THE DEVELOPMENT OF GRADIENT DAMPING WIGGLER FOR ALPHA STORAGE RING

Z. 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,
NSRRC, 101 Hsin-Ann Road, Science Industrial Park, Hsinchu 30076, Taiwan
S. Y. Lee, Department of Physics, Indiana University ,U.S.A

Abstract

A novel gradient-damping wiggler (GDW) was developed for the ALPHA storage ring at Indiana University. The GDW will be used to vary effectively the momentum-compaction factor and the damping partition in the ALPHA storage ring. One middle pole and two outer poles that have a gradient field were assembled together on the same girder as a full set for a GDW magnet system. 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, but the integral $\int[(dB/dx)/B]ds = 1.9m^{-1}$ is kept constant. The magnet gaps of the middle and outer poles are 40 and 35.87 mm, respectively; the three combined functions of the dipole magnet can be charged with the same power supply. There is a trim coil on the three poles to adjust the first and second integral fields to zero. The region of effective field of the middle and outer poles along the transverse x-axis ($\Delta B/B$=0.1 %) are ±50 and ±40 mm respectively. After fabrication of a prototype GDW magnet, a Hall probe was used to measure the magnetic field to verify the design and construction performance of the magnet.

INTRODUCTION

An ALPHA storage ring, to be constructed at Indiana University Cyclotron Facility (IUCF), has as its main purpose to provide projects on inverse Compton scattering with an x-ray source and some radiation experiments for NASA. Before the ALPHA storage ring, there was a cooler injector synchrotron (CIS), a proton accelerator that was built in 1998 and decommissioned in 2002; some of its element devices stored in a warehouse include four dipoles, RF cavity etc. A problem that will cause the ALPHA storage ring to be unstable is that the 12^o edge of the dipole combines vertical focusing so that the damping partition number is negative. To solve this problem, we decided to add two sets of damping wigglers opposite each other straight section in the storage ring; they vary the damping partition number effectively and more cheaply than other methods [1].

The damping wiggler is a combination of three poles including one middle pole and two outer poles. These poles are made with a silicon-steel slice (50cs1300), of which the thickness is 0.5 mm. Glue (3M 2216) serves to paste the slices together. The shape of the damping wiggler is cut from silicon-steel block with wire-cutting.

Here we discuss the design concept, the results of measurements and some special problems on the damping wiggler, first illustrating the design concept of a damping wiggler. After describing the construction and some mechanical problems of a damping wiggler, we present some measurement data for this prototype construction.

DESIGN CONCEPT AND SIMULATION RESULT OF DAMPING WIGGLER

The damping wiggler is already used widely in contemporary accelerators. A main purpose is to decrease the emittance and to improve the beam size of the accelerator. In the ALPHA storage ring that uses the combined function dipoles of CIS, the damping partition number is caused to become negative, so that the storage ring becomes unstable. Four methods to solve this problem are to redesign the dipole magnet, to add a focusing quadrupole, to add a Robinson wiggler, and to add a gradient damping wiggler. To redesign and construct a dipole is costly. Adding a focusing quadrupole or Robinson wiggler is ineffective. As a result of simulations, the most effective method is to use a damping wiggler. Varying the radius and the ratio of the quadrupole and dipole terms, the dispersion function in the dipole can be corrected. The specific parameter of damping wiggler is in the table1.

The damping wiggler is a structure of C type with a removable coil installation; the electron beam circulates counter-clockwise in the ALPHA storage ring. Three poles are assembled together on the same girder. The direction of the field of the middle pole (D_m) is upward, and a widened gap is on the inward side; the middle pole gap is 40 mm. The magnetic field of the outer pole (D_o) points downward and the widened gap is on the outward side; the outer pole gap is 35.87 mm. The main coil has three pancakes, and a trim coil on one pole has one pancake. Magnet coils made of copper have a square profile 5.6 ×5.6 mm^2 with a coolant orifice of diameter 3 mm. In the simulation, we used TOSCA and RADIA software and compared their results. If the curve of a pole is simulated with a straight line as gradient, the sextupole term becomes too large, causing the region of the defined good field not to satisfy the requisite of ALPHA storage ring. To treat this problem, we added an inverse sextupole term; the curve of the pole profile combines $3x^2y-y^3=R^3$

and $y=(2Q/w)x$ to yield the dipole and quadrupole; one pole separates into two sides with distinct R in the transverse x-axis. For the middle pole case for which Q is 3.665 to adjust the ratio B_1/B_0, R_L is 10650 mm and R_R is 13100 mm to modify the regions of the defined good field at the center point of the outer pole. For the outer pole for which Q is 3.906, R_L is 106007 mm and R_R is 7800 mm. The magnet gaps of the middle and outer pole are 40 and 35.87 mm, respectively; the three combined functions of dipole poles are charged with the same power supply. The regions of the defined good field of the middle and outer poles along the transverse x-axis ($\Delta B/B$=0.1 %) are ±50 and ±40 mm separately. Some problems exist for the region of the defined good field of the integral magnetic field. In the Fig2&3, when $x > 0.02$ m, the $\Delta B/B$ will >0.1 %. An end shim is designed to correct this problem; Figure 2 and 3 shows that the region of the defined good field of the outer and middle pole is improved after this correction

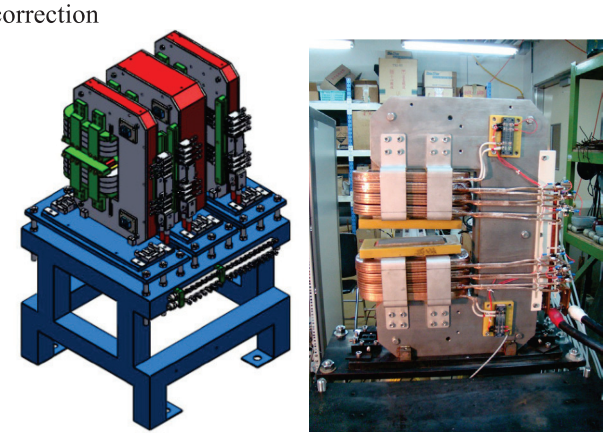

Figure1: schematic drawing and the photography of prototype pole of the gradient damping wiggler system.

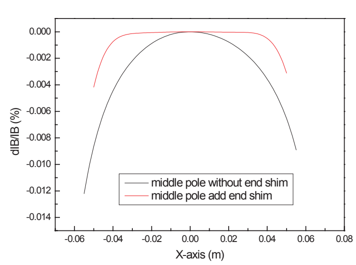

Figure 2: Good field region of the middle pole with and without end shim.

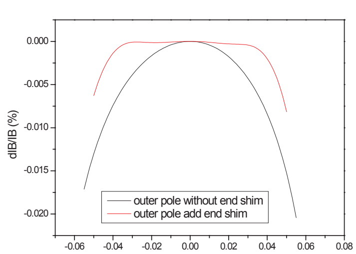

Figure 3: Good field region of the outer pole with and without end shim.

Table 1: Damping wiggler Specifications.

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)	0.317 to 1.273	0.317 to 1.273
(dB/dx)/B (m^{-1})	1.9	-1.9
Ramping frequency (Hz)	1	1
∫Bds (T-cm)	13.4	-6.7
$\int B_1 ds$ (G)	0 to 2546	0 to 1273
$\int B_1 ds / \int Bds$	1.9	1.9
∫Bds (G-cm) of one D_M and two D_O	0	
∫∫Bdsds' (G-cm^2) of one D_M and two D_O	0	
good field region in the horizontal transverse x-axis (mm) ΔB/B=0.001	±50	±40

CONSTRUCTION PROCESS AND SOME MECHANICAL PROBLEMS

The damping wiggler was made from a piece of silicon steel that has the advantage of decreasing the remanent magnetization. We applied a glue (3M 2216 B/A Translucent) to the surface of the piece of silicon steel; this glue has characteristics of working life 2 h and satisfactory retention of strength after environmental aging. We folded each piece of silicon steel using oil pressure machine; then we put the entire silicon steel into the oven and cured it for 240 min at 66 ^{o}C. The middle pole required 300 pieces of silicon steel and much duration to manufacture. After curing the mass of silicon steel, we proceeded with the wire cut to machine the yoke first, then clipped both sides to a stainless-steel plank and drilled a horizontal hole to fix the position. We proceeded with the wire cut to machine the datum plane and curve of the pole finally. For the outer pole for example, two or three weeks was required to complete this work. Of coils of two kinds, a main coil provides the main current, and a trim coil provides a correction current. Main coils were made of copper wire which was made by Luvata in Finland have a square profile 5.6 ×5.6mm^2 with a coolant orifice with a diameter of 3mm. We winded the copper wire with fiber-glass and wound it into the shape of a coil of a pole, then put it into a tub filled with glue and drew it out into a vacuum about 10 $^{-2}$ torr for the vacuum impregnation. After 5 – 6 h, we withdrew it from the tub and left it in air for three days. Finally we ground the surface of the coil and added a thermal sensor on the outlet of each coil to avoid overheating when a current is applied to the coil.There are 12 water tubes contact the end of coil in one pole, in order to avoid the coil heat up; we will connect all water pipes into the same cooling system which is one inlet and one outlet. However, there is a problem, when the coils are charged; the magnetic force will separate the silicon steel slice of pole. For this reason, we add two fiberglasses to reinforce the iron lamination

MEASUREMENT DATA FOR THE PROTOTYPE CONSTRUCTION OF POLE

We have already constructed one outer pole, which was installed on a girder. The automatic measurement system was build up with a high precision x-y-z table and Group 3 Hall-probe that has a temperature sensor, and was calibrated with nuclear magnetic resonance (NMR). The advantage of the NMR system is that it is unaffected by room temperature, and it measures the magnetic field with high precision. To measure the magnetic field with increasing magnitude is inconvenient. The resonance frequency varies with the magnetic field, so that a separate NMR probe must be applied to each range of magnetic field.

We measured the magnetic field from 50 mm to -50 mm on the transverse axis and from 250 mm to -250 mm on the longitudinal axis. Figure 4 shows that the field strength of dipole and quadrupole terms vary with excitation current. The magnet field strength becomes saturated beyond 120 A. The normal field 0.67 T had been obtained at an excitation current 165 A.

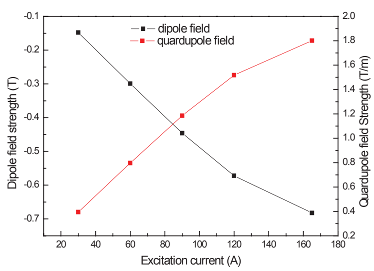

Figure 4: Field strength of dipole term and quadrupole term is as a function of the excitation current.

Figure 5 reveals the good field region (defined here) of the calculated and measured at the central region of the outer pole (z=0 mm). From the result of these measurements, the region of the defined good field (< 0.1 %) is larger than ± 55 mm, so fulfilling the specification ± 40 mm. Meanwhile, figure 6 shows the good field region (defined here) of the calculated and measured integral field of the outer pole. The region of the defined integral good field is consistent with the designed magnetic field. The good field region of the integral field can be improved by means of an iron-shimming algorithm at both end.

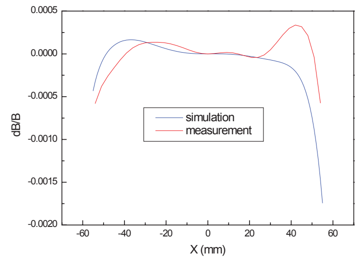

Figure 5: Simulation and Measurement of good field at the central region of the outer pole.

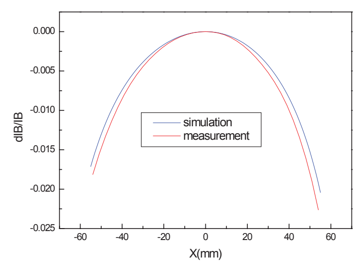

Figure 6: Simulation and measurement of the integral good field region of the outer pole.

CONCLUSION

The pole profile combines $3x^2y-y^3=R^3$ and $y=(2Q/w)x$ to yield the dipole and quadrupole fields; Q is adjusted for the ratio B_1/B_0 and a variable pole R can modify the regions of good field region. One prototype of an outer pole has been constructed and measured; the results show that it is consistent with the magnet design. The girder design and fabrication is completed and was used to support and to adjust the three poles precision position. The dipole and quadrupole field strengths at the magnet center are 0.6502 T and 1.7253 T/m, respectively, at the designed current 150 A. The difference of ratio B_1/B_0 between simulation and measurement is 1 %. The integral dipole and quadrupole field strengths are -6.7523 T-cm and 0.12363 T, and the difference of ratio $\int B_1 ds/\int B_0 ds$ between simulation and measurement is about 3.6 %. The end shim of the two outer poles serves to improve the region of the defined good integral field.

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." , REVIEW OF SCIENTIFIC INSTRUMENTS 78, 075107 (2007)