NCSX Preliminary Design Report

Metrology Needs Assessment

NCSX Preliminary Design Review

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1 METROLOGY NEEDS

A basic requirement for NCSX is the precise manufacture and assembly of the critical components. This in turn requires a precise means to inspect the components and determine their position in 3-D space. Areas of the NCSX that have been identified as having particular measurement/metrology needs include:

- Vacuum vessel (VV) manufacture and preparation
- Modular coil winding form (MCWF) manufacture
- Modular coil (MC) winding
- Test cell (TC) preparation
- Field period assembly
- Machine assembly

Each of these areas is described in the following sections.

1.1 Vacuum Vessel Manufacture and Preparation

The vacuum vessel shall be manufactured by welding several contoured sections to create 120º sub-assemblies. The vendor shall be responsible for the metrology required to fabricate the finished deliverable components. The vendor shall deliver a CADD model of the as-built VV geometry. The NCSX team shall be responsible the following tasks which involve metrology:

- Inspection of the vacuum vessel geometry including measurement of the vacuum vessel shape, location of port openings, and location of assembly joints.
- Installation of external magnetic loops.
- Installation of monuments to facilitate field period and machine assembly.

1.2 Modular Coil Winding Form (MCWF) manufacture

The MCWF shall be manufactured by casting the rough shape, followed by machining of the critical areas. The vendor shall be responsible for the metrology required to fabricate the finished deliverable components. The vendor shall deliver a CADD model of the as-built geometry. The NCSX team shall be responsible the following tasks which involve metrology:

- Modular Coil Winding Form geometry inspection.
- Installation of magnetic loops.
- Installation of reference monuments in addition to those provided by the vendor

1.3 Modular Coil winding

NCSX team members shall wind the modular coils at PPPL. The conductor is hand wound, held in position with clamps, and epoxy impregnated to form the coil. The following tasks involve metrology:

- Measurement of the copper chill plate surfaces.
- Measurement of each turn location to verify position and to determine shim thickness required prior to placement of subsequent turn.
- Measurement of the completed winding packs and calculation of best fit of winding pack geometry with reference monuments.

- Installation of any additional monuments needed to facilitate Field Period Assembly.

1.4 Test Cell Preparation

Preparation of the NCSX Test Cell involves the following metrology tasks:

- Establishment of a global reference coordinate system that allows the repositioning if the metrology hardware.
- Installation of monuments on walls, floor and ceiling to allow local positioning systems (e.g., FARO arms and laser trackers) to reference the global coordinate system.

1.5 Field Period Assembly

Field period assembly consists of the marriage of the vacuum vessel, VV port extensions, modular coils, TF coils, and support structure. The following field period assembly tasks involve metrology:

- Assembly, with precise alignment, of three modular coils to each other to form 3-coil subassemblies. This includes calculation of best relative position of one coil to another, calculation of interface shim dimensions, and calculation of the best fit of 3-coilsubassemblies with monuments and global machine reference system.
- Manipulation of the 3-coil subassemblies over the vacuum vessel.
- Precise alignment and assembly of the two 3-coil subassemblies to form a 6-coil subassembly (with the VV subassembly in place).
- Alignment and fixturing of VV port extensions for welding.
- Installation of monuments to facilitate machine assembly, including calculation of best fit of 6-coil subassemblies (with monuments and the global machine reference system).

1.6 Machine Assembly

During machine assembly, the three field period assemblies (FPAs) are placed on the base support structure. The PF coils are then installed to complete the assembly of the stellarator core. The following machine assembly tasks involve metrology:

- Assembly, with precise alignment, of three FPAs to each other.
- Alignment of the vacuum vessel segments, prior to welding.
- Final alignment of conventional coils.
- Final measurement of all coil arrays, vacuum vessel interior surface, and vacuum vessel port extension locations relative to global machine reference system.

2 PROPOSED METROLOGY SYSTEM ELEMENTS

Advanced metrology will be required to successfully fabricate and assemble the NCSX device. In tokamaks, the symmetrical nature of their design allows the use of simple measurement devices (lasers, levels, plum bobs, transits). Stellarators require sophisticated, computerized measurement systems as well as metrology software. A comprehensive suite of hardware and software, which will operate as an integrated system, is proposed. This suite consists of the following elements:

- Hardware for measuring the orientation and global position of machine components.
- Hardware for efficiently measuring complex, contoured shapes.
- Specialty measurement devices, custom-built for unique processes.

- Software that can operate various hardware systems simultaneously.
- Software for the post-processing of metrology data. Post-processing operations include comparison of measured data with theoretical CAD data, determination of the best fit of an actual measured part to the global machine reference system, and incorporation of measured data into as-built models/drawings.

2.1 Hardware

2.1.1 Arcsecond Constellation 3DI

The Constellation 3DI system uses triangulation to create a universal coordinate frame, similar to GPS. The system employs multiple transmitters that emit "eye-safe" infrared laser signals. Sensors receive these signals, creating real-time, 3-D coordinates. Sensors can be permanently mounted onto structures, or can be incorporated into pointing devices. Sensors require line of sight to the laser transmitters.

This system is proposed for the establishment of a global coordinate system and for the alignment and positioning of large structures. It shall be used for the alignment of modular coil subassemblies to each other during the FPA task and for machine assembly. It will also be employed during the experimental operations phase, for positioning ancillary equipment. The Constellation 3DI is accurate to approximately 0.005 inch anywhere in the NCSX Test Cell. This system has been included in the cost estimate and is recommended for procurement.

2.1.2 FARO Measuring Arm

The FARO arm is a mechanical measurement system, which employs a jointed, articulating arm. Integrated software allows the arm to measure in either local or global coordinates. The FARO arm is limited to approximately a twelve-foot reach from a single placement position, but by using fixed monuments, the device can be repositioned while maintaining alignment to a known reference.

The FARO arm shall be used to perform quality control (QC) inspections of deliverables (vacuum vessel, MC winding forms, flanges, etc.). It shall also be used to locate smaller components, i.e., magnetic diagnostics, onto the NCSX device. The FARO arm is accurate to 0.001 inch within its operating volume.

PPPL owns an older FARO arm, which marginally meets the NCSX metrology requirements. A newer, more accurate arm is included in the cost estimate.

2.1.3 Laser Tracker

The laser tracker is an interferometer-based measuring system. It employs reflectors that are mounted (or held against) any location to make measurements. The laser tracker is a highly accurate and precise system, capable of measuring to an accuracy of 0.0002 inch. The laser tracker requires unbroken line of site from the laser base to the measured location, which often limits its functionality in congested spaces.

The laser tracker will see limited use for field period and machine assembly. It will be employed where ultra-high accuracy is required. Since it can be used as a "pointing device", it will be used simultaneously, and in conjunction with the FARO arm and Constellation 3DI to locate critical points in the NCSX test cell.

PPPL owns a Leica Laser tracker, so no additional costs were included in the cost estimate for this capability.

2.1.4 NVision "ModelMaker" Scanner

The NVision "ModelMaker" surface scanner is a laser scanning device that is capable of capturing 3D geometry. The scanner is attached to and works in conjunction with a FARO arm. The scanner is a non-contact system, making it ideal for scanning soft surfaces, such as fiberglass wrapped coils (prior to impregnation). The ModelMaker shall be used to scan the "as-built" geometry of the vacuum vessel and the modular coil winding forms. It can also be used to scan the modular coil during the winding process.

The NVision "ModelMaker" surface scanner is recommended for procurement and is included in the cost estimate.

2.1.5 Specialty Measurement Devices

Special measuring devices shall be designed and fabricated in instances where the aforementioned systems are inappropriate or inefficient at taking measurements. One example of this is the measurement of the Modular Coil conductor as it is wound onto the coil form. Since the coil is mounted on a turning fixture, its orientation with respect to a reference coordinate system is constantly changing, making the use of stationary measuring devices difficult. A measuring device, which clamps onto the winding form and can be positioned wherever a measurement is required, will be employed.

2.2 Software

2.2.1 Spatial Analyzer

Spatial Analyzer (SA) is a metrology 3D graphical software platform that can simultaneously communicate to virtually any number and type of dimensional measurement systems. It provides simple common interfaces for each of the technologies. SA's graphical environment allows the user to download the CAD model and then make all the measurements and perform the analysis on the shop floor. With the SA system, the various metrology systems, which typically operate under unique proprietary software, can be integrated in to one single operator interface.

This package is being recommended for procurement and is included in the cost estimate.

3 APPLICATION MATRIX

Table 3-1 indicates which tool is capable of performing the tasks outlined earlier. In the case where multiple devices can perform certain tasks, the preferred (or optimal) device has the asterisk.

Table 3-1 Application Matrix

	Activity	3DI	FARO arm (solo)	Laser tracker	FARO arm with ModelMaker	Specialty devices	SA
1a	VV inspection		x		x*		x
1b	VV mag loop installation		x				x
1c	VV monument installation		x		x*		x
2a	Mod coil winding form inspection		x		x*		x
2b	Mod coil mag loop installation		x				x
2c	Mod coil monument installation		x		x*		x
3a	Mod coil chill plate position		x		x*	x	x
3b	Mod coil turn placement		x		x	x*	x
3c	Mod coil winding pack geometry and position				x		x
3d	Mod coil monument installation for field period assembly		x		x*		x
4a	Establish global reference system for repositioning metrology hardware	x*					x
4b	Install monuments in test cell	x		x			x
5a	3 mod coil subassembly	x					x
5b	Manipulate 3 coil subassemblies over vacuum vessel	x					x
5c	Relative alignment of two, 3-coil subassemblies	x					x
5d	VV port extension alignment	x					x
5e	Field period monument installation for final machine assembly	x					x
6a	Alignment of three field period assemblies	x					x
6b	Alignment of three VV segments prior to welding	x					x
6c	Final alignment of conventional coils and support structure	x					x
6d	Final measurement of coil arrays and port extensions	x					x
6e	Final measurement of VV interior surface position	x	x		x*		x