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1.3 GeV SYNCHROTRON RADIATION FACILITY

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ABSTRACT

Design study of a low emittance 1.3 GeV storage ring for a synchrotron radiation facility has been carried out. Main feature of this study consists in achieving the emittance as low as possible with the edge focusing type triplet bending achromatic lattice. Moreover, for an efficient interaction between the beam and the radiation a high gain single pass FEL device is placed in a special bypass section, which is optimized for the wave length of 100 nm. The obtained emittance is $\sim 1.6\times10^{-8}$ πm·rad and the circumference of the storage ring is 126.0 m.

1. INTRODUCTION

Recently the synchrotron radiation is applied for various fields of research. Especially, in the VUV to X ray region very strong light sources with high brightness are required. So called insertion devices such as wiggler, undulator and FEL[1),2),3)] have become indispensable for present day experimental requirements. In the present study we present the results of our calculation of the storage ring which satisfy these requirements.

For the conventional use of this storage ring, we have set following criteria.

1) Electron energy of 1.3 GeV or more is necessary for the soft X ray production. (Brightness dependence on the wave length in the present work is shown in Fig. 1.)
2) The circumference is to be smaller than 130 m for the restricted available area. Therefore, linac and injection synchrotron must be placed inside of the storage ring.
3) The aimed emittance of the beam is $1\sim2\times10^{-8}$ πm·rad.
4) Several dispersion free long straight sections must be reserved for conventional insertion devices. In this section, the beam size and divergence should be smaller than 1 mm and 0.03 mrad, respectively.
5) The longer beam lifetime than 10 hours is assumed. Maximum beam current is more than 500 mA.

In addition to these criteria, we have to take into consideration of setting FEL in the bypass. Following requirements are to be satisfied.

6) For FEL operation, the storage ring should be stably operated in the energy of $600\sim800$ MeV.
7) High peak current of $100\sim200$ Amp. is required.
8) The FEL bypass will induce large perturbations to the electron bunch. So that the synchrotorn damping time should be small.

For the normal operation (bending magnet operation), the FEL bypass is made to be isolated from the main storage ring so as not to disturb the beam trajectory.

2. CALCULATION AND RESULTS

2-1. LATTICE

A layout of the storage ring and its injection systems are shown in Fig. 2 schematically. In order to achieve those conditions described above, especially to realize the emittance requirement, the use of larger number of the bending magnets are essential, we adopted the TBA (Triplet Bending Achromatic) lattice which consists of three edge focusing type bending magnets, four quadrupole magnets (QF1x2,QD1x2) to satisfy the achromatic condition, four quadrupole magnets (QF2x2,QD2x2) for betatron tune adjustment and four sextupole magnets (SF1x2,SD1x2) for chromaticity correction. This lattice configuration is shown in Fig. 3. Six of this lattice and four 6 m dispersion free long straight sections compose the whole storage ring. We have adopted the outward slanted bending magnets with field strength of 1.26 T for 1.3 GeV operation. Since the magnets have a slant angle of 10°, the focusing effect is produced.

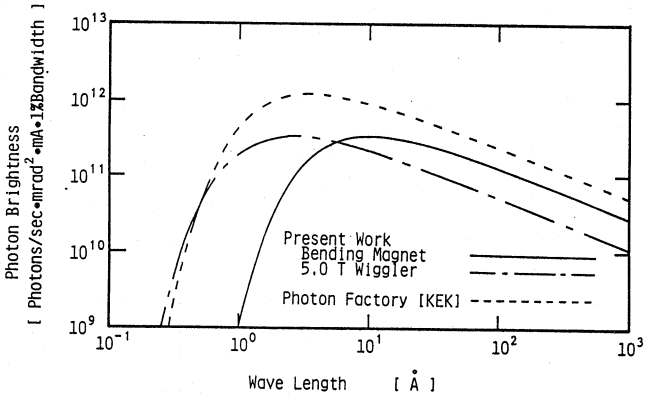

Fig. 1. Spectral distribution of the synchrotron radiation.

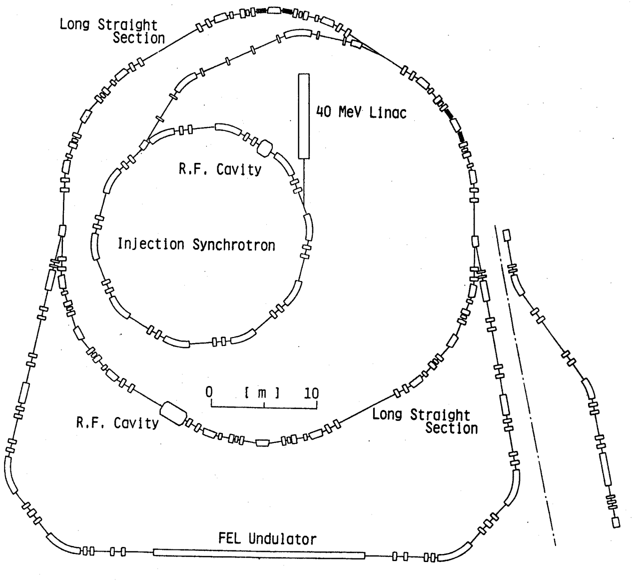

Fig. 2. Layout of the 1.3 GeV synchrotron radiation facility.

For TBA lattice with ordinary sector type bending magnets, either large β_y value($70\sim80$ m) or large emittance with reasonable β_y value at QD2 results in the frame work of present design study. As mentioned above, therefore we adopted edge focusing to overcome these problems.

Finally determined lattice functions are shown in Fig. 4, which are adopted for normally operating storage ring (without wiggler). Design parameters of the storage ring are shown in Table 1. Achieved natural emittance is 1.566×10^{-8} πm·rad, and the

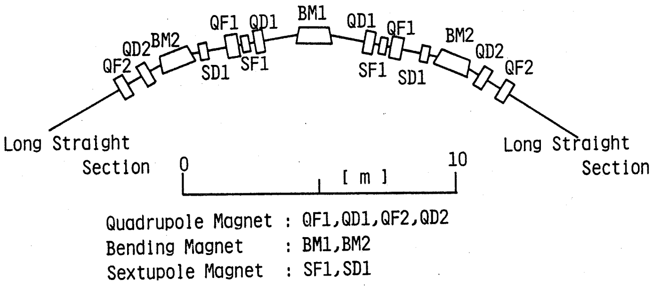

Fig. 3. TBA Lattice configuration.

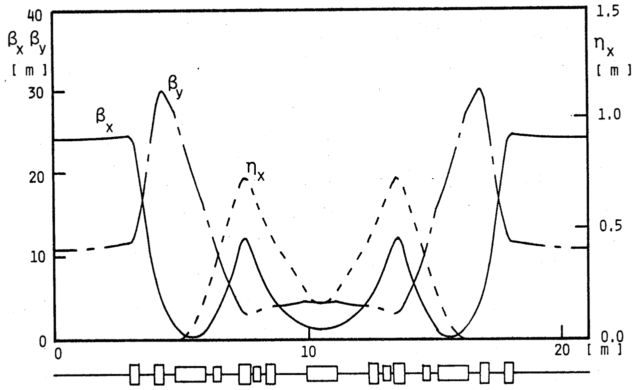

Fig. 4. Lattice functions through a unit cell.

circumference is 126.0 m. The betatron tune (ν_x,ν_y) for normal operation mode is (7.78,2.72). Since the natural chromaticity of the lattice designed for low emittance beam is usually rather large, strong sextupole magnets for the correction are needed. This lattice also has strong sextupole magnets(k_s=2.0 m^{-2}) and considerably narrow dynamic aperture. Therefore, the tracking code (that is somewhat similar to "PATRICIA"[4]) included in "MAGIC"[5] revised at KEK is used and the search of the good operation modes with large dynamic aperture is made. As a result,we found two operating modes. One is the normal operation mode described above. However, in this operation mode the storage ring is sensitive to quadrupole magnet error because of $\sim$1/2 of the vertical betatron tune through one lattice. Another operation mode is (7.78,2.36). This operation mode, however, is more stable than the normal operation mode, the emittance becomes a little bit larger and dynamic aperture smaller. This operation mode will be used as a wiggler insertion mode. The betatron tune will have to be corrected by quadrupole magnets (QF2,QD2) in the wiggler section before injection. The dynamic apertures for these operation modes are shown in Fig. 5. We also show the horizontal phase space trajectory in Fig. 6.

In both operation modes, the dispersion in the long straight section is completely zero and beam size requirements are fully satisfied.

2-2. EFFECTS OF THE FIELD ERRORS

The lattice structure designed for the low emittance and achromatic operation is susceptible to the field errors. In the normal operation mode, because of $\sim$1/2 of the vertical betatron tune through one lattice, especially the field error of the quadrupole magnet QD2 affects the operation. This behaviour is shown in Fig. 7. The stability of the quadrupole magnets will have to be smaller than $\sim 2\times10^{-4}$ to maintain β_y within ±1%. Furthermore, the closed orbit displacement(COD) is also large because of the strong quadrupole magnetic field of QF1.

TABLE 1. Design Parameters of the Storage Ring.

Energy	E	1.3 GeV
Critical Wave Length	λ_c	0.873 nm
Circumference	L	126.0 m
Bending Magnet:	No.	18
	Field	1.26 T
	Length	1.20 m
	Type	20° Edge Focusing
Quadrupole Magnet:	No.	48
	Field Gradient	< 9 T/m
	Length	0.35 m x36 0.45 m x12
Sextupole Magnet:	No.	24
	Field Gradient	< 70 T/m²
	Length	0.30 m
Betatron Tune	ν_x, ν_y	7.78 , 2.72
Chromaticity	ξ_x, ξ_y	-19.9 , -5.13
Momentum Compaction	α	0.005223
R.F. Frequency	f_{RF}	500.0 MHz
Harmonic Number	H	210
R.F. Voltage	V_P	500 kV
Radiation Loss	U_0	73.53 keV/turn/el.
Natural Emittance	ε_{x0}	$1.566\times10^{-8}\pi$ m·rad
Damping Time	τ_x	14.11 msec
	τ_y	14.86 msec
	τ_e	7.64 msec
Beam Current	I_B	500 mA
Touschek Lifetime	τ_T	21.0 hours

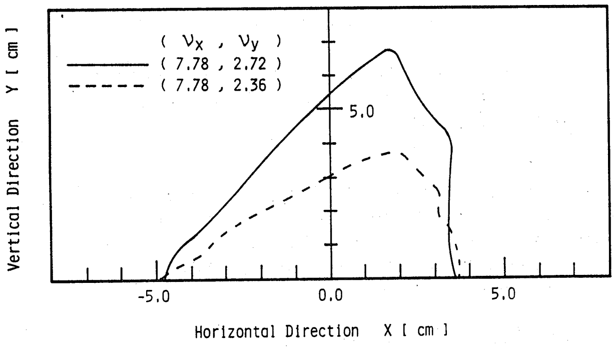

Fig. 5. Dynamic apertures of the storage ring at the center of the long straight section for the two operation modes.

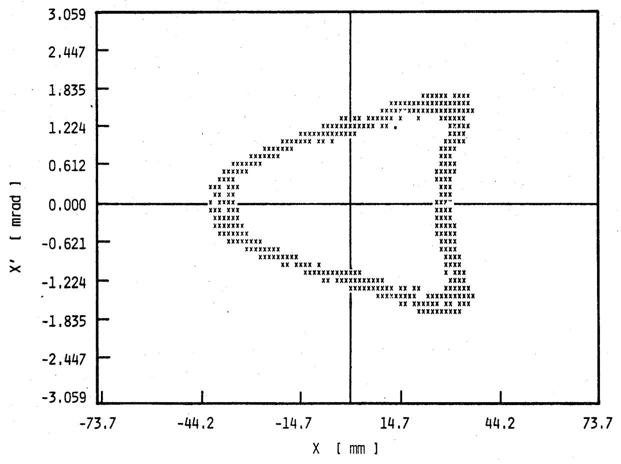

Fig. 6. Horizontal phase space trajectory. (Normal operation mode.)

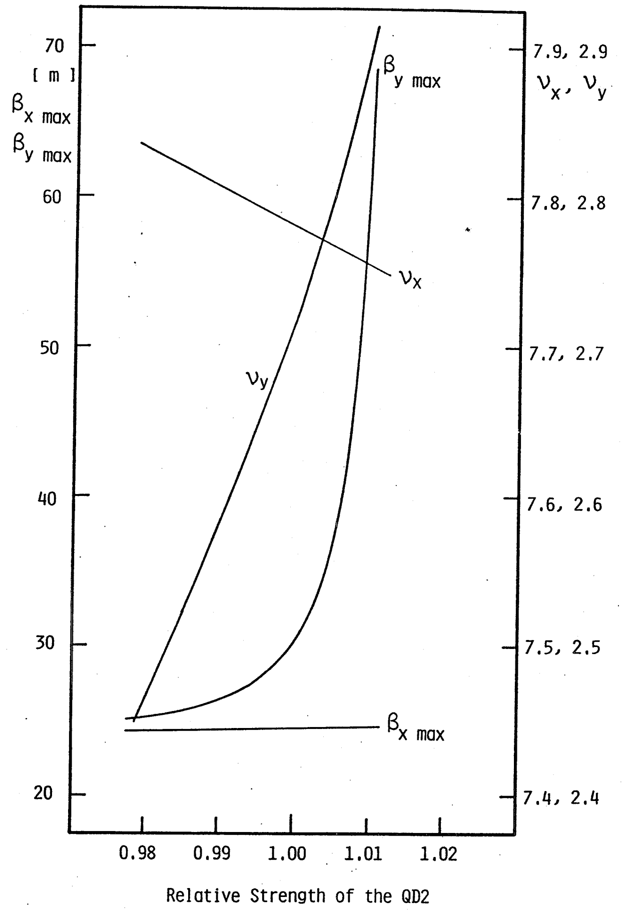

Fig. 7. The maximum β functions and betatron tunes against the change of K value of the quadrupole magnet QD2.

We have estimated the COD for the normal operation mode. Since the largest value is ~20 mm, it must be corrected, especially for the injection. The tune spread caused by quadrupole magnet errors is $\sim 10^{-3}$ which is reasonably small.

2-3. BEAM LIFETIME AND R.F. SYSTEM

Reasonable Touschek lifetime[6] (~20 hours) is achieved with the R.F. peak voltage of 500 kV at 500 MHz. The relationship between Touschek lifetime and R.F. voltage is shown in Fig. 8. With this R.F.system we obtained following lifetimes. The quantum lifetime is supposedly almost infinite. Furthermore the lifetime of ~40 hours due to the scattering with residual gas at 1×10^{-9} Torr of CO equivalent pressure[7] may also be expected. Based on these lifetimes, we expect the beam lifetime of ~14 hours to be attainable. For FEL operation, the R.F. voltage shuold be raised to 1.2 MV for 750 MeV electron beam energy, because its high peak current of more than 100 Amp. demands the momentum acceptance of ~3% for reasonable Touschek lifetime.

3. FEL UNDULATOR AND BYPASS[1,2,3]

For the high gain FEL for VUV region, we have placed in the specially designed removable bypass a very long and high K value undulator. Here we consider the undulator for λ=100 nm. High gain FEL is designed by using the following equation;

$$\rho = \left[\frac{1}{16\pi}\,\frac{r_e}{e\,c}\,\frac{K^3[JJ]}{2(1+K^2/2)}\,\frac{\lambda}{\gamma^2}\,\frac{I_P}{\sqrt{\varepsilon_x\varepsilon_y}}\right]^{1/3} \qquad (1)$$

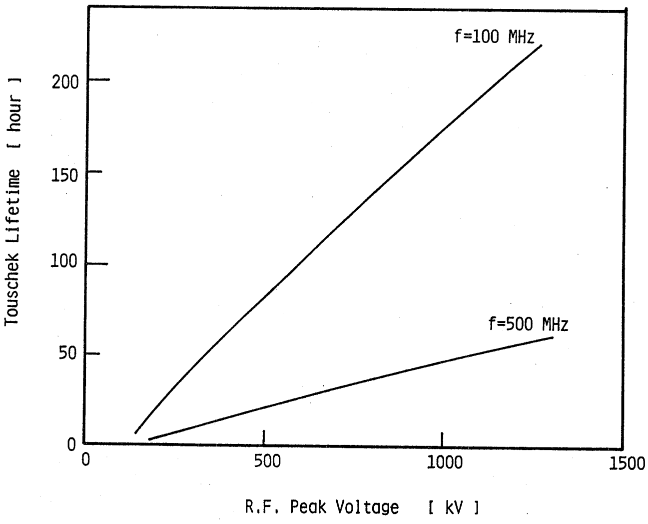

Fig. 8. Relation between Touschek lifetime and R.F. voltage.

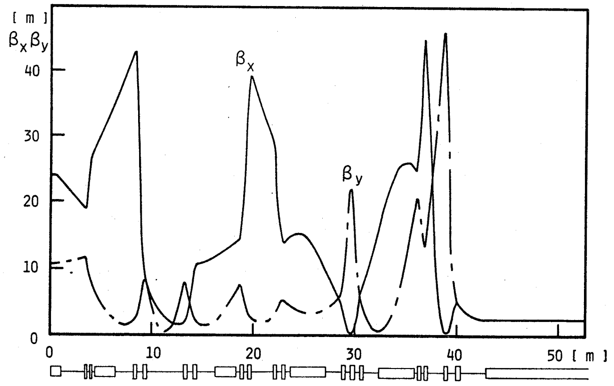

Fig. 9. β functions through the FEL bypass.

where $$[JJ]=\left[J_0\left(\frac{K^2}{4(1+K^2/2)}\right)-J_1\left(\frac{K^2}{4(1+K^2/2)}\right)\right]^2$$

r_e is classical electron radius, I_P is peak current. This equation is derived under the assumption of equal focusing force in the vertical and the horizontal directions in the undulator. In other words;

$$\beta_x=\beta_y=\frac{\lambda_u\gamma}{K\pi} \qquad (2)$$

We estimated these parameters as follows. The electron energy will be reduced to increase ρ value and for the present work we choose 750 MeV electron energy. I_P is limited by the microwave instability and I_P of ~100 Amp. is required for momentum spread σ_p=0.002. Beam emittance will increase from the natural emittance $\sim5\times10^{-9}$ to $\sim1\times10^{-8}$ πm·rad by the intrabeam scattering. The emittance coupling is assumed to be 10 %. To make the ρ value larger than 0.002 of σ_p, we determined K value of 3.8 which resulted ρ value of ~0.003.

The saturation period number N_{sat} obtained is

$$N_{sat}\sim 1/\rho = 330 \qquad (3)$$

The length of one period is λ_u=5.24 cm and the magnetic field along the undulator axis is 0.776 T. To satisfy our present criteria on FEL, we have to insert the undulator of length of ~20 m. Then, we will have peak laser power of ~200 MW. Assuming the beam pulse length of 100 ps and a repetition time of 100 ms, the average laser power becomes ~0.2 W.

The function of the bypass is to extract the electron bunch from the storage ring and to channel it with well defined shape through the FEL undulator. Then, the electron beam is reinjected into the storage ring with high transfer efficiency. The designed layout is shown in Fig. 2. Extraction from the storage ring will be done by horizontal deflection into the ordinary septum magnet. The FEL undulator is located 5 m under the median plane of the storage ring. The optical properties of the undulator demand electron beam parameters of $\beta_x=\beta_y\sim 6$ m (given from eq. 2), $\alpha_x=\alpha_y=0$, and $\eta_x=\eta_y=0$ at the entrance to the undulator. The β functions through the bypass are shown in Fig. 9. This bypass has many elements and very complicated β and η functions because of the level difference of 5 m between the storage ring and the undulator.

4. CONCLUSION

We have described results of conceptual design study of the 1.3 GeV electron storage ring using the new type of lattice with edge focusing bending magnet and obtained considerably good operational characteristics. Though the obtained parameters of either the storage ring or the FEL are not completely optimized, our feeling is like that the new magnet lattice structure is worthwhile to be considered for obtaining the low emittance for the future synchrotron radiation facility. Of course, furthere investigations for realization of the present proposal will be indispensable.

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