The Proposed Low Emittance Lattice for the PF Storage Ring

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Abstract

The beam emittance of the Photon Factory storage ring can be reduced by doubling the number of the quadrupoles and sextupoles in the FODO cells, to less than 44 nm-rad and possibly to 27 nm-rad, depending on the dynamic aperture. The prototypes of the magnets for the new lattice were designed and fabricated, and the field measurement is under way.

1. INTRODUCTION

The performance of the Photon Factory (PF) storage ring has been steadily improved since the start of its operation in 1982 [1]. Now the ring stores 300 mA positron beam on average with a lifetime of more than 60 hours. The beam energy is normally 2.5 GeV and can be ramped up to 3 GeV.

The beam emittance, which had been 460 nm-rad in the early stage of the operation, was reduced to 130 nm-rad by changing the quadrupole strengths in 1986. However, the emittance is still larger than those of the third generation synchrotron light sources by one order of magnitude [2] and the brilliance of the SR beam from insertion devices is smaller by one or two orders of magnitude.

To compete with the new generation machines in the next decade, a more emittance reduction is desirable. In this paper, a low emittance lattice is described, in which the emittance could be reduced to 27 nm-rad. The details of this upgrading program are described in Ref. [3], [4].

2. LINEAR OPTICS

The basic lattice structure of PF is FODO (see Figure 2).. The normal cells occupy one third of the ring and determine the beam emittance. As shown in Figure 1, the emittance depends strongly on the horizontal betatron phase advance of a unit cell and has a minimum at around 145 degree. In the low emittance program in 1986 [4], the phase advance was increased from 90 degree to 144 degree by reinforcing the magnet power supplies. Thus, to reduce emittance more, some modification of the lattice structure is inevitable.

We have selected a lattice shown in Figure 3 as the most favorable one. No change is required for the bendings. This would minimize the influence on the existing SR beam lines. The quadrupoles and the sextupoles are doubled in number and reinforced. The emittance with this new lattice is shown in Figure 1. The emittance of around 20 nm-rad can be achieved

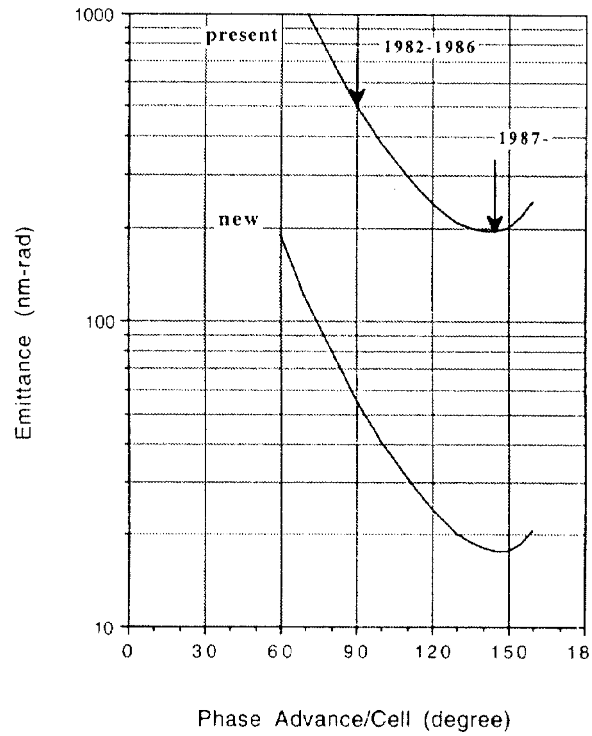

Figure 1. Horizontal betatron phase advance vs. Emittance. It is assumed that the whole ring consists of normal cells only. The upper curve is for the present lattice and lower is the new one (see Figure 2 and 3). The operating point before and after the 1986 low emittance program is shown by arrows.

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.

for the phase advance of around 145 degree.

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 5. The beam parameters are summarized in Table 1.

By turning off some of the magnets and changing the polarities of some of others in the normal cells, an optics almost same as the present one can be reproduced. This enables us to re-start the operation just after the reconstruction work with our familiar optics.

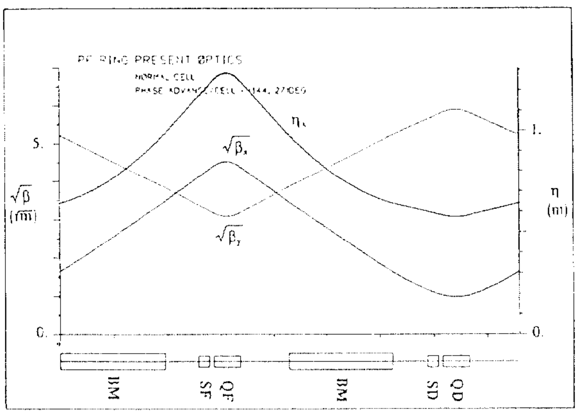

Figure 2. The optical functions of the present FODO cell. The phase advances are 144 degree in horizontal and 27 degree in vertical.

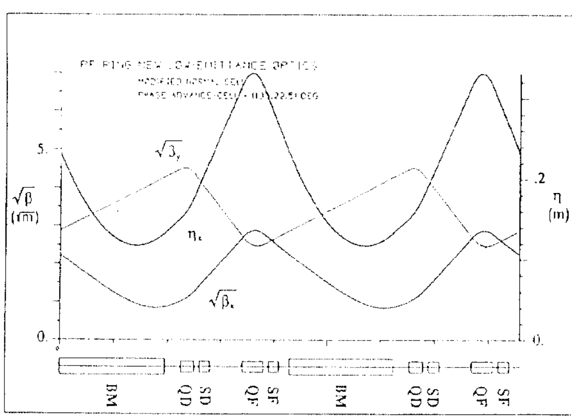

Figure 3. The optical functions of the normal cell for the new low emittance configuration. Two unit cells are shown. The phase advances are 135 degree in horizontal and 22.5 degree in vertical.

3. MAGNETS

All the present quadrupoles and sextupoles in the normal cells will be replaced with the new magnets with higher field gradiants. They are designed as Collins type, not to disturb the synchrotron radiation extraction to the existing beam lines. Their field strengths were determined so as to realize a 3 GeV operation with 135 degree lattice. Since the spaces are very limited, they have relatively short lengths and small bore diameters. The sextupoles have auxiliary windings for vertical steering. Their principle parameters are summarized in Table 2. The prototypes were already fabricated and the field measurements are under way.

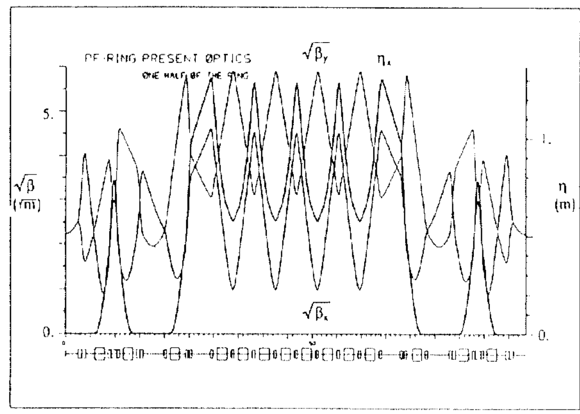

Figure 4. The optical functions of one half of the ring for present configuration.

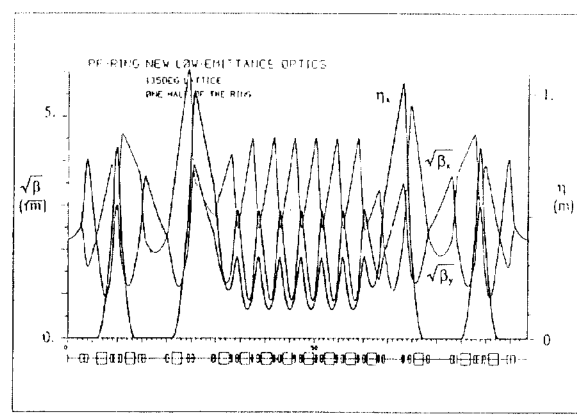

Figure 5. The optical functions of one half of the ring for new low emittance configuration.

Table 2
Parameters of the new magnets

	QF	QD	SX
Length(m)	0.4 m	0.25 m	0.20 m
Bore Radius	40 mm	40 mm	45 mm
Max. Field Strength	24 T/m	24 T/m	600 T/m^2

4. DYNAMIC APERTURE

In the new lattice, the sextupole fields will be stronger than the present ones by a factor of 5 to 10, to compensate the larger chromatisity with smaller dispersion. This strong non-linearity reduces the dynamic aperture significantly, as shown in Figure 6. With a simple two-family sextupole correction scheme, the dynamic apertures of 90 degree and 105 degree lattice are considered to be large enough for injection and storage. On the other hand, that of 135 degree lattice is almost as small as the aperture required for injection. A more sophisticated sextupole correction scheme may 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. In this sense, the emittance which can be achieved will depend on the dynamic aperture problem.

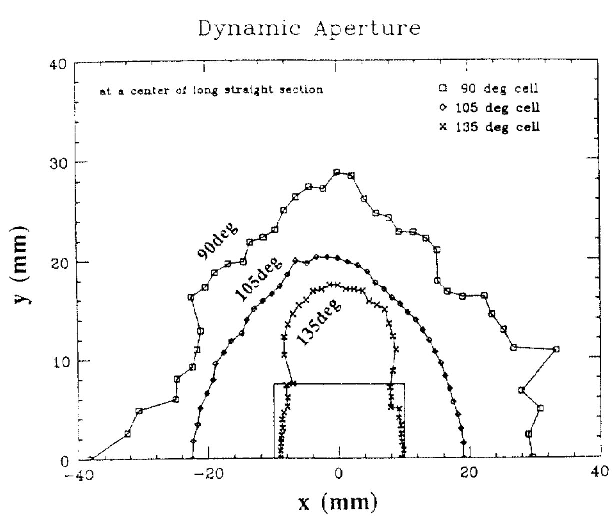

Figure 6. The dynamic aperture of the low emittance lattice. Those of 90, 105 and 135 degree lattice are shown. The square in the figure indicates the horizontal aperture required for injection and the vertical physical aperture determined from the narrow vacuum chambers at the insertion devices. The results without machine errors and energy deviation are shown here. With these errors, the dynamic aperture is reduced typically by 20%

5. SUMMARY AND CONCLUSION

The beam emittance of the Photon Factory storage ring can be reduced by doubling the quadrupoles and sextupoles in the normal cells. The small dynamic aperture due to the strong sextupole fields could be a critical problem in the commissioning of the new lattice. The commissioning will be started with a moderately small emittance optics whose dynamic aperture is expected to be large enough for injection and storage, and the smaller emittance optics will be challenged step by step. The smallest emittance which could be achieved is about 27 nm-rad, which is one fifth of the present value. The brilliance of the SR beam from the exsisting insertion devices would be increased typically by a factor of 10 [3], [4].

The beam lifetime, which is determined by the residual gas scattering for the present lattice [6], would be reduced by the strong Touschek effect for the new lattice. However the lifetime longer than 40 hours would be likely achieved [3], [4] It is shorter than the present value but still long enough for a continuous 24 hour operation without a beam injection.

The reconstruction work for the new configuration includes modification of the vacuum chambers and BPM's in the normal cells, reinforcement of the injection kickers, and so on, in adding to the reinforcement of the magnets and their power supplies. The details of the reconstruction is described in ref. [3] and [4].

The fabrication of the accelerator components has started in this year, 1994, and will be finished in 1996. In 1997, the reconstruction of the ring will be started and finished within a 6 month shut down.

6. REFERENCES

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