The 9th Symposium on Accelerator Science and Technology, Tsukuba, Japan 1993

Design Study on a High Brilliance Lattice of the PF Storage Ring

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Abstract

A high brilliance lattice of the PF storage ring is proposed. A small beam emittance of 27 nm-rad (about one fifth of the present value) can be achieved by doubling the number of the quadrupoles in the FODO cells. This emittance reduction will result in ten times brighter synchrotron light from the existing insertion devices. The problems incidental to the low emittance lattice, the small dynamic aperture and the short Touschek lifetime, will be discussed.

I. INTRODUCTION

More than ten years have been past since the start of the operation of the Photon Factory (PF) storage ring [1]. In these ten years, many efforts have been made to achieve high beam current, long lifetime, high stability and low emittance. Now the ring stores 300 mA positron beam with the lifetime of more than 50 hours and with the excellent beam stability. The beam emittance was reduced from 460 nm-rad to 130 nm-rad by changing the beam optics in 1986, which resulted in about ten times brighter synchrotron lights.

The PF ring is, now, one of the best performance ring among the first and second generation synchrotron radiation sources. However, recently, some of the third generation synchrotron light sources have been successfully commissioned. Other several third generation sources are under construction and will be commissioned within several years [2]. The beam emittances of these rings are around 10 nm-rad, which are smaller by one order of magnitude than those of the older generation rings, and the brilliance of the synchrotron radiation, especially from the insertion devices, is higher by one or two orders of magnitude.

To compete with these new generation machines, a more emittance reduction in the PF ring is desirable. In this paper, a high brilliance lattice, which has a small emittance of 27 nm-rad, is proposed. The details of this upgrading program are described in Ref. [3].

II. LINEAR OPTICS

The emittance of the PF ring is mostly determined by the optics in the normal cells, whose basic structure is FODO. In Figure 1, the beam emittance of the ring is shown as a function of the horizontal betatron phase advance of a unit cell. For simplicity, it is assumed that the ring consists of FODO cells only. In the early stage of the ring operation, the phase advance was 90 degree. In the low emittance program in 1986[4], the phase advance was increased to 144 degree by reinforcing the magnet power supplies. As shown in Figure 1, this phase advance gave the minimum emittance for the present lattice structure. Thus, to reduce emittance more, some modification of the lattice structure is inevitable.

Since the ring has many beamlines and many users, its reconstruction should be done in a short period, hopefully within half a year. It should not require any changes of the existing beamlines. Thus the bendings should not be moved. A high cost performance is also desirable, of course.

Considering the requirements above, the lattice modification shown in Figure 2 seems to be most favorable. The numbers of the quadrupoles and the sextupoles in the normal cells are doubled. These magnets should be newly constructed since much higher filed gradients are required. In addition, they should be so-called Collins type not to disturb the synchrotron radiation extraction.

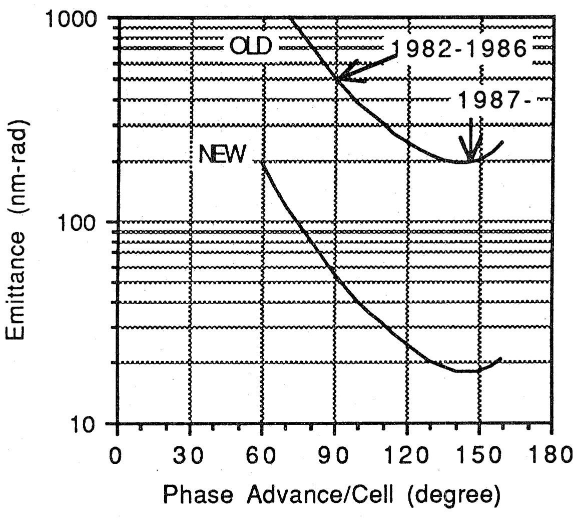

Figure 1. Beam emittance as a function of the horizontal phase advance of a FODO cell.
Note: For simplicity, the ring is assumed to consist of the FODO cells only. The upper curve is for the present lattice and the lower is for the new lattice. The operating points before and after 1986 are shown by arrows.

The emittance with these new normal cells is shown in Figure 1 as a function of the phase advance of a unit cell. Again, the ring is assumed to consist of the normal cells only. The emittance of around 20 nm-rad can be achieved for the phase advance of around 145 degree. Similar lattice modification was applied to the low emittance program of SRS and successfully reduced the emittance from 1500 nm-rad to 110 nm-rad [5].

The optics of the whole ring was designed for three cases of the phase advance, 90, 105 and 135 degree. The emittance is 44, 33 and 27 nm-rad, respectively. The phase advance larger than 135 degree did not give smaller emittance. The optical functions of the 135 degree lattice are shown in Figure 3. The beam parameters are summarized in Table 1.

A unique feature of this new configuration is that, by turning off some of the magnets in the normal cells and changing polarities of some others, an optics almost same as the present one can be realized. This enables us to start the operation just after the reconstruction work with our accustomed optics.

III. DYNAMIC APERTURE

Because of the small dispersion and the larger chromatisity, the sextupoles are required to be at most ten times stronger than the present ones. Their strong non-linear fields result in a small dynamic aperture as shown in Figure 4. With a simple two-family sextupole correction scheme, the dynamic aperture of the 135 degree lattice is smaller than the physical aperture and may be a serious problem for the operation. A more sophisticated sextupole correction scheme should be adopted in this case. The commissioning of the new lattice will be started with the 90 degree optics and then the smaller emittance optics will be challenged.

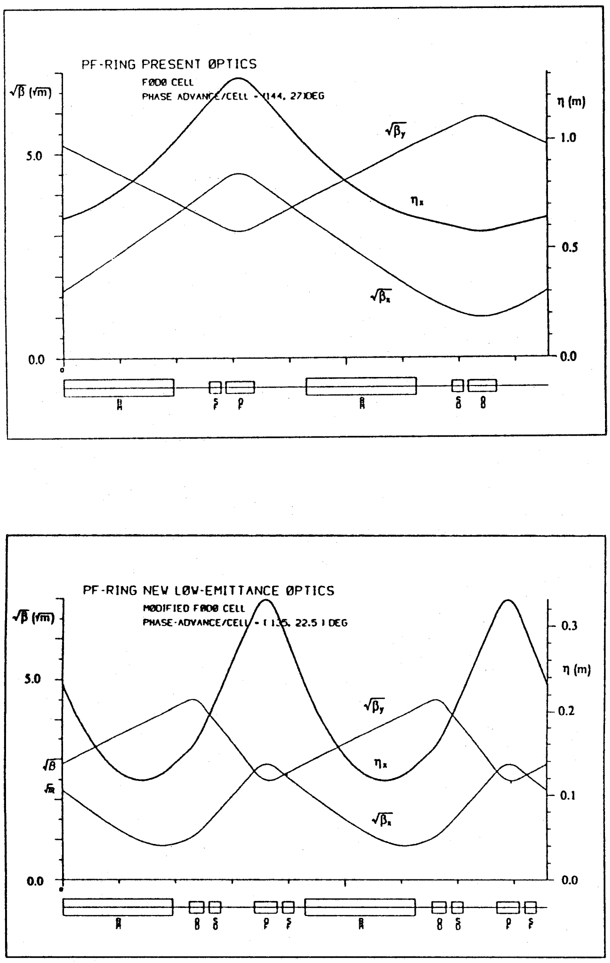

Figure 2. Optical functions of a FODO cell. Upper figure is the present lattice and the lower is the new lattice.

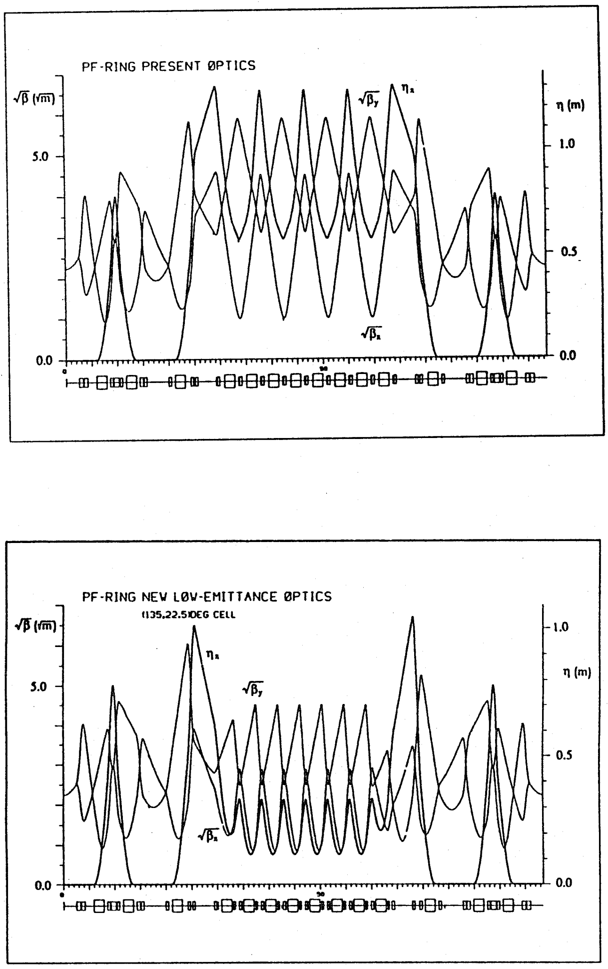

Figure 3. Optical functions of a half of the ring. The upper figure is the present optics and the lower is the new high brilliance lattice.

Table 1
Beam Parameters

	high-ε optics	medium-ε optics	new low-ε optics (90deg)	new low-ε optics (105deg)	new low-ε optics (135deg)
emittance[nm-rad]	460	130	44	33	27
energy spread	7.3×10^{-4}	7.3×10^{-4}	7.3×10^{-4}	7.3×10^{-4}	7.3×10^{-4}
momentum compaction factor	0.040	0.016	0.0079	0.0061	0.0043
betatron tune(H)	5.40	8.44	9.27	9.85	10.85
(V)	4.20	3.30	3.67	4.20	4.20
chromatisity(H)	-6.5	- 13.5	- 12.2	- 14.1	- 16.1
(V)	-5.1	- 9.0	- 10.4	- 12.0	- 13.3
RF voltage [MV]	3.3	1.7	1.5	1.5	1.5
synchrotron tune	0.051	0.023	0.015	0.013	0.011
bunch length [cm]	1.70	1.52	1.14	1.00	0.84

Note : The "high-ε optics" is the one used before 1986. The "medium-ε optics" is the present one. The "new low-ε optics"s are the new high brilliance optics.

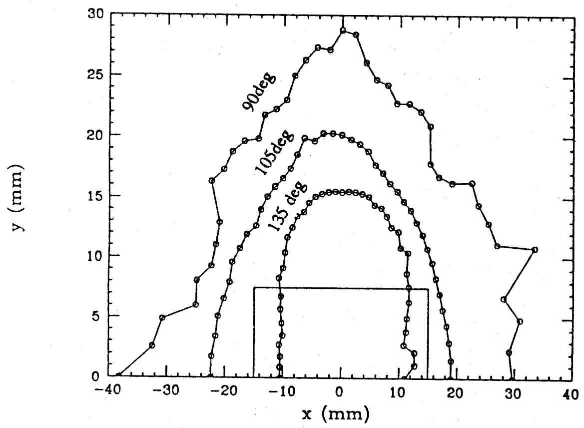

Figure 4. Dynamic Aperture of the high brilliance lattice. Those of the 90deg, 105deg and 135 deg lattice are shown. The square in the figure indicates the physical acceptance.

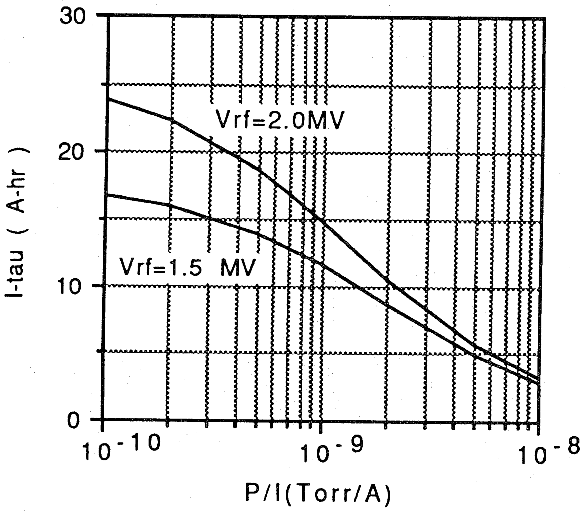

Figure 5. Beam lifetime as a function of the average pressure (normalized by the beam current). The lifetime is expressed as a product of the lifetime and the beam current. Touschek scattering and the residual gas scattering are included in the calculation. Two cases of the RF voltage (2.0MV and 1.5MV) are calculated as indicated in the figure.

IV. BEAM LIFETIME

The beam lifetime of the PF ring is now determined by the residual gas scatterings [6]. For the new optics, because of the smaller beam dimensions (about one fifth) and the shorter bunch length (about one half), the particle density is ten times higher and the Touschek scatterings will be as important as the gas scatterings. Considering these two effects, the beam lifetime was estimated for two cases of the RF voltage, as a function of the average pressure in the beam pipe (normalized by the beam current). The result is shown in Figure 5. The pressure around 10^{-9} [Torr/A] is expected to be achieved. For the beam current of 300 mA, the lifetime is about 40 hours for the RF voltage of 1.5 MV and 50 hours for 2.0 MV. According to the RF reinforcement plan [3], the RF voltage of 2.0 MV will be possible. Thus, although the lifetime will be somewhat shorter than present typical value (about 60 hours), it will be still long enough for a continuous 24 hours operation without a beam injection.

V. SUMMARY

A high brilliance lattice of the PF storage ring is proposed. The beam emittance of 27 nm-rad can be achieved by doubling the quadrupoles and sextupoles in the normal cells. The small dynamic aperture may be serious problem in the machine operation. Some sophisticated sextupole correction scheme should be applied for the smallest emittance optics. The beam lifetime of more than 40 hours can be achieved in spite of the strong Touschek effect. The increases of the brilliance of the synchrotron radiation are described in ref [3]. For all the existing beamlines, the brilliance is increased by factors from 5 to 10.

VI. REFERENCES

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