DESIGN AND MEASUREMENT OF THE NSLS II CORRECTORS*

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Abstract

Discrete corrector magnets are used for the 230 horizontal and vertical steering magnets in the NSLS-II storage ring. A unique design incorporates both dipole and skew quad correctors for (DC) steering in the same magnet. Separate AC (orbit feedback) correctors have also been designed. Comparison with alternate designs are presented as well as prototype measurements.

INTRODUCTION

The National Synchrotron Light Source II (NSLS-II) under construction at Brookhaven National Laboratory will be a new state-of-the-art 3 Gev electron storage ring designed to deliver world-leading intensity and brightness, and will produce x-rays more than 10,000 times brighter than the current NSLS at Brookhaven. The 792-meter circumference storage ring is comprised of approximately 1000 magnetic elements, 300 of which are discrete corrector magnets. The three variants are: 120 of the 100 mm aperture correctors, 60 of the 156 mm aperture correctors, and 90 of the air core correctors.[1] The 100 mm and 156 mm horizontal and vertical dipole correctors come in two varieties: with and without a DC skew quad corrector. The air core is strictly an AC horizontal and vertical dipole corrector. The specifications are listed in Table 1.[2]

Table 1: Corrector Magnet Parameters.

Description	100 mm	156 mm	Skew Quad 100/156	Air Core
Aperture[mm]	100	156	65/97	30
DC Operating Field [T]	0.0400	0.0294	-	-
AC Operating Hor. Field [T]	-	-	-	0.0020
AC Operating Vert. Field [T]	-	-	-	0.0036
Field Gradient Skew Quad [T/m]	-	-	0.46	-
Iron Yoke Length [mm]	150	100	-	-

INITIAL DESIGN

The correctors needed for the operation of the NSLS-II ring were: dipole horizontal corrector, vertical corrector, skew quadrupole corrector, and an AC horizontal and vertical dipole corrector. But girder space in the NSLSII ring was at a premium. The cost of the magnets, power supplies, and controls was also a consideration. The solution was to combine all five correctors into one magnet. The initial design of this DC/AC combined function magnet corrector was a challenging task.

The stringent field requirements needed a unique and innovative design . A short length in the longitudinal direction was necessary to minimize their girder space. The large apertures were necessary to clear the large vacuum flanges. The 156 mm aperture correctors are located over stainless steel bellows at either end of a dipole. The 100 mm aperture correctors are located over the aluminum vacuum chamber in the matching sections of the cell. There are four 156 mm and two 100 mm correctors per cell. The design had to incorporate a skew quadrupole coil where needed. The 100 mm corrector is strictly a DC magnet while the 156 mm would handle the DC and AC tasks

COMBINED FUNCTION CORRECTORS

After much thought and many iterations, a feasible 2D magnet design was produced. The correctors are operated with 3 bi-polar power supplies, one for vertical field, one for horizontal field., and one for the skew quadrupole. There are eight coils that make up the corrector (see Fig. 1) . Coil pair 1 produces the vertical field, coil pairs 2 and 3 produce a horizontal field while coil pair 4 produces the skew quadrupole field. The good field region (GFR) is ± 15 mm horizontally and ±10 mm vertically. (see Fig. 1)

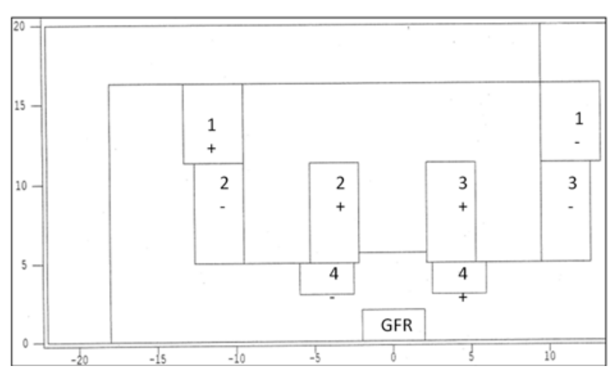

Figure 1: 2D 156mm corrector design - top half only.

The horizontal field corrector proved to be the challenge. Looking at the poles, the horizontal flux tended to be shorted by the center pole (see Fig. 1). By pushing the center pole back approximately 5 mm for the 156 mm aperture and 10 mm for the 100 mm aperture, the horizontal field quality improved tremendously. Figures

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2 through 4 show the 2D flux patterns for the all three configurations.

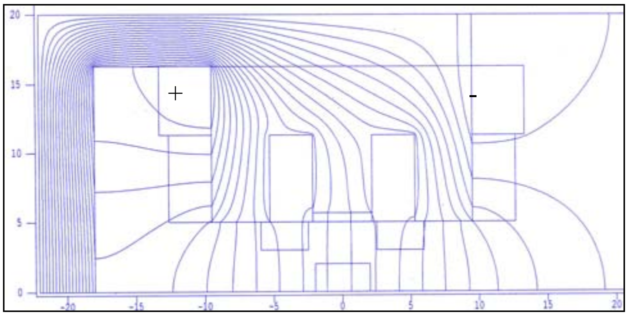

Figure 2: Vertical field corrector.

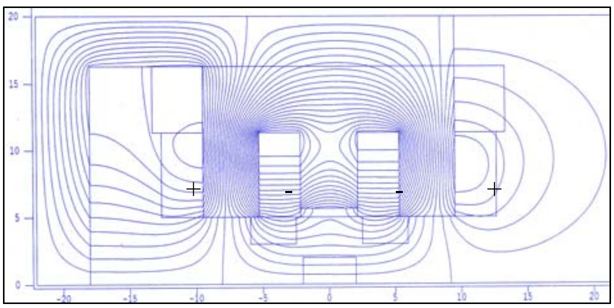

Figure 3: Horizontal field Corrector.

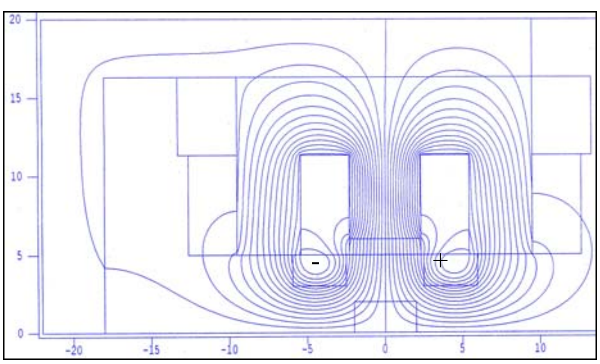

Figure 4: Skew quadrupole corrector.

3D DESIGN

Tosca 3D models were created. (see Fig. 5 and 6). The field quality for the dipole horizontal and vertical field correctors and the skew quadrupole is of the order of 1% and a 20% in a good field region (GFR). The operating current is a nominal 15A.

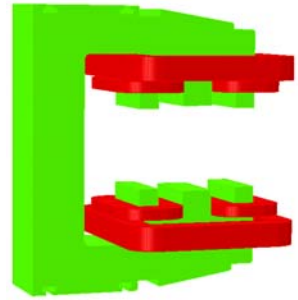

Figure 5: 3D Design- 156mm corrector without the skew quadrupole coils.

Integrated field maps normalized to the integral field at x=0,y=0 for the 100 mm and 156mm correctors show that the field quality meets the specifications. Only the 156 mm horizontal and vertical field maps are shown below (see Tables 2 and 3)

Table 2: Horizontal Field Map.

Integral Bx/Bx0 [Percent]

Horizontal [mm]

Vert. [mm]	-15	-10	-5	0	5	10	15
-10	0.48	0.11	0.12	0.25	0.28	0.22	0.04
-8	0.63	0.23	0.03	0.16	0.19	0.12	0.09
-6	0.75	0.32	0.05	0.09	0.12	0.04	0.19
-4	0.84	0.39	0.11	0.04	0.07	0.02	0.26
-2	0.89	0.43	0.14	0.01	0.04	0.06	0.30
0	0.90	0.44	0.15	0.00	0.03	0.07	0.31
2	0.89	0.43	0.14	0.01	0.04	0.06	0.30
4	0.84	0.39	0.11	0.04	0.07	0.02	0.26
6	0.75	0.32	0.05	0.09	0.12	0.03	0.19
8	0.63	0.23	0.03	0.16	0.19	0.12	0.09
10	0.48	0.11	0.12	0.25	0.28	0.22	0.04

Table 3: Vertical Field Map.

Integral By/By0 [Percent]

Horizontal [mm]

Vert. [mm]	-15	-10	-5	0	5	10	15
-10	0.29	0.10	0.04	0.12	0.14	0.10	0.01
-8	0.32	0.14	0.00	0.08	0.10	0.06	0.03
-6	0.35	0.17	0.03	0.04	0.06	0.03	0.06
-4	0.37	0.19	0.06	0.02	0.04	0.01	0.08
-2	0.39	0.20	0.07	0.00	0.03	0.01	0.09
0	0.39	0.21	0.08	0.00	0.02	0.01	0.09
2	0.39	0.20	0.07	0.00	0.03	0.01	0.09
4	0.37	0.19	0.06	0.02	0.04	0.01	0.08
6	0.35	0.17	0.04	0.04	0.06	0.03	0.06
8	0.33	0.14	0.00	0.08	0.10	0.06	0.03
10	0.29	0.10	0.04	0.12	0.14	0.10	0.01

PROTOTYPE MEASUREMENTS

The prototype each of the 156 mm and 100 mm designs was produced. The prototypes were measured at BNL for DC field quality as well as AC performance up to 1 khz. They were found to meet the specifications.

ALTERNATE CORRECTOR DESIGN

The design is somewhat complicated by the power supply and controls requirements. Though the prototypes performed well, a study was begun to simplify this corrector. An alternate design began in earnest. The idea was to separate the DC and AC function of the 156 mm corrector. The lattice was changed slightly to accommodate this. In the initial design, there were four of the 156 mm correctors and two of the 100 mm correctors. Now there would be four of the 100 mm correctors and only two of the 156 mm correctors per cell. A separate AC corrector had to be addressed. An alternate design of the AC horizontal and vertical dipole corrector was produced.. The 156 mm is now foreseen as a strictly DC magnet while the 100 mm DC corrector remains unchanged. Two designs were considered: a window frame magnet and a simple air core consisting of four coils. Models of both were produced and compared.

The air core corrector was chose due to its simple design, small profile 60mm length), short fringe field, and low cost. The air core corrector consists of four coils wrapped around the vacuum chamber (see Fig. 6).

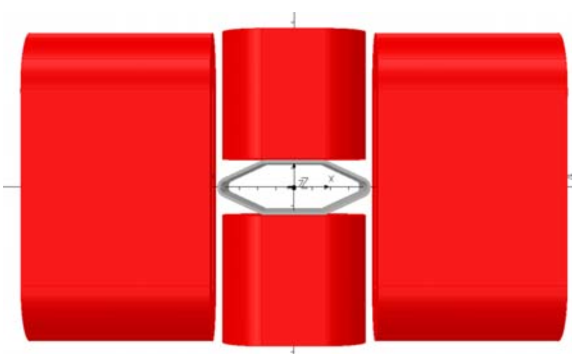

Figure 6: Air Core Corrector.

Its specifications are given in Table 1. The air core was modeled. The sizes of the coils were adjusted to achieve the desired specification. The integrated field maps of the horizontal and vertical air core correctors showing the percent variation are found in Tables 4 and 5.

Table 4: Horizontal field corrector map.

Integral Bx/Bx0 [Percent]

Vert [mm]	Horizontal [mm] -15	-10	-5	0	5	10	15
-10	5.67	0.43	2.62	4.09	4.12	2.52	1.33
-8	7.96	2.10	1.23	2.67	2.41	0.24	4.52
-6	9.63	3.38	0.13	1.53	1.01	1.63	7.06
-4	10.69	4.24	0.64	0.69	0.05	3.08	8.98
-2	11.15	4.64	1.05	0.18	0.76	4.06	10.30
0	11.01	4.59	1.10	0.00	1.09	4.59	11.01
2	10.29	4.06	0.76	0.18	1.05	4.64	11.14
4	8.98	3.08	0.06	0.69	0.64	4.24	10.69
6	7.07	1.64	1.01	1.53	0.13	3.38	9.63
8	4.53	0.24	2.41	2.68	1.22	2.11	7.96
10	1.34	2.52	4.12	4.08	2.62	0.43	5.67

Table 5: Vertical field corrector map.

Integral By/By0 [Percent]

Vert. [mm]	Horizontal [mm] -15	-10	-5	0	5	10	15
-10	17.42	10.65	5.54	0.91	4.18	10.70	19.75
-8	13.88	8.57	4.42	0.58	3.72	9.25	16.80
-6	10.06	6.31	3.26	0.32	3.06	7.48	13.43
-4	6.08	3.94	2.07	0.14	2.24	5.44	9.78
-2	2.05	1.51	0.90	0.03	1.28	3.23	5.94
0	1.98	0.90	0.23	0.00	0.22	0.89	1.98
2	5.94	3.23	1.29	0.03	0.90	1.52	2.04
4	9.78	5.45	2.24	0.14	2.07	3.94	6.08
6	13.43	7.48	3.06	0.33	3.26	6.31	10.06
8	16.80	9.25	3.72	0.58	4.42	8.57	13.88
10	19.74	10.69	4.18	0.91	5.54	10.65	17.42

ACKNOWLEDGEMENTS

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[1] J. Skaritka, "The Design and Construction of NSLS II Magnets.", MO6PFP008 PAC '09

[2] J. Skaritka, et al, Specifications for Design, Engineering, Manufacture, and Testing of Corrector Magnets for the NSLS-II Synchrotron., LT-SPC-SR-MG-CRR-001.