A Panofsky Quadrupole for a Low Energy FFAG

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The present muon collider design is considering the use of a Fixed Field Alternating Gradient (FFAG) accelerator which would be able to accelerate the muons from 16 to 64 GeV[1]. This machine could either be used as part of a ~100 GeV collider used to study the Higgs, or as part of a chain of accelerators used in even higher energy acceleration.

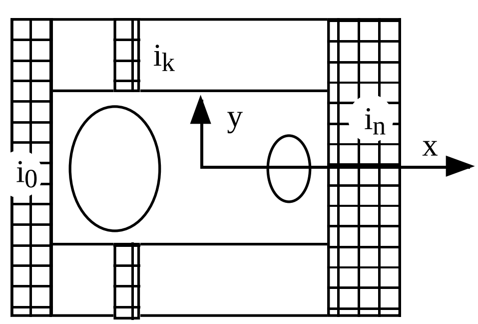
In the design of a scaling radial sector FFAG proposed by Johnstone, Wan and Garren, each of the magnets has a magnetic field $B(\rho) \sim \rho^n$, where the exponent n is equal to 707. This lattice has the extreemly desirable feature that the dispersion is a constant, and thus the rf phase advance per turn is a constant. The F and D magnets have opposite sines for B and n and differ only in their length. The ring has constant tune values with energy. In addition the radial width of the orbit excersion can be made small. The disadvantages of the design are that the circumference if the ring is comparatively large, $R/\rho \sim 5$, and the optical complexities have been absorbed in the magnet, which cannot be constructed using standard accelerator magnet technology.

This note describes a preliminary look at an adaptation of a Panofsky quadrupole design. The beam optics are determined by the parameters shown below.

	Injection	median	Extraction
Energy, GeV	16	40	64
Normalized Emittance, mmmr	300	300	300
Horizonatal beta maximum, m	7.8	7.8	7.8
Vertical beta maximum, m	15.3	15.3	15.3
Dispersion, m	3.87	3.87	3.87
Horizontal position, cm	-2.32	0.00	2.32
3 sigma horizontal, cm	1.65	1.04	0.82
3 sigma vertical, cm	1.18	0.74	0.59

Although the classic FFAG has a wide horizontal vacuum chamber, this device requries a vacuum chamber with similar aspect ratio to normal accelerators.

The model assumes a current distribution shown in the following figure, where the current in the elements is determined by the algorithm

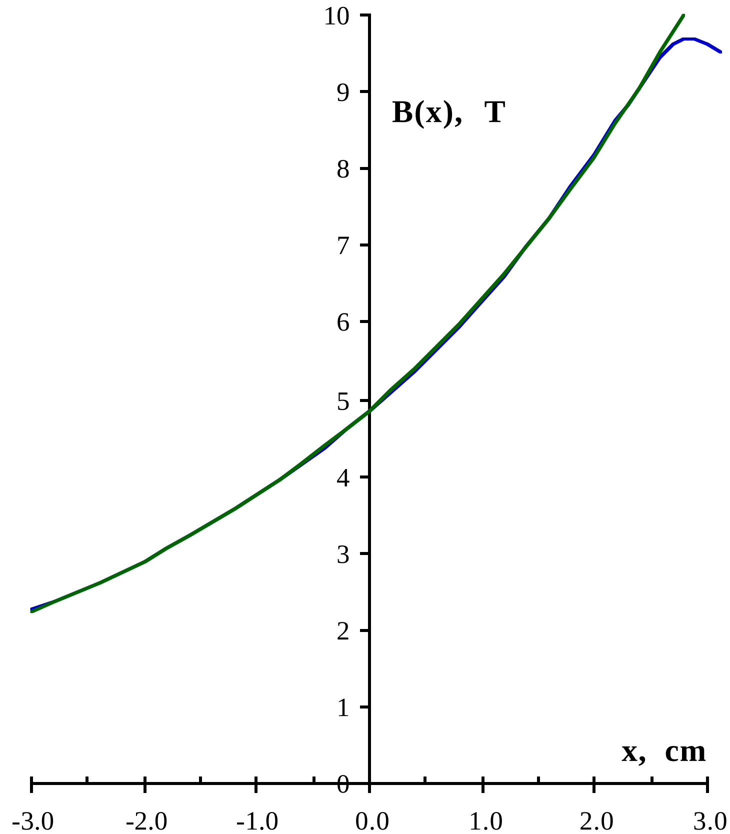


$$i_k = a + bx + cx^2,$$

$$i_n = -\,(\, i_0 + \Sigma\, i_k\,),$$

with i_0, a, b, and c being the variables. In practice, i_0 and a are much larger than b and c.

The fitting was done with a simple two dimensional model which calculated the required field on the median plane (green) from the required central field and gradient, and then fitted the field produced by the sums of currents due to the current elements to the required field (blue).



Only a preliminary fit was made at this stage because vacuum chamber dimensions, coil supports, and beam orbit errors have not been considered. The field is comparatively easy to fit at the low energy, low field side, however it becomes somewhat more difficult on the higher energy side, since the required field can rapidly become larger than 10 T. The individual currents used to generate the field are shown in TABLE I. The general field shape was produced easily from a variety of coil positions.

Assuming pancakes 3 cm high gives current densities of ~170 A/mm at the low field side and 100 A/mm on the low field side, which are somewhat reasonable for this stage of optimization.

It is assumed that the magnet would be constructed of pancake coils of various widths with all current being returned on the high field side. This model assumes no iron would be used for the return flux. It might be possible, however, to insert iron boxes between magnets to produce a field free region between the ends of the coil pancakes.

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[1] C. Johnstone, W. Wan, and A Garren, "Fixed Field Circular Designs for Muon Acceleration" draft note dated March 2, 1999

TABLE I

Positions and currents used to generate field

x, cm	±y, cm	i_k, MA
-5.00	1.00	0.0725
-4.66	3.00	0.0187
-4.32	3.00	0.0183
-3.97	3.00	0.0180
-3.63	3.00	0.0176
-3.29	3.00	0.0173
-2.95	3.00	0.0169
-2.61	3.00	0.0166
-2.26	3.00	0.0163
-1.92	3.00	0.0159
-1.58	3.00	0.0156
-1.24	3.00	0.0152
-0.90	3.00	0.0149
-0.55	3.00	0.0146
-0.21	3.00	0.0142
0.13	3.00	0.0139
0.47	3.00	0.0135
0.81	3.00	0.0132
1.16	3.00	0.0128
1.50	3.00	0.0125
1.84	3.00	0.0122
2.18	3.00	0.0118
2.52	3.00	0.0115
2.87	3.00	0.0111
3.21	3.00	0.0108
3.55	3.00	0.0105
3.89	1.00	-0.3807

with

i_0	0.0725	MA
a	0.0140	MA/cm
b	-0.001	MA/cm^2
c	0.000	MA/cm^3

0.7