

## Princeton Plasma Physics Laboratory Procedure

Procedure Title: **Metrology for Field Period Assembly (FPA)**

Number: <b>D-NCSX-FPA-010</b>	Revision: <b>0</b>	Effective Date: <b>1/14/2008</b>  Expiration Date: <i>(2 yrs. unless otherwise stipulated)</i>
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### Procedure Approvals

Author: **Steve Raftopoulos**

ATI: **Steve Raftopoulos**

RLM: **Larry Dudek**

Responsible Division: **NCSX**

### Procedure Requirements Designated by RLM

**LABWIDE:**

<b>X</b>	Work Planning Form # <b>WP-1138 &amp; WP-1188</b> (ENG-032)		Lockout/Tagout (ESH-016)
	Confined Space Permit (5008, SEC.8 Chap5)		Lift Procedure (ENG-021)
	Master Equip. List Mod (GEN-005)		ES&H Review (NEPA, IH, etc.) NEPA 1283
	RWP (HP-OP-20)		Independent Review
	ATI Walkdown		Pre-Job Brief
	Post-job Brief *		Hazard analysis

**D-SITE SPECIFIC:**

<b>X</b>	D-Site Work Permit (OP-AD-09)		Door Permit (OP-G-93)
	Tritium Work Permit (OP-AD-49)		USQD (OP-AD-63)
	Pre-Job Brief (OP-AD-79)		T-Mod (OP-AD-03)
	** DCA/DCN (OP-AD-104) # _____		

\*\* OP-AD-104 was voided by procedure ENG-032. However, DCAs that were open at the time of adoption of ENG-032 are still considered valid for work approval purposes.

<b>REVIEWERS</b> (designated by RLM)	<b>Rec'd/ Incorp.</b>
<b>Comments</b>	
Accountable Technical Individual	
Test Director	
Independent Reviewer	
D-Site Shift Supervisor	
Independent	
NCSX Dimensional Control Representative .....	<b>R. Ellis</b>
Vacuum	
FPA Field Supervisors.....	<b>M. Viola</b>
Project Engineer for Stellerator Systems (WBS 1) Manager	
WBS Manager for Modular Coils (WBS14)	
Quality Assurance/Quality Control. ....	<b>Judy Malsbury</b>
Maintenance and Operations Division	
Energy Conversion System/Motor Control Division	
Engineering .....	<b>T. Brown</b>
Environmental Restoration & Waste Management Division	
Environmental, Safety & Health	
Industrial Hygiene	
Health Physics	
RLM .....	<b>Larry Dudek</b>

<b>TRAINING</b> (designated by RLM)			
No training required _____		Instructor <b>Steve Raftopoulos</b>	
Personnel (group, job title or individual name)	Read Only	Instruction- job Briefing	Hands On
<b>Lead Tech.</b>		<b>X</b>	
<b>Technicians performing task</b>		<b>X</b>	
<b>Field Supervisors</b>		<b>X</b>	
<b>Quality Control Representative</b>		<b>X</b>	
<b>Training Rep.</b>			

## RECORD OF CHANGE

<b>Revision</b>	<b>Date</b>	<b>Description of Change</b>
00		Initial release

## 1. Purpose

- 1.1. The purpose of this procedure is to provide guidance for measurements for Field Period Assembly (FPA) activities. This procedure, used in concert with the Field Period Assembly Procedure(s) and the Dimensional Control Plan(s), provides guidance for the measurement process required to complete the Field Period Assembly task

## 2. Scope

- 2.1. This procedure provides instruction proper set-up and operation of metrology hardware, and for proper measurement technique for the following devices:
  - 2.1.1. Leica LTD500 and Faro Tracker X Laser Trackers
  - 2.1.2. Romer pCMM arm.
- 2.2. This procedure provides guidance for the gathering and archiving of data collected during the measurement/inspection process.
- 2.3. Measurements shall be made by individuals that are trained in the operation of the LTD500 Laser Tracker, the FARO Tracker X, Romer pCMM arm(s), and the use of Verisurf and/or PowerINSPECT software. This procedure **DOES NOT** provide instruction and is not a substitute for proper training on the metrology hardware and software.
- 2.4. This procedure does not cover the sequence of steps required to measure, position or assemble the Modular during Field Period Assembly process. These steps are covered in the Field Period Assembly Procedure(s) and Dimensional Control Plan(s).
- 2.5. In the event that a requested measurement is not covered by an approved FPA Procedure or Dimensional Control Plan, then the Metrology Request Form (appendix A) and the Measurement Documentation Form (appendix B) shall be used to plan and document the measurement.

## 3. Definitions

- 3.1. **CAD** Computer Aided Design Drafting.
- 3.2. **pCMM** Portable Coordinate Measurement Machine.
- 3.3. **Fiducial Points** Reference features located on the component used for alignments.
- 3.4. **Global Points** Reference typically points located off the measured component that are used for moving and re-aligning measurement equipment to the coordinate system
- 3.5. **Superpoint** A laser tracker measured point which consists of an average of (a minimum of) 100 points

- 3.6. **“Length Check” procedure** Process for validating the hardware to a NIST traceable length standard.
  - 3.7. **“Point Check” procedure** Process for establishing or verifying the calibration of a probe.
  - 3.8. **FPA** Field Period Assembly
  - 3.9. **Metrology Engineer** Individual responsible for the metrology program. Oversees the measurement process.
  - 3.10. **Metrology Technician** Individual trained to operate the metrology equipment for taking measurements.
  - 3.11. **Dimensional Control Representative** Individual Responsible for the definition of dimensional requirements.
- 4. References**
- 4.1. **Verisurf Operating Manual**
  - 4.2. **Verisurf Training Manual**
  - 4.3. **CimCore Arm Utilities Guide**
  - 4.4. **Leica EmScon Manual**
  - 4.5. **Faro Utilities Manual**
  - 4.6. **NCSX-PLAN-MFOP** “Manufacturing Facility Operations Plan”
  - 4.7. **D-NCSX-FPA-002,** “Field Period Assembly Station Two” Procedure
  - 4.8. **NCSX-PLAN-FPA2DC-00,** “NCSX Modular Coil Half Period Assembly (Station 2) Dimensional Control Plan”
- 5. Tools and Special Equipment**
- 5.1. Romer pCMM Arm
  - 5.2. Leica LTD500, (EmScon) Laser Tracker
  - 5.3. Faro Tracker-X, Laser Tracker
  - 5.4. Laser Tracker Length Standard – 80” Steel bar with 1.5” SMR/CCR nests
- 6. Precautions and Limitations**
- 6.1. The ROMER pCMM arm and the Laser Trackers are delicate instruments. They will be damaged if mishandled.

- 6.2. The Probe tips are susceptible to damage. If the operator suspects that the probe has been damaged, a different probe shall be used until the damaged probe has been recalibrated and/or repaired.
- 6.3. The accuracy and precision of measurements is greatly affected (or rendered invalid) if either the measuring instrument or the measured component moves during the measurement. Ensure that both the measuring instrument and the measured component are secure and will not move relative to each other during the measurement process.
- 6.4. The measuring instrument must remain at a constant, stable temperature (the same as the part being measured) during calibration and subsequent measurements.
- 6.5. Each Romer arm has a dedicated set of standard probes. Do not interchange these components without the consent of the Metrology Engineer.
- 6.6. Each Romer arm has a set of unique calibration files which must be loaded into its operating computer. If the wrong calibration files are loaded the arm will not pass the “Length Check” procedure. Ensure that the correct calibration files are loaded into the operating computer prior to the start of measurements. Calibration files are stored on the “P-drive” at the following location:

P:\web\ncsx.pppl.gov\NCSX\_Construction\Dimensional\_Control\_Metrology\Metrology\_Measurements\Romer Arm Calibration files

## **7. Prerequisites for Using Metrology Equipment**

- 7.1. When starting up either laser tracker from an “off and cold” condition, ensure that it has reached stable operating temperature prior to starting measurements.
  - 7.1.1. For the FARO tracker, perform the startup checks.
  - 7.1.2. For the Leica tracker, perform the two-face field checks.
- 7.2. At least once per day [during measurements] and/or prior to the start of a critical measurement, the measuring instrument shall undergo a “Length Check” procedure. This procedure involves measuring a N.I.S.T. traceable standard to within a specified accuracy.
  - 7.2.1. For the Romer pCMM, perform the “Length Check” per Appendix C. The “average value” shall be within 0.100mm of the value on the length bar label. The Std. Dev. value shall be less than 0.100mm. If either of these values are not within these limits, then remove the arm from service and contact the Metrology Engineer.
  - 7.2.2. For the Laser trackers, measure the length bar and compare the measurement to the value printed on the label. Note that the calibrated value is for a specific temperature (also printed on label). If the room temperature is different, then apply temperature compensation via the Verisurf VDI control screen. The measured length shall be within 0.005” of the calibrated length, otherwise remove the tracker from service and contact the Metrology Engineer.

**7.3.** At the start of a measurement, the probe(s) being used shall be checked for accuracy and calibrated (if necessary).

**7.3.1.** For the laser trackers, perform the following:

**7.3.1.1.** Place the FARO “Break Resistant” 1.5” SMR in a magnetic nest at a distance approximately 2 meters from the tracker and take a superpoint. Record position of point - will be the reference that subsequent probe data is compared against.

**7.3.1.2.** In the same nest location, repeat this process with any additional probes (surface reflector, ½” CCR/SMR and radius bar). Take superpoints when possible.

**7.3.1.3.** Compare the data from 7.3.1.2 with the data from 7.3.1.1. If the difference is greater than 0.002”, then remove this probe from service and notify the Metrology Engineer.

**7.3.2.** For the Romer pCMM arms.

**7.3.2.1.** Using CimCore Arm Utilities (access directly or via the Verisurf VDI) perform the “Probe Calibration” procedure as outlined in Appendix C.

## **8. Procedure for Taking Measurements:**

**8.1.** A CAD model of the coils to be measured or assembled is to be loaded into the *Verisurf* software. Contact the System Integrator (ext. 2156) to verify that the latest revision CAD file is being used.

**8.2.** Establish a new *Verisurf* file for the measurement. The file should be named in the following format: (Date)\_(Part Identifier)\_measurement description, where:

**8.2.1.** (Date): mm\_dd\_yy

**8.2.2.** (Part Identifier):

**8.2.2.1.** Coils: A1 to A6, B1 to B6, C1 to C6;

**8.2.2.2.** Modular Coil Half Period: MCHP-1 to 6

**8.2.3.** (Measurement description): Shall be a short description of the measurement or condition of the component measured.

**8.2.3.1.** “warped” for coil pre-measurements

**8.2.3.2.** “AB\_assembled” for the A/B MCHP assembly phase

**8.2.3.3.** “ABC\_assembled” for the A/B/C MCHP assembly

*Note: An example of a correctly named file is as follows:*

“02\_22\_08\_MCHP2\_ABC\_assembled”

**8.2.4.** In addition to the CAD model, the measurement file should include the uniquely named layers to contain the following:

**8.2.4.1.** Layer (or layers) for the fiducial point reference locations

**8.2.4.2.** Layer(s) for any measured data taken during the measurement or assembly process.

**8.2.4.3.** A layer with no data, with a title that refers to the Verisurf measurement file that is the basis for the fiducial reference data of this new file. For the MCHP there shall be three such layers, each one referring to the individual coil's Verisurf data file.

**8.2.4.4.** A layer for recording the measurement of the length standard used to verify the measurement equipment during the measurements. The title of the layer should be the serial number and the calibrated length of the standard.

### **8.3. Aligning to component**

**8.3.1.** Operators shall survey the component(s) to be measured and determine the position (or multiple positions if required) for measurements. Move the tracker to the first location.

**8.3.2.** If not already installed, locate and install global monuments (preferably using 1.5" CCR/SMR) so that they are in the line-of-site of the tracker from all measurement positions.

**8.3.3.** Install at least two reflector nests (alignment reference points 1 and 2) *on the component being measured* so that they can be measured from all tracker positions. Create a separate layer (align\_ref\_pts) in Verisurf software for the measurement of these points from the initial alignment.

**8.3.4.** Align tracker to the part being measured.

**8.3.5.** Rename and save the alignment report(s). Use the name established in 8.2 as the basis for the alignment report name. Future realignments to the component will use the same name with a sequential number appended (e.g., xxx\_1, xxx\_2).

**8.3.6.** Measure all Global Points using the superpoint method.

**8.3.7.** Measure the two reference points using the superpoint method.

### **8.4. Taking Measurement Data**

**8.4.1.** Take measurements from this position. Ensure that the measuring system and the measured component are not displaced from contact during the measurement process.

**8.4.2.** When measurements from this position are complete, recheck alignment by:



- 8.4.2.1.** Re-measuring the “align\_ref\_pts”. Compare the X,Y,Z coordinate values before/after. The values shall not deviate by more than 0.004” in total, or by more than 0.002” in any one axis. If the deviation is higher than the specified amount (after repeated measurement), then delete all data taken since last valid alignment check.
- 8.4.2.2.** Check alignment established in step 8.3.4 by re-measuring a minimum of 3 of the Global Points established in 8.3.6. If the Global Point values are within 0.003”, but the “align\_ref\_pts” check fails, this implies that the part has shifted with respect to the Global Points and re-alignment is necessary, unless the shift is an anticipated event such as distortion due to welding or fastening. The Dimensional Control Plan and/or Dimensional Control Coordinator should be consulted in this situation.
- 8.4.2.3.** If the Global Point values are different by more than 0.004”, then proceed back to step 8.3.4 and realign to the part coordinate system via component fiducial points.
- 8.4.2.4.** If the deviation is within the allowable tolerance, then proceed to next step.
- 8.4.3.** Move tracker to next position and re-align using fiducials points on the part in combination with the global monuments.
- 8.4.4.** Rename and save alignment report(s).
- 8.4.5.** Repeat steps 8.4.2 to 8.4.6 until component is fully measured from all required tracker locations.

## **8.5. Archiving data**

- 8.5.1.** When measurements are complete, save copy Verisurf data file, as well as any other relevant files (IGES data files, Alignment and Inspection Reports, etc) on the local backup drive.
- 8.5.2.** Transfer copy of data files to the backup folder located on the “P” drive at the following location:

P:\web\ncsx.pppl.gov\NCSX\_Construction\Dimensional\_Control\_Metrology\Metrology\_Measurements\FPA

**Appendix A - Metrology Request Form**

REQUESTER \_\_\_\_\_ PHONE \_\_\_\_\_ DATE REQUESTED \_\_\_\_\_  
JOB TITLE \_\_\_\_\_ DATE NEEDED \_\_\_\_\_  
CHARGE NUMBER \_\_\_\_\_ - \_\_\_\_\_ - \_\_\_\_\_

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

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**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  Surface Scan  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:**

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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 \_\_\_\_\_

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### DESCRIPTION OF MEASUREMENTS MADE

- 
- **Type of measurement(s) made:**
    - Surface Inspection    Use metrology to alter shape or location    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: \_\_\_\_\_
    - 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

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*Comments:*

Measurements performed by: \_\_\_\_\_

Date: \_\_\_\_\_

*Metrology Engineer/Technician*

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## ***Appendix C – Romer Arm Length Check and Probe Calibration***

### **1. Length check Procedure:**

This procedure verifies the calibration of the arm by making 5 measurements of a known standard length. The **Accuracy** is determined by the average of the measurements and the **Precision** is determined by the standard deviation (Range/2) [as reported by the CimCore software] of the measurements.

- Using CimCore Arm Utilities (access directly or via the Verisurf VDI), start the “Arm Checkout-Length” and measure the length standard as outlined in the CimCore Arm Utilities Guide.
- The calculated “Average Length” should be within the range of the length standard value (printed on the label on the bar) +/-0.100mm. If it does not fall within this range then repeat measurement.
- The measured “Range/2” should be less than 0.100mm.
- **If the arm cannot measure the length standard within the specified tolerance, AND achieve the required “Range/2” value, then remove this arm from service and notify the Metrology Engineer.**

### **2. Point Check Procedure:**

This process checks the calibration of ball probes. The 15mm steel ball probe is considered a “standard” and cannot be re-calibrated. It is validated during the length check procedure. If a length check continually fails, then run the 15mm probe through a Probe Calibration. If it fails, then it must be returned to Romer for service. Other probes can be re-calibrated if they have been bent or damaged. Note that the acceptance criteria are for the standard length probes that are delivered with the arm (Probes 2 and 3). Other probes (especially longer probes) typically have greater “Range/2” values.

- Using CimCore Arm Utilities (access directly or via the Verisurf VDI), start the Point Checkout application. Choose “Single Point” method, and choose “No” for “Measure Against Nominal Data”.
- Seat the probe into a conical seat (or appropriately sized hole) and complete the measurement sequence as outlined in the CimCore Arm Utilities Guide. It is imperative that the probe be seated firmly and only rotate about the center of the sphere during this process.
- The measured “Std Dev.” value should be less than 0.100mm, otherwise do not accept the calibration.
- **If the “Std Dev.” is greater than 0.100mm after repeated calibration attempts then take probe out of service and notify the Metrology Engineer.**