OPERATION OF THE PHOTON FACTORY WITH A HIGH BRILLIANCE OPTICS

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Abstract

The Photon Factory storage ring was successfully re-commissioned after 9 months shut down for a reconstruction work toward low emittance. The emittance could be reduced down to 29 nm-rad which is close to the design goal. The users operation was started in this May with a moderately small emittance of 36 nm-rad, that assures a longer lifetime to keep average beam current higher than 300 mA with injections every 12 hours.

1 INTRODUCTION

The Photon Factory storage ring has been operated since 1982. In 1987, the emittance was reduced from 460 nm-rad to 130 nm-rad by optimizing the quadrupole field strengths in the normal cells[1]. However, the emittance was still larger by one order of magnitude than the typical value of the 3rd generation light sources. In Japan, there are a few proposals of third generation light sources in VUV and soft X-rays[2]. However none has been approved yet. To meet strong demands for high brilliance, a low emittance optics was designed and proposed for the Photon Factory[3].

Table 1: Beam Parameters

	old	new 90deg	new 105deg	new 135deg
Circumference	187 m	---	---	---
Energy	2.5 GeV	---	---	---
Emittance	130 nm-rad	45 nm-rad	36 nm-rad	27 nm-rad
Energy Spread	7.3×10^{-4}	7.3×10^{-4}	---	---
Mom. Comp. (α)	0.016	0.0079	0.0061	0.0043
Betatron Tunes	(8.44,3.30)	(9.15,4.20)	(9.85,4.20)	(10.85,4.20)
Chromatisity	(-13.5,-9.0)	(-11.8,-11.7)	(-12.5,-12.3)	(-16.1,-13.5)
RF voltage	1.7 MV	1.5 MV	---	---
Synchrotron Tune	0.023	0.015	0.013	0.011
Bunch Length	1.52 cm	1.14 cm	1.00 cm	0.84 cm

The new optics is realized by doubling the numbers of the quadrupoles and sextupoles in the normal cell sections. The smallest emittance which can be achieved is 27 nm-rad. Main beam parameters of the old and new optics are summarized in Table 1. The optical functions of these optics are shown in Figure 1.

A design report for this program was published in '93[4]. Soon after, R&D's on the accelerator components were started. Until the end of '96, developments and fabrications of all the components were completed. The storage ring was shut-down from Jan. to Sept. in '97 for the reconstruction works [5].

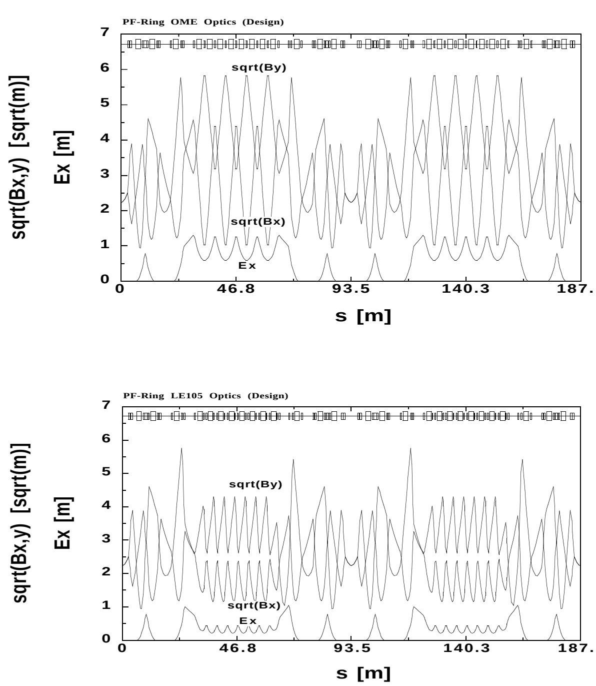

Figure 1: Old (upper) and new (lower) optics(105 degree). There are large changes in the normal cell sections but very little in remainder parts.

2 COMMISSIONING

Commissioning was started on Oct. 1st '97. Since users operation had been scheduled to start on Nov. 4th, we should have complete all the commissioning works within one month. To make them easier, we decided to start the operation with an optics very similar to the old optics which were familiar to us (even after the reconstruction, we can operate the machine with such an optics[4]). The emittance was 130 nm-rad and the dynamic aperture was expected to be sufficiently large.

On the first day, after adjusting the injection position and angle by utilizing a single pass beam position monitor[6], we confirmed the beam circulation of about 100 turns without RF. On the second day, a beam could be stored with RF on and without steerers excited. 10 days later, maximum beam current reached to 500 mA.

New vacuum chambers were not baked after the installation. The vacuum conditioning was done only through SR irradiation in the high current operation. About one month later, the average pressure normalized by beam current reached to $1x10^{-9}$ [Torr/A].

New damped RF cavities were successfully commissioned[7]. Any beam instability caused by the higher order modes of the cavities was not observed for the beam current as high as 400 mA.

A new beam position monitor system[8] and a new orbit stabilization system were also successfully commissioned[9]. The closed orbit can be measured with an accuracy of 1 μm (rms) and with a sampling speed of 100 Hz. By using these data, the orbit can be stabilized within 10 μm with a feedback cycle of 10 Hz.

The betatron tune shifts caused by wigglers are corrected by changing the near-by quadrupole strengths[10]. Tune shifts were measured for each devices and the correction parameters were re-taken. End correction parameters were also re-taken and the orbit movements were carefully checked for all the magnetic gap values of each insertion devices. After these works, users are allowed to change the magnetic gap values anytime during a run.

After all these machine tunings, the users operation was re-started on Nov. 4th with an emittance of 130 nm-rad.

Table 2: Summary of the low emittance operation

	design goal	achieved	users run
Emittance	27 nm-rad	29 nm-rad*	36 nm-rad*
XY coupling	< 2%	~1%*	~1%*
Maximum Beam Current	400 mA	400 mA	400 mA
Beam Lifetime (@300mA)	40 hr.	~12 hr.	~20 hr.

Note; *) These values were obtained from a beam size measurement.

3 LOW EMITTANCE OPERATION

Studies on the low emittance optics were done in parallel to the users operation, by utilizing the machine study time assigned on every Monday.

In figure 2, the emittance is shown as a function of the horizontal phase advance of the normal cells. The emittance has a minimum at 135 degree. A tracking study showed that, as the phase advance increases, the dynamic aperture gets smaller[11]. Thus, we started the low emittance operation at 90 degree.

During the first machine study, we could store a beam at 90 degree. Then we increased the phase advance step by step. We have succeeded to store a 400 mA for the phase advance between 90 degree and 125 degree so far. The design emittance for 125 degree is 30 nm-rad. We tried to store the beam at around 135 degree, but we still cannot. The main reason of this seems to be a small dynamic aperture. A further study will be done in future by utilizing a dynamic aperture measurement system[12].

In Table 2, the results of the machine studies are summarized. From a beam size measurement[13], the horizontal emittance was estimated to be 29 nm-rad for the 125 degree optics, that is very close to the design value, 30

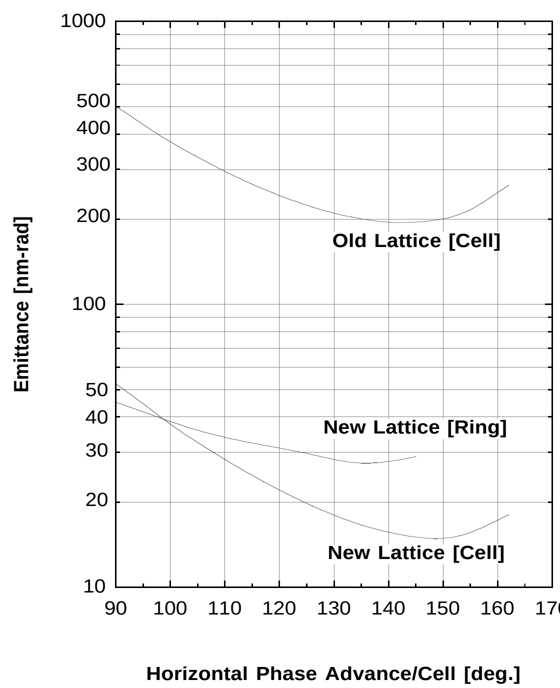

Figure 2: Emittance curve for old and new lattice. The natural emittance is shown as a function of horizontal phase advance of the normal cell. Upper curve is for old lattice. The lower two are for new one. Lines indicated as 'Cell' are curves for normal cells only. 'Ring' is for the whole ring (including the contribution from other parts).

nm-rad and is not so far from the minimum emittance of the new lattice, 27 nm-rad. As for the vertical emittance, a measurement by using an interferometer[14] was carried out. The result indicated a XY coupling of about 1%.

A high current accumulation was tested for 105 degree optics (36 nm-rad). A 500 mA beam in multibunch mode and 100 mA in single bunch mode could be stored.

In the low emittance optics, the gas scattering and the Touschek effect have almost same beam loss rate even for multibunch mode[4]. Touschek lifetime measured in single bunch operation is consistent with XY coupling of 1%.

In multibunch operation, a vertical instability due to ion trapping was observed. This was successfully suppressed with a 'partial filling' (successive 250 of 312 RF bucket are filled and remainders are empty) and by exciting octupole magnets.

Photon spectra of undulator radiation was measured at a beam line BL02 both for old (130 nm-rad) and new optics (36 nm-rad). Increases of the photon flux densities observed for 1st, 3rd and 5th harmonics agreed well with the calculation. The details of the measurement are described elsewhere[15].

After all these machine studies, we decided to start low emittance users operation at 36 nm-rad (105 degree phase advance; see Figure 2). This moderately small emittance was chosen to keep average beam current higher than 300 mA with injection twice a day. The tune correction parameters and the end correction parameters were re-taken for all the insertion devices. The orbit stabilization was carefully tested for the optics.

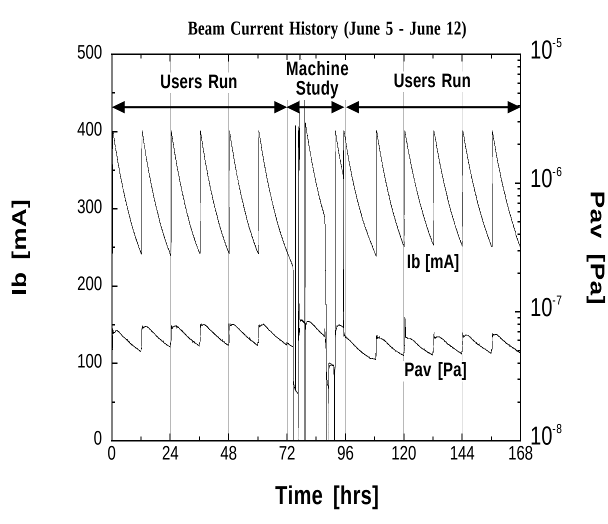

Figure 3: Typical beam current history for a week. The emittance is 36 nm-rad. Every Monday is assigned to machine studies and the remainder is for users.

After these works, users operation with low emittance started on May 15. The operation has been very stable. A typical beam current history in a week is shown in Figure 3. Injection is twice a day(9 a.m. and 9 p.m.). A run starts at 400 mA and ends at around 250 mA. The average beam current exceeds 300 mA.

4 SUMMARY

The Photon Factory storage ring is successfully in operation with a low emittance optics. The smallest emittance achieved so far is 29 nm-rad, which is close to the design goal. The users operation was started in May with a moderately small emittance of 36 nm-rad which gives a longer lifetime. Beam injection is twice a day and average beam current is about 300 mA. Users operation at 500 mA will be tested in this June. 3 GeV operation with low emittance will be tried in this Autumn. Users runs with smaller emittance will be tried after the ring vacuum is sufficiently recovered.

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6 REFERENCES

[1] Y. Kamiya et al., Proc. of 1987 IEEE PAC, 1, p.452 (1987)
[2] A. Ando, presented at 1st Asian Particle Accel. Conference (in Tsukuba) (1988)
[3] M. Katoh et al., Proc. of EPAC'94, vol.1, p.636 (1994)
[4] M. Katoh and Y. Hori (ed.), KEK-Report 92-20 (in Japanese) (1993)
[5] M. Katoh et al., Proc. of SRI'97 (to be published)
[6] T. Honda and M. Katoh, Proc. of EPAC'96, 2, p.1660 (1996)
[7] M. Izawa et al., presented at 1st Asian Particle Accel. Conference (in Tsukuba) (1988)
[8] K. Haga et al., in these proceedings
[9] T. Obina et al., in these proceedings
[10] M. Katoh et al., Particle Accelerators, 30, 1813 (1990)
[11] E. S. Kim, Y. Kobayashi and M. Katoh, Jpn. J. Appl. Phys., 96, p.7415 (1997)
[12] Y. Kobayashi et al., Proc. of EPAC'96, 2, 1666 (1996)
[13] T. Mitsuhashi et al., presented at 1st Asian Particle Accel. Conference (in Tsukuba) (1988)
[14] T. Mitsuhashi et al., in these proceedings
[15] Photon Factory Activity Report '97 (in preparation)