LOW EMITTANCE OPTICS AT THE PHOTON FACTORY

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Abstract

We successfully reduced the emittance of the Photon Factory storage ring (PF ring) to as low as 28 nm·rad, which is very close to the theoretical minimum (27.3 nm·rad) under the present lattice configuration. The new low emittance optics had been already tried, however, we could not examine it sufficiently because of a poor injection rate. Recently, new kicker magnets developed for the new optics were installed in the ring. Since the injection rate of more than 1 mA/sec became steady, the new optics was fully examined. No difficulty was found up to the stored current of 500 mA. The operation with the new optics for users' experiments will start in near future.

INTRODUCTION

Figure 1 shows the lattice configuration of PF ring which was reconstructed in order to realize the low emittance optics in 1997 [1]. Since then, the ring has been operated with the optics having the emittance of 35.7 nm·rad at 2.5 GeV, which is one-fourth smaller than previous one (130 nm·rad). It was clearly known that we could reduce the emittance by increasing the horizontal phase advance of normal cell in the arc sections of the ring. However, the stronger focusing makes the dispersion function smaller, therefore, the strength of sextupole magnets should be larger in order to correct the chromaticity, resulting in a very narrow dynamic aperture due to the large non-linearity produced by the sextupole magnets [2]. This makes the beam injection very difficult. In order to improve the injection rate, we designed new travelling wave kicker magnets, and installed them in October 2002 [3]. In this paper, we will introduce the optics with the emittance of 28.0 nm·rad, and show the results of measurements carried out in the machine development.

LOW EMITTANCE OPTICS

The horizontal phase advance of normal cell in present optics is set to be 105 degree. The emittance is 35.7 nm·rad. If the phase advance is set to be 125 degree, the emittance is reduced to 28.0 nm·rad. We call the optics as low emittance optics in this paper. Figure 2 shows the comparison of optical functions between present and low emittance optics in some normal cells. It is clearly found that the dispersion function of low emittance optics is much smaller than that of present optics. Both of optical functions of the ring measured using the response matrix methods [3] are shown in Fig. 3. The comparisons of dynamic apertures are shown in Fig. 4. It is clear that the horizontal aperture of the low emittance optics is only one-half of that of present optics. This is reason why the beam injection is quite difficult.

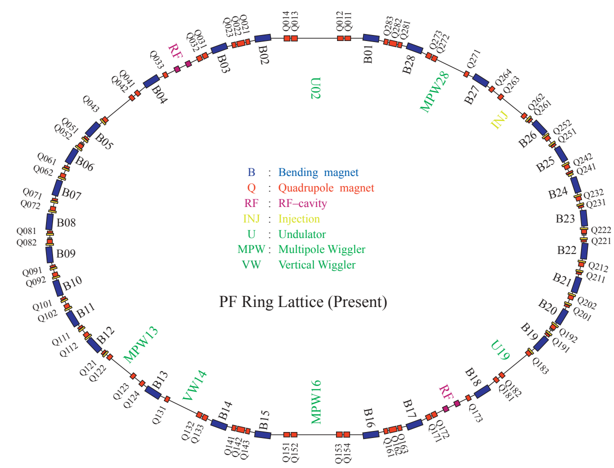


Figure 1: Lattice configuration of PF ring.

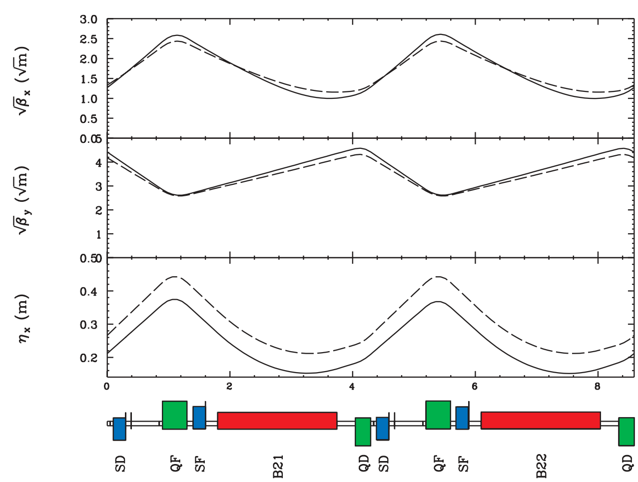
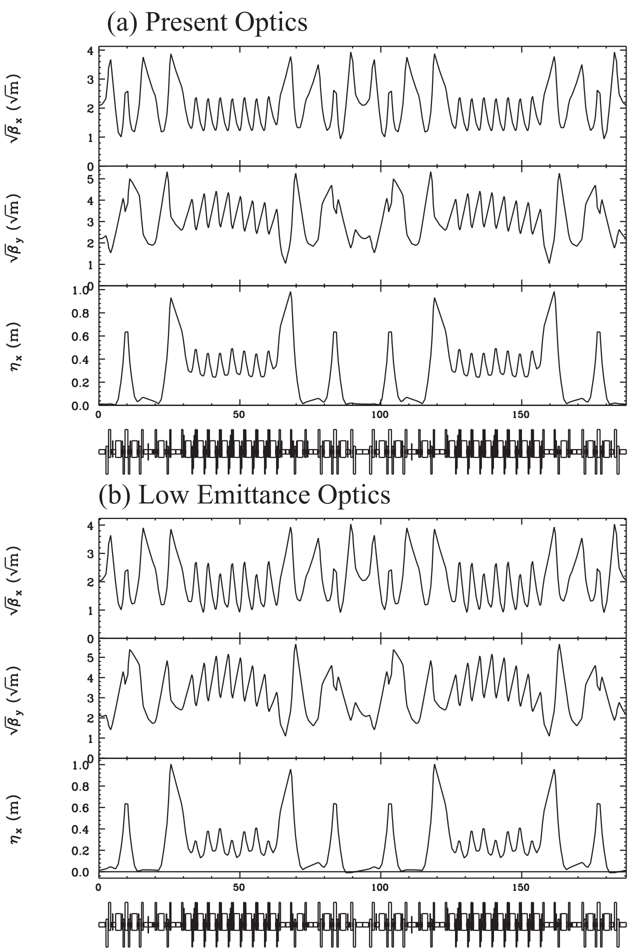


Figure 2: Comparison of optical functions between present and low emittance optics in some normal cells. The solid line shows low emittance optics, and the dashed line present optics.

INJECTION PARAMTERS

A set of parameters of the injection magnets is given in Table 1. The maximum kick angle of previous kicker magnets was limited to 3 mrad. As shown in Table 1,the kick angle of K3 and K4 magnets reached almost maximum value even in present optics. Since the kick angle required for the low emittance optics had been estimated to be more than 3 mrad, the beam injection was expected to be quite severe in the use of the same parameters. Actually, the injection rate was less than 0.2

mA/sec at a repetition rare of 25 Hz. New kicker magnets were designed to have maximum kick angle up to 3.5 mrad. They enabled us to set new injection parameters over 3 mrad for low emittance optics as shown in Table 1.



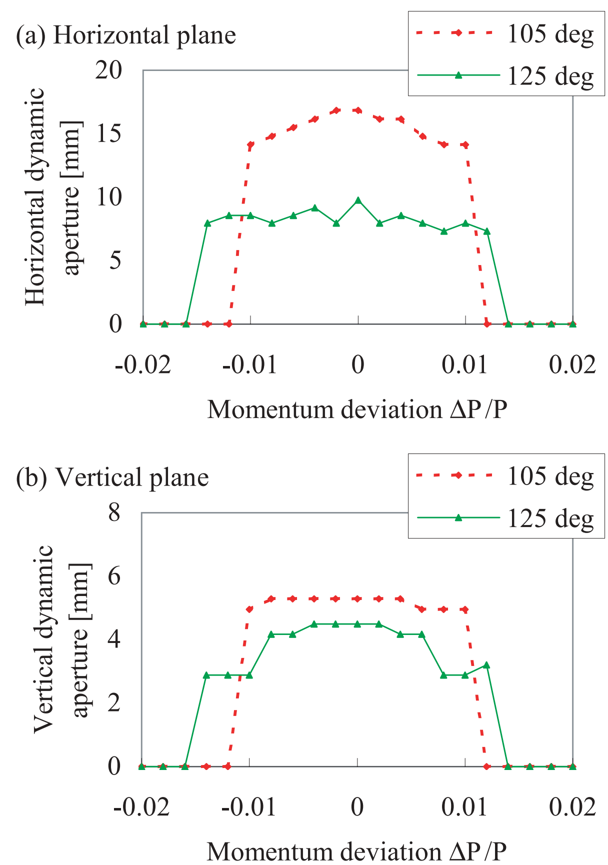
Figures 3: Fig. (a) shows optical functions of the ring for present optics, and (b) for low emittance optics.

Table 1: Set parameter of the injection magnets. The first initial K and S indicate kicker magnets and septum magnets, respectively.

	105 deg	125 deg
K1 (mrad)	2.507	3.107
K2 (mrad)	-1.649	-2.549
K3 (mrad)	2.928	3.428
K4 (mrad)	2.912	2.812
S1 (mrad)	117.74	117.64
S2 (mrad)	101.7	102.8

COHERENT OSCILLATION OF THE INJECTED BEAM

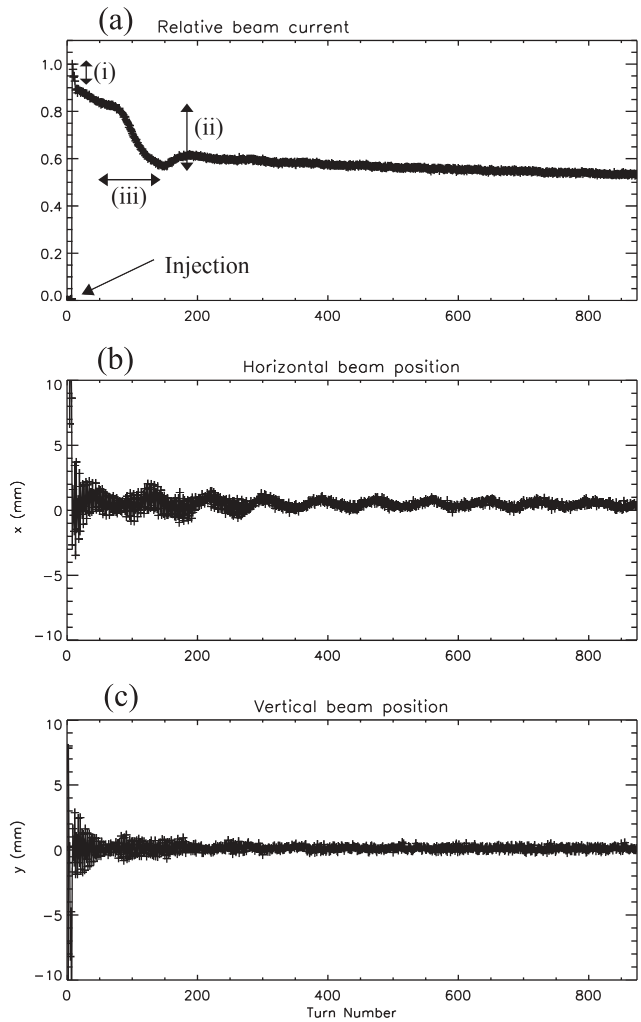
We measured the coherent oscillation of injected beam using turn-by-turn position monitor [5]. Before the measurement, the kicker parameters were roughly adjusted so as to increase the injection rate. Typical results of the measurement are shown in Figs. 5. During several turns just after the injection, the amplitude of the injected beam is so large to be scraped by the septum wall and about 10% of the injected beam is lost, indicated as region(i) in Fig. 5 (a). The damping time is about 11000 turns but the amplitudes of the injected beam rapidly decrease by the smear effect due to the non-linear fields, as shown in figures (b) and (c). The part of the beam indicated as region (ii) is injected outside of the dynamic aperture and lost in several hundred turns. In the region (iii), the beam current seems to be decreased, however, in this region, the bunch length may become long and it may cause the lower sensitivity of the beam monitor. The stored beam is cleared by the RF knock out before the next measurement. The optimization was done so as to minimize the beam loss in the region(i). The improvement of the injection rate is about 10% in this case.



Figures 4: Fig. (a) shows dynamic aperture at a center of 5m long straight in the horizontal plane, and (b) in the vertical plane. The solid line indicates the aperture for low emittance optics, and the dashed line for present optics.

OPTICS TUNING

Since the injection rate was strongly sensitive for the betatron tunes, we carried out the tune survey around the designed tune. The tune point giving the injection rate of 1 mA/sec at a repetition rate of 25 Hz was found and fixed. In this point we measured the response matrix of all steering magnet to investigate the beta functions, and also dispersion function as shown in Fig. 2(b). Through the analysis of the response matrix, we estimated that the emittance was 28.0 nm·rad, and that betatron tunes were $(\nu_x, \nu_y)=(10.42, 4.37)$. The values of tunes agreed well with those obtained from the tune measurement. The typical injection history is shown in Fig. 6.



Figures 5: Coherent oscillation of the injected beam:(a) shows the turn-by-turn relative beam current, (b) the horizontal beam position and (c) the vertical one. The horizontal axis indicates the turn number from the injection.

FUTURE PLAN

Even in low emittance optics the beam lifetime was quite long. When the beam current(I) was stored up to 450 mA, the beam lifetime(τ) was over 45 hours, and I·τ was over 1200 (A·min). These values are comparable for the present optics. It might be due to the XY coupling. In the next step, we challenge to minimize the emittance, which is 27.3 nm·rad. The minimum emittance will be realized when the horizontal phase advance of the normal cell is set to be 135 degree. We had tried this optics before installing new kickers, however, only the current of 4.6 mA could be stored without excitation of sextupole magnets. The dynamic aperture is, therefore, extremely small. It will be interesting to study this optics with the new kicker magnets.

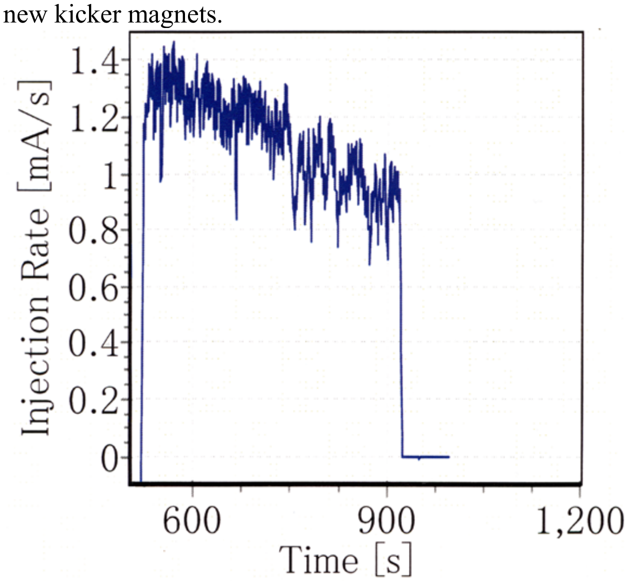


Figure 6: Typical injection history is shown when beam was stored from a current of 0 mA to 450mA .

SUMMARY

We tried to reduce emittance much less. The emittance of as low as 28.0 nm·rad was achieved under the new low emittance optics using new kicker system. Though the dynamic aperture was one-half of that of the present optics, the kicker system enabled us to improve the injection rate over 1 mA/sec at a repetition rate of 25 Hz. We measured the coherent oscillation of the injected beam, and found that over 50% of them were captured. Consequently, we could smoothly store the beam current up to 450mA, the nominal beam current at present PF ring.

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