A VACUUM CHAMBER SYSTEM FOR HIGH RADIATION ENVIRONMENT*

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Summary. As the radiation environment in the proximity of high energy beams becomes an ever increasing problem, the need for radiation resistant vacuum chambers and seals of inorganic materials has become apparent. The long range plans for the ZGS have been in this direction. A three-year development program has resulted in a design which will withstand radiation levels several orders of magnitude greater than at present. Such a chamber will be installed early in 1968——five years after original machine startup.

ZGS Vacuum Chamber

The ZGS is a weak focusing synchrotron making it necessary to have a large beam aperture. It consists of 54-ft octants with the vacuum chamber and coil running the entire length of each octant. The distance between pole faces is 5-3/4-in and that between coils is about 35-in. As much of this opening as possible must be provided for beam aperture.

The vacuum chamber system which best satisfies this requirement is a double chamber utilizing the ring magnet itself to carry the major atmospheric load across the 35-in span with a thin liner to maintain the high vacuum required. The liner, called the inner vacuum chamber, must then carry only the differential pressure caused by the "rough" vacuum maintained inside the magnets. This is the system which is now used and will continue to be used with the new chamber. The present inner chamber is constructed of a 3/16-in thick corrugated stainless steel "sandwich" material called Spacemetal. The chamber consists of 9-in panels insulated with ceramic to limit eddy currents and bonded with organic adhesive. At a vacuum differential of 5 Torr, it will begin to deflect away from the pole faces; and, therefore, it must be protected by a control system which opens the inner chamber to the outer chamber if the pressure differential exceeds 6 Torr. The inner chamber is further protected by highly sensitive burst diaphragms which blow at 10 Torr should the control system fail.

Need For New Chamber

The need for an all-metal chamber was recognized during the original design, but the state-of-the-art of material technology had not yet reached the point that such a chamber could be fabricated which would meet the stringent electrical, magnetic, vacuum, and structural requirements. As expected, there has been a gradual deterioration of the organic material used in the chamber system during the 3-1/2 years of machine operation, becoming more evident as the intensity has increased. Also, it has become apparent from machine operation that it would be desirable to incorporate pole face windings which will act as tuning elements to modify the magnetic field making possible even higher intensities.

Chamber Development

In the eight-year period since the design of the original chamber, great strides have been made in material technology in conjunction with the national space effort. Titanium alloy was considered a rare metal in the '50's, whereas this year over 10,000 tons are expected to be used. Titanium alloy is particularly suited for a synchrotron vacuum chamber because of its high electrical resistivity, high strength, and nonmagnetic characteristics.

The aspect which makes the design and fabrication of an all-metal chamber difficult is that eddy currents, induced in the top and bottom walls of the metal chamber by the rapidly changing field of the ring magnet, distort the precisely designed spacial variation of the magnetic field which is critical for providing stability of the proton beam. Also, these currents can produce severe heating which could be harmful to vacuum seals, cause extreme thermal gradients and even cause melting of the metal. To date, all vacuum chambers for this application have been constructed of plastic or of small sections of metal bonded together with plastic adhesives. With the ever increasing beam intensities at which synchrotrons operate, these inorganic materials become subjected to serious radiation damage. For an all-metal chamber one must use high resistivity metals in very thin gauges to limit the eddy currents. The eddy currents can be limited by increasing the resistance of the material used in the chamber or by decreasing its cross section. Therefore, high resistivity materials, such as austenitic stainless steel, Inconels, and the titanium alloys are increasingly better materials. An all-metal chamber of stainless steel could have a skin thickness of no more than two mils. Utilizing titanium alloy with a resistivity of nearly three times that of stainless steel, the thickness can be five to six mils. By providing pole face windings which can compensate for some of the eddy currents produced, the titanium vacuum chamber thickness can be increased to about 15 mils. Even 15 mils in itself will barely carry its own weight let alone any vacuum loads. Therefore, the chamber must be reinforced in some manner. The addition of radial ribs to the skin has little affect on

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the eddy currents, but produces a very substantial increase in the strength of the chamber. As long as the rib spacing to rib thickness is kept large, at least ten to one, the affect on eddy currents is small. To compensate for this addition, however, the skin thickness must be reduced to 12 mils. The rib itself can be large, just so that the portion joined to the skin remains small (note the "T" shaped ribs in Fig. 4). The technique used for joining the rib to the thin skin is important. When using conventional welding techniques such as tungsten inert gas (TIG), resistance welding, and electron beam welding which cause the metal to be brought to the melting point, potential leakage problems occur. Also, with a relatively large space between ribs, fatigue of the thin skin at the weld joints can be a problem. With these considerations, a relatively new technique of joining was investigated as part of the development program. This technique is called diffusion bonding.

The unique properties that make diffusion bonded titanium alloy superior to any other combination of material and technique are:

1. It permits the most efficient use of material and technique from a standpoint of minimum eddy currents and maximum structural strength.

2. The vacuum integrity of the thin skin is undisturbed by the joining process.

3. The joints are completely bonded as though they were forged.

4. There are no fillet radii, brazing alloys or welding flanges to increase eddy currents.

With 10 miles of such joining required, these features become very significant.

Diffusion bonding is accomplished by the proper control of heat, pressure, and time. The temperature (1700°F) is considerably less than its melting point. Furthermore, with limited contact area permissible between the skin and ribs, its ability to approach 100 percent joint efficiency is an important feature. The surfaces to be joined must be clean and free from contaminates. The bond is made in a vacuum purged with Argon. The pressure can be applied in a number of ways. The larger the pressure the less time required for diffusion bonding and less preparation of the parts necessary. The technique used on the chamber is called blanket bonding which utilizes only vacuum pressure to give the required joint pressure required for bonding. The resulting pressure is 250 lbf/in^2. There is about 10 percent reduction in the rib height. Another common technique, called roll bonding, subjects the parts to severe hot rolling, actually reducing the size by 60 percent. In this case, the bond takes place in a few minutes as compared to several hours for blanket bonding. This process does not lend itself to the requirement for precise location of ribs necessary for this application.

Figure 1 illustrates the pack used for diffusion bonding. Figure 2 is a photomicrograph (75X) of one of the diffusion bonded joints of a prototype chamber.

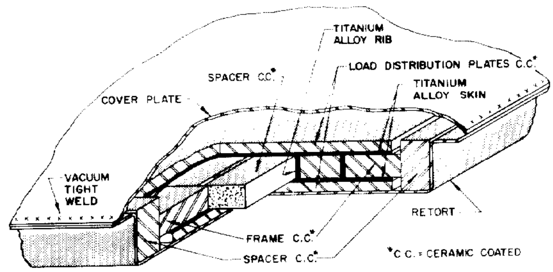

Figure 1
Diffusion Bonding Pack

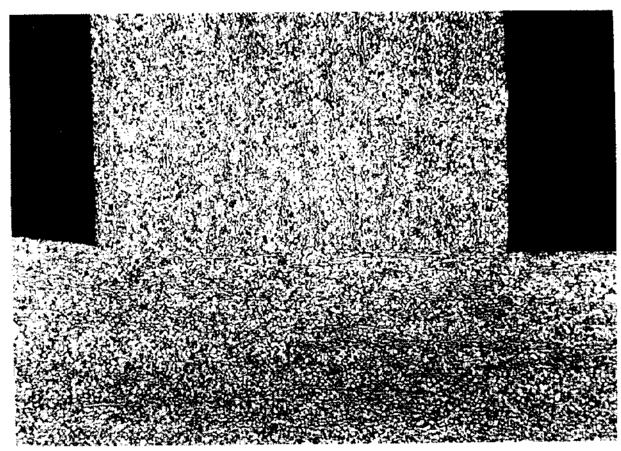

Figure 2
Photomicrograph of Diffusion Bond

A Prototype Chamber. An eight-foot prototype chamber was fabricated by North American Aviation to test the feasibility of producing a diffusion bonded titanium alloy vacuum chamber. The alloy used was 6 Al-4V. This was selected over 8 Al-1V-1Mo which has a 12 percent higher resistivity, because 6-4 is more weldable and formable. The chamber, shown in Fig. 3, was completely successful. The bonded joints proved stronger than surrounding parent material. Conventional welding techniques were used for joining panels to each other and to the sidewalls. These proved to be vacuum tight.

Magnetic measurements verified that the effect on the magnetic field was about as expected, and necessary correction with the pole face windings was accomplished.

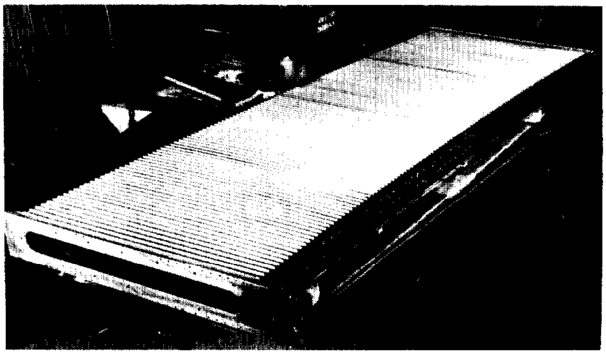

Figure 3
Titanium Vacuum Chamber Prototype

One aspect used in the prototype chamber which was not applied to the final design was that heavy glass-coated Inconel 718 reinforcing bars were attached to the "T" shaped ribs to make the chamber capable of withstanding full atmospheric load. This would have eliminated the need for an outer chamber. This worked very well, but necessitated a considerable sacrifice in both horizontal and vertical aperture, the size of the pole face winding conductors, and cost. Therefore, this aspect was dropped from the final design on the basis that the present outer vacuum chamber could be redesigned to be more reliable.

The Final Design

The final design selected increased the aperture from 4-1/2-in x 30-in to 4-7/8-in x 32-in. The "T" stiffening ribs were enlarged to make the design load 30 Torr differential vacuum. Forty-two equally spaced 1/8-in diameter solid conductors pass through each rib. The chamber is arched to prestress its horizontal walls against the pole faces. Figure 4 illustrates the final design of chamber. The inner skin is chemically milled to a thickness of 0.012-in leaving a 0.025-in land around the edges for welding. The rib flanges and webs are 0.040-in thick. The diffusion bonded panels are 11-ft in length. They are TIG welded to each other and finally resistance seam welded to the sidewalls. The sidewalls are beaded for reinforcement.

Outer Vacuum Chamber. An all-metal sidewall of light rigid construction has been designed. It eliminates the need for organic plastics, bonding materials, and sealants in the walls themselves. There is still an azimuthal rubber gasket between the sidewalls and the magnet pole faces, but it is inflatable to permit it to be replaced from the ends of the octants without removing any magnet blocks. There are also silicone rubber seals from block to block; but these will be removable, also without removing magnet blocks. The magnet lamination-to-lamination joint which is sealed with an impregnated epoxy resin will have to continue to be used as it now is but this joint is small and protected somewhat from radiation. Because a gradual increase in leakage is expected from these joints, the pumping speed along the length

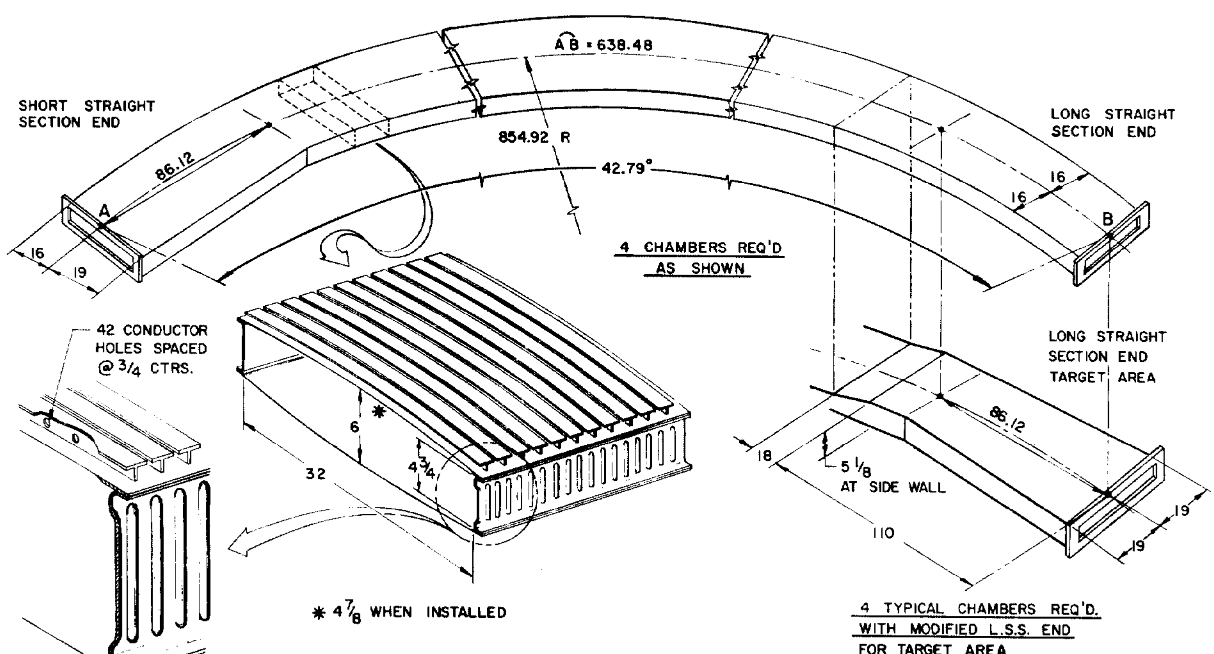

Figure 4
Titanium Vacuum Chamber

of the octant has been considerably improved and the operable rough vacuum pressure has been increased from 5 Torr to 30 Torr. If the rough vacuum ever reaches this point, additional blowers will have to be installed. Finally, if the leakage through the magnet blocks becomes too bad, the coil and yokes could be shrouded and the remainder of the magnet "cacooned" from the outside.

Figure 5 illustrates the magnet end condition showing the titanium vacuum chamber, outer chamber and pole face windings.

Pole Face Windings. Various inorganic insulating systems for the pole face windings have been investigated. These include glass-and ceramic-coated copper wire and anodized alumimum. These were found to be quite fragile for handling of 54-ft lengths and stringing them through the ribs of the vacuum chamber. Also, glass and ceramic tubing to sleeve the insulated wire was investigated. With the glass, consideration was given to welding 10-ft long tubes to make continuous 54-ft lengths to prevent any possibility of getting a glow discharge in the rough vacuum. Fear of glass breakage at the ribs and thermal expansion problems eliminated this concept. Tests were run showing that at the operating voltage (150 V) no glow discharge occurs. It does occur at about 300 V when a relatively large area (1/8-in in length) is exposed. The system found best consists of a fiber glass-mica insulation with a small percentage of silicone used as a binder to aid in installation and further protected by ceramic sleeves (about 4-in long) butted end for end along the entire length. The ceramic sleeves not only add insulation, but withstand the abrasion caused by stringing and by pulsations set up in operation. The complete insulated conductor will be potted in place with inorganic potting compound at close intervals along the length. This is necessary to prevent movement of the conductors in the magnetic field.

The heat generated by the windings in a vacuum have not proved to be a problem. The measured temperature rise of the 8-ft prototype chamber without the windings energized was about 21^{o}F. With the windings carrying twice the normal current, the steady state condition was reached at about 25^{o}F rise. To verify the above results, a 54-ft long conductor in vacuum is now under test, but no data are yet available.

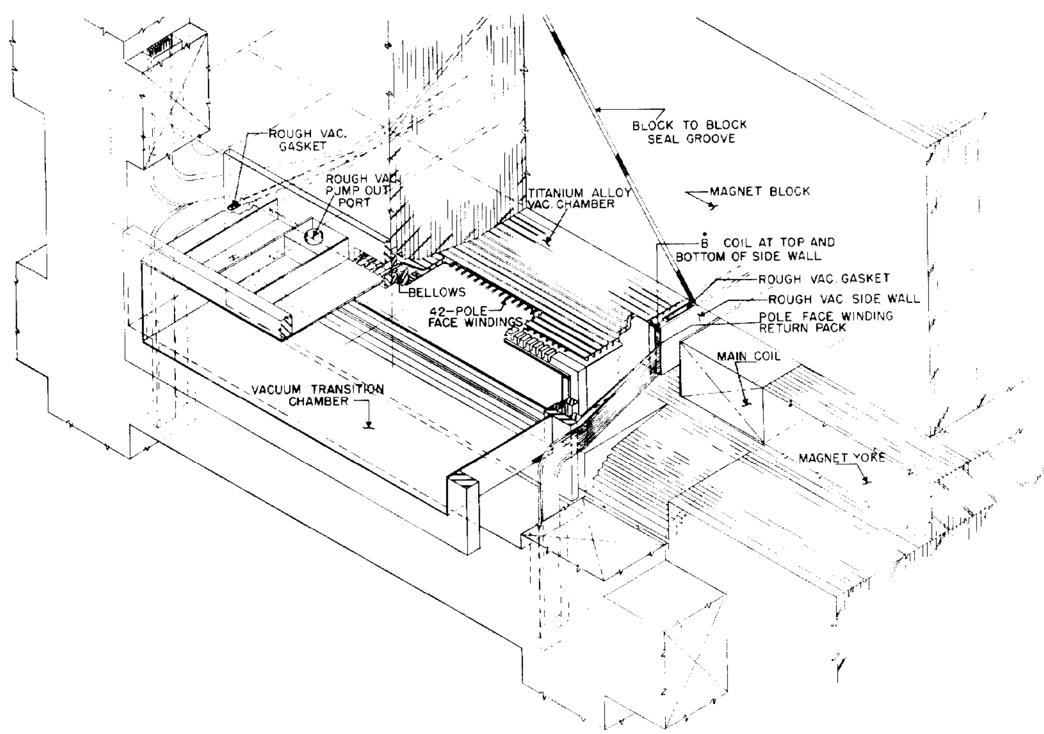

Figure 5
Vacuum Chamber With Pole Face Windings
In The Installed Position

Construction

The titanium chamber (Fig. 4) has been under construction since November 1966 and will continue through May 1968. The titanium is now being rolled and the tooling is under construction. Five 2-ft × 3-ft panels (Fig. 6) have been made to verify the aspects of fabrication different than the 8-ft prototype, that is; larger ribs which must accept the pole face windings and arching of the chamber to counter the vacuum loads.

The other items of the construction package will be started in the summer of 1967. Installation of the chambers is planned for two periods, one in May 1968 and the other in September 1968.

Acknowledgements

Some 15 scientists and engineers have contributed much to this program. They are too numerous to mention, but we do wish to especially acknowledge the efforts of our designer, Walter Pelczarski, and our Program Manager at North American Aviation, Carl Muser.

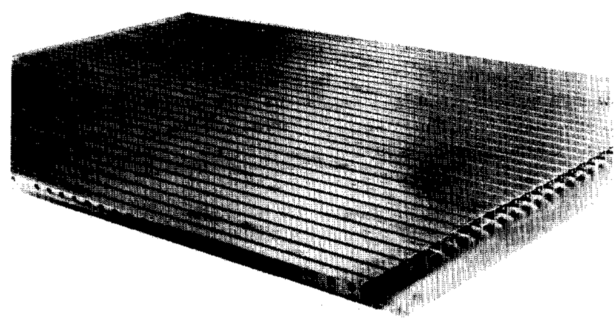

Figure 6
A 2-ft Panel From Prototype Chamber