FIELD CHARACTERISTICS OF A 9-POLE ADJUSTABLE PHASE HYBRID UNDULATOR

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ABSTRACT

The study of an adjustable phase undulator (APU) is an interesting topic in the concept of designing the elliptically-polarzing undulator (EPU). The vertical field integral and focusing strength of the conventional pure Halbach undulator are unchanged when the phase changed. These field characteristics are better than the adjustable gap undulator (AGU). Therefore a 9-pole hybrid prototype APU has been constructed and measured in SRRC to know what difference between the pure and hybrid structure of APU. The field measurement was performed by means of the two-orthogonal Hall probes that were installed on a high speed automatic measurement bench. One probe is for the vertical field and the other probe is for the longitudinal field measurement. The multipole field correction was made by shim, pole tilt and the magic finger methods. The field measurement results show that the vertical field integral has changed over 600 G-cm and the multipole strength is also changed when the phase is changed. Field measurement also showed that the field characteristics exist a little difference between the phase and gap was changed to match the same deflection parameter *K*.

1 INTRODUCTION

The undulator generally relies on a change of gap between the two parallel jaws of magnets to tune the photon energy. This called the adjustable gap undulator (AGU). An Adjustable phase undulator (APU) is a conventional Halbach undulator whose magnetic field strength is varied by moving the jaw of magnets longitudinally with respect to each other[1]-[3], while keeping the gap fixed. Therefore, the APU will consist of an upper jaw of stationary magnets and a lower jaw that is mounted on two slides at the two rails. An stepper motor can move the lower jaw longitudinally by half period, for a phase shift of $\theta = \Delta z/\lambda = 1/2$. Where Δz is displacement of the moving jaw with respect to the fixed jaw and λ is period length. The phase changing will vary the vertical field strength and will couple with the longitudinal field strength. The field strength changes on the longitudinal direction will induce a strong magnetic force $F_Z = -\nabla_Z U$ at the same direction. Where U is the magnetic energy. Therefore, the mechanical design should be careful to deal with the longitudinal force. An effect on horizontal steering and vertical focusing is much greater when the gap is varied than the one jaw of magnet are phased. According to Roger Carr calculation[1]-[2], he predicted the vertical field integral and vertical focusing strengths of the pure structure were unchanged when the phase is changed. Base on this reason, we try to know what difference between the pure and hybrid structure.

The APU is a hybrid structure which with 9 poles and period length 10 cm[4]. The physical length of this APU is 0.65 m. The peak field is 1.11 Tesla at gap g=22 mm. The magnet structure was mounted on a one meter long C-frame support structure in which the gap can be moved in parallel or in phase motion. The upper jaw of magnets fixed and then move the lower jaw of magnets. Therefore, the vertical and longitudinal field distribution will exist a phase shift that is equal to be one half of the phase θ. The field characteristics between the gap motion and phase motion will be compared. Several shims and two magic fingers were used to correct the peak field, the vertical field integral and the multipole field. The magic finger[5]can be used to correcte the fringe field which will induce a strong sextupole strength. However in our case, the magnetic circuit design of the magic finger also can be used to correct the vertical field integral. There are also two correctors coil to compensate the first integral field on different gap or phase.

Field measurement was performed by two-orthogonal Hall probes with an automatic measurement stage. One probe is for vertical field measurement and the other probe is for the longitudinal field measurement. However, the centers of the two Hall probes are not simultaneously at the same midplane and the Hall probe surface is not perpendicular to each other exactly. This is due to the machine error and the uncertainty of the Hall probes center and plane. Therefore, in the near future a three-orthogonal Hall probes which's angle and center can be adjusted relative to each other.

The vertical and longitudinal field will exist simultaneously when changes the phase. If the phase $\theta = \Delta z/\lambda$ was changed, the maximum vertical (longitudinal) field and minimum longitudinal (vertical) field will occur at $\theta = 0$ ($\theta = 0.5$). We find the vertical peak field strength is stronger than the longitudinal peak field strength at the same gap in this type of APU. The study of the hybrid structure tells us that the vertical field integral changed 600 G-cm and the higher multipole field strengths are also changed when the phase is changed.

2 MEASUREMENTS AND ANALYSIS RESULTS

Measurements of the magnetic field were performed by moving a two-orthogonal Hall probes along the axis of the APU magnet, and recording the vertical and longitudinal magnetic field strength as a function of position. There is 1800 measurements at 0.8 mm interval for each Hall probe. When the gap was set to 22 mm, the vertical (longitudinal) field distribution were measured at different phase and shown in Fig. 1 (Fig. 2). These two figures show the field distribution along the longitudinal axis is a sin-like wave and the peak field center has shifted. In the APU structure the peak field is a slower, sinusoidal variation of field with longitudinal position. The field variation of B_y and B_z was shown in equation (1) and (2).[2]

$$B_y = B_{y0}\cos(\pi\theta) \qquad (1)$$

$$B_z = (k\,B_{y0})\sin(\pi\theta) \qquad (2)$$

Where $\theta = \Delta z/\lambda$ is the phase change and B_{y0} is the vertical peak field strength at phase $\theta = 0$, and $k < 1$ is a unknown factor which may come from the saturation behavior.

The amount of phase shift of the peak field at different phase is $\Delta\theta = \theta/2$.[2] The peak field strength between the vertical ($\theta = 0$) and longitudinal directions ($\theta = 0.5$) are different (see Fig. 1 and 2). Therefore, the peak field strength of B_y and B_z at different gap were measured to get the relationship between the vertical and longitudinal field at the same phase $\theta = 0.5$. The results show that they are all close to the empirical formula of equation (3).

$$B_{y0}(T) = 3.44\exp[(-g/\lambda)(5.08 - 1.54g/\lambda)] \qquad (3)$$

The electron trajectories in the AGU and the APU at equivalent undulator parameters by tuning the gap or the phase to get an equal value of the peak magnetic field strength. Fig. 3 reveals the electron trajectories has 30 μm offset and a phase shift $\Delta\theta = 0.15$ between the gap change and phase change which are under the same deflection parameter $K = 0.934B\lambda = 5.07$. Where B is the peak field and λ is the period length.

The first integral field strength as a function of transverse direction (x-axis) with and without field modification was shown in Fig. 4. When the shims, pole tilt and magic finger were adjusted then the first integral field strength has been corrected and within 100 G-cm at the range of $-30 \le x \le 30$ mm. Fig. 4 shows that the dipole, quadrupole, and sextupole strength are too strong when APU is without any correction. However, after the correction of each period pole shim and tilt as well as the fringe field was corrected by the magic finger, then the dipole and the other higher multipole field are all reduced as minimum as possible. Fig. 4 also revealed that the field strength of the magic finger at the two end sides of APU has not only reduced dipole integral strength but also reduces the sextupole strength which was created by the fringe field.

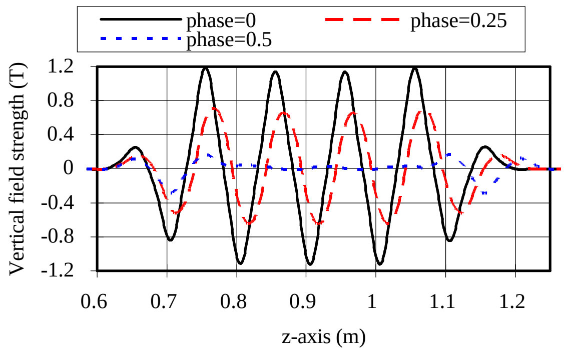

Figure:1 The on-axis B_y magnetic field was measured at gap g=22 mm and change the phase. The B_y field is maximum at phase $\theta = 0$, and is zero at phase $\theta = 0.5$.

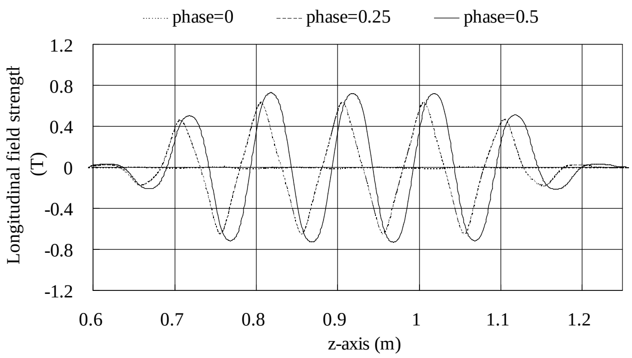

Figure:2 The on-axis B_z magnetic field was measured at gap g=22 mm and change the phase. The B_z field is maximum at phase $\theta = 0.5$, and is zero at phase $\theta = 0$.

However, Fig. 5 and 6 (without any field correction) tell us that when the phase was changed, the first integral strength was changed. The vertical and longitudinal harmonic field strengths with different phase were shown in Fig. 5 and 6. Fig. 5 reveals that the dipole and higher multipole strength of the vertical component have been changed when the phase is changed. However, the longitudinal field strength the higher harmonic strength was kept constant except the dipole strength when the phase is changed (see Fig. 6). The longitudinal dipole field strength changed about 950 G-cm when the phase change from 0 to 0.5.

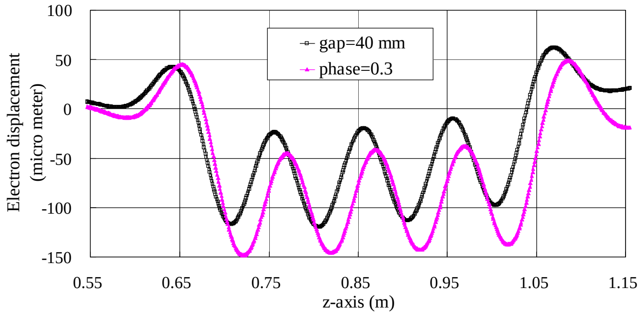

Figure: 3 The electron trajectories are calculated at the same *K=5.07* value but under the different phase and gap. One is at gap=22 mm and phase $\theta = 0.3$, and the other one is at gap=40 mm and phase $\theta = 0$.

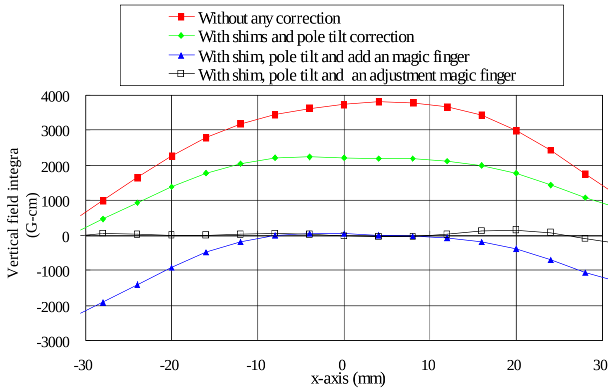

Figure: 4 The integral field strength as a function of x for the different kind of correction skill at gap= 22 mm and phase=0.

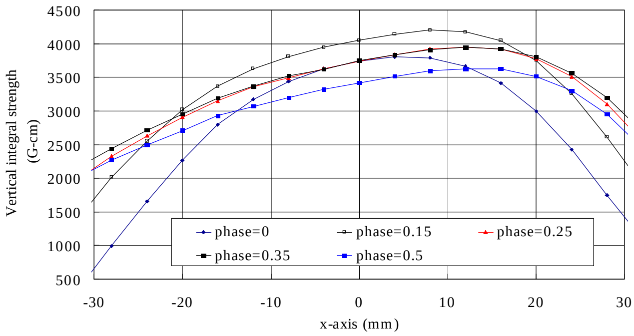

Figure: 5 Vertical field integrated strength as a function of x at different phase (without any shim or magic finger correction). The dipole and the higher multipole strength have been changed when the phase is changed.

3 CONCLUSION

We have presented the field characteristics of the APU magnet that was measured by the two-orthogonal Hall probes. The first integral strength changed 600 G-cm when the phase is changed. This value should be compensated by the end correction. We think that if the peak field and period length of each half period were closed to exact value then the vertical field integral changed should be minimized. Beside the dipole strength, the higher multipole strengths are also changed when the phase is changed. Baes on the same reason, the higher multipole strength change also will be minimized. The longitudinal field integral only changes the dipole strength when the phase changed. However, the higher multipole strength of the longitudinal field integral kept constant in any phase.

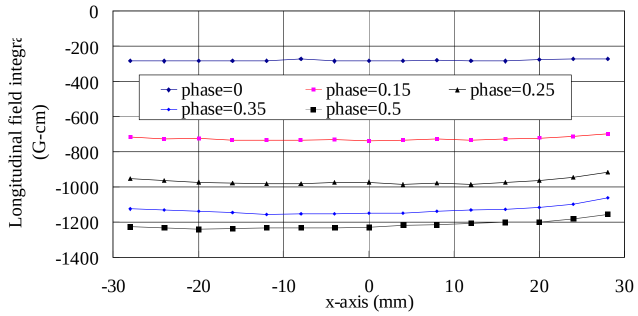

Figure: 6 Longitudinal field integrated strength as a function of x at different phase. The dipole strength has been changed but the higher multipole strength is fixed when the phase is changed.

In the next step, we will build a three-orthogonal Hall probes to measure the transverse field B_x. Because of the horizontal transverse field will induce a vertical kicker on the electron trajectory. At the same time, the multipole and spectrum shim will be done to improve the field performance and to keep the vertical dipole and the other higher multipole strength unchanged when the phase is changed. The electron trajectories exist a little difference between the gap and phase changed. We think that the trajectories difference is also can be improved by the same method.

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