CONF-851102--51

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DE86 003273

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DESIGN AND FABRICATION OF THE VACUUM VESSEL FOR THE ADVANCED TOROIDAL FACILITY*,+

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Abstract: The vacuum vessel for the Advanced Toroidal Facility (ATF) is a heavily contoured and very complex formed vessel that is specifically designed to allow for maximum plasma volume in a pure stellarator arrangement. The design of the facility incorporates an internal vessel that is closely fitted to the two helical field coils following the winding law $\theta = 1/6\phi$. Metallic seals have been incorporated throughout the system to minimize impurities. The vessel has been fabricated utilizing a comprehensive set of tooling fixtures specifically designed for the task of forming 6-mm stainless steel plate to the complex shape. Computer programs were used to develop a series of ribs that essentially form an internal mold of the vessel. Plates were press-formed with multiple compound curves, fitted to the fixture, and joined with full-penetration welds.

Introduction

The ATF program has been described previously [1] and is being reported again at this conference [2]. The preliminary design description of the ATF vacuum vessel has also been reported in detail [3]. Since these efforts were reported, the design has been completed and fabrication of the vessel is now about 75% complete.

The major components of the ATF are shown in Fig. 1. The vacuum vessel appears in this figure as the thin plate structure with the square ports on the top and the large parallelogram ports around the outside. A sketch of the vessel alone is shown in Fig. 2. The vessel is fabricated from 6-mm-thick 304L stainless steel plate.

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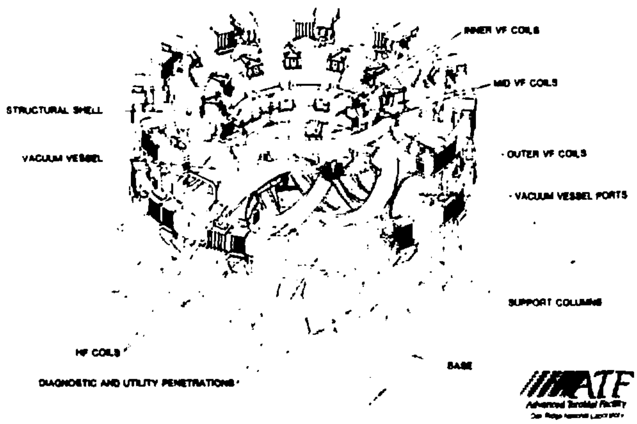

Fig. 1. ATF isometric.

Design Activity

One major change from the vessel configuration reported earlier [3] is the port and flange design. Detailed examination of plasma confinement plots and the vertical port openings indicated that the full plasma width would not be available for Thomson scattering diagnostics if the round ISO ports were retained.

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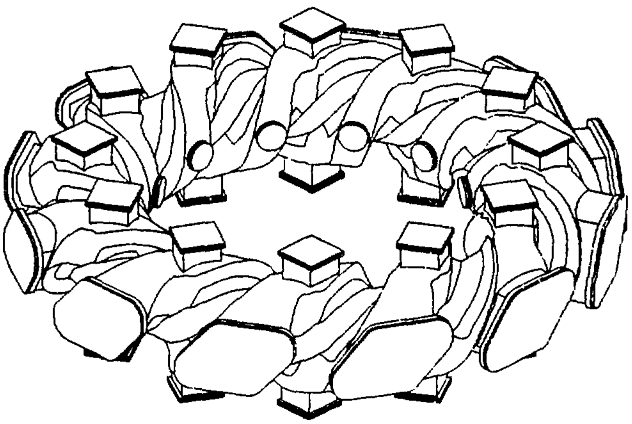

Fig. 2. Vacuum vessel isometric.

For this reason, alternative port designs were examined, and a novel square configuration (nominally 40.5-cm square) was chosen. This is a commercial offering from Thermionics Laboratory, Inc. (Hayward, Calif.) using knife-edge flanges on flat copper gaskets similar to the more familiar round Conflat design (Fig. 3). These flanges were tested and determined adequate for use on ATF. They are also being used on the Radio Frequency Test Facility (RFTF) with some success [4]. The inner ports are now a standard Conflat design of 25.4-cm diameter.

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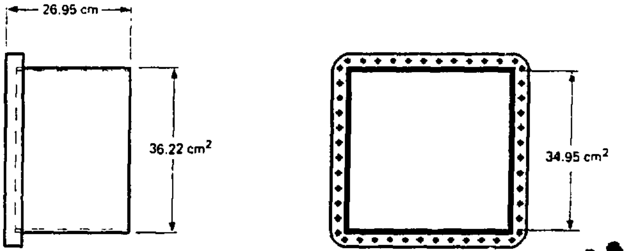

Fig. 3. Pyraflat flange.

The outer ports remain as special parallelogram-shaped openings following the helical contour of the vessel. The flanges are sealed with special-purpose Helicoflex HN200 metal seals using an aluminum jacket

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*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under Contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

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on an Inconel 600 liner with a Nimonic spring. Helicoflex Company (Boonton, New Jersey) imports these seals from the French manufacturer. These seals have also been tested and found adequate. These ports allow clearance for the beam line access in an almost tangential orientation (Fig. 4).

The completed design package consisted of assembly drawings; detail drawings of the flanges; a series of 30 computer-generated, cross-section plots showing the outer contour of the basic vessel; and a complete specification. The request for proposals (RFP) that accompanied the design package attracted a great deal of attention, and six proposals were received. After a lengthy technical and business evaluation, Pittsburgh-Des Moines Corporation (PDM), (Pittsburgh, Penn.) was awarded the fabrication contract in September 1984.

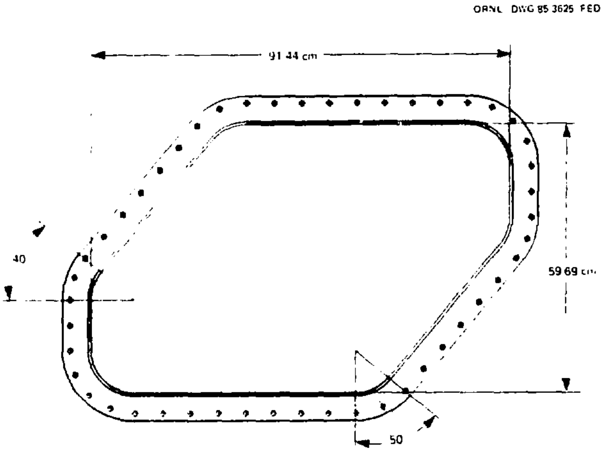

Fig. 4. Outer port flange.

Analysis Activity

The vessel has been analyzed for structural integrity using a series of analysis tools. A preliminary finite-element method (FEM) analysis of portions of the vessel using PAFEC [5] was reported earlier [3]. A contract to Lockheed Missiles and Space Company (Oak Ridge, Tenn.) resulted in a complete FEM analysis of the early basic vessel configuration using MSC/NASTRAN [6]. This model was based on contour information taken at [illegible] increments for 30° and did not include any of the ports. The results were encouraging, with maximum stresses of about 55.8 MPa (8100 psi) and a factor of safety on buckling of 11.5 based on atmospheric pressure loading.

A new FEM model of the vessel has been constructed at Martin Marietta Energy Systems, Inc., using the contract drawings (taken at 1° increments for 30°) and including all the ports. This model was constructed with PATRAN [7] as a pre- and post-processor for use with MSC/NASTRAN (Fig. 5). Results from this analysis have tended to confirm and reinforce the previous efforts. The ports and flanges are tending to support the vessel wall and the maximum principal stresses are about 86.2 MPa (12,500 psi) in a localized area at the base of the square nozzles. The stress in the trough region remains about 55.2 MPa (8000 psi), corresponding to results of the Lockheed effort. A cyclic symmetry run for this model is planned to determine the eigenvalue solution for buckling.

Fabrication Activity

Fabrication efforts at PDM began with the preparation of a proposal for the vacuum vessel for ATF. This proposal served as the initial document for planning engineering and shop activities. A detailed Quality Assurance Plan and Manufacturing Plan were developed during the early stages of the program. Engineering drawings for the numerous fixtures and flat developments have been generated at PDM.

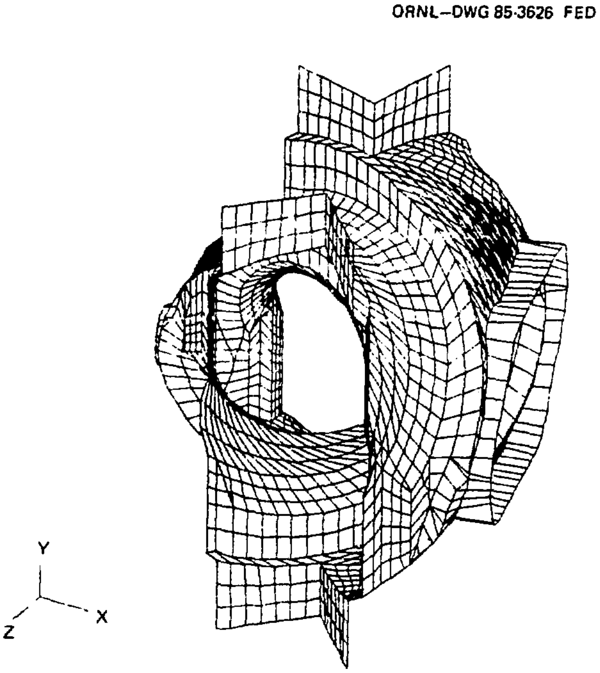

Fig. 5. Vacuum vessel FEM model.

The fabrication concept has consisted of developing an extensive set of fixtures used to form, rotate, measure, and support the vessel. Of primary importance is the assembly fixture (Fig. 6) that forms an internal mold of the vessel contour. This fixture consists of 360 carbon steel rib plates that were machined using a numerically controlled (NC) milling machine. The Energy Systems' FEM data defined the exterior surface of the vacuum vessel. To manufacture the 1° forming ribs, PDM had to develop a special FORTRAN program to convert to the interior vessel dimensions. The rib plates are all 12-mm thick and have holes and precuts to facilitate later removal.

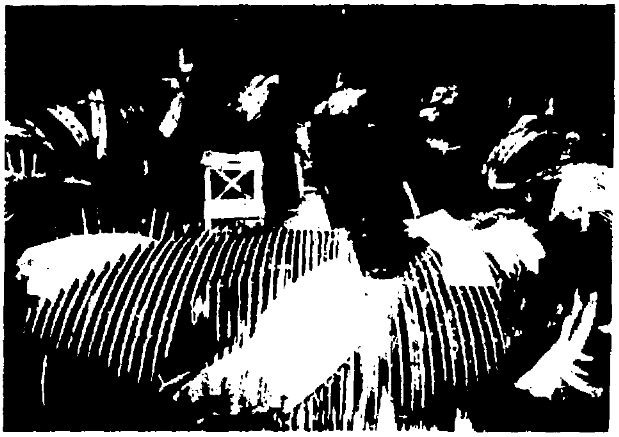

Fig. 6. Photo of assembly fixture.

These rib plates were accurately erected in place on another fixture known as the "precision base plate." The base plate has a machined top surface and is flat within 0.25 mm.

The 6-mm stainless steel vessel plates were cut using an NC plasma arc cutting table to the correct flat development shapes. PDM Engineering utilized the data from Energy Systems in their own ANSYS program and developed a number of subprograms to create a computer-generated isometric plot of the vessel configuration from which PDM draftsmen were able to generate flat developments of the shell plates. Because the shell plates require forming in three dimensions, the flat plate developments were only an approximation. The PDM fabricating plant personnel then further refined and subdivided the plates into sizes that could be formed in three dimensions. There are almost 100 different plate shapes repeated 12 times each for a total of about 1200 plates to form the vessel. Each plate is formed on a hydraulic press to its nominally correct complex curved shape and test fitted on a form-checking fixture located near the press. The final forming and fitting occur at the assembly fixture when each plate is individually custom fitted to conform to the ribs of the assembly fixture. Completed stainless plates are tack welded to their adjacent neighbors (Fig. 7). The completely fitted basic vessel (without ports) is full-penetration welded from both outside and inside using Inconel filler rod to minimize magnetic permeability. The carbon steel assembly fixture is removed from the inside of vessel after outside welding is complete. The inside surface will be ground and polished after welding to simulate an ASTM #4 plate finish.

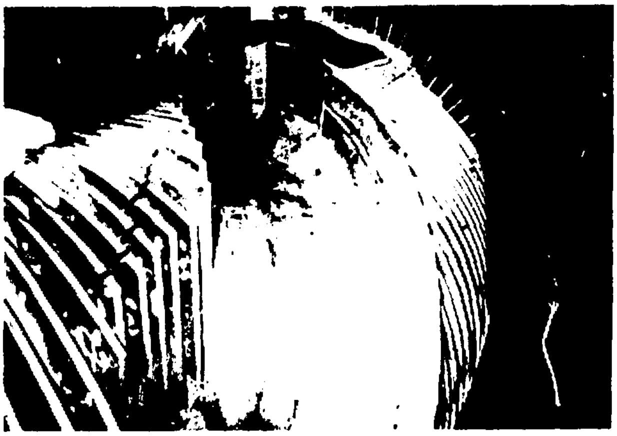

Fig. 7. Vessel plates (tack welded).

Penetrations for the ports will be cut into the basic vessel, and the nozzles and flanges will be welded into place. The vessel will be vacuum- and leak-tested before shipment by barge to Oak Ridge, Tenn.

Current Status

All design activities for the vessel are complete at this time. The analysis models will continue to be exercised to determine compliance to various operating modes. Vessel fabrication is proceeding at a rapid pace, and delivery is expected in mid-March 1986. A recent photograph of the vessel and fixture is shown in Fig. 8. The vessel will be installed in the facility almost immediately after it is received. The vessel is expected to supply an excellent operating environment for the plasma and will conform to the complex helical shape of the ATF.

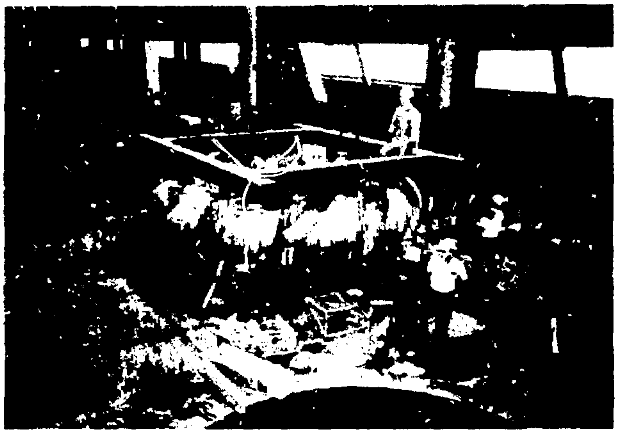

Fig. 8. Vacuum vessel in fabrication.

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[1] B. E. Nelson et al., "Design Description of the Advanced Toroidal Facility (ATF)," in Proceedings of the 10th Symposium on Fusion Engineering, 1983.

[2] R. L. Johnson et al., "The Advanced Toroidal Facility," these proceedings.

[3] K. K. Chipley et al., "Design Description of the Vacuum Vessel for the Advanced Toroidal Facility," in Proceedings of the 10th Symposium on Fusion Engineering, 1983.

[4] W. L. Gardner et al., "The Oak Ridge RF Test Facility," these proceedings.

[5] PAFEC, PAFEC Limited, Strelley Hall, Strelley, Nottingham, GB, NG86PE

[6] MSC/NASTRAN, MacNeal-Schwendler Corp., 815 Colorado Bldg., Los Angeles, CA 90041

[7] PATRAN, PDA Engineering, 1560 Brookhollow Dr., Santa Ana, CA 92705-5475

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