STATUS OF THE PF RING AND ITS NEW UPGRADE PROJECT

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Abstract

While six insertion devices including one super-conducting wiggler are currently in operation, we have proceeded with a new upgrade project to create six new short-straight sections and to lengthen the existing straight sections. The short-straight sections will provide an opportunity to install short-period narrow-gap undulators, and the extension of existing straight sections will be taken advantage of updating current insertion devices to the latest models in future. As a part of the project, two straight sections of B04-B05 and B18-B19 have been reconstructed to extend their free space and a new multipole wiggler has been installed at BL-5 in the summer shutdown of 2003. The whole reconstruction for the upgrade project will be completed in FY 2005.

INTRODUCTION

Since the first commissioning in 1982 as one of the pioneering second-generation synchrotron light sources, the 2.5-GeV Photon Factory (PF) storage ring has been upgraded twice in 1986 and 1997 [1] in order to reduce the beam emittance from 450 nmrad to 36 nmrad. In 1997, the ring lattice was largely reconstructed by the reinforcement of the quadrupole magnets and the sextupole magnets in the normal cell sections. At the same time, some hardwares such as the RF cavities [2] and the orbit stabilization system [3] were renewed. As a result, the stability and reliability of the machine operation have been improved greatly.

The PF ring has had seven free straight sections for insertion devices since the beginning. During the summer shutdown of 2003, a new multipole wiggler [4] has been installed into BL-5, and a new beamline for protein crystallography is in commissioning now. The BL-5 was the last free straight section in the present configuration. Increasing needs for the undulator radiation in the x-ray range, including higher harmonics, and demands for various types of new insertion devices prompted us to contemplate the new upgrade program. The main purpose of the present project is not an emittance reduction, but to produce new short-straight sections and to extend existing straight sections.

OPERATION STATUS

A history of the operation time from the first commissioning is shown in figure 1. In FY 2002, the total operation time was 5130 hours. It slightly decreased from the previous year due to the renewal of the PF computer system. Scheduled user time was 4267 hours, and the effective user time excluding time lost due to machine trouble and daily injections was 4179 hours. Its ratio to the scheduled time was 98 %. Total failure time during the FY 2002 was 20.8 hours, and the failure rate, defined as the failure time to the total operation time, was about 0.4 %. This failure rate was the lowest during the 21-year operation since 1982.

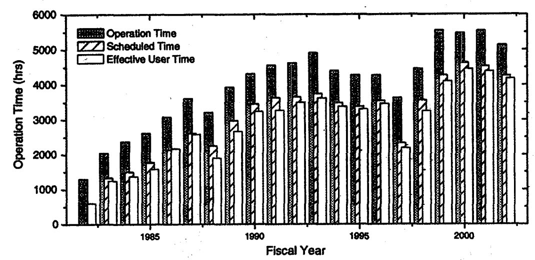

Figure 1: Operation time history of the PF ring.

The PF ring is usually operated in a multiple bunch mode with an initial current of 450 mA. The higher energy operation is also available at 3 GeV with a lower initial current of 200 mA. Two periods of 3-GeV operation was scheduled during the FY 2002, and its total time was about 3 weeks. The product of beam current I and the beam lifetime τ ($I\tau$) was about 1300 A min in 2002. Even though the beam emittance has been much lower, the lifetime recovers a comparable value as before the low-emittance reconstruction [5].

Manufacturing of traveling wave kicker magnet was completed, and the new kicker magnet system started the operation in October 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 [6]. Study to search for practical operation near the theoretically minimum emittance of the present lattice has been performed successfully in reducing the emittance to 28 nmrad, and a practical injection rate was obtained by using the new kicker system even under the lower emittance operation [7].

NEW UPGRADE PROJECT

Outline of the upgrade project

An overview of the project is given in figure 2. The main part of this project is modification of the lattice configuration around the straight sections, keeping the orbital polygon itself. As done in the second upgrade program in 1997 for the normal-cell sections, we will replace existing quadrupole magnets with new ones having shorter length and higher field gradient, and place them closer to the adjoining bending magnets. Due to this modification, new straight sections of 1.4 m (in free space) will be produced, and the existing straight sections will be almost doubled in their free space. Such modification of lattice configuration, on the other hand, alters the physical boundary conditions around the vacuum chambers in the bending magnets and around the beamline front ends. To satisfy the new boundary conditions, preparatory measures such as the installation of redesigned front ends have already been under way since 2002.

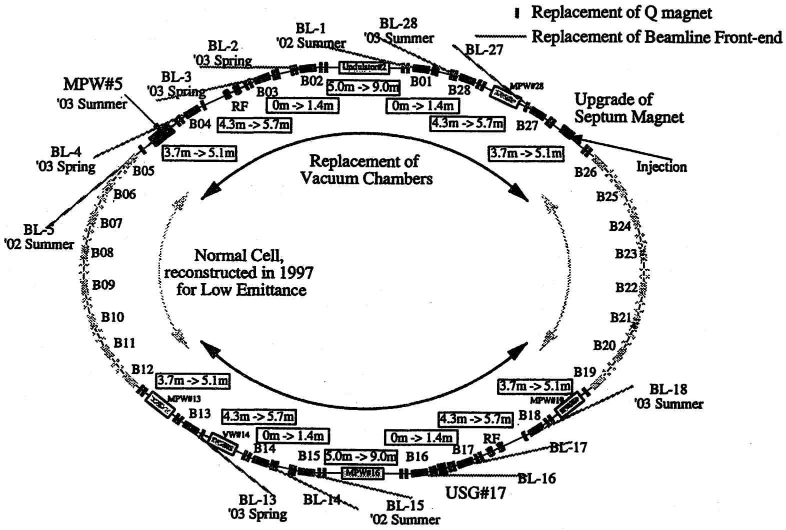

Figure 2: Outline of the upgrade project.

The creation of new short-straight sections and the extension of two long-straight sections are illustrated in figures 3 and 4, respectively. The PF storage ring will then have the straight sections of two 9 m-long, four 5 m-long, four 5.7 m-long, and four 1.4 m-long. When the upgrade alterations are completed, eleven straight sections among them will be available for insertion devices. In addition, two short insertion devices may be installed in the two 5.7 m-long straight sections where the RF cavities are placed. The dispersion and the beta functions of those sections are optimized to be as low as possible. In particular, the vertical beta function of the short straight section is reduced to 0.4 m at the minimum value as shown in figure 5, which is very suitable for mini-pole undulators. A beam emittance of 27.5 nmrad is expected with the new optics, which is slightly lowered than the present value of 36 nmrad.

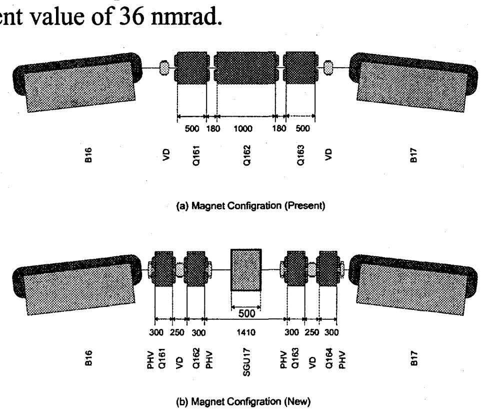

Figure 3: Creation of the short straight section.

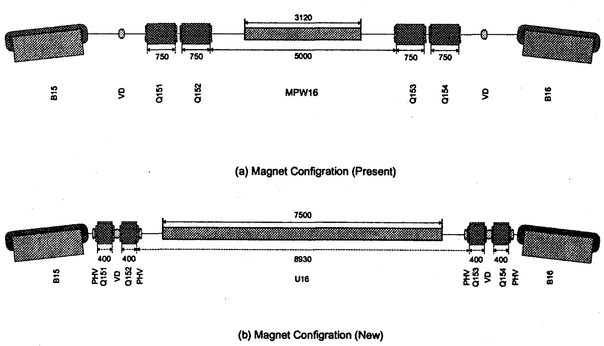

Figure 4: Extension of the long straight section.

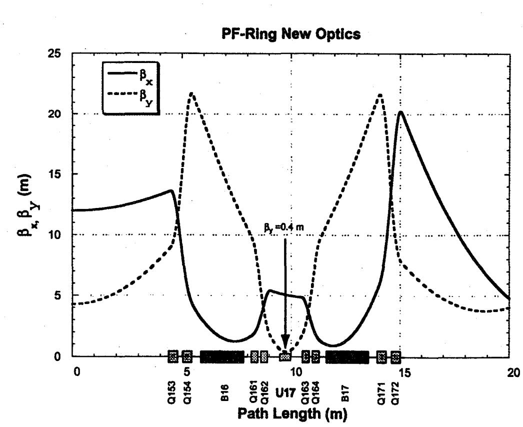

Figure 5: Improvement in optics at the short straight section.

Since the new quadrupole magnets have a different bore diameter from the old ones, and will be placed very close to the bending magnets, a number of vacuum chambers including those in twelve bend sections should be replaced with new ones. The design of the new B (bending magnet section)-chambers and Q (quadrupole magnet section)-chambers, including beam-position monitor (BPM) chambers, has been finished. The conceptual design of the B-chamber is shown in figure 6. A prototype chamber is now being manufactured.

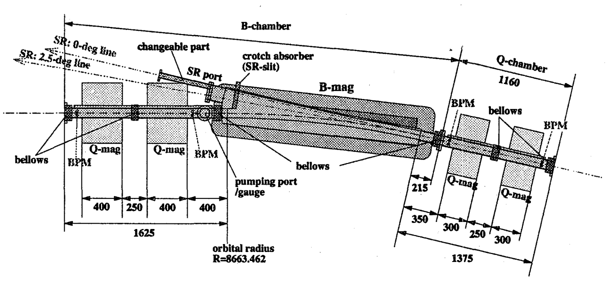

Figure 6: Conceptual chamber design in the bend section.

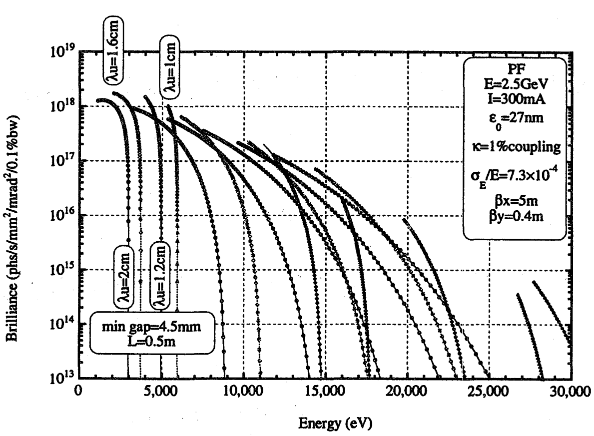

Figure 7: Example spectra of the radiation from short-period narrow-gap undulators.

Expected spectra of short period undulators

Figure 7 shows the expected radiation brilliance from the possible short-period undulators, indicating the envelopes of peak brilliance for the odd harmonics up to the 7th order. For these calculations, we have assumed the minimum gap of 4.5 mm, a total magnet-array length of 0.5 m, and four kinds of period lengths: 10 mm, 12 mm, 16 mm, and 20 mm. The nominal beam emittance of 27 nmrad was assumed. Using the 3rd or 5th harmonics of these short-period undulators, sufficiently high brilliance within a spectral range from 8 to 16 keV will be available. This spectral range is desired by the majority of x-ray research fields, especially the field of structural biology.

Time schedule of the project

The shutdown for installation of new components and rearrangement of related ones is scheduled to take place from April to September, 2005. This timetable was decided on to minimize the loss of user operation time, taking into account the administration of electric power supply in our country. The removal and installation of the redesigned new components for the front ends were already started in fiscal 2002 for the beamlines related to this project and eight front-ends out of twelve have been replaced by this summer. The new quadrupole magnets are to be completed in fiscal 2003, and the new vacuum chambers of the bending-magnet section will be fully prepared in fiscal 2004. In addition to these main parts of this project, the Q-magnet power supplies and the septum magnet will be replaced; the design of new BPM system is also in progress with the aim of higher precision beam-position monitoring.

In parallel with these preparatory works, the new Q-magnet arrays were already installed this summer into downstream end at the two straight sections, B4-5 and B18-19, bordering area between the normal cell and straight sections. Also in this summer a multipole wiggler was newly installed into the section B4-5 so as to complete a new beamline dedicated to structural biology.

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