercial level as compared to those used in research laboratories in this field and national standards laboratories.

The information contained here was compiled through measurement surveys that included the National Institute of Standards and Technology (NIST). We are indebted to NIST and the people there who generously share their technical expertise. Many of our member companies also perform specialized round-robin studies to gain better insight into measurement problems. In addition, leading specialists in the field have contributed their knowledge and the results of their considerable experience to make this guide a practical working document.

'Searching For Zero' is not intended to be a training program, but we hope it will become a helpful reference on the realities of dimensional metrology whether you are calibrating our products or measuring your own. And if you are experiencing difficulty with a particular type of calibration process or dimensional measurement and would like some assistance, contact the AMTMA member who supplied this publication to you or call AMTMA Headquarters.

— *The American Measuring Tool Manufacturers Association*

TERMINOLOGY

The terms used in this publication are in general use in the field of dimensional metrology. Simplified definitions are given here for easy reference but ISO and ANSI standards are available that outline the full technical definitions of these and other terms.

ABBE ERROR
An error that occurs when the axis of a measuring device's scale, for example, is not on the axis of measurement. Vernier, dial or digital calipers are examples of this situation.

ACCREDITATON
A process used by a qualified independent agency to verify the quality system and technical capability of a calibration laboratory to a recognized standard such as ISO 17025. Agencies such as NVLAP or A2LA in the U.S.A. or S.C.C. in Canada are recognized internationally in this field due to the technical expertise they bring to the evaluation process and the fact they have passed accreditation of their operations in compliance with international standards.

ACCURACY
How close a measured value is to the true value of the dimension.

A2LA
American Association for Laboratory Accreditation. A non-profit accrediting agency specializing in the accreditation of calibration and testing laboratories.

BEST MEASUREMENT CAPABILITY
This term refers to the measurement uncertainty values shown on the Scope of Accreditation for a calibration laboratory. The values shown do not include elements of uncertainty contributed by the item being calibrated and may be the result of using equipment that is not used for everyday work. In some cases, they apply to work done in a laboratory in comparison to work done on-site where the equipment used or the working environment is different. Due to these conditions, different values will appear on calibration reports covering similar measurements.

BLUEING
A process where one wishes to determine the extent or percentage of contact between two precision surfaces, one of which is coated with toolmaker's blue. Some people use markers for the same purpose.

CALIBRATION
A system whereby the measuring instruments, gages and masters used in dimensional metrology are measured to ensure they retain the required operating characteristics within acceptable calibration limits.

CALIBRATION FREQUENCY
The time intervals at which instruments, gages and masters are calibrated. These intervals are determined by their user based on the conditions of their use to ensure their performance or size remain within acceptable limits.

CALIBRATION LIMITS
A tolerance applied to gages and instruments beyond which they are not considered suitable for use. Users are cautioned that such limits should be determined with respect to the tolerances of the work they are being used for as opposed to 'new' standards. To do otherwise means many suitable devices would be unnecessarily discarded. An effective calibration program will ensure these items will be withdrawn from service before they have a detrimental effect on everyday measurements.

CHECK STANDARDS
When measured over a period of time, readings from these 'artifacts' can indicate if your process is shifting to an out-of-control situation and provide data for long term reproducibility.

COEFFICIENT OF THERMAL EXPANSION
This term relates to the fact that different materials grow or shrink at different rates due to changes in their temperature. In dimensional calibration most masters are steel gage blocks and the gages being calibrated are also steel so that variation from the standard temperature is not a problem. However, there are variations within any batch of steel, let alone different types of steel that can have a significant effect on critical calibration such as gage blocks.

COMPARING
A process where the unknown is compared to the known. Typically, a gage or component being compared to a build-up of gage blocks. Irrespective of the resolution of the instrument used for such an application, accuracy of the result can never be better than that of the master(s) used.

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CO-SINE ERROR
This error is encountered when the axis of measurement is not aligned with the axis of the characteristic being measured. This is frequently encountered with dial test indicators when their contact point axis is at an extreme angle to the measurement axis.

FUNCTIONAL SIZE
The actual size of a gage taking all its characteristics into account such as roundness, taper, finish, etc. compared to an single measurement for diameter only. In the case of thread gages, these characteristics plus angle, linear pitch variations would have to be accounted for.

GEOMETRICAL IRREGULARITIES
Variations in shape or form of the item being calibrated or the surfaces of the measuring device.

INDIRECT/ FUNCTIONAL CALIBRATION
A method of calibrating the overall performance of an instrument as opposed to verifying each of the characteristics required to achieve that performance. This is determined by 'measuring' a series of masters of suitable accuracy. Ideally, the master's features will be the same shape as the articles the device is normally used to measure. This will ensure that the effects of variations in such things as anvil parallelism will be incorporated in the readings taken.

ISO 17025
An international standard that outlines both the quality system and technical competence requirements for calibration and testing laboratories.

LINEARITY
A characteristic of a measuring device. An instrument is said to be 'linear' if, for every unit of input, the output is the same throughout the scale. As an example, for every .0001" or .002mm an indicator spindle is moved, the dial or display would show the same values.

MASTERS
In dimensional work, this term refers to physical representations of length to which a component or gage is compared. The most used masters for everyday calibration work are precision gage blocks.

METROLOGY
The science of measurement. This publication deals with Dimensional Metrology and related matters compared to other branches in the field such as mass, light, time, temperature etc.

N.I.S.T
National Institute of Standards and Technology. Formerly known as the National Bureau of Standards, this agency is the legal authority for measurement in the United States.

NORMALIZING PLATE
This simple device can help you achieve commonality of temperature between masters and gages being calibrated. It is a steel or aluminum plate with a ground surface the size of which will vary with your needs. It is left in the laboratory and items being calibrated and the masters being used are left on it for a period of time before calibration to ensure all are the same temperature.

N.P.L.
National Physical Laboratory, England's national metrology authority.

N.R.C.C.
National Research Council of Canada. Canada's national metrology authority.

N.V.L.A.P
National Voluntary Laboratory Accreditation Program. Operated by N.I.S.T. for the accreditation of calibration laboratories

OPTICAL FLATS
Blocks or discs of quartz that have been lapped to produce one or two extremely flat surfaces to which others may be compared. When in contact with a work piece, 'fringes' or bands of shadows which will vary in shape are produced by optical interference and give an indication of the flatness of the work and the surface topography. A monochromatic light is used to produce fringes of a known value.

PROFICIENCY TESTING
A process where artifacts are sent to various laboratories for measurement and the results compared to ensure each is maintaining the measurement uncertainties they have been recognized for. This is an ongoing requirement of ISO 17025 and is also referred to as 'round-robin testing'.

REPEATABILITY
A measuring instrument's inherent ability to repeat its readings over a short period of time assuming all factors that could affect those readings do not change. It is not an indication of accuracy although accuracy is directly affected by repeatability.

RESOLUTION
Represents the smallest reading unit provided by an instrument.

S.C.C.
Standards Council of Canada. Provides a laboratory accreditation program among others.

SCALE ERROR
Basic error in a measuring device over a range. It may be increased by other elements of the device in various measurement situations.

SCOPE OF ACCREDITATION
A list of the measurements a laboratory has been accredited to perform and the measurement uncertainties they have demonstrated they are capable of achieving. It's a way for the user of independent laboratories to select one with the proven capabilities they require. Readers of laboratory scopes should bear in mind that while the laboratory may be accredited to calibrate an item within its' permanent facility, it may not be accredited to do the same work on site.

SINE BAR/PLATE
A device used to assist in the measurement of angles where a nominal or master angle is created for the work to be measured placing the opposite side of the work parallel to the surface plate on which the device is used. The work is measured with variations of the readings representing deviations of the angle in linear measurement terms.

STANDOFF
Most commonly encountered when comparing tapered mating parts such as a plug and it's mating ring. Where two perfect mating parts are assembled, their end faces will be aligned. Variations between them with respect to size or taper will cause one component's surface to be offset from the other, the linear amount of which is referred to as the 'standoff'.

TEMPERATURE GRADIENT
While not usually noticeable, the temperature at various levels from the floor to the ceiling of a room will vary. Thus it is important to ensure that devices monitoring temperature within a laboratory get their input(s) from the right location.

TRACEABILITY
The path by which a measurement can be traced back to the source from which it is derived. In dimensional metrology, this is typically the national standards authority of a country such as NIST in the United States or NRCC in Canada. Direct traceability implies that the laboratory in question has its primary masters calibrated directly by such agencies for reduced measurement uncertainty.

Common Sources of Error

TEMPERATURE:

By international agreement, all measurements in dimensional metrology are made at 68° Fahrenheit or 20° Celcius. Measurements can be made at other temperatures provided they are stable and the results are corrected accordingly. Temperatures of the work piece, instrument and master must accounted for.

— Allow adequate in-lab time for all equipment to reach a common temperature.

— Avoid handling items with bare hands during the measurement process to avoid heat transfer.

— Heat radiated from the technician's body can have a noticeable effect as can temperature fluctuations from localized sources such as lighting, fans from computers etc.

— Temperature variations within the laboratory that remain undetected because the temperature sensors or thermometers are located at levels other than where the specific measurement is being taken.

— Wringing gage blocks and making mechanical adjustments to equipment generate heat that must be allowed to dissipate before taking the reading.

CLEANLINESS:

Dust particles and lint etc., are measurable by many high magnification instruments. Keep everything clean by using lint-free wipers. Oils from uncovered hands can be highly acidic and destroy precision surfaces.

HUMIDITY:

While humidity usually does not have a direct effect on most dimensional calibration work, high levels of humidity can cause rusting to occur on precision surfaces. Humidity in the 15% or below range can affect the performance of some delicate instruments or attract dust like a magnet.

VIBRATIONS:

Vibrations can cause equipment to vibrate in sympathy and result in erroneous readings that are not visually detectable or cause mechanical shifting of settings that will affect repeatability. Rubber mounting pads for the equipment will eliminate this problem in most cases.

THE INDIVIDUAL:

Measurements to a high order of precision require more than just the ability to read a display. The human side of the process often introduces errors in the following ways:

— Poor choice of masters or gage block buildups that are poorly wrung together

— Observational errors where instruments are misread

— Manipulative bias where equipment is adjusted to force the reading being sought

— Computational errors

THE EQUIPMENT:

Measuring equipment having verified performance characteristics is essential. A high-resolution display is not necessarily an indicator of how accurate the device may be. Similarly, auxiliary devices required for the measurement must have verified values. Included in this category are masters, gage blocks, anvils, surface plates or thread measuring wires and accessory items used with universal measuring devices.

HINTS FOR BETTER MEASUREMENTS

1. Temperature normalizing plates should be used whenever possible to maintain common thermal stability of the items being measured with the masters being used.

2. Ensure the 'right' master is being used to set equipment and if this is not possible, apply corrections to the readings obtained to allow for this. The 'right' master is one that is the same shape, nominal size and material of the item being measured.

3. Always refer to an original version of any given standard that is applicable to the item you must calibrate as it may contain specific conditions and/or techniques that are required to ensure agreement on measured values. Most quality standards have a requirement that you not only have the latest standards but a system in place to ensure they are the latest issue.

4. Know that gage block build-ups may not be parallel due to variations in flatness and parallelism of the individual pieces used. Due to this situation, the overall size of the build-up may be different than the mathematical sum of the calibrated sizes of the blocks in it.

5. Comparative devices should have their setting checked against the master after a reading is taken.

6. Long range comparative devices that check several sizes from a single setting must be mounted carefully on their stands. This is to ensure that spindle travel is normal to the anvil or worktable to avoid cosine errors.

7. The way a device contacts an item being measured can lead to wide variations in readings as can variations in measuring force. Errors in flatness and/or parallelism in flat contacts can also make a significant difference. Make sure your equipment re-calibration procedure takes them into account.

8. Do not accept computer programs as complying with standards you may need to work to. Always refer to the original standard. Your calibration system should include verification of any computer programs you are using that will effect accept/reject decisions or measurement results.

9. Use a 'check standard' system to ensure your process is stable and operating within acceptable limits.

10. When doing hardness tests on items such as adjustable thread ring gauges, be careful not to take the tests in areas around the terminal holes which are drawn back after hardening.

11. Always create an uncertainty budget for each measurement procedure you employ to ensure you keep priorities right and take all factors into account. Similarly, ensure all staff realize that if they depart from the methods and equipment listed in that budget, it must be adjusted to reflect such changes.

12. When doing calculations be aware of what system should be used for rounding the numbers.

MEASUREMENT UNCERTAINTY

INTRODUCTION:

Measurement is a process where we use an instrument to determine the 'size' of the item being measured. In practical terms, the instrument produces a 'reading' that may or may not reflect the true value or size of the item. The difference between the two is due to the fact that the 'reading' includes the effects of errors in masters etc. while the 'true' value accounts for all elements that effect the measurement.

Experienced users of measuring equipment have always recognized this situation and would offer guesstimates as to how "close" their readings were to the true size. Unfortunately, the guesstimates would vary with the experience and integrity of the person giving them which means they were not always very reliable. Metrologists involved in critical areas of measurement have always computed measurement uncertainty as part of their everyday work, but it is only in recent years that the concept and what it means has become part of everyday life for those working at lower echelons of metrology.

WHAT IT MEANS:

Measurement uncertainty represents a range - plus or minus – of a reading where the true value is likely to be. It does not mean the reading is in error by that amount although that possibility exists. All measurements have an element of uncertainty attached to them, including those made by national standards laboratories such as NIST, NPL or NRCC.

You can see from the forgoing that a measurement without an uncertainty statement attached to it is simply a 'reading'. The uncertainty statement provides value or inherent worth to the reading since the lower the uncertainty, the closer the reading is likely to be to the true value or size.

Realistic uncertainty values for a measurement have many benefits that can explain problems we encounter every day. For example, when a shaft is measured and found to be "on size" but won't assemble with a component having similar appearing attributes, knowing the uncertainty attached to the two measurements involved can lead to a solution of the problem.

Another benefit of measurement uncertainty information related to a given measurement process can lead to changes that will improve the process while avoiding changes that will have little effect but may be quite expensive to implement.

Knowledge of the uncertainty adds meaning and credibility to the measurements you are producing.

The key to achieving this credibility is to determine measurement uncertainty following internationally recognized procedures as outlined in standards noted elsewhere in this publication. The tool that is used to do this is the 'Uncertainty Budget'.

THE UNCERTAINTY BUDGET:

Like a budget you may prepare for your living expenses, the uncertainty budget is a way of estimating an outcome by taking all of the factors that will effect it into account. The mathematics involved in the process are relatively simple for most dimensional metrology work. The critical requirement is a knowledge of metrology - the mathematics can be handled by a simple pocket calculator.

We recommend the use of a form in preparing a budget so each element is methodically processed to arrive at a final value. It also enables you to review those elements to see where improvements can be made and evaluate the effects of any changes you make to the measurement process. It also assists an auditor or assessor in reviewing your work as it will show every element you have considered.

The budget requires you to take each of the elements and process them to arrive at a common dimensional effect in the form of a standard deviation. It you run a statistical study for repeatability for about thirty readings, you obtain the standard deviation for that element. In the case of temperature, you have to take the variations in degrees and convert them to linear terms and then determine the distribution. In most cases it is likely that the effect of a source of uncertainty could be plus or minus by the same amount meaning a rectangular distribution. This gives you a factor to apply to the basic linear value as shown in the standards. There may be situations where a common element has a different distribution due to specific conditions that produce it.

In some cases, the effects of an element may not be precisely known and an estimate on your part is required for a value that is then processed in a similar manner to the others in the budget. If you do not have the experience to render a reliable estimate, you have two choices – change the process or do some tests to determine a value. The best budget has proven values instead of estimates but not everyone has the time or capability to do this. Fortunately, in our field, many standards contain the information you need, such as contact tip deformation tables that are the result of research done by others.

On the following pages we outline the elements to be considered in an uncertainty budget for the work being done using the outlined process. In some cases the effect of a listed element may be small in relation to the others but we recommend you include all elements in order to provide consistency in your work so that you don't forget one in situations where it could be a dominant factor. You should be aware that a measurement uncertainty budget applies to a specific situation so it is not uncommon for two laboratories having identical equipment and masters to have different values. This also means that there is no 'generic' uncertainty applicable to a process although there is a range of values that the uncertainty of competent laboratories will tend to fall within.

APPLYING MEASUREMENT UNCERTAINTY:

In an ideal world, the uncertainty attached to a given measurement would represent about ten percent of the tolerance on the item being measured. In our world, this cannot always be achieved for various reasons and thus uncertainties that are within twenty five percent of the tolerance are considered a worst case acceptable ratio for most work. If this ratio – or better – cannot be maintained, there should be agreement between the laboratory and its customer.

Studies conducted by this Association make it clear that the published tolerances for some gages cannot be verified within the acceptable ratios noted above. This is due to standards being prepared before actual uncertainties in this field were applied at a commercial level. Typical of this situation are plain plug gages finer than 'XX' tolerance, plain ring gages better than 'X' tolerance and thread gages to 'W' tolerance for pitch diameter.

It is common practice in North America to accept a gage as being in limits if the reading for diameter is at or within the prescribed limits. If this is not satisfactory for your application, you should discuss the matter with the supplier of your gages or any laboratory you are using to calibrate them. In Europe and elsewhere, the reported size plus the uncertainty must be within the prescribed limits for the gage. This fact must be taken into account when calibrating gages made to foreign standards.

GAGE BLOCK CALIBRATION

PROCEDURE:

The lowest uncertainty in gage block calibration is obtained by using interferometry but this process is time consuming. Most commercial laboratories use a one-to-one comparative process where a block is compared to a master block of the same nominal size and material. The length of a block is determined by taking several readings over its' area in accordance with the standards. This will give an indication of parallelism while flatness is usually checked on request. Since the length of a block is the feature most often calibrated, the notes that follow are directed to that part of the process.

EQUIPMENT:

— High magnification comparators with .000 001" or .000 02mm resolution or better, provide the basic length measurements.

— Calibrated master gage blocks preferably of the same material as those being calibrated.

— An optical flat and a monochromatic light are usually used for flatness inspection.

— Normalizing plate to help keep both blocks and masters at a common temperature.

— Surface finish analyzer for surface texture.

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Uncertainty of the master block calibration

— Scale error of the comparator being employed

— Repeatability or resolution of the comparator

— Thermometer calibration uncertainty

— Temperature differences between the masters, the blocks and the reference temperature

— Differences in the co-efficient of thermal (CTE) expansion between the masters and blocks. While both may be made of steel, their CTE will vary

— Differences in temperature over the length of long blocks

— Cosine errors for comparators having long range measuring heads or situations where blocks may not be positioned properly

— Sag or deflection when long blocks are being horizontally positioned for calibration or are vertically positioned and are compressed by their own weight

— Surface finish of the gage block faces

— Contact deformation corrections when the material of the masters is different from the blocks being calibrated

HINTS FOR REDUCING UNCERTAINTY:

1. Blocks must be thoroughly demagnetized, cleaned and de-burred prior to calibration.
2. Allow adequate normalizing time, from 1/4 - 6 hours depending on block lengths.
3. Handle all blocks with tongs to prevent heat transfer from the hands.
4. Shield equipment to reduce the effects of radiated body heat on the equipment.
5. Allow time for the comparator to cool down after making mechanical adjustments.
6. Wear lint-free clothing to keep the work area clean.
7. Wear gloves for cleanliness reasons and to reduce heat transfer.
8. Check the comparator setting after each block is calibrated to ensure it did not change.
9. Use check standards to cover the range of blocks being calibrated.

Thread Measuring Wire Calibration

PROCEDURE:

Thread wire calibration involves measurements of the wire diameter over a central portion of the wire that is about 1" or 25mm long. One method employs master wires to which working wires are compared and since the masters have been calibrated using the appropriate forces and anvil configurations, the process is a simple comparative technique. The direct method usually employs a bench micrometer type of instrument able to provide the measuring forces specified in the standard and a supplementary round anvil or roll over which the wires are measured.

Roundness requirements can be met noting diameter variations of the wire as it is rotated in a 60°vee under the appropriate load. A roundness analyzer can be employed for coarse pitch (larger) wires.

EQUIPMENT:

— High magnification comparator or bench micrometer with .000 001" or .000 02mm resolution and a system to apply appropriate measuring forces for the direct measurement method

— Calibrated master wires for the comparative method

— Normalizing plate

— Vee block with a 60° included angle

— A plain cylindrical anvil for diameter calibration per the standard

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Scale error of the measuring device

— Repeatability or resolution of the measuring device – whichever is worst

— Uncertainty of master wires being used

— Thermometer errors

— Temperature differences between masters and wires

— Differences in coefficient of thermal expansion between masters and wires

— Measuring face or anvil flatness and/or parallelism

— Measuring force variation

— Variation in the vee block's included angle

— Roundness errors in the wires

HINTS FOR REDUCING UNCERTAINTY:

1. Check the published standard for thread wires to ensure you are using the correct measuring forces where applicable and anvil configurations.
2. Keep wires and masters on a common normalizing plate before and during calibration.
3. Manipulate wires using soft-tipped tweezers or tongs.
4. Ensure wires are not restrained in any way. They should be held in place by the measuring faces.
5. The three wires comprising a set for a particular pitch of thread should be calibrated at the same time.
6. Variations in straightness on fine wires can introduce errors. Check them against an optical flat or straightedge of known accuracy and an optical comparator.

NOTES:

— The above procedures and requirements apply to thread measuring wires made to North American standards only. European thread wire specifications are different and require different practices.

— Each set of wires should have their 'constant' calculated based on their newly calibrated size.

Plain Gage Calibration

PROCEDURE:

A variety of methods can be used to calibrate plain plug gages, the more popular being by comparison to masters, usually a buildup of gage blocks. Here, we focus on the gage diameter while roundness and surface texture are requirements that can be checked with the appropriate analyzers.

EQUIPMENT:

— High magnification comparator whose calibration is suitable for the gage tolerances involved

— Contact points with hard materials such as diamond, carbide or ruby

— Gage blocks with an accuracy appropriate for the gage tolerances involved.

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Scale error of the comparator

— Instrument repeatability or resolution, whichever is the larger value

— Uncertainty of the gage block calibration

— Measuring face flatness/parallelism if applicable

— Anvil flatness when vertical comparators are used

— Cosign error introduced by gage misalignment

— Deformation of contacts and/or the gage being measured

— Inappropriate measuring forces (Check the standard)

— Wringing intervals, flatness and/or parallelism conditions of the gage block buildup

— Thermometer calibration uncertainty

— Variations in coefficient of thermal expansion between blocks and gage

— Temperature of blocks, gage and instrument

— Cosine error introduced when long range comparator heads are not aligned properly

— Geometrical irregularities of the gage being calibrated

HINTS FOR REDUCING UNCERTAINTY:

1. Allow adequate soak time for gages to reach lab temperature.
2. Allow adequate time for the master block buildup to recover from temperature changes brought on by wringing the blocks.
3. Keep gage block buildups on the same normalizing plate as the gage to be calibrated.
4. Ensure the gage block buildup's actual size is correctly calculated.
5. Avoid excessive handling of blocks and the gage. Use tweezers or tongs when practical or wear gloves to reduce heat transfer.
6. Ensure the normalizing plate is clear of sources of heat variation – including the inspector.
7. Follow standard procedures for comparative measurement:

   A – Set the instrument with the gage block build-up.

   B – Take the readings on the gage.

   C – Check the instrument setting with the gage block build-up.
8. Ensure the measuring force being used is appropriate for the gage size being measured.

Plain Ring Gage Calibration

PROCEDURE:

Most plain ring gages are calibrated by one-to-one comparison using a gage block buildup representing the nominal size of the ring and is the method most of the following information refers to. However, there are other specialized instruments for such work and elements peculiar to them are noted as well. Roundness and surface finish requirements are accommodated using the appropriate analyzers.

EQUIPMENT:

— High magnification internal comparator with .000 01" resolution or better

— Gage blocks for masters with accessory jaws to create master 'inside' dimensions

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Temperature of the masters and ring to be calibrated

— Differences in the coefficient of thermal expansion between master and ring

— Uncertainty of the gage block buildup

— Uncertainty of setting rings used on some direct measuring instruments

— Scale error of the comparator

— The higher of instrument resolution or repeatability

— Misalignment of the measuring contacts

— Flats on the measuring contacts

— Deformation of the ring and the measuring contacts

— Cosine error due to out-of-square datum faces on the ring

— Cosine error due to inaccurate centralizing of the ring

— Geometrical irregularities in the ring

— Abbe offset error in some equipment

HINTS FOR REDUCED UNCERTAINTY:

1. When gage blocks with accessory jaws are used as masters, ensure all pieces are wrung together rather than using unreliable clamps/bolts. Alternatively, use a torque controlled screw driver.
2. The highest precision achieved using gage blocks as a master will be obtained if the complete buildup is calibrated, as this incorporates any wringing intervals and the effects of flatness and parallelism errors.
3. Use accessory jaws with surfaces that extend beyond the ends of the gage blocks they are wrung to so that parallelism of the buildup can be determined.
4. Always keep rings and masters on a common normalizing plate to reduce temperature differences.
5. Use the appropriate size measuring tips so that the percentage of the ring surface in contact with them is kept to a minimum.
6. Allow adequate time for gage block buildups to cool down after wringing.
7. The faces of ring gages may not be square to their bore. Allow the ring to float or align it to eliminate cosine errors.
8. Take three readings along the bore, rotate and repeat at ninety degrees.
9. Setting rings should be calibrated across the marked axis only.
10. Always recheck the setting of the instrument after the readings are taken.

Plain Tapered Plug Gage Calibration

PROCEDURE:

Most gages of this type are measured using comparators of various kinds. Depending on the requirements, a sine plate or centers can be used to establish a reference taper the gage can be compared to. Two diameter measurements over a specified length may be used as a more accurate method. Budget information deals with diameter and length measurements only.

EQUIPMENT:

— High magnification comparator and/or height gage with resolution in the order of .000 010" or .000 2mm or better for diameter measurements

— Calibrated gage blocks wrung together to provide master dimensions

— Sine bars/centers and a surface plate in a known state of calibration if used for taper measurements

— Calibrated pins, rolls or wires as intermediate contacts for diameter measurements

— Analyzers for roundness and surface texture measurements

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Uncertainty of the gage block calibrated values, wringing intervals, parallelism

— Differences in the height of the two gage block buildups

— Scale error of the comparator and/or height gage

— Repeatability of comparator and/or height gage

— Resolution of the instrument(s) measuring diameters or heights

— Measuring face parallelism

— Errors arising from the use of sine bars or centers and surface plate when measuring taper

— Uncertainty of two diameter measurements if used for taper measurement

— Uncertainty in the calibrated values for any rolls or pins used

— Differences in the diameters of the two rolls if used

— Temperatures of the gage, gage blocks and rolls

— Cosine errors produced by end faces of the gage not being square to its centerline

HINTS FOR REDUCING UNCERTAINTY:

1. Keep all items on a normalizing plate to reduce temperature variations.
2. Ensure the gage is securely held in position and does not shift during diameter measurement. A weight placed on top of vertically oriented gages will ensure this does not occur if the gage is not mounted on centers.
3. Use the actual calibrated diameters of rolls or wires in your calculations.

Plain Tapered Ring Gage Calibration

PROCEDURE:

The inside diameter of these rings is measured in the same manner as parallel plain rings except that two readings at a controlled length along the bore may be used to determine the taper. Alternatively, the taper may be determined using a sine bar or plate. Diameter at the small end of the gage may be measured directly and gaging lengths determined by calculations based on the known taper.

An alternative method of calibration is by using a master plug gage and blueing but this method has high measurement uncertainty and is not covered in the following notes.

EQUIPMENT:

- — High magnification internal comparator with resolution in the order of .000 010" or .000 2mm or better for diameter measurements
- — Calibrated gage blocks wrung together to provide master dimensions
- — Sine bars/centers and a surface plate in a known state of calibration if used for taper measurements
- — Analyzers for roundness and surface texture measurements

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

- — Uncertainty of the gage block calibrated values, wringing intervals, parallelism of the accessory jaws
- — Errors in the length between two diameter measurements taken to determine taper
- — Scale error of the internal comparator
- — Repeatability of the comparator
- — The higher of resolution or repeatability of the instruments used
- — Measuring contact parallelism when measuring the small inside diameter
- — Errors arising from the use of sine bars or centers and surface plate when measuring taper
- — Uncertainty of two diameter measurements if used for taper measurement
- — Contact height differences if ball contacts are used for two inside diameter measurements
- — Temperatures of gage, and blocks
- — Cosine errors produced by faces of the gage not being square to its centerline
- — Flats on ball contacts

HINTS FOR REDUCING UNCERTAINTY:

1. Keep all items on a normalizing plate or the comparator work table to reduce temperature variations.
2. Ensure the ring is securely clamped in place and does not shift during diameter measurement.

NOTE:

The most frequent sources of errors in the calibration of all tapered gages are due to conflicting drawing dimensions and tolerances. These elements should be verified before commencing calibration.

THREAD PLUG GAGE CALIBRATION

PROCEDURE:

Simple pitch diameter is determined by a measurement taken over thread measuring wires while the major diameter can be measured directly. Thread prisms can be used to enable a minor diameter reading to be taken or an optical comparator or toolmaker's microscope can also be used. Linear pitch of the thread, often called 'lead' requires specialized equipment. For functional pitch diameter – required for setting plug gages – measured values for linear pitch and angles would be required. Our focus in the following notes is on simple pitch diameter measured in accordance with North American standards.

EQUIPMENT:

— Bench micrometer having .000 01"/.000 2mm resolution or better with adjustable measuring force

— Calibrated gage blocks

— Calibrated thread measuring wires for the pitch of thread being measured

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Scale error of the bench micrometer

— The higher of repeatability or resolution of the bench micrometer

— Variation in the measuring forces required in the standard

— Measuring face flatness/parallelism

— Uncertainty of gage block calibration, wringing intervals

— Uncertainty of thread wire calibration

— Roundness variation of thread wires

— Size differences of thread wires

— Temperatures of blocks, wires, instrument and gage

— Co-sine errors when gage is resting on a worktable

HINTS FOR REDUCING UNCERTAINTY:

1. Keep blocks, wires and gage to be measured on a normalizing plate to maintain common temperatures.
2. Avoid handling wires to reduce heat transfer or allow them to normalize after handling.
3. Use the central 1"/25mm of the wires only for the measurement.
4. Ensure adequate time for gage block build-ups to normalize after wringing.
5. Helix angle corrections of .000 15" /.003mm or less are disregarded when calculating the measurement over wire dimensions for gages to North American standards.
6. Thread wires must be free to locate on the pitch line.
7. When measuring some Acme threads, flats may have to be ground on the wires to prevent them from bottoming on the minor diameter and causing apparent oversize readings.
8. Flank angle measurements may require corrections if they were measured optically.

NOTE:

This process may not be suitable for gages made to European or Asian standards.

Thread Ring Gage Calibration

PROCEDURE:

Thread ring gages commonly used for parallel thread inspection to North American standards are the adjustable type. Their calibration is achieved by adjusting them for size on a setting plug gage designed for that specific purpose. Direct measurement of such gages is not a practical consideration unless variations in linear pitch are determined and the computed size incorporates them plus mismatched ring segments and out of roundness characteristics due to the adjustments being made without re-lapping the gage.

The 'functional' calibration obtained by adjustment on a setting plug gage incorporates all of these elements as does checking of the minor diameter of the ring using plain plug gages. Flank angles are inspected by taking a cast of the form and checking it on an optical comparator or toolmakers microscope.

EQUIPMENT:

— Calibrated setting plug gauges specifically made for adjustable thread ring gages.

— Calibrated plain plug gages to check the minor diameter

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Uncertainty in the setting plug calibration

— Roundness errors in the setting plug

— Variations in 'feel' when adjusting the gage

— Roundness errors in the ring

— Linear pitch errors in the ring and the setting plug

HINTS FOR REDUCING UNCERTAINTY:

1. Careful visual inspection of the gage is required to ensure it is not burred or loaded with materials from the products it has been gaging, dirt or burrs.
2. The setting plug must be carefully checked to ensure it is clean and does not contain burrs.
3. Optimum uncertainty can only be achieved if the setting plug the ring was made to is used to set it.
4. Gently tap the ring near the alignment bushing after adjustment and recheck the setting.
5. The ring should exhibit a similar amount of drag when screwed from one section of the setting plug to the other. If it doesn't, there may be interference at the crest or root of the thread.

NOTES:

— Since each ring is made to fit a specific setting plug, it may need adjustment in order to fit a different setting plug. This is due to the fact that perfectly made plugs could be at opposite acceptable limits for size and be .000 3"/.006mm apart.

— This process is not suitable for solid thread ring gages made to European or Asian standards.

TAPERED THREAD PLUG GAGE CALIBRATION

PROCEDURE:

There are two popular methods for calibration of this type of gage. The taper block method uses three thread measuring wires to measure the gage which is mounted on a block the angle of which enables the gage to be measured as though it were a parallel thread. The other is the two-wire method that requires the location of a line of measurement on the gage. This method is slower but usually more accurate.

The two key features for calibration are the pitch diameter at a specified length called L-1 and the taper of the gage. Thread form and major diameter are also verified. Since the L-1 position on the gage is a flat ground through the thread, it cannot be directly measured. Our notes refer to the measurement of pitch diameter and taper only.

EQUIPMENT:

— Bench micrometer having .000 01"/.000 2mm resolution or better and adjustable measuring force

— Calibrated gage blocks

— Calibrated thread measuring wires for the pitch of thread being measured

— Calibrated sine block or measurement line location fixture

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Scale error of the bench micrometer

— Resolution/Repeatability of the bench micrometer

— Measuring force variation

— Measuring face flatness/parallelism

— Uncertainty of gage block calibration, wringing intervals

— Uncertainty of thread wire calibration

— Roundness variation of thread wires

— Size differences of thread wires

— Temperatures of blocks, wires, instrument and gage

— Cosine errors when gage is resting on a worktable or taper block

— Uncertainty of sine block calibration or measurement line fixture, whichever is used

HINTS FOR REDUCING UNCERTAINTY:

1. Keep blocks, wires and gage to be measured on a normalizing plate to keep temperatures constant.
2. Avoid handling wires to reduce heat transfer or allow them to normalize after handling.
3. Use the central 1"/25mm of the wires only for the measurement.
4. Ensure adequate time for gage block build-ups to normalize after wringing.
5. Helix angle corrections of .00015" /.003mm or less are disregarded when calculating the measurement over wire dimensions.
6. Thread wires must be free to locate on the pitch line.
7. Flank angle measurements may require corrections if they were measured optically.
8. The PD at L-1 must include the variation in taper if it is determined from a PD reading at the small end of the gage using the taper block method.
9. Linear pitch measurements and PD corrections will be required if the gage is being used as a master for ring gages.

Tapered Thread Ring Gage Calibration

PROCEDURE:

Thread ring gages used for tapered threads are usually the solid type since the errors introduced by an adjustable ring are compounded due to the thread taper. Calibration of this type of gage is usually done by a functional verification using a master thread plug gage. It can also be done by direct measurement but measurements for pitch must be taken into account in addition to other geometrical features. The following notes refer to the functional verification method due to its popularity.

EQUIPMENT:

— Calibrated master plug gage

— Calibrated master plug for the small end and one for the large end to verify taper

— Calibrated plain tapered plug gage for checking minor diameter

— Depth micrometer

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Uncertainty of the master plug calibration

— Linear pitch error of master plug if this has not been included in its calibrated value

— Linear pitch error of the ring

— Uncertainty in the calibration of the plain tapered plug

— Depth micrometer error in measuring standoff between plug and ring

— Variations in taper

HINTS FOR REDUCING UNCERTAINTY:

1. Careful visual inspection is required to ensure the surfaces of both master plug and the ring are clean and free of burrs or foreign material.
2. A gentle rap on the ring when screwed finger tight on the master will ensure it is seated properly.
3. The master plug calibration should show the total standoff error which includes corrections for pitch diameter, linear pitch and half angle.
4. Thickness and steps on the ring should be measured in several places.

Surface Plate Calibration

PROCEDURE:

The primary feature calibrated for surface plates is flatness and various types of equipment can be used. While small plates may be checked using a straight-edge and a gap reading gage, our notes refer to the use of the two most popular instruments required for larger plates.

The principal instruments take readings over the plate in what is referred to as the Union Jack pattern, which, on large plates, leave large wedge-shaped areas of the surface unverified. To ensure these areas are satisfactory, a repeat reading gage can be tracked over the surface quickly to determine if they have significant departures from flatness compared to the measured lines that bound them. The following notes refer to flatness calibration only.

Customers wishing more detailed analysis of the surface can ask for a grid pattern of inspection.

EQUIPMENT:

— Autocollimator, or laser system with mirrors or

— Electronic level system comprising one or two measuring heads

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Temperature differentials between top and underside surfaces of the plate

— Vibration

— Inappropriately located mounting pads for mirrors or heads

— Accuracy of instruments

— Accuracy of mirrors when used

— Environmental conditions affecting lasers

— Closure error

— Repeatability of each line of measurement

HINTS FOR REDUCING UNCERTAINTY:

1. Readings are taken 1" or 25mm or more inside the edges of the plate.
2. Surfaces must be carefully cleaned.
3. Target mirror positions must be consistent to ensure repeatability. Use a straightedge to do so.
4. Plates should be calibrated on their permanent stands.
5. Only equipment needed for the calibration should be on the plate during calibration.
6. Target mirrors should be on base plates whose dimensions comply with the specifications.
7. Plates should be on their permanent stands for one or more days before calibration.

Outside Micrometer Calibration

PROCEDURE:

Since we do not know all of the various measurements this versatile instrument will be used for, we must calibrate it on the basis that it could be used for measuring round or flat work or a combination of the two. The following information is based on a 1"/25mm capacity instrument.

The calibration process involves comparison of micrometer readings to the calibrated values of the masters.

EQUIPMENT:

— Gage blocks or specially made masters with several diameters over the 1"/25mm range

— Optical flats or parallels to check anvil conditions or precision balls

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Uncertainty in gage block or master calibration

— Flatness of optical flats

— Resolution or repeatability – whichever is greater

— Accuracy of the optical flat

— Temperature of the instrument and masters

— Cosine errors

— Variation in measuring force provided by the ratchet or friction stop

— Zero setting errors

— Ball roundness if used to check measuring face parallelism

HINTS FOR REDUCING UNCERTAINTY:

1. Ensure the force required to move the micrometer head through its range is uniform.
2. When instruments larger than 1'/25mm capacity are being calibrated, the uncertainty associated with the zero setting master must be included in the uncertainty budget.
3. Clamp the instrument in a micrometer stand or padded vise with the spindle axis in a vertical position during calibration.
4. Avoid excessive handling of the masters during calibration.
5. Do not spin the spindle onto the master.
6. Use the same number of 'clicks' on a ratchet stop for zero setting and calibration.
7. Take two or more readings when setting zero and on each master dimension.
8. Confirm the zero setting.

UNIVERSAL CALIPER CALIBRATION

PROCEDURE:

These notes cover most vernier, dial and digital calipers that have a combination of internal and external measuring jaws and a depth measuring rod. Calibration of these instruments involves comparison of the instrument's readings of various masters for these features over a measuring range of 6" or 150mm in our example.

While gage blocks are often used for calibration, specially designed masters that incorporate all of the functional features are available for more efficient calibration. Measurement intervals typically represent 25%, 50%, 75% and 100% of the range. In the case of vernier and dial calipers, increments that represent less than one revolution of the dial or several points over the vernier scale may also be included.

EQUIPMENT:

— Gage blocks and accessories or specially designed masters for length calibration

— Plain ring gages to determine the condition of the internal jaws

— Gage pin for checking parallelism of external jaws

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Uncertainties in the calibration of the masters used for length calibration

— Variations in measuring force

— Repeatability or resolution, whichever is greater

— Errors in jaw parallelism

— Temperature of the instrument and masters

— Errors caused by a bowed or bent main beam or depth rod

HINTS FOR REDUCING UNCERTAINTY:

1. Inspect the datum surfaces on the beam for burrs or other damage.
2. Ensure the measuring faces are free of damage, dirt and foreign material.
3. Make sure the beam is not bent.
4. Clean the rack gear on dial calipers carefully to remove easily hidden foreign material.
5. Wear gloves to reduce heat transfer during calibration.
6. Adjust the sliding jaw gibs so it moves with uniform feel or friction throughout the range.
7. Take readings at front, center and rear of the jaws at each calibration point.
8. Ensure the hand or pointer on dial calipers is not loose.
9. Check zero settings several times before beginning calibration.
10. If gage blocks are used, orient them for minimal contact in the center of the jaws when verifying linearity. Jaw parallelism can be determined by taking readings at the front, center and rear of the jaws.

Indicator Calibration

PROCEDURE:

Dial and digital indicators or plunger type indicators and their lever or test type counterparts are covered in this section. Calibration of them uses masters to provide incremental changes over part of each revolution covering the range of the instruments for the mechanical models or several points over the range of digital models.

Standards covering the various types or manufacturer's specifications will indicate recommended calibration intervals and other characteristics to be verified.

EQUIPMENT:

— Gage blocks

— Comparator stand or height stand with surface plate

— An alternative to the above is a specially made test fixture

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Temperature of blocks, fixture and indicator

— Cosine error in the mounting of the indicator

— Resolution or repeatability – use the larger of the two values

— Uncertainty of the calibration of the blocks or test fixture

HINTS FOR REDUCED UNCERTAINTY:

1. Test indicator action to ensure it is smooth and not sticking.
2. Ensure the contact point is securely fastened to the instrument.
3. Replace contact points that have signs of a flat worn on them or that are bent.
4. Test to ensure the indicator is firmly attached to the stand or fixture.
5. Verify that the hand or pointer on mechanical models is not loose.
6. To reduce cosine errors on test indicators, ensure the angle between the contact centerline and the master is less than 15°.
7. If calibration of a test indicator reveals significant or accumulating errors, it could be due to a contact point being used that the instrument was not designed for ie; it's too long or short or has the wrong ball diameter.

Bore Gage Calibration

PROCEDURE:

The following notes refer to bore gages that are comparative short range instruments employing dial or digital indicators for readouts and interchangeable contacts to cover their capacity.

Most of these instruments measure across a diameter and are often called two-point bore gages. They usually employ contact systems to centralize the instrument in the bore.

Calibration is achieved by setting them to zero on a master following which other masters covering their limited range are used to verify performance.

EQUIPMENT:

— Gage blocks and accessory jaws to provide internal master dimensions

— A better alternative is setting ring gages

— A specially designed test fixture may also be used

SOURCES OF ERROR FOR THE UNCERTAINTY BUDGET:

— Uncertainties associated with the calibration of masters or test fixtures

— Repeatability or resolution – whichever gives the highest value

— Errors due to poor centralization in the bore which create a cosine error

— Errors induced in rocking the gage to find the smallest diameter which create a cosine error

— Flats on the contacts, especially on small diameter models

— Wringing intervals, parallelism errors on gage block/accessory systems

— Temperature of masters, fixture, rings and the instrument

HINTS FOR REDUCING UNCERTAINTY:

1. Reduce centralizing and contact geometry errors by using setting rings as masters.
2. Ensure the instrument action is smooth and not sticking at any point.
3. Use an eye loupe or optical comparator to check for contact point flats. Alternatively, set the gage to zero on a ring having the same size as a single gage block. Check the setting using a gage block. Differences are usually due to unseen flats on the contact.
4. All interchangeable contacts must be checked for flats, not just the sensitive one.
5. Repeatability problems may be due to loosely fitted balls in the contacts or interchangeable contacts that are not properly seated or secured to the instrument.
6. Wear gloves to reduce heat transfer when handling the instrument.
7. If significant errors are detected, verify the calibration of the indicator independently of the instrument. If errors of a similar magnitude are not found, it means the mechanical transmission is worn or defective and repair is required.

Resolving Measurement Disputes

Disputes over measurements can be costly for both parties to resolve and may hinder ongoing relations between suppliers and users of gages and instruments. Often it is simpler for both parties to agree to accept an average value of their readings as the final 'size' or the point at which their readings plus measurement uncertainties overlap.

The obvious way to avoid such problems is to agree beforehand on a method that will be used to resolve them if they arise. Often, the degree of separation between the readings dictates the best approach to take. Where the uncertainty of each party is significantly different, the party with the lowest uncertainty in the calibration would be considered more reliable.

The AMTMA offers the following methods as options you can choose from. If the Referee Method fails to bring a resolution, then the Universal Standard Method should be used due to the fact it is technically based and internationally accepted by metrologists in all disciplines.

THE REFEREE METHOD

The two parties agree on a third party to provide a referee measurement that it is agreed will be considered as the actual value. An alternative on this is where the reading by either party that is closest to that provided by the referee is considered the accepted value.

Other variations of this method include averaging the readings of three or more outside laboratories and may also include the readings produced by the parties to the dispute

Unless otherwise agreed to, the costs of using outside laboratories in this method are paid by the losing party.

THE UNIVERSAL STANDARD METHOD

National and international standards agencies have produced methods of resolving measurement disputes that focus on the uncertainty budgets of those that have produced the measurements. The advantage of this method is that its technical base tends to remove personalities from the equation and may indicate that neither party to a dispute has the capability required to resolve it.

Using this method, the onus of proving a measurement falls on the party who has questioned the results of calibration. If requested, this party must provide a copy of their uncertainty budget for the measurement to the other party for review.

Such a review should focus on seeking agreement between both parties respecting each element included in the budget since it will rarely, if ever, be all right or all wrong. The mathematics should take care of the rest. There may be cases where one or more elements have not been included in the budget and when they are, the outcome changes significantly.

In the event one or more assumptions in the budget cannot be resolved, a third party can be asked to provide an opinion on them.

Reference Standards

One of the greatest sources of measurement problems is the use of outdated standards and specifications. It is the responsibility of all users of published standards to ensure they have the latest version of the documents they are using. We offer the following list to help you find the information you need for calibration and many general measurement applications:

ANSI/ASME B1.2
Gages, and Gaging for Unified Inch Screw Threads

ANSI/ASME B1.3M
Screw Thread Gaging Systems for Dimensional Acceptability

ANSI/ASME B1.16M
Gages and Gaging for Metric M Screw Threads

ANSI/ASME B1.20.1
Pipe Threads, General Purpose (Inch)

ANSI/ASME B1.20.5
Gaging for Dryseal Pipe Threads

ANSI/ASME B1.20.6M
Metric Translation of ANSI/ASME B1.20.5

ANSI/ASME B1.22M
Gages and Gaging for MJ Series Metric Screw Threads

ANSI/ASME B46.1
Surface Texture, Roughness, Waviness and Lay

ANSI/ASME B47.1
Gage Blanks

ANSI/ASME B89.1.2M
Calibration of Gage Blocks by Contact Comparison Method

ANSI/ASME B89.1.6M
Measurement of Qualified Plain Internal Diameters for use as Master RingsAnd Ring Gages

ANSI/ASME B89.1.9
Gage Blocks (2002)

ANSI/ASME B89.3.1
Measurement of Out of Roundness

ANSI/ASME B89.6.2
Temperature and Humidity Environment for Dimensional Measurement

ANSI/ASME B89.1.17
Measurement of Thread Measuring Wires

ANSI/ASME B89.7.3.1
Guidelines for Decision Rules. Considering Measurement Uncertainty in Determining Conformance to Specifications

ANSI/NCSL Z-540-1
Calibration Laboratories and Measuring and Test Equipment – General Requirements

ANSI/NCSL Z-540-2
American National Standard for Expressing Uncertainty

ANSI/ASME B89.1.13
Micrometers

ANSI/ASME B89.1.10
Dial Indicators for Linear Measurement

ANSI/ASME B89.1.14
Vernier Gages and Digital Calipers

FED-STD-H28/22
Gages and gaging for Metric Screw Threads -M and MJ Thread Forms

ISO GUM
Guide to the Expression of Uncertainty in Measurement

ISO/IEC 17025
General requirements for the competence of testing and calibration laboratories

Refrence Sources for Standards & Papers

The documents we have listed are available from the following sources:

ANSI STANDARDS:

American National Standards Institute
1430 Broadway
New York, New York 10018
Attn: Sales Dept
Phone: 212/ 642-4900
Website: www.ansi.org

American Society of Mechanical Engineers (ASME)
22 Law Dr. PO Box 2900
Fairfield, NJ 07007-2900
Phone: 800/843-2763
Fax: 973/882-1717
Website: www.asme.org/catalog

FEDERAL STANDARDS:

General Services Administration
Specification and Consumer Information
Distribution Branch
Washington Navy Yard, Bldg. 197
Washington DC 20407
Website: www.gsa.gov

MILITARY STANDARDS:

NIST Documents
Superintendent of Documents
U.S. Government Printing Office
Washington, DC 20402
Phone: 202/783-3238
Website: www.nist.gov

National Conference of Standards Laboratories International
Suite 107
2995 Wilderness Place
Boulder. CO 80301-5404
Phone: 303/440-3339
Fax: 303/440-3384
Website: www.ncsli.org

American Association for Laboratory Accrediatation (A2LA)
Suite 350
5301 Buckeystown Pike
Frederick MD 21704-8373
Phone: 301/644-3248
Fax: 301/662-2974
Website: www.a2la.org

International Organization for Standardization (ISO)
1, rue de Varembé
Case postale 56
CH1211 Genève 20
Switzerland
Website: www.iso.org

OTHER DOCUMENTS:
If you can't find the document you need, the following company may be able to supply it:

Global Engineering Documents
15 Inverness Way East
Inglewood, CO 80112-5776 USA
Phone: 303/397-7956
Fax: 303/397-2740
Website: www.global.his.com

Notes

8562 East Avenue
Mentor, OH 44060
Phone: (440) 974-6829 | Fax: (440) 974-6828

www.amtma.com