MULTI-FUNCTION CORRECTOR MAGNET

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Abstract

Storage rings require corrector magnets for a variety of tasks. Foremost are small dipole magnets for both horizontal and vertical correction. In light sources, for example, other corrector magnets are needed to compensate for the effect of changing insertion device operation points. These can include quadrupole, skew quadrupole, sextupole and skew sextupole corrections. As well octupole magnets may be desirable to improve dynamic aperture in small emittance lattices. One magnet can perform all these tasks. This is achieved by having separate windings with separate power supplies on an octupole yoke. The simultaneous excitation of any combination of modes can be achieved through superposition. Corrections are necessarily limited to avoid saturation effects that will degrade the superposition.

INTRODUCTION

To increase the performance of the Canadian Light Source (CLS) [1] additional quadrupole and sextupole magnets are being contemplated. Space is limited so the use of multifunction magnets is being considered. These magnets can be located at the position now occupied by X/Y corrector magnets. As well, the impact of insertion devices in the lattice can be reduced with multi-function magnets.

A Multi-function magnet has been modelled in 2D using POISSON. Initial modelling was done with a coil about each pole as shown in figure 1. Each coil had separate current control in order to excite different magnet modes. Also shown in the figure is an alternate coil configuration which gives essentially the same results. In this configuration there is only one coil in each gap between poles. This both reduces the current density in the coils and reduces the overall power requirements for multi-function operation. Seven magnet modes and the superposition of these modes are possible. The modes include horizontal and vertical steering correctors, normal and skew quadrupoles and sextupoles, and normal octupole.

For multi-function operation each coil requires a separate power supply resulting in eight power supplies for seven functions. [For limited functionality with some symmetry fewer power supplies could be considered.] In the discussion that follows each coil will be referred to by number. Coil 1 is the top-most coil. From there the coils are numbered in a clockwise sequence. The magnet discussed in this paper has an aperture radius of 37 mm. Coil dimensions are adequate to include water cooling.

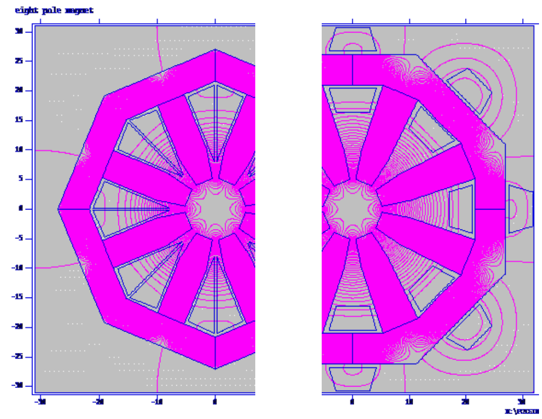

Figure 1: Cross section of eight pole magnet. Left: windings around each pole. Right: single winding between poles (final configuration). (Octopole mode)

INDIVIDUAL FUNCTIONS

Octopole Mode

In this mode each coil is excited with the same current and with the sign alternating from one coil to the next. In short hand: [+][-][+][-][+][-][+][-]. With a current of 2000 Amps in each coil the octopole field is 895 T-m^{-3}. Other harmonics contribute to a deviation from the ideal octopole. The field error at a radius of 10 mm is about 2%. This mode is shown in figure 1.

Quadrupole and Skew Quadrupole Modes

For the quadrupole mode the even numbered coils are not used. The configuration is: [+][0][-][0][+][0][-][0]. With a current of 2000 Amps the quadrupole field is -1.18 T-m^{-1}. This mode is shown in figure 2. A skew quadrupole is achieved by rotating the coil currents by one coil: [0][+][0][-][0][+][0][-]. In this mode the field error is about 0.1% at 10 mm as shown in figure 3.

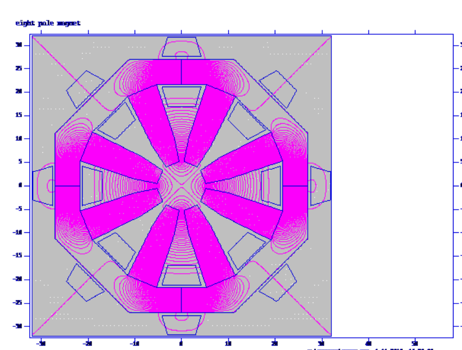

Figure 2: Quadrupole mode. The coils inside the field lines are used. A skew quadrupole is achieved by rotating the coil excitation one coil.

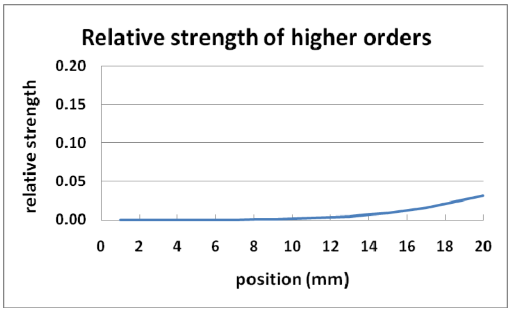

Figure 3: Field error in the quadrupole mode. The relative strength of the sum of all higher order modes is shown.

Sextupole and Skew Sextupole Modes

In the sextupole mode the top and bottom coils are not used. The side coils have the maximum current. To get the best sextupole field the coils flanking the null coils are run at 70.7% (sin 45). The coils configuration is now [0][-.707][+1][-.707][0][.707][-1][.707]. With 2000 Amps as the maximum current the sextupole field is 23.1 T-m^{-2}.

The sextupole fields are shown in figure 4 and the field error in figure 5. The field error at 10 mm is about 5%. This error can be reduced somewhat by suppressing the quadrupole and octopole components by superimposing the appropriate fields. A skew sextupole is achieved by rotating the coil excitation by one coil given a coil configuration of [.707][0][-.707][+1][-.707][0][.707][-1].

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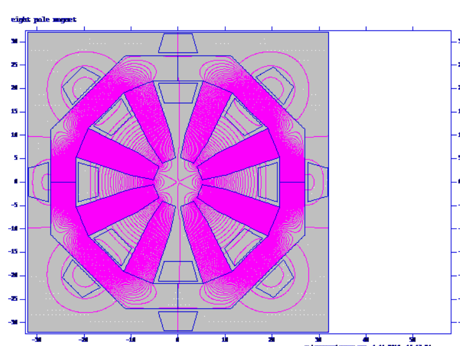

Figure 4: Sextupole mode. The top and bottom coils are not used. A skew sextupole is achieved by rotating the coil excitation.

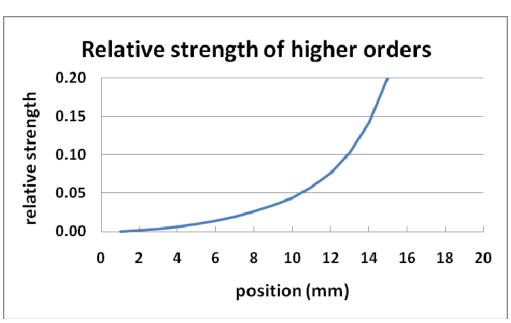

Figure 5: Sextupole mode field error.

Horizontal and Vertical Corrector Modes

Crudely the horizontal corrector mode is produced with the coil configuration: [0][0][+][0][0][-][0][0]. With this excitation pattern a strong sextupole components accompanies the vertical field produced. The sextupole component can be removed by superimposing the appropriate negative sextupole field. The coils are: [0][.682][1][.682][0][-.682][-1][-.682].

Using 2000 Amps for the maximum coil excitation a vertical field of 0.062 T is produced. The horizontal corrector (vertical field) is shown in figure 6. The field quality is excellent as shown in figure 7. A vertical corrector (horizontal field) is achieved by rotating the coil configuration by two coils. (For the 2.9 GeV CLS a 0.05 m long corrector at 0.06 T would produce a 0.3 mrad kick.)

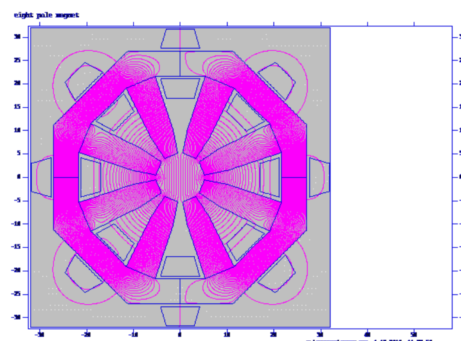

Figure 6: Horizontal corrector (vertical field) mode. Coils are excited in such a way as to minimize the sextupole field.

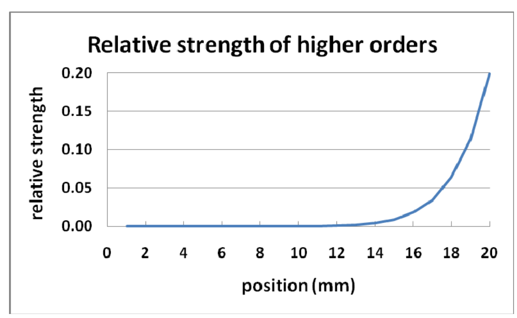

Figure 7: Corrector mode field error.

MULTI-FUNCTION MAGNET

A summary of the coil configurations is given in Table 1. Also included in the table are the field strengths that can be achieved with a maximum current of 2000 Amps. [Note: 2000 Amps actually means Amp-turns. The coils shown in this report can accommodate about 40 turns of water cooled conductor.]

Operating as a multi-function magnet the individual modes described above are superimposed. When this is done all symmetry among the coil excitations is lost. (Consequently individual power supplies for each coil are required.) The total current delivered to any coils must be limited in order to avoid saturation of the magnet.

Various possible multi-function configurations have been investigated. Magnet saturation is avoided and the desired multipole modes preserved if the maximum current in any coil is limited to 7000 Amps.

Table 1: Summary of coil configurations and field strengths for 2000 Amp (max) excitation. For sextupole modes # = 0.707. For corrector modes # = 0.682.

Mode	Coil configuration	Field
Oct.	[+][-][+][-][+][-][+][-]	895 T-m^{-3}
Quad.	[+][0][-][0][+][0][-][0]	1.19 T-m^{-1}
Skew quad.	[0] [+][0][-][0][+][0][-]	"
Sext.	[0][-#][+1][-#][0][#][-1][#]	23.1 T-m^{-2}
Skew sext.	[#][0][-#][+1][-#][0][#][-1]	"
X corr.	[0][#][1][#][0][-#][-1][-#]	0.062 T
Y corr.	[-1][-#] [0][#][1][#][0][-#]	0.062 T

Multi-function Results

An example of a multi-function setup is shown in figure 8. In this example an octopole, a sextupole, a quadrupole and a horizontal (X) kick are superimposed. For the first three modes a maximum field of 2000 Amps is considered. For the X kick the maximum current is 1060 Amps. Summing the current contributions in each coil gives a maximum coil current of 4000. Overall I = [4000][-2724][3020][-2724][4000][-1276][-3020][-1276].

The resulting field is shown in figure 8. A comparison of the single function fields and the multi-function fields is shown in table 2. In the multi-function mode the single fields are reproduced with little error. In this example the maximum coil current is 4000 Amp-turns.

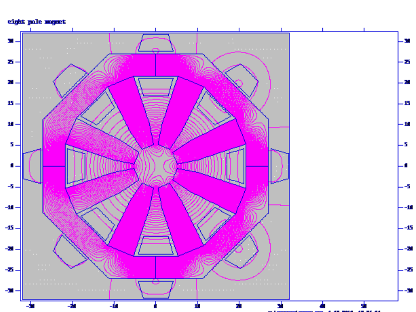

Figure 8: Superposition of four modes: octopole, sextupole, quadrupole and X-corrector.

Table 2: Comparison of fields generated in multi-function mode with fields generated as single fields.

Mode	Single field value	Multi-field value
Oct.	894 T-m^{-3}	895 T-m^{-3}
Quad.	1.20 T-m^{-1}	1.19 T-m^{-1}
Sext.	23.3 T-m^{-2}	23.1 T-m^{-2}
X-corr.	0.031 T	0.031 T

APPLICATIONS

Corrector/ Quadrupole / Sextupole

Some CLS XY orbit correctors in the 2.9 GeV CLS lattice could be replaced with a multifunction magnet in order to have additional quadrupoles and sextupoles. The existing orbit correctors are 0.15 m long and are used to produce horizontal and vertical kicks of about 0.25 mrad. Consequently coil excitations up to 1000 Amp-turns are required for each of the correctors. About 5000 Amp-turns are available for either a quadrupole mode or sextupole mode. In either case a quadrupole or sextupole could be available with strengths about 10% of the existing lattice elements. Preliminary studies of the CLS lattice have indicated small sextupole corrections could increase the beam lifetime.

Multi-function Corrector for EPUs

Elliptically polarizing undulators (EPUs) require steering corrections, quadrupole corrections, and sextupole corrections. Corrector strengths are typically small. A study [2] of EPUs for the CLS indicates quadrupole strengths of k_1L = 0.01 m^{-1} are required. This could be achieved with a magnet of length 0.05 m with 3200 Amp-turns excitation. As well, off-axis tune shifts can be corrected with modest skew or normal sextupoles depending on the mode of operation of the EPU. A layout of the multi-function magnet at one end of an EPU array is shown in figure 9. Correction can be done with one or two magnets. An alternative approach is current strips distributed on the EPU vacuum chamber [3][4]. For such setups a multi-function approach could be considered.

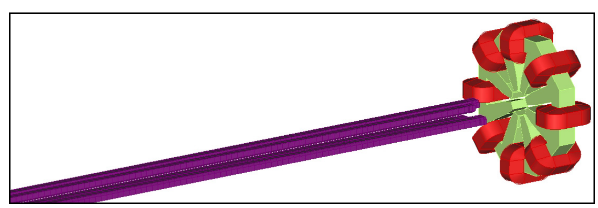

Figure 9: Multi-function corrector magnet shown at the end of an EPU array.

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[3] J. Bahrdt, W Frentrup, A. Gaupp, M. Scheer, G. Wuestefeld, "Active Shimming of the Dynamic Multipoles of the BESSY UE112 APPLE Undulator", EPAC08, p 2222.

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