

**NCSX**

**Product Specification**

**Modular Coil Winding Forms**

NCSX-CSPEC-141-03-06

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## Record of Revisions

Revision	Date	Description of Changes
Rev. 0	7/1/2004	Initial issue
Rev 1.	7/5/2004	Revised Table 6-1
Rev 2	7/20/2004	Updated Table 6-1 to Production Drawings
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Rev 4	9/17/2004	Updated specification to reflect final negotiated configuration: <ul style="list-style-type: none"><li>• Added vendor information on alloy in Sections 3.1.1.1 and 3.1.1.2;</li><li>• Revised Sections 4.2.5 and 4.2.7.2.1; and</li><li>• Updated Table 6-1</li></ul>
Rev 5	9/23/2004	Updated Table 6-1
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# 1 INTRODUCTION AND SCOPE

## 1.1 INTRODUCTION

Stellarators are a class of magnetic fusion confinement devices characterized by three dimensional magnetic fields and plasma shapes and are the best-developed class of magnetic fusion devices after the tokamak. The stellarator concept has greatly advanced since its invention by Dr. Lyman Spitzer, the founding director of the Princeton Plasma Physics Laboratory (PPPL), during the 1950's. A traditional stellarator uses only external magnetic fields to shape and confine the plasma. The National Compact Stellarator Experiment (NCSX) is the first of a new class of stellarators known as "compact stellarators." The differentiating feature of a compact stellarator is the use of plasma current in combination with external fields to accomplish shaping and confinement. This combination permits a more compact device. The NCSX project is managed by PPPL in partnership with the Oak Ridge National Laboratory. This Subcontract will be administered by PPPL. Operation of NCSX is scheduled to begin in July 2008.

The winding forms are austenitic (non-magnetic) stainless steel structures that are one of the most important components of the modular coils and the NCSX device. The winding forms perform two very important functions: (1) the conductors are wound on the winding forms, and are located in precise position by these forms; (2) the winding forms serve as their structural support during assembly and operation. There are three (3) distinct shapes of winding forms. Six (6) of each are required for a total of eighteen (18). The winding forms shall be manufactured by casting followed by machining. A machined winding form is illustrated in [Figure 1-1](#). This figure is intended to be illustrative only and not to be used for manufacture; specific models and drawings shall provide the technical details needed for manufacturing.



**Figure 1-1 Typical machined modular coil winding form**

## 1.2 SCOPE

This specification establishes the manufacturing and acceptance requirements for the National Compact Stellarator Experiment (NCSX) Modular Coil Winding Forms. There are three different types of Winding Forms, identified as type A, B, and C.

## 2 APPLICABLE DOCUMENTS

### 2.1 CODES AND STANDARDS

#### 2.1.1 American Society for Testing and Materials (ASTM) Documents <sup>1</sup>

- A703/A703M-03 “Standard Specification for Steel Castings, General Requirements for Pressure Containing Parts”.
- A800/A800M-01 “Standard Practice for Steel Casting, Austenitic Alloy, Estimating Ferrite Content Thereof”.
- A802/A802M-95 “Standard Practice for Steel Castings, Surface Acceptance Standards, Visual Examination”.
- A903/A903M-99 “Standard Specification for Steel Castings, Surface Acceptance Standards, Magnetic Particle, and Liquid Penetrant Inspection”.

#### 2.1.2 Manufacturers Standardization Society (MSS) of the Valve and Fittings Industry, Inc. Documents <sup>2</sup>

- MSS SP-54-2001: “Quality Standard for Steel Castings for Valves, Flanges, Fittings, and Other Piping Components; Radiographic Inspection Method”.

## 3 REQUIREMENTS ITEM DEFINITION

The items covered by this Specification are Type A, Type B, and Type C winding forms. This includes the castings, all associated machining, all poloidal break hardware, and all associated processing, testing, quality control, documentation, packaging, and shipping.

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<sup>1</sup> Publications are available from

<http://www.astm.org/cgi-bin/SoftCart.exe/index.shtml?E+mystore>.

<sup>2</sup> Publications are available from Manufacturers Standardization Society of the Valve and Fittings Industry, Inc., 127 Park Street, NE , Vienna, Virginia 22180p, Tel. (703)-281-6613.

**3.1 CHARACTERISTICS**

3.1.1 Performance

3.1.1.1 Chemical Composition of the Casting Alloy

The winding forms are to be cast of the alloy developed and qualified by the subcontractor during their manufacturing development and prototype manufacturing activities. The chemical composition shall be in accordance with [Table 3-1](#).

	<u>C</u>	<u>Mn</u>	<u>Si</u>	<u>Cr</u>	<u>NI</u>	<u>Mo</u>	<u>P</u>	<u>S</u>	<u>N</u>
Min. %	.040	2.3	--	18.0	13.0	2.1	--	--	.24
Max.%	.070	2.8	0.5	18.5	13.5	2.5	.015	.015	.28

**Table 3-1 Weight % of Chemical Constituents in Casting Alloy**

3.1.1.2 Mechanical Properties of the Casting Alloy and Welding Material

The properties of the winding form casting alloy and welding material for each casting shall meet or exceed the mechanical properties requirements stated in [Table 3-2](#).

**Table 3-2 Minimum Mechanical Properties**

<b>Temperature</b>	<b>77K</b>	<b>293K</b>
Elastic Modulus	21 Msi (144.8 Gpa)	20 Msi (137.9 Gpa)
0.2% Yield Strength	72 ksi (496.4 Gpa)	34 ksi (234.4 Gpa)
Tensile Strength	95 ksi (655 Gpa)	78 ksi (537.8 Gpa)
Elongation	32%	36%
Charpy V – notch Energy	45 ft. lbs. (61.0 J)	60 ft-lbs (81.3 J)

3.1.1.3 Electrical Requirements for the Poloidal Electrical Break

The resistance of the mid-plane insulation and of the bolt insulation shall be >500 kohms when tested at 100 VDC.



### 3.1.1.4 Surface Finish

All machined surfaces must have a RMS (root mean square) surface finish <125 μ-inches. Uniform “scallop” which exceed 125 μ-inches, which may result from some machining processes, may be acceptable, subject to PPPL approval of the non-conformance that would be generated in this case. The finished part shall be free of sharp edges and burrs.

### 3.1.1.5 Relative Magnetic Permeability

The local relative magnetic permeability shall not exceed 1.02.

### 3.1.1.6 External Defects

#### 3.1.1.6.1 Visual Examination

Each casting shall be free of visual external defects as defined in ASTM A802/A802M (using graded reference comparators available from Castings Technology International) Level II with the exception that the surface texture in areas that will not be machined shall meet the requirements of ASTM A802/A802M, Level III . Discontinuities not meeting the evaluation criteria shall be repaired per Section 3.3.3.2. (Repairs).

#### 3.1.1.6.2 Liquid Penetrant Examination of Casting

Each casting shall be free of external defects as defined in ASTM A903/A903M Level II. Discontinuities not meeting the evaluation criteria shall be repaired per Section 3.3.3.2 ( Repairs).

#### 3.1.1.6.3 Liquid Penetrant Inspection of High Stress Regions

High stress regions (<10% of the machined surface) shall be free of external defects when checked by liquid penetrant inspection as defined in ASTM A903/A903M Level I. Discontinuities not meeting the evaluation criteria shall be repaired per Section 3.3.3.2.3 (Repairs in High Stress Areas).

### 3.1.1.7 Radiographic Inspection

Each casting shall be free of internal defects as defined in MSS SP 54 for radiography. Discontinuities not meeting the evaluation criteria shall be repaired per Section 3.3.3.2 (Repairs).

## 3.2 DESIGN AND CONSTRUCTION

### 3.2.1 Production Drawings

These items shall be fabricated in accordance with the models and drawings Pro/Engineer CAD files listed in

[Table 6-1](#). These files are located at the production winding form ftp site:

[ftp://ftp.pppl.gov/pub/ncsx/manuf/production\\_winding\\_form](ftp://ftp.pppl.gov/pub/ncsx/manuf/production_winding_form)

### 3.2.2 Dimensions and Tolerances

#### 3.2.2.1 Measurement

Strict adherence to the dimensions and tolerances defined in the production drawings referenced in Section 3.2.1. All dimensions are for 20 C; actual measurements shall be temperature compensated for 20 C.

#### 3.2.2.2 Fiducials

Supplier to provide eighteen (18) or more permanent targets that are in known relationship to the CAD model of the winding form. Three (3) fiducials (spherical seats) shall be provided on each flange surface; four (4) targets shall be visible for each setup of machined features, and four (4) targets shall be visible from any exterior view of the winding form.

### 3.2.3 Standards of Manufacture

#### 3.2.3.1 Heat Treatment

The castings shall be heat treated prior to final measurements of mechanical properties and relative magnetic permeability. Heat treatment records shall be prepared and maintained as defined in S21 of ASTM Spec. A703/A703M, and supplied to PPPL.

#### 3.2.3.2 Repairs

##### 3.2.3.2.1 Non-Weld Repairs

When defects are removed by grinding without violating minimum wall thickness requirements, the ground area shall be re-inspected by the original inspection method to verify complete defect removal. Discontinuities which are/ will be completely removed during machining operations do not need to be weld repaired.

##### 3.2.3.2.2 Weld Repairs

###### 3.2.3.2.1.1 Minor Weld Repairs

When defect removal involves excavation beyond wall thickness limitations, the excavation shall be repaired by welding. Weld preparation shall be per Section S10 of ASTM Spec. A703/A703M. Weld repairs must meet the inspection criteria of sections 3.2.1.6 through 3.2.1.8.

Welding procedure qualification tests shall include evidence of compliance with the magnetic permeability requirements of Section 3.2.1.5, as well as compliance with the mechanical properties listed in Table 3-2.

###### 3.2.3.2.1.2 Major Weld Repairs

Repairs shall be considered major when the depth of the cavity prepared for welding exceeds 10% of the actual wall thickness or 1 inch, whichever is smaller, or when the extent of the cavity exceeds approximately 10 in<sup>2</sup>. Major repairs shall be welded and shall be processed and

documented as defined in Sections S12 and S20 of ASTM Spec. A703/A703M. Weld preparation shall be per Section S10 of ASTM Spec. A703/A703M. Weld repairs must meet the inspection criteria of sections 3.2.1.6 through 3.2.1.8. Welding procedure qualification tests shall include evidence of compliance with the magnetic permeability requirements of Section 3.2.1.5, as well as compliance with the mechanical properties listed in Table 3-2. Non-conformance reports for major repairs (which include in the disposition the proposed corrective action) shall be prepared for each major weld repair and will be subject to the prior approval of PPPL.

#### 3.2.3.2.3 Repairs in High Stress Areas

Any indications which do not meet the requirements of Section 3.2.1.6.3 (Liquid Penetrant Inspection of High Stress Regions) must be repaired. Defects which are less than 0.125" in depth shall be eliminated by grinding. Defects which exceed this depth shall be reported in a non-conformance report for evaluation by PPPL. When the non-conformance report disposition requires weld repair, it must be repaired per 3.3.3.2.2 (Weld Repairs).

## 4 QUALITY ASSURANCE PROVISIONS

### 4.1 RESPONSIBILITY FOR INSPECTION

The responsibility for performing all tests and verifications rests with the supplier. PPPL reserves the right to witness or separately perform all tests specified or otherwise inspect any or all tests and inspections.

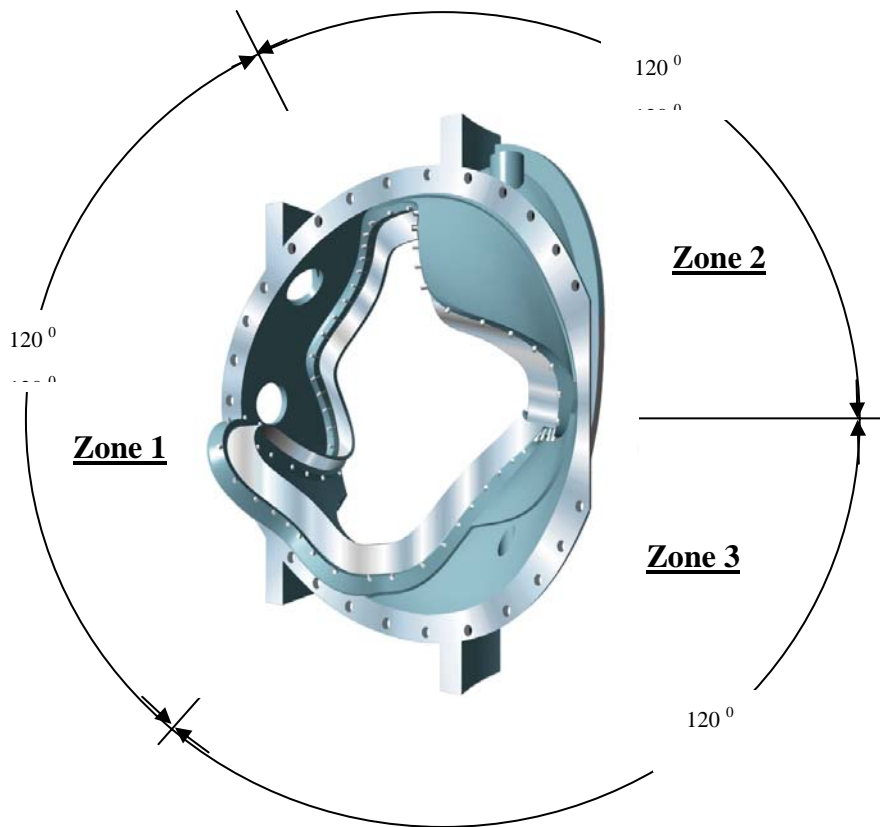
### 4.2 QUALITY CONFORMANCE INSPECTIONS / VERIFICATIONS

#### 4.2.1 Verification of Chemical Composition

The material chemical composition shall be measured and provided for each casting and for each heat used in the winding form.

#### 4.2.2 Verification of Mechanical Properties of the Casting Alloy

The mechanical properties of the casting alloy for each winding form must be verified by testing of specimens made from sections of the gating located as near as possible to the winding form casting. Each test requires testing of three specimens (1 each from the 3 zones identified in Fig. 4.-1 below) made in the transverse direction to the major axis of the gating section and three specimens (1 each from the 3 zones identified in Fig. 4-1 below) made in the longitudinal direction. The specimen material shall be heat treated simultaneously with the winding form; During the heat treatment this material shall be located adjacent to the area from which it was derived in order to represent as closely as possible the properties of that material. Each specimen shall be engraved to permit traceability – for example, C1-2T would indicate a specimen for the first type C casting, cut from Zone 2 in the transverse direction. All test data must be referenced to the test specimen identifiers. (NOTE: Table3-2 will be replaced with the successful offeror's minimum guaranteed properties for the range of chemical composition prior to the award of the subcontract.)



**Figure 4-1 Definition of Zones for Test Specimens**

#### 4.2.2.1 Verification of Yield Strength and Elastic Modulus

The yield strength at 0.2% offset elongation and the elastic (Young's) modulus shall be verified for the cast stainless steel in the as heat-treated condition at room temperature and 77K for each casting. Test specimen coupons shall be tested in accordance with ASTM A703/A703M-03, Paragraphs 6 and 7.

#### 4.2.2.2 Verification of Ultimate Tensile Strength and Elongation

The ultimate tensile strength and elongation for the cast stainless steel in the as heat-treated condition at room temperature and 77K shall be verified for each casting. Tensile test specimen coupons shall be tested in accordance with ASTM A703/A703M-03, Paragraphs 6 and 7.

#### 4.2.2.3 Verification of Charpy V-Notch Energy

The Charpy V-Notch energy of the casting alloy at room temperature and 77K shall be measured for each casting. Specimen coupons shall be cast and heat treated with each winding form and tested in accordance with ASTM A703/A703M-03, Paragraph 6.

#### 4.2.2.4 Additional Test Material

Sufficient additional heat treated material from each of the (3) zones, as described in Section 4.2.2 shall be provided to allow NCSX to fabricate (3) longitudinal specimens sized 3" x 3" x 3/4" thick and (3) transverse specimens sized 3" x 3" x 3/4" thick. All supplied material shall have its identification information engraved in it as described in Section 4.2.2.

#### 4.2.3 Verification of the Electrical Properties of the Poloidal Break

##### 4.2.3.1 Mid-Plane Insulation

The poloidal joint mid-plane shall be electrically connected (jumpered) to the modular coil for this test. The insulation resistance shall be measured between it and each bolt. The insulation resistance of the bolt insulation electrical properties and the mid-plane electrical insulation resistance shall be measured for compliance with the requirements stated in Sections 3.2.1.3.

##### 4.2.3.2 Bolt Insulation

All of the bolts shall be electrically connected (jumpered) together and connected to the modular coil winding form for this test. The insulation resistance between the electrically connected (jumpered) combination and the mid-plane shall be measured for compliance with the requirements stated in Section 3.2.1.3.

#### 4.2.4 Verification of Surface Finish

All machined surfaces shall be inspected for compliance with surface finish requirements specified in Section 3.1.1.4. Either a surface profilometer or comparator can be used.

#### 4.2.5 Verification of Relative Magnetic Permeability

All cast surfaces and features shall be checked with a calibrated Severn Permeability Indicator for compliance with Section 3.2.1.5. Relative magnetic permeability that exceeds 1.02 must be documented on a nonconformance report and will require approval on a case-by-case basis. Accessible weld repairs shall be checked at a minimum of 1 point per every 2 sq. in. of surface area. Relative magnetic permeability measurements shall be made on all surfaces of the final casting at locations approximately 6 inches apart (to approximate a 6 inch x 6 inch grid). Final machined surfaces shall be inspected on a 2 x 2" grid. Permeability measurements shall be per Supplementary Requirements S24 of ASTM Spec. A703/A703M and S1 of ASTM A800/A800M, except that the results shall be expressed as relative permeability,  $\mu$ , Mu, rather than ferrite content (FN)

#### 4.2.6 Verification of Dimensions and Tolerances

All cast surfaces, machined surfaces and features such as holes, ports, supports, etc. shall be dimensionally checked to assure compliance with Section 3.2.2. Cast surfaces shall be checked with measurements taken to approximate 4" x 4" grid; machined surfaces shall be checked with

measurements taken to approximate a 2" x 2" grid; features such as holes, ports, supports, etc. shall be verified per standard machine shop practices.

#### 4.2.7 Inspection for External Defects

##### 4.2.7.1 Visual Inspection

All of the casting features shall be inspected to assure compliance with Section 3.2.1.6.1 (Visual Inspection).

##### 4.2.7.2 Liquid Penetrant Inspections.

###### 4.2.7.2.1 General Liquid Penetrant Inspection

All surfaces of the casting shall be liquid Penetrant inspected to assure compliance with Sect. 3.2.1.6.2 (Liquid Penetrant Examination of Casting). Certified test reports shall be per ASTM A903, Supplementary Requirement S1. Surfaces shall be prepared by abrasive blast per standard foundry procedures.

###### 4.2.7.2.2 Post Machining Liquid Penetrant Inspection

All machined surfaces shall be liquid Penetrant inspected to assure to assure compliance with Sect. 3.2.1.6.2 (Liquid Penetrant Examination of Casting). Certified test reports shall be per ASTM A903, Supplementary Requirement S1.

###### 4.2.7.2.3 Liquid Penetrant Inspection of High Stress Regions

High stress regions shall be liquid Penetrant inspected to assure compliance with Sect. 3.2.1.6.2 (Liquid Penetrant Examination of High Stress Regions). Certified test reports shall be per ASTM A903, Supplementary Requirement S1.

#### 4.2.8 Inspection for Internal Defects

##### 4.2.8.1 Pre-Machining Inspection for Internal Defects

Each casting shall be examined for internal defects as defined in ASTM Spec.A703/A703M using radiographic inspection per Supplementary Requirement S5. Acceptance criteria shall be per MSS SP 54 for radiography.

##### 4.2.8.2 Post Machining Inspection for Internal Defects

High stress areas of the casting (not to exceed 10% of the machined area of the winding form "T" sections") shall be examined for internal defects as above with the exception that the sensitivity of the technique shall be 1% of the thickness being inspected.

## **5 PREPARATION FOR DELIVERY**

### **5.1 MARKING**

Each winding form shall have the supplier's name, a serial number (drawing number and a unique identifier), and the part weight engraved or stamped with characters ¼ inches high. The marking shall be located as shown in the part drawing.

## 5.2 CLEANING

The winding forms shall be degreased/cleaned using a solvent which must be able to dissolve grease, oils and other soils, and leave the casting residue free. No chips, burrs, oil, etc. shall remain in any of the tapped holes.

## 5.3 CRATING

The crate shall protect the winding form from shock and weather conditions, including precipitation. The crate shall be built for moving on rollers, handling with slings from overhead cranes, and transport by forklifts. The part shall be totally wrapped with a plastic protective film.

## 5.4 SHIPPING

Supplier is responsible for arranging shipment, and for the safe arrival of each winding form at PPPL in Princeton, New Jersey, USA. Subcontractor's name, shipper, purchase order number, contents and gross weight shall be marked on the shipping container.

# 6 ATTACHMENTS

## 6.1 TABLE OF MODELS AND DRAWINGS

The following table provides the complete listing of zip files which includes all the approved drawings, ProE models, and STEP files. They can be found on the Supplier FTP site at:

[ftp://ftp.pppl.gov/pub/ncsx/manuf/production\\_winding\\_form](ftp://ftp.pppl.gov/pub/ncsx/manuf/production_winding_form)

**Table 6-1 Production Modular Coil Winding Form Models and Drawings**

<b>ZIP File</b>	<b>Model Description (from Pro/Intralink database, edited)</b>
production_mcwf_proe_050114.zip	ZIP file containing all ProE models for the winding forms.
production_mcwf_stp_050114.zip	ZIP file containing all STEP files for the winding forms.
production_mcwf_pdf_050114.zip	ZIP file containing all pdf drawing files.