

NCSX
Product Specification
Prototype Modular Coil Winding Form

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REVISIONS

Revision No.	Description of Changes	Date
0 (Initial Release)	All	10/15/02
1	Expanded signature page. Changed nomenclature from Type BA to Type A, etc. throughout. Deleted content of Sections 3.2.1.2 and 3.2.1.3, which required copper cladding on the prototype winding form. Added caveat that drawings are not yet released for prototype fabrication. Copper cladding has to be removed and recent changes in coil geometry have to be reflected. Deleted content of Sections 4.2.2 and 4.2.3, which specified verification of copper cladding requirements.	1/24/03
2	Pg. 4- revised yield and ultimate strengths to be ~90% of former values; reduced k from 13 to 9.5. Pg. 5 – added repairs to machined sfc. using filled epoxy; pg. 6 revised drawing list; pg. 8, 4.2.2.6 – revised details of permeability measurements; pg. 3-updated fig. 3.1.1.	10/09/03
3	Pg. 5&6: Revised reference winding form model; associated drawings will be supplied as soon as available. (Ref: ECP-04-002). Revised Fig. 3.1.1 on pg. 3.	11/17/03
4	pg. 2- removed ref. to copper cladding. Pg. 3 – changed 316 to CF8M. Pg. 5 – revised requirements for epoxy paste in Para. 3.1.1.5. Pg. 6 – added schedule dates to drawings in Table 3.1.3. Pg. 6- corrected grammar in sect. 3.3.2.2. Pg. 8 – clarification added to last sentence of 4.2.6.	11/25/03
5	Revised drawing list (Table 3.3-1) to reflect modified poloidal break design.	6/29/04

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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 2007

1.2 SCOPE

This specification establishes the manufacturing and acceptance requirements for the National Compact Stellarator Experiment (NCSX) Prototype Modular Coil Winding Form.

2 APPLICABLE DOCUMENTS

2.1 CODES AND STANDARDS

ASTM (American Society for Testing and Materials)¹

- A703/A703M-01 "Specification for Steel Castings".
- 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".
- A 903/A903/M-99 "Standard Specification for Steel Castings, Surface Acceptance Standards, Magnetic Particle, and Liquid Penetrant Inspection".

Manufacturers Standardization Society of the Valve and Fittings Industry, Inc. ²

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

¹ Publications are available from <http://www.astm.org/cgi-bin/SoftCart.exe/index.shtml?E+mystore>.

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

3 REQUIREMENTS

3.1 WINDING FORM DEFINITION

The winding forms are austenitic (non-magnetic) stainless steel structures which are one of the most important components of the modular coils. 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 distinct shapes of winding forms; six of each are required for a total of 18. The winding forms shall be manufactured by casting followed by machining. One type of winding form is shown in Figure 3.1-1. The finished weight of the heaviest winding form is approximately 5000 lbs.

The prototype winding form will be of the Type C corresponding to the modular coils in the center of the assembled field period. It is a cast and machined structure with a single poloidal, electrically insulating break located on the outboard (large major radius) side of the module. There is a machined tee-shaped feature that protrudes on the interior of the shell. The structure features planar flanges on the ends of the module which are used to provide a bolted connection to adjacent modules. Adjacent modules will be electrically insulated from one another except at the field assembly joint (Type C to Type C).

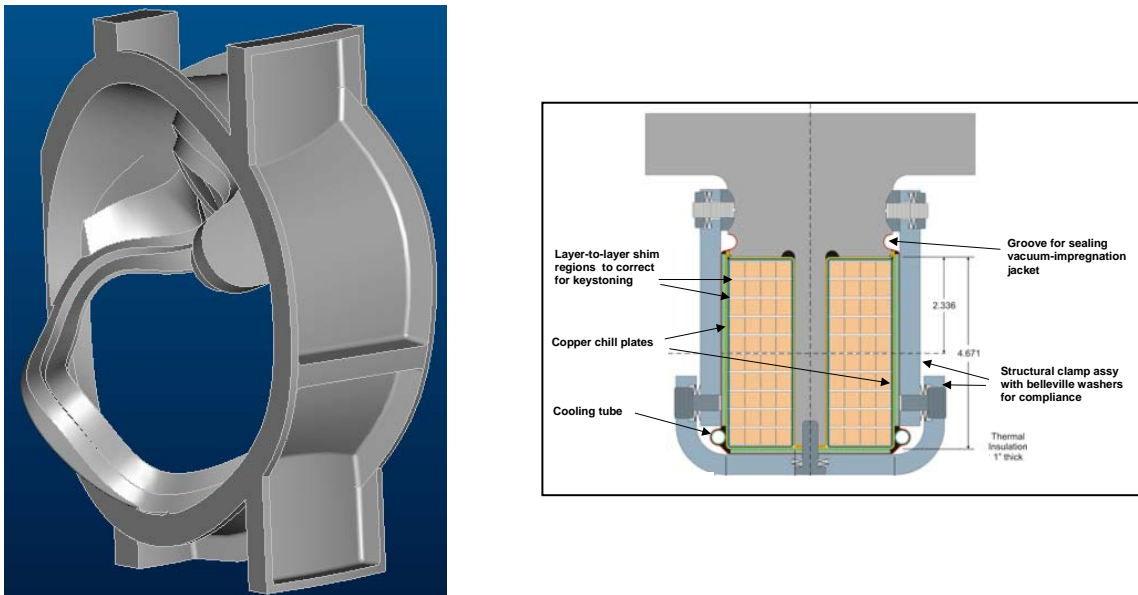


Figure 3.1-1 Type “C” Winding Form

NOTE: Figure 3.1-1 is illustrative only and not to be used for manufacture.

3.2 CHARACTERISTICS

3.2.1 Performance

3.2.1.1 Mechanical and Physical Properties of Casting Alloy

Background

For the prototype winding form, the casting alloy is not specified. This is done to allow potential suppliers the opportunity to propose casting alloys that they feel are superior from the standpoints of cost and performance. Mechanical properties similar to those of cast CF8M at 77K are considered adequate for this application. Higher strength, lower electrical resistivity, and higher thermal conductivity would all be favorable. Slightly less favorable properties might be tolerable. Such alloys might be considered if there were compelling reasons to do so.

Requirement

The prototype winding form shall be fabricated from stainless steel alloy that meets the following requirements:

- 0.2% Yield strength: >180 MPa (>26 ksi) at room temperature (RT); >360 MPa (>52 ksi) at 77K.
- Ultimate tensile strength: >360 MPa (52) at RT; >690 MPa (99.7 ksi) at 77 K.
- Elongation: 30% (min.) at RT and 77⁰K.
- Thermal conductivity: >9.5 W/m-K at RT; >7W/m-K at 77K.
- Electrical Resistivity: >83 x 10⁻⁸ Ω-m at RT; >64 x 10⁻⁸ Ω-m at 77K
- Fracture Toughness: TBD

3.2.1.2 DELETED³

3.2.1.3 DELETED⁴

3.2.1.4 Electrical Properties of the Poloidal Electrical Break

Background

A poloidal electrical break will be provided, with electrical insulation physically separating the shell through the entire thickness. The bolts providing the structural continuity will be electrically isolated from the shell, i.e. double insulated.

Requirement

³ The copper cladding has been removed from the prototype winding form to be fabricated by the Subcontractor in Rev. 1 of this specification.

⁴ The copper cladding has been removed from the prototype winding form to be fabricated by the Subcontractor in Rev. 1 of this specification.

The electrical resistance between any bolt to the winding form and the insulation break mid-plate to winding form shall be $>500 \text{ k}\Omega$ when tested at 100 VDC.

3.2.1.5 Surface Finish

All machined surfaces must have a RMS (root mean square) surface finish $<125 \text{ }\mu\text{-inches}$. Uniform “scallop” which exceed $125 \text{ }\mu\text{-inches}$, which may result from some machining processes, may be acceptable, subject to PPPL approval. Areas less than 4 sq. in. which have depressions less than 10% of the wall thickness may be filled with an epoxy paste, subject to PPPL’s approval on a case-by-case basis. The Subcontractor must demonstrate that the epoxy paste chosen is capable of withstanding 150 C for 4 hours (for coil bake-out) and be capable of sustained operation at 77 K (for normal operation). It also must have a compressive strength $>83 \text{ MPa}$ (12 ksi), must be electrically non-conductive, and must be chemically compatible with the CTD-101K epoxy that will be used in the coil winding. Subcontractor must provide chemical formulation and properties to PPPL for approval.

3.2.1.6 Relative Magnetic Permeability

The local relative magnetic permeability shall not exceed 1.02.

3.3 DESIGN AND CONSTRUCTION

3.3.1 Production Drawings

The Pro/Engineer CAD files listed in Table 3.3-1 shall be used to manufacture the prototype winding form. They reside in a zip file (se-141-116p.zip) located at the prototype winding form ftp site (ftp://ftp.pppl.gov/pub/ncsx/manuf/prototype_winding_form/).

Table 3.3-1 List of Pro/ENGINEER Models and Drawings

File #	Next Assembly	Document / Part #	Type	Rev	Title / Description
1	SE140-103P	SE141-103P	ASM	0	Prototype Type-C Winding Form Assembly
2	SE140-103P	SE141-103P	DRW	0	Prototype Type-C Winding Form Assembly
3	SE140-103P	SE141-103P	PDF	0	Prototype Type-C Winding Form Assembly
4	SE140-103P	SE141-103P_ASM	STP	0	Prototype Type-C Winding Form Assembly
5	SE141-103P	SE141-116P	PRT	1	Prototype Winding Form
6	SE141-103P	SE141-116P	STP	1	Prototype Winding Form
7	SE141-103P	SE141-116P	DRW	1	Prototype Winding Form
8	SE141-103P	SE141-116P	PDF	1	Prototype Winding Form
9	SE141-103P	SE141-078P	ASM	0	Poloidal Break Shim w/ Bushing
10	SE141-103P	SE141-078P	DRW	0	Poloidal Break Shim w/ Bushing
11	SE141-103P	SE141-078P	PDF	0	Poloidal Break Shim w/ Bushing
12	SE141-103P	SE141-071P	PRT	0	Insulating Sheet, G11CR
13	SE141-078P	SE141-073P	PRT	0	Poloidal Break Shim, Cast SS
14	SE141-078P	SE141-073P	STP	0	Poloidal Break Shim, Cast SS
15	SE141-078P	SE141-074P	PRT	0	Insulating Sheet, G11CR
16	SE141-078P	SE141-077P	PRT	0	Insulating Sleeve, G11CR
17	SE141-103P	SE141-037P	PRT	0	Insulating Sleeve, G11CR
18	SE141-103P	SE141-036_GENERIC	PRT	0	Double End Threaded Stud, Steel
19	SE141-103P	DS141-036P	DRW	0	Double End Threaded Stud, Steel
20	SE141-103P	DS141-036P	PDF	0	Double End Threaded Stud, Steel
21	SE141-103P	SE141-038	PRT	0	Insulating Washer, G11CR
22	SE141-103P	DS141-038P	DRW	0	Insulating Washer, G11CR
23	SE141-103P	DS141-038P	PDF	0	Insulating Washer, G11CR
24	SE141-103P	SE141-079	PRT	0	Flat Washer, Steel
25	SE141-103P	DS141-079P	DRW	0	Flat Washer, Steel
26	SE141-103P	DS141-079P	PDF	0	Flat Washer, Steel
27	SE141-103P	SE141-060_GENERIC	PRT	0	12PT Hex Nut, Steel
28	SE141-103P	DS141-060P	DRW	0	12PT Hex Nut, Steel
29	SE141-103P	DS141-060P	PDF	0	12PT Hex Nut, Steel
30	---	SE141-114	PRT	0	Type-A Winding Form Assembly (Reference)
31	---	SE141-115	PRT	0	Type-B Winding Form Assembly (Reference)
32	---	DS01	FRM	0	Data Sheet Format (ProE)
33	---	ORNL_NCSX_E-SIZE_PART	FRM	0	Part Drawing Format (ProE)
34	---	ORNL_NCSX_E-SIZE_ASSY	FRM	0	Assembly Drawing Format (ProE)

3.3.2 Standards of Manufacture

3.3.2.1 Heat Treatment

The castings are to be heat treated per the applicable ASTM specification for the alloy chosen and as required for dimensional stability and materials property control 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. Test specimens shall be heat treated together with the castings they represent per Supplementary Requirement S22 of ASTM Spec. A703/A703M.

3.3.2.2 Repairs

Unacceptable defects must be repaired. Major repairs shall be welded and documented as defined in Sections S12 and S20 of ASTM Spec. A703/A703M. Repairs shall be considered major when the depth of the cavity prepared for welding exceeds 10% of the actual wall thickness or 1", whichever is smaller, or when the extent of the cavity exceeds approximately 10 in². 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. Weld preparation shall be per Section S10 of ASTM Spec. A703/A703M. Weld repairs are to be inspected per Sections 4.2.8, 4.2.9, and 4.2.10 of this specification.

4 QUALITY ASSURANCE PROVISIONS

4.1 GENERAL

Tests shall be conducted at the supplier's facility or otherwise suitable location.

4.1.1 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

4.2.1 Verification of Mechanical and Physical Properties of Casting Alloy

Yield Strength: The yield strength at 0.2% elongation for the cast stainless steel in the as heat-treated condition at room temperature and 77K shall be provided. Tensile test specimen coupons shall be cast with the prototype in accordance with ASTM A703/A703M-01, Supplementary Requirement 7.

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 provided. Tensile test specimen coupons shall be cast with the prototype in accordance with ASTM A703/A703M-01, Supplementary Requirement 7.

Elastic Modulus: The elastic (Young's) modulus at room temperature and 77K shall be provided.

Chemical Composition: The material chemical composition shall be measured and provided.

Thermal Conductivity: The thermal conductivity of the casting alloy at room temperature and 77K shall be provided.

Electrical Resistivity: The electrical resistivity of the casting alloy at room temperature and 77K shall be provided.

Fracture Toughness: The K_{IC} and the Paris Constants (C, n) of the casting alloy at room temperature and 77K shall be provided.

4.2.2 DELETED

4.2.3 DELETED

4.2.4 Verification of the Electrical Properties of the Poloidal Break

The insulation resistance of the poloidal break insulator and the insulation for each bolt shall be measured by performing an insulation resistance (Megger ®) test.

4.2.5 Verification of Surface Finish

All machined surfaces shall be inspected for compliance with surface finish requirements specified in Section 3.2.1.5.

4.2.6 Verification of Relative Magnetic Permeability

All cast surfaces and features shall be checked with a calibrated Severn Permeability Indicator for compliance with Section 3.2.1.6. Flange faces and edges shall be checked at locations no greater than 2 inches apart and at all weld repairs. Relative magnetic permeability measurements on all other surfaces shall be made at locations approximately 2" apart (to approximate a 2" x 2" grid). Relative magnetic permeability of any final machined casting that exceeds 1.02 must be documented on a nonconformance report and will require approval on a case-by-case basis. 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, μ , rather than ferrite content (FN).

4.2.7 Dimensional Inspection

All cast surfaces and features shall be dimensionally checked on a maximum of 1-inch centers using instruments having resolution at least ten times the tolerance and compared to the tolerances indicated on the applicable drawings listed in Sect. 3.3.1. All out-of-tolerance conditions shall be documented on nonconformance reports. With experience and based on the repeatability of manufacturing tolerances, the granularity of the measuring grid may be increased upon PPPL's written approval.

4.2.8 Visual Inspection

Visual surface inspection and treatment of unacceptable surface defects shall be performed per ASTM Spec. A703/A703M, paragraph 10.1. Evaluation criteria shall be per ASTM A802/A802M, Level II using graded reference comparators available from Castings Technology International⁵.

4.2.9 Liquid Penetrant Inspection

Each casting shall be examined for surface discontinuities using liquid penetrant inspection per Supplementary Requirement S6 of ASTM Spec. A703/A703M. Evaluation criteria shall be per

⁵ <http://www.castingsdev.com/>

ASTM A903/A903M Level I for those regions of the winding forms shown shaded in the drawings in Attachment 1 and Level II for all other areas. Certified test reports are required per ASTM A903, Supplementary Requirement S1.

4.2.10 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.

5 PREPARATION FOR DELIVERY

5.1 MARKING

The prototype winding form shall have a serial number and its weight engraved or stamped at its outer horizontal centerline with characters 1/4" high.

5.2 CLEANING

The prototype winding form shall be degreased/cleaned using a solvent, which has been agreed upon by both parties. This solvent must be able to dissolve grease, oils and other soils, and be residue free.

5.3 CRATING

The crate shall protect the prototype 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.

5.4 SHIPPING

Subcontractor is responsible arranging shipment, and for the safe arrival of the prototype 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.