STRAIGHT-SECTIONS UPGRADE PROJECT OF THE PHOTON FACTORY STORAGE RING

T. Honda, S. Asaoka, K. Haga, K. Harada, Y. Hori, M. Izawa, T. Kasuga, M. Kobayashi, Y. Kobayashi, H. Maezawa, A. Mishina, T. Mitsuhashi, T. Miyajima, H. Miyauchi, S. Nagahashi, T. Nogami, T. Obina, C.O. Pak, S. Sakanaka, Y. Sato, T. Shioya, M. Tadano, T. Takahashi, Y. Tanimoto, K. Tsuchiya, T. Uchiyama, A. Ueda, K. Umemori, S. Yamamoto, KEK, Tsukuba, Japan

Abstract

We have proceeded with a large upgrade project to create six new straight sections and to lengthen the existing 8 straight sections for the Photon Factory storage ring. The lattice configuration around the straight sections will be modified by replacing the quadrupole magnets with new shorter ones and by placing them closer to the nearby bending magnets. The beam ducts in two thirds of the storage ring will be replaced by newly designed components. Although the new straight sections will be short as about 1.4 m, they will provide an opportunity to install short-period narrow-gap undulators. The extensions of existing straight sections will be taken advantage of updating the aged insertion devices to the latest models in future. The installation of the majority of new components will take place during a six-month shutdown in the first half of FY2005.

PF RING OPERATIONAL OVERVIEW

The Photon Factory (PF) storage ring was commissioned in 1982 as a dedicated 2.5-GeV synchrotron light source. The racetrack lattice of the PF ring is based on a FODO lattice and consisits of normal-cell sections and matching sections separated by several straight sections. Including two long straight sections of 5 m, 10 straight sections have been provided in the original design.

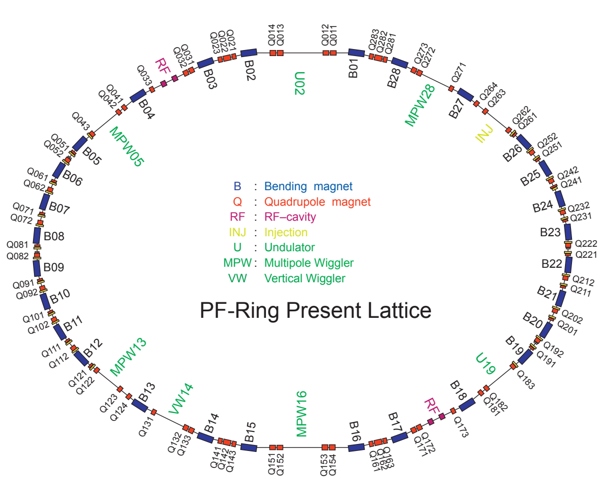

Figure 1: Present lattice of PF ring.

Three of them are occupied by an injection system and two RF acceleration stations. Using the other free straight sections, various insertion devices such as several type of undulators, a superconducting wiggler and multipole wigglers were installed and have been used for synchrotron radiation experiments from the early stage of the PF ring.

The original horizontal emittance 450 nm-rad was reduce to 130 nm-rad in 1986 by replacing a small number of quadrupole magnets [1]. During 1996-97, all four accelerating cavities were replaced with dumped type cavities having microwave absorbers against harmful higher-order mode [2]. In 1997, the emittance was reduced once more by a large reconstrunction of the normal-cell sections [3]. All quadrupoles and sextupoles making the FODO cells in the arc sections were replaced with new ones. Both type of magnets were doubled in number and were reinforced in field strength. This high brilliance arrangement shown in fugure 1 is the present lattice of the PF ring. The theoretical minimum emittance of the present lattice is 27 nm-rad. In order to avoid some difficulties resulting from the small dynamic aperture, usual operation for user time has been performed at a moderate emittance of about 36 nm-rad by slightly decreasing a phase advance of the normal cell.

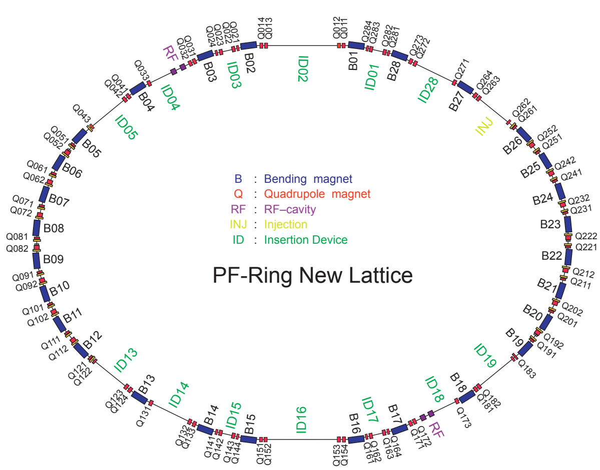

Figure 2: New lattice for the straight section upgrade project.

Manufacturing of travering wave kicker magnet proved successful and the new kicker system started the operation in 2002. By a shorter pulse length and a larger kick angle of the new system, a wide acceptance for the injected beam has been obtained. The efficiency and stability of the injection have been improved [4]. Study to search for practical operation near the theoretical minimum emittance is continued. A practical injection rate has been already achieved near the theoretical minimum [5].

For most user time, the PF ring is operated in a multiple bunch mode with an initial current of 450 mA. In 2004, the product of beam current I and the beam lifetime τ (Iτ) exceeds 1500 A min or τ exceeds 60 hours at I = 400 mA. Even though the emittance has been much lower, the beam lifetime recovers a comparable value as before the low-emittance reconstrucion in 1997 [6].

Table 1: Extension and production of straight sections.

Section	Length	Device at present
B01 - B02	9.0 m	U
B15 - B16	(5.0 m)	U/MPW
B03 - B04	5.7 m	* (RF cavities)
B13 - B14	(4.3 m)	VW
B17 - B18		* (RF cavities)
B27 - B28		U/MPW (elliptical)
B04 - B05	5.1 m	U/MPW
B12 - B13	(3.7 m)	U/MPW
B18 - B19		U (revolver type)
B26 - B27		(injection)
B02 - B03	1.4 m	*
B14 - B15	(0 m)	*
B16 - B17	- new straight	*
B28 - B01	sections	*

U: undulator, MPW: multipole wiggler,
VW: superconducting vertical wiggler,
*: new space for IDs.

During the summer shutdown of 2003, a new multipole wiggler [7] has been installed into BL-5, and a new beamline for protein crystallography has been commissioned. The BL-5 was the last free straight section in the present lattice. We have increasing needs for the undulator radiation in the x-ray range and continuous claims for various types of new insertion devices. In order to meet our demands, we contemplate the new upgrade program for the PF ring [8].

SUMMARY OF THE STRAIGHT-SECTIONS UPGRADE PROJECT

New lattice and optics

The main purpose of the straight-sections upgrade project is to produce new short-straight sections and to extend existing straight sections. Extensions and production of the straight sections are summarized in table 1 with the existing insertion devices. In order to realize this upgrade, all quadrupole magnets around the straight sections are to be replaced with new ones having shorter length and higher fields. The bore diameter of the newly designed quadrupole is 70 mm, while the original quadrupoles have a diameter of 110 mm and the quadrupoles of the normal cells have a diameter of 80 mm.

The new lattice designed for this upgrade project is shown in figure 2. All quadrupoles of the straight sections is rearranged in positions closer to their neighboring bending magnets. For example, the longest straight sections between bending magnets B01-B02 and B15-16 will be extended to 9.0 m from 5.0 m at present. The triplet quadrupoles at B02-B03 and its symmetry points will be replaced by a pair of doublets. As a result of this replacement, four new straight sections of 1.4 m will be produced between the doublets.

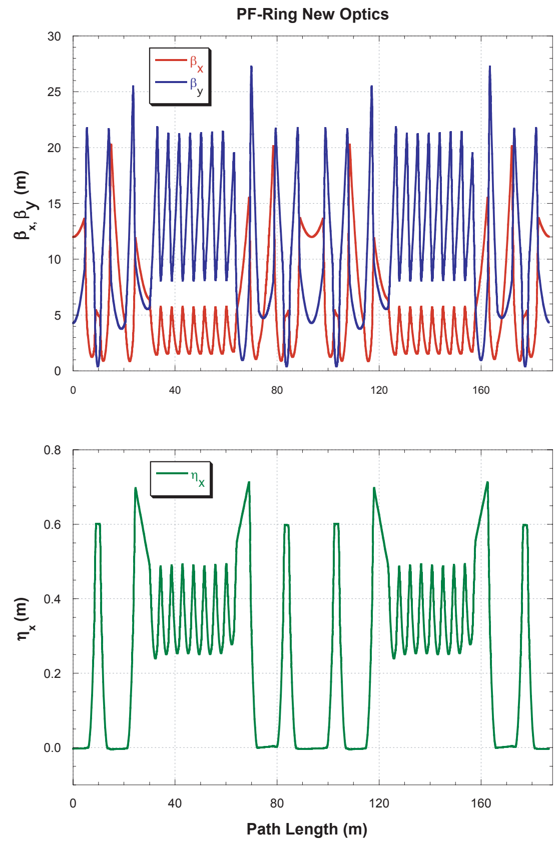

Figure 3: Optics for the straight-sections upgrade.

The betatron functions and the horizontal dispersion function prepared for the new lattice is shown in figure 3. General shapes of these functions are unchanged from those of the present optics. Without increasing the phase advance at the normal cell, the horizontal emittance of 28 nm-rad is expected for the new optics, slightly lowered than the present value of 36 nm-rad. The vertical betatron function, βy, takes a minimum value of 0.4 m at the centers of the new short straight sections. This is a result of optimization for a narrow-gap short-period undulator suitable for X-ray research fields, which is planned to be installed in that section.

The two RF cavity sections will also be extended by 1.4 m. Short-period undulators may also be installed in these short free spaces nearby the cavities. So after the upgrade project is accomplished, 13 straight sections will be available for insertion devices, while only 7 sections are available at present.

Vacuum system

Due to the change in bore of quadrupoles and their rearrangement, a number of beam ducts including those in twelve bending magnets will be replaced with newly designed components, though the RF cavities, the existing insertion devices and some beam diagnostic devices will survive. The range of the replacement extends to two thirds of the storage ring. Most of the aged vacuum components such as bellows without any RF shields will be swept away from the ring.

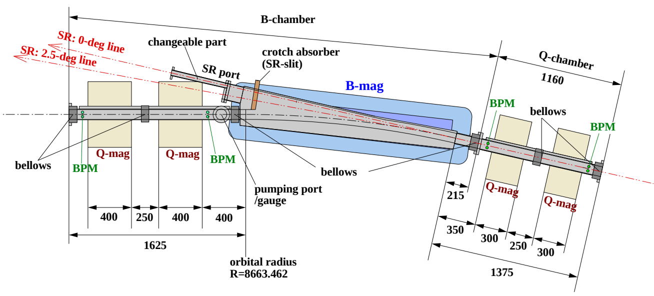

Figure 4: Conceptual chamber design.

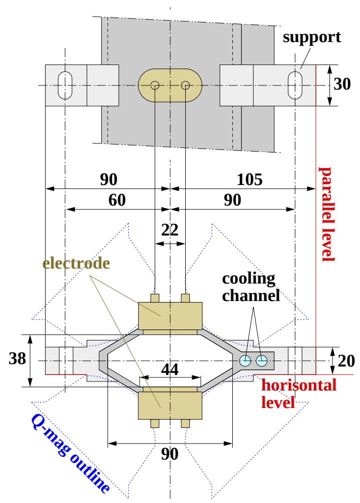

Figure 5: Design of beam position monitor.

Figure 4 shows the conceptual design of the beam duct around a bending magnet section. A beam position monitor (BPM) will be equipped nearby each quadrupoles. A cross sectional view of the BPM is shown in figure 5. Total number of BPMs in the PF ring will increase to 78 including 44 BPMs to be installed in the straight sections.

The BPMs and the crotch part of the synchrotron radiation (SR) port are fixed points of installation. So there is a bellows with RF contact at their intervals. Each BPM will be directly fixed to the magnetic pole of the quadrupole using a solid support with a required precision. The downstream part of the SR port is exchangeable to allow for difference in the source point and the acceptance of each beamline.

Insertion Devices

As described above, a short-period undulator is planned to be installed in a new short straight section of 1.4 m. The short-period undulator provides useful spectra at X-ray range including higher harmonics [8]. In order to obtain an optimal brilliance in those spectra, narrow gap configuration depending on in-vacuum technology is indispensable. A minimum gap of 4.5 mm is estimated to be practical since the very small βy will be realized in the new optics. It has been confirmed by calculation that the undulator spectra suitable for the X-ray fields such as structural biology can be obtained at several period lengths with a total magnetic length of 0.5 m.

UPGRADE SCHEDULE

The shutdown for the reconstruction of the straight sections is scheduled to take place from March to September, 2005. After a few-week re-commissioning period, the user time will be re-started in October, 2005.

Total number of quadrupoles to be replaced amounts to 46. Manufacturing all of the quadrupoles already finished in FY2003. In FY2004, all beam ducts necessary for the reconstruction will be manufactured. A reinforcement of the power supplies for the quadrupoles is another important matter of this upgrade project. The required power supplies will also be manufactured in FY2004.

For the rearrangement of quadrupoles, replacement of a lot of beamline front ends is inevitable. Installations of redesigned front ends already started in 2002. Thirteen beamlines are related to this project and most of them will be replaced in advance of the ring reconstruction.

REFERENCES

[1] Y. Kamiya et al., ”Low emittance optics of Photon Factory storage ring at KEK”, PAC’87, p455.

[2] M. Izawa et al., J. Synchrotron Rad. 5, p369 (1998).

[3] M. Katoh et al., J. Synchrotron Rad. 5, p366 (1998).

[4] Y. Kobayashi et al., “Injection performance with a traveling wave kicker magnet system at the Photon Factory storage ring”, PAC’03, p3204.

[5] K. Harada et al., “Low emittance optics at the Photon Factory”, PAC’03, p3201.

[6] S. Sakanaka et al., “Improvement in the beam performance by an RF phase modulation at the KEK Photon Factory storage ring”, EPAC’00, p690.

[7] K. Tsuchiya et al., “Design and construction of a new multipole wiggler (MPW#05) at the Photon Factory”, to be published in Proc. SRI’03, San Francisco, August 2003.

[8] S. Asaoka et al., “New upgrade project for the Photon Factory storage ring”, to be published in Proc. SRI’03, San Francisco, August 2003.