NCSX

Product Specification

Prototype Modular Coil Winding Form

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REVISIONS

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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".

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

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".

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. A typical 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 BA 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 tee-section features a thin copper cladding which is electrically insulated from 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 BU to Type BU).

[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.

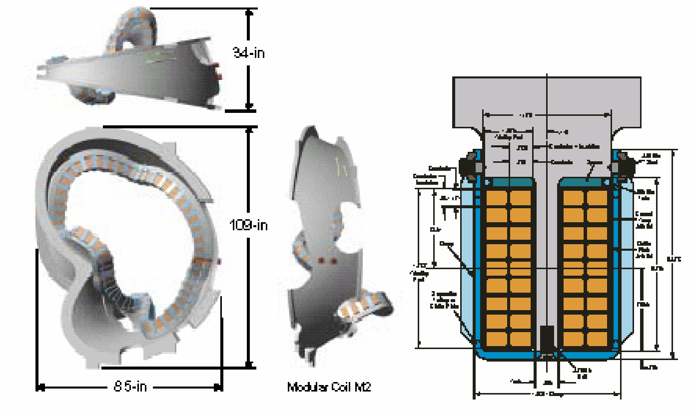

Figure 3.1-1 Details of a Typical Winding Form

NOTE: Dimensions and details given in Figure 3.1-1 are illustrative only and are 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 SS316 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: >200 MPa (>28.9 ksi) at room temperature (RT); >400 MPa (>57.8 ksi) at 77K.

Ultimate tensile strength: >400 MPa (57.8 ksi) at RT; >800 MPa (115.6 ksi) at 77 K.

Elongation: 30% (min.) at RT and 77 ^{0}K.

Thermal conductivity: >13.7 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 Copper Cladding

Background

The purpose of the copper cladding is to provide a path to conduct heat from the winding pack to the coolant tubes, which are attached to the clamps. The copper cladding must be electrically insulated from the stainless steel portion of the tee and must be cut into lengths (measured in the direction of the winding) as shown on the drawings. (All of this is to minimize the electrical time constant of the winding form.)

3.2.1.3 Physical Properties and Electrical Insulation Requirements for the Copper Cladding

Physical Properties: The thermal conductivity of the as applied cladding shall >270 W/m-K at 77K and >200 W/m-K at room temperature.

Electrical Insulation: The electrical resistance between a section of copper cladding and the tee and adjacent sections of copper cladding must have a resistance >500 kΩ when tested at 100 VDC.

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

The electrical resistance between any bolt to the winding form and the insulation break mid-plate to winding form shall be >500 kΩ when tested at 100 VDC.

3.2.1.5 Surface Finish

All machined surfaces must have a RMS (root mean square) surface finish <125 μ-inches. Uniform "scallops" which exceed 125 μ-inches, which may result from some machining processes may be acceptable, subject to PPPL approval.

3.2.1.6 Magnetic Permeability

The local 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. Tolerance requirements are provided in those drawings.

The Pro/ENGINEER models and drawings of the machined winding forms are available through the PPPL anonymous FTP server. The following FTP commands can be used to access the files:

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ftp ftp.pppl.gov

User: anonymous            <- login as anonymous

Password:                  <- enter your email address

ftp> cd pub/ncsx/manuf     <- lowercase

ftp> bin                   <- binary transfer mode

ftp> mget *                <- retrieve files

ftp> quit
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The files may also be accessed through a web browser using the following URL address:

ftp://ftp.pppl.gov/pub/ncsx/manuf/

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

Document Type	File Name	Rev	Description
Assembly (.asm)	se141-500.asm	0	Full assembly (18 winding forms)
Assembly (.asm)	se141-501.asm	0	Field period assembly (6 forms)
Assembly (.asm)	se141-502.asm	0	Half field period asm (3 forms)
Part (.prt)	se141-511.prt	0	Prototype winding form (Type A)
Part (.prt)	se141-512.prt	0	Winding form, Type B
Part (.prt)	se141-513.prt	0	Winding form, Type C
Drawing (.drw)	se141-521.drw	0	Overall dimensions, Type A
Drawing (.drw)	se141-522.drw	0	Section views, Type A
Drawing (.drw)	se141-523.drw	0	Flange details, Type A
Drawing (.drw)	se141-524.drw	0	Port openings, Type A
Drawing (.drw)	se141-525.drw	0	Tee cross-section details, Type A
Drawing (.drw)	se141-526.drw	0	Crossover machining details, Type A
Drawing (.drw)	se141-527.drw	0	Winding pack clamp details, Type A
Drawing (.drw)	se141-528.drw	0	Electrical lead details, Type A
Drawing (.drw)	se141-529.drw	0	PF/TF interface details, Type A
Drawing (.drw)	se141-530.drw	0	Gravity support details, Type A
Drawing (.drw)	se141-531.drw	0	Vac vessel support details, Type A
Drawing (.drw)	se141-532.drw	0	Inspection requirements, Type A
Drawing (.drw)	se141-533.drw	0	Overall dimensions, Type B
Drawing (.drw)	se141-534.drw	0	Overall dimensions, Type C

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 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 in^2. Non-conformance reports for major repairs (which includes in the disposition the proposed corrective action) shall be prepared for each major weld repair and is 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.

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 Verification of the Mechanical and Physical Properties of Copper Cladding

Thermal conductivity: The thermal conductivity of the copper cladding at room temperature and 77K shall be measured for a minimum of six specimens from the as-applied cladding.

Electrical Resistivity: The electrical resistivity of the copper cladding at room temperature and 77K shall be measured for a minimum of six specimens from the as-applied cladding.

4.2.3 Verification of the Electrical Isolation of the Copper Cladding

The electrical isolation of each section of copper cladding from the stainless steel tee and adjacent sections of copper cladding shall be measured by performing an insulation resistance (Megger ®)[3] test.

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.

[3] ® Biddle Instrument Co.

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 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. The casting surfaces shall be mapped into a 2 inch x 2 inch grid and magnetic permeability checks made at each grid point. 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. The ferrite content range shall be per Supplementary Requirements S24 of ASTM Spec. A703/A703M and S1 of ASTM A800/A800M.

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 International[4].

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[4] http://www.castingsdev.com/

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 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.