Chapter 13.
The Vacuum System

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13.1. The Vacuum Chambers

A plan view of the assembled vacuum chamber ring is shown in Fig. 13.1.1. The vacuum chamber ring includes twelve 28 degree chamber sectors, the bellows adapters (2 degrees) between sectors, and the support frames which are installed inside the sectors. There are nine sectors which have the same geometric features and three sectors which have special features. The similar sectors, which are referred to as "standard" sectors, are shown in Fig. 13.1.2. The special sectors are the inflector, trolley garage, and the traceback chambers. The kicker will also require a special design, but it will not be installed at the time the experiment is first commissioned.

The chambers have a scalloped shape on the inside to accommodate the twenty-four electron detectors while minimizing the showering in the vacuum chamber walls[1]. There are two detector regions per vacuum chamber sector. The detector region is shown in Fig. 13.1.3. The vacuum wall adjacent to the calorimeter is only 3 mm thick to allow the detector to be as close to the storage region as possible. The calorimeter is inclined at an angle of 70 mrad, which is the mean angle of electrons with high analyzing power (actually NA2) which miss the outer edge of the detector and hit the next detector. The outside wall of the chamber is at a radius of 721 cm to allow free space for the incoming pion or muon beam.

The inflector, which is installed in chamber 1, cancels the field for the incoming particle beam, and directs (i.e., inflects) the beam tangentially into the storage region. The kicker will be located approximately 90 degrees clockwise from the inflector end. Two sets of beam monitors determine the particle distribution at approximately 180 degrees and 270 degrees from the inflector end. There are four regions in the vacuum chamber ring for electrostatic quadrupoles: Q1, Q2, Q3, and Q4. Each region has 39 degrees of electrodes mounted in standard chambers for a total azimuthal coverage of 156 degrees. The trolley garage is at the chamber 10 position, and the electron traceback detector is at the chamber 11 position.

Figure 13.1.1: Plan view of the storage ring vacuum system.

Figure 13.1.2: Plan view of the standard vacuum chamber.

Figure 13.1.3: Plan view of detector station. There are 23 such stations around the ring.

The vacuum chamber sectors are a welded fabrication of aluminum alloy 6061 plate. The standard chambers have 5 conflat flange ports with a 203 mm outside diameter and a 124 mm inside diameter facing radially inward. These flanges are available for the quadrupole electrical feedthroughs, beam monitors, vacuum pump connections, for removal of the distributed ion pumps (DIPs), for access when installing the quadrupole feedthroughs, and for positioning of the internal support frame. There are 30 fixed NMR probes per chamber which are mounted in grooves in the upper and lower chamber plates. These grooves are on the outside faces of the plates, external to the vacuum.

The support frame inside each chamber sector serves primarily to provide rails for the NMR trolley cable car. The support frame is shown in Fig. 13.1.4. The quadrupole electrodes are mounted to the support frame. To ensure accurate frame assembly and precise positioning of the rails and electrodes, 3 mm upper and lower plates of the frame are CNC machined to the exact radius for a 28 degree arc. A short aluminum bellows adapter is placed between each vacuum chamber section. The bellow adapter facilitates installation and removal of a sector, provides for any angular misalignment of chamber end flanges, allows expansion for small temperature differences between the yoke iron and aluminum chamber ring, and allows independent, and therefore more precise, setting of chamber radial position. The rectangular end flanges of the sectors and bellows adapters are sealed with viton O-rings. NMR plunging probes and collimators (scrapers) will be installed in the bellows adapters.

The accurate positioning of the NMR trolley rails and quadrupole electrodes which are mounted on the support frame is critical to the experiment. The alignment of internal components of the vacuum chamber will be accomplished in the following steps: assembly of the support frame on a very flat surface using gauging and tooling, machine chamber upper and lower surfaces to a flatness of .010 inch (.25 mm) to serve as a datum for support frame positioning, installation and alignment of the support frame in the sector relative to end flanges and sector upper and lower surfaces, and finally positioning and alignment of the sector in the magnet gap.

To minimize electron trapping and high voltage breakdown at the quadrupole electrodes[2], a pressure of 10^{-7} $Torr$ is required for the storage ring vacuum. The total gas load of the storage ring vacuum system is estimated to be 1×10^{-3} $Torr - \ell/s$ 24 hours after roughing down. To reach pressure of 5×10^{-7} $Torr$ in 24 hours, a pumping speed of $\simeq 2000\ell/s$ is needed.

Figure 13.1.4: The support frame which goes inside of the vacuum chamber to support the trolley rails and the electrostatic quadrupoles.

13.2. Vacuum Pumps, Pumping Speeds and Outgassing

A prototype vacuum chamber has been constructed which is identical to the standard vacuum tank section. In the prototype sector chamber, an outgassing rate of $1 \times 10^{-9}\ Torr - \ell/s\ cm^2$ was reached 24 hours after roughing down. The outgassing of twelve sector chambers with an internal surface area of $5 \times 10^5\ cm^2$ will therefore be $\sim 5 \times 10^{-4}\ Torr - \ell/s$ or 50% of the estimated gas load. The quadrupole electrodes will contribute a gas load of $2 \times 10^{-4}\ Torr - \ell/s$ or 20% equivalent. The 24 Viton O-ring seals will add a gas load of $\sim 1 \times 10^{-4}\ Torr - \ell/s$ from both outgassing and permeation. The remaining 20% of the gas load budget is set aside for other vacuum components, such as kicker, profile monitors, etc. With careful selection and evaluation of the material used in each component and proper cleaning and handling, the total gas load shall not exceed the estimated $1 \times 10^{-3} Torr - \ell/s$ 24 hours after pumping down.

Turbomolecular pumps will be used to rough the ring vacuum from ambient to $\sim 10^{-5}\ Torr$ before the high vacuum pumps can be started. The turbopumps can also be used as high vacuum pumps when the need arises. Identical turbopump stations will be used to maintain the insulating vacuum of the cryostats of the magnet coils and the inflector.

Sputter ion pumps, which provide clean, vibration free vacuum, have been chosen as the high vacuum pumps for the storage ring vacuum system. Instead of lumped ion pumps, distributed ion pumps(DIPs) mounted inside the vacuum chambers will be used here. With the existing bending field and vacuum chambers, only Penning discharge cells are needed. These on-the-spot pumps eliminate the conductance restriction of the manifolds associated with the lumped pumps. The other major advantage of using DIPs in the $(g-2)$ storage ring vacuum is the absence of permanent magnets of the lumped ion pumps, which might disturb the 1 *ppm* field uniformity requirement. The absence of pump manifolds also frees up the space in the storage ring midplane and simplify the chamber design.

Two areas of $5\ cm \times 50\ cm$ at the inner radius of the sector chambers, as shown in Fig. 13.2.1, have been identified[3] to be outside the trajectories of the decaying electrons and will be used for positioning the DIPs. The DIP will be installed and retrieved through the down stream Conflat port. The maximum allowable cross section of the DIPs through the port is approximately 5 cm wide and 10 cm high. The DIP design is shown in Fig. 13.2.2. It consists of two sections, each with three layers of anode elements. Flexible braids are used to joining the anode elements together. Both the anodes and the cathodes of the DIPs are made of titanium therefore they will not disturb the uniformity of the magnetic field at the muon storage region.

Figure 13.2.1: A sample of muon decay electron trajectories showing the optimum location inside the vacuum chamber for the distributed ion pumps.

Figure 13.2.2: A schematic view of the distributed ion pump elements.

The pumping speed of the sputter ion pumps is a function of the geometry of the Penning discharge cells and the magnetic field intensity. The lumped ion pumps, using permanent magnets, usually have a field intensity of $\leq 1.5\ kG$. The magnetic field at $(g-2)$ DIP locations ranges from 12 kG to 15 kG. At this high field, DIPs with anode cell radius around 6 mm have been found[4] to have the highest pumping speed of approximately 0.4 ℓ/s per cell. The pumping speeds drops off with decreasing and increasing cell radii. Each $(g-2)$ DIP will have over 270 cells, therefore a pumping speed over 100 ℓ/s. A total pumping speed of 2000 ℓ/s can be obtained with 20 DIPs distributed around the ring.

13.3. Monitoring the Vacuum

To monitor the vacuum level, the storage ring will be instrumented with a few sets of vacuum gauges. Due to the distortion of the electron orbits inside the gauge heads by the fringe magnetic field, hot filament ionization gauges will not function correctly. Cold cathode gauges will be used instead. The effect of the fringe field on the cold cathode readings will be negligible if the gauge heads are located more than 1.5 meters away from the storage region where the fringe field is less than 50 G. Alternatively, the gauge discharge can be sustained by the storage ring magnetic field if the gauge is positioned near the storage region and the permanent magnet is removed. The gauge readings will supplement the pressure readings derived from the discharge current of the DIPs. With over twenty DIPs distributed around the ring, an accurate pressure profile will be readily available for interlock and trouble shooting.

13.4. References

1. F. Krienen and D. Brown, *(g-2) Note No. 62*, April 1991.
2. Y.K. Semertzidis, *(g-2) Note No. 169*, August 1993.
3. S. Hou, Private Communication, August 15, 1992.
4. H.C. Hseuh, M. Mapes, L. Snydstrup, Proc. 1993 PAC, IEEE 93CH3279, 3897.