CIRCULAR POLARIZING QUASI-PERIODIC UNDULATOR*

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Abstract

Investigation into a circular polarizing quasi-periodic undulator is presented here. Electromagnets are used to generate the vertical field. Permanent magnets are used to generate the horizontal field. Calculated maximum effective vertical and horizontal magnetic fields on the undulator axis higher than 8.5 kGauss are achieved at a 10.5-mm gap for a 9-cm-period undulator. Fields of this magnitude are difficult to achieve in purely electromagnetic devices. Switching the sign of the current for the vertical field electromagnets allows for right- or left-handed circular polarization. A laminated core can be introduced to allow for fast helicity switching in order to utilize lock-in detection techniques. Quasi-periodicity can be introduced in the vertical electromagnet field by reducing the current at the quasi-periodic poles and can be turned on, off, or somewhere in between. Quasi-periodicity can be introduced in the horizontal permanent magnet field by inserting weakened magnets at the quasi-periodic poles. Since it is built into the magnet structure, this quasi-periodicity cannot be turned off.

INTRODUCTION

Users at the Advanced Photon Source (APS) requested a 9-cm circular polarizing undulator with effective horizontal and vertical magnetic fields higher than 8.5 kGauss. Requests were made to make the undulator with electromagnets so that circular polarization could be right or left handed and horizontal and/or vertical quasi-periodicity could be introduced by reducing the current at the quasi-periodic poles. Once it was established that fields of this magnitude were not achievable with electromagnets only, the technique of vertical electromagnets and horizontal permanent magnets was introduced as a possible method for a 9-cm-period circular polarizing quasi-periodic undulator (CPQU). This paper discusses two possible configurations for a CPQU, a solid core and a laminated core configuration. Table 1 lists selected parameters and calculated values for these configurations.

THE SOLID CORE MODEL

Figure 1 shows a model of a 9-cm-period CPQU solid core model around a model of the APS vacuum chamber. The model in Figure 1 only shows a 4-period-long section. The actual device is expected to be about 26 periods long. The circular polarization can be right or left handed depending on the direction of the current. Magnetic field calculations were done using the Vector Fields Tosca solver [1]. The gap actuators, strongback, frame, coil leads, and water cooling lines are not shown or presented here but are required to complete the undulator system.

Solid Core Assembly

Figure 2 shows an exploded view of the bottom half of the assembly for one period of the CPQU. The poles are made of vanadium permendur to maximize the vertical field. The core is made of 1008 steel. The poles can be precisely mounted to the core with locating pins and mounting bolts.

Table 1: Selected Parameters and Calculated Values

Description	Solid	Lam.	Unit
Water cooled coil	yes		yes/no
Copper conductor size	5.65		mm SQ
Conductor cooling hole diameter	2.52		mm DIA
Calculated Bx effective field at 10.5-mm gap	8863	8247	Gauss
Calculated By effective field at posted amperage and 10.5-mm gap	8515	7241	Gauss
Permanent magnet remanent magnetization	12,000		Gauss
Permanent magnet coercive force	11,000		Oersted
Turns per coil	17		each
Current	296		amperes
Watts per coil at posted amperage	220		watts
Calculated coil cooling water temperature rise at posted amperage	21		°C
Expected max temperature rise of permanent magnets at posted amperage	11		°C

* Work supported by U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under contract number DE-AC02-06CH11357.
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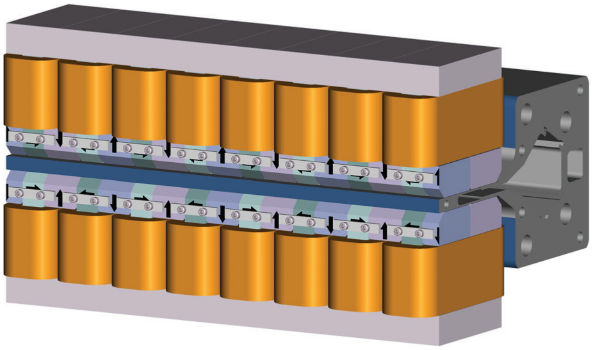

Figure 1: Circular polarizing quasi-periodic undulator (only four periods shown).

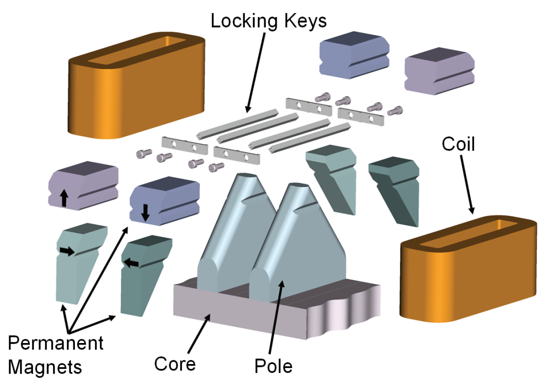

Figure 2: Exploded view assembly.

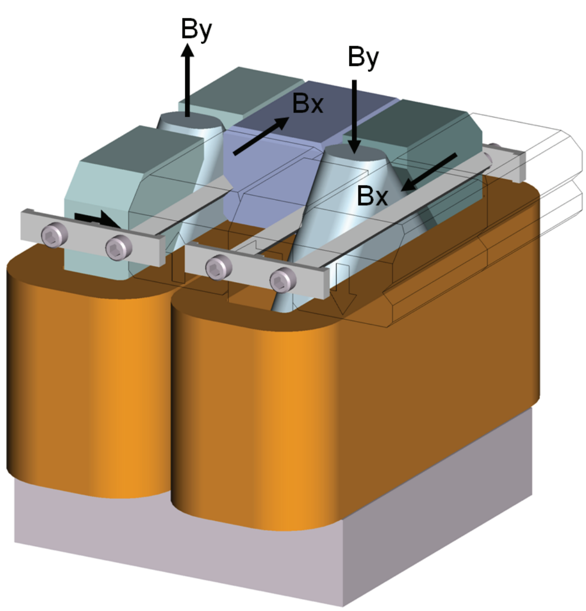

Figure 3: One period of the lower half assembled for the CPQU.

The coils are made with square copper wire with a hole through the center for water cooling. The wire is insulated with HPT (polyimide enamel) and double polyester glass.

Two geometries of permanent magnets are used, each with two different magnetization directions creating a total of four different permanent magnets. The permanent magnets are chamfered in strategic locations to minimize the demagnetization fields.

Figure 3 shows a model of one period for the lower half of the CPQU. Four permanent magnets are shown as transparent to show the keying concept used to mechanically mount the permanent magnets. The poles and permanent magnets are supplied with grooves so locking keys can be used to rigidly fasten the permanent magnets to the structure.

LAMINATED ASSEMBLY

If fast switching of helicity is desired then a laminated core must be used. Figure 4 shows a lamination configuration that could be used for a CPQU. The large chamfers could be machined after the laminations are stacked or the pole tips could be nibbled to different lengths before stacking such that the chamfer is formed while stacking. Several lamination stacks can be butted end to end in the z direction accurately located with keys mounted onto the strongback. T-slots are provided for clamping the lamination stack to the strongback.

The geometry of the laminated yoke in Figure 4 is the same for that of the solid-core yoke in Figures 1, 2, and 3 except that the radius on the poles was eliminated. The magnetic field analysis was done using an M22 steel BH curve causing the effective fields for the laminated core to be lower than the effective field for the solid core listed in Table 1.

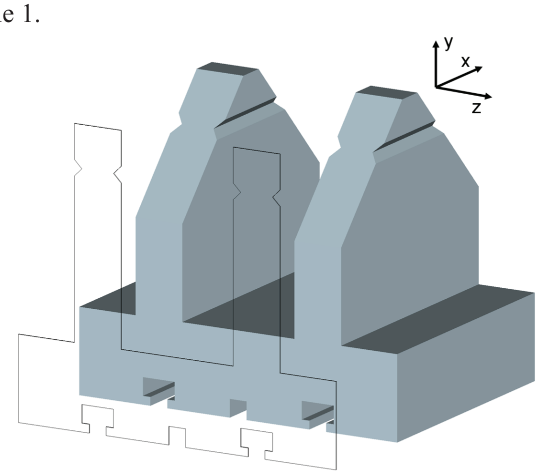

Figure 4: Configuration for a laminated core.

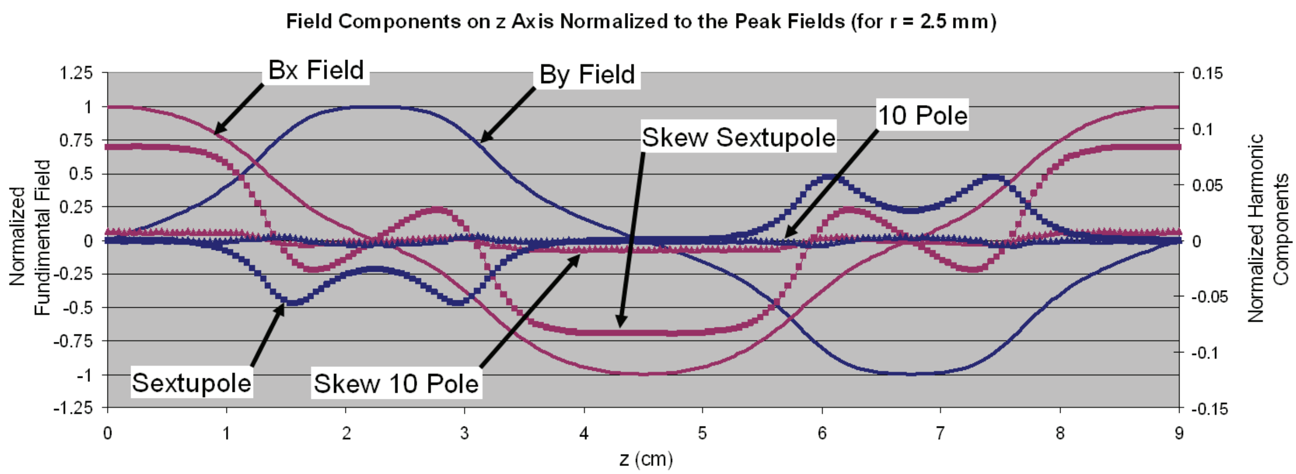

Figure 5: Plot of calculated normalized field profile with normalized harmonic components for the solid-core model.

QUASI-PERIODICITY

Quasi-periodicity can be introduced in the By field direction by reducing the current at quasi-periodic poles. Two power supplies will be required for horizontal linear polarization, one supply to power the main By poles and another supply to power the quasi-periodic By poles. The magnitude of quasi-periodicity is adjustable. Quasi-periodicity can be turned off when both these supplies are set to the same current.

Less heat will be generated at quasi-periodic poles where the current is reduced. This will cause permanent magnets near these poles to run at a slightly cooler temperature. This may cause the Bx field to rise in the vicinity of the By quasi-periodic poles depending on the thermal characteristics of the permanent magnets. Care should be taken to understand the effect. The inside of the coils should be the supply side of the cooling water to minimize the temperature rise of the permanent magnets. No permanent magnet calculations done in this paper took into account any reduction in field due to temperature rise.

Quasi-periodicity can be introduced in the Bx field direction by inserting weaker permanent magnets at the quasi-periodic poles. Since these weaker magnets are permanently mounted in the structure, the quasi-periodicity cannot be turned off nor can the magnitude of the quasi-periodicity be adjusted.

FIELD QUALITY

The calculated Bx and By peak fields are 9234 and 9601 Gauss, respectively, at the posted current and with no quasi-periodicity for the solid-core model. Figure 5 shows a full-period plot of the calculated normalized fundamental harmonic components at r = 2.5 mm for the non-quasi-periodic circular polarizing undulator. The methods for calculating multi-pole field errors are given in Tanabe [2]. The sextupole and 10-pole are the dominant harmonic components. The skew sextupole component has the largest magnitude, about 9% of the horizontal dipole field for r = 2.5 mm. Peak values of other calculated harmonic components are less than 0.24% of the fundamental fields and are not shown here.

MODES OF OPERATION

The modes that this CPQU can operate are:

1. Vertical quasi-periodic linear polarization.
2. Circular polarizing with quasi-periodic in vertical and horizontal planes.
3. Circular polarizing with quasi-periodic in vertical plane only.
4. Modes 2 and 3 above but with helicity reversed.

CONCLUSION

This paper presents two possible configurations for a CPQU. Only a general idea of these configurations is presented. As the users refined their definition of what they wanted in an undulator it became clear that this design would not meet their needs. So we have not completed the design or addressed issues of temperature changes in the permanent magnets. There is no discussion on which poles are quasi-periodic. There is no discussion on trim coils to keep the beam on axis. Different permanent magnets and different gap settings could be altered to achieve the desired fields. Further analyses and engineering are required to complete and build a CPQU like the ones presented here.

REFERENCES

[1] Opera 3D finite element code, Vector Fields Ltd., Oxford, England.

[2] J. Tanabe, Iron Dominated Electromagnets: Design, Fabrication, Assembly and Measurements. Singapore: World Scientific Publishing Co. Pte. Ltd. (2005).