CONCEPT FOR A NEW MAGNETIC SEPTUM QUADRUPOLE

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Abstract

We propose removing much of the material from a standard quadrupole mirror plate, such as found in a HERA QS-type interaction region quadrupole, to create a magnetic septum quadrupole (MSQ). Septum saturation is avoided through choice of geometry and correction current coils. Applications for a MSQ include: HERA IR luminosity increase, optics matching for beam extraction and/or injection beamlines and forward angle particle detection.

1 INTRODUCTION

A historically difficult accelerator problem is how to provide focusing for one charged particle beam traveling in close proximity to another without unduly affecting the other beam. In collider rings one wants focusing as close as possible to the interaction point (IP) but is forced to wait for spatial separation. Getting quadrupoles close translates as smaller IP spot size for greater luminosity. For injection beamlines differential focusing is often quite desirable. For the PEP-II B-factory a current septum quadrupole (CSQ) has been designed for independent focusing of the high- and low-energy beams[1]. In a PEP-II CSQ the full excitation current for one coil flows through a small region between the beams. The thinness of such a septum is limited by achievable current density.

In the HERA e-p collider, the first proton focusing magnet is a half quadrupole with a thick mirror plate. The plate completes the magnetic circuit and separates the p- and e-beams. The 70 mm mirror plate thickness limits placement to 27 m from the IP. HERA luminosity could be increased 2–3.5$\times$ with a radically cut away mirror plate for placement 12.5 m from the IP[2]. Whether such a thin septum plate is feasible, especially given $\frac{\Delta B}{B}$ = few$\times 10^{-4}$ as a typical design goal, is the subject of this study.

2 PRELIMINARY CONSIDERATIONS

Since the B-field goes to zero at a quadrupole center, a deep notch in the septum might indeed be livable. Lambertson style dipoles[3], such as those planned for the SSC beam abort[4], are routinely designed to accommodate fields of $\approx$1 T. For comparison a 20 T/m gradient evaluated at 2 mm from the center yields a modest 0.04 T.

A critical issue is highlighted in Fig. 1. Here we show a closeup of a MSQ with a cut-away septum plate. The septum plate acts as a bridge for flux passing between the poles. Flux follows the path along the septum until the septum saturates (B_{max} $\approx$1.8 T) and develops a high "magnetic resistance." A broad region of the septum saturates in an uncontrolled way for significant field perturbation; however, if even more of the septum is cut away, as shown in Fig. 2, more flux returns around the coil and there is a smaller region of high saturation.

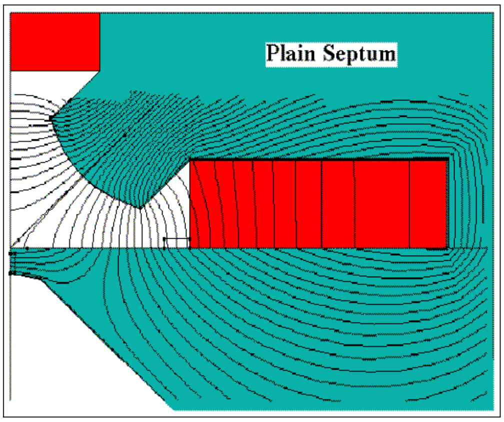

Figure 1: Center of MSQ with 45° cut ending at 10 mm septum thickness. Only right half shown due to horizontal symmetry.

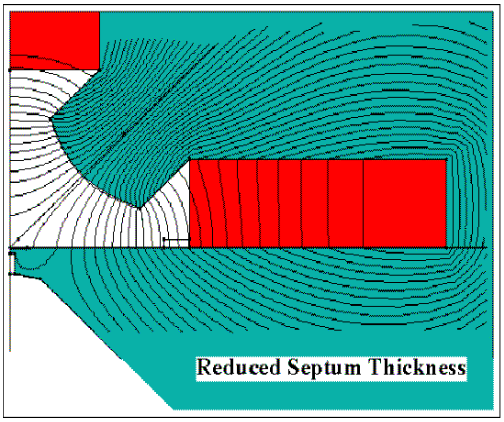

Figure 2: MSQ same as Fig. 1 but with additional 2$\times$8 mm cut leaving 2 mm thick septum.

In Fig. 3 the cut extends completely to the center and ends at a gap. None of the septum material in the vicinity of the center is highly saturated but there is an appreciable field perturbation due to the gap. The perturbation can be reduced by adding material inside the mirror plate for field

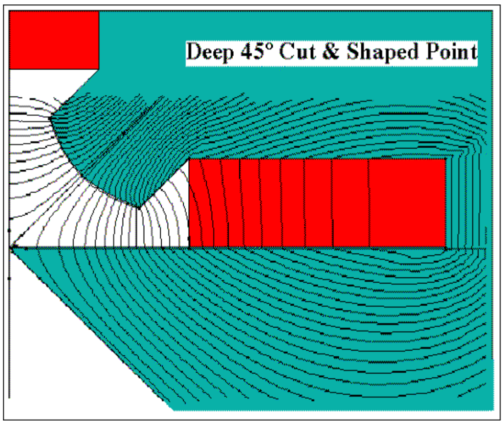

Figure 3: MSQ with 45° cut extending to origin.

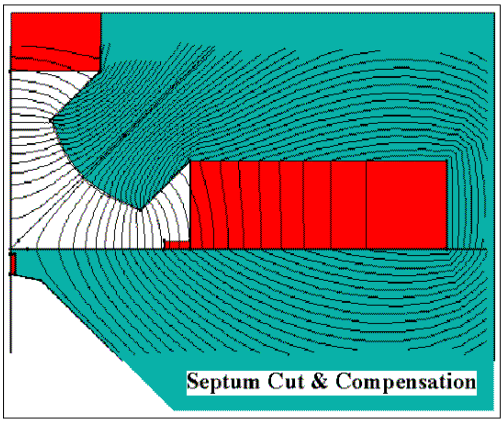

Figure 4: MSQ same as Fig. 2 but with correction coil in 2×8 mm cut. Return coil is mounted on mirror plate.

shaping purposes. The combined gap and septum cut acts as a knife edge for splitting the flux from the poles. Varying the angle of the cut away from the 45° example shown in Fig. 3 changes the balance of fields inside and outside the septum plate. With a smaller angle cut, the field distribution inside the magnet is more purely quadrupole; however, more field leaks into the region outside. A larger angle cut has the reverse effect with lower field outside but a poorer field quality distribution inside.

These qualitative observations are based on 2D calculations for a variety of septum geometries. However, even with repeated iterations reshaping and shimming the septum it is difficult to bring the field error, $\frac{\Delta B}{B}$, much below the few $\times$ 10^{-3} level. Also shimming is effective at only a single excitation level (not desirable for a magnet which ramps with beam momentum).

Our solution is to introduce a small trim coil as indicated in Fig. 4. Even a relatively small trim current, of the order of 10^{-3} of the main current, is adequate to achieve the desired 10^{-4} $\frac{\Delta B}{B}$. The trim coil performs like a current septum but with only amps of correction current instead of kiloamps of main current. Placement of the return coil is found not to be excessively critical as discussed in the next section.

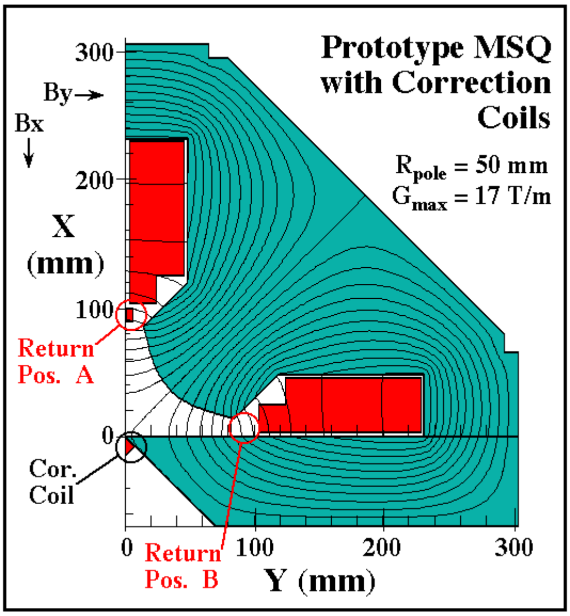

Figure 5: MSQ with 45° cut in 70 mm thick mirror plate mounted on half QC-type quadrupole. Correction coil is placed near center with possible return positions as indicated at points A and B.

3 PROTOTYPE-MSQ CALCULATIONS

Magnets have ends and calculation of end effects necessitates using 3D field-solvers which are difficult to use and yield results sensitive to input assumptions (i.e. B-μ curve). It was pointed out[5] that a way to gain experience with a 3D MSQ as quickly as possible would be to build a model magnet and directly test various septum/trim current configurations. With this approach we also gain early experience concerning important mechanical design and magnet assembly issues. For example having a thin (flimsy) septum plate suggests constructing rigid external/internal supports to keep the magnet from collapsing due to magnetic self forces.

Fortunately the rebuilding of HERA west for HERA-B, where 4 p-ring QC-type quadrupoles were removed, provides magnets for testing. These quadrupoles can be split in half and with a 1 m yoke length they are easy to handle. We plan to make a prototype-MSQ using a half-QC and have made detailed 2D calculations with this goal in mind.

An initial geometry assumed for the prototype MSQ is shown in Fig. 5. The prototype will be constructed using a 70 mm mirror plate having a 45° cut. Calculations have been made at high, medium and low excitation for a few correction coil scenarios for guidance in choosing the initial test configuration. In evaluating these results we use the ratio R(d) = [B_y(d)-B_x(d)]/B_x(d) as a convenient and sensitive measure of the effectiveness of the correction current. B_y(d) is the field perpendicular to the x-axis at a position y = 0, x = d and B_x(d) is the field perpendicular to the y-axis at the position x=0 and y = d. The ratio R(d) compares the field at equivalent positions of the x- and y-axes and for

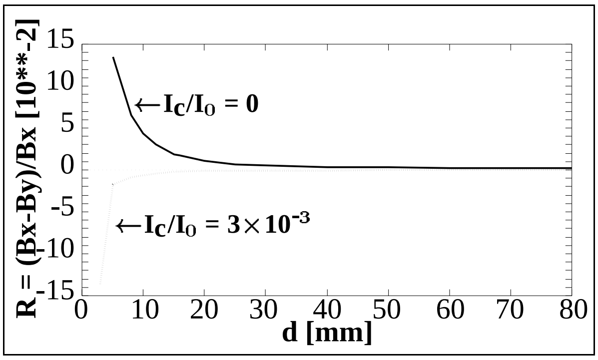

Figure 6: Field difference ratio R, in percent, as a function of distance from origin (coordinates as shown in Fig. 5).

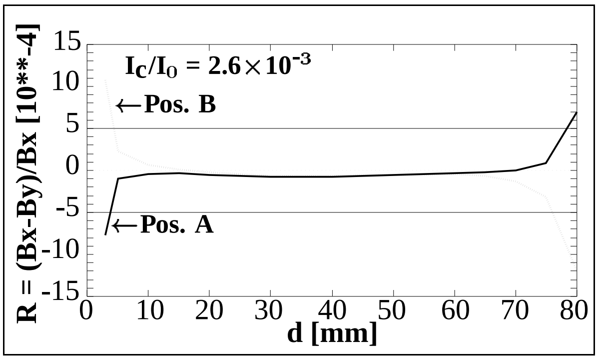

Figure 7: Field difference ratio R, in units of 10^{-4}, as a function of distance d from origin. A and B refer to positions shown in Fig. 5.

the case of a perfect quadrupole distribution R would be zero. The ratio R tends to highlight small field errors near the origin as shown in Fig. 6.

In Fig. 6 the upper curve is the result for R (in percent) for no correction current. Note that turning the correction current on, with a value of 3×10^{-3} of the main current, is more than enough to completely reverse the sign of R everywhere and thus an optimum correction value is slightly smaller. A better estimate for the correction current

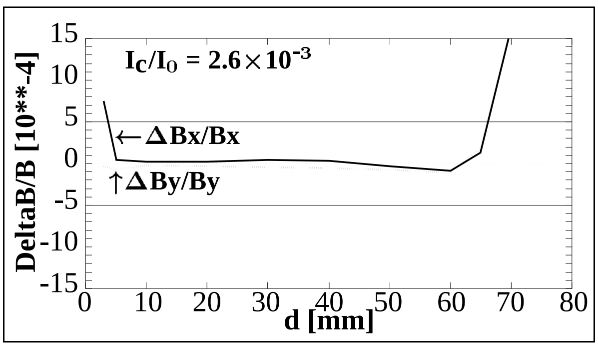

Figure 8: $\frac{\Delta \mathbf{B}}{\mathbf{B}} = \frac{\mathbf{B}-\mathbf{B}_I}{\mathbf{B}_I}$, in units of 10^{-4}, as function of distance from origin. $\mathbf{B_I}$ is field calculated for an ideal quadrupole given by $\mathbf{B_I}$(d) = Gradient$\times$d.

is shown in Fig. 7 where the scale is now expanded a factor of 100 (i.e. units of 10^{-4}). With 2.6×10^{-3} correction current, R is between $\pm5\times10^{-4}$ over the region d = 4 to 76 mm.

The two curves shown in Fig. 7 differ only in the positioning of the correction coil return path (locations A and B from Fig. 5). Moving the return from A to B reverses the shape of the R(d) curve and we find that configurations with return current split equally between A and B work the best; however, as a practical matter, results for all placements are adequate. We favor the B placement, on the septum plate, for magnet assembly reasons (i.e. simple coil support, independent of quadrupole yoke).

Since it may not be obvious that R(d) = 0 insures a proper quadrupole field distribution, in Fig. 8 we plot the actual $\frac{\Delta B}{B}$ distributions at the x- and y-axies. Note that $\frac{\Delta B}{B}$ is within $\pm1\times10^{-4}$ from 4 to 64 mm. For a final magnet specification, we would define tolerable multipole field errors with respect to the intended beam center.

The required correction current scales non-linearly with the main excitation. This is not so surprising in that at high field strength the main current also has a non-linear dependence due to saturation effects. The correction coil, to some extent, has also to correct for saturation. For a MSQ used in a HERA IR, such a non-linear correction current could be implemented via a lookup table in much the same way as is already done for other HERA corrector magnets. Ideally the values used in the table would be based on actual magnetic measurements.

4 CONCLUSIONS

We conclude that a MSQ with incorporated trim coil holds promise for providing selective focusing of spatially close particle beams. For applications, such as a beam transport line, where larger field errors (up to 10^{-3}) might be tolerable and/or only a fixed operating point (i.e. for injection beamline or forward particle detector) the trim coil could either be eliminated or combined in a shunt circuit with the main excitation. In a most extreme case it is conceivable to have a MSQ with an appreciable septum gap; however, with poorer field quality.

5 REFERENCES

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