J. Synchrotron Rad. (1998). **5**, 366–368

Reconstruction for the brilliance-upgrading project of the Photon Factory storage ring

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(*Received 4 August 1997; accepted 20 October 1997*)

Reconstruction of the Photon Factory storage ring (PF ring; 2.5 GeV) is now in progress to provide very brilliant synchrotron radiation to users, *i.e.* the emittance is being reduced by a factor of five. Components, such as the quadrupole and sextupole magnets, vacuum chambers, beamlines and beam-position monitors, are being replaced by new ones in 16 normal-cell sections of the PF ring. The accelerating cavities, injection systems and control systems are also being replaced. Operation will commence when the improvements are completed on 1 October 1997.

Keywords: electron storage rings; low emittance; high brilliance; Photon Factory storage ring.

1. Introduction

The Photon Factory storage ring (PF ring; 2.5 GeV) has been operating since 1982 as a dedicated synchrotron radiation source with a critical energy of 4.0 keV from bending magnets. The beam lifetime (τ) and stored current (I_B) have been very high; *i.e.* their product ($I_B\tau$) was 1200 A min in user runs during the past years (Katoh *et al.*, 1995). At the end of the last user run in 1996, we succeeded in storing the highest beam current of 773 mA; the beam lifetime was about 700–1000 min at 650 mA.

In addition to such high performances of the PF ring, reconstruction is now in progress in order to reduce the emittance from 130 nm rad to 27 nm rad, and to obtain a brilliance ten times higher (Katoh *et al.*, 1993, 1995). By doubling the number of quadrupole magnets and sextupole magnets in a normal (FODO) cell, we intend to achieve such high brilliance without replacing any bending magnets; *i.e.* the synchrotron radiation source points will not be changed. We describe here the upgrade modifications of many components of the PF ring.

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Table 1
Beam parameters.

Low-ε optics are those with a horizontal phase advance of 135° in a FODO cell.

	Present	Low ε
Emittance (nm rad)	130	27
Energy spread	7.3×10^{-4}	7.3×10^{-4}
Momemtum compaction	0.016	0.0043
Betatron tunes	(8.44, 3.30)	(10.85, 4.20)
Chromaticity	(−13.5, −9.0)	(−16.1, −13.3)
RF voltage	1.7 MV	1.7 MV
Synchrotron tunes	0.023	0.011
Bunch length (cm)	1.52	0.84

2. Lattice and magnets

The FODO-type cells, which occupy one-third of the ring, are being modified for the high-brilliance configuration (Katoh *et al.*, 1994) as shown in Fig. 1. The quadrupoles and sextupoles are being doubled in number and reinforced in field strength. The optics of the whole ring has been designed for three cases of the horizontal betatron phase advance: 90, 105 and 135° per unit cell. The emittances are 44, 33 and 27 nm rad, respectively. These low emittances will result in a higher brilliance of synchrotron radiation at all existing beamlines by a factor of 5–10. The beam parameters are given in Table 1, and the typical brilliance is given in Fig. 2.

All of the quadrupoles and sextupoles in the normal cells are being replaced by new ones having higher field gradients. All of them are of the C-type, and do not disturb the synchrotron radiation extraction to the existing beamlines. The field measurements have been completed (Kobayashi *et al.*, 1995), as have the installation and alignment in the storage ring. The parameters of the new magnets are given in Table 2.

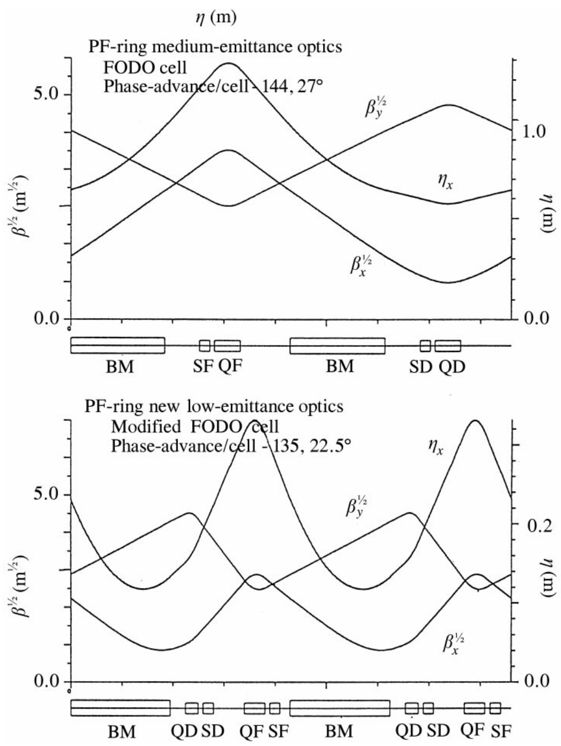

Figure 1
Optical functions of the present (upper) and low-emittance (lower) lattice in a normal cell. BM: bending magnets; QD, QF: quadrupole magnets; SD, SF: sextupole magnets.

Commissioning of the new lattice will start with the 90° optics, because it has a relatively larger dynamic aperture (Katoh *et al.*, 1994). The lower emittance will be challenged step by step.

3. Vacuum system

About half of the vacuum ducts of the PF ring are being replaced by new or improved ones. The main part of the replacement will take place in normal-cell sections. A typical view of the normal-cell section is shown in Fig. 3. The vacuum duct, called the 'normal-cell duct', was assembled within an accuracy of 1 mm. The effective pumping speed in the new duct was maintained so that a ring pressure of below 4×10^4 Pa could be maintained during operation. An adequately long beam lifetime is expected to be achieved in the new optics (Katoh *et al.*, 1995).

In order to reduce the broad-band impedance, the inner walls of the beam ducts are made to be as smooth as possible. The bellows and gate valves were especially designed to have the same cross section as the vacuum ducts; moreover, their RF shield was adopted to minimize the RF excitation.

Every vacuum duct is pre-baked and filled with dry nitrogen gas until installation. We intend to start-up the ring vacuum without *in-situ* baking.

4. RF system

We have developed a 500 MHz RF-damped cavity (Koseki *et al.*, 1994). The cavity has beam ducts with a somewhat large diameter. Higher-order modes (HOMs), having frequencies above the cut-off frequency of the duct, propagate out to the beam duct and are sufficiently absorbed by silicon carbide (SiC) (Izawa *et al.*, 1995).

During the summer shutdown in 1996, two of the four present cavities were first replaced by new ones. Fig. 4 shows these cavities installed in the ring. The new cavities, together with the old-type cavities, were successfully operated during the last scheduled user run from October to December in 1996. A maximum stored current of 773 mA, a new record at the PF ring, was achieved. The remaining cavities were replaced in July 1997. Details concerning the installation and operation of these new cavities are reported elsewhere in these proceedings.

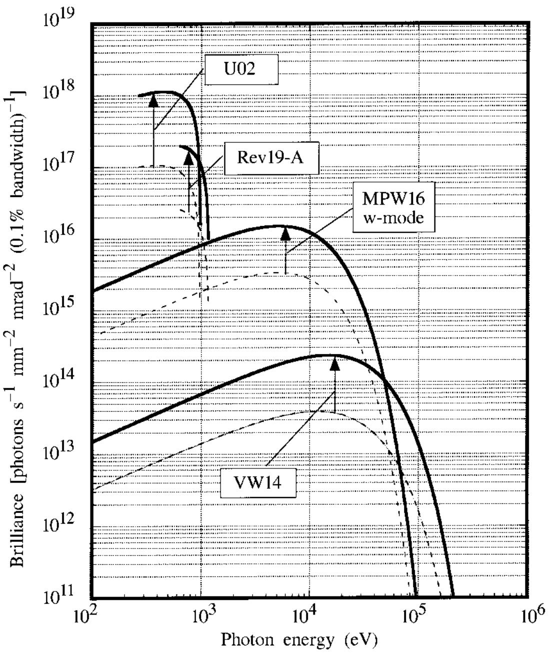

Figure 2
Brilliance of the insertion devices. The solid lines correspond to low-emittance optics, and the thin lines correspond to middle emittance of the present PF ring.

Table 2
Parameters of the new magnets.

	Field	Length
Defocusing quadrupoles	24 T m^{-1}	0.25 m
Focusing quadrupoles	24 T m^{-1}	0.40 m
Sextupoles	600 T m^{-2}	0.20 m

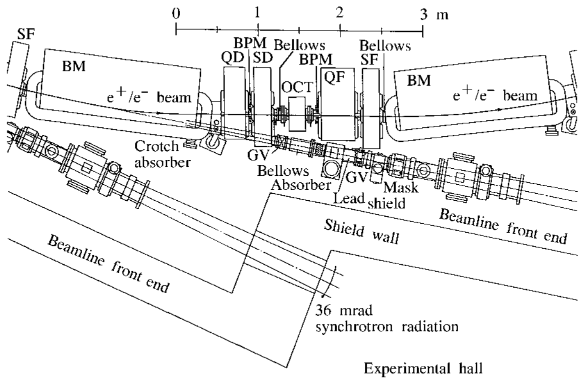

Figure 3
View of the new normal-cell section, where the front end is shown for the normal-cell bending-magnet sources. BM: bending magnet; QD, QF: quadrupole magnet; SD, SF: sextupole magnet; OCT: octupole magnet; BPM: beam-position monitor; GV: gate valve.

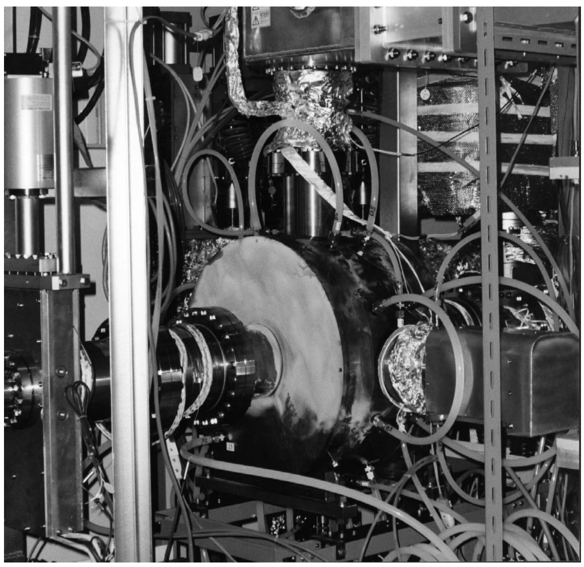

Figure 4
Cavities installed in the ring.

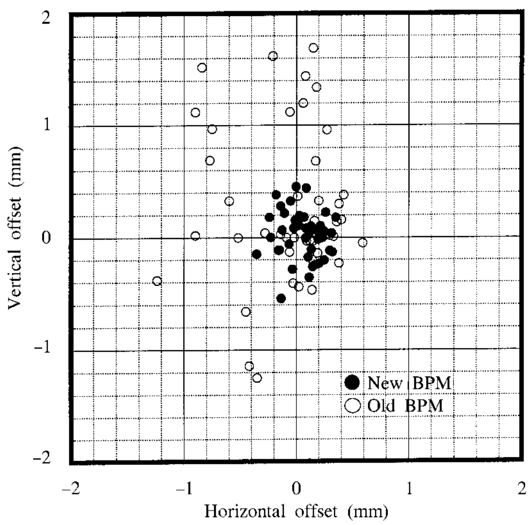

Figure 5
Distribution of the measured offsets of the electrical centre relative to the mechanical centre. The offsets of the new BPMs are shown as closed circles and those of old BPMs are shown as open circles for comparison.

5. Injection system

A travelling-wave-type fast-kicker magnet was newly designed for the high-brilliance configuration of the PF ring (Mitsuhashi *et al.*, 1995). The pulsed magnetic field of the kicker should have a rise time of 450 ns, a flat top of 100 ns and a falling time of 450 ns to obtain a sufficiently wide dynamic aperture. A line pulser-type power supply which drives the new kicker magnet was also newly developed.

6. Monitor system

6.1. *Beam-position monitor*

The new beam-position monitor (BPM) was designed to stabilize the orbit position during user runs.

The pickup units for normal-cell sections have been doubled in number, making a total of 65 BPMs. The new BPM units were designed to fit the narrow space between the magnets. The electrode (button-type) is set in symmetry at the centre of the assembly within ± 50 μm. Each BPM unit is fixed to an end of the quadrupole magnet.

Before installing the new-type BPMs, each BPM assembly was calibrated on a test stand in order to determine the electrical centre of the BPM relative to its mechanical centre. Fig. 5 shows the distribution of the measured electrical-centre offsets for the new-type BPMs. The offsets for the new-type were 1/2–1/3 of those of the old-type.

In order to improve the reliability, p-i-n diode switches are to be adopted in the signal-processing units. The fluctuation of the insertion loss over many switchings is less than ± 0.01 dB, which corresponds to a position error of -3 μm. In the fastest mode, this system is capable of measuring the COD to within about 2 ms. This very fast acquisition will allow us fast suppression of the beam movement for frequencies up to 100 Hz using a global feedback system (Haga, 1994). Details concerning the BPM are presented elsewhere in these proceedings.

6.2. *Single-pass BPM*

A single-path beam-position monitor for the injection beam has been developed (Honda *et al.*, 1997). The injected beam orbit during the first to the fourth turn could be measured with a single injection pulse. The resolution of the measurement was estimated to be 0.15 mm for the electron beam. The results and the system of the single-path BPM are reported elsewhere in these proceedings (Honda *et al.*, 1998).

7. Beamline front ends and insertion devices

In the new lattice configuration, reinforced quadrupole and sextupole magnets in the normal-cell sections interfere with the old-beamline front ends. About half of the beamlines should be modified. User operations with a higher beam current (>500 mA) or with a higher energy (>200 mA at 3 0 eV) prompted the renewal of the front-end components so as to be capable of handling higher heat loads. In the beamlines, the beam stopper/absorbers located in the uppermost stream should withstand the most severe heat loads. The new front end for the bending-magnet source is shown in Fig. 3, where the geometrical boundary conditions were serious for the high-brilliance magnet configuration.

All of the insertion devices were realigned according to the new arrangement of the magnets.

8. Control system

An overview of the new control system is as follows. VME systems are used to perform real-time processing of various equipment of the storage ring (Equipment Control Layer). UNIX workstations are used to process upper-level control programs (Application and Presentation Layer). A server computer is also incorporated for CPU-consuming calculations, such as simulations and database processing. A large-capacity disk is connected to the server in order to save operation data.

An ATM has been adopted for the backbone of the network system. 12 switching hubs, each of which has 12 10BASE-T ports, are connected to an ATM switch by optical-fibre cables in 155 Mbps. The VME and workstations are connected to the 10BASE-T port as an ordinary ethernet node.

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