CONF-891007--77

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CONF-891007--77

LOCATION AND REPAIR OF AIR LEAKS IN THE ATF VACUUM VESSEL*

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ABSTRACT

On the basis of partial pressure rate-of-rise and base pressure measurements, it was determined that the Advanced Toroidal Facility (ATF) vacuum vessel had an air leak in the low 10^{-4} mbar·ℓ/s range. Pinpointing this leak by conventional helium leak-checking procedures was not possible, because large portions of the outside of the vessel are covered by the helical field coils and a structural shell. Various alternative leak-detection schemes that were considered are summarized and their advantages and disadvantages noted. In the method ultimately employed, gum-rubber patches of various sizes ranging from 12.7 by 12.7 cm to 20.3 by 30.5 cm were positioned on the inside surfaces of the vessel and evacuated by the leak detector (LD). After roughly 5% of the surface was inspected in this way, a leak of $>10^{-5}$ mbar·ℓ/s was discovered and localized to an area of 5 by 5 cm. Dye penetrant applied to this area disclosed three pinholes. Two small slag pockets were discovered while these points were being ground out. After these were rewelded, no further leakage could be found in the repaired area. Global leak rates measured after the machine was reevacuated indicated that this leak was about 30% of the overall leak rate.

INTRODUCTION

The ATF vacuum vessel (Fig. 1) was welded together from more than 1500 pieces of type 304 stainless steel. Inconel rod was used as the weld fill material to minimize the magnetic susceptibility of the weld region. The vessel forms the complex toroidal shape required to accommodate the helical field coils. On the basis of the observed rate of rise of the nitrogen partial pressure and calculations using the observed base pressure and pumping speed, it was estimated that the vessel had an air leak in the range of 10^{-4} mbar·ℓ/s. Conventional helium leak-checking procedures were applied, and the leak was localized to a sector containing 1/12 of the area of the vessel. However, pinpointing the leak in this way was not possible, because the outside of the vessel was completely covered by the coils and the structural shell. A number of alternative leak-detection schemes were considered and are discussed here. In the method ultimately employed, the suction cup method, the vessel was checked by applying a large-area helium spray to the outside; gum-rubber patches of various sizes were positioned on the inside surface and evacuated by the LD to detect helium leakage. Details of the method and results obtained with it are described.

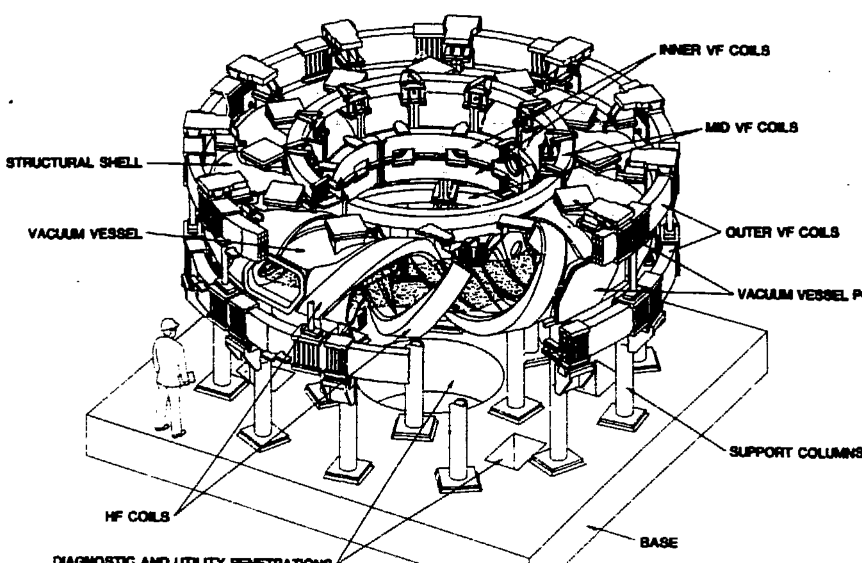

Fig. 1. Diagram of ATF vacuum vessel.

*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

LEAK-CHECKING METHODS

It was clear from the outset that the vessel had to be checked from the inside because there was essentially no access to the outside surface. Four different detection techniques were considered.

Suction Cup

With the vessel at ambient pressure but with helium-free air blown through the vessel, large suction cups are positioned on the inner surface and evacuated by the LD. Helium gas is flooded over the outside of the vessel through the nearest opening in the structural shell. Leaks are indicated as usual by an increasing LD signal.

Movable Ion Gauge

In this method, the vessel is pumped down to high vacuum, and a remotely manipulated ion gauge with an aperture to direct any incoming flow is moved about over the inside surface. Regions of increased pressure near leaks are sensed by the ion gauge. The gauge can be mounted either on a device that moves through the whole vessel or on a mechanical manipulator on a flange. Since ambient air is the leak-check medium, no helium gas is needed around the outside of the vessel.

Remotely Operated Movable Sniffer

The vessel is pumped to roughly 0.15 bar below ambient atmospheric pressure, and the outside surface is flooded with helium gas. A sniffer connected to an LD is moved over the inside surface to locate leaks with a manipulator similar to that for the movable ion gauge.

Manually Operated Movable Sniffer

In this technique, an operator carries the sniffer inside the vessel. With a large blower, the vessel pressure is reduced to about 0.15 bar below ambient, and the outside is flooded with helium gas. A continuous air leak into the vessel prevents the blower from reducing the pressure below the desired level and maintains breathability of the atmosphere. Pressure changes (particularly increases) must be made gradually to avoid discomfort or injury to the operator. This method was used successfully by the Doublet III group to locate a leak in their vacuum vessel [1].

Table I summarizes the perceived advantages and disadvantages of the different methods. A major concern was the ability to detect long-time-constant leaks (i.e., those with a trapped volume with low-conductance paths to both the inside and the outside vessel surfaces). These could be extremely difficult to find with helium leak detection because the partial pressure of helium in the trapped volume could take several hours to change appreciably. Only the movable ion gauge could find these leaks, with the added advantage that no helium would be needed around the outside of the vessel. However, no equipment for remotely manipulating either the ion gauge or the sniffer was readily available, so it was decided to proceed with the suction cup method. The manually operated sniffer method was rejected as being too difficult to satisfy administrative and safety concerns within the allowable time frame.

SUCTION CUP APPARATUS

Although much of the interior of the vessel is quite smooth, many rough areas remain from weld-grinding operations. There are also many inside and outside corners and compound-curve surfaces. In early attempts to use commercial suction cups, a sufficiently leaktight seal was possible only in the flat areas. After several trials, the arrangement shown in Fig. 2 was developed and used to fabricate several suction cups. The body of each suction cup was a 0.32-cm-thick patch of gum-rubber sheet. A 0.6-cm-diam plastic nozzle was sealed into a hole in the patch with RTV adhesive for the LD connection. The outer edge was sealed with an O-ring made of thin-wall, 0.32-cm-diam surgical tubing, which was also glued to the rubber sheet with RTV. RTV was used to join the ends of the tubing. The surgical tubing greatly improved the edge seal because it was soft enough to follow irregularities in the surface while still concentrating the local downforce on the patch along a narrow line. A layer of copper screen was installed under the patch to allow helium from a leak anywhere under it to reach the nozzle. For the larger suction cups, slits were cut in the screen to allow it to conform more easily to compound curves. Figure 3 shows a view of the underside of a completed suction cup, and Fig. 4 shows a cup installed around a typical corner weld in the vessel. Cup dimensions ranged from 7.6 by 12.7 cm to 25 by 30 cm. Another fixture, shown in Fig. 5, was found useful in 90° inside corners and was fabricated from a piece of aluminum angle and a soft PVC gasket.

LEAK-CHECK PROCEDURE

Because there was some residual leakage around the suction cups, it was necessary to use an LD of the backflow type with the test port on its roughing line. It was also important to minimise helium contamination in the vessel atmosphere so that the most sensitive ranges on the LD could be used. Automatic venting of liquid helium vapor during operation of a nearby liquefier was a significant source of contamination, and we tried to have liquid helium users delay transfers until leak checking was finished for the day. To limit contamination from the helium blanketing the outside of the vessel, the vessel was ventilated with filtered air piped from a blower in an adjacent air-conditioned shop area.

Table I. Summary of leak-checking methods

Method	Advantages	Disadvantages
Suction cup (vessel at ambient pressure)	All operations can be performed inside the vessel. Equipment can be prepared in advance. Only one TN flange needs to be removed. Leaks can be localized with progressively smaller suction cups. Leak can be marked easily for repair. Can check entire vessel.	Outside of vessel must be flooded with helium gas. If helium cannot reach certain areas, leak may not be detected. May have to bag the vessel. Will not detect long-time constant leaks. Sealing may be a problem at rough spots, inside and outside corners, etc. Cannot use lubricants, sealants, or tape inside vessel. May contaminate building atmosphere for leak checking elsewhere.
Ion gauge manipulated from outside vessel (vessel at high vacuum)	No helium needed outside the vessel. Leak can be localized by moving gauge closer to surface. No need to touch the surface and perhaps contaminate it. Can find the long-time-constant leaks.	Limited area can be reached from a single flange. Vessel must be backfilled and reevacuated each time the manipulator is moved. A window is needed near each manipulator position, or else a fiberscope must be put on the manipulator. There may not be a removable flange on each sector. More difficult to mark leak.
Ion gauge on remotely controlled carrier inside vessel (vessel at high vacuum)	Same as method 2. Only one TN flange needs to be removed. Can check whole vessel with one pumpdown.	Time frame longer than 3 weeks. Expensive and complicated equipment. Need accurate indexing to tell where device is in vessel. Difficult to mark discovered leaks. Should be able to "feel" the wall to keep from bumping into it.
Sniffer manipulated from outside vessel (vessel at slight negative pressure)	Short pumpdown time after moving manipulator. Can localise leak by moving sniffer closer to surface. No need to touch surface.	Has all the disadvantages of methods 1 and 2 except for suction cup sealing problem and multiple backfill-evacuation cycles. Sensitivity may be low because of low pressure across leak. Long-time-constant leaks will respond even more slowly.
Sniffer operated by man inside vessel (vessel at slight negative pressure)	Whole vessel can be checked with only one flange removal. Leaks can be localized and marked easily. Basic equipment is simple.	Very complicated administrative problems in satisfying safety procedures. Complicated communication equipment (intercom, in-vessel TV) needed. Vessel pressure, pressure change rate, and CO_2 must be carefully monitored. Cannot find long-time-constant leaks. Outside of vessel must be flooded with helium. Sensitivity may be marginal.

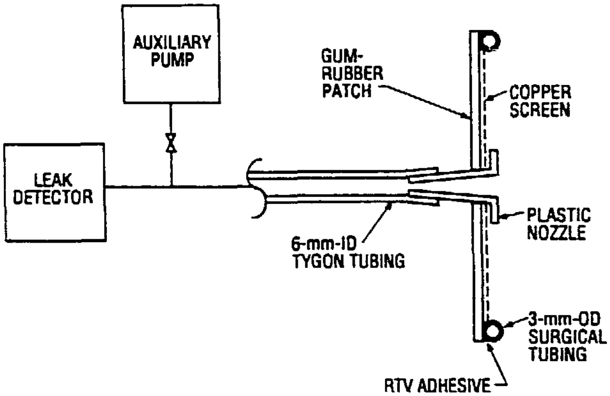

Fig. 2. Diagram of suction cup apparatus.

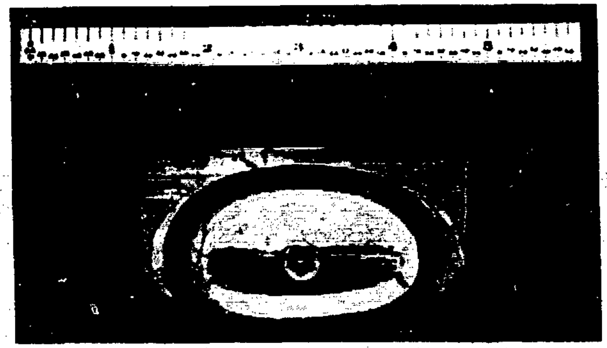

Fig. 5. Suction cup for 90° inside corners.

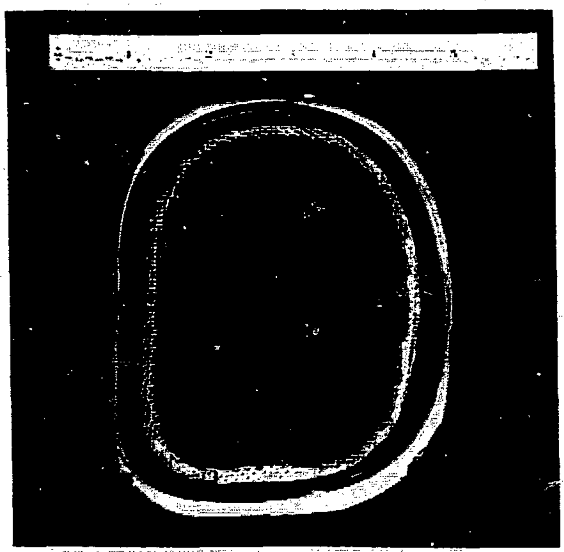

Fig. 3. Underside of completed suction cup.

Fig. 4. Suction cup installed around a typical corner weld in vessel.

This also greatly improved operator comfort. Breathability of the vessel atmosphere was checked by Industrial Hygiene personnel before each shift, and an attendant was present outside the vessel at all times during leak-checking operations.

The LD calibration was checked in the usual way with a 1.4×10^{-7} mbar·ℓ/s standard leak inserted into the LD tube in place of the suction cup. Helium from the standard leak was also injected into the outer edge of each suction cup with a hypodermic needle to verify that it could reach the LD. The suction cup was then positioned at the desired location in the vessel and pumped out with the LD. Usually, backgrounds in the low 10^{-7} mbar·ℓ/s range could be reached within a minute or two. Helium gas was then flooded over the outside of the vessel through an opening in the structural shell closest to the cup location, at a flow of roughly 500 sccm. If no change in background was observed after 3 to 5 min, the helium was shut off, the location of the suction cup was marked by tracing around it with a pen having alcohol-soluble ink, and the cup was moved to the next location. Since the screen defined the sensitive area, the locations were overlapped slightly. If a particularly high reading was observed at a given location, the cup was repositioned to a convenient "standard" location where a reliable seal could be obtained. In this way, we could determine whether a high background reading resulted (1) from a bad edge seal or a possible vessel leak or (2) from helium contamination in the vessel atmosphere. An auxiliary mechanical pump was usually connected in parallel with the LD, as shown in Fig. 2, to aid in pumping down the suction cups. This generally did not reduce the effective sensitivity, because it usually allowed us to reach a more sensitive LD range. However, a new calibration factor had to be determined with the standard leak when the auxiliary pump was used.

About six or seven locations could be checked per hour, so the largest suction cups were used wherever possible to speed up the work. However, these were difficult to use in any but the flattest locations because the operators could not hold the entire perimeter of the cup tightly enough against the surface to make the initial vacuum seal required for pumpdown. Early restrictions on use of adhesive tape in the vessel were later relaxed to allow use of woven fiberglass tape, which did not leave much adhesive residue on the surface. The large patches were then held down with tape around the edges, which greatly reduced sealing problems. Plastic electrical tape left much more residue and in one case sealed up a leak that had been found earlier.

RESULTS

Altogether, about ten days were spent in leak-checking one sector of the vessel, an area of perhaps 4 m^2. At one location near the inner midplane of the torus, the LD signal rose from 5×10^{-7} to 1×10^{-5} mbar·ℓ/s when helium was applied. The leak was localized to a 5-cm square by overlapping the suction cup positions, and this square was then checked with dye penetrant. This disclosed three pinholes; while these were being ground out, two small slag pockets were discovered. The ground-out areas were repaired by heliarc welding, after which there was no further indication of leaks.

CONCLUSIONS

When the vessel was pumped down, the nitrogen leak rate was reduced by only about 30%. In retrospect, it appears that what was though to be a single leak was really two leaks located close together. However, it has been proved that the suction cup method is a feasible way of locating leaks from the inside of a vacuum vessel. Though the method is time-consuming, it is faster and much cleaner than using dye penetrant over the entire inside surface, and it yields more definitive results. The method is most useful if the leak can first be localized to some portion of the vessel by other means. Another method, the movable ion gauge, appears to be even more attractive if an appropriate manipulator can be constructed, installed, and operated.

ACKNOWLEDGMENTS

The authors acknowledge helpful discussions with D. Santeler of Process Applications Inc., R. A. Langley, P. K. Mioduszewski, T. F. Rayburn, and J. E. Simpkins. The efforts of G. Bell, C. Crume, A. England, J. Glowienka, T. Jernigan, R. Langley, W. Lue, M. Murakami, and W. Redmond in carrying out the leak-check operations are greatly appreciated.

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