

NCSX

Product Specification

Modular Coil Winding Forms

NCSX-CSPEC-141-03-07

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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
Rev 3	8/4/2004	Updated Table 6-1 – Drawings se141-116 to se141-116r1 and Drawing se141-116-nf.stp to se141-116-NFr1.stp
Rev 4	9/17/2004	Updated specification to reflect final negotiated configuration: <ul style="list-style-type: none"> • Added vendor information on alloy in Sections 3.1.1.1 and 3.1.1.2; • Revised Sections 4.2.5 and 4.2.7.2.1; and • Updated Table 6-1
Rev 5	9/23/2004	Updated Table 6-1
Rev 6	1/14/2005	Updated Table 6-1
Rev 7	04/19/2005	Incorporated ECP-026 (MCWF Fast Response), ECP-028 (RFD-14-001), and RFD-14-002. Changes made include: <ul style="list-style-type: none"> • Removed reference to a specific operation date in Section 1.1. • Updated Table 3.2 to reflect correct units; • Updated and/or revised Sections: 3.1.1.6.3; 3.1.1.7; 3.2.3.2.3; 4.2.1; 4.2.2; 4.2.2.5 (New); 4.2.8.1; 4.2.8.2; 6.1; and 6.2. • Added Appendix A which identifies the high stress regions.

Table of Contents

1	INTRODUCTION AND SCOPE.....	1
1.1	INTRODUCTION.....	1
1.2	SCOPE.....	2
2	APPLICABLE DOCUMENTS.....	2
2.1	CODES AND STANDARDS	2
2.1.1	American Society for Testing and Materials (ASTM) Documents	2
2.1.2	Manufacturers Standardization Society (MSS) of the Valve and Fittings Industry, Inc. Documents ...	2
3	REQUIREMENTS ITEM DEFINITION.....	2
3.1	CHARACTERISTICS	3
3.1.1	Performance.....	3
3.1.1.1	Chemical Composition of the Casting Alloy.....	3
3.1.1.2	Mechanical Properties of the Casting Alloy and Welding Material.....	3
3.1.1.3	Electrical Requirements for the Poloidal Electrical Break	3
3.1.1.4	Surface Finish.....	4
3.1.1.5	Relative Magnetic Permeability	4
3.1.1.6	External Defects	4
3.1.1.6.1	Visual Examination	4
3.1.1.6.2	Liquid Penetrant Examination of Casting.....	4
3.1.1.6.3	Liquid Penetrant Inspection of High Stress Regions	4
3.1.1.7	Radiographic Inspection.....	4
3.2	DESIGN AND CONSTRUCTION	5
3.2.1	Production Drawings	5
3.2.2	Dimensions and Tolerances	5
3.2.2.1	Measurement	5
3.2.2.2	Fiducials	5
3.2.3	Standards of Manufacture	5
3.2.3.1	Heat Treatment.....	5
3.2.3.2	Repairs	5
3.2.3.2.1	Non-Weld Repairs	5
3.2.3.2.2	Weld Repairs	5
3.2.3.2.1.1	Minor Weld Repairs.....	5

3.2.3.2.1.2	Major Weld Repairs	6
3.2.3.2.3	Repairs in High Stress Areas	6
4	QUALITY ASSURANCE PROVISIONS.....	6
4.1	RESPONSIBILITY FOR INSPECTION	6
4.2	QUALITY CONFORMANCE INSPECTIONS / VERIFICATIONS.....	6
4.2.1	Verification of Chemical Composition	6
4.2.2	Verification of Mechanical Properties of the Casting Alloy and Weld Material	6
4.2.2.1	Verification of Yield Strength and Elastic Modulus	7
4.2.2.2	Verification of Ultimate Tensile Strength and Elongation	8
4.2.2.3	Verification of Charpy V-Notch Energy	8
4.2.2.4	Additional Test Material	8
4.2.2.5	Weld Filler Material	8
4.2.3	Verification of the Electrical Properties of the Poloidal Break.....	8
4.2.3.1	Mid-Plane Insulation	8
4.2.4	Verification of Surface Finish.....	8
4.2.5	Verification of Relative Magnetic Permeability	9
4.2.6	Verification of Dimensions and Tolerances.....	9
4.2.7	Inspection for External Defects	9
4.2.7.1	Visual Inspection.....	9
4.2.7.2	Liquid Penetrant Inspections	9
4.2.7.2.1	General Liquid Penetrant Inspection	9
4.2.7.2.2	Post Machining Liquid Penetrant Inspection.....	9
4.2.7.2.3	Liquid Penetrant Inspection of High Stress Regions	9
4.2.8	Inspection for Internal Defects.....	10
4.2.8.1	Pre-Machining Inspection for Internal Defects	10
4.2.8.2	Post Machining Inspection for Internal Defects in High Stress Areas	10
5	PREPARATION FOR DELIVERY	10
5.1	MARKING	10
5.2	CLEANING	10
5.3	CRATING	10
5.4	SHIPPING	10
6	TABLES OF APPROVED MODELS/DRAWINGS AND DEVIATIONS	10
6.1	TABLE OF MODELS AND DRAWINGS.....	10

NOTE: FILENAME INDICATES REVISION OF ZIP FILE ONLY. REVISION NUMBERS OF DRAWINGS/FILES WITHIN THE ZIP FILE ARE INDICATED BY THE INDIVIDUAL FILENAME OF EACH DRAWING/FILE. 11

6.2 TABLE OF APPROVED DEVIATIONS 11

7 APPENDICES 11

7.1 APPENDIX A: IDENTIFICATION OF HIGH STRESS REGIONS FOR PRODUCTION MCWF 11

List of Figures

Figure 1-1 Typical Machined Modular Coil Winding Form 1

Figure 4-1 Definition of Zones for Test Specimens 7

Figure 7-1 – Identification of High Stress Zones 12

Figure 7-2 – High Stress Region Identification for Type-C MCWF 13

Figure 7-3 – High Stress Region Identification for Type-B MCWF 14

Figure 7-4– High Stress Region Identification for Type-A MCWF 15

List of Tables

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

Table 3-2 Minimum Mechanical Properties 3

Table 6-1 Production Modular Coil Winding Form Models and Drawings 11

Table 7-1 Definition of High Stress Region Based on Flange Hole Numbers 12

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.

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 ¹

- 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 ²

- 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.

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 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.

Temperature	77K	293K
Elastic Modulus	21 Msi (144.8 Gpa)	20 Msi (137.9 Gpa)
0.2% Yield Strength	72 ksi (496.4 Mpa)	34 ksi (234.4 Mpa)
Tensile Strength	95 ksi (655 Mpa)	78 ksi (537.8 Mpa)
Elongation	32%	36%
Charpy V – notch Energy	35 ft. lbs. (47.4 J)	50 ft-lbs (67.8 J)

Table 3-2 Minimum Mechanical Properties

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 3.2.3.2. (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 3.2.3.2 (Repairs).

3.1.1.6.3 Liquid Penetrant Inspection of High Stress Regions

High stress areas, as defined in Appendix A, shall be free of external defects as defined in ASTM A903/A903M Level I when checked by liquid penetrant inspection . Discontinuities not meeting the evaluation criteria shall be repaired per Section 3.2.3.2.3 (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 3.2.3.2 (Repairs). In addition, High Stress Areas (as defined in Appendix A) shall be free of defects exceeding 0.180” (major dimension) in the base of the Tee and free of defects exceeding 0.060” (major dimension) in the web region of the Tee. Defects exceeding these limits shall be repaired per Section 3.2.3.2.3 (Repairs in High Stress Areas).

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

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

The Supplier shall 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 3.1.1.6 and 3.1.1.7. Welding procedure qualification tests shall include evidence of compliance with the magnetic permeability requirements of Section 3.1.1.5, 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 in². 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 3.1.1.6 and 3.1.1.7. Welding procedure qualification tests shall include evidence of compliance with the magnetic permeability requirements of Section 3.1.1.5, 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 and a weld map showing size and locations as required in A703) shall be prepared for each major weld repair cycle. The NCR (or EIO equivalent) shall be delivered to PPPL within 24 hours of the start of welding. PPPL will respond with concurrence or disapproval within 1 working day.

3.2.3.2.3 Repairs in High Stress Areas

Rejectable surface defects which are less than 0.125" in depth shall be eliminated by grinding. Rejectable surface defects which exceed this depth, as well as any rejectable subsurface defects 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 3.2.3.2.2 (Weld Repairs). The High Stress Areas are defined in Appendix A.

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 lot of welding material.

4.2.2 Verification of Mechanical Properties of the Casting Alloy and Weld Material

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

Figure 4-1) made in the transverse direction to the major axis of the gating section and three specimens (1 each from the 3 zones identified in Figure 4-1) 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. It is requested that this data be supplied to PPPL within 30 days of the casting date.

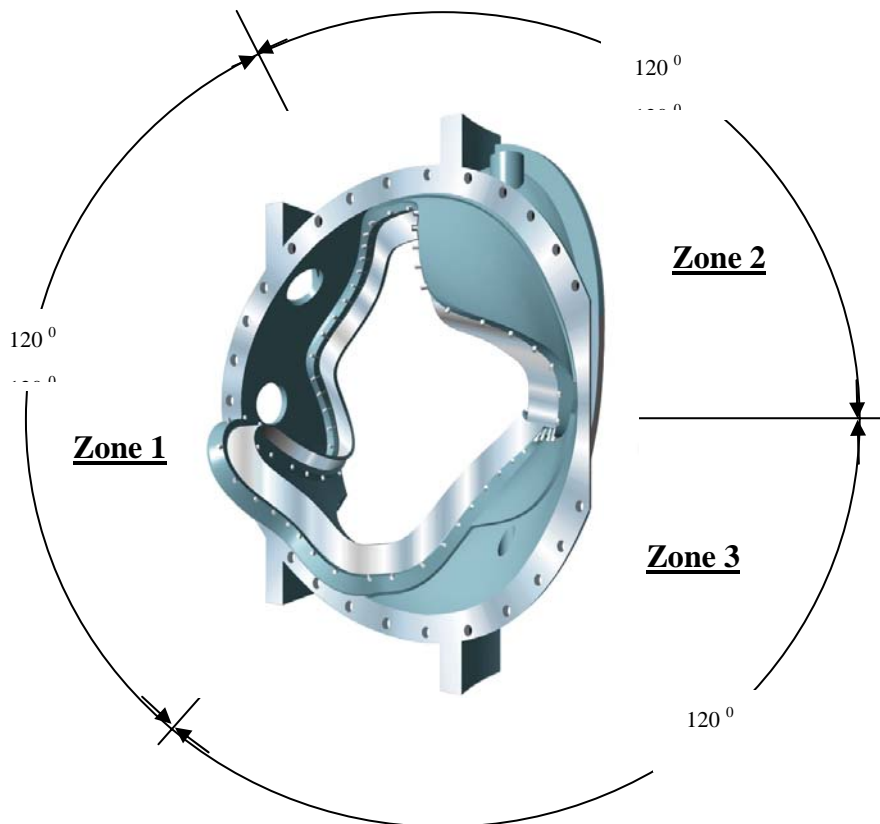


Figure 4-1 Definition of Zones for Test Specimens

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.

4.2.2.5 Weld Filler Material

Weld material ultimate tensile strength and Charpy V-notch at RT and 77K shall also be verified.

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 0.

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 3.1.1.5. 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, μ , 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 3.1.1.6.1 (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 Section 3.1.1.6.2 (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 Section 3.1.1.6.22 (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 Section 3.1.1.6.2 (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. Penetrimeters shall be used to demonstrate a sensitivity of at least 2% of the thickness being measured. Acceptance criteria shall be as defined in Section 3.1.1.7.

4.2.8.2 Post Machining Inspection for Internal Defects in High Stress Areas

High stress areas of the casting defined in Appendix A shall be examined for internal defects by repeating the inspections defined in 4.2.8.1 (Pre-Machining Inspection for Internal Defects). Since the post machined thicknesses are appreciably reduced, these inspections will be able to detect smaller flaws and will assure that the no defects exceeding the acceptance criteria of 3.1.1.7 exist.

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 TABLES OF APPROVED MODELS/DRAWINGS AND DEVIATIONS

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

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

ZIP File	Model Description (from Pro/Intralink database, edited)
production_mcwf_proe_Rev3.zip	ZIP file containing all ProE models for the winding forms.
production_mcwf_stp_Rev3.zip	ZIP file containing all STEP files for the winding forms.
production_mcwf_pdf_Rev3.zip	ZIP file containing all pdf drawing files.

NOTE: Filename indicates revision of Zip File only. Revision numbers of drawings/files within the Zip File are indicated by the individual filename of each drawing/file.

6.2 TABLE OF APPROVED DEVIATIONS

Deviation Number	Description	Date Approved	Impacted Documents
NCSX-RFD-14-001	RFD-14-001, Revised Location of Part Number in MCWF Casting	3/30/2005	Drawing SE-141-114 shows the reference location of the pattern/casting identification number for Type A coils. No change in that drawing is planned, at least not until all of the Type A coils are fabricated.
NCSX-RFD-14-002	RFD-14-002, Change in dimensional inspection for C1 casting.	4/15/2005	Deleted requirement for second dimensional inspection – deemed redundant.

7 APPENDICES

7.1 Appendix A: Identification of High Stress Regions for Production MCWF

Figure 7-1, Figure 7-2 , Figure 7-3, Figure 7-4, and Table 7-1 of this this appendix identify the high stress areas and show a numbering scheme for the 3/8-16UNC tapped holes in the tee. Per the proposal of Major Tool, every tenth hole shall be identified by etching. The high stress region shall be identified as:

- The web of the “tee” cross-section; and
- The base of the “tee” cross-section in all regions where the minimum machined thickness is ≤ 2 ” between profile points “P” and “Q” on Detail A, Sheet 2 of drawings SE141-114 (shown below for illustrative purposes) , SE141-115, and SE141-116, that is located in between the hole numbers shown in Table 7-1 or be or between the coordinates shown in Figure 7-1 (for type C for illustration only) and Table 7-1.

FOR h

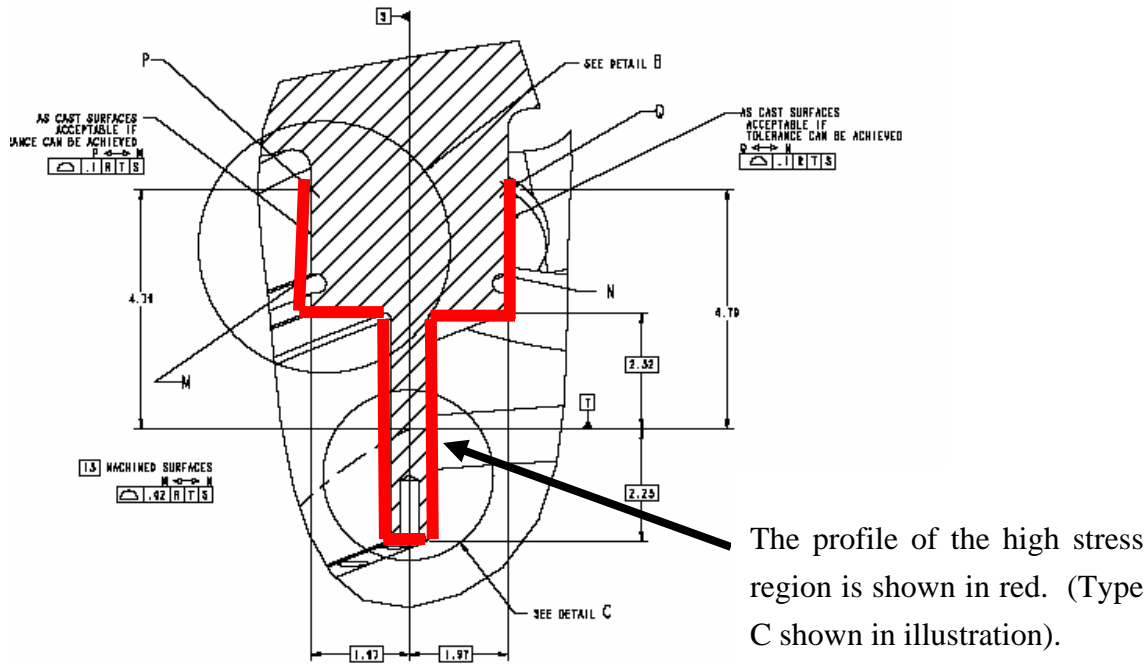


Figure 7-1 – Identification of High Stress Zones

MCWF Type	Hole No. (Start)	Hole No. (End)
C (Fig. 1)	45	65
B (Fig. 2)	55	75
A (Fig. 3)	20	35

Table 7-1 Definition of High Stress Region Based on Flange Hole Numbers

The figures also show approximate dimensions, including 1/2-in. stock material allowance, from the flat surfaces of the casting to the start and end locations. These dimensions shall be used to identify the high stress regions prior to machining. Figure 7-2 (Type C), Figure 7-3 (Type B), and Figure 7-4 (Type A) depict the high stress region identification for each type casting.

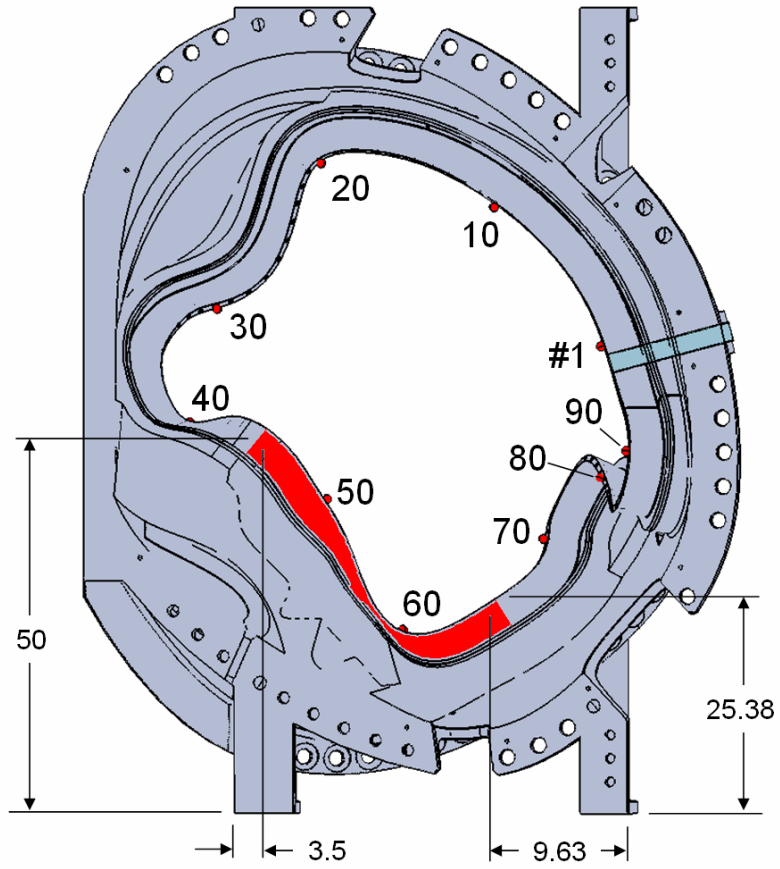


Figure 7-2 – High Stress Region Identification for Type-C MCWF

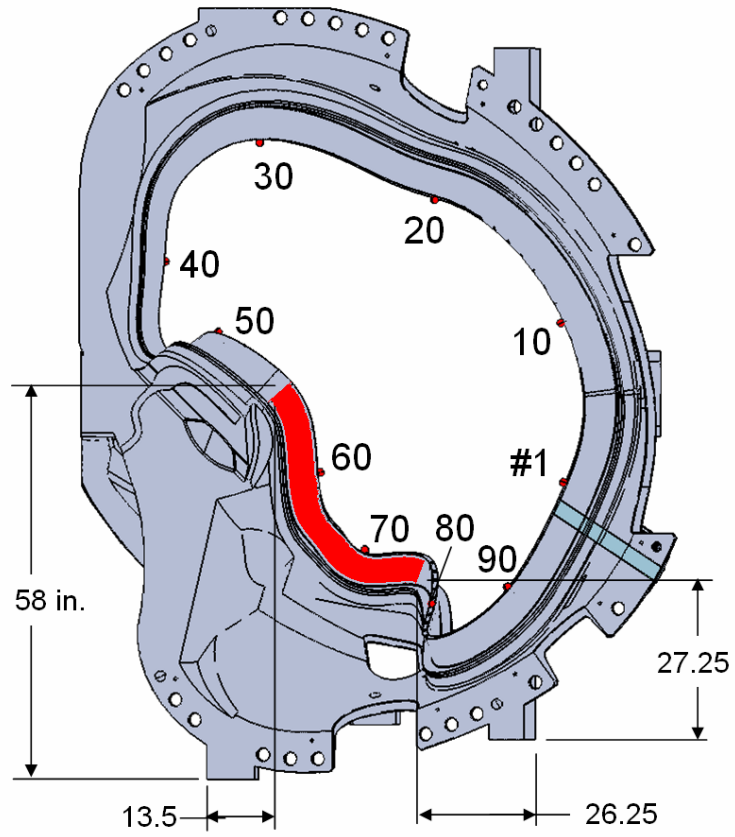


Figure 7-3 – High Stress Region Identification for Type-B MCWF

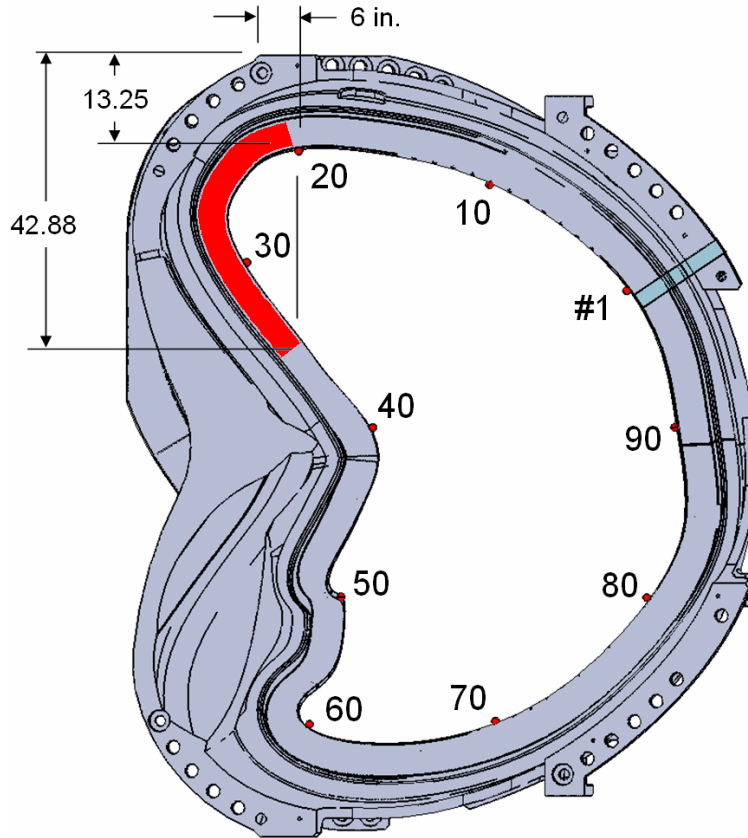


Figure 7-4– High Stress Region Identification for Type-A MCWF