# DESIGN OF VARIABLE POLARIZING UNDULATOR (APPLE-TYPE) FOR SX BEAMLINE IN THE SPRING-8

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***Abstract***

This paper describes the design of a variably polarizing undulator (APPLE-type) to be installed in a soft X-ray beamline in the SPring-8 facility. The magnetic field strength in this undulator is varied by changing the gap distance of upper and lower jaws, so it changes the photon energy in soft X-ray range. By moving the relative position of the pairs of magnet rows (phase shift), the polarization of radiation is varied circularly, elliptically, and linearly in the horizontal and vertical directions. We expect that right- and left-handed circular polarization to be obtained alternately at a rate of 1Hz by high speed phase shifting. The repulsive and attractive magnetic forces working on the magnet rows were calculated which interfere in phase shift at high speed. The construction of this undulator is started in 1996, and will be installed in the storage ring in 1997.

## 1. INTRODUCTION

The storage ring of the SPring-8 is under construction and some of insertion devices to be installed in straight sections are also under construction. There will be three beamlines for Japan Atomic Energy Research Institute (JAERI) use in the SPring-8. As one of the light source for the JAERI beamline, we designed the insertion device which provides variably polarized soft X-rays. This is a type of the variably polarizing undulator ,called APPLE-type[1-3], which is capable to change the polarization of radiation such as right- and left-handed circularly or elliptically and linearly in the horizontal and vertical directions by shifting of the magnet row phase. In order to make the experiment using circular polarized radiation highly-sensitive, right- or left-handed circular polarization will be switched at a maximum rate up to 1Hz. In this paper, the magnetic field strength and magnetic force working on a row, and radiation spectrum expected from this undulator are calculated.

## 2. MAGNETIC STRUCTURE

Figure 1 shows the magnetic structure of this undulator. It consists of two pairs of rows of permanent magnets. Here, $g$ is the gap distance between the upper and lower rows, $\lambda_u$ is the magnetic period length which corresponds to four magnet blocks, $h$ and $w$ are the height and the width of each magnet block, respectively. $D$ is the position shift distance (phase shift) between row-1 and row-2, and between row-3 and row-4. At the phase shift $D$=0, the position of the four rows are the same in $z$-direction (base position). In the case of $D$=$D_1$, the pair of row-2 and row-4 is moved with a distance of $D_1$/2 and another pair of row-1 and row-3 is moved with a distance of -$D_1$/2 coincidentally. The main parameters of this undulator are shown in Table 1.

Table 1 Undulator design parameters

| | |
|---|---|
| Device type | APPLE-2 |
| Period length | $\lambda u$=120mm |
| Number of periods | $N$=16 |
| Total length | $L$=1920mm |
| Minimum gap | $g$=20mm |
| Phase shift range | $D$=-120~120mm |
| Phase of horizontal polarization | $D$=0mm,±120mm |
| Phase of vertical polarization | $D$=±60mm |
| Peak field at vertical polarization ($g$=20mm) | $B_{xp}$=0.71 T |
| Peak field at horizontal polarization ($g$=20mm) | $B_{yp}$=0.74 T |
| Peak field at circular polarization ($g$=20mm) | $B_{xp}$=$B_{yp}$=0.53 T |
| Magnet width | $w$=50mm |
| Magnet height | $h$=25mm |
| Remanent field | Br=1.2 T |

Changing the phase shift leads to variation of polarization, so horizontal polarization is obtained at $D$=0, ±120mm and vertical polarization is obtained at $D$=±60mm. The phase shift $D$ generating circular polarized radiation depends on the gap distance $g$; for example, it is $D$=31.4mm at $g$=20mm.

Figure 2 shows the peak magnetic field variation on $z$-axis depending on the phase shift and the gap distance. The $B_{yp}$ represents the peak strength of vertical magnetic field. The $B_{yp}$ and $B_{xp}$ vary sinusoidally with the phase shift, and when $B_{yp}$ equals $B_{xp}$ (it is open circle point in Fig. 2) the circular polarization is obtained. The phase shift $D$ generating circular polarization at each gap is generally

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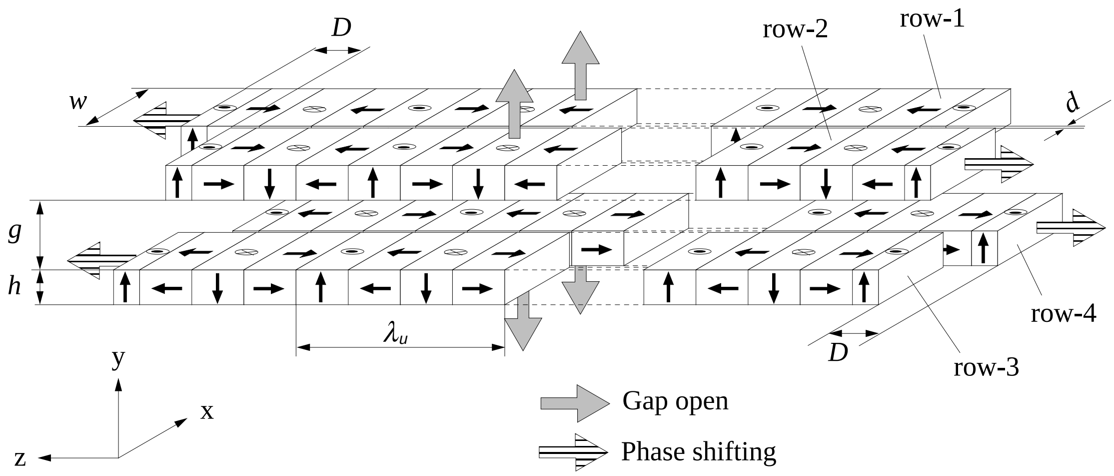


Figure 1 Schematic view of the magnetic structure

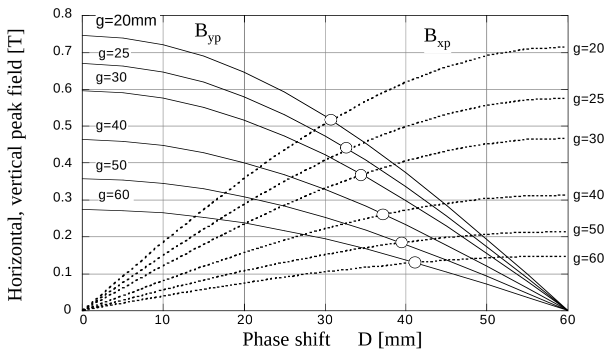


Figure 2 The horizontal and vertical peak fields on-axis as function of the phase shift D. Open circles are points of circular polarization. $B_{yp}$ represents vertical peak field.

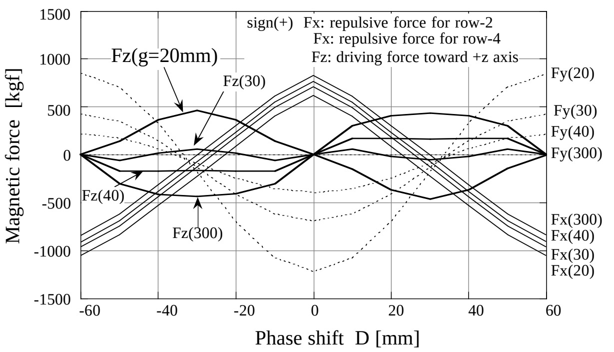


Figure 3 Magnetic force working on the magnet row-1. Fx is x-component of the magnetic force.

presented as

$$D[\text{mm}]=120/\pi \bullet \tan^{-}(B_{ypmax}/B_{xpmax}),$$

where $B_{ypmax}$ is the maximum of $B_{yp}$ at each gap (i.e. $B_{yp}$ at $D$=0mm), but this equation is not valid when gap is very small.

## 3. HELICITY SWITCHING OF CIRCULARLY POLARIZED RADIATION

We will be able to generate the right- and left-handed circular polarization alternately at a maximum frequency of 1Hz by changing the phase shift periodically. Because two pairs of magnet rows are moved in reverse directions to each other by the same distances during phase shift, the center of gravity of the undulator remains fixed and the vibration of magnet rows cannot be transferred to floor level. In this undulator, right-handed elliptical polarization is obtained at $0<D<60$mm and left-handed elliptical polarization is obtained at $-60<D<0$mm. As shown in Fig. 2, in the case of $g$=20mm right-handed and left-handed circular polarization is generated at $D$=31.4mm and $D$=-31.4mm respectively, because of the symmetry to the phase shift. Then we can get the right- and left-handed circular polarization periodically by reciprocating the rows between $D$=31.4mm and $D$=-31.4mm.

The repulsive and attractive magnetic forces are strongly working on all magnet rows. Figure 3 shows that the magnet force working on row-1 varies by the phase shift at each gap. Regarding the force working on other rows, the sign is different in Fig. 3 simply. The $F_z$ in Fig. 3 is z-component of magnetic force, works in the same direction as phase shifting, so $F_z$ mainly interferes with phase shifting. The $F_z$ has sine-like dependence on the phase shift, and its amplitude changes with the gap. At a gap of 20mm, the $F_z$ is about 450kgf at maximum, and it makes rows head for the base position. At $20<g<30$mm, the larger the gap distance is, the smaller $F_z$ is. When gap is 30mm, the $F_z$ is about zero, and its sign changes there. At $g>30$mm, the larger the gapdistance is, the stronger $F_z$ is. The maximum of the $F_z$ is about 450kgf at a very large gap distance, but in the reverse direction compared to the case of g=20mm. Because the $F_z$ is too strong to ignore, we decided to utilize the $F_z$ to move the magnet rows. The $F_z$ makes rows head for the base position at $g$=20mm, that is, the base position is the lowest point of potential energy. Therefore while phase shifting is between $D$=31.4mm and $D$=-31.4mm, restitutive force is always working on the moving row. The frequency of oscillation by the restitutive force is estimated at 1~3Hz, supposing the weight of row is 1000kgf, so we will not need such a high power motor to move the rows. In the case of $g$>30mm, the position of $D$=60mm (and $D$=-60mm) is the valley of potential, and it is the center of reciprocating motion.

Accuracy of polarizing rate is required as follows:

$$|\Delta P|<1\%$$

$$P=(I_x-I_y) / (I_x+I_y),$$

where $I_x$ is the $x$-component of polarizing intensity. In order to satisfy the above accuracy, error of the phase shift needs to be smaller than ±0.3mm.

## 4. PHOTON ENERGY AND BRILLIANCE

Figure 4 shows the fundamental photon energy and brilliance expected from this undulator at a circular polarization mode at each gap, calculated for the storage-ring parameter of electron energy 8GeV and current 100mA. The shape of envelope curve is the same as the case of linear polarization mode. The energy range mainly used are between 0.5 and 1.5keV, and in this range the brilliance is over $10^{17}$. The radiation spectrum calculated at $g$=40mm is also shown in Fig. 4. In the circular polarization mode, higher harmonics hardly exist on-axis, but in the linear polarization mode considerable power is emitted on-axis and the heat load of optics is rather severe.

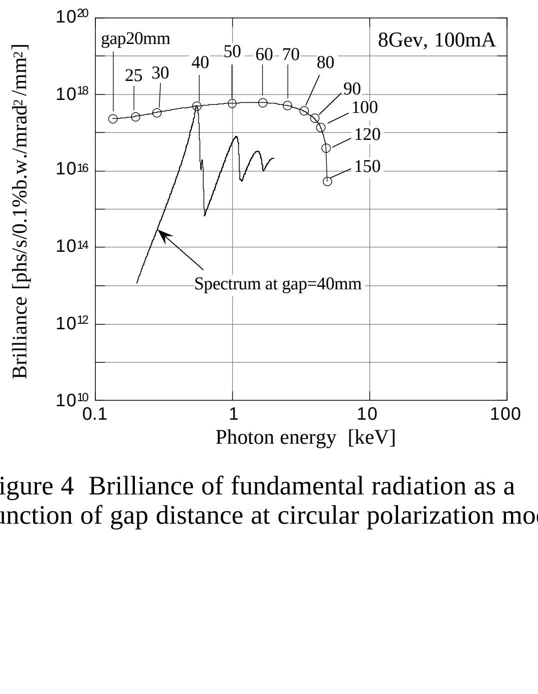


Figure 4 Brilliance of fundamental radiation as a function of gap distance at circular polarization mode.

## 5. CONCLUSIONS

The magnetic field strength, magnetic force working on a row, and radiation spectrum expected from the undulator to generate variably-polarized radiation were calculated. We found that the magnetic force working on the magnet rows is very strong, and it changes greatly by not only the phase shifting but also the gap distance variation. This undulator will be able to emit right- and left-handed circularly polarized radiation alternately at a maximum rate of 1Hz by high speed phase shifting which is eased by utilizing the magnetic force in direction of phase shifting. The calculated brilliance of fundamental radiation is over $10^{17}$ at a range of photon energy 0.5~1.5keV.

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