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〈연구논문〉

Effects of the Insertion Device for the Electron Storage Ring DELTA

Soon-Kwon Nam

Department of Physics, Kangwon National University, Chuncheon 200-701, Korea
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전자 저장링 DELTA에 대한 삽입장치의 효과

남 순 권

강원대학교 물리학과
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Abstract – The project of a superconducting asymmetric multipole wiggler in the 1.5 GeV electron storage ring DELTA is in progress. In this work, the influences of nonlinear effects due to the this insertion device are investigated. The standard lattice is tolerable on the beam dynamics problems for all errors which are considered in our work.

요 약 – 독일의 1.5 GeV 전자 저장링 델타(DELTA)에 대한 초전도 비대칭 다극 위글라에 대한 연구계획이 진행 중에 있다. 본 연구에서는 이 삽입장치의 비선형 효과에 대한 영향이 연구되었다. 표준 라티스(lattice)는 고려된 오차들에 관한 빔역학적인 문제에 대해서 안정함을 보였다.

1. Introduction

Recently, in the third generation of synchrotron light sources, the spectral properties of the photon beams will be considerably enhanced by utilizing special magnetic devices called wiggler and undulators that are placed in the straight sections of the storage ring. Compared with bending magnet sources, these insertion devices can produce far more intense photon beams with greater flexibility in terms of their characterisics. Unfortunately the radiation from the 1.51 T bending magnets has a charicteristic wave length of 5.47 Å. To enhance the performance of the machine for short wave length users, the installation of a superconducting wiggler is foreseen. The standard optics (STD) and low emittance optics (LOW) based upon the triplet cell [1] have a circumference of 115.2 m consisting of two about 20 m long dispersion-free straight sections providing space for insertion devices. Two kind of linear optics[2] with different emittances (STD, LOW) have been recalculated. Insertion devices not only break the linear optics of the lattice but also introduce high oder field components that may excite non-systematic resonances and induce change in tune and distortion of the betatron function. In this work, the effects of the STD and LOW optics with the 5.5 T superconducting asysmmetric (SCA) wiggler are also investigated for without errors and with field errors, alignment errors and multipole errors, respectively.

2. The Effects for the Insertion Device

2.1. The Influences of the SCA Wiggler

The magnetic fields of insertion devices can cause distortions of particle motion in the storage ring. The nonlinear magnetic field used for the derivation of the equations of motion were obtained from the Maxwell equations by K. Halbach[3].

$$B_x=(k_x/k_y)B_0\sinh(k_x x)\sinh(k_y y)\cos(k_w z)$$
$$B_y=B_0\cosh(k_x x)\cosh(k_y y)\cos(k_w z)$$
$$B_z=-(k_w/k_y)B_0\cosh(k_x x)\sinh(k_y y)\sin(k_w z) \quad (1)$$

with $k_x^2+k_y^2=k_w^2=(2\pi/\lambda_w)^2$, where λ_w is the period length of the insertion device and B_0 is its magnetic field strength. The x, y and z are fixed coordinates with respect to an insertion device.

An analytical approach to such nonlinear effects by the use of a Hamiltonian averaged over the insertion device period has developed by Smith[4].

$$H=\frac{1}{2}(p_x^2+p_y^2)+\frac{1}{4k^2\rho^2}(k_x^2x^2+k_y^2y^2)+\frac{1}{12k^2\rho^2}(k_x^4x^4+k_y^4y^4+3k_x^2k_y^2x^2y^2)+\text{higher order terms} \quad (2)$$

where each terms indicate a free motion, the linear optics distortion due to the insertion devices and higher order nonlinear interactions. Since there exists in general no analytical solution for the equation of motion, a computer simulation must be performed to investigate the particle dynamics in the presence of arbitrary field distributions. These nonlinear pertubations depend upon the ampltude of the particle oscillation and induce unstable motion at an oscillation amplitude that defines the dynamic aperture. The dynamic aperture is determined by tracking test electron trajectories through a computer model of the magnet lattice and observing whether or not the motion is bounded.

The dynamic aperture can be recovered to some extent by tune matching which employs quadrupole readjustments in the insertion region after α matching. In obtaining the dynamic aperture through particle tracking for the 5.5 T asymmetric SC wiggler[5] of field parameter 149, number of periods 5, period length 29 cm, number of poles 19 and total magnetic length 1.5 m as shown in Table 1, computer code MAD[6] and RACETRACK code[7] are utilized for up to 400 orbital turns.

The SCA wiggler can produce intense radiation of circular polarized light up to the soft X-ray region and 1-3 user ports. Since the field distribution can be made more or less asymmetric by using the additional coil windings, the component of circular polarized light up to the soft X-ray region is not cancelled out even off axis. Magnetic field, angular deflection and orbit displacement along the wiggler axis for the asymmetric mode[5] are also calculated by POISSON code. The theoretical maximum magnetic flux density at the orbit is about 6.3 T and based on Nb-Ti superconductor with a critical overall current density of 210 A/mm^2 (inner coil) and 400 A/mm^2 (outer coil) at 4.2°K. The radiation parameters for the asymmetric mode are the critical energy 8.2 KeV, opening angle of the light cone 25 mrad and vertical integrated photon flux 1.25×10^{11} photons/sec/mrad/mA/0.1%BW. The main parameters are given in Table 1(a) and Table 1(b).

Fig. 1 shows the dynamic aperture for the STD optics with and without SCA wiggler. In this case, the horizontal and vertical tunes are matched as 6.18 and 5.42 which are the same as original linear optics.

The natural beam emittance[8] is expressed by

$$\varepsilon=C_q\gamma^2\frac{I_5}{I_2-I_4} \quad (3)$$

where $C_q=3.8319\times10^{-13}$ m, the I's are called synchrotron radiation integrals, I_5 gives the quantum excitation effect, and I_2-I_4 gives the radiation damping. The relation of the new emittance with insertion devices to the old emittance, in general, is given by

$$\varepsilon_x=\varepsilon_x^0\frac{1+\left(\frac{I_5^w}{I_5^0}\right)}{1+\left(\frac{I_2^w-I_4^w}{I_2^0-I_4^0}\right)} \quad (4)$$

where I_i^0 and I_i^w (i=1 to 5) are the original and the new radiation integrals. We need to add the new radiation integrals for the superconducting asymmetric wiggler. From our calculation, the horizontal and vertical emittances for 10% coupling are 2.97E-08(without wiggler : 4.38E-08) mrad and 2.97 E-09(without wiggler : 4.38E-09) mrad, respectively. The emittances of the optics with wiggler are dec-

Table 1. (a) Main parameters of the proposed superconducting wiggler

Wiggler parameters	Asymmetric-mode	Symmetric-mode
Field-range at the orbit	$B^{+}=4.5\sim6.0$ T	$B^{\pm}=2.0\sim3.5$ T
	$B^{-}=2.0\sim3.0$ T	–
Nominal field-value	$B^{+}_{max}=5.5$ T	$B^{\pm}_{max}=2.75$ T
	$B^{-}_{max}=2.5$ T	–
Period length	$\lambda_w=29$ cm	$\lambda_w=14.5$ cm
Number of periods	$N_p=5$	$N_p=10$
Wiggler-parameter	$K_{max}\cong149$	$K^m\cong27\sim47$
Number of poles:		
full strength	$N_{full}=19$	
half strength	$N_{half}=2$	
Minimum beam aperture	$G_{beam}=7$ mm	
Magnetic full gap heigth:		
'cold' vacuum chamber	$Gap_{cold}=17.5$ mm	
'warm' vacuum chamber	$Gap_{warm}=30.0$ mm	
Total magnetic length	$L_{total}\cong1.5$ m	

(b) The influnces of the SCA wiggler (Main parameters of the optics)

Energy	STD	STD with SCAW	LOW	LOW with SCAW
Energy (GeV)	1.5	1.5	1.5	1.5
Tune hor.	6.182	6.182	9.165	9.165
ver.	5.429	5.429	3.271	3.271
Natural emittance (10% coupling)				
hor.	4.38×10^{-8}	2.97×10^{-8}	1.13×10^{-8}	7.73×10^{-9}
ver.	4.38×10^{-9}	2.97×10^{-9}	1.13×10^{-9}	7.73×10^{-10}
Momentum compaction (%)	1.32	1.29	0.49	0.50
Energy spread $\Delta E/E$	6.87×10^{-4}	9.0×10^{-4}	6.95×10^{-4}	9.07×10^{-4}
Synchrotron damping τ_s (msec)	4.29	2.90	4.39	2.94
Energy loss/Turn ΔE (KeV)	129.65	194.27	129.65	194.27
Harmonic number	192	192	192	192
Revonution frequency	2602.37	2602.37	2602.37	2602.37

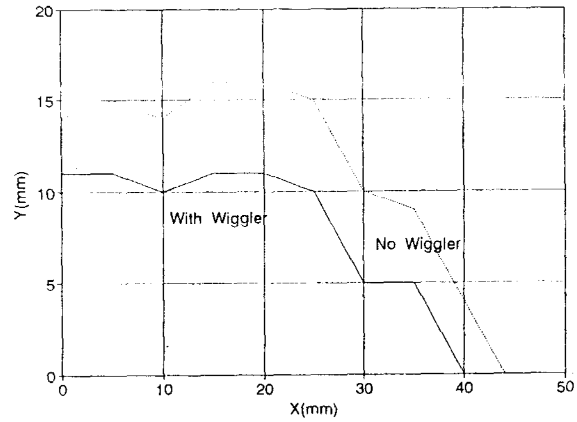

Fig. 1. The dynamic aperture for the STD optics with and without SCA wiggler.

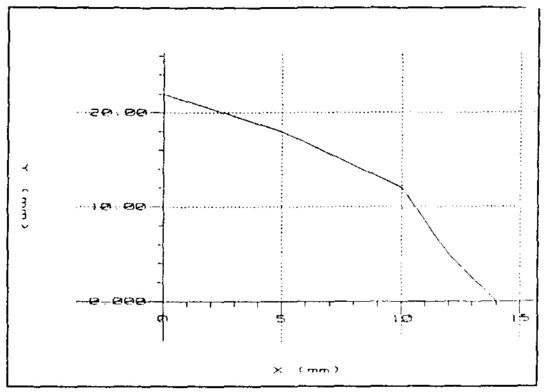

Fig. 2. The dynamic aperture for the LOW optics with SCA wiggler.

reased due to the SCA wiggler with 5 periods and 19 poles compared with the STD optics. Fig. 2 shows the dynamic aperture for the LOW optics with SCA wiggler in the maddle of the long straight section.

The reduction in the dynamic aperture is noticeable compare with STD optics with wiggler because of the strong sextupole strengths. The horizontal and vertical tunes are matched as 9.165 and 3.271 which are the same as original linear optics without wiggler.

2.2. The Effects for the Field Errors

All field errors are specified as the integrated value along the design particle trajectory. The di-

Table 2. The input data for the field errors

Magnets	Error components	Values
BM	DBL	5.0E-04
	DKL(2)	2.0E-05
	DKL(4)	2.0E-05
QM	DKL(1)	2.0E-03
	DKL(5)	2.0E-04
	DKL(9)	2.0E-05
SM	DKL(2)	2.0E-05
	DKL(8)	2.0E-05
WM	DBL	0.0
	DKL(1)	0.0
	DKL(2), (4), (6)	2.0E-05
	DKL(8), (10)	2.0E-05

pole may have errors of the type dipole (BM), quadrupole (QM), sextupole (SM) and octupole etc. The dipole, 6 pole and 10 pole components of the error field are considered in a bending magnet as DBL=5.0E-04, DKL(2)=2.0E-05 and DKL(4)=2.0E-05, respectively. The normal quadrupole component, 12 pole and 20 pole components of the field error are considered for quadrupoles. The error field components are assumed the values of 2.0E-03, 2.0E-04 and 3.0E-05, respectively. The field errors of the sextupoles are considered 6 pole component of 2.0 E-05 and 18 pole component of 2.0E-05. For the SCA wiggler, DKL(2), DKL(4), DKL(6), DKL(8) and DKL(10) components are considered as the values of 2.0E-05 except for dipole and quadrupole component as shown in Table 2. The input data for the field errors are summarized in Table 2. Fig. 3(a) and Fig. 4(a) show the dynamic aperture for the field errors of the STD and LOW optics with SCA wiggler (WM). The limit of the horizontal dynamic aperture for the field errors of the STD and LOW optics with SCA wiggler are shown in Fig. 3(b) and Fig. 4(b), respectively. In this case, we used the data in Table 2 for the tracking simulations of 1000 turns. Fig. 3(b) and Fig. 4(b) show the reduction in the horizontal dynamic aperture for the field errors of the all manets (BM, QM, SM and wiggler) of the STD and LOW optics with the SCA wiggler. Table 3 and 4 show tune shift of STD optics and LOW optics for the field errors.

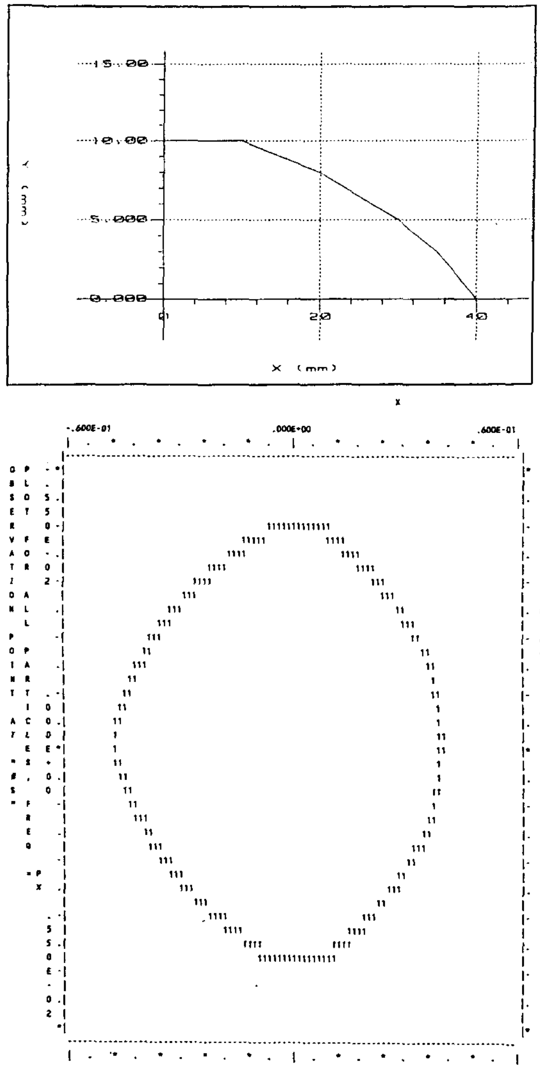

Fig. 3. (a) The dynamic aperture for the field errors of STD optics with SCA wiggler. (b) The limit of the horizontal dynamic aperture for the field errors of the STD optics with the SCA wiggler.

2.3. The Effects for the Alignment Errors

Possible misalignments are displacements along the three coordinate axis and rotation about the coordinate axis. All magnets of the storage ring are considered as the beam elements in which the error occur. The misalignlment in the x and y direction for the entry of the beam element are assumed 0.002×((RANF( )−0.5)×2) and 0.004×((RANF( )−0.5)×2), respectively. The misalignment of the ro-

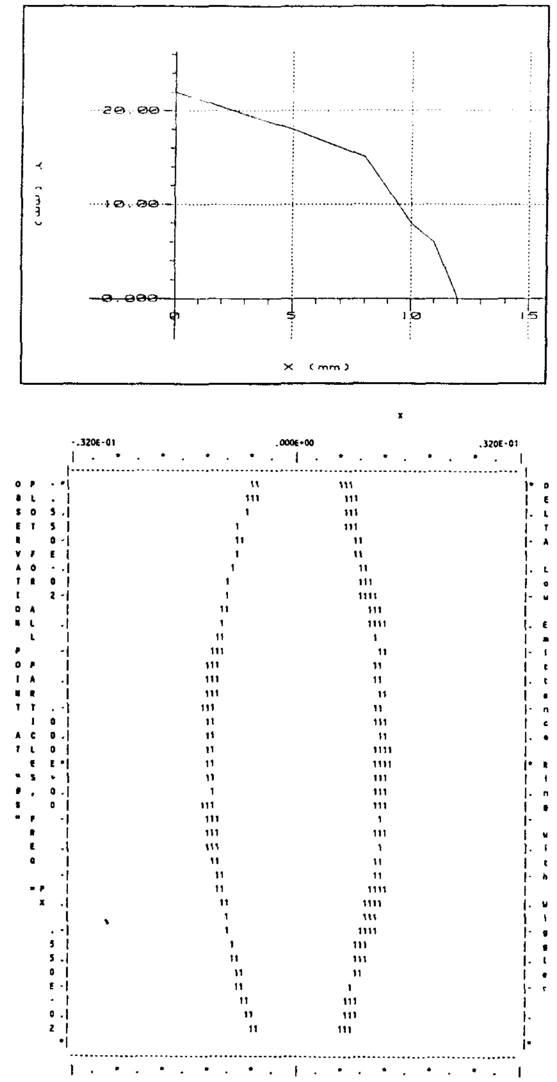

Fig. 4. (a) The dynamic aperture for the field errors of LOW optics with SCA wiggler. (b) The limit of the horizontal dynamic aperture for the field errors of the LOW optics with the SCA wiggler.

tation around the x-axis and the y-axis according to the right hand rule are assumed as 0.0002× GAUSS() for random value formats[6]. The dynamic apertures of the STD ring and LOW optics with the SCA wiggler are shown in Fig. 5(a) and Fig. 6(a) for the alignment errors of the all dipoles, quadrupoles, sextupoles and wiggler. The limits of the dynamic aperture for the alignment errors of STD and LOW optics and plotted in phase space for 1000

Table 3. Tune shift of STD optics for the field errors

Magnets	Error components	Horizontal (dQ)	Vertical (dQ)
All	without	0.0	0.0
BM QM SM WM	same as Table 2	0.0442	0.0513

Table 4. Tune shift of LOW optics for the field errors

Magnets	Error components	Horizontal (dQ)	Vertical (dQ)
All	without	0.0	0.0
BM QM SM WM	same as Table 2	0.0477	0.1205

Table 5. Tune shift of STD optics for the alignment errors

Magnets	Error components	Horizontal (dQ)	Vertical (dQ)
All	without	0.0	0.0
BM QM SM WM	same as Table 2	0.00477	0.1127

turns as shown in Fig. 5(b) and Fig. 6(b), respectively. Table 5 and 6 show tune shift of STD and LOW optics for the misalignments.

2.4. The Effects for the Multipole Errors

The multipole coefficient of order n is the multipole coefficient integrated over the length of the multipole. The order n may take the values 0 to 9. The number of poles of the component is 2n+2. The multipole components are incorporated using a field expansion in tracking codes.

$$B_y(x,\ \phi)=B\rho\sum_n \frac{k_n x^n}{n!}\cos[(n+1)\phi+\delta] \quad (5)$$

where k_n is the multipole amplitude, ϕ is the angle

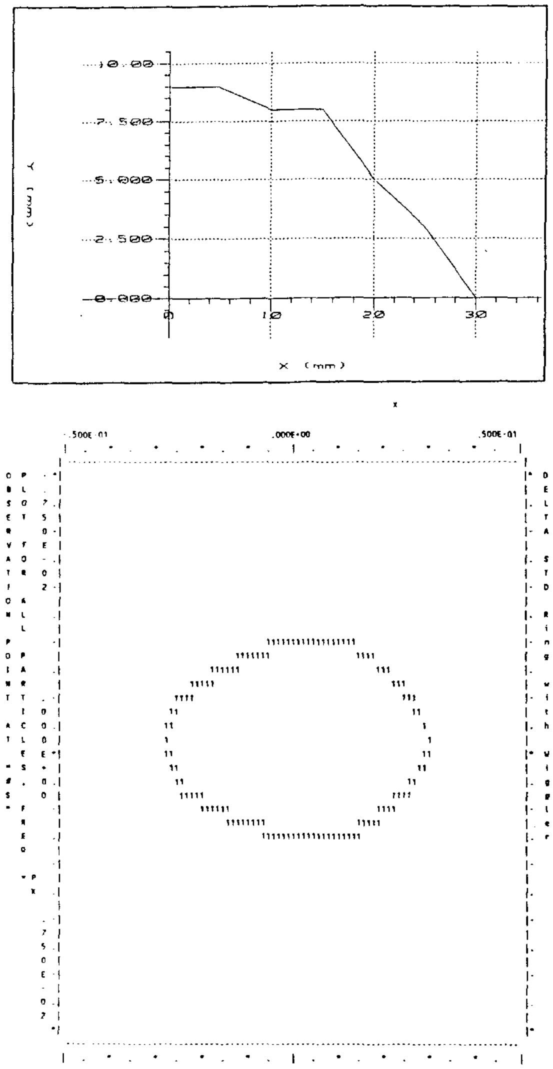

Fig. 5. (a) The dynamic aperture for the misalignment of STD optics with SCA wiggler. (b) The limit of the horizontal dynamic aperture for the alignment errors of the STD optics with the SCA wiggler.

about the beam axis, and δ is a measure of the skew with respect to the normal orientation. In this case, we used the data which were used in the SRRC lattice design[9] and LBL CDR[10] for input to the simulation code MAD. Fig. 7(a) and Fig. 8 show the reduction in the dynamic aperture when all the systematic and random errors from K1L to K9L are applied as input data for the tracking simulations. The data was obtained by tracking for

Table 6. Tune shift of LOW optics for the alignment errors

Magnets	Error components	Horizontal (dQ)	Vertical (dQ)
All	without	0.0	0.0
BM QM SM WM	same as Table 2	0.01106	0.01576

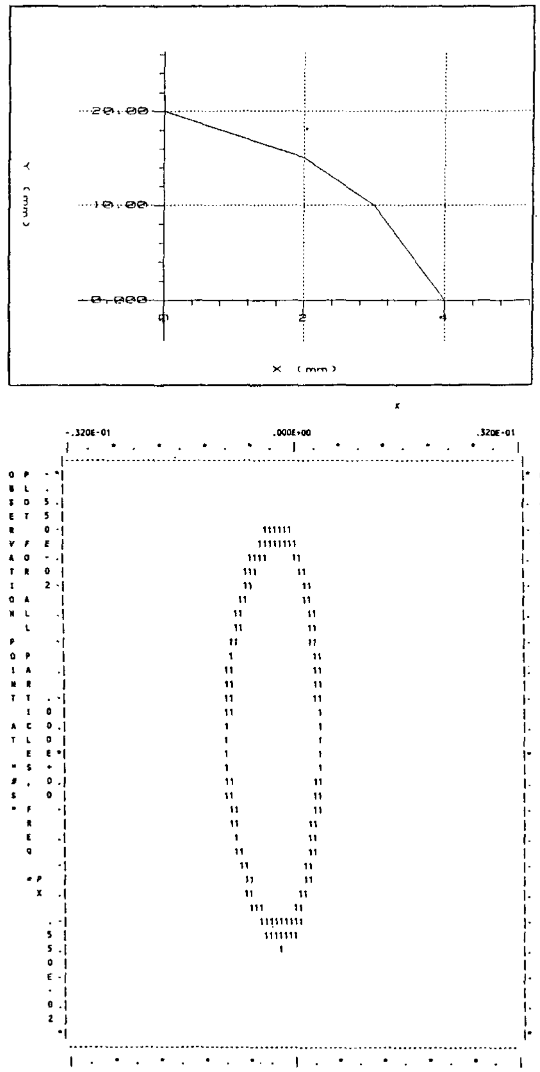

Fig. 6. (a) The dynamic aperture for the misalignment of LOW optics with SCA wiggler. (b) The limit of the horizontal dynamic aperture for the alignment errors of the LOW optics with the SCA wiggler.

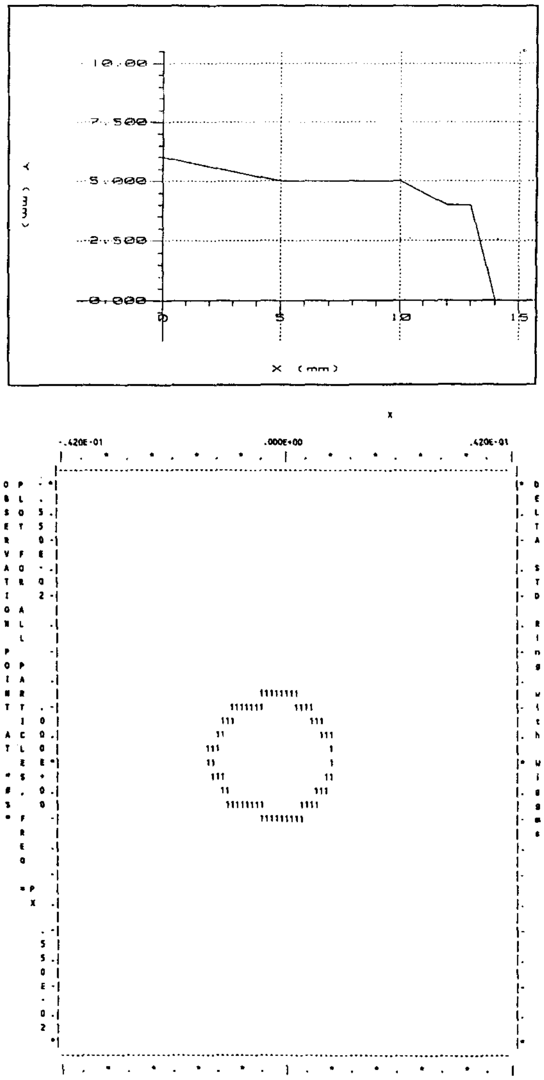

Fig. 7. (a) The dynamic aperture for the multipole errors of STD optics with SCA wiggler. (b) The limit of the horizontal dynamic aperture for the multipole errors (random/normal) of the STD optics with the SCA wiggler.

400 turns with MAD. The multipole error datas are used at both sides and middle of the all magnets in the storage ring. Phase-space plot of the dynamic aperture of STD optics for the random and normal multipole errors is shown in Fig. 7(b). Table 7 and 8 show tune shift of STD and LOW optics for the multipole errors.

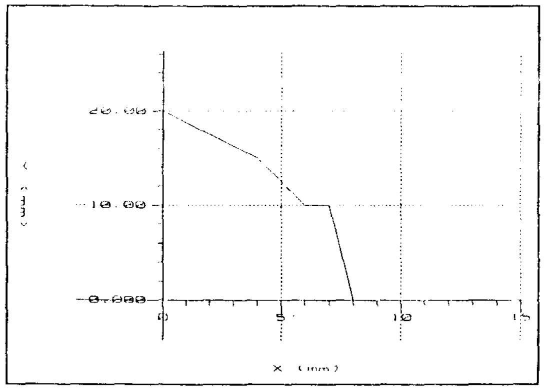

Fig. 8. The dynamic aperture for the multipole errors of LOW optics with SCA wiggler.

Table 7. Tune shift of STD optics for the multipole errors

Magnets	Error components	Horizontal (dQ)	Vertical (dQ)
All	without	0.0	0.0
BM QM SM WM	K1 to K9	0.01592	0.00343

Table 8. Tune shift of LOW optics for the multipole errors

Magnets	Error components	Horizontal (dQ)	Vertical (dQ)
All	without	0.0	0.0
BM QM SM WM	K1 to K9	0.03907	0.00220

3. Conclusion

The influences of the SC asymmetric multipole wiggler as an insertion device for DELTA ring are investigated for the nonlinear errects without errors, and with field errors, alignment errors and multipole errors. For the STD optics with SC asymmeric multipole wiggler, we see that it is reasonable optics for the several errors which was mentioned above. The horizontal and vertical emittances for 10% coupling are 2.9E-08 (without wiggler : 4.38E-8) mrad and 2.9E-09 (without wiggler : 4.38E-09) mrad. But in the case of LOW optics with SC asymmetric multipole wiggler, the reduction in the dynamic aperture is noticeable compare with STD optics with SCA wiggler because of the strong sextupole strength. We also see that the emittances with wiggler are lower than the without wiggler case.

For the worst scenario, all magnets of the storage ring are considered as the beam elements in which the errors occur in our calculations. Even in this cases, STD optics is tolerable for beam dynamics including dynamic aperture and tune shift for the all errors which is considered in our work.

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Reference

1. DELTA Group, DELTA status report (1990).
2. D. Schirmer, DELTA Int. Rep., 92-001 (1992).
3. K. Halbach, *Nucl. Inst. Meth.*, **187**, 109 (1981).
4. L. Smith, ESG TECH NOTE, 24 (1986).
5. D. Schirmer, DELTA Int. Rep., 92-004 (1992).
6. F. Christoph Iselin and J. Niederer, The MAD program, CERN/LEP TH., 88-38 (1988).
7. A. Wrulich, RACETRACK, DESY, 84-026 (1984).
8. M. Sands, SLAC Rep., 121 (1970).
9. SRRC Status Rep. (1988).
10. LBL PUB-5172 (1986).