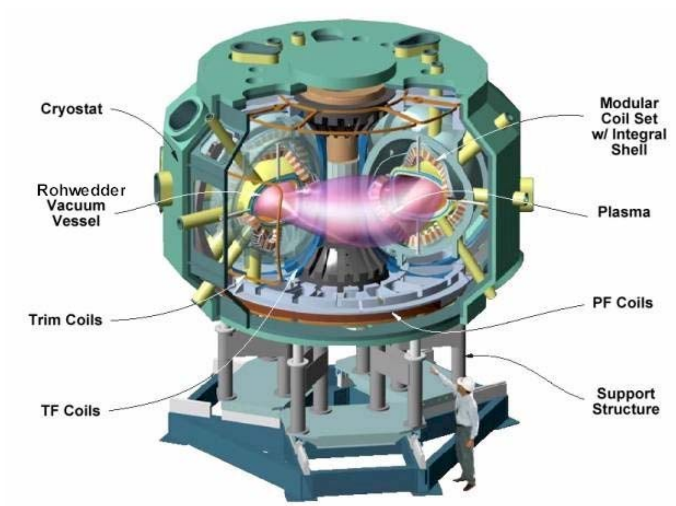
Princeton University
Plasma Physics Laboratory

National Compact Stellarator Experiment (NCSX)

Vacuum Vessel Manufacturing Development and Prototype Fabrication



3.1.2 Subcontractor Recommendations

In Reference to Section 3.1.2 of NCSX-SOW-121-01-01

May 30, 2003

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3.1.2 Subcontractor Recommendations
In Reference to Section 3.1.2 of NCSX-SOW-121-01-01

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1.0 ELECTRO-POLISHING OF VESSEL INTERIOR SURFACES

Section 3.2.1.2.1 of NCSX-CSPEC-121-02-00 requests electro-polish of all interior surfaces of the VVSA. Due to the size and complex shape of the system, electro-polishing will most likely have to take place on individual segments prior to welding them together to form the vessel shell. A significant amount of welding, machining and surface finishing will take place after that point, which will reduce the final effectiveness of the electro-polishing. Areas around each weld seam would not have as high a quality surface finish as the electro-polish will provide on the segment and port extension surfaces. As a result of these circumstances, Rohwedder has discussed the usefulness of this specification with Princeton Plasma Physics Lab (PPPL) in previous correspondence. It was stated that this was not a rigid requirement and was open for discussion, however, the conversation did re-emphasize the UHV base pressure (10^{-9} torr range) at which PPPL plans to operate the NCSX. The reduced surface area associated with the electro-polish will reduce pump-down times and pumping speed necessary to maintain base pressure.

Because of the UHV nature of the system, Rohwedder Inc does recommend that the interior surfaces of the VVSA be electro-polished even if the effectiveness is somewhat reduced due to the amount of area around weld seams that would not receive electro-polish. Rohwedder will include pricing of the VVSA with and without electro-polishing in the report *3.1.4 Budgetary Cost and Schedule Estimate for the VVSA* to allow PPPL to weigh the benefits vs. cost for this process step. Rohwedder will also investigate the feasibility of electro-polishing a full 120˚ vessel shell segment, reducing the area without electro-polish to the weld seams at the connection of the port extensions to the vessel shell, thereby increasing the effectiveness of the procedure.

2.0 SPACER MANUFACTURE APPROACH

An area of the manufacturing process of the VVSA that is not yet completely defined by the NCSX Statement of Work or Product Specification is the design and manufacturing of the section spacers. The variance that will occur between the computer models of the vessel surfaces and the actual end product, and even between the three fabricated segments dictates that even if the surfaces are within tolerance (+/- 0.188") and even with proper fit-up of the segment end flanges, a single segment designed prior to the completion of the vessel segment manufacturing will not suffice. The build-up of tolerances in the fabrication of the segments would undoubtedly prevent the bolt holes from aligning or the segments from sealing with the spacer surfaces. As explained in *3.1.1 Manufacturing Methods for the VVSA Section 3 Machining and Finishing,* the initial plan for manufacturing the segment spacers is to reverse engineer the final geometry of each spacer based on the variations in actual manufactured geometry of the VVSA segments to assure proper fit-up. First, the three VVSA sub-sections will be fixtured to match their final assembled positions relative to each other and using a CMM, several data points will be taken from the two respective section end flanges for each joint to indicate surface and hole locations. The inferred surfaces and hole locations will be used in the creation of computer models of the three custom segment spacers. The computer models of the spacers will then be imported into Pro/E Prismatic Milling Software (a CAM package) in order to set tooling paths, speeds and feeds, and finally to create machine code to control the CNC milling stations that will be used in final machining of the flanges and hangers. A CMM will be used for verification of part tolerances.

The fit-up and design of the segment spacers could be a difficult and critical process step in the manufacture of the VVSA that, at this point, is not addressed in the prototype segment. Therefore, Rohwedder/NVSI would like to propose including a segment spacer fabrication development program in parallel with the PVVS program. This would not involve an addition or modification to the proposed prototype segment, but a separate prototype of the segment joint area (end flanges and spacers), scaled down both in size and in geometric complexity. This would provide the opportunity to develop a solution, including testing the feasibility of the reverse engineering approach proposed by Rohwedder/NVSI. The geometry chosen for the prototype end flanges would be simplified in respect to the actual VVSA end flanges to reduce costs, yet would be complex enough to assure test results are applicable to the joint design of the VVSA. To represent the joint area of two VVSA segments, two prototype end flanges would be placed in fixtures designed to provide 6 DOF adjustments independently to each flange. Multiple test configurations of the relative positioning of the two end flanges could be created and the planned manufacturing approach tested for each. A verification of fit-up and compliance to dimensional tolerances set by PPPL for the prototype assembly would be performed. The prototype end flanges could also be designed to allow for pump-down and leak checking of the joint seals. Rohwedder/NVSI will create a budgetary estimate for this development effort.

3.0 REUSABLE DIE SETS

PPPL has expressed their desire for prototype segment (PVVS) forming dies that will be usable in the forming of the full vessel segments (VVSA) to reduce costs for the fabrication of the VVSA, if it is at all possible. Rohwedder/NVSI has looked into methods to partially reuse the prototype die sets on the full assemblies. Rohwedder/NVSI is not optimistic that a die could be created for the PVVS in which new "sections" can be added at a later date to create a die set that is usable on the larger sections of the VVSA. The die design and fabrication procedures described in *3.1.1 Manufacturing Methods for the VVSA Section 2 Forming Methods*, are based on the recommendations of forming houses and conform to standards in the forming industry, however, they are not conducive to simple modifications or additions that would allow the prototype dies to be used in forming the larger segments of the VVSA. With the present approach, the die ribs and enclosure are welded together, the spaces between ribs are partially filled with concrete and the scab plate is welded in place on the contact surface. These features would make additions difficult and some components like the prototype segment-sized scab plates would have to be scrapped and replaced completely. The reuse of only some components may still be a cost savings, however, it may be found that the design and labor costs that would go into salvaging prototype die components will exceed the material savings of component reuse. Rohwedder/NVSI is currently looking into alternate die designs that will allow for easier additions and modifications to make the prototype segment die sets more conducive to reuse on the VVSA, such as bolted assemblies that use removable cross bracing instead of concrete for reinforcement. It is not clear at this point if such designs are feasible either in functionality or cost-effectiveness. Rohwedder/NVSI will advise PPPL as soon as a more informed recommendation of die reuse feasibility can be made.

4.0 MACHINING AND WELD FIXTURES

Stainless steel "cage" type fixtures will be developed and designed to completely capture the VVSA sections after fabrication to allow accurate positioning of the vessel for aligning, welding and machining of the port extensions and when boring out each individual port diameter/shape in the VVSA sections after the ports are cut off. The cages will also be used to fixture the three VVSA sub-sections in their final assembled positions relative to each other for the reverse engineering and fabrication of the section spacers. Fixtures will be necessary in the alignment and re-weld of the port extensions at PPPL, and for cost-efficiency, it would be beneficial to use the Rohwedder/NVSI cage fixtures during this process. However, at the time of the re-weld procedure at PPPL the modular coil units and coil support structure will be in place, undoubtedly interfering with the support beams and vessel interface points of the weld fixtures. The coil units will also cover the reference points placed throughout the vessel shell that would be used in initial alignment of the fixtures and, later, the alignment of the ports themselves. Accommodations in the geometry of the modular coil units and coil support structure would be necessary for utilization of weld fixtures. The support beams of weld fixtures used in the port re-weld process will also have to be offset further from the vessel surface than would be standard, potentially increasing location errors. It may not be feasible to create cage fixtures that can be effectively used during the Rohwedder/NVSI fabrication of the VVSA and during the re-weld process at PPPL. Close cooperation between Rohwedder/NVSI and the PPPL design engineers responsible for integration on-site (and the required support equipment) will be necessary to assess the feasibility of designing cage fixtures with this dual functionality and to ensure access to the VVSA reference points critical for alignment of the port extensions during the re-weld process.