ZERO GRADIENT SYNCHROTRON RING VACUUM SYSTEM

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Summary

The Zero Gradient Synchrotron is a weak focusing machine. This makes possible multiturn injection which results in a high intensity beam. Ideally, all of the space between the magnet pole faces and the magnet coil would be utilized for beam at injection. This need requires the vacuum chamber for the machine to have a large vertical aperture across a broad radial width.

The chamber of the ring magnet vacuum system is a closed ring about 560 ft in circumference (Fig. 1). Approximately three-fourths of this chamber length is within the eight magnet sections where the minimum cross-section exists (32 in. wide by 5-1/4 in. high). The closed magnet design restricts the pumps to positions on the straight section boxes between magnets, thus spacing these pumping stations approximately 70 ft apart.

Space limitations, eddy current problems, and heat problems determined the design approach to the vacuum chamber within each of the eight ring magnets. The resulting design necessitates the need for both an inner and outer chamber, since the inner (high vacuum chamber) design cannot withstand a pressure differential of one atmosphere.

Inner Vacuum Chamber

A major consideration for a synchrotron vacuum chamber is the effect of eddy currents which flow in a conductive material subjected to a rapidly changing magnetic field. Eddy currents cause a magnetic field distortion of the "zero gradient" field. An effect of one or two gauss at low injection fields is significant. The effect of eddy currents setup in a flat sheet of metallic material within a changing magnetic field is a function of thickness (t), width (w), and electrical resistivity (ρ), as shown in the relationship:

$$\text{Eddy current effect, } H = k\frac{w^2 t}{\rho} \qquad (1)$$

It is evident then that it is desirable to use a thin, high resistivity material cut in narrow widths, which are insulated from one another.

From a standpoint of good vacuum integrity and radiation resistance, an all-metal chamber would have been desirable but the material had to be extremely thin to offset the effect of width (w) in Eq. (1). A chamber of thin, corrugated stainless steel was originally investigated, but it was found to be beyond the limit of practicability for the initial construction of the ZGS.

Although it was realized that organic bonding materials were limited in life by radiation degradation, it was decided that by careful selection of materials and shielding of joints, a metal chamber, insulated and joined with plastic bonding materials, would have satisfactory life under predicted levels of radiation. The primary material used for the ZGS inner vacuum chamber was a corrugated stainless steel sandwich called "Spacemetal" made by North American Aviation, Inc. This material consists of two 0.008 in. skins of annealed 316 stainless steel separated by a corrugated 0.002 in. thick stainless sheet. The total sandwich height is about 3/16 in. It is quite rigid, yet the eddy currents are kept small by using 9 in. wide panels running across the 32 in. wide aperture. Figure 2 compares the Spacemetal chamber with other chambers investigated.

The Spacemetal vacuum chambers were bonded with a nitrile phenolic structural bonding film under high pressure. The joints were ceramic coated for insulation with plasma sprayed aluminum oxide. Materials selection and cleanliness were combined to minimize the outgassing rate of each chamber to about 1 micron liter per second. Figure 3 shows the 54 ft long chamber upon completion of bonding in the final assembly fixture. Note an upward camber in the Spacemetal to compensate for the deflection caused by the vacuum load. Figure 4 shows a cutaway of the ring magnet with the vacuum chamber in place. The chamber will withstand only about 15 Torr, hence, it is necessary to protect it against a full atmospheric load (760 Torr). The outer chamber normally operates at about 1 Torr. Differential and absolute pressure switches prevent pressure in excess of 6 Torr. Due to human failure to use the system as designed, there have been occasions when the chambers were severely damaged during operation. To increase the protection, rupture diaphragms were added in the walls of the chambers. These consist of a 6 in. disc of 0.00035 in. thick hard aluminum in a highly prestressed condition which when deflected sufficiently strikes a knife blade and bursts. They are set at 12 Torr.

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After a year of operation with the diaphragms in use, we find that they are doing an adequate job; but there are indications that some loss of prestress takes place due to either creep of bonding materials used or radiation degradation of the materials. About nine months of operation causes an increase of about 2 Torr. Therefore, we have a program of routine replacement of the diaphragms.

Outer Vacuum Chamber

The outer chamber uses the laminated ring magnets, vacuum impregnated, for its top and bottom surfaces. Its walls consist of eight-foot linen phenolic planks bonded end to end to form the required length of approximately 54 ft. During assembly of the octant, the planks were bonded to a 1/8 in. thick rubber strip on the inner surfaces of the magnet coils. This four-inch wide Buna N strip, bonded to the coil before its placement on the bottom magnet poles, serves to minimize stress in the planks due to expansion of the coil and from loading of the upper magnet poles. A Buna N rectangular gasket bonded to the top of the plank serves as the primary seal between the plank and the upper pole face. Silicone rubber, applied as a caulking compound, provides the seal between the bottom of the plank and the lower pole face. The sealant also serves to minimize inleakage due to surface imperfections between the gasket and upper pole face. Block-to-block sealing along the length of the magnet is accomplished by forcing silicone rubber through a long metal tube inserted into seal grooves (Fig. 4) machined into those surfaces of the blocks facing each other. Filling the seal grooves, which are positioned to meet the top and bottom plank seals, completes the block-to-block seal.

The outer chamber is not without problems. Most problems involve leaks. Leaks are located by response time measurements with a helium leak detector and repaired with a reasonably high degree of success by forcing low viscosity, RTV silicone rubber into the suspected areas.

The main disadvantages with the outer vacuum chamber are the large volume difference between it and the inner chamber; its low conductance characteristics, especially during high rate pressure rise conditions in the outer chamber; and its inaccessibility to repair.

The concern of subjecting the inner chamber to excessive pressure differentials has abated considerably, however, since the installation of the rupture diaphragms which respond faster to these differentials.

Vacuum Pumping System

The ring magnet vacuum pumping system consists of seventeen 32-inch oil diffusion pumps, sixteen 140 CFM rotary piston pumps, and eight 1000 CFM "Roots" type blowers. The 32-inch oil diffusion pumps are modified by expanding the pump casing to accommodate a 48-inch diameter "Z" type chevron baffle, mechanically refrigerated to -35°F. These diffusion pumps, mounted beneath the straight section boxes to maximize experimental access, have been in operation for over a year and a half without any apparent signs of backstreaming. See Fig. 5.

Ideally, the 4000 cu ft volume ring vacuum system can be split, both physically and control-wise, into eight similar segments. The unique feature of segment control enables any one segment to be brought up to atmospheric pressure for operating adjustment and then returned to normal operation without destroying the high vacuum in the other seven segments.

Pumpdown time of any one segment to diffusion pump range can be achieved in one hour or less. Assuming the normal operating pressure (approximately 1×10^{-6} Torr) exists in seven segments, an average pressure of 3×10^{-6} Torr can be reached in two hours or less after the eighth segment has reached diffusion pump range.

The ultimate pressure achieved, of course, is a function of the total continuous gas load. This gas load, a combination of surface outgassing and inleakage, is approximately 144 micron liters per second in the ZGS ring vacuum system, twice that of the original design estimate. With the high cost of accelerator operation, it is our opinion that accelerator design should allow for the largest permissible vacuum pumps consistent with existing conductances to reach operating pressure in a minimum of time.

Other features have been incorporated into the system which have proven their worth many times. The use of double seals with pumpouts and the availability of an auxiliary or house vacuum system have permitted the use of equipment which otherwise would have interrupted operation. The versatility of the piping arrangement allows the transfer of large Roots type blowers from the inner chambers to the outer chambers when high inleakage occurs, and permits operation to continue even though half of the mechanical pumps become inoperative.

Vacuum System Controls

Control of the ring vacuum system pumps, valves, and auxiliary equipment is centered in panels located remotely from the components.

Each of the eight vacuum segments can be operated independently from its own panel, and all panels are grouped together for convenience and co-ordination of operation.

The segments are pumped down in a three-step procedure by means of a master selector switch with four positions labeled OFF, START, INTERMEDIATE, and NORMAL. Each position permits or commands specific valves to open so that the vacuum chambers are exposed to pumps with the proper pressure capability. Permissive interlocking is also obtained from pressure sensing devices, temperature switches, flow switches, etc.

Operation of the pumps is not dependent on the position of the master switch, however, valve interlocking is such that if a pump is not running it is blanked off regardless of other conditions. All pumps are interlocked to stop operating in case of over-temperature, and/or loss of cooling water. Diffusion pumps are isolated and turned off if the foreline pressure is high and the Roots pumps are turned off if the inlet pressure is high.

Controlling pressure sensitive devices used are mechanical switches, thermocouple gauges, and Phillips gauges. Their contacts are used in the permissive interlock chains of valves and the master selector switch. Redundancy of control components is used where failure may jeopardize the vacuum system. Mechanical switches, sensitive to the pressure difference across the inner chamber wall, are used to operate the valves which expose the two vacuum chambers to each other. These valves and the differential pressure switches are provided with a separate power source, dc battery, for continued protection of the inner chamber wall should ac voltage be interrupted. DC distribution is by a conventional feeder and branch circuit arrangement using breakers. Each branch circuit is monitored by an alarm system with annunciator and printout. One segment of the inner chamber was crushed when the alarm system was disarmed and the dc distribution opened at the breakers to achieve a "floating" vacuum system. In this condition, the protective system could not function.

Pressure indication is combined with control functions in the panel meters. Ion gauges are used to provide readout only. Multipoint recorders monitor inner chamber pressure, diffusion pumps foreline pressure, and outer chamber pressure in each of the vacuum system segments.

Overall response time from pressure sensing to valve closure is adequate for surges from auxiliary apparatus exposed to the chamber without proper pumpdown. Deformation of inner chamber walls has occurred in some segments from what is thought to be a transient pressure pulse with duration less than the effective response time of the permissive system.

Future Vacuum System Plans

With future plans for increased beam intensities, interest in an all-metal chamber is now even more pronounced. Whereas the predicted order of magnitude of life of the present chamber at 10^{13} protons is one to ten years, an increase to 10^{14} protons would be cause for concern. Fortunately, in the interim, considerable progress has taken place in the use of high-strength, high-electrical resistivity titanium alloy. An all-metal chamber using this material would allow a gauge thickness which approaches practicability. Furthermore, experience with the ZGS has indicated that a lower divergence of beam can later be expected, thus allowing a reduction in the required vertical aperture from 5-1/4 to 4-1/2 in. In this additional space, pole face windings can be provided to offset the effect of eddy currents, permitting even thicker materials. A continuous, all-welded titanium alloy 0.014 in. thick is permissible under these circumstances.

Since the outer rough chamber is also sealed with organic materials, the problem of radiation degradation exists here too. Optimizing the use of the space available, it is possible to construct a vacuum chamber which will withstand full atmospheric loading. The addition of radial ribs running across the width of the 0.014 in. thick chamber does not substantially increase the eddy currents. Then by adding the outer supporting yoke in each of the spaces between the ribs, the full load can be supported. The basic design being considered is shown in Fig. 6. The supporting members must be electrically insulated from the ribs and skin, otherwise, very large currents would flow. Heating and even melting of the metal could be caused by electrical shorting, therefore, the insulation used must be very reliable. An insulated tie is required to carry the vacuum load from the ribbed skin to the outer supporting members.

Future requirements of the ZGS ring vacuum system also include remote handling and leak checking techniques, quick yet simple disconnects for high vacuum application, and replacement of present organic adhesives and sealants. All these changes must be met to avoid exposure to, and deterioration from, high radiation fields resulting from an expected increase in beam intensity.

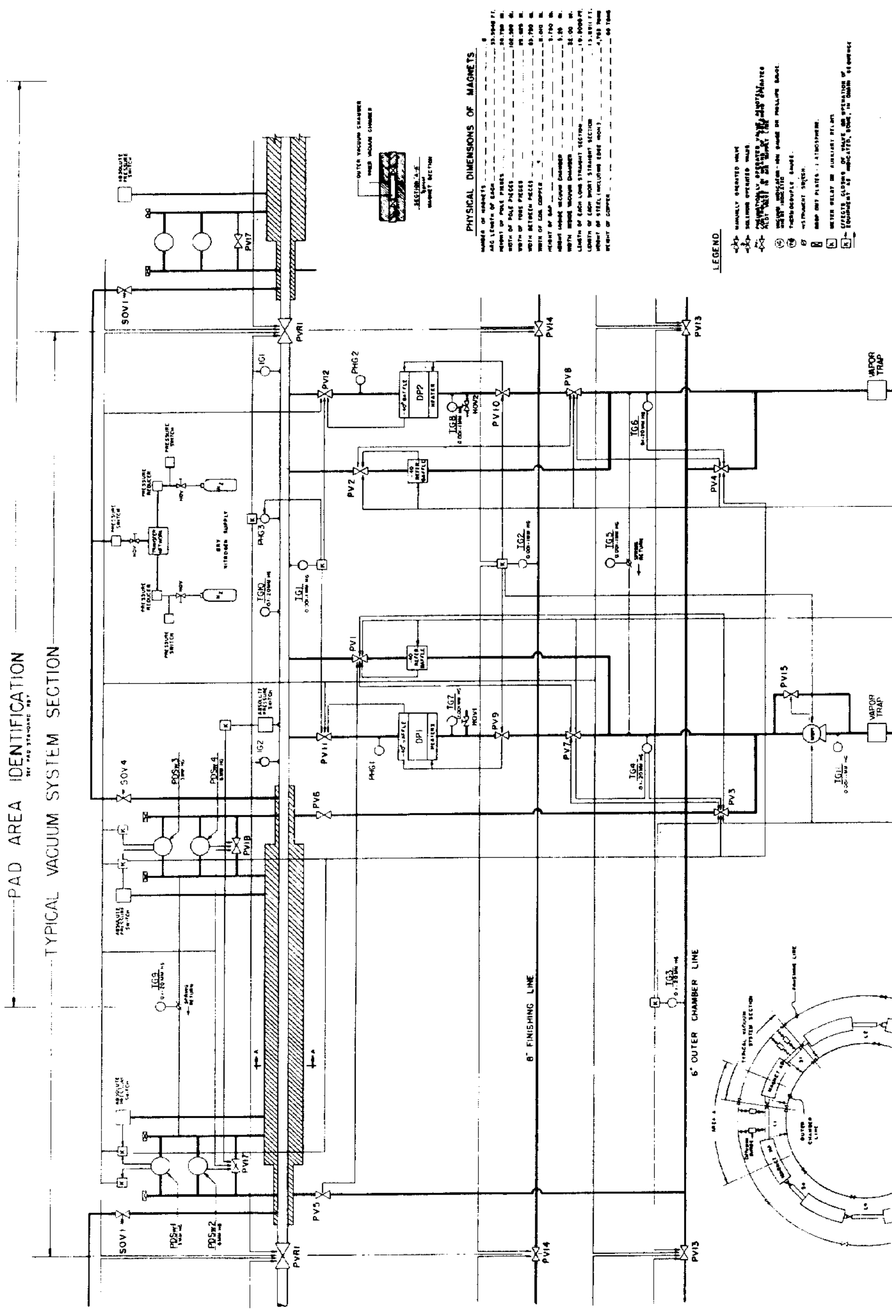


Fig. 1. Typical Segment - Ring Vacuum System.

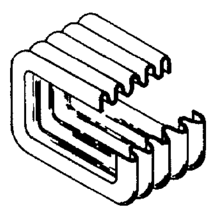
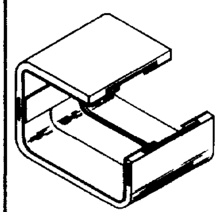
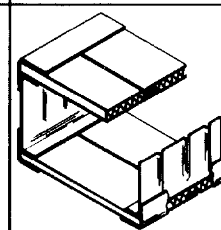
	ALL-METAL CONVOLUTED	METAL LINED EPOXY FIBERGLASS	SPACEMETAL	
				
			PLASTIC COATED JOINTS	CERAMIC COATED JOINTS
EDDY CURRENT EFFECT-GAUSS	4.0	.9	.5	.5
STIFFNESS FACTOR-E x I	1290	1260	2780	2780
OUTGASSING PER 54' CHAMBER-μℓ/SEC	≈ .9	7.65	1.2	1.1
ULTIMATE PRESSURE-mm. Hg.	NOT TESTED	3.0×10^{-6}	4.4×10^{-7}	3.0×10^{-7}

Fig. 2. Types of Chambers Investigated.

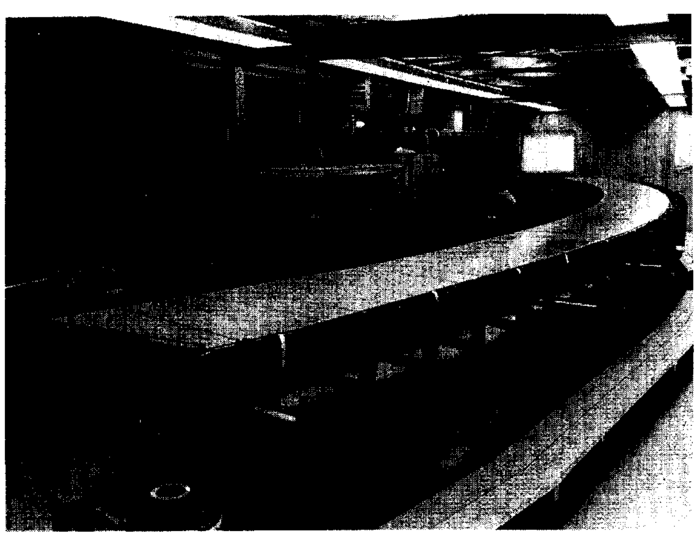


Fig. 3. 54-Ft. Inner Vacuum Chamber in Final Assembly Fixture.

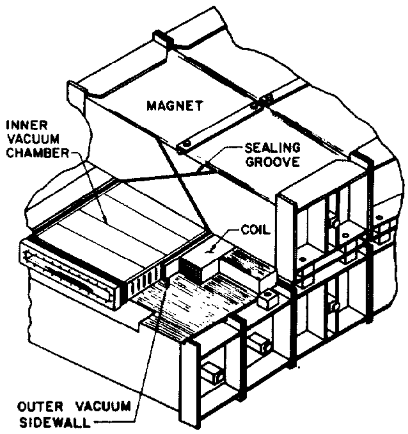


Fig. 4. Cutaway of Ring Magnet Showing Double Vacuum Chamber.

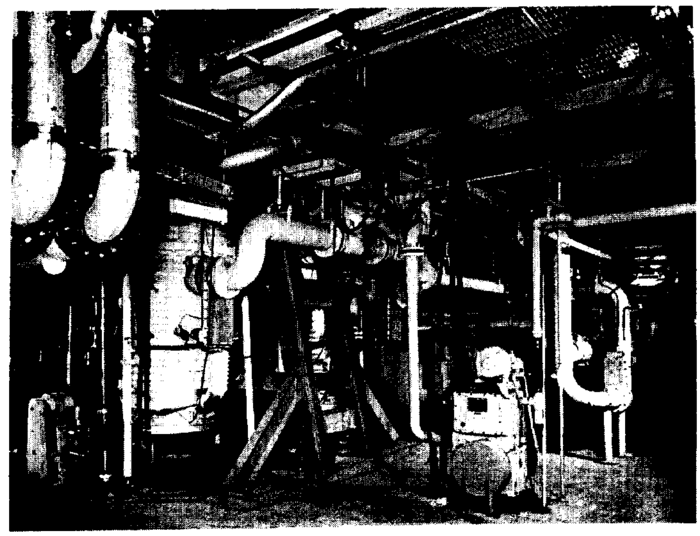


Fig. 5. Pumping Station - S1 Segment.

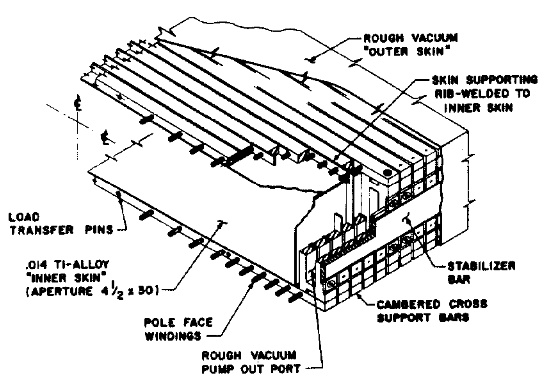


Fig. 6. Proposed Titanium (All Metal) Vacuum Chamber.