NCSX Vacuum Vessel Fabrication


October 2005
Princeton Plasma Physics Laboratory
Report Disclaimers

Full Legal Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Trademark Disclaimer

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

PPPL Report Availability

Princeton Plasma Physics Laboratory

This report is posted on the U.S. Department of Energy's Princeton Plasma Physics Laboratory Publications and Reports web site in Fiscal Year 2006.

The home page for PPPL Reports and Publications is:

http://www.pppl.gov/pub_report/

Office of Scientific and Technical Information (OSTI):


Available for a processing fee to U.S. Department of Energy and its contractors, in paper from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
Telephone: (865) 576-8401
Fax: (865) 576-5728
E-mail: reports@adonis.osti.gov
I. INTRODUCTION

The National Compact Stellarator Experiment (NCSX) is being constructed at the Princeton Plasma Physics Laboratory (PPPL) in conjunction with the Oak Ridge National Laboratory (ORNL). The goal of this experiment is to develop a device which has the steady state properties of a traditional stellarator along with the high performance characteristics of a tokamak. A key element of this device is its highly shaped Inconel 625 vacuum vessel shown in Fig. 1. This paper describes the manufacturing of the vessel. The vessel is being fabricated by Major Tool and Machine, Inc. (MTM) in three identical 120° vessel segments, corresponding to the three NCSX field periods, in order to accommodate assembly of the device. The port extensions are welded on, leak checked, cut off within 1” of the vessel surface at MTM and then reattached at PPPL, to accommodate assembly of the close-fitting modular coils that surround the vessel. The 120° vessel segments are formed by welding two 60° segments together. Each 60° segment is fabricated by welding ten press-formed panels together over a collapsible welding fixture which is needed to precisely position the panels. The vessel is joined at assembly by welding via custom machined 8” (20.3 cm) wide spacer “spool pieces” shown as bands in Fig. 1. The vessel must have a total leak rate less than $5 \times 10^{-6}$ t-l/s, magnetic permeability less than 1.02µ, and its contours must be within 0.188” (4.76 mm). It is scheduled for completion in January 2006.

II. PROTOTYPE VACUUM VESSEL (PVVS)

The NCSX team decided to solicit fabrication of a prototype vacuum vessel. This would both solicit interest and develop techniques for the fabrication of the final vacuum vessel. A Statement of Work (SOW) was written which defined the manufacturing development activities for the 120° Vacuum Vessel Sub-Assembly (VVSA) and the production of a full-scale 20° prototype vacuum vessel segment (PVVS). These activities were also meant to give the fabricator the experience needed to develop and submit a firm fixed price and schedule proposal for producing the three VVSA units. The SOW focused on the critical aspects of manufacturing the vessel:

- Forming methods to be used in the fabrication of the shell,
- Methods for locating, machining, and welding the ports. (The spatial and angular orientation of ports is critical on NCSX.),
- Methods of controlling distortion of the vessel shell and maintaining the required tolerances,
- Welding and Non Destructive Examination (NDE),
- Vacuum testing (both to locate leaks in welds and verifying leak rate and base pressure),
- Cleaning and surface finishing operations,
- Measurements of the complex formed surfaces and comparison with the reference Pro/Engineer model,
- Magnetic permeability control and verification,
- Quality assurance plans that address all of the requirements of the SOW and the applicable specification,
- Methods for locating the port cut line and actual method of cutting of the ports within the surface profile, as indicated on the drawings,
- Method of cutting the hole in the vessel shell inside the port after it is cut in the above step,
- Method of reattaching the port by welding it from the inside.
Two companies were chosen that submitted competitive solutions with the most promising technique. Both companies produced prototype vacuum vessels and Major Tool and Machine was chosen for the production of the VVSA based on performance (see Fig. 2).

III. FABRICATION OF THE VACUUM VESSEL SUBASSEMBLY

Major Tool chose to segment the Vacuum Vessel Subassembly (VVSA) into ten pieces for optimization of complexity of forming vs. weld distortion (see Fig. 3). The VVSA is fabricated by first forming the ten individual panels using kirksite dies (see Fig. 4). Each panel is formed and then trimmed to size. Once trimmed the panel is annealed and then pressed a second time in the die set. Pieces of wood and/or rubber are used to make any further adjustments. A set of ten gauges (see Fig. 5) have been fabricated to enable the die operator to quickly determine where the panel is within the shape tolerance or where rework is necessary. Once the panel is formed, it is set aside for mounting onto the 60° fixture.

Once all ten panels have been formed, they are placed on the 60° fixture (see Fig. 6), aligned in groups, and final trimming is performed. Measurements are made using a laser tracker coordinate measuring machine (see Fig. 7). The 60° fixture (see Fig. 8) is ingeniously designed with many features. It allows for the mounting of the ten panels in two 5–panel sections upper and lower. It is also keyed and segmented to allow for easy disassembly after the 60° segment is welded. Additionally it provides the stiffness necessary to hold shape and control distortion of the segments during welding. It can be bolted together as one assembly or as two individual upper and lower assemblies. It has cutouts to allow a person to stand and weld within the fixture as well as allow for seams to be made which cross the fixture plates.

The panels are tacked together in a three panel and a two panel configuration on the upper or lower fixture. Once these two partial assemblies are made then they can be joined into one complete upper or lower five panel segment. Final measurements are taken; the upper and lower segments are mounted back onto the complete 60° fixture and welded into their final configuration. This completes the formation of a 60° segment.
Once two 60° segments have been completed (see Fig. 9), they are mounted onto the 120° fixture (see Fig. 10). This fixture allows two 60° segments to be aligned and a best fit analysis is performed using Verisurf® software. The two 60° segments are then welded together to form the final 120° shell (see Fig. 11). The 120° fixture also has some unique features serving multiple needs. This fixture is used to position and join two 60° degree vessel segments together, provide support and rigidity for machining the port holes, and is also the basis for support during the installation of the port extensions and vacuum testing operations. It is designed to uniformly support the highly shaped vessel surfaces (minimizing gravity induced distortion). It includes features such as strategically placed adjusting rods (used for “fine tuning” the position of the two 60° vessel segments prior to welding), personnel access (necessary for completing the circumferential weld), a separate center support structure (which locates inside the vessel to eliminate gravity induced distortion and provide a solid backing at the center weld seam), datum reference monuments (used for accurate re-positioning of the laser tracker during profile inspection, and ensure geometrical accuracy during machine tool setup).
The 120° segment is then placed on a five axis mill in order to bore the various holes required for the ports (see Fig. 12). Once bored, the shell is placed back onto the 120° fixture and the ports are then welded into place. The ends will then be capped to allow for a vacuum leak check and also thermal cycling three times to 375°F. During this thermo-cycle the ports may not exceed 150°F C because of the material property differences between the 316 S. S. flanges and the Inconel 625 port tube extensions. After successful completion of these tests, the ports are then cut off within 1” of the shell surface. This allows for the future installation of the modular coil sets over the vacuum vessel as part of the final assembly process at Princeton Plasma Physics Laboratory. A sketch of one completed VVSA is shown in Fig. 13.

ACKNOWLEDGMENTS

Sketches and photographs provided by Major Tool and Machine Inc.

This research is supported by the U.S. DOE under contract DE-AC02-76CH03073 with Princeton University and contract DE-AC05-00OR22725 with UT-Battelle, LLC.
External Distribution

Plasma Research Laboratory, Australian National University, Australia
Professor I.R. Jones, Flinders University, Australia
Professor João Canalle, Instituto de Fisica DEQ/IF - UERJ, Brazil
Mr. Gerson O. Ludwig, Instituto Nacional de Pesquisas, Brazil
Dr. P.H. Sakanaka, Instituto Fisica, Brazil
The Librarian, Culham Science Center, England
Mrs. S.A. Hutchinson, JET Library, England
Professor M.N. Bussac, Ecole Polytechnique, France
Librarian, Max-Planck-Institut für Plasmaphysik, Germany
Jolan Moldvai, Reports Library, Hungarian Academy of Sciences, Central Research
Institute for Physics, Hungary
Dr. P. Kaw, Institute for Plasma Research, India
Ms. P.J. Pathak, Librarian, Institute for Plasma Research, India
Dr. Pandji Triedyaksa, Fakultas MIPA Universitas Diponegoro, Indonesia
Professor Sami Cuperman, Plasma Physics Group, Tel Aviv University, Israel
Ms. Clelia De Palo, Associazione EURATOM-ENEA, Italy
Dr. G. Grosso, Instituto di Fisica del Plasma, Italy
Librarian, Naka Fusion Research Establishment, JAERI, Japan
Library, Laboratory for Complex Energy Processes, Institute for Advanced Study,
Kyoto University, Japan
Research Information Center, National Institute for Fusion Science, Japan
Professor Toshitaka Idehara, Director, Research Center for Development of Far-Infrared Region,
Fukui University, Japan
Dr. O. Mitarai, Kyushu Tokai University, Japan
Mr. Adefila Olumide, Ilorin, Kwara State, Nigeria
Dr. Jiangang Li, Institute of Plasma Physics, Chinese Academy of Sciences, People’s Republic of China
Professor Yuping Huo, School of Physical Science and Technology, People’s Republic of China
Library, Academia Sinica, Institute of Plasma Physics, People’s Republic of China
Librarian, Institute of Physics, Chinese Academy of Sciences, People’s Republic of China
Dr. S. Mirmov, TRINITI, Troitsk, Russian Federation, Russia
Dr. V.S. Strelkov, Kurchatov Institute, Russian Federation, Russia
Kazi Firoz, UPJS, Kosice, Slovakia
Professor Peter Lukac, Katedra Fyziky Plazmy MFF UK, Mlynska dolina F-2, Komenskeho Univerzita,
SK-842 15 Bratislava, Slovakia
Dr. G.S. Lee, Korea Basic Science Institute, South Korea
Dr. Rasulkhuzha S. Sharafiddinov, Theoretical Physics Division, Insitute of Nuclear Physics, Uzbekistan
Institute for Plasma Research, University of Maryland, USA
Librarian, Fusion Energy Division, Oak Ridge National Laboratory, USA
Librarian, Institute of Fusion Studies, University of Texas, USA
Librarian, Magnetic Fusion Program, Lawrence Livermore National Laboratory, USA
Library, General Atomics, USA
Plasma Physics Group, Fusion Energy Research Program, University of California at San Diego, USA
Plasma Physics Library, Columbia University, USA
Alkesh Punjabi, Center for Fusion Research and Training, Hampton University, USA
Dr. W.M. Stacey, Fusion Research Center, Georgia Institute of Technology, USA
Director, Research Division, OFES, Washington, D.C. 20585-1290

05/16/05
The Princeton Plasma Physics Laboratory is operated by Princeton University under contract with the U.S. Department of Energy.

Information Services
Princeton Plasma Physics Laboratory
P.O. Box 451
Princeton, NJ 08543

Phone: 609-243-2750
Fax: 609-243-2751
e-mail: pppl_info@pppl.gov
Internet Address: http://www.pppl.gov