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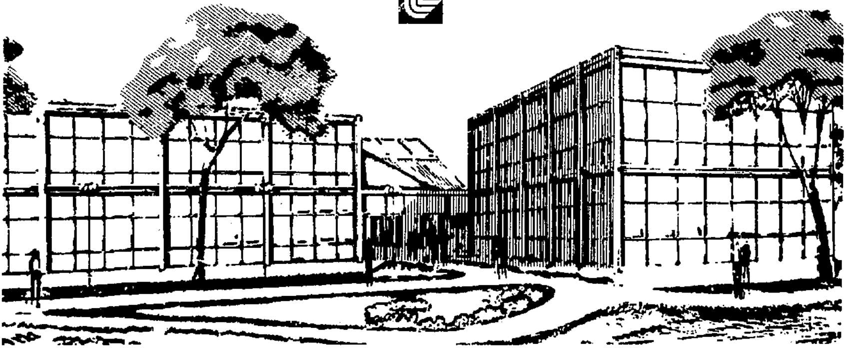

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THE 2XIIB VACUUM VESSEL: A UNIQUE DESIGN[*]

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Summary

The 2XIIB mirror confinement experiment makes unique demands on its vacuum system. The confinement coil set encloses a cavity whose surface is comprised of both simple and compound curves. Within this cavity and at the core of the machine is the operating vacuum which is on the order of 10^{-9} Torr. The vacuum container fits inside the cavity, presenting an inside surface suitable for titanium getter pumping and a means of removing the heat load imposed by incandescent sublimator wires. In addition, the cavity is constructed of nonmagnetic and nonconducting materials (nonmetals) to avoid distortion of the pulsed confinement field. It is also isolated from mechanical shocks induced in the machine's main structure when the coils are pulsed. This paper describes the design, construction, and operation of the 2XIIB high-vacuum vessel that has been performing successfully since early 1974.

Introduction

The conceptual design satisfying the requirements outlined above is due originally to M. O. Calderon and was first used in 2XII, 2XIIB's immediate predecessor. The 2XIIB vacuum vessel is much larger, more complex, and contains some refinements over the original. This is the first published report on either vessel. Discussion will be confined to the 2XIIB version without referring to the differences between the two.

Three concentric shells, taken together, are called the <u>vacuum vessel</u>. The vessel consists of three layers:

1. The <u>vacuum wall</u> consists of Corning[†] Glass Works' Pyroceram sheets, sealed at the edges with Dow Corning RTV silicone rubber.
2. Closely surrounding the vacuum wall is an <u>exostructure</u> made of NEMA G-10 fiberglass-epoxy laminate sheets.
3. Fitting closely inside the vacuum wall is a <u>liner</u>, also of pyroceram sheets.

Beginning Requirements

Materials

Three factors contributed to the selection of materials:

1. The pressure inside the vacuum wall had to be 1×10^{-9} Torr or lower. This required an impermeable material with a smooth surface and no capacity for water absorption.
2. The vessel had to exist inside a pulsed coil set[1,2] where the field strength increases from 3 to 19 kG in 550 μs,[3] requiring all materials to be nonconducting and nonmagnetic. This implied that metals had to be excluded.
3. The inside surface of the liner had to be roughened so that sublimated titanium, the getter pumping medium, would adhere. The liner also had to be able to withstand exposure to the incandescent titanium wires.

Geometry

When design work began on the vacuum vessel, the coil set geometry was already fixed. The coil set was designed so that the inside cavity would permit the installation of a vacuum vessel whose walls would not be struck by escaping plasma. Emphasis was also placed on providing the largest possible minor lobe radius in the yin-yang compression coil set to leave large ports for neutral beam injection. The vacuum vessel was generally proportioned to use as much space inside the coil set cavity as was possible. Special attention was devoted to maximum utilization of the large ports that had been so carefully designed into the compression coil set. Because the side arms of the vacuum vessel are most constricted where they pass through the minor lobes, they flare outside the coil set, forming a horn shape. This was necessary to permit access by the largest possible number of neutral beams as well as by one retractable titanium sublimator per port. The materials chosen were, and still are, available only in flat sheets, restricting the capability of filling the entire available space in the coil set cavity.

Cooling

Although the 2XIIB plasma temperature is on the order of 100×10^6 K,[4] the plasma particle density of about 10^{13} cm^{-3} still has virtually the thermal emissivity of a vacuum and the plasma is therefore not a significant heat source.

The principal heat source is the incandescent titanium sublimator wires. They impose a thermal load on the liner surfaces of about 26 kW and ordinarily operate at a duty cycle of about 17%, requiring a means of cooling the vacuum vessel.

The Design

From the foregoing requirements grew the design of the three complete layers for the vacuum vessel, all closely conforming to the coil set cavity and to the openings leading out of it (Fig. 1). Conceptually, it is best to begin by visualizing just the middle layer, the vacuum wall, in the coil set cavity. The pyroceram from which it is made is a proprietary devitrified glass-ceramic that is smooth, rigid, and nonporous.

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[†] Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Energy Research and Development Administration to the exclusion of others that may be suitable.

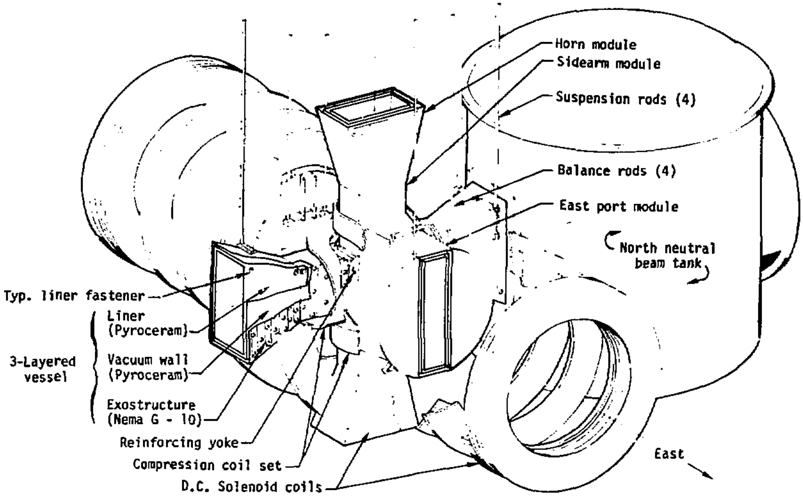

Fig. 1. 2XIIB vacuum vessel.

It is sold in its unstrengthened condition in 4 ft × 8 ft × 0.2-in.-thick flat sheets, originally as architectural facing for high-rise buildings, but lately only for use as benchtops. Gaps 1/8-in. wide exist at all edge and corner joints. RTV silicone rubber is used at these joints to make the vacuum seal. All the space within the vacuum wall is maintained at the 2XIIB operating pressure of 1×10^{-9} Torr. The space between the vacuum wall and the coil set cavity surface is kept at about 1×10^{-5} Torr and is called the guard vacuum. This is a low quality vacuum, compatible with the epoxy surface of the cavity. The resulting pressure differential across the vacuum wall offers no significant loading of the pyroceram.

Pyroceram is only slightly stiffer and stronger than ordinary plate glass, so it is surrounded by and bonded to the exostructure, which is made of the 1/2-in.-thick laminated sheet already described. All joints in the exostructure are closely fitted, joined with pins of the same material, and epoxied into match-drilled holes. The edge surfaces themselves are not bonded, although this would yield a stronger structure. Bonding only the pins makes future disassembly possible, though difficult, by drilling out the pins.

A space of 0.1 in. is maintained between the vacuum wall and the exostructure by RTV rubber, which resiliently ties the layers together. The exostructure exists entirely within the guard vacuum, and the holes through the laminate maintain both sides at guard vacuum pressure. It is cooled by a network of polypropylene water tubes embedded in grooves milled in its outer surface. The central region of the exostructure is inherently weak, having no continuous load-carrying members crossing it. A reinforcing yoke was added there to correct the deficiency. No detailed analytical work was done on the yoke; it was simply sized to occupy most of the space remaining in the coil set cavity, and its members were oriented as advantageously as possible. The yoke is made of pieces of 1-in.-thick NEMA G-10 laminate, pinned and epoxy bonded together.

The complete exostructure is suspended on rods, made of spiral-wound NEMA G-10 laminate, from outside the machine. It hangs free, without touching the surface of the coil set cavity. The four rods attached at the north and south horns bear the 3000-lb weight of the entire vacuum vessel, while the reamining four rods are left slightly slack and serve only to balance the vessel. Flexible silicone rubber boots and diaphragms seal off the guard vacuum at the ports while still permitting the vessel to be mechanically isolated from the rest of 2XIIB.

Because the RTV rubber joints and mounts of the Pyroceram vacuum wall will not tolerate exposure to the hot sublimators, a liner, also of Pyroceram panels, is installed inside the vacuum wall. The liner panels are all supported mechanically within the vacuum wall by various fasteners (Fig. 2) and by each other. The liner is virtually a house of cards. Corners and edges of the liner panels overlap to protect the RTV rubber seals. The fasteners are of alumina ceramic with a few stainless steel straps. The straps are the only metal parts in the entire vessel and simply have to be tolerated. The fasteners support the liner and maintain a 0.2-in. space between it and the vacuum wall. Heat from the sublimators is transmitted by radiation and conduction through the two Pyroceram walls to the water-cooled exostructure. The inner

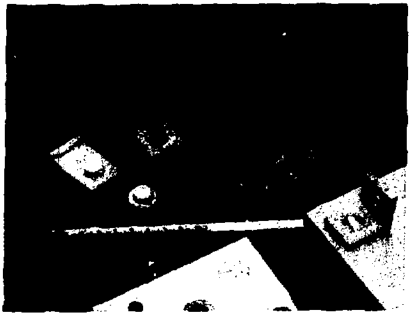

Fig. 2. Ceramic liner fasteners.

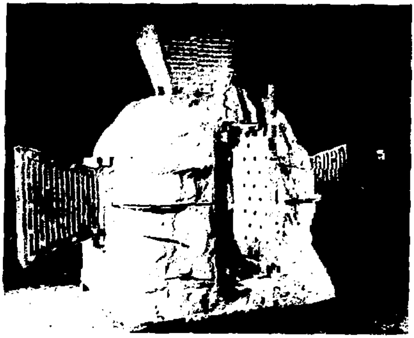

Fig. 3. Exostructure preassembly in cavity model.

surface of the liner is sandblasted before installation to provide good adhesion of the getter titanium. The panels may be *periodically* (and very carefully) removed and sandblasted again to remove the titanium deposit when it becomes so thick that it peels.

Further Requirements

The design choices described above lead in turn to some additional considerations that must be satisfied.

More Geometry

The form in which the materials were supplied made it necessary to conform a vessel made of flat plates to a cavity of curved surfaces. It was obviously impossible to use all of the cavity volume so a continuous process of optimization was required to get the largest inside volume consistent with the best possible access.

Suspension

The fast risetime of the coil set induces large impulsive forces in the adjacent metal parts that are rigidly attached to the coil set. The choice of a fragile material for the vacuum wall and liner makes it necessary to minimize shock transmission to the vacuum vessel from the main structure. From this requirement came the rod suspension system already described.

Vacuum Wall Pressure Differential

The inherent fragility of the vacuum wall dictates that no significant differential pressure may be imposed across it. We have never tested the wall's tolerance for a pressure differential, but when 2XIIB is under vacuum the pressures on both sides of the vacuum wall are continuously monitored by a capacitance manometer. If the differential reaches 0.2 Torr, a crossover valve opens to connect the high vacuum region with the guard vacuum, protecting the vacuum wall. This system was never called upon to perform in 2XIIB, but the vacuum wall in 2XII survived a sudden up-to-air accident through a 1/2-in.-diam. hole without damage.[5]

Construction

Given a predetermined coil set cavity, one starts either designing or building from the outside layer (exostructure) and works inward. Detailed drawings with full tolerances were prepared for the exostructure and then it was built that way. Fully toleranced drawings of the vacuum wall were also prepared, but the Pyroceram parts were not cut immediately. Scale drawings were made of the liner panels and their computed dimensions penciled in, but final dimensioning and tolerancing were not done until later.

Because vacuum vessel construction had to be done in parallel with coil set construction, a method was needed to test the fit of the exostructure inside the cavity before the cavity actually existed. This was made possible by a cavity model, shown in Fig. 3, made of plywood, light aluminum sheet, and foamed-in-place polyurethane. As exostructure parts were finished, they were worked and fitted by hand to ensure perfect fits and squareness throughout. The first completed exostructure preassembly is shown in the cavity model with temporary assembly brackets (also visible) maintaining squareness. With the brackets left in, the exostructure was disassembled into its twelve boxlike modules and the pin holes were drilled. The pins were epoxied into their holes, the corner brackets were removed, and the entire exostructure was assembled again outside the cavity model (Fig. 4). The vacuum wall was modeled in 1/4-in. Masonite hardboard from the detailed drawings and fitted inside, duly considering that the Masonite was not of the same thickness as the pyroceram. These model vacuum wall panels were trimmed and fitted by hand and their corrected dimensions transferred back to the drawings. Then the pyroceram vacuum wall panels were cut.

The next step was installing the polypropylene water lines in the grooves visible in the illustrations and potting them in place with Dow Corning 732 RTV rubber. The third and final test assembly is shown in Fig. 5 with all the tubing in place. After final installation, all the water lines were fed out through the guard vacuum wall to the atmosphere through drilled-out Swagelok bulkhead fittings. All 64 water circuits were continuous; there were no connections inside the guard vacuum.

Fig. 4. Second exostructure preassembly.

Finally, the exostructure and its reinforcing yoke were assembled inside the real coil set cavity, which by then was in place in 2XIIB. One module at a time was inserted through the various ports and joined to the others with more epoxied pins. The suspension rods were put in and adjusted and, as the cavity model had indicated, the exostructure was free to swing about 5/8 in. in all directions before striking the cavity surface.

This was immediately followed by the permanent installation of the vacuum wall. Although the exostructure would have tolerated it, we were careful not to put our weight on it, working instead on platforms cantilevered from the outside. The RTV rubber supporting the panels was applied around each of the holes visible in the exostructure illustrations. A gap was left in each "doughnut" to permit gas flow through the hole it surrounded, keeping the pressure equal on both sides of the exostructure. Dow Corning 3145 RTV rubber was used here because it allows 30 min of working time before skinning over. The less expensive formulations skin over in only about 10 min. All the edge and corner joints were sealed with clear Dow Corning 732 RTV rubber, chosen so that flaws and bubbles would be easy to locate. Diaphragm and boot seals cut from sheet silicone rubber made flexible connections between the vacuum wall and the main structure of 2XIIB, isolating the high vacuum from the guard vacuum and the vessel's extremities.

Because the vacuum wall will not support any significant pressure difference, sulfur hexafluoride (SF_6) gas was introduced into the air inside the guard vacuum space. A portable SF_6 sniffer was used to search the joints and seals for leaks. This was a difficult technique to use because the silicone and RTV rubbers are slightly permeable to SF_6, making leaks difficult to distinguish from the resulting background. In addition, SF_6 is a heavy, exceptionally persistent gas. In the end, though, the vacuum wall proved to be tight.

Concurrent with leak checking, complete measurements were taken inside the finished vacuum wall and used to derive the actual liner panel dimensions. As we had initially suspected, tolerance accumulations created dimensional differences even between panels that should have been identical. The liner panels were then cut and installed in a carefully predetermined order that avoided exposing the installers to the danger of having panels suspended overhead while they worked.

Notes on Cutting Pyroceram

It is characteristic of unstrengthened pyroceram to be extremely notch sensitive. Any crack or sharp-cornered cut will immediately propagate, even in the absence of applied stress, and destroy the sheet. We have developed a cutting technique in which a Pyroceram sheet is placed flat on a table flooded with melted wax. The wax places the entire panel in compression when it cools, and the panel may be safely cut by repeated passes of increasing depth with a diamond-edged circular saw blade. Our saw is suspended very much as it would be in a radial arm saw, and it can be positioned to make a cut anywhere on the panel. All cuts must pass from edge to edge and fully penetrate the sheet before the wax is reheated or the panel will be destroyed. Residual wax is removed from the panels by an ordinary steam cleaner. Pyroceram may be drilled in the free condition with diamond-faced core drills, and we countersink some

Fig. 5. Final preassembly with cooling lines installed.

holes with diamond-impregnated steel countersinks. Drilling must be done with great care because pyroceram has a laminar structure that spalls easily.

Conclusion

The completed vacuum vessel has been in service for about ten months. It has been almost trouble free. The diaphragm seals at the ends of the coil set were replaced when their failure permitted leakage between the guard and high vacuum regions. It was discovered that voltages induced in the titanium layer by the pulsed magnetic fields were causing sparking at the corners and joints between liner panels, dislodging large bursts of cold gas from the titanium layer within the plasma region. The panels were sandblasted clean and all the edges carefully stoned to a full radius. This did not completely end the sparking, but reduced it to a tolerable level.

Only one thing would be done differently if such a vacuum vessel as this were to be built again. The ceramic liner panel fasteners in use have not failed, but neither have they inspired great confidence. A more secure fastener has been developed and will be used the next time the liner is cleaned and reinstalled.

Both the 2XII and 2XIIB vacuum vessels have been satisfactory. The materials, suspension, sealing, and construction have all been entirely adequate.

Acknowledgments

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References

1. R. H. Bulmer and A. R. Harvey, "2XIIB Pulse Coil Design," in Proc. 5th Symp. Engineering Problems of Fusion Research (Princeton, New Jersey, 1973).

2. R. H. Bulmer et al., "2XIIB Status," in Proc. 6th Symp. Engineering Problems of Fusion Research (San Diego, California, 1975).

3. G. E. Vogtlin et al., "The Electrical Aspects of the Livermore 2XIIB Containment Magnet and Associated Equipment," in Proc. 5th Symp. Engineering Problems of Fusion Research (Princeton, New Jersey, 1973).

4. F. H. Coensgen et al., "Recent Experiments on the 2XIIB Mirror Machine," in Proc. 7th European Conf. Controlled Fusion and Plasma Physics (Lausanne, Switzerland, 1975).

5. C. J. Anderson, "Review of the 2XIIB Project," in Proc. 5th Symp. Engineering Problems of Fusion Research (Princeton, New Jersey, 1973).