ELECTROSTATIC QUADRUPOLE FOCUSING IN THE AGS g-2 STORAGE RING*

G. Bennett, R. Larsen, W. Morse, Y. Semertzidis, J. Yelk
AGS Department, Brookhaven National Laboratory
Associated Universities, Inc., Upton, New York 11973
Z. Liu, Physics Department, Boston University, Boston, MA 02215

Abstract

Electrostatic quadrupole focusing is to be used in the high precision measurement of the anomalous magnetic moment of the muon, AGS Experiment 821. The final design uses planar rather than hyperbolic electrodes, and the field is pulsed to minimize the effect of trapped electrons. The mechanical design is described. Performance in a 1.5T magnetic field at less than 10^{-6} Torr is reviewed.

I. INTRODUCTION

Experiment 821 at the AGS will measure the magnetic moment of the muon to unprecedented precision.[1] Muons at 3.094 GeV/c will be contained in a superconducting storage ring with a magnetic field of 1.45T homogeneous and controlled to 1 part in 10 million. At that momentum the effects of electric fields are null to first order so that focusing is provided by electrostatic quadrupoles without compromising magnetic field homogeneity.

Design requirements include conflicts such as low stopping power (low density, thickness, and atomic number) to allow efficient detection of the electrons from muon decay, yet mechanical strength for precise positioning and shape, and high stopping power to scrape the tails of the muon distribution. Magnetic permeability must be low. Good vacuum properties are also required.

The crossed electric and magnetic fields cause "trapping" of electrons with maximum energy equal to electrode voltage. These trapped particles oscillate between and circulate about the electrodes, causing further ionization with charge build up and ultimately, breakdown with potentially destructive consequences for the electrodes and insulators. Trapping is a major design consideration.

Pulsed electrostatic quadrupole focusing was used in the previous measurement of the muon g-2 at CERN. The asymmetric electrodes were hyperbolic in form and operated at 5 and 38 kV. The problems of electron and ion trapping were analyzed thoroughly.[2]

II. MECHANICAL DESIGN AND ANALYSIS

The layout of he storage ring is shown in Fig. 1. The quadrupoles subtend 39 degrees per quadrant. The electrodes are fabricated in modules about 13 degrees long. The vacuum chamber sections are each 28 degrees in azimuth with interstitial bellows sections of 2 degrees free of electrodes. Each vacuum chamber carrying electrodes has feedthroughs. Note the scalloping of the inner wall of the vacuum chamber for placement of the electron detectors signaling muon decay.

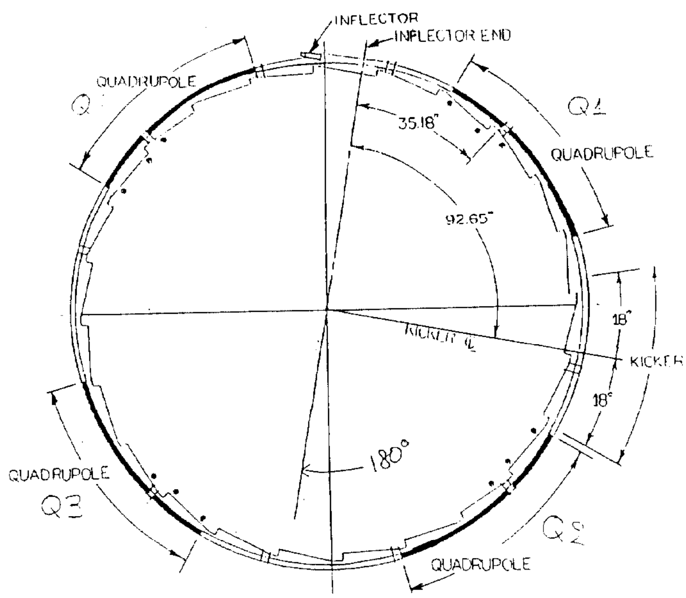


Fig. 1. Plan view of the storage ring showing quadrupoles and other major components.

A major simplification is the concept of flat electrodes . [3] Because of the fourfold symmetry all multipoles vanish except the 4, 12, 20 ... poles, and the 12-pole can be made arbitrarily small by choice of the electrode dimensions. A cross section through the quadrupoles is seen in Fig. 2. The electrodes are supported by an aluminum cage with sturdy corner rails, solid plates on top and bottom, and thin strips forming the sides. The cages and electrodes can be precisely assembled before installation in the vacuum chambers. Final positioning in the chambers utilizes adjustment screws.

Analysis of the electric fields was performed using the two dimensional modeling code POISSON to assay voltage instability, positioning errors, and various other geometrical changes.[4] The resulting allowed tolerances are shown in Fig. 3. Table I shows the relative multipole content up to 28 pole for the ideal geometry of Fig. 2 (columns 2 and 3), for the case with the maximum inward extension of the scalloped vacuum chamber inner radius wall (columns 4,5) with two diagonally opposite corner rails missing (columns 6,7), with the upper and lower plates at maximum inward displacement, 0.5 mm, while the side plates have the maximum displacement outward, 0.75 mm, plus the inner vacuum chamber wall

* Work performed under the auspices of the U.S. Department of Energy.

has maximum inward extension (columns 8,9). All these conditions are seen to be acceptable.

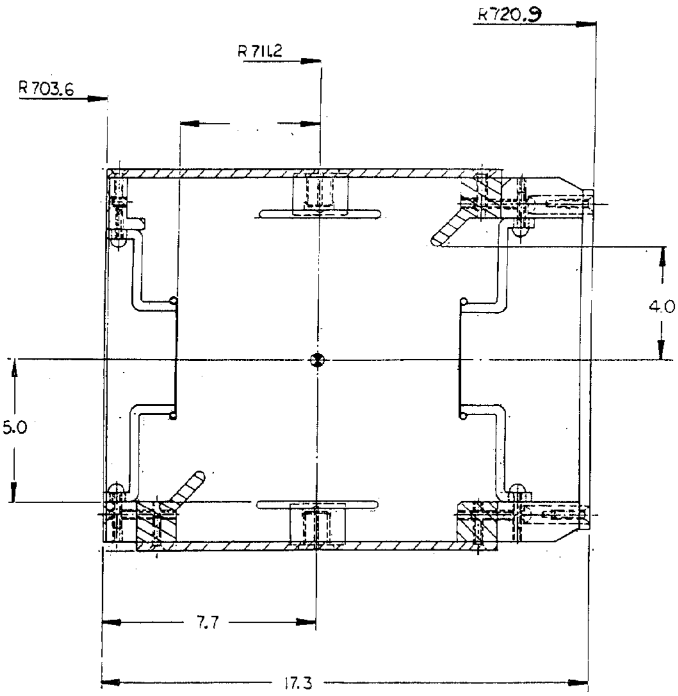


Fig. 2. Cross section through the vacuum chamber showing the cage assembly, quadrupole electrodes, and insulators.

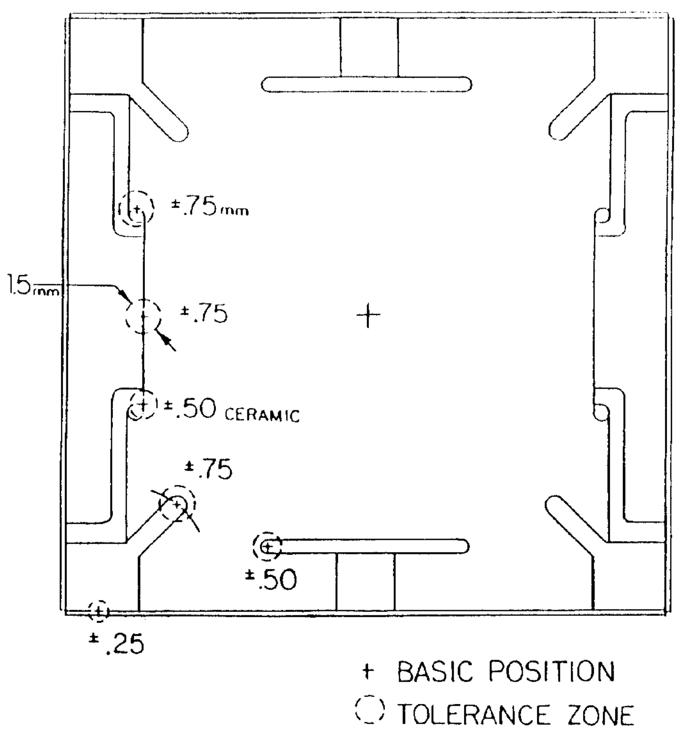
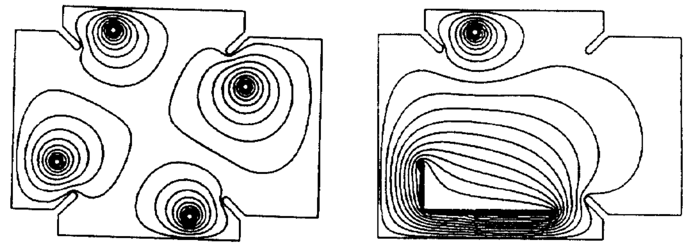


Fig. 3. Construction tolerances for the quadrupole assemblies.

The connections from electrodes to the feedthroughs shown in Fig. 4 were designed to interrupt the trajectories of the trapped particles, channeling them to grounded structures in the vacuum chamber



k	AN(%)	BN(%)
1	1.45	-0.05
2	22.11	19.50
3	0.71	0.00
4	1.02	0.03
5	0.26	0.11
6	-5.12	4.82
7	0.03	0.13
8	0.20	0.02
9	-0.05	0.07
10	-1.02	-1.53
11	-0.05	0.00
12	0.04	0.10
13	-0.02	-0.03
14	0.38	-0.26

k	AN(%)	BN(%)
1	-13.17	-53.20
2	-0.55	16.86
3	-3.25	5.19
4	2.44	0.02
5	5.60	-0.79
6	-2.26	-0.21
7	-0.75	-1.67
8	-0.02	0.26
9	-0.19	1.29
10	-0.03	-0.44
11	0.50	-0.11
12	-0.04	0.03
13	-0.32	-0.06
14	0.11	-0.02

Fig. 4. Cross sections through the interconnections from electrodes to feedthroughs showing equipotential contours and multipoles.

III. ELECTRICAL PARAMETERS

The electric gradient required to achieve a desired focusing index n, is

$$|dE/dr| = nvBo/Ro$$

where v is the muon velocity, Bo the magnetic field, and Ro the muon orbit radius. The potential on the plates is then

$$V = dE/dr\,(r_m^2/2f)$$

where the field index, n is 0.139, the orbit radius is 1.112 m, r_m is 48 mm, half the separation of the quadrupole plates, and f is the fraction of the azimuth subtended by the electrodes, 0.4. The resulting plate potentials are thus ± 22.6 kV.

The capacitance of each electrode was calculated to be 54 pF/m,[5] or about 250 pF per electrode per quadrant. Other electrical parameters include:

Voltage stability	± 1%
Pulse duration	1 ms
Maximum jitter	100 ns
Minimum pulse interval	25 ms
Stored energy per electrode	.08 J

Pulsing the quadrupoles is another means of reducing the effects of trapped particles.

Solid state high voltage switches[6] have been used to date to test the design in vacuum and evaluate the measures taken to minimize trapping. A section of the quadrupoles 6 degrees in length was tested in a vacuum chamber at 5×10^{-7} Torr in a magnetic field of 1.5 T. After conditioning the electrodes were tested to more than 10,000 pulses at 28 kV with polarities appropriate to muons of both signs with no sparking or breakdown with pulse durations of 1 to 3 msec!

Since the trapped electrons oscillate at an angular frequency

$$w = \sqrt{2eV/mr_m^2}$$

where e and m are the charge and mass of the electron. For V, the electrode potential, at 28 kV the electron frequency is about 330 MHz. We have measured this frequency using an rf oscillator and amplifier capacitively coupled to the electrodes, observing a resonant build up at the appropriate frequency. This technique can be used to measure the effective field strength in the presence of trapped electrons.

V. REFERENCES

[1] L.M. Barkov et al., "The Anomalous Magnetic Moment of the Muon," Proc. of the 9th International Symposium on High Energy Spin Physics. Nov. 1990.

[2] W. Flegel and F. Krienen, "Pulsed Electrostatic Focusing for the CERN Muon Storage Ring," NIM 113 (1973) 547-560.

[3] S.R. Mane, "Electrostatic Quadrupole Design," Brookhaven National Laboratory Internal Report g-2 #103, Feb. 1992, unpublished.

[4] Y. Semertzidiz, "Quadrupole Tolerances, Rails and More," Brookhaven National Laboratory Internal Report g-2 #149, April 1992, unpublished.

[5] S.R. Mane, "Quadrupole Capacitance," Brookhaven National Laboratory Internal Report g-2 #150, April 1992, unpublished.

[6] Behlke, A.G. Model HTS 301 from Euroteck Inc., Morganville, New Jersey.

TABLE I

Multipole Analysis of the Electrostatic Field for Various Geometries. An's are the normal and Bn's the skew components. Amplitudes shown are percent of the normal quadrupole compoent for the ideal geometry, column 2.

	Ideal Geometry		Inner wall at min radius		2 corner rails missing		Side plates out top and bottom in inner wall at min radius	
k	An	Bn	An	Bn	An	Bn	An	Bn
1	0.14	0.10	-0.08	0.02	0.18	0.07	2.48	1.71
2	100.00	0.09	100.16	-0.42	100.04	-0.22	100.18	-0.50
3	-0.11	0.04	0.04	0.02	-0.14	0.01	0.86	-0.60
4	-0.54	-0.02	-0.92	-0.09	-0.76	-0.08	-0.94	-0.04
5	-0.05	-0.04	0.05	-0.01	-0.07	-0.03	0.01	-0.01
6	-0.02	0.00	-0.19	0.15	-0.04	0.12	-0.18	0.16
7	0.01	0.02	0.00	-0.01	0.02	0.03	-0.24	0.18
8	0.03	0.01	0.12	0.06	0.09	0.07	0.10	0.03
9	0.01	0.00	-0.01	0.00	0.01	-0.01	-0.25	-0.16
10	-2.67	-0.02	-2.59	-0.02	-2.64	-0.04	-2.61	0.00
11	0.02	-0.02	-0.01	0.00	0.02	-0.02	-0.07	0.05
12	0.08	0.00	0.08	-0.02	0.07	-0.02	0.09	-0.02
13	0.00	0.01	0.00	0.00	0.00	0.01	0.02	0.01
14	0.25	0.25	0.00	0.25	0.24	0.00	-0.25	-0.01