LA-UR -79-3111

TITLE: CERAMIC TOROIDAL VACUUM CHAMBER FOR THE ZT-40 EXPERIMENT

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MASTER

SUBMITTED TO: 8th Symposium on Engineering Problems of Fusion Research
San Francisco, CA
November 13-16, 1979

University of California

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UNITED STATES
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CONTRACT W-7405-ENG. 36

CERAMIC TOROIDAL VACUUM CHAMBER FOR THE ZT-40 EXPERIMENT*

by

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SUMMARY

We discuss the design and fabrication of the large ceramic vacuum vessel now in use in the ZT-40 experiment. ZT-40 is the latest experiment in the Los Alamos Reversed-Field Pinch program. It has been preceded by two smaller devices, ZT-1 and ZT-S, both of which employed similar ceramic vessels. The new torus has a major diameter of 228 cm, a minor diameter of 40 cm, and it is made of 99.5% pure alumina. The design includes a number of sapphire viewing windows as well as ceramic diagnostic and pump ports. Presented are several design features unique in toroidal chamber fabrication using segmented ceramics. The segments are sealed together by way of a newly developed glazing technology or joined by means of Viton O-rings of special fabrication and seat design. We also discuss the electrical and thermal insulation applied to this vessel as well as the handling technique used to accomplish final installation in the experiment.

The vacuum chamber is one of the main constituents of most magnetic fusion devices. This vessel serves as the container for the ionized plasma and it must be capable of achieving a very low base pressure. Many different materials either of a conducting or dielectric nature are suitable for such a chamber. Because of the fast rising magnetic fields in our reversed-field pinch studies at Los Alamos, we have used non conducting material almost exclusively. The present ZT-40 machine, see Fig. 1, uses 99.5% pure alumina, as did its predecessors, the ZT-1 and ZT-S experiments[1].

*Work performed under the auspices of the U.S. Department of Energy.

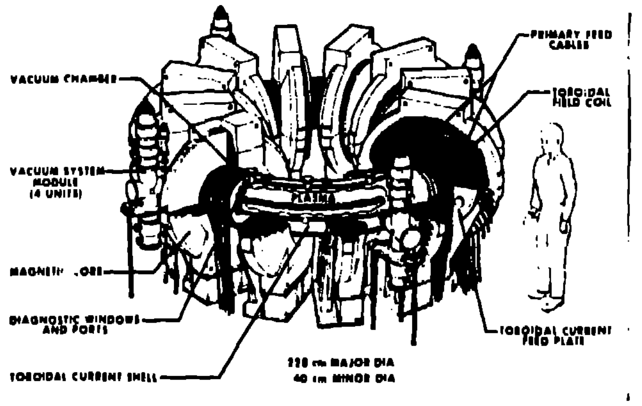

Figure 1
ZT-40 experiment, artist's concept.

All the ceramic torus assemblies used in these studies were fitted within a solid conducting shell. The shell acts as the primary, and the ionized deuterium gas within the ceramic torus acts as the secondary of an electrical transformer. As primary current is applied to the shell, an approximately equal and opposite current is induced in the gas. In order to obtain efficient coupling between these two conductors, the fit of the torus within the shell must be extremely precise. Therefore, the control of the roundness tolerance on both geometries is a major concern, and strict adherence to it is mandatory.

Ceramic tori of the nature required for such experimentation are most difficult to fabricate in large monolithic shapes with reasonable tolerances. To overcome the state-of-the-art limitation, the present ZT-40 chamber, as prior devices, is divided into several small, wedge-shaped segments. Each segment is ground as a straight cylinder, then tapered at some predetermined angle, and finally step jointed as shown in Fig. 2. When these segments are fitted together, a toroidal-shaped vessel is obtained with very close tolerances in both major and minor diameters. The angle chosen for tapering the segments is determined so that the chord length deviation from a true circular arc is held to an acceptable value. Another factor in angle choice is the desirability of having the number of segments divisible by a factor consistent with the electrical, pumping, and diagnostic requirements. Vacuum is maintained in these vessels through the use of Viton O-rings installed between the segments at the step joint area. Figure 3 shows a typical O-ring joint where the step arrangement shields the O-ring from plasma radiation. Seating or compressing the O-ring is accomplished by atmospheric pressure, and as the vessel is being evacuated, the torus decreases in major diameter. This reaction is a function of the amount of squeeze experienced by each O-ring.

With our first ceramic torus, designed in the early 1970's and shown in Fig. 4, we had some difficulty in achieving reliable seals with the

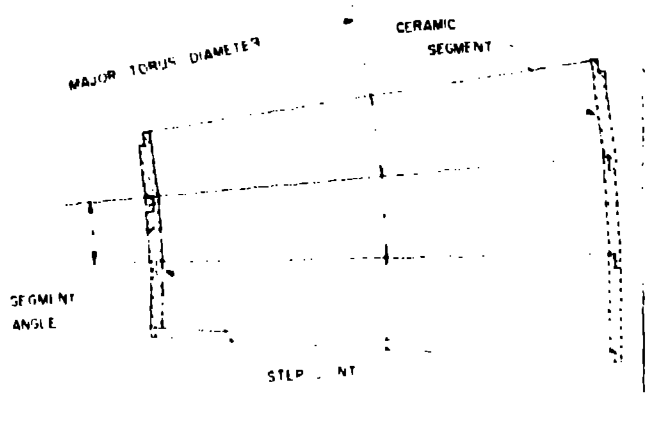

Figure 2
Fitted ceramic segments.

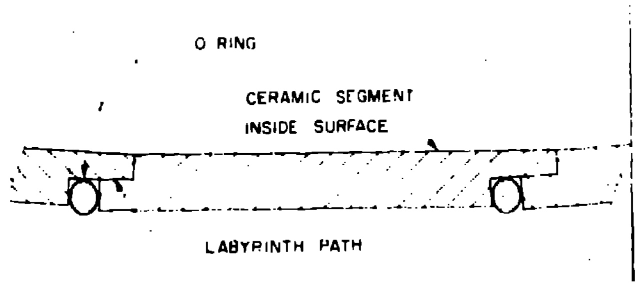

Figure 3
O-ring joint, early design.

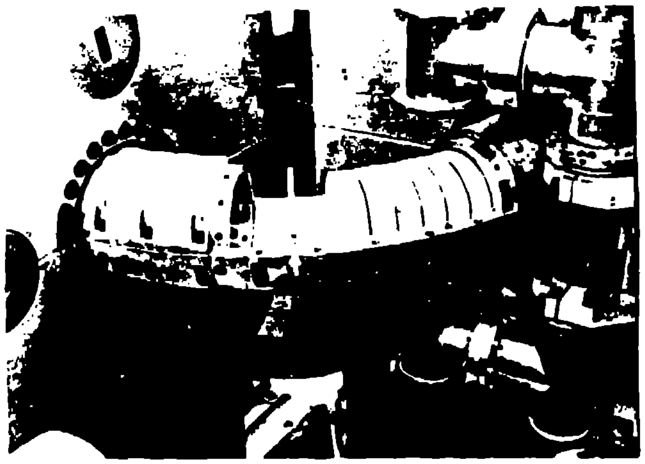

Figure 4
Ceramic segments, ZT-1 experiment.

circular O-ring joints. This was partially due to the relatively small minor diameter (4" I. D. or 10.16 cm) and resultant small compressive load available from atmospheric pressure (proportional to the square of the radius). It was found that by changing the O-ring cross section from round to square, a larger sealing area adjacent to the ceramic walls was achieved. This and the use of lubricant on the O-rings made it possible to obtain good sealing conditions. Other improvements were gradually introduced that further enhanced the vacuum and operating conditions of this earlier machine and the experience gained during this work helped determine the design philosophy of the ZT-40 torus.

Figure 5 shows a typical ZT-40 ceramic segment. It has 15.75" (40 cm) I. D. and a wall thickness of .315" (8mm). It has a taper of 6^{0} and sixty such segments are therefore required to form a complete toroidal shape. This particular segment, which is one of four, has three tubulations. The two small ones are for diagnostic purposes, whereas the larger tube is used as one of the pump ports. The tubulations shown here, as in other segments, have been attached to the cylindrical shape by means of a new type of glass seal[2] developed at LASL by the local ceramics section. The sealing material is a glass powder specifically chosen to match the expansion coefficient of the ceramic and to control the flow of the mix in its molten condition. The glass powder is applied at the joint of the two assemblies and fired at an elevated temperature. The result, after firing, is a strong hermetic joint that is completely non organic.

Figure 5
Tubulation segment, ZT-40.

Figure 6
Group of four segments, ZT-40.

Figure 6 shows a group of four segments, stacked one upon each other. It can be observed here that the straight chord lengths of the segments present a noticeable though small deviation from the major circular arc. This group of four segments was assembled using the same sealing method as explained above. The sealing was performed by the ceramic fabricator after technology transfer from LASL[3].

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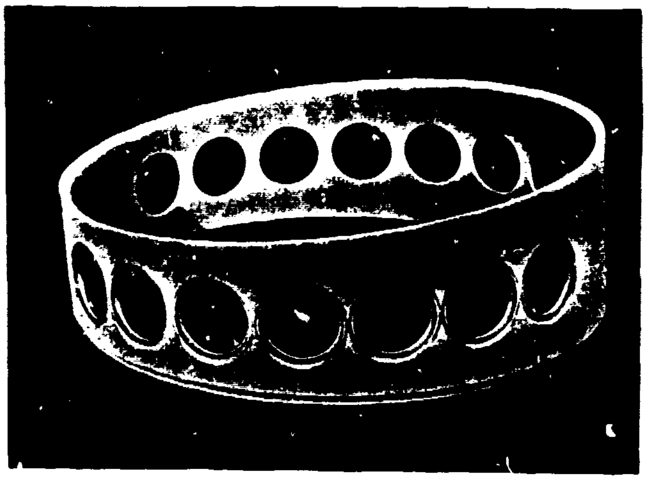

Figure 7
Window segments, ZT-40.

Figure 7 shows another single segment that is used for diagnostic viewing. This particular segment has 14 holes bored into its side, and in each opening is inserted a sapphire window. The windows are also glass sealed in place, and here, as in the other glass-seal joints, extreme care was taken to assure that no glass migrated to the inside ceramic surfaces. Figure 8 shows a typical window cross section.

Figure 9 shows the general arrangement of the various segments in the toroidal configuration. There are twelve diagnostic segments 30° apart and between these segments are 12 glass-sealed groups of four segments. The torus has a major diameter of 228 cm and is joined together by 24 O-ring seals. These O-rings and their seat design were formulated to provide optimum sealing with as little outgassing as possible. Figure 10 shows a typical joint cross section. It can be seen that the sides or sealing surfaces of the ceramic have been tapered at 15°. This feature prevents excessive outward extrusion of the O-ring as well as providing better confinement while under compression. The O-ring used here is actually rectangular in cross section and here again

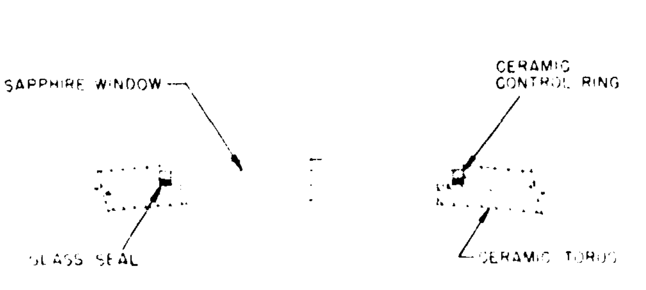

Figure 8
Window cross section, ZT-40.

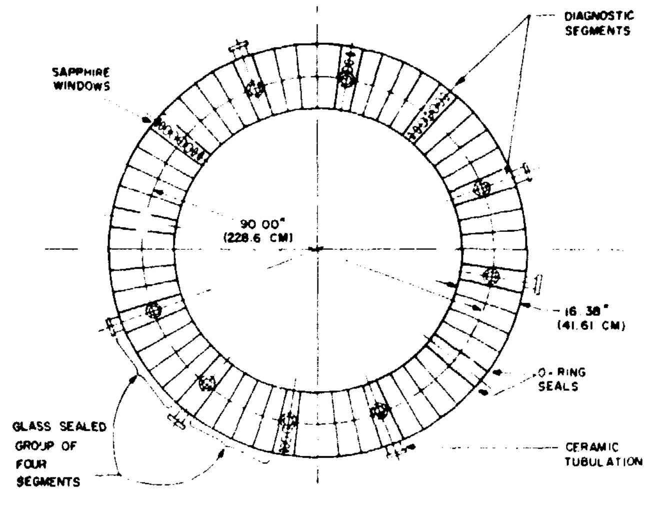

Figure 9
Torus segment arrangement ZT-40.

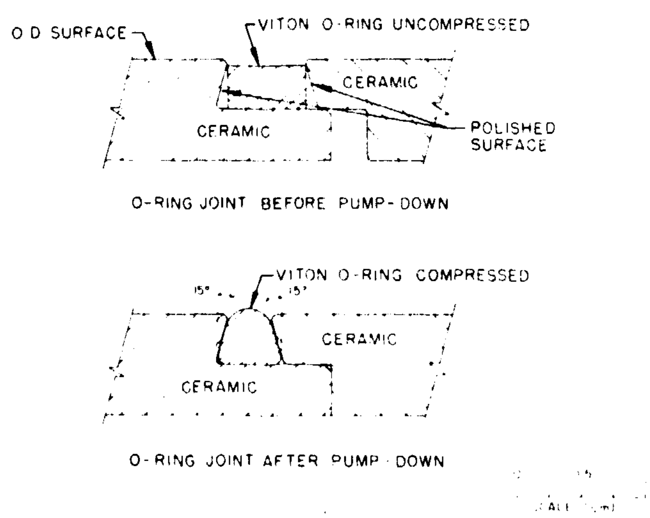

Figure 10
O-ring joint, ZT-40 design.

it was found to be better even after testing round and oval cross sections. The material is Viton with the carbon black eliminated from the mix, to make the material much softer--perhaps in the 50-60 durometer range. No grease is used on the O-ring surfaces since hydrocarbons in this area will eventually seep into the vacuum chamber and seriously contaminate the plasma. The no-grease requirement placed serious restrictions on the quality of surface finishes that would be tolerable, not only on the ceramic surfaces adjacent to the Viton but also on the surfaces of the seal itself. The surfaces of the O-ring mold were ground and polished so that the seal would have a mirror quality finish, and the ceramic fabricator[3] was required to polish the tapered surfaces of the ceramic segments to a 4-2 micro inch finish.

We discussed above how the pump ports and diagnostic tubulations were secured to the segment itself. The other end of the tubulations presented more problems. The method of attaching appropriate flanges to this ceramic end could not be used by applying the customary ceramic metalizing technique and subsequent braze to stainless steel. One reason was that Kovar (a nickel alloy), ordinarily used as one of the interface metals, is ferro magnetic and its presence could have perturbed the plasma. Figure 11 shows our alternative design of the attachment arrangement to the ceramic. It will be noted that the tapered flare on the end of the ceramic tube effectively captures the lower flange thus making it possible, through bolting, to tighten the upper flange down and thereby compress an O-ring against the top surface of the ceramic. These surfaces were also highly polished and here again it became possible to achieve a leak-tight joint without the use of grease on the O-ring.

After the segments had been individually leak tested and measured for dimensional accuracy, they were assembled into the toroidal shape as shown in Fig. 12. The out-of-roundness of the assembly turned out to be less than one millimeter. While the torus was in the pumped-down condition, several electrical features were installed including heater wires for subsequent bake-out capability, R. F. antenna strips for possible pre-ionization use, and several helical sensors to provide a means of detecting magnetic field perturbations during machine operation.

Electrical and thermal insulation made of silicone rubber was then wrapped over the diagnostic wires and around the torus assembly, as shown in Fig. 13. Several layers were installed. Most insulation pieces were cut in shapes that matched the outer surface of the ceramic segments. These pieces were wrapped so that each succeeding layer overlapped the gaps of the former layer underneath. This pattern creates a path of several inches to prevent voltage tracking from the ceramic surface to the primary shell. This labyrinth arrangement and the multiple layers of silicone rubber also provide a

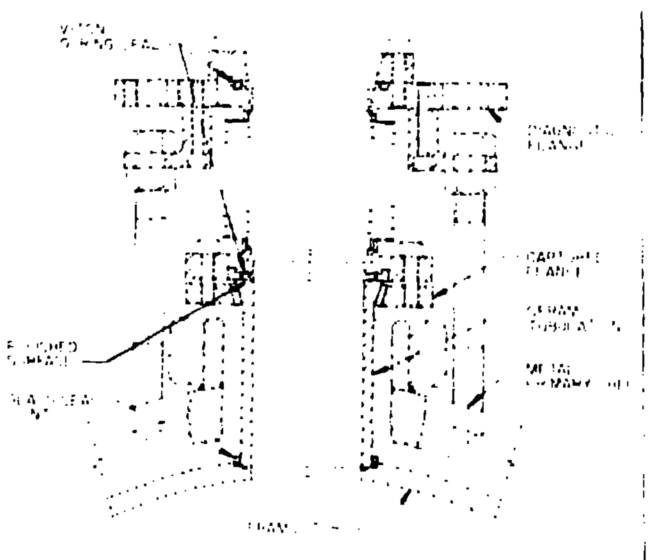

Figure 11
Ceramic tubulation attachments, ZT-40.

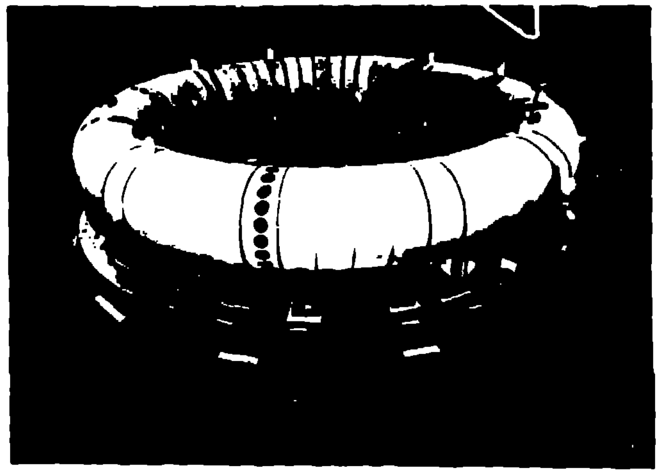

Figure 12
Ceramic torus, ZT-40.

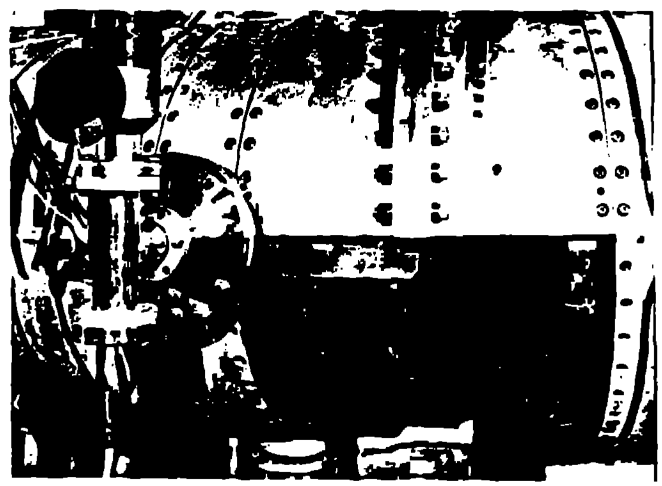

Figure 13
Insulation wrap, ZT-40.

degree of thermal insulation between the ceramic and metal shell when the machine is being out-gassed by energizing the heater wires and by discharge cleaning.

The completed torus was moved from its assembly and testing area to the primary shell as a single unit. During this operation, the chamber was under vacuum and was disconnected from the pump. Figure 14 shows the unit suspended from an overhead crane, ready for installation. An array consisting of strongback, lifting bridles, and nylon harness was designed to perform this function. The harness acted as the main constraining member around the torus and had two girth straps that tightened around the periphery. At right angles to these, twelve other straps tightened around the minor circumference. From the juncture of each strap, lifting chains were secured in series with tension springs which were in turn attached to a circular strongback.

The tension springs were used to provide equal tension in each of the 12 chain lengths, further assuring uniform support of the torus during its transportation. After a travel of about 35 feet,

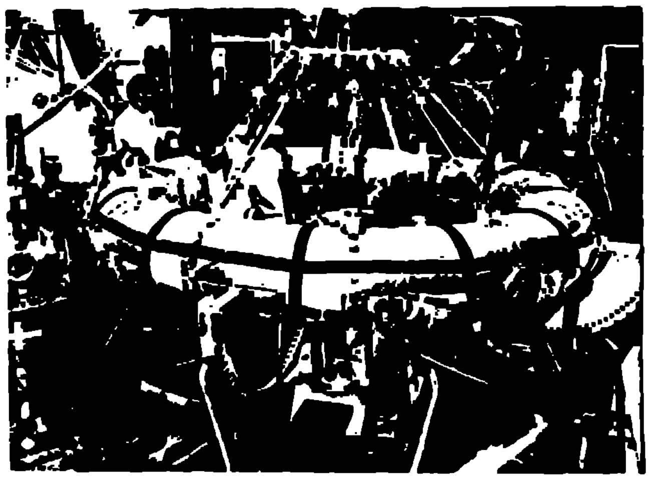

Figure 14
Lifting harness, ZT-40.

from the assembly area to a position above the bottom half of the pre-assembled primary shell, the torus was slowly lowered and seated in place. The remaining shell pieces were installed shortly thereafter. Figure 15 shows the final machine assembly. ZT-40 has been in operation since the first plasma shot was fired on October 5, 1979.

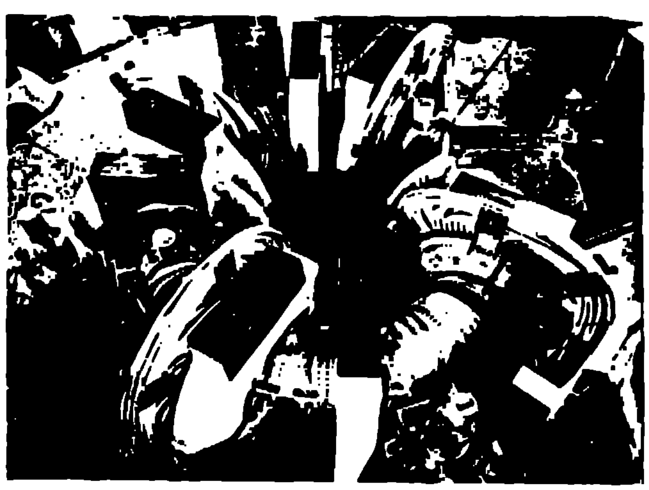

Figure 15
Present ZT-40 experiment.

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2. W. E. Hauth, et al., "Fabrication of an Alumina Torus for Thermonuclear Fusion Containment," LASL Report LA-7255-MS, May 1978.
3. Western Gold and Platinum Co., Belmont, CA.

Acknowledgments

The authors wish to express their appreciation to the following for their assistance in this effort: J. N. DiMarco, D. A. Baker, P. C. T. van der Laan, K. S. Thomas, W. E. Hauth, S. E. Newfield, L. J. Iko, N. L. Salazar, and E. J. Baron.