

# HARMONIC CORRECTION RINGS FOR THE PEP-II I.R. QUADRUPOLE MAGNETS

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## Abstract

Two harmonic corrector ring magnet designs have been developed to correct field error harmonics generated by quadrupole magnets in the interaction region of PEP-II [1]. They consist of circular arrays of cylindrical permanent magnet pairs which can be both arbitrarily oriented and counter-rotated for strength. This arrangement allows the correctors to be tuned to generate a correction field with arbitrarily selected combinations of harmonics. These correctors are designed such that they can be pre-fabricated and then tuned after the quadrupole magnets have been built and their residual harmonic error content ascertained. The correctors can thus be used to cancel any residual combination of error harmonics in the completed quadrupoles.

## 1. GENERAL

The theory of harmonic corrector rings (HCRs) is a recent development which is described in mathematical detail in reference [2]. Harmonic correctors are an outgrowth of permanent magnet (PM) multipole theory which describes pure permanent magnet multipole magnets, usually constructed of fixed trapezoidal elements, with orientations which give the particular desired multipole field. [3]

These magnets are generally constructed from “analytic” material, i.e. samarium cobalt or neodymium-iron boron which is linear in the second quadrant of the B-H curve with  $\mu_r \cong 1$ . These structures can be immersed in high fields from adjacent magnets without being significantly affected. When combined with other PM structures, their fields superimpose nearly linearly.

While it is possible to utilize a series of multipole magnets to correct integrated multipole errors, it is expensive and the mix of multipoles in need of correction cannot generally be ascertained until the magnetic system to be corrected is built and measured.

## 2. A PRACTICAL APPROACH

To achieve a more practical mechanism, we use cylindrical magnet elements rather than the usual fixed trapezoidal segments of the standard PM multipole magnet. This immediately allows us to tune the magnet array to any harmonic N up to  $N=M/2$  where M is the

number of cylindrical elements. The magnitude of the generated harmonic depends on the number of elements M, the length of the elements L, the radius of the circular magnet array R and the radius of the individual cylindrical elements  $r_c$ .

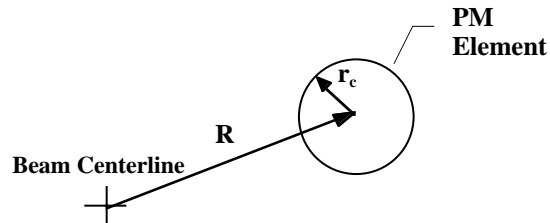


Fig. 1. Corrector array primary geometric variables.

We could now fix M, R and  $r_c$  and create a series of multipole corrector magnets whose strengths vary by the length of their respective elements. These arrays could be stacked together to produce a given desired corrector field. Since M, R and  $r_c$  are the same, at each element position we have a superimposed set of magnetic vectors which are equivalent to a single cylindrical PM element with a resultant orientation vector and a length which is in general not equal to the sum of the individual element lengths.

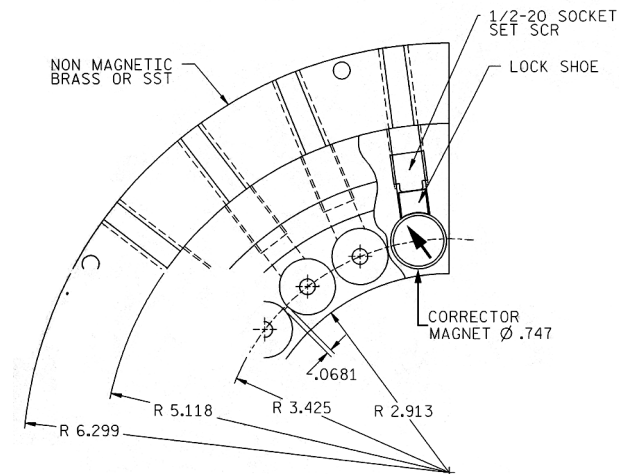


Fig. 2. One quadrant of Q1 HCR showing housing and locking mechanism. Dimensions are in inches.

Thus the stacked arrays could be replaced with a single array of unequal length PM cylinders having the same M, R and  $r_c$  as the original arrays. The final step in achieving a practical system is to now replace the unequal length single cylinder array with an array of pairs of same length cylinders. The two cylinders of each pair are placed end to end and counter-rotated to achieve the same integrated

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multipole field as the unequal length single cylinder array.

We now have a system that can be designed and built to accommodate the expected approx. error range of the field we desire to correct. The length of the corrector pairs can be fixed to provide a reasonable total harmonic capacity and the HCR can be tuned to provide the exact harmonic content required to correct the error fields immediately after magnetic measurements are performed.

Other practical geometries ( e.g., with coaxial inner PM cylinders and outer PM annuli ) are described in [2].

### 3. APPLICATIONS

#### Q1 Harmonic Corrector

In the B-Factory interaction region, harmonic correctors are applied to both the Q1 and the Q2 quadrupoles [4],[5]. The Q1 magnets are pure permanent magnet structures that reside in the solenoid field of the Babar detector. These are 24 element HCRs with an array radius  $R$  of 8.7 cm, an element radius  $r_c$  of 1.0 cm and a magnetic length of 6 cm.

The integrated correction capacity of this configuration is given in the graph of figure 3. This graph gives integrated capacity per harmonic per unit length of corrector element. To determine the total required corrector length for multiple error harmonics we add the lengths required to correct maximum expected individual harmonics. This graphical approach to capacity allows us to easily calculate the total required corrector length for any combination of error harmonics.

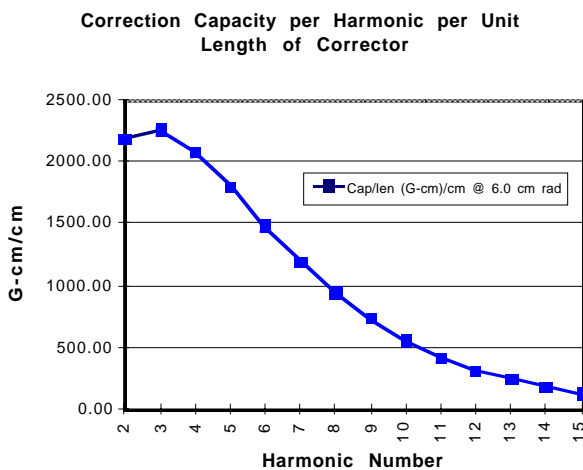


Fig. 3. Q1 HCR integrated correction capacity curve.

#### Feed-Down Harmonics

In the course of generating a corrector field, the harmonic corrector will also generate higher order feed-down harmonics. These are shown in figure 4 for the Q1 HCR configuration. They are represented in similar fashion to the corrector capacities, i.e., they are given as a function of generator harmonic per unit length of corrector.

The lowest order feed-down harmonic is the number of the lowest order corrector harmonic plus  $M$ , the number of elements in the corrector array. Thus for the Q1 HCR which has 24 elements, the lowest order feed-down harmonic possible is  $N=25$ . As is shown in figure 4, these feed-down harmonics are small and decay rapidly as  $r_p$ , the calculation radius, is reduced.

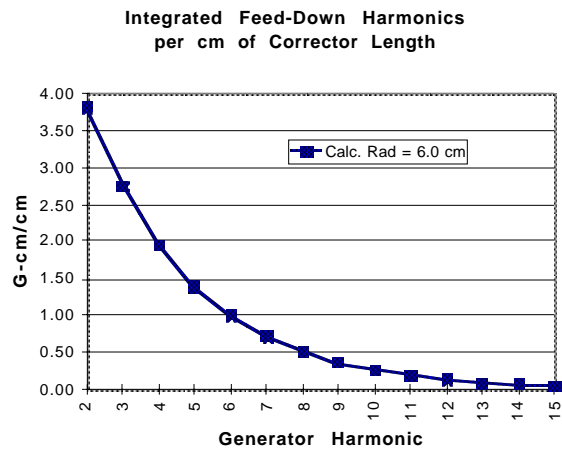


Fig. 4. Q1 HCR integrated feed-down harmonics.

#### Q2 Harmonic Corrector

The Q2 quadrupoles reside in the interaction region outboard of the Q1 quads. They are conventional electromagnets with rigorous field quality requirements. These magnets span the two converging beams of the accelerator with a high current density septum which isolates the high and low energy beams.

A two stage harmonic corrector ring is under development for use in conjunction with these magnets. The first stage or primary Q2 HCR is intended to correct residual field errors which are produced by the Q2 magnet. The secondary HCR is designed to correct harmonics that may be generated by interaction between the detector solenoid stray fields and the body of the Q2 magnet.

While all error harmonics could be corrected with a single HCR, installation logistics dictates that the Q2 magnets be tuned with the primary HCR prior to installation. The secondary HCR is adjusted and installed within a limited

time frame after solenoid effects on the installed Q2 are determined.

The Q2 HCRs are concentrically configured around the low energy beam and are enclosed by a cylindrical ferromagnetic shield which isolates their effect from the adjacent high energy beam.

Integrated correction capacity curves are shown in figure 5 for both correctors. The nominal dimensions of the Q2 HCRs are given in Table I.

Table I. Design Parameters for Q2 HCR.

	Primary	Secondary
Array Radius R cm	5.95	7.75
Element Radius $r_c$ cm	0.65	0.5
Number of Elements	24	24

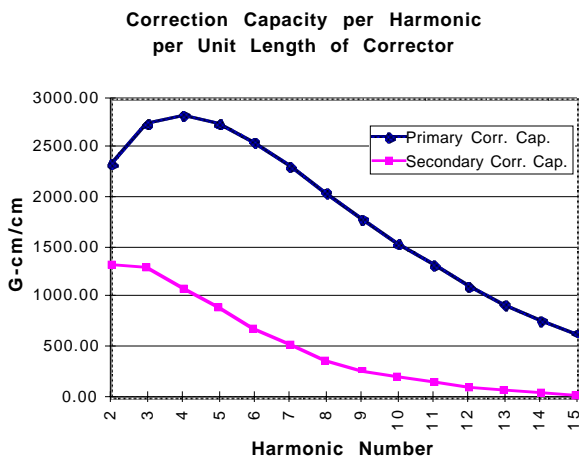


Fig. 5. Q2 HCR integrated correction capacity curves.

#### 4. MECHANICAL DESIGN

The mechanical design of the HCRs is relatively simple. The magnetic elements or cylinders must be contained in a non-magnetic housing which allows for tuning of the system by rotating the elements and locking them in position afterwards. Half of the aluminum housing for the Q1 HCR is shown in figure 6. A longitudinal retaining ring to prevent the escape of the magnets during tuning can also be seen in the figure.

A system of dual locking mechanisms can be seen in figure 2. After rotation to the appropriate orientation, individual magnetic elements are locked in place by redundant friction mechanisms which consist of a set screw which bears on a follower or shoe which in turn bears on the PM element. PM materials are inherently fragile and so the PM element is encased in a thin

stainless steel tube to prevent damage by the locking shoe.

A thin disk is bonded to the end of each element which has slotted features aligned to the transverse magnetization axis of the cylindrical element. This disk allows for positive engagement of an orienting tool and also protects the magnet.

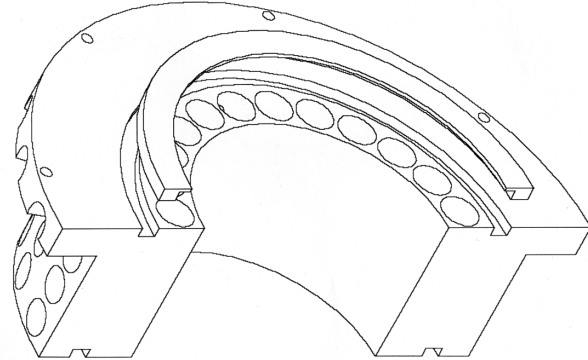


Fig. 6. Upper half of Q1 HCR housing and longitudinal retainer ring.

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