Purpose: This standard defines roles, responsibilities and requirements for the PPPL portable Coordinate Measuring Machine (pCMM) based metrology program.

Scope/Applicability:

This Standard applies to PPPL personnel using pCMM metrology equipment for measurements at both PPPL and offsite locations.

This standard defines the following:

- Classification of measurements
- Training/Qualification for metrology pCMM operators
- pCMM Hardware and Software

Metrology personnel shall be qualified within three months of the "Effective Date" of this standard in order to continue performing Critical Measurements.

This Standard does not provide guidance for measurements, if such guidance is needed the requesting Project and/or Metrology group should generate a unique metrology procedure.

The design and installation of fixturing (for equipment being measured) is not governed by this procedure, even though its application may critically affect the accuracy of the results.

Reference Documents:

PPPL Policy P-086 "Specifying, Using and Calibrating Measuring and Test Equipment"

Romer Manual
Verisurf Manual
Faro Tracker X manual
Faro Silver Arm Manual
Faro Utilities Manual
CAM2 Manual
Leica LTD500 Manual
Leica EmScon Manual
PowerINSPECT Manual
PowerINSPECT Training Manual

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1.0 TERMINIOLOGY AND DEFINITIONS

Compensation	The process of applying a correction factor to the calibration of a metrology system in order to correct for measurement drift or offset of the system
Conical Seat	A conically shaped depression for seating spherical targets
Coordinate Measuring Machine (CMM)	Generic term used for a device that measures using an internal or externally provided coordinate system
Corner Cube Reflector (CCR)	Reflector target used by Laser Tracker systems
Spherically Mounted Reflector (SMR)	Same as CCR
Coded Target	Photogrammetry target that employs a code which is recognized by the Photogrammetry software
Global Coordinates	Term used to describe a set of operator defined fiducial targets that are created external to the measured part. Global coordinates are used to “leap frog” around a measured part or to re-establish alignment to the part
Laser Tracker (LT)	Measurement system that uses a reflected laser beam and angular encoders to determine three-dimensional coordinates
Leap Frog	The process of moving and re-alignment of a measurement system around the measured part to obtain data not measureable from one location
Length Check	The measurement of a certified Length Standard that is used to validate the performance of the measurement equipment
Operator	Individual operating the metrology system. Typically a Metrology Technician or Metrology Engineer

Part Coordinate System (PCS)	The coordinate system of a part (or assembly of parts. It typically defined during the CAD/design phase. If a PCS or CAD model is not supplied with the component, the measurement system's default coordinates will be applied to the component.
Photogrammetry	Measurements using multiple two-dimensional photographic images (of a pattern of points) to generate a three-dimensional data.
Pin Nest	A target holder that has a precision "pin" aligned (to a known offset) below the center of a CCR
portable CMM (pCMM)	A CMM that is transported to the measurement location
Prismatic Data	A term used to describe geometric shapes in the form of cubes, squares, triangle, cones, etc.
Radius Arm	An extension bar used in conjunction with an LT CCR to obtain a series of points (on the radius of a sphere) whose center is the desired measurement target
Startup Check	A test (or series of tests) to verify that the FARO LT is operating within acceptable limits
Surface Probe	An LT reflector (with interchangeable probe tips) that facilitates handheld measurements.
Uncoded Target	Photogrammetry target that does not employ a code

2.0 DETERMINING MEASUREMENT CATEGORY

2.1 Determining Measurement Category

The individual requesting the measurement (Requestor) and the Metrology Engineer shall use the table in section 2.2 to determine if the measurement will be an Ordinary or Critical, then proceed to Chapter 3 for an Ordinary Measurement or Chapter 4 for a Critical Measurement.

Generally, an ordinary measurement is defined as a measurement for which the accuracy required is low, and measurement errors do not adversely impact cost, schedule or performance of the system for which the measurements are being taken.

A critical measurement is defined as a measurement for which N.I.S.T traceability is required, or the error may adversely impact cost, schedule or performance of the system.

The measurement is Critical if any of the following conditions from the "Critical" column of the table is met. The requestor (requesting Project) can waive the requirement for critical measurement if desired

2.2 Measurement Requirements

CLASSIFICATION		
CONDITIONS	**ORDINARY [all conditions must be met]**	**CRITICAL [any one condition]**
SCHEDULE IMPACT	LESS THAN TWO MONTHS	MORE THAN TWO MONTHS
COST IMPACT	LESS THAN $50K	MORE THAN $50K
PERFORMANCE IMPACT	SYSTEM PERFORMANCE NOT CRITICALLY AFFECTED	SYSTEM PERFORMANCE CRITICALLY AFFECTED
N.I.S.T. TRACEABILITY	NOT REQUIRED	REQUIRED

3.0 PERFORMING ORDINARY MEASUREMENT

3.1 Background

In an ordinary measurement, the metrology equipment should be operating per manufacturer's stated performance parameters, the measured component and its environment should be thermally and dynamically stable (mechanical perturbations and thermal fluctuations as low as reasonably achievable). Deviations from these conditions will yield larger measurement error. Additionally, the alignment to the measured component should be accurate and repeatable.
Essentially, the ordinary measurement is identical to the critical measurement, with the exception that the operator is not required to use N.I.S.T. traceable standards to prove that the equipment is operating properly.

3.2 Responsibilities

Responsibility	Action
Requestor or Project	• Determine that a metrology-based measurement is required. This individual may consult with a Metrology Engineer or Technician in this determination • Complete a Measurement Request Form • Provide CAD model, or access to CAD model of part to be measured. • Provide a clear description of the desired goal(s). • Provide any known fiducial coordinates (alignment points) • Provide access to the area • Delineate the form of data to be output. (i.e., CAD data, Excel Report, Point Report) • Ensures the items in the measurement area are free of any hazardous/unsafe conditions.
Metrology Engineer or Technician	• Evaluate the Measurement Request Form and determine which measurement equipment is best suited for the measurement. • If furnished with a CAD model of the measured part, import the model into the metrology software and create the measurement routine. • Survey the metrology site for hazardous/unsafe conditions. • Transport measurement equipment to area and allow to thermally equilibrate to surroundings • Perform measurement • Provide measurement data to requestor. • Archive copy of measurement file in metrology database.
Requestor	• Archive data in project database

4.0 PERFORMING CRITICAL MEASUREMENT

4.1 Background

In a critical measurement, the operator must validate that the equipment is operating per manufacturer's stated performance parameters. This is accomplished by using the pCMM to measure an N.I.S.T. traceable Length Standard and verifying that the measured length matches the certified length to within the acceptable tolerance (typically the measurement error for the device).

In a critical measurement, the metrology equipment should be operating per manufacturer's stated performance parameters, the measured component and its environment should be thermally and dynamically stable (mechanical perturbations and thermal fluctuations as low as reasonably achievable). Additionally, the alignment to the measured component must be accurate and repeatable. Deviations from these conditions will yield larger measurement error. If these conditions are not met, measurements can proceed, however it should be acknowledged by all parties the required accuracy may not have been achieved.

4.2 Responsibilities

Responsibility	Action
Requestor	• Determine that a metrology-based measurement is required. This individual may consult with a Metrology Engineer or Technician in this determination • Complete a Measurement Request Form • Provide CAD model, or access to CAD model of part to be measured. • Describe the desired goal, and provide accuracy and error requirements. • Provide any known fiducial coordinates (alignment points) • Provide access to the area • Delineate the form of data to be output. (i.e., CAD data, Excel Report, Point Report) • Ensures the items in the measurement area are free of any hazardous/unsafe conditions. • Provides special fixturing (or provides cost center for fabrication of special fixturing) if such fixturing is determined to be necessary for achieving the accuracy and measurement error requested. • Generate a metrology procedure that delineates particular specifics if deemed necessary.

Metrology Engineer or Technician	• Perform the following: • Evaluate the Measurement Request Form and determine which measurement equipment is best suited for the measurement. • If furnished with a CAD model of the measured part, import the model into the metrology software and create the measurement routine. • Survey the metrology site for hazardous/unsafe conditions. • Transport measurement equipment to area and allow to thermally equilibrate to surroundings. • Verify the annual certification of applicable length standards has not expired. • Performs Startup Tests, Length Checks and Compensations for measurement equipment. • Perform measurement • Provide measurement data to requestor. • Archive copy of measurement file in metrology database
Requestor or Project	• Archive data in project database.

5.0 PERSONNEL TRAINING AND QUALIFICATIONS

5.1 Initial Training and Qualifications Responsibilities

Responsibility	Action
Candidate's Supervisor or Manager	• Determine the hardware, system, or software package for which qualification is required (Sections 5.3 and 5.4) and requests training and qualification of personnel by contacting Human Resources. Requests guidance from the Metrology Group, as necessary.
Metrology Manager	• Consult with PPPL Human Resources (HR) Group and select the appropriate method to obtain this training. The training may be via a non-PPPL course, in-house classroom training, practical training, and/or required tests or demonstration. • Make necessary logistical arrangements for in-house training. (Candidate makes travel arrangements for off-site training) • Notify the candidate of scheduled training and arranges for practical training, as necessary.
Candidate	• Attend the scheduled training course, or arranges to challenge any tests or demonstrations through the Metrology Manager. • Makes travel arrangements for off-site training
Qualified Instructor	• Provide the appropriate training and testing. • Fill out and sign training sheets for each module taken by the Candidate • Complete the Candidate's Metrology Training Evaluation Sheet for each system that the trainee obtains qualification. • Forwards copies of all training records to HR.
Metrology Manager or Designee	• Approves the PPPL Metrology Qualification
Human Resources (Training Staff)	• Maintain training and qualification records. Forms in appendix C constitute the record of training for an individual's successful qualification on a hardware system or software package. • Monitor due dates and notifies the individual's manager or supervisor of actions needed to maintain or renew qualifications.

5.2 Continuing Training and Qualifications Responsibilities

Responsibility	Action
Metrology Manager	• Perform periodic performance evaluation of metrology group personnel during measurement sessions and assess whether individual requires remedial or additional training. • Perform periodic program evaluation with PPPL Metrology Group. Distribute industry operating experience and Lessons Learned (both PPPL and external) to metrology group personnel. • Perform periodic evaluation of metrology industry to determine whether enhanced, updated or additional training is warranted for the metrology personnel. • Arrange training for new metrology hardware or software systems.
All	• If additional training is desired, then proceed per section 5.1

5.3 Metrology Technician Qualification Requirements

	(Hardware) Laser Tracker(s)	(Hardware) Articulating Arms	(System) GSI-VSTARS Photogrammetry	(Software) Delcam PowerInspect	(Software) Verisurf
LEVEL 1					
Prerequisite	Basic computer skills	Basic computer skills	Basic computer skills	Basic computer skills	Basic computer skills
Prerequisite	Basic computer skills	Basic computer skills	Basic computer skills	Basic computer skills	Basic computer skills
Initial Training (given by Qualified PPPL Metrology Operator or Vendor Representative)	Laser Tracker Instructional Basics (classroom and/or reading material)	Articulating Arm Instructional Basics (classroom and/or reading material)	GSI VSTARS Instructional Basics (classroom and/or reading material)	Delcam PowerINSPECT Instructional basics (classroom and/or reading material)	Verisurf Instructional Basics (classroom and/or reading material)
Initial OJT and/or Practical Test (given by qualified PPPL Metrology Operator)	**Demonstrate:** -Setting up system. -Performing diagnostic checks -Handling reflectors, probes, & targets.	**Demonstrate:** -Setting up the system. -Performing "length check" and "probe calibration".	**Demonstrate:** -Ability to handle the camera and associated hardware. - Demonstrate ability to operate the VSTARS software. -Ability to place reflective targets -Ability to properly photograph project. -Execute a pre-established Photogrammetry Project.	**Demonstrate:** -Ability to follow pre-established measurement routine. -Ability to align to measured part -Ability to measure simple geometric and prismatic shapes.	**Demonstrate:** -Ability to create alignment. -Ability to create levels and segregate data. -Ability to import IGES files. -Ability to save data and create reports.
LEVEL 2					
Advanced Skills	**Demonstrate:** -Ability to compensate tracker. -Understanding of the effect of environmental condition on measurements.	**Demonstrate:** -Ability to troubleshoot arm operation via Vendor's diagnostic software. -Understanding of the effect of environmental condition on measurements.	**Demonstrate:** -Ability to create and complete a simple photogrammetry project unassisted. -Understanding of the effect of environmental condition on measurements.	**Demonstrate:** -Ability to align to part that does not have known fiducial points. -Ability to create and execute measurement routine. -Understanding of error propagation	**Demonstrate:** -Ability to align to part that does not have known fiducial points. -Ability to create measurement routine. -Understanding of error propagation

5.4 Metrology Engineer Qualification Requirements

	(hardware) Laser Tracker(s)	(hardware) Articulating arms	(System) GSI-VSTARS Photogrammetry	(Software) Delcam PowerINSPECT	(Software) Verisurf
Prerequisite	Engineering Degree; Basic computer skills	Engineering Degree; Basic computer skills	Engineering Degree; Basic computer skills	Engineering Degree; Basic computer skills	Engineering Degree; Basic computer skills
Initial Training (given by qualified Level 2 operator or vendor representative)	Laser Tracker Instructional Basics (classroom and/or reading material)	Articulating Arm Instructional Basics (classroom and/or reading material)	GSI VSTARS Instructional Basics (classroom and/or reading material)	Delcam PowerINSPECT Instructional basics (classroom and/or reading material)	Verisurf Instructional Basics (classroom and/or reading material)
Initial OJT and/or Practical Test (given by qualified PPPL Metrology Operator)	**Demonstrate:** -Setting up system. -Performing diagnostic checks -Handling reflectors, probes, & targets.	**Demonstrate:** -Setting up the system. -Performing "length check" and "probe calibration".	**Demonstrate:** -ability to handle the camera and associated hardware. - Demonstrate ability to operate the VSTARS software. -Ability to properly target a project. -Ability to properly photograph a project. -Execute a photogrammetry Project.	**Demonstrate:** -Ability to follow pre-established measurement routine. -Ability to align to measured part -Ability to measure simple geometric and prismatic shapes.	**Demonstrate:** -Ability to create alignment. -Ability to create levels and segregate data. -Ability to import IGES files. -Ability to save data and create reports.
Advanced Skills All skills required for Metrology Technician Level 2 **PLUS** (Approved by Metrology Manager)	**Demonstrate:** -Competence in designing rigid mounting systems for the LT and/or the measured part -Advanced understanding of error propagation as it relates to multiple re-alignments.	**Demonstrate:** -Competence in designing rigid mounting systems for the Arm and/or the measured part. --Advanced understanding of error propagation as it relates to multiple re-alignments.	**Demonstrate:** -Competence in refining the targeting and photographing tasks with the goal of increasing overall accuracy and precision. -Create and execute a complex Photogrammetry project	**Demonstrate:** -Ability to create complex measurement routines. -Ability to perform best fit refinements. -Ability to interface with CAD design software to enhance Pre and Post processing of data.	**Demonstrate:** -Ability to create complex measurement routines. -Ability to perform best fit refinements. -Ability to interface with CAD design software to enhance Pre and Post processing of data.

5.5 Metrology Personnel Qualification Requirements (Records & Examination)

5.5.1 Qualification Records

5.5.1.1 Personnel qualifications shall be documented in an easily auditable format and shall include, as a minimum, the following types of information:

- Records of training completed at PPPL, or elsewhere, such as attendance sheets or computer summaries or certificates.
- Records of training exceptions (per TR-006)
- Record of training and performance evaluations.

5.5.2 Performance Evaluations

5.5.2.1 Performance evaluations are based upon the performance items enumerated in sections 5.3 and 5.4

5.5.2.2 Candidates must initially qualify for each metrology system they operate.

5.5.2.3 Qualified Metrology pCMM Operators will be periodically assessed do determine whether they require repeat (remedial) or additional training.

5.5.2.4 Qualified Metrology pCMM Operators shall demonstrate capability after prolonged absence (greater than one year) of measurement.

5.5.2.5 No numerical value is assigned to operational evaluations. The candidate's demonstrations are evaluated by the examiner as "satisfactory" or "unsatisfactory" based upon the following criteria:

- The individual exhibits a basic ability in the performance area.
- The individual is capable of correctly performing the action after some clarification by the examiner.

5.5.2.6 The job functions demonstrated, the candidate's performance in these demonstrations, and the examiner's evaluation shall be documented using the Metrology Training (Hardware/Software) Evaluation Sheets (Appendix C).

6.0 METROLOGY HARDWARE

6.1 Laser Trackers

6.1.1 Background

Laser Trackers (LTs) are measuring devices that measure in three dimensional coordinate locations. LTs utilize a retro-reflected beam of laser light to determine distance and precise angular encoder measurements to establish the angular position.

6.1.2 Typical Applications

Laser Trackers can be used in most any situation, however to obtain maximum precision the tracker, the part must be mechanically stable and the environment conditions (temperature, humidity and air movements) must also be stable.

6.1.3 Typical Obtainable Accuracy

Laser Trackers accuracy is derived from the sum of the accuracies of the "laser distance" measuring components AND the accuracy of the "angular displacement" measuring components. The distance measurement error is typically on the order of 0.0005" (13μm) and is not proportional to the distance measured, while the angular measurement error is 5 to 10 times greater than the distance measurement error and **IS** proportional to the measurement distance.

When determining whether a measurement (measurement error) is acceptable, the operator should consult the vendor's specified accuracies (for the particular laser tracker used) for the distances and pointing angles observed during that measurement

6.1.4 Calibration/Compensation Requirements

The laser tracker should be checked upon startup, as specified by the manufacturer. In addition to the startup check, a length standard is available to validate the operational readiness.

6.2 Articulating Arms

6.2.1 Background

Articulating Arms are measuring devices comprised of precision length tubes joined by high accuracy encoders at the joints. They employ multiple probe tip styles (spherical, point, scanner) that are tailored to measuring various surfaces. The operator typically touches the measured part with the probe tip and then presses a button on the arm to take the measurement. This equipment is used in conjunction with a metrology software package to make the measurements.

6.2.2 Typical Applications

Articulating Arms are typically used to make close-range measurements, specifically those measurements that span a range equal or less than the operating length of the device. When the measurement range exceeds the size of the arm's capability, then the arm must be moved and re-aligned (Leap Frog), which can result in accumulation of measurement error.

6.2.3 Typical Obtainable Accuracy

Articulating arm accuracy is defined by the manufacturers for each particular model however in general, the longer the arm, the larger the measurement error. This is due to the incrementally increasing deflection of the longer tubes used in the larger arms. The measurement error is typically given for the spherical volume that an arm can measure from a fixed location. Note that the manufacturer quoted specifications are for the arm, mounted and used in an ideal situation (perfectly rigid arm mount, rigidly mounted part and stable environmental conditions). Measurement errors in actual field work will typically be greater since the conditions are rarely ideal. The Metrology Engineer should assess each particular measurement setup and estimate the accuracy and measurement error.

6.2.4 Articulating Arm/Probe Calibration/Compensation Requirements

6.2.4.1 Articulating Arm(s)

Calibration is set at the manufacturer's facility and is not altered in the field. The calibration is checked in the field (prior to measurements) by measuring against a standard.

For the FARO Silver arm, a 1-inch sphere (mounted to the base of the unit) is measured each time a new probe is attached to the arm. The software analyzes the measurement and compensates for any discrepancy.

For the Romer arm, a certified length standard is measured at the start of any Critical Measurement. This measurement is made with ***Probe1***, which is considered a "reference standard" and cannot be calibrated. The actual length measured **MUST** be within the vendor specified range (the range varies with each Arm Type and Length) of the certified length standard. The values are available in the Romer WinRDS Arm Utilities Guide.
At a minimum, the length check is used to validate the performance of the arm, however if the length standard is mounted on the measured part or on the same foundation as the arm, the "length check" can be used to validate the measurement process as a system.

If a Romer Arm does not meet its "Length Checkout" criteria, the measurement should be delayed and/or the arm should be removed from service until the discrepancy is resolved.

6.2.4.2 Probe Calibration

If a Romer Arm does not successfully meet "length check", then the operator should not perform a probe calibration.

As mentioned above, probe compensation is performed for the FARO Arm at the start of a measurement, or whenever a probe is changed.

For the Romer arm, probe calibration shall be performed after successful "Length Check", at the start of a critical measurement **AND** at any time that the operator deems it necessary during the measurement. The probe calibration involves taking multiple data points at the same location allowing the software to derive a new calibration for the probe. The criteria for successful calibration are listed in the Romer WinRDS Arm Utilities Guide. If an arm passes length check but a particular probe cannot meet its calibration criteria, then it should be removed from service until the discrepancy is resolved.

6.3 Photogrammetry

6.3.1 Background

Photogrammetry is a method for making three-dimensional measurements using two-dimensional photographic images. Photogrammetry employs the latest generation of high resolution digital cameras and sophisticated computer software to solve complex mathematical algorithms. It is a measurement system that is ideally suited for measuring discreet points (as opposed to contoured surfaces).

Unlike Articulating Arms and Laser Trackers which are "real-time" measurement systems, photogrammetry results are provided only after a large number of photographs are taken and processed by the software. Advances in computer processing have recently reduced this processing time down to a point where photogrammetry results are available in a timeframe that makes this technology a viable alternative to the "real-time" systems

The measurement process involves placing light-reflective targets onto the measured component. Photographs are taken until all the targets are recorded, ensuring that subgroups of the targets are recorded on multiple images. The software then calculates the three-dimensional relationship of all the targets. A calibrated scale bar must be included in the project if true scale is desired.

6.3.2 Typical Applications

Photogrammetry is ideally suited to making measurements of items that can be encircled by the operator.

6.3.3 Calibration/Compensation Requirements

Photogrammetry relies on an external reference for true scale (absolute dimensional measurement) therefore it is a system without an internal calibration. The software provides feedback in the form of statistical data regarding the solution derived from processing the 2D image data into the 3D information. This feedback is reflective of the quality of the photographic coverage and used by the operator to determine whether the number of photographs and/or technique is adequate.

6.4 Metrology Hardware Inspection Responsibilities

Responsibility	Action
Metrology Operator	Assess operational capability of metrology equipment at start of, during and end of each measurement. If equipment does not meet manufacturer's stated accuracy/measurement error performance criteria then: • Perform manufacturer's recommended remedial action for particular equipment and, if necessary, redo measurements already performed. If this action does not result in properly functioning equipment, then remove equipment from service and arrange for manufacturer/factory service.
Procurement Group	Process service request, arrange for shipping of equipment to/from manufacturer/vendor.
Metrology Operator	Inspect equipment after it is returned from manufacturer/vendor service. Verify that performance meets or exceeds manufacturer's stated performance criteria.

7.0 METROLOGY SOFTWARE

7.1 Verisurf (Verisurf)

7.1.1 Description

Verisurf is a CAD-based metrology software package. It is metrology software grafted onto the Mastercam CAD/CAM software package. It is capable of operating many metrology hardware platforms, including all those owned by PPPL. The benefit of using a CAD-based system is that measured data is compared to the CAD model with deviations displayed for the operator. Additionally, measured data can be used to refine the alignment of the metrology system to the part by performing "best fit" refinements of the data to the CAD model. Because of the integration with Mastercam, Verisurf has the ability to store metrology data into multiple layers which allows the operator to organize their project by displaying or hiding any particular layer, along with its data. This also allows the operator to selectively include (or exclude) data from analyses or best fits. Verisurf has the ability to generate user-customizable reports of the measurement results.

7.1.2 Software Updates and Validation

It is permissible to use any officially released version. Note that metrology software packages are typically backward compatible, but not always forward compatible.

7.2 PowerINSPECT (Delcam)

7.2.1 Description

PowerINSPECT is a CAD-based metrology program that was bundled with the Romer pCMM arms. Unlike Verisurf, multiple layers are not available – the operator must set up multiple files if all the data cannot be obtained in the original file. PowerINSPECT excels at measurements that are well defined and repeated multiple times. The operator can create a template of the measurement routine, ensuring that particular measurements be taken in a specific sequence, as desired.

7.2.2 Software Updates and Validation

It is permissible to use any officially released version. Note that metrology software packages are typically backward compatible, but not always forward compatible.

7.3 CAM2 (Faro)

7.3.1 Description

CAM2 is a software package that was bundled with the FARO Silver arm. Unlike Verisurf, it can only be used with the FARO arm. It is NOT a CAD-based program; rather it is a package that is used to obtain either point data or Prismatic data.

7.3.2 Software Updates and Validation

It is permissible to use any officially released version. Note that metrology software packages are typically backward compatible, but not always forward compatible.

7.4 Responsibilities – Metrology Software

Responsibility	Action
Metrology Manager	Ensure that software used for measurements is a vendor approved release.
Metrology Manager	Approve requisitions for new software and/or software support.
Metrology Engineer & Technician	Install new software and/or software updates onto metrology computers.

8.0 LENGTH STANDARDS

8.1 Definition

Length standards are devices that are employed by metrology operators to validate that the measurement device is operating within the Manufacturer's stated performance specifications.

In general, Length Standards are durable objects that maintain their physical parameters. A length standard should always be used to validate the operation of metrology hardware, however if the certification has expired, that standard cannot be used for a Critical Measurement.

8.2 Description of Length Standards

8.2.1 Romer Length Standards

One-meter length steel bars with conical seats (for Romer 15mm ball Probe1) at one-half meter and one meter separations

8.2.2 LT Length Standard

80-inch steel bar with 1.5" CCR mounts

8.2.3 Photogrammetry Length Standards

Brunson Scale Bar Kit with reflective photogrammetry targets.

8.3 Certification Requirements

8.3.1 Length Standards shall be maintained in accordance with PPPL Policy P-086 "Specifying, Using and Calibrating Measuring and Test Equipment"

8.3.2 To retain valid N.I.S.T certification, Length Standards shall be recertified on an annual basis.

8.3.2 A Length Standard with an expired certification (older than 1 year) CAN be used in an ordinary measurement, but CANNOT be used for a Critical Measurement.

8.3.3 The Length Standard identification number and certification date(s) shall be recorded as part of any Critical Measurement.

8.4 Responsibilities – Inspecting Length Standards

Responsibility	Action
Metrology Manager	Keep list of specific Length Standards. List shall include description of standard, identifying number, certified length, dates of calibration.
Metrology Engineer/Tech	Periodically inspect Length Standards for wear or damage every occasion the Length Standard is used. Remove damaged Length Standards from service.
Metrology Engineer/Tech	Arrange for Annual re-certification of Length Standard.
Metrology Manager	Update Length Standard database to reflect any changes, additions and re-certifications.

9.0 TARGETS, TOOLING BALLS & OTHER FIDUCIAL SYSTEMS

9.1 Background

9.1.1 Targets are measurement reference points that are often (but not always) external to the measured part. Targets provide convenient, repeatable measurement locations that are typically easier to access than the actual features of the measured part. When targets are not a feature of the measured part (on-part target), they must be brought into the Part Coordinate System (PCS) after alignment to the part is established. After targets are measured, they often represent the most repeatable, accurate means of re-aligning to the part.

9.1.2 When metrology is considered early in the design process, provisions for target locations can be incorporated into the design and manufactured into the part.

9.2 Responsibilities – Inspecting Targets

10	Responsibility	11	Action
12	Equipment Owner	13	Provide targets to Metrology Group for inspection.
14	Metrology Engineer/Tech	15	Periodically inspect targets for wear or damage per appropriate section. Remove damaged or worn targets from service.
16	Equipment Owner	17	Replace targets removed from service with new or refurbished targets.

9.3 Laser Tracker Reflector Inspection Criteria

PERIODIC INSPECTIONS
PERIODICITY: Every use
DOCUMENTATION: NO RECORDS REQUIRED

INSPECTION CHECK LIST:

Reflectors shall be removed from service if any of the following conditions apply

9.3.1 Scratches/gouges that can be felt with fingernail.

9.3.2 Cracked/broken reflector surface.

9.3.3 Excessive measurement error when measured in fixed location while turning reflector through several measurements.

9.4 Tooling Ball Inspection Criteria

PERIODIC INSPECTIONS
PERIODICITY: Every use
DOCUMENTATION: NO RECORDS REQUIRED

INSPECTION CHECK LIST:

Tooling balls shall be removed from service if any of the following conditions apply

9.4.1 Scratches/gouges that can be felt with fingernail.

9.4.2 Cracked/broken shoulder.

9.4.3 Visible signs of bending or distortion

9.4.4 Shoulder does not seat flat

9.4.5 Excessive measurement error when measured in fixed location while turning tooling ball through several measurements.

9.5 Photogrammetry Target Inspection Criteria

9.5.1 Coded Targets

PERIODIC INSPECTIONS
PERIODICITY: Every use
DOCUMENTATION: NO RECORDS REQUIRED

INSPECTION CHECK LIST:

Coded targets shall be removed from service if any of the following conditions apply

9.5.1.1 Software repeatedly fails to recognize target

9.5.2 Pin-nest Targets

PERIODIC INSPECTIONS
PERIODICITY: 1) Visual inspection prior to each use
2) Annual
DOCUMENTATION: NO RECORDS REQUIRED

INSPECTION CHECK LIST:

Pin-nest targets shall be removed from service if any of the following conditions apply

9.5.2.1 Failure of annual check in Tooling Plate.

9.5.2.2 Reflective coating damaged.

9.5.2.3 Visible signs of bending or distortion.

9.6 On-Part Targets (built into part)

PERIODIC INSPECTIONS
PERIODICITY: Every use
DOCUMENTATION: NO RECORDS REQUIRED

INSPECTION CHECK LIST:

On-Part targets shall be re-measured/redefined or removed from service if any of the following conditions apply

9.6.1 Scratches/gouges that can be felt with fingernail.

9.6.2 Damaged or distorted

9.6.3 Excessive deviation from value previously obtained during measurements.

Appendix A - Measurement Request Form

REQUESTER_____PHONE_____DATE REQUESTED_____

JOB TITLE_____DATE NEEDED_____

CHARGE NUMBER_____-_____-_____

TYPE OF MEASUREMENT CRITICAL ☐ ORDINARY ☐

Section A: To be completed by Requesting Individual:
DESCRIPTION OF MEASUREMENT

Type of measurement:

☐ Surface Inspect ☐Reference point determination ☐ Feature determination ☐Determine present condition(location/alignment) ☐ Use metrology to alter shape or location

☐ Accuracy required:_____

☐ CAD model(s) provided:_____

☐ Location of component(s):_____

☐ Reference points for alignment provided?_____ (If yes, attach data)

☐ Is component and/or environment mechanically stable:_____

☐ Is component and/or environment thermally stable:_____

☐ Accuracy required:_____

☐ Desired format of data output:_____

Post processing required:

☐ Best Fit ☐Summary report ☐Point Inspection/Analysis ☐ transfer/convert to PPPL CAD system

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Section B: To be completed by Metrology Engineer after a field review/site inspection of the measurement is done:

☐ Proposed metrology equipment:_____

☐ Proposed metrology software:_____

☐ Job requires fabrication of special tooling or fixtures:_____

☐ Job required additional environmental control:_____

☐ Estimate of attainable accuracy:_____

Comments:

Estimate of man-days required: _____ Date: _____

Metrology Engineer

Estimate accepted by:_____ Date: _____

Requesting Individual

Appendix B- Measurement Documentation Form

(To be completed by Metrology Engineer or Technician)

REQUESTER_____

JOB TITLE_____DATE NEEDED_____

DESCRIPTION OF MEASUREMENTS MADE

- **Type of measurement(s) made:**
  ☐ Surface Inspection ☐ Use metrology to Install/locate ☐Reference point determination
  ☐ Feature determination ☐Determine present condition (location/alignment)
- **Metrology Hardware System used**:_____
- **Software used:**_____
- **Name(s) of data file(s) generated :**_____ _____ _____
  _____ _____ _____
- **Length Check against standard:**
  - Serial # of Standard Used:_____ Expiration date of certification:_____
  - Length of Standard Used:_____
  - Length Check Measurement:_____
- **RMS Error of Alignment Achieved:**_____
- **Number of re-alignments (if any):**_____
- **Estimate of typical data point measurement accuracy:**_____
- **Estimate of total accuracy (alignment and measurement):**_____
- **Post processing done:**
  ☐ Best Fit ☐Surface Scan ☐Point Inspection/Analysis ☐ transfer/convert to PPPL CAD system

Comments:

Measurements performed by: _____ Date: _____

Metrology Engineer/Technician

Appendix C - Metrology Hardware Training Evaluation Sheet

Metrology Hardware:_____

	Demonstrate Skills	Training received (type of training & duration)	Evaluator initials & Date
TECH LEVEL 1			
Prerequisite Basic Computer Skills	-Manipulate data files and folders in Microsoft Windows OS. -Retrieve and store data files to networked drives.		
Initial Training (given by Qualified PPPL Metrology Operator or Vendor Representative)	-Demonstrate theoretical understanding of the operation of the system.		
Initial OJT and/or Practical Test (given by qualified PPPL Metrology Operator)	-Demonstrate understanding of system operation as described in section 5.3.		
TECH LEVEL 2			
Advanced Skills (given by qualified PPPL Metrology operator?)	-Demonstrate understanding of system operation as described in section 5.3		
ENGINEER			
Additional Skills	-Ability to designing rigid mounting systems for the pCMM and/or the measured part.		

Approved:_____ Date:_____
Metrology Manager

Appendix C - Metrology Software Training Evaluation Sheet

Metrology Software:_____ Version:_____

	Demonstrate Skills	Training received (type of training & duration)	Evaluator initials & Date
TECH LEVEL 1			
Prerequisite Basic Computer Skills	-Manipulate data files and folders in Microsoft Windows OS. -Retrieve and store data files to networked drives.		
Initial Training (given by Qualified PPPL Metrology Operator or Vendor Representative)	-Understanding of the operation of the software.		
Initial OJT and/or Practical Test (given by qualified PPPL Metrology Operator)	-Ability to follow pre-established measurement routine. -Ability to create a simple measurement routine. -Ability to align to measured part. -Ability to measure lines, planes rectangles, circles, spheres, cones. -Ability to project measurements onto a planar surface.		
TECH LEVEL 2			
Advanced Skills (given by qualified PPPL Metrology operator?)	-Ability to create complex measurement routines. -Ability to import CAD models into software. -Ability to align to part that does not have known fiducial points. -Ability to perform best fit refinements. -Ability to set up and run data analysis. -Ability to generate inspection reports.		
ENGINEER			
Additional Skills	-Advanced understanding of error propagation as it relates to multiple re-alignments. -Ability to interface with CAD design software to enhance Pre and Post processing of data.		

Approved:_____ Date:_____
Metrology Manager