NIST HANDBOOK 150-2F

National Voluntary Laboratory Accreditation Program

Calibration Laboratories

Technical Guide for Dimensional Measurements

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Carroll S. Brickenkamp, Editors

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Preface

The Calibration Laboratories Accreditation Program was developed by the National Voluntary Laboratory Accreditation Program (NVLAP) at the National Institute of Standards and Technology (NIST) as a result of interest from private industry and at the request of the National Conference of Standards Laboratories (now the NCSL International). The goal of the program is to provide a means by which calibration laboratories can be assessed for competency. This voluntary program is not designed to serve as a means of imposing specific calibration procedures or minimum uncertainties on applicant laboratories; instead, the program allows for all scientifically valid calibration schemes and requires that laboratories derive and document their measurement uncertainties.

To accomplish this goal, NVLAP employs technical experts on a contract basis to serve as assessors in each of the following eight fields of physical metrology calibration:

- electromagnetic dc/low frequency,
- electromagnetic rf/microwave frequency,
- time and frequency,
- ionizing radiation,
- optical radiation,
- dimensional,
- mechanical, and
- thermodynamics.

NIST Handbooks 150-2A through 150-2H are technical guides for the accreditation of calibration laboratories, with each handbook corresponding to one of the eight fields of physical metrology calibration. They are intended for information and use by:

- NVLAP technical experts in assessing laboratories,
- staff of accredited laboratories,
- those laboratories seeking accreditation,
- other laboratory accreditation systems,
- users of laboratory services, and
- others needing information on the requirements and guidelines for accreditation under the NVLAP Calibration Laboratories Accreditation Program.

NOTE The Calibration Laboratories Accreditation Program has been expanded to cover chemical calibration for the providers of proficiency testing and certifiers of spectrophotometric NTRMs. (See NIST Handbooks 150-19 and 150-21.) Other NVLAP handbooks in the chemical calibration area are expected in the future.

The assessor uses NIST Handbook 150, *NVLAP Procedures and General Requirements*, and the appropriate guides (NIST Handbooks 150-2A through 150-2H) to validate that a laboratory is capable of performing calibrations within the laboratory's stated uncertainties. These technical guides and other relevant technical information support assessors in their assessments of laboratories. Along with inspecting the facilities, documentation, equipment, and personnel, the assessor can witness a calibration, have an item recalibrated, and/or examine the results of measurement assurance programs and round-robins to collect objective evidence.

NIST Handbooks 150-2A through 150-2H supplement NIST Handbook 150, which contains Title 15 of the U.S. Code of Federal Regulations (CFR) Part 285 plus all general NVLAP procedures, criteria, and policies. The criteria in NIST Handbook 150 originally encompassed the requirements of ISO/IEC Guide 25:1990 and the relevant requirements of ISO 9002 (ANSI/ASQC Q92-1987). These handbook criteria have been updated to incorporate the requirements of ISO/IEC 17025:1999. The entire series of Handbooks 150-2A through 150-2H comprises information specific to the Calibration Laboratories Program and neither adds to nor detracts from requirements contained in NIST Handbook 150.

Any questions or comments on this handbook should be submitted to the National Voluntary Laboratory Accreditation Program, National Institute of Standards and Technology, 100 Bureau Drive, Stop 2140, Gaithersburg, MD 20899-2140; phone (301) 975-4016; fax (301) 926-2884; e-mail NVLAP@nist.gov.

Acknowledgments

NIST Handbook 150-2 was first available as a draft covering all eight fields of physical metrology calibration in one volume. It has been separated into eight handbooks to allow easier updating and electronic downloading from the NVLAP web site. The preparation of these documents has been a joint effort, with input from representatives of other government agencies, laboratories, and the private sector. Acknowledgment of their efforts is in order; however, the listing of individual names is impractical. The submissions by individuals and companies offering suggestions for improvement to this document were also very welcome, as were the contributions of those who attended the public workshops.

Special recognition is made to the NIST measurement divisions for their work in writing or contributing to the individual handbooks. Dr. Theodore D. Doiron deserves special thanks for his assistance with this handbook for dimensional calibrations.

Additional thanks go to those who actively participated in the Technical Guide Workshop held November 1993 and to those who served as points of contact within fields of calibration. They include: Ms. Georgia L. Harris, Mr. Norman B. Belecki, Dr. Theodore D. Doiron, Mr. Robert M. Judish, Mr. Thomas C. Larason, Ms. Sally S. Bruce, and Dr. Donald B. Sullivan. A special thanks is owed to Mr. James L. Cigler for work in developing the content and format of this guide, and to Ms. Vanda White for her editorial expertise in making this a readable document.

Above all, we wish to thank Mr. Jon M. Crickenberger, the editor of the first three drafts of this document, for literally hundreds of hours of his work in creating this guide. It was he who tasked the contributors to produce the technical content, assembled the results of their efforts into a consistent format, and provided the general commentary. Without Jon's dedicated effort to this monumental task, this guide would never have been published.

NVLAP has edited the individual handbooks and made changes resulting from comments by individuals to earlier draft versions. This editing has been to a different extent for each parameter. Every effort was made to include all pertinent information relevant to an ISO/IEC 17025-derived technical guide.

C. Douglas Faison and Carroll S. Brickenkamp, Editors
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Summary

This guide presents the general technical requirements (i.e., on-site assessment and proficiency testing) of the laboratory accreditation program for calibration laboratories along with specific technical criteria and guidance applicable to dimensional measurements. These technical guidelines are presented to indicate how the NVLAP criteria may be applied.

Any calibration laboratory (including commercial, manufacturer, university, or federal, state, or local government laboratory) engaged in calibration in dimensional measurements listed in this handbook may apply for NVLAP accreditation. Accreditation will be granted to a laboratory that complies with the criteria for accreditation as defined in NIST Handbook 150. Accreditation does not guarantee laboratory performance – it is a finding of laboratory competence.

Fields of calibration covered: Specific calibration parameters and related stimulus and measurement devices in areas of dimensional measurement.

Scope of accreditation:
- Calibration parameter(s), range, and uncertainty level
- Types of measuring and test equipment
- Quality assurance system for measuring and test equipment

Period of accreditation: One year, renewable annually.

On-site assessment: Visit by an assessor(s) to determine compliance with the NVLAP criteria before initial accreditation, in the first renewal year, and every two years thereafter. Preassessment and monitoring visits are conducted as required. All calibration parameters or general areas of calibration within the specific scope of accreditation requested will be assessed.

Assessors: Selected from technical experts with experience in the appropriate areas of calibration and quality systems assessment.

Proficiency testing (measurement assurance): Each laboratory is required to demonstrate its capability to successfully perform calibrations as part of on-site assessment or by documented successful completion of an approved Measurement Assurance Program (MAP) or round-robin intercomparison. Proficiency testing may be required for initial accreditation, or where other evidence of measurement assurance is not evident, and may be conducted annually thereafter. Advance notice and instructions are given before proficiency testing is scheduled.

Fees: Payments are required as listed on the NVLAP fee schedule, including the initial application fee, administrative/technical support fee, on-site assessment fee, and proficiency testing fee.

1 General information

1.1 Purpose

The purpose of this handbook is to amplify the general requirements for accreditation by NVLAP of calibration laboratories in the area of dimensional measurements covered by the Calibration Laboratories Program. It complements and supplements the NVLAP programmatic procedures and general requirements found in NIST Handbook 150, *NVLAP Procedures and General Requirements*. The interpretive comments and additional guidelines contained in this handbook make the general NVLAP criteria specifically applicable to the Calibration Laboratories Program.

This handbook does not contain the general requirements for accreditation, which are listed in NIST Handbook 150, but rather provides guidelines for good calibration laboratory practices, which may be useful in achieving accreditation.

1.2 Organization of handbook

The handbook is organized in two sections. The first section provides additional explanations to the general procedures and requirements contained in NIST Handbook 150. The second section provides details and guidance very specific for dimensional calibration laboratories.

1.3 Description of Calibration Laboratories Accreditation Program

On May 18, 1992, as a result of the petition and public notice process, the Director of the National Institute of Standards and Technology published in the *Federal Register* a notice of intent to develop the Calibration Laboratories Accreditation Program under the procedures of the National Voluntary Laboratory Accreditation Program . On June 2, 1994, the procedures and general requirements under which NVLAP operates, Title 15, Part 285 of the U.S. Code of Federal Regulations (CFR), were revised to:

a) expand the procedures beyond testing laboratories to include accreditation of calibration laboratories,

b) update the procedures to ensure compatibility with generally accepted conformity assurance and conformity assessment concepts,

c) incorporate international changes, especially with relevant International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) documents (e.g., ISO/IEC Guides 25 (now ISO/IEC 17025:1999), 38, 43, and 58, and the ISO 9000 series), and

d) facilitate and promote acceptance of the calibration and test results between countries to avoid barriers to trade.

Calibration laboratory accreditation is offered in eight fields of physical metrology calibration covering a wide variety of parameters and includes accreditation in multifunction measuring and test equipment calibrations. Specific requirements and criteria have been established for determining laboratory qualifications for accreditation following prescribed NVLAP procedures. The criteria address the laboratory's management organization, quality system, personnel, methods and method validation, equipment, control of environmental effects, measurement traceability, sampling methods, handling of test and calibration items, methods to assure the quality of its measurement results, reports, service to clients, review of requests and contracts, subcontracting, purchasing, control of nonconforming work, handling of complaints, document and record control, corrective and preventive actions, internal audits, and management reviews.

On September 18, 1992, a public workshop was held at NIST Gaithersburg and attended by a mix of private sector and government personnel. The workshop reviewed a draft handbook, which included general requirements, as well as very specific technical requirements for dc voltage calibrations at all levels. As a result of the workshop, the draft handbook was revised to take the form of a Calibration Laboratories Program Handbook, which included the general requirements for laboratories (using ISO/IEC Guide 25 as a basis), and eight companion Technical Guides covering the specific requirements for each field of calibration offered for accreditation.

On May 18, 1993, a public workshop on the revised draft program handbook was held at NIST Boulder and attended by more than 60 industry and government personnel. Comments from this workshop, as well as responses to a survey/checklist mailing, were used to prepare the final draft of the handbook, now entitled *NVLAP Procedures and General Requirements* (NIST Handbook 150), published in March 1994. NIST Handbook 150 has since been revised to incorporate ISO/IEC 17025.

A public workshop for the Calibration Laboratories Technical Guides was held at NIST Gaithersburg, on November 22 through 24, 1993. More than 60 industry and government personnel attended and provided comments on the draft version of the Technical Guide for each of eight fields of calibration. As a result, the eight Technical Guides were incorporated into a draft Handbook 150-2, *Calibration Laboratories Technical Guide*, covering the fields being offered for accreditation. [In 2000, Handbook 150-2 (draft) was divided into eight handbooks, one for each calibration area.]

The need for technical experts to serve as assessors was advertised, and the first group of assessors was selected and trained during a four-day session held from November 16 through 19, 1993, in Gaithersburg, using materials developed by NVLAP.

The Calibration Laboratories Accreditation Program officially began accepting applications when notification was given in the *Federal Register* dated May 11, 1994. Applications are accepted and processed following procedures found in NIST Handbook 150.

1.4 References

1.4.1 The following documents are referenced in this handbook.

a) NIST Handbook 150, *NVLAP Procedures and General Requirements*; available from:

National Voluntary Laboratory Accreditation Program
National Institute of Standards and Technology
100 Bureau Drive, Stop 2140
Gaithersburg, MD 20899-2140

Phone: (301) 975-4016
Fax: (301) 926-2884
E-mail: nvlap@nist.gov
NVLAP Web site: http://www.nist.gov/nvlap

b) ISO/IEC/BIPM (BIPM is the Bureau International des Poids et Mesures, the International Bureau of Weights and Measures) *Guide to the Expression of Uncertainty in Measurement* (GUM), 1993.

c) ISO/IEC 17025: 1999: *General requirements for the competence of testing and calibration laboratories.*

d) ISO/IEC Guide 43: 1997, *Proficiency testing by interlaboratory comparisons, Part 1 and Part 2.*

e) ISO/IEC/BIPM *International Vocabulary of Basic and General Terms in Metrology* (VIM), 1993.

ISO documents b) through e) are available from:

Global Engineering Documents (paper copies)
Order phone: (800) 854-7179

American National Standards Institute (ANSI) (electronic copies)
Electronic Standards Store
ANSI web site: http://www.ansi.org

f) NIST Technical Note 1297, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*. Available on-line at http://physics.nist.gov/Document/tn1297.pdf.

g) NCSL International Recommended Practice RP-15: *Guide for Interlaboratory Comparisons*, 1999.

h) ANSI/NCSL Z540-1-1994, *Calibration Laboratories and Measuring and Test Equipment—General Requirements.*

i) ANSI/NCSL Z540-2-1997, *U.S. Guide to the Expression of Uncertainty in Measurement.*

j) NCSL International Recommended Practice RP-7: *Laboratory Design*, 1993.

NCSL International documents g) through j) are available from:

NCSL International
1800 30th Street, Suite 305
Boulder, CO 80301-1026
Phone: (303) 440-3339
Fax: (303) 440-3384
E-mail: orders@ncsli.org
Web site: http://www.ncsli.org

k) Ehrlich, C. D., and Raspberry, S. D., "Metrological Timelines in Traceability," *J. Res. Natl. Inst. Stand. Technol.* **103**, 93 (1998).

l) Croarkin, M. C., Measurement Assurance Programs, Part II: Development and Implementation, *NBS Special Publication 676-II* (U.S. Government Printing Office, Washington, DC, 1985).

m) ANSI/ASME B89.6.2, *Temperature and Humidity Environment for Dimensional Measurements.*

n) ANSI/ASME B89.7.3.1-2001, *Guidelines for Decision Rules: Considering Measurement Uncertainty in Determining Conformance to Specifications.*

1.4.2 Additional references specific to dimensional measurements are listed in Sections 2.2 through 2.12.

1.5 Definitions

Definitions found in NIST Handbook 150 apply, but may be interpreted differently or stated differently, when necessary to amplify or clarify the meaning of specific words or phrases as they apply to specific technical criteria.

1.5.1 **Proficiency Testing:** Determination of laboratory performance by means of comparing and evaluating calibrations or tests on the same or similar items or materials by two or more laboratories in accordance with predetermined conditions. For the NVLAP Calibration Laboratories Accreditation Program, this entails using a transport standard as a measurement artifact, sending it to applicant laboratories to be measured, and then comparing the applicant's results to those of a reference laboratory on the same artifact.

1.5.2 **Traceability:** Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties. [See reference 1.4.1 e), section 6.10.]

A single measurement intercomparison is sufficient to establish uncertainty relationships only over a limited time interval (see reference 1.4.1 k)); internal measurement assurance (see reference 1.4.1 l)), using control (check) standards, is required to fully demonstrate that uncertainties remain within stated levels over time. For the purposes of demonstrating traceability for NVLAP accreditation, a laboratory must demonstrate not only that there is an unbroken chain of comparisons to national standards, but also that this chain is supported by appropriate uncertainties, measurement assurance processes, continuous standard maintenance, proper calibration procedures, and proper handling of standards. In this way, traceability is related to these other areas of calibration.

1.6 NVLAP documentation

1.6.1 Accreditation documents

Laboratories granted NVLAP accreditation are provided with two documents: Scope of Accreditation and Certificate of Accreditation.

The Scope of Accreditation lists the "Best Uncertainty" that a given accredited laboratory can provide for a given range or nominal value within a given parameter of measurement. This "Best Uncertainty" is a statement of the smallest uncertainty that the laboratory has been assessed as capable of providing for that particular range or nominal value. The actual reported value of uncertainty for any particular measurement service that the accredited laboratory provides under its scope may vary depending on such contributors as the statistics of the test and uncertainties associated with the device under test.

1.6.2 Fields of calibration/parameters selection list

The Calibration Laboratories program encompasses eight fields of physical metrology calibration, with multiple parameters under each field. Each field is covered by a separate handbook (NIST Handbooks 150-2A through 150-2H). (Fields of accreditation under Chemical Calibration are covered by separate handbooks.) Depending on the extent of its calibration capabilities, a laboratory may seek accreditation to all or only selected fields and parameters within the scope of the program. The fields of calibration and their related parameters are given on the Fields of Calibration and Parameters Selection List, which is provided to a laboratory seeking accreditation as part of the NVLAP application package for the program. Other fields of calibration and/or parameters may be added to the Calibration Laboratories program upon request of customer laboratories and/or if decided by NVLAP to be in the best interest of the Calibration Laboratories Program.

The laboratory is requested to indicate on the Fields of Calibration/Parameters Selection List the parameter(s) for which accreditation is desired, along with appropriate ranges and uncertainties. There is also provision for an applicant laboratory to request accreditation for parameters not currently listed on the Selection List, or for accreditation of the quality system employed for assuring Measurement and Test Equipment (M & TE) used in support of product certification. Request for accreditation of quality assurance systems for M & TE will be treated as a separate field of calibration for the purpose of setting appropriate fees. Once a laboratory meets all the requirements for accreditation for the Fields of Calibration/Parameters Selection List, this information will become the basis for the Scope of Accreditation document.

1.6.3 Checklists

Checklists enable assessors to document the assessment of the laboratory against the NVLAP requirements found in NIST Handbook 150. The NVLAP Calibration Laboratories Accreditation Program uses the NVLAP General Operations Checklist. The questions are applicable to evaluating a laboratory's ability to operate a calibration program, and address factors such as the laboratory's organization, management, and quality system in addition to its calibration competency.

The NVLAP General Operations Checklist is numbered to correspond to the requirements in NIST Handbook 150. Comment sheets are used by the assessor to explain deficiencies noted on the checklist. Additionally, the assessor may use the sheets to make comments on aspects of the laboratory's performance other than deficiencies.

1.7 Assessing and evaluating a laboratory

1.7.1 On-site assessment

1.7.1.1 The NVLAP lead assessor will schedule with the laboratory the date for on-site evaluation, and will request the quality manual and documented quality and calibration procedures in advance of the visit to reduce time spent at the laboratory; such materials will be returned by the assessor. NVLAP and the assessor will protect the confidentiality of the materials and information provided. The laboratory should be prepared to conduct routine calibrations, have equipment in good working order, and be ready for examination according to the guidance contained in this handbook, the requirements identified in NIST Handbook 150, and the laboratory's quality manual. The assessor will need time and work space to complete assessment documentation while at the laboratory, and will discuss these needs at the opening meeting of the on-site assessment.

1.7.1.2 NVLAP technical assessors are provided with the NVLAP General Operations Checklist to help ensure the completeness, objectivity, and uniformity of the on-site assessment.

1.7.1.3 When accreditation has been requested for a considerable number of fields of calibration and parameters, the assessment may range from observing calibrations in progress, requiring repeat measurements on completed calibrations, to listening to laboratory staff describe the calibration process. The depth into which the assessor performs the assessment depends on the number of fields of calibration and associated parameters for which accreditation is requested and the time required to perform a given calibration.

1.7.1.4 The assessor, or the assessment team, does the following during a typical on-site assessment:

a) Conducts an entry briefing with the laboratory manager to explain the purpose of the on-site visit and to discuss the schedule for the day(s). At the discretion of the laboratory manager, other staff may attend the briefing.

b) Reviews quality system manual, equipment and maintenance records, record-keeping procedures, laboratory calibration reports, and personnel competency records. At least one laboratory staff member must be available to answer questions; however, the assessor may wish to review the documents alone. The assessor(s) does not usually ask to take any laboratory documents with him/her, and previously supplied documents will be returned.

c) Physically examines equipment and facilities, observes the demonstration of selected procedures by appropriate personnel assigned to perform calibrations, and interviews the personnel. The demonstrations must include preparation for calibration of devices, and the setup and use of measuring and test equipment, standards and systems.

d) Holds an exit briefing with the laboratory manager and staff to discuss the assessment findings. Although the assessor does not make the final accreditation decision, he/she discusses the deficiencies found with the laboratory and may even tentatively agree to deficiency resolutions by the laboratory. Items that must be addressed before accreditation can be granted are emphasized, and outstanding deficiencies require response to NVLAP within 30 days. Items that have been corrected during the on-site and any recommendations are specially noted.

e) Completes an On-site Assessment Report, as part of the exit briefing, summarizing the findings. The assessor(s) attaches copies of the completed checklists to this report during the exit briefing. The report is signed by the lead assessor and the laboratory's Authorized Representative to acknowledge the discussion. This signature does not necessarily indicate agreement; challenge(s) may be made through NVLAP. A copy is given to the representative for retention. All observations made by the NVLAP assessor are held in the strictest confidence allowed by applicable laws and regulations.

1.7.2 Proficiency testing

1.7.2.1 Background

Once the quality system review and on-site assessment steps have been satisfactorily completed, it is necessary to gather another set of data points to aid in deciding whether or not the applicant laboratory is competent to perform calibrations within the fields of interest to the uncertainties claimed. In the eight fields of calibration covered by Handbooks 150-2A through 150-2H, there are approximately 85 parameters of interest. Ther are several subsets under most parameters, referred to as ranges. For example, in the dimensional arena, calibrations may include displacement, distance, position, form, and size over a range of fourteen orders of magnitude (from picometers to 100 meters). Measurement technologies include laser trackers, coordinate measuring machines (CMMs), gages, and several different types of scanned probe microscopes. In view of the many possible combinations, proficiency testing could be conducted in hundreds of areas. NVLAP reserves the right to test by sampling in any area; applicant laboratories must therefore be prepared, with reasonable notice, to demonstrate proficiency in any of a number of parameters.

1.7.2.2 Proficiency testing vs. measurement assurance

There is an important difference between proficiency testing and measurement assurance. The objective of proficiency testing is to determine through actual performance of a measurement process that the laboratory's measurement results compare favorably with the measurement results of the audit laboratory (NIST or one designated by NVLAP), taking into account the relative uncertainties assigned by both the applicant and audit laboratories. The objective of proficiency testing is not to determine and certify the total uncertainty of the applicant laboratory, as is done in a Measurement Assurance Program (MAP) with NIST, but to verify (through the assessment process) that the uncertainty claimed by the applicant laboratory is reasonable, and then use the claimed uncertainty to test that the measurement result obtained through the proficiency test is acceptable.

It is neither the intention nor the mission of NVLAP to conduct MAPs or to otherwise provide traceability for laboratories. Laboratories obtain these services from the NIST measurement divisions. NVLAP assesses the implementation, application, and documentation of MAPs by laboratories. NVLAP accreditation encourages the use of MAPs by the calibration laboratory community, and MAP results produce objective evidence that NVLAP assessors look for as part of the assessment process.

1.7.2.3 Requirements

NVLAP's proficiency testing program uses a sampling approach. All applicant laboratories are required to complete an annual proficiency test in one parameter under each field of calibration for which it has applied to be accredited. For the purposes of the NVLAP Calibration Laboratories Accreditation Program, the results of the proficiency test are considered as objective evidence, along with the on-site visit, of a laboratory's ability to perform competent calibrations. Proficiency testing is conducted annually using different parameters in each field; however, those laboratories accredited in only one parameter within a field are retested in the same parameter.

1.7.2.4 Uncertainty determination

The applicant laboratory is required to perform a measurement or series of measurements on an artifact using the same calibration method, apparatus, and personnel that it uses to calibrate its customers' equipment. The laboratory must be able to identify and quantify all sources of uncertainty that affect the measurement. The laboratory should attach an overall uncertainty to the measurement by combining all uncertainty contributions, in their type A and type B components, in the root-sum-squared method as described in the *Guide to the Expression of Uncertainty in Measurement* (see reference 1.4.1 b)). The confidence limit $k = 2$ should be used, which is equivalent to a 95% confidence probability.

1.7.2.5 Pass/fail criteria

The performance of the proficiency test is judged by calculating the error of the measurement, normalized with respect to the uncertainty of the measurement, using the following equation:

$$E_{normal} = \left| (Value_{lab} - Value_{ref}) / (Uncertainty_{ref}^2 + Uncertainty_{lab}^2)^{1/2} \right|$$

where

E_{normal} = normalized error of the applicant laboratory
$Value_{lab}$ = the value as measured by the applicant laboratory
$Value_{ref}$ = the value as measured by the reference laboratory
$Uncertainty_{ref}$ = the uncertainty of the reference laboratory
$Uncertainty_{lab}$ = the uncertainty of the applicant laboratory

To pass the proficiency test, the applicant laboratory must have a value for E_{normal} less than 1 (i.e., $E_{normal} < 1$). When there are sets of artifacts, such as gage block sets, that are part of the proficiency test, the laboratory must have a value for $E_{normal} < 1$ for more than 95% of the artifacts tested. The results may be plotted graphically, with lines representing the limits of uncertainty of the measurements. The anonymity of each applicant laboratory is always preserved.

1.7.2.6 Scheduling and handling

Proficiency testing is scheduled by NVLAP-designated reference laboratories. These sites are NIST laboratories or NVLAP-accredited laboratories that have been found to have the ability to perform the required proficiency tests to an uncertainty level appropriate for the laboratories they evaluate. The proficiency test is scheduled independently and not required to correspond with the on-site visit. Applicant laboratories are notified in advance as to the approximate arrival time of the measurement artifact. Instructions for performing the test, reporting the results, communicating with the reference laboratory, and shipping are included along with the artifact as part of the proficiency test package. Applicant laboratories are instructed to perform all required measurements within a reasonable time and are told where to ship the artifacts once the testing has been completed.

1.7.2.7 Notification of results

NVLAP notifies each laboratory of its own results in a proficiency test. If a laboratory has received its on-site assessment prior to the completion of the proficiency test, the status of that laboratory's accreditation is contingent upon successful completion of proficiency testing. The laboratory's accreditation status may be changed to reflect a partial accreditation, or may be completely suspended pending demonstration of the laboratory's ability to successfully complete the proficiency test at a later date.

1.7.3 Traceability

1.7.3.1 Establishing traceability

Laboratories must establish an unbroken chain of comparisons leading to the appropriate international or national standard, such that the uncertainties of the comparisons support the level of uncertainty that the laboratory gives to its customers. Generally speaking, the uncertainties of the comparisons increase as they move from a higher (international or national level) to a lower level standard. This uncertainty chain is the evidence of traceability and must be documented accordingly. Traceability does not simply mean having standards calibrated at the national laboratory, but must consider how a measurement, with its corresponding uncertainty, is transferred from the national level to the calibration laboratory's customers.

1.7.3.2 Considerations in determining traceability

Without some type of measurement assurance process, one cannot be reasonably certain that the comparisons have been transferred properly to the laboratory's customers. The measurement process itself must be verified to be in control over time. Traceability is not a static concept that, once established, may be ignored; it is dynamic. Process control exercised in each calibration provides the assurance that a valid transfer of the international or national standard continues to take place. This assurance may be accomplished through the use of tools such as check standards and control charts. Also, the laboratory's primary standards must be maintained in such a way as to verify their integrity. Examples of this may be having more than one primary standard to use for intercomparisons, monitoring the primary standard with a check or working standard (looking for changes), and verifying a primary standard on a well-characterized measurement/calibration system. Using scientifically sound measurement procedures to transfer the primary standard value to the working level and the customer's item is essential to establishing traceability. Process control should be in place and exercised in each calibration in order to ensure that the measurement results provided the customer are traceable. Handling the laboratory's standards affects the measurement process, and therefore the ability to transfer the standard's value to the customer. Examples of handling problems are dirty or improperly cleaned standards, maintaining standards in an improper environment, not maintaining custody and security, and improper handling of standards during the measurement process.

1.7.3.3 Relationship to existing standards

The above discussion illustrates how traceability is dependent on many aspects of the measurement process and therefore must be considered in all phases of calibration. It is not just coincidental that the factors addressed above are main topics of concern in ISO/IEC 17025:1999.

1.7.4 Uncertainty

NVLAP recognizes the methodology for determining uncertainty as described in the *Guide to the Expression of Uncertainty in Measurement*, published by ISO. To be NVLAP-accredited, a laboratory must document the derivation of the uncertainties that it reports to its customers. These uncertainties will appear on the scope issued to each accredited laboratory to an accuracy appropriate to the standards, procedures, and measuring devices used.

2 Criteria for accreditation

2.1 Introduction

2.1.1 Applicant laboratories are assessed using the requirements in NIST Handbook 150, *NVLAP Procedures and General Requirements*. This guide, NIST Handbook 150-2F, was developed from a NIST measurement laboratory perspective and provides examples and guidelines, not requirements, to assessors and interested calibration laboratories, on good laboratory practices and recommended standards. Therefore, the guide language reflects this philosophy through the use of "shoulds" instead of "shalls" (along with other less prescriptive language) when describing criteria. The requirements presented here are not absolute since specific requirements depend on the measurement uncertainty for which an applicant laboratory wishes to be accredited. This is a business decision for each laboratory and beyond the scope of NVLAP. Simply stated, to be accredited, an applicant laboratory must have a quality system and be able to prove (and document) that it is capable of doing what it says it does (i.e., correctly calibrate to a stated uncertainty) within the framework of NIST Handbook 150. Accreditation will be granted, and therefore may be referenced in calibration reports, etc., only for those specific parameters, ranges and uncertainties using calibration methods and procedures for which a laboratory has been evaluated. Calibrations performed by a laboratory using methods and procedures not considered appropriate for the level of measurements being made, and which have not been evaluated by the accreditation process, are outside the scope of accreditation and may not be referenced as "accredited" calibrations on calibration reports, etc.

2.1.2 Section 2.2 amplifies and interprets the general criteria of NIST Handbook 150 for selected dimensional calibrations. Sections 2.3 through 2.12 cover the specific assessment criteria for the individual parameters (i.e., standard artifacts) within the dimensional field of calibration. This guide is dynamic in that new parameters may be added and existing criteria updated and improved.

2.2 Technical criteria for dimensional calibrations

2.2.1 Scope

2.2.1.1 This section contains specific technical criteria for a laboratory to be recognized as competent to carry out calibrations of simple dimensional artifacts. The artifact calibrations currently included in the accreditation program are:

a) Gage blocks and end standards,

b) Plain ring gages,

c) Plain plug gages, cylinder gages, and thread and gear wires,

d) Gage balls,

e) Roundness standards,

f) Angle blocks,

g) Polygons and indexing tables,

h) Optical reference planes (flats),

i) Step gages, and

j) Ball bars.

2.2.1.2 Measuring artifacts a) through j) above with a coordinate measuring machine (CMM) is acceptable as long as the uncertainty calculations are specific to the simple measurand. In this way a complex instrument like a CMM is accredited for these specific measurements only, but not accredited for "CMM measurement." For an example, see 2.11.6.

2.2.2 Assuring the quality of test and calibration results

2.2.2.1 All sources of variability for the calibration should be monitored by subsystem calibration (e.g., thermometer, force gage calibration). Additionally, check standards to ensure that the calibrations are carried out under controlled conditions are highly recommended. The laboratory should maintain and document some form of systematic process monitoring commensurate with the uncertainty levels of the calibration. While the use of check standards for statistical process control (SPC) is recommended for the highest levels of accuracy, some check standard data is invaluable for documenting the calibration uncertainty even if SPC is not used. The frequency and number of process control checks should be appropriate for the number of calibrations as well as the level of uncertainty and reliability claimed for the calibration.

2.2.2.2 The laboratory should have check standards which adequately span the range of materials and sizes normally calibrated by the laboratory. Every measured value of each check standard should be recorded and compared to its historical value to determine that the process is in control. The use of only a few check standards at weekly intervals will produce values of the reproducibility of the calibration process with excellent statistical validity.

2.2.3 Accommodation and environmental conditions

2.2.3.1 The temperature in the calibration area should nominally be 20 °C with a maximum variation and rate of change depending on the materials and the uncertainty level needed for the calibration. If measurements are made at temperatures other than 20 °C, the uncertainties of the appropriate thermal corrections for the artifacts should be included in the total uncertainty. For comparison measurements, the uncertainty component should reflect the uncertainty in the thermal corrections of both the master and unknown artifacts, as well as the temperature difference between them, and the uncertainty of the thermometer used.

2.2.3.2 The temperature stability of the environment should be sufficient for the gage and measurement system to be in thermal equilibrium. Measurements may be made in slowly changing environments if a suitable measurement model, which includes the effects of the drift, is used. Theoretical and experimental verification of the model should be available.

2.2.3.3 For typical gages made of well-characterized materials (steel, carbide or ceramic), $1.0 \times 10^{-6}/$ °C should be used as the standard uncertainty of the thermal expansion coefficient unless there is documentation of a lower value.

2.2.3.4 The relative humidity in the calibration room should not exceed 50 % to avoid corrosion. This is critical because most dimensional measuring equipment is made of steel. While customer gages are in the laboratory for only a short period, the laboratory equipment is there all the time! Appropriate protection should be applied if the humidity ever exceeds 50 %.

2.2.3.5 Excessive vibration should be avoided in the calibration room. If an obvious source of vibration exists, precautions should be taken to prevent adverse effects on the laboratory's measurements.

2.2.3.6 The laboratory should have a documented policy regarding responses to problems with the environment.

2.2.4 Equipment

2.2.4.1 The laboratory should have the equipment needed to make auxiliary measurements on artifacts (e.g., flatness of gage blocks, roundness of ring gages).

2.2.4.2 The laboratory should have temperature measuring capabilities suitable for the calibration procedure and the desired measurement uncertainty. Calibrations involving direct comparisons of artifacts of similar size and materials will, in general, have modest requirements. Absolute calibrations or comparisons between artifacts of different sizes and/or materials will require more accurate temperature measurement.

2.2.4.3 A laboratory that certifies artifacts to tolerance grades should consult with the customer which tolerance rule is needed and how uncertainty will be used in the decision. Guidance is available in the ASME B89.7.3 standard (see reference 1.4.1 n)).

2.2.4.4 A laboratory that makes mechanical comparisons of masters and test pieces of dissimilar materials should have force measuring equipment to determine the force on the probe or probes. A correction for differential probe penetration should be applied as long as the probe has maintained its desired geometry. On old comparators, the probe radius may be worn down to the point where a correction would induce error. It is necessary to accommodate probe tip geometry issues in the overall uncertainty, whether or not a correction for differential probe penetration is applied.

2.2.4.5 A laboratory that makes absolute measurements using displacement measuring sensors, such as interferometers or linear scales, should have environmental monitoring equipment appropriate to the sensor.

2.2.4.6 A laboratory that makes absolute measurements using a contact device should have force measuring equipment to determine the force on the probe or probes. A correction for probe penetration should be applied if appropriate (see 2.2.4.4 above).

2.2.4.7 A laboratory that makes interferometric measurements using a laser or spectral lamp for the scale should have:

a) Equipment for making high-accuracy temperature measurements, and

b) Equipment for determining the index of refraction of air.

2.2.5 Handling of test and calibration items

2.2.5.1 Artifacts should be cleaned and stored in a manner to prevent accidental contact with material that could damage the gaging surfaces.

2.2.5.2 Care should be taken to prevent steel artifacts from rusting. Steel artifacts should be coated with a rust inhibiting grease whenever there is a potential for exposure to an environment over 50 % relative humidity. If artifacts cannot be greased, other materials (e.g., rust inhibiting paper) or methods should be used to inhibit rust.

2.2.5.3 After cleaning, artifacts should be allowed to come to adequate thermal equilibrium in the calibration environment before measurement. Artifacts should be placed on a soaking plate or in position on the measuring machine long enough to ensure that they are at the proper temperature. The soaking time will depend on the size and the thermal properties of the artifacts and plate. Specific guidelines for soaking times should be stated in the measurement procedure. The heating effects from optical radiation, body heat, and system location should be minimized.

2.2.5.4 In general, to prevent thermal changes and corrosion of the gaging surfaces, artifacts should not be handled with bare hands. Gloves or tongs should be used whenever possible.

2.2.6 Test and calibration methods and method validation

2.2.6.1 When calibrations are made by comparison to master gages of different nominal size, the temperature control of the gages and the measurement environment should be increased.

2.2.6.2 The laboratory should have a manual outlining the procedures to be followed for each type of calibration. For calibration of graded sets, the procedure should name the grades that are calibrated by the procedure and how the decision is made that the gages meet the grade requirement.

2.2.6.3 The procedures used for related services, such as checks of roundness, relapping, repair, or replacement of damaged or out-of-tolerance gages, should be clearly stated.

2.2.7 Records

2.2.7.1 All measurement data should be recorded. If corrections are applied by hand, the worksheets should show the measurement data, corrections, and final answers. The master, control and test pieces, temperature, operator, instrument, date and other pertinent process information should be included.

2.2.7.2 Information relating to the procedures, equipment, standards, results, and personnel involved for a particular calibration should be maintained for a period of time specified in the quality manual.

2.2.7.3 Records associated with a particular standard or control should be kept during the lifetime of the standard.

2.2.8 Reporting the results

2.2.8.1 All content of certificates or reports of calibration should conform to the requirements of ISO/IEC 17025 as set forth in NIST Handbook 150.

2.2.8.2 All certificates or reports of calibration should contain an uncertainty statement which is scientifically determined from measurement data and which agrees with the laboratory's stated definition.

2.2.8.3 The uncertainty should be derived from a model of the measurement system that includes (as applicable) the uncertainties caused by:

a) Master artifact calibration

b) Long-term reproducibility of measurement system

c) Thermal expansion correction for gages and measurement scales

    1) Thermometer calibration

    2) Thermal expansion coefficient

    3) Thermal gradients (internal, gage-gage, gage-scale)

d) Scale

    1) Uncertainty of scale

    2) Environmental properties of scale (temperature, pressure, humidity, etc.)

e) Instrument geometry

    1) Abbe offset and instrument geometry errors

    2) Scale and gage alignment (cosine errors)

    3) Gage support geometry (anvil flatness, block flatness)

f) Probe deformation correction

g) Rotary axis errors (radial and axial displacements, tilt)

h) Analysis algorithms (data fitting, filtering)

i) Geometry of artifact under test

j) Other factors as appropriate.

2.2.8.4 The method used to affix the calibration items should be described in detail. In general, differences in fixture configurations between calibration and use will introduce errors in the calibration.

2.3 Gage blocks

2.3.1 Scope

This section contains specific technical criteria that a laboratory should meet if it is to be recognized as competent to carry out gage block calibrations or certifications to accuracy grade by interferometry or mechanical comparison.

2.3.2 References

a) Federal Specification GGG-G-15C, *Gage Blocks and Accessories (inch and metric).*

b) ANSI/ASME B89.1.9M-1989, *Precision Gage Blocks for Length Measurement (Through 20 in. and 500 mm).*

c) ANSI/ASME B89.1.2M-1991, *Calibration of Gage Blocks by Contact Comparison Method.*

2.3.3 Assuring the quality of test and calibration results

The laboratory should have control gage blocks that span the range of materials and sizes normally calibrated by the laboratory. A number of appropriate control blocks should be measured each time a set is calibrated.

2.3.4 Accommodation and environmental conditions

2.3.4.1 For all gage blocks calibrated by interferometry the immediate environment of the gage block should be within 0.1 degree of 20 °C, and be measured with an accuracy of 0.02 °C. The measured length should be corrected to 20 °C using the known thermal expansion coefficient of the material. Other environmental conditions may be used as long as they are accounted for in the uncertainty determination. Grade 0.5 blocks should be calibrated by interferometry, but may be calibrated by comparison if the measurement uncertainty is acceptable to the customer.

2.3.4.2 For grade 1 and 2 gage blocks up to 100 mm long measured by comparison, the environmental temperature fluctuation should be less than ± 0.25 °C over 24 hours and ± 0.1 °C in any 1-hour period. For grade 3 or lower grade blocks the fluctuation should be less than ± 1 °C over 24 hours and ± 0.5 °C over any 1-hour period. For comparison measurements of blocks of different materials, differential thermal expansion corrections will be made.

2.3.4.3 For blocks over 100 mm calibrated by comparison, the temperature should vary less than ± 0.25 °C over at least a 6-hour period before measurements are made.

2.3.5 Equipment

The laboratory should have the equipment needed to make required flatness and parallelism measurements.

2.3.6 Test and calibration methods and method validation

Gage blocks may be measured by interferometry (wrung to a platen) or by comparison to calibrated gage blocks. If a long range comparator is used to compare blocks with nominal sizes differing by more than 10 mm, environmental control approaching that for interferometry should be used.

2.3.7 Handling of test and calibration items

For mechanical comparison the blocks should be manipulated using tongs with soft flexible contact surfaces. Manipulation by hand causes unacceptable thermal changes in the blocks. For interferometry, blocks may be wrung by hand, but the platen should be placed in the interferometer and a suitable waiting period should be observed before measurement.

2.3.8 Reporting the results

2.3.8.1 The calibration report should denote blocks that do not meet the grade tolerance. Blocks that are replaced as out of tolerance need not be reported, but may be included at the discretion of the laboratory or customer.

2.3.8.2 For gage blocks measured by comparison, the geometry of the anvil used to support the block should be reported. For high accuracy measurements, the bottom sensor should not support the weight of the block.

2.4 Plain ring gages

2.4.1 Scope

This section contains specific technical criteria that a laboratory should meet, if it is to be recognized as competent to carry out ring gage calibrations, or certify gages to accuracy grade.

2.4.2 References

a) ANSI/ASME B89.1.7M-1984, *Measurement of Qualified Plain Internal Diameters for Use as Master Rings and Ring Gages.*

b) ANSI/ASME B89.3.4M-85, *Axes of Rotation, Methods for Specifying and Testing.*

c) ANSI/ASME B89.3.1M-1972, *Measurement of Out-of-Roundness.*

d) ISO 4291-85, *Methods for the assessment of departure from roundness - measurement of variation in radius.*

e) ISO 4292-85, *Methods for the assessment of departure from roundness - measurement by two- and three-point methods.*

f) ISO 6318-85, *Measurement of roundness - terms, definitions and parameters of roundness.*

2.4.3 Assuring the quality of test and calibration results

The laboratory should have control ring gages that span the range of materials and sizes normally calibrated by the laboratory. A number of appropriate control gages should be measured during each measurement session.

2.4.4 Accommodation and environmental conditions

2.4.4.1 For grade XX and XXX gages measured by comparison, the temperature should vary less than ± 0.25 °C over 24 hours and ± 0.1 °C in any 1-hour period. For comparison measurements of gages of different materials, differential thermal expansion corrections should be made.

2.4.4.2 For lower accuracy grades the temperature variation should be less than ± 1 °C over 24 hours and ± 0.5 °C over any 1-hour period.

2.4.5 Equipment

2.4.5.1 The laboratory should have the equipment needed to make appropriate roundness measurements.

2.4.5.2 Ring gages can be calibrated by comparison to master ring gages or gage block stacks, along with a variety of other techniques. Where applicable, the uncertainty in the length of the master artifact should be documented.

2.4.6 Handling of test and calibration items

Manipulation of rings to find the maximum diameter should be done with proper precautions to prevent thermal changes.

2.5 Plain plugs and cylinders

2.5.1 Scope

This section contains specific technical criteria that a laboratory should meet, if it is to be recognized as competent to carry out calibration of gage cylinders, gage wires, and plain plug gages by interferometry or mechanical comparison, or certify gages to accuracy grade.

2.5.2 References

a) FED-STD-H28, *Screw-Thread Standards for Federal Services.*

b) ANSI/AGMA 2002-B88, *Tooth Thickness Specification and Measurement.*

c) ANSI/ASME B89.3.4M-85, *Axes of Rotation, Methods for Specifying and Testing.*

d) ANSI/ASME B89.3.1, *Measurement of Out-of-Roundness.*

e) ISO 4291-85, *Methods for the assessment of departure from roundness - measurement of variation in radius.*

f) ISO 4292-85, *Methods for the assessment of departure from roundness - measurement by two- and three-point methods.*

g) ISO 6318-85, *Measurement of roundness - terms, definitions and parameters of roundness.*

2.5.3 Assuring the quality of test and calibration results

The laboratory should have control gages that span the range of materials, sizes and types of gages normally calibrated by the laboratory. A number of appropriate control gages should be measured during each calibration session. The laboratory may use suitably chosen cylindrical controls for all calibrations. Separate controls for each type of thread or gear wire are not necessary.

2.5.4 Accommodation and environmental conditions

2.5.4.1 For comparison measurements the temperature variation should be less than ± 1 °C over 24 hours and ± 0.5 °C over any 1-hour period.

2.5.4.2 For absolute measurements the temperature variation should be less than ± 0.25 °C over 24 hours and ± 0.1 °C over any 1-hour period.

2.5.5 Equipment

2.5.5.1 The laboratory should have the equipment needed to make roundness and taper measurements where required.

2.5.5.2 The laboratory should have force measuring equipment to determine the force on the probe or probes. An appropriate correction for probe penetration should be applied.

2.5.6 Test and calibration methods and method validation

2.5.6.1 In general a number of diameters at the gaging position should be measured and averaged. The range of these measurements may be reported as a measure of the wire diameter fluctuation.

2.5.6.2 Multiple measurements of a specific diameter should be made only if the measured diameter is clearly marked on the cylinder.

2.5.7 Handling of test and calibration items

Wires and cylinders should not be handled with bare hands. For small gages light gloves should be worn. For sizes over 5 mm handling techniques should be appropriate to the claimed uncertainty level.

2.5.8 Reporting the results

2.5.8.1 The reported diameter for thread and gear wires will be the deformed diameter as specified in the thread and gear standards.

2.5.8.2 The position of the measured diameter should be marked on the cylinder and recorded in the calibration report.

2.6 Gage balls

2.6.1 Scope

This section contains specific technical criteria that a laboratory should meet if it is to be recognized as competent to carry out gage ball calibrations or certifications to accuracy grade by interferometry or mechanical comparison.

2.6.2 References

a) ANSI/ASME B89.3.1M-1972, *Measurement of Out-of-Roundness*.

2.6.3 Assuring the quality of test and calibration results

The laboratory should have control balls that span the range of materials and sizes normally calibrated by the laboratory. A number of appropriate control balls should be measured each time a set is calibrated.

2.6.4 Accommodation and environmental conditions

2.6.4.1 For comparison measurements the temperature variation should be less than ± 1 °C over 24 hours and ± 0.5 °C over any 1-hour period.

2.6.4.2 For absolute measurements the temperature variation should be less than ± 0.25 °C over 24 hours and ± 0.1 °C over any 1-hour period.

2.6.5 Equipment

The laboratory should have the equipment needed to make roundness measurements.

2.6.6 Test and calibration methods and method validation

2.6.6.1 The number and orientations of the diameters measured may be random, specified or agreed to by the customer.

2.6.6.2 Two or more roundness traces along different longitudes of the ball should be used to characterize the ball roundness.

2.6.7 Handling of test and calibration items

Tongs should be used to move balls for high accuracy calibrations because manipulation by hand can cause unacceptable thermal changes in gages.

2.6.8 Reporting the results

The number and orientation of the diameters and roundness traces measured should be reported.

2.7 Roundness standards

2.7.1 Scope

This section contains specific technical criteria that a laboratory should meet if it is to be recognized as competent to carry out roundness calibrations.

2.7.2 References

a) ANSI/ASME B89.3.1M-1972, *Measurement of Out-of-Roundness*.

b) ISO 4291-85, *Methods for the assessment of departure from roundness - measurement of variation in radius.*

c) ISO 6318-85, *Measurement of roundness - terms, definitions and parameters of roundness.*

2.7.3 Assuring the quality of test and calibration results

The laboratory should have a control roundness standard and/or measure roundness by multi-step methods. Multi-step methods will provide a calibration of the spindle roundness, which can be used as the check standard. A separate procedure must be used for determining the instrument scale magnification or gain correction.

2.7.4 Accommodation and environmental conditions

Temperature variation should be less than ± 1 °C over 24 hours and ± 0.5 °C over any 1-hour period.

2.7.5 Equipment

The laboratory should have appropriate magnification standards to span the range of amplifier magnification used for calibrations.

2.7.6 Test and calibration methods and method validation

2.7.6.1 Calibrations may be made by a number of methods. The gage may be calibrated by multi-step or reversal methods that measure the spindle error as well as calibrate the roundness standard. The spindle error may be measured and compensation made for the test gage. If the spindle error is very small or the calibration is aimed at a modest uncertainty level, the error of the spindle may be characterized and treated as an item in the uncertainty budget.

2.7.6.2 The response band (filter setting) of the instrument will be set as specified by the customer, calibrating laboratory, or appropriate standard and noted in the calibration report.

2.7.6.3 The stylus force should be set at the minimum needed to maintain contact with the standard being calibrated.

2.7.7 Handling of test and calibration items

The standard being calibrated should be affixed so that there are no stresses which affect the roundness.

2.7.8 Reporting the results

The report should note the response band of the calibration instrument and the method used to calculate the center of rotation.

2.8 Angle blocks

2.8.1 Scope

This section contains specific technical criteria that a laboratory should meet if it is to be recognized as competent to carry out angle block calibrations.

2.8.2 Assuring the quality of test and calibration results

2.8.2.1 For comparison processes the laboratory should have control angle blocks that span the range of sizes normally calibrated by the laboratory. A number of appropriate control blocks should be measured each time a set is calibrated.

2.8.2.2 For closure measurements, the measured error in the indexing table may be used as the control parameter.

2.8.3 Accommodation and environmental conditions

Care should be taken to allow the blocks to come to thermal equilibrium before measurements.

2.8.4 Equipment

The laboratory should have facilities to measure the flatness of angle block faces.

2.8.5 Test and calibration methods and method validation

The block should be affixed so that there are no residual stresses that would change either the angle or block face flatness.

2.8.6 Handling of test and calibration items

Gloves or tongs should be used when moving blocks to reduce thermal gradients within the blocks.

2.8.7 Reporting the results

2.8.7.1 The face flatness should be reported if measured.

2.8.7.2 The brand and model of the autocollimator used should also be reported, as well as the size of the area illuminated.

2.9 Polygons and indexing tables

2.9.1 Scope

This section contains specific technical criteria that a laboratory should meet if it is to be recognized as competent to calibrate polygons and indexing tables by closure and comparison.

2.9.2 Assuring the quality of test and calibration results

2.9.2.1 For calibrations made by comparison with a calibrated indexing or rotary table, the laboratory should have a control polygon with enough sides to adequately span the range of angles normally calibrated by the laboratory.

2.9.2.2 For closure measurements, the measured error in the indexing table may be used as the control parameter.

2.9.3 Accommodation and environmental conditions

The angles of a polygon are not affected by changes in temperature as long as there are no gradients. Care should be taken to allow the polygon to come to thermal equilibrium before measuring.

2.9.4 Equipment

The laboratory should have the equipment needed to make flatness measurements.

2.9.5 Test and calibration methods and method validation

2.9.5.1 The polygon or reference mirror should be affixed so that there are no residual stresses that would change either the angle or face flatness.

2.9.5.2 The procedures used for measuring face flatness should be clearly stated.

2.9.6 Reporting the results

The brand and model of the autocollimator used should also be reported, as well as the size of the area illuminated.

2.10 Optical reference planes (flats)

2.10.1 Scope

This section contains specific technical criteria that a laboratory should meet if it is to be recognized as competent to carry out optical flat calibrations or certifications to accuracy grade by interferometry or mechanical comparison.

2.10.2 References

a) Federal Specification GG-O-635A, *Optical Flats.*

2.10.3 Assuring the quality of test and calibration results

The laboratory should have control flats that span the range of sizes normally calibrated by the laboratory.

2.10.4 Accommodation and environmental conditions

2.10.4.1 Care should be taken to allow the flat to come to thermal equilibrium before measurements.

2.10.4.2 The beam path between the master optical surface and the flat to be calibrated should be protected to reduce air turbulence.

2.10.5 Equipment

The laboratory should have fixtures that will accommodate flats of various geometries. The customer should be consulted for information about how the flat is affixed or mounted when used so that it can be calibrated in the same manner. If the calibration and customer fixtures are different the accuracy of the calibration will be degraded.

2.10.6 Test and calibration methods and method validation

Flats may be calibrated either vertically or horizontally, depending on their intended use. The calibration may consist of the flatness of one or more diagonals or a map of the entire surface.

2.10.7 Reporting the results

The method used to fixture and support the flat should be specified in the report of calibration.

2.11 Step gages

2.11.1 Scope

This section contains specific technical criteria that a laboratory should meet if it is to be recognized as competent to conduct the calibration of step gages (one-dimensional, multiple-length gages).

2.11.2 References

a) ANSI/ASME B89.1.12M-1990, *Methods for Performance Evaluation of Coordinate Measuring Machines.*

b) ISO 10360-2, *Coordinate Metrology - Part 2: Performance Assessment of Coordinate Measuring Machines (CMMs).*

2.11.3 Assuring the quality of test and calibration results

2.11.3.1 The laboratory should have control standards that span the range of materials and sizes normally calibrated by the laboratory. A step gage, at least 80 % as long as the longest customer gage to be calibrated, would be the most appropriate control standard, but alternatives such as sets of long end standards could be substituted.

2.11.3.2 For calibration processes using coordinate measuring machines, the control standard may be placed in close proximity to the customer gage and measured directly before the customer calibration. For other systems that measure along only one line, a control standard should be measured in the place of the customer gage before the customer calibration.

2.11.4 Accommodation and environmental conditions

2.11.4.1 Step gages are high accuracy transfer standards, which demand good control over the temperature of the gage and measuring machine. Particular attention should be given to the uncertainty associated with the thermal expansion of the step gage. If the thermal expansion is not known to 0.1×10^{-6} ppm/ °C or better, the measurement temperature should be very close to 20 °C.

2.11.4.2 The temperature of the step gage should be monitored at a number of places to assure adequate characterization of the thermal state of the gage.

2.11.5 Equipment

The laboratory should have suitable equipment to monitor the environment. For laser based measuring systems, the air temperature, pressure and humidity should be monitored during the calibration and corrections applied for changes in the laser wavelength.

2.11.6 Test and calibration methods and method validation

2.11.6.1 Each calibration should consist of multiple measurements of each calibrated interval of the gage. The data should be analyzed for evidence of instrumental drift and repeatability.

2.11.6.2 For bidirectional step gage calibration using CMMs, the probe should be calibrated using a gage block or equivalent one dimensional artifact.

2.11.6.3 For step gages using gage balls as reference points, the CMM probe should be calibrated using a gage ball.

2.11.6.4 A separate technique for verifying the CMM scale accuracy should be developed and followed.

2.11.7 Handling of test and calibration items

After cleaning, the gage should be placed on a soaking plate or the measuring machine to ensure thermal stability. The soaking time will depend on the size and the thermal properties of the gage. Specific guidelines for soaking times should be stated in the measurement procedure.

2.12 Ball bars

2.12.1 Scope

This section contains specific technical criteria that a laboratory should meet if it is to be recognized as competent to carry out ball bar calibrations.

2.12.2 References

a) ANSI/ASME B89.1.12M-1990, *Methods for Performance Evaluation of Coordinate Measuring Machines.*

2.12.3 Assuring the quality of test and calibration results

2.12.3.1 The laboratory should have control standards that span the range of materials and sizes normally calibrated by the laboratory. A check standard, at least 80 % as long as the longest customer gage to be calibrated, would be the most appropriate control standard, but alternatives such as sets of long end standards could be substituted.

2.12.3.2 For calibration processes using coordinate measuring machines, the control standard may be placed in close proximity to the customer gage and measured directly before the customer calibration. For other systems that measure along only one line, a control standard should be measured in the place of the customer gage before the customer calibration.

2.12.4 Accommodation and environmental conditions

The temperature of the ball bar should be monitored at a number of places to assure adequate characterization of the thermal state of the bar.

2.12.5 Equipment

The laboratory should have suitable equipment to monitor the environment. For laser based measuring systems, the air temperature, pressure and humidity should be monitored during the calibration and corrections applied for changes in the laser wavelength.

2.12.6 Test and calibration methods and method validation

2.12.6.1 Each calibration should consist of multiple measurements. The data should be analyzed for evidence of instrumental drift.

2.12.6.2 For CMM calibrations, the CMM probe should be calibrated using a gage ball.

2.12.6.3 Care should be used in the fixturing and support of the ball bar. Details of the fixturing methods used should be included in the report of calibration.

2.12.7 Handling of test and calibration items

After cleaning, the bar should be placed on the measuring machine and allowed to reach thermal equilibrium. The soaking time will depend on the size and the thermal properties of the bar.