PROGRESS OF A GRADIENT DAMPING WIGGLER OF THE ALPHA STORAGE RING

C. W. Huang, D. J. Huang,
Department of Physics, National Tsing Hua University, Hsinchu 30043, Taiwan
C. S. Hwang, M. H. Huang, C.Y. Kuo, S.D. Chen, Y.T. Yu, F. Y. Lin, C. H. Chang,
NSRRC, 101 Hsin-Ann Road, Hsinchu Science Park, Hsinchu 30076, Taiwan
S. Y. Lee, Department of Physics, Indiana University, USA

Abstract

The main purpose of a gradient damping wiggler (GDW) to be installed in the Alpha storage ring in Indiana University is to correct the momentum-compaction factor and the damping partition in the Alpha storage ring. One middle pole and two outer poles in one set of the GDW are installed on the same girder. Two sets of GDW will be installed in the two short straight sections. The dipole and gradient-field strengths of the middle (outer) pole are 0.67 T (-0.67 T) and 1.273 T m^{-1} (1.273 T m^{-1}), respectively. One completed set of GDW is already fabricated; we shall add an end shim to improve the region of effective good field within which the middle and outer poles along the transverse x-axis ($\triangle B/B = 0.1$ %) are +/-50 and +/-40 mm respectively. We used a trim coil on the three poles to adjust the first and second integral fields to zero. Here we discuss the integral magnetic field features along the straight trajectory and the ideal orbital trajectory with a Hall probe mapping system, and present an analysis of the magnetic field.

INTRODUCTION

A cooler injector synchrotron (CIS) for the Indiana University Cyclotron Facility (IUCF), built in 1998 and decommissioned in 2002, accelerated a proton beam from 7 to 240 MeV. After its decommissioning, some elements of CIS, including four dipoles and a RF cavity, were stored in a warehouse. To facilitate projects on inverse Compton scattering with an x-ray (ICSX) source and some radiation experiments for NASA, these elements were recalled to construct a new ring called Alpha storage ring. This storage ring is formed with four dipoles of CIS; its total circumference is 20 m. A problem that might cause the Alpha storage ring to be unstable is that these four dipoles of CIS combine magnets that have a vertical focusing effect at the end 12^{o} edge, causing the damping partition number to become negative. Four methods to solve this problem are (1) to rebuild the main dipole magnets, (2) to use Robinson wigglers, (3) to add focusing quadrupoles, and (4) to add a gradient damping wiggler. As a result of simulation, we decided to add two sets of damping wigglers opposite each other in the straight section of the storage ring; they adjust the damping partition number effectively and more cheaply than other methods [1].

In this paper we discuss the design concept and the construction of a gradient damping wiggler, and present an analysis of results of measurements and the solution of special problems of this gradient damping wiggler.

DESIGN CONCEPT AND CONSTRUCTION OF DAMPING WIGGLER

The electron beam circulates counter-clockwise in the Alpha storage ring. Using a gradient damping wiggler to vary the radius of the electron beam and the ratio of the quadrupole and dipole terms, the dispersion function in the four dipole magnets can be corrected. Three combined function dipole magnets in one set serves as the gradient damping wiggler (GDW) which include one middle pole and two outer poles on the same girder. The GDW is a C-type magnet with coils of two kinds for each pole; one is the main coil that provides the main current, and the three main coils of the dipole poles are charged with the same power supply. Another is a trim coil that provides the current to correct the first-order or second-order integral magnetic field of the electron beam orbit. The main coils are made from copper with a square profile 5.6 ×5.6 mm^2 and with a coolant orifice of diameter 3 mm. The direction of the field of the middle pole (D_m) is upward, with a widened gap on the inside; the middle pole gap at magnet centre is 40 mm. The magnetic field of the outer pole (D_o) points downward and the widened gap is on the outside; the outer pole gap at magnet centre is 35.87 mm. The dipole and gradient-field strengths of the middle (outer) pole are 0.67 T (-0.67 T) and 1.273 T/m (1.273 T/m), respectively. The specific parameters of the damping wiggler appear in Table 1.

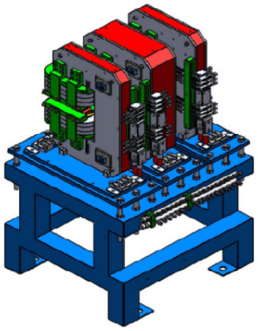

Figure 1: Schematic drawing of the GDW

Table 1: Specifications of the damping wiggler

Type	Middle pole (D_M)	Outer pole (D_O)
Total straight section	2	
Magnet numbers of each straight section	1	2
Magnet gap /mm	40	35.87
Dipole field strength B_0 /T	0.167 to 0.67	-0.167 to -0.67
Gradient field strength B_1 /T m^{-1}	0.317 to 1.273	0.317 to 1.273
(d*B*/dx) / B m^{-1}	1.9	-1.9
Ramping frequency /Hz	1	1
∫*B*ds /T m	0.134	-0.067
∫B_1ds /T	0 to 0.2546	0 to 0.1273
∫B_1ds /∫*B*ds	1.9	1.9
∫*B*ds /G cm of one D_M and two D_O	0	
∫∫*B*dsds' /G cm^2 of one D_M and two D_O	0	
Region of effective region along the horizontal transverse *x*-axis /mm with Δ*B*/*B*=0.001	±50	±40

We used TOSCA and RADIA software codes to simulate the magnetic-field performance of the GDW but a problem arose that, if the curve of a pole profile is simulated as a straight wire, it causes the sextupole term to become too large. To solve this problem, we added an inverse sextupole term into the function of the curve. The pole profile combines $3x^2y - y^3 = R$ and $y = (2Q/w)x$ to produce the dipole and quadrupole fields. Q is adjusted for the ratio B_1/B_0 and varying pole R can modify the region of effective field [2]. Another problem about that region of the integral magnetic field is that it can be improved by means of an iron-shimming algorithm at both ends, called end shims. To treat this problem, we try to add end shim of varied size. Figures 2 and 3 show that the region of the defined effective good field of the outer and middle pole is improved after this correction.

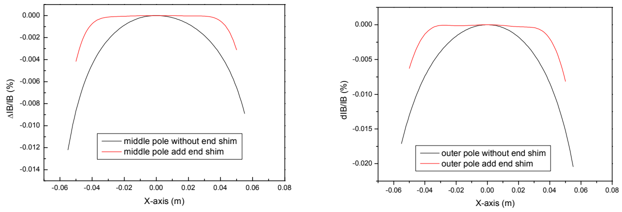

Figure 3: Region of effective good field of the middle pole and outer pole with and without end shim. (Where ΔIB/IB is defined $\int B - [B_0 + B_1 x]ds \Big/ \int Bds$)

The GDW was made from a piece of silicon steel of thickness 0.5 mm; a glue (3M 2216 B/A Translucent) that was applied to the surface of the piece of silicon steel has a characteristic working life 2 h to hold each piece of steel with an oil-pressure machine. We then placed the entire silicon steel into the oven and cured it for 240 min at 66 °C. We used a wire cutter to cut the entire silicon steel and clipped two stainless-steel sheets at both sides of the silicon steel. We next installed the trim coil and the main coil that were fixed on the pole with a hook of fibre glass. To avoid the coil heating, 12 water tubes are in contact with the end of the coil in one pole; all water pipes will be connected into the same cooling system with one inlet and one outlet.

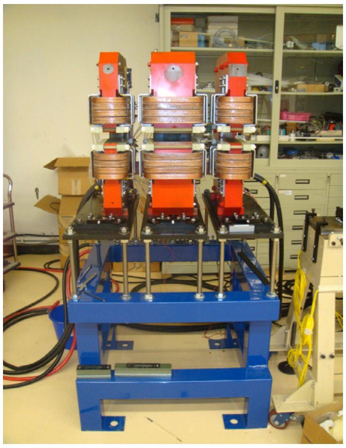

Figure 4: One set of GDW includes three dipoles on the same girder.

MEASUREMENT DATA FOR THE GRADIENT DAMPING WIGGLER

We constructed one set of GDW including power supply and cooling systems, and we set up an automatic measurement using a Group3 Hall probe (model MPT-141) and a highly precise *x*-*y*-*z* table. This Hall probe has precision ±0.01 % of reading ±0.006 % of full-scale maximum at 25 °C. Before measurement of the magnetic field of the GDW, we calibrated the Hall probe with a nuclear-magnetic-resonance (NMR) system; its advantages are that it is unaffected by room temperature and that it measures the magnetic field with great precision, but it is inconvenient to measure a magnetic field with increasing field strength. As the resonance frequency varies with the magnetic field, a separate NMR probe must be applied to each range of magnetic field. The center point of the middle pole is set as the origin. We measured the region of magnetic field from 50 mm to -50 mm on the transverse axis (*x*-axis) and from 550 mm to -550 mm on the longitudinal axis (*z*-axis), with excitation current from 0 to 160 A. The normal field 0.67 T is operated at 149.14 A. We measured the magnetic field and adjusted concurrently the trim coil operating current to ensure that the first- and second-order integral magnetic fields are less than 20 G cm and 2500 G cm^2, respectively. When electron beam passes through the GDW, the trajectory of electron beam shifts about 40 mm on the *x*-axis. To make the total orbit of the ideal electron beam in the region of effective good field, we shifted the GDW to be distant from the ring center by 17.5 mm. Table 2 presents the exciting trim coil with varied operating current of the main coil. Figure 4 shows that the field strength of the dipole and quadrupole terms varies with excitation current. The magnet field strength of the outer pole becomes a little saturation beyond 120 A. The normal field 0.67 T was obtained at excitation current 149.14 A. In the specifications of the GDW, the regions of effective good field of the middle and outer poles that degrade less than 0.1 % must be ± 55 mm and ± 40 mm (including the center region and the first- order integral magnetic field).

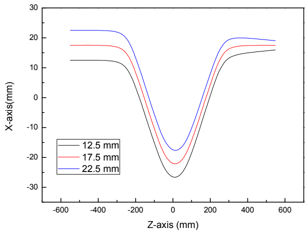

Figure 2: Trajectory of the electron beam with varied *x*-axis position and the focusing effect at the end of GDW

Table 2: Exciting trim coil current with varied operating current of the main coil

main coil current/A	middle pole trim coil current /A	outer pole trim coil current /A	1st order integral B-field /G cm	2nd order integral B-field /G cm^2
160	9.85	10	8	-900
150	5.9	4.5	27	-600
120	-2.75	-3.5	79	-700
90	-3.85	-5.1	132	1500
60	-2.85	-3.5	14	-2400
30	-1.35	-1.2	-40	-2300
0	0.2	1.45	-83	-2000

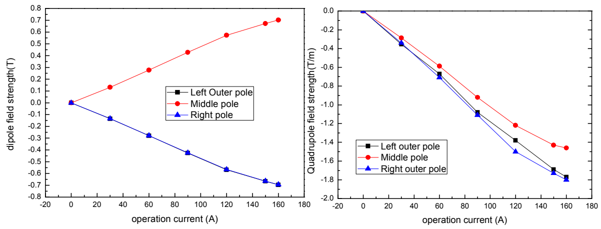

Figure 4: Dipole terms of three poles with varied exciting current (left), and sextupole terms (right). The outer pole becomes saturated with exciting current more than 120 A.

Figure 5 shows the center regions of the middle and outer poles. Adding an end shim does not affect the region of effective field of the middle pole, but extends both sides of this region of the outer poles. Figure 6 shows the region of effective good field of the measured integral field of the GDW with and without an end shim. When we added an end shim at both side of the poles, the region of effective integral good field of the middle and outer poles are extended 10 mm along the *x*-axis.

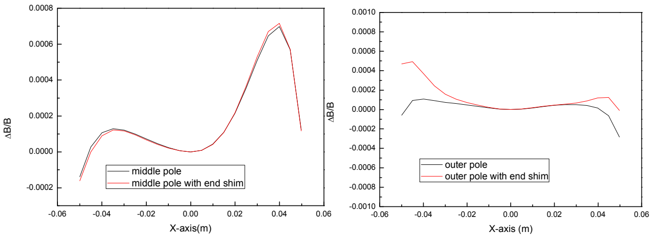

Figure 5: Regions of effective good field of middle and outer poles with or without an end shim (Where ΔB/B is defined $B-[B_0+B_1x]/B$)

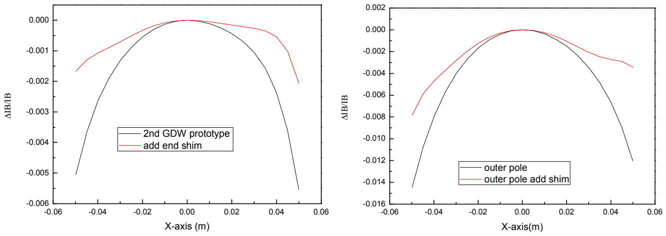

Figure 6: Regions of effective good integral field of middle and outer poles with or without an end shim. (Where ΔIB/IB is defined $\int B-[B_0+B_1x]ds \Big/ \int Bds$)

CONCLUSION

The pole profile combines $3x^2y-y^3=R^3$ and $y=(2Q/w)x$ to produce the dipole and quadrupole fields; Q is adjusted for the ratio B_1/B_0 and varying pole R modifies the regions of effective good field. The dipole and gradient-field strengths of the middle (outer) pole are 0.67 T (-0.67 T) and 1.273 T m^{-1} (1.273 T m^{-1}), respectively. To set the total trajectory of the ideal electron beam in the region of effective good field, we shifted the initial position 17.5 mm from the original position along the *x*-axis, then adjusted the exciting current of the trim coil to correct the first- and second-order integral magnetic fields, adding an end shim on both sides of the poles to correct the region of effective integral good field. One set of GDW including a girder has been constructed and measured, and will be packaged and sent to Indiana University. In the near future, we shall set up the GDW in the ALPHA storage ring and have a trial run of the machinery.

REFERENCES

[1] Lee SY, Kolski J, Liu Z, X. Pang, C. Park, W. Tam, and F. Wang "Low energy electron storage ring with tunable compaction factor", Rev. Sci. Instr. **78**, 075107 (2007)

[2] Z. W. Huang, D. J. Huang, C. S. Hwang, M. H. Huang, C.Y. Kuo, S.D. Chen, Y.T. Yu, F. Y. Lin, S. Y. Lee, "The Development of Gradient Damping Wiggler for ALPHA storage ring." IPAC'10, Kyoto, Japan