BEAM VACUUM CHAMBERS FOR BROOKHAVEN'S MUON STORAGE RING*

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Abstract

An experiment is being built at Brookhaven to measure the g-2 value of the muons to an accuracy of 0.35 ppm. The muon storage ring of this experiment is designed to produce a dipole field with homogeneity to 1 ppm using a continuous superconducting magnet. The beam vacuum system in the storage ring will operate at 10^{-7} Torr and consists of twelve sector chambers. The chambers are constructed of aluminum and are approximately 3.5 m in length with a rectangular cross-section of 16.5 cm high by 45 cm at the widest point. The design features, fabrication techniques and cleaning methods for these chambers are described. Monte Carlo simulation of the pressure distribution and finite element analysis of the chamber deflection are summarized with good correlation shown to measured values obtained during tests of the prototype chamber.

I. INTRODUCTION

The principle equipment of the g-2 experiment[1] is the muon storage ring and its continuous superconducting magnet which bends and stores the injected pion and muon particles. The magnet has a diameter of 14 m and a gap of 18 cm facing the inside of the storage ring. The cross sectional view of the magnet, its cryostats and the muon storage chamber is shown in Fig. 1. A magnetic field of 14.5 KG with a field homogeneity of 1 ppm is required in the muon storage region, which rules out the use of any material with magnetic susceptibility higher than 0.001. The muon chambers and the associated components are made of aluminum, titanium, ceramic, and polymeric materials. The design, selection of material, fabrication and evaluation of these vacuum chambers will be presented here.

II. DESIGN and FABRICATION OF SECTOR CHAMBERS

A plan view of the ring vacuum system without the superconducting magnet is shown in Fig. 2. It consists of twelve 28-degree chambers, of which ten are identical (i.e., standard). The detail of a standard sector chamber is shown in Fig. 3. The chamber has an arc length of 3.5 m and a

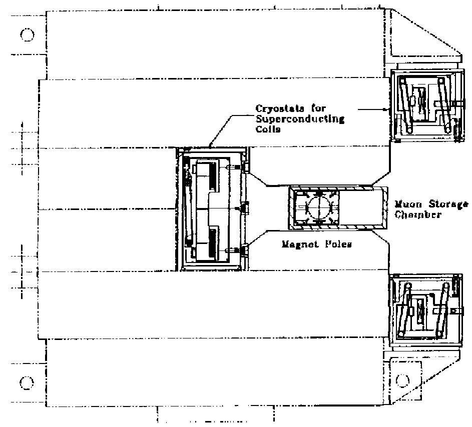

Fig. 1. The cross sectional view of the 45 m continuous superconducting magnet, its cryostats and the muon chamber.

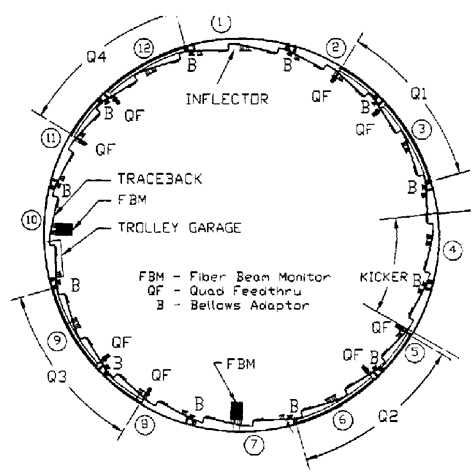

Fig. 2. The layout of the muon storage ring vacuum system without the superconducting magnet, consisting of twelve sector chambers; ten standard ones and two special ones for inflector magnet and for NMR trolley garage.

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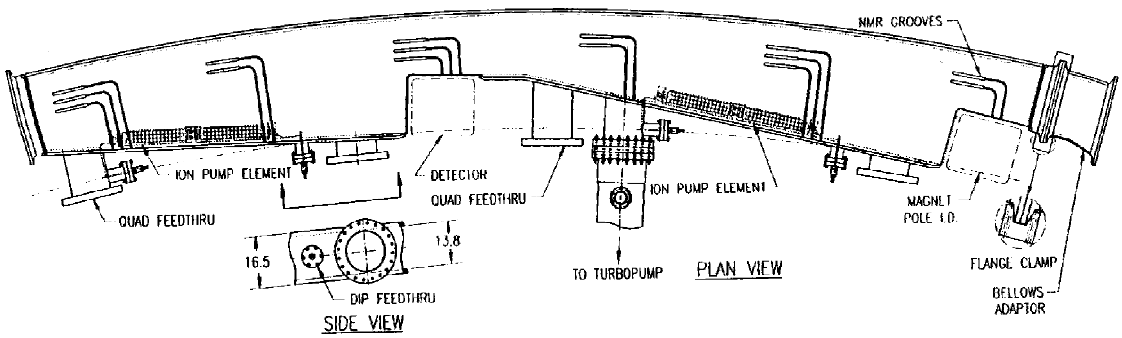

Fig. 3. The design of the standard sector chamber together with distributed ion pumps and turbopump manifold. The scalloped areas are for electron detectors.

rectangular cross-section with inner vertical height of 13.8 cm. The horizontal width of the chamber varies from 15 cm at the narrow point to 45 cm at the widest point, forming two scalloped areas on the inside to accommodate the twenty-four electron detectors. Conflat access ports are provided at the inner radius of the chambers for pump connections and installation of various internal components. A short bellows adaptor is placed between the chambers. It allows for the installation of the chambers and for the alignment of the end flange clamps and seals which are only accessible from the inner radial side.

The sector chamber is a welded fabrication of aluminum alloy 6061 plates. The top and bottom plates are 13.5 mm thick and the side wall 19 mm thick. The wall adjacent to the detectors is only 3 mm thick thus minimizing the energy loss of the electrons. After machining and chemical cleaning, the plates are welded on a 4 m long weld fixture table in a clean room. The post-weld flatness and loss of arc of the chambers are approximately 1 mm. The top and bottom surfaces are then machined to a flatness of 0.25 mm. The Conflat access port flanges and the rectangular end flanges are then welded.

Four electrostatic quadrupoles, occupying 45 percent of the ring circumference, are to focus the injected muons and pions. They are pulsed at ± 25 kV during the storage period. The electrodes are mounted on the curved support frames which are installed inside the sector chambers through the end flanges. The cross sectional view of the chamber, the support frame and the electrodes are shown in Fig. 4. An NMR trolley containing up to 25 NMR probes will be used periodically to map the magnetic field of the storage region around the ring. This NMR trolley, operated in storage vacuum, will ride on the corner rails of the support frame, and parked at a 'garage' when not in use. There are also 30 fixed NMR probes per chamber which are mounted in external grooves in the upper and lower chamber plates.

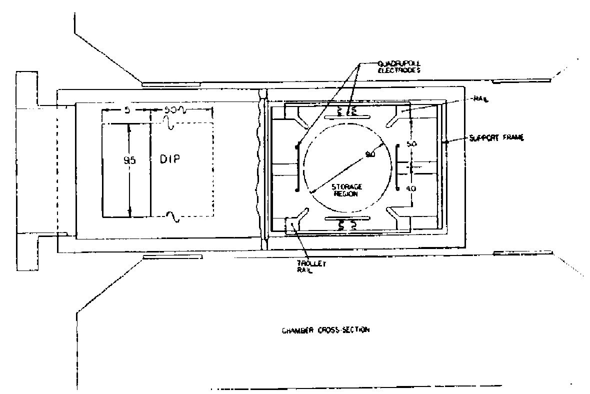

Fig. 4. The cross sectional view of the sector chamber at its widest point. The rectangular frame supports the quadrupole electrodes and the rails for NMR trolley. Dimensions are in cm.

III. MECHANICAL and VACUUM EVALUATION

After fabrication and cleaning, the chambers are pumped down, leak checked and measured for deflection of top/bottom plates under vacuum load. The deflection of the top plates of the prototype chamber at its widest span was found to be 0.45 mm. This is in good agreement with the calculated value of 0.4 mm using ANSYS finite element code.[2]

Without a large on-site chemical cleaning facility to handle the completed sector chambers, the chambers were cleaned with pressurized hot water spray mixed with mild-etch alkaline detergent. The effectiveness of the cleaning steps can be judged by measuring the outgassing of the chambers. The outgassing rates of the prototype chamber after various cleaning treatments are plotted in Fig. 5 versus pumpdown time. Outgassing rate of mid 10^{-10} Torr.ℓ/sec.cm^2 can be reached one day after pumpdown with mild-etch detergent rinse (pH = 11.5). The slope of the outgassing curves are consistent with $q \propto k*t^{-1.1}$ which is the characteristic of the outgassing of water.

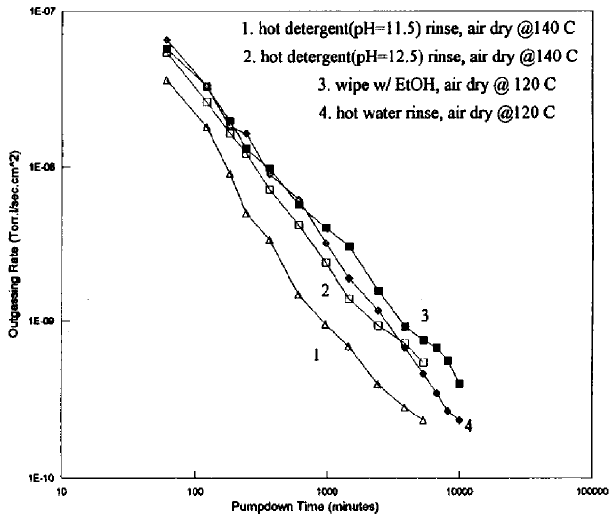

Fig. 5. Outgassing rates of the prototype sector chamber after various cleaning treatments. The designed outgassing rate of $1x10^9$ Torr.ℓ/sec.cm^2 at t = 24 hours can be reached with mild-etch detergent rinse.

IV. PRESSURE DISTRIBUTION

The injected pions and muons are to be stored for a few milliseconds which only requires a medium range vacuum. However, to minimize electron trapping and high voltage breakdown at the quadrupole electrodes, pressure of 10^{-7} Torr is needed especially when π^- and μ^- particles are stored. At this mode of operation, the upper and lower electrodes are at -25 kV and two side electrodes at +27 kV.

The storage ring vacuum will be pumped down and maintained at high vacuum with the combination of two turbomolecular pumps, two cryopumps and 24 distributed ion pumps (DIPs). The distributed ion pumps will not be installed during the commissioning stage in early 1996. The turbomolecular pumps and cryopumps will be positioned at every third chamber two meters radially away from the storage region, which reduces the effective pumping speed to less than 200 ℓ/sec. The long manifold is necessary to minimize the disturbance of the field uniformity at the storage region and to allow the reliable operation of the pumps under the fringe magnetic field.

The pressure distribution at the storage region is calculated using a Monte-Carlo simulation program[3] 'Molflow' as shown in Fig 6. Without DIPs, pressure of low 10^{-6} Torr will be reached one day after pumpdown and low 10^{-7} Torr with DIPs. Excessive breakdown of the quadrupole high voltage has been observed in the prototype testing when operated with π^-/μ^- mode at 10^{-6} Torr. This limits the experiment to π^+ and μ^+ modes during commissioning. The π^- and μ^- modes are only possible with the installation of the DIPs.

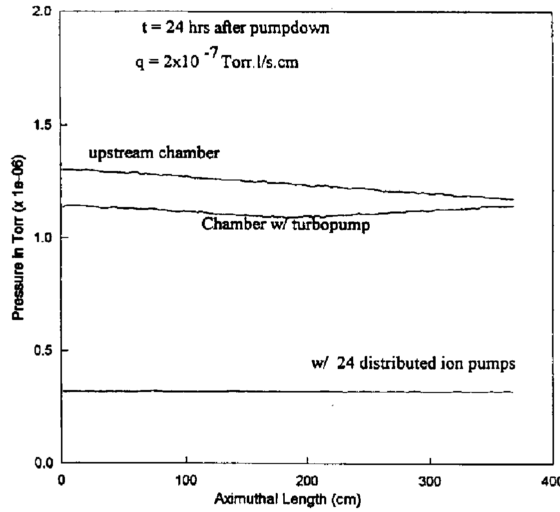

Fig. 6. Monte-Carlo simulation of pressure distribution inside the quadrupole electrodes using "Molflow" with 4 turbopumps; and with 24 distributed ion pumps. The x-axis represents the azimuthal length of the chamber. Total molecules generated in the simulation is approximately 30,000 per sector chamber.

V. SUMMARY

Due to the unique physics requirement, the vacuum chambers of the Brookhaven's g-2 muon storage ring have to be made of wide aluminum plates. The dimensional tolerances of the completed chamber are within the design values. The measured deflection of the prototype chamber under vacuum load is agreeable with ANSYS analysis. The outgassing rate of the chamber after mild etching is acceptable. The pressure distribution inside the quadrupole electrodes will be sufficiently low for the reliable operation when the distributed ion pumps are installed.

VI. REFERENCES

[1] V.W. Hughes, *Particle, Strings & Cosmology* (World Scientist, Singapore, 1992), p. 868.
[2] ANSYS code, ver. 5.0, Swanson Analytical Systems Inc., Houston, PA.
[3] A PC based Monte Carlo simulation program for vacuum systems written by Roberto Kersevan, Sincrotrone Trieste, ST/M-91/17, September, 1991.