RESULTS OF THE STRAIGHT-SECTIONS UPGRADE OF THE PHOTON FACTORY STORAGE RING

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Abstract

At the 2.5-GeV light source of the Photon Factory, a large reconstruction around the straight sections has been accomplished in 2005. In the area over two thirds of the storage ring, all the quadrupole magnets and all the beam ducts have been renewed and rearranged to modify the lattice configuration. As a result, four short straight sections of 1.5 m have been newly created and the lengths of the existing ten straight sections have been extended. The short straight sections are exploited for mini-pole x-ray undulators. A new undulator of VUV-SX is being designed for one of the extended straight sections. Since the successful recommissioning of the ring at October 2005, recovery of the beam lifetime has favorably progressed due to the vacuum scrubbing by the synchrotron radiation. As the beam ducts have been replaced in a large portion of the ring, some interesting changes have been observed in the appearance of the beam instability.

INTRODUCTION

The Photon Factory (PF) storage ring is a synchrotron radiation source which has an energy of 2.5 GeV and a circumference of 187 m. The lattice is constituted of 28 bending magnets and there were ten straight sections originally. The PF ring has about 70 experimental stations and the all available straight sections were used for various types of insertion devices, such as undulators, multi-pole wigglers (MPW) and a super conducting wiggler. In order to satisfy increasing demands for the undulator radiation in the x-ray range and needs for new-type undulators, a large-scale upgrade project for the straight sections was proposed [1]. Reconstruction of the storage ring as a main part of the upgrade project was accomplished in 2005.

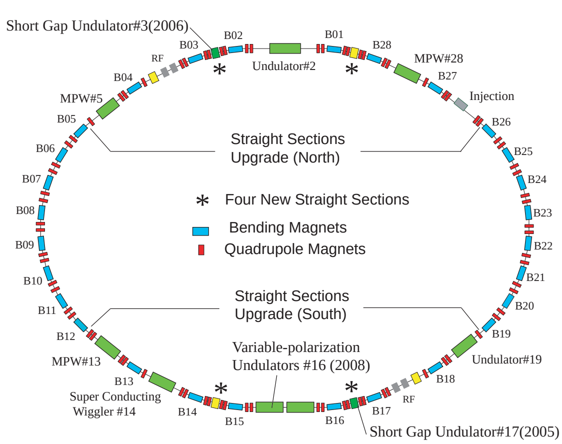

Figure 1: Reconstructed area for the straight sections upgrade of the PF ring.

STRAIGHT-SECTIONS UPGRADE

Reconstruction of the storage ring

The reconstruction work of the storage ring was conducted during a scheduled shutdown from March to September, 2005. The magnetic configurations of the straight sections, as shown in Fig. 1, have been modified by replacing all the quadrupole (Q) magnets. The bending (B) magnets and the existing insertion devices including the RF cavities have been left untouched. The bore diameter of the Q magnets has been reduced to 70 mm from the original value of 110 mm. Details of the new lattice and the new optical functions for the straight-sections upgrade were reported previously [1].

The beam ducts for the Q magnets (Q ducts) and the B magnets (B ducts) were entirely replaced by newly designed ones [2]. The pumping speed of the distributed ion pumps (DIP) in the B duct has been improved 80 % by renewal of the pumping cells and by increasing the applied voltage. Main material of the crotch absorbers has been improved to a heat-resistant copper alloy from OFHC copper. The small gaps between the ICF flanges which cause impedance increase have been smoothed using RF contacts, and the old vacuum bellows without any RF shields were almost purged from the ring.

Development of new undulators

The lengths of the extended straight sections and the newly created four straight sections are summarized in

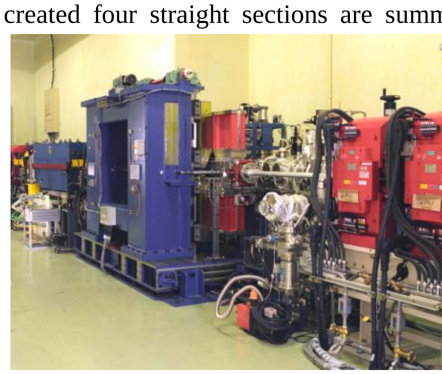

Figure 2: Example of extension of a straight section. A free space of about 1.5 m has been created between the MPW#5 and the quadrupole doublet on this side.

table 1. Figure 2 shows the photograph of an extended straight section between B04 and B05. The MPW#5 with 3-m magnetic length is being installed in this section. The original length of 3.5 m has been extended to about 5.3 m. The newly created free space between the MPW#5 and the doublet magnets has spread about 1.5 m.

The new short straight sections are used for short gap mini-pole undulators (SGU). The vertical beta function at the short straight section is reduced to 0.4 m for the very short gap undulators in vacuum. Even with a medium energy of 2.5 GeV, a high brilliant hard x-ray is available by using the mini-pole undulators. The first mini-pole undulator was installed in 2005 at the one of the newly created straight sections between B16 and B17. The SGU#17 [3] has a magnetic period of 16 mm, a periodicity of 29 and the designed minimum gap of 4.5 mm. The second model of the SGU is scheduled to be installed at BL#3 in 2006.

Taking advantage of the extended straight sections, new undulator devices will be installed in place of the existing devices. A design of a fast polarization switching undulator for the longest straight section between B15 and B16 has already progressed.

OPERATION AFTER THE RECONSTRUCTION

Recommissioning of the ring

Commissioning of the storage ring was started from the end of September, 2005. The maximum stored current could be restored to the typical value of 450 mA in five days, though the beam lifetime of the early stage was less than 30 minutes and the beam was unstable due to the strong ion instability. Against to the deteriorated vacuum pressure to the order of 10^{-5} Pa, the stable beam injection came to be possible by starting up a transverse bunch-by-bunch feedback system [4, 5]. Along with the orbit correction and the adjustment of other beam parameters, the vacuum scrubbing at the maximum current of 500 mA was continued. After the one-month commissioning, the user operation resumed with a beam lifetime of 200 A min,

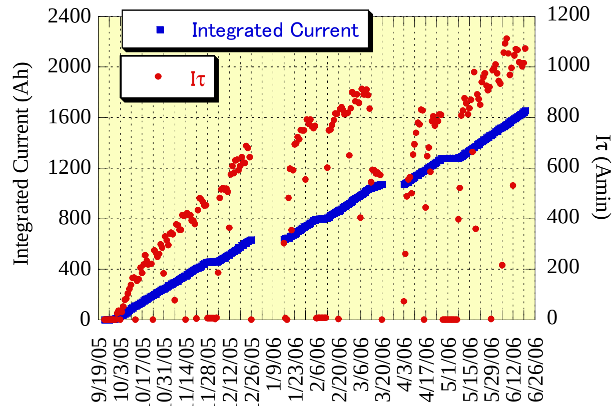

Figure 3: Integrated current and the recovery of the bean lifetime during 9-month operation after the recommissioning.

or about 8 hours at 450 mA.

Recovery of the beam lifetime

The PF ring had a merit of long beam lifetime. The product of the beam lifetime and the beam current, $I\tau$, exceeded 1600 A min just before the reconstruction. As shown in Fig. 3, in the nine-month operation after the reconstruction, the lifetime has recovered to 1100 A min, about 70 percent of the previous value. Though we made no in-situ baking after the installation for the beam ducts, the vacuum scrubbing by the synchrotron radiation has favorably progressed. A temporary deterioration of the lifetime was recorded from March to May, 2006. It was caused by an accidental vacuum leak of the synchrotron radiation absorber. The trouble occurred at a 9-year old absorber made of OFHC copper in the normal cell section, not in the reconstructed sections. All absorbers of the same type and history are prepared to be replaced as soon as possible.

In order to investigate the effect of the pre-baking to the vacuum scrubbing, the beam ducts for the south sections were pre-baked in advance of the installation, and those for the north sections were not pre-baked at all. At the very first stage of the beam operation or while the integrated current was less than several tens of Ah, a

Table 1: Creation and extension of the straight sections and the upgrade plan of the insertion devices.

Section	Before Upgrade	After Upgrade	Insertion Devices (Light source)
B01 – B02	5.0 m	8.9 m	Undulator#02
B15 – B16			Fast polarization switching Undulator (2007)
B03 – B04	4.3 m	5.4 m	Bending (RF cavities)
B13 – B14			Super Conducting Wiggler (5 T)
B17 – B18			Bending (RF cavities)
B27 – B28			Elliptical U/MPW#28
B04 – B05	3.5 m	5.3 m	MPW#5
B18 – B19			U#19 (revolver)
B12 – B13	4.3 m	5.4 m	U/MPW#13
B26 – B27			injection
B02 – B03	No space	1.4 m	Short Gap Undulator#03 (2006)
B14 – B15			Bending (Short Gap Undulator in future)
B16 – B17			Short Gap Undulator#17 (2005)
B28 – B01			Bending (Short Gap Undulator in future)

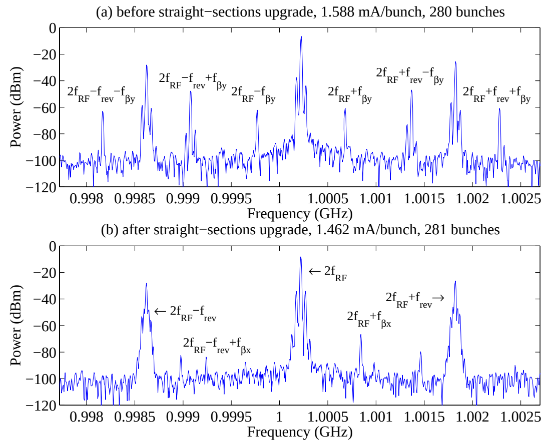

Figure 4: Betatron sidebands observed in the usual partial filling changed from the vertical (a) to the horizontal (b) after the upgrade.

slight difference remained between the vacuum pressures of the north sections and the south sections. Thereafter no significant difference of the vacuum pressure was observed for the both sections [2].

Beam based alignment and COD correction

During the commissioning, the x-ray of the in-vacuum undulator SGU#17 was successfully introduced to the beamline. It was confirmed that a minimum gap of 3.8 mm, slightly shorter than the designed value, can be achieved. By the process of the minimum gap search and the simultaneous photon beam alignment at the beamline, the vertical electron orbit was aligned to the center of the undulator with considerable accuracy.

The offset of the beam position monitor (BPM) against to the Q magnet has been independently determined by a beam based measurement. The center orbit determined by the beam based alignment of the BPM accorded with the orbit to get the minimum gap with a precision of 10 μm. The BPM was calibrated on the bench prior to the installation. The standard deviation of the vertical COD was obtained as 100 μm using the beam based alignment data. It could be improved by a factor of two compared to that based on the bench calibration.

Condition of beam instability

Before and after the reconstruction, typical spectrum observed as the transverse instability is changed. The PF ring is operated usually at 450 mA with a partial filling pattern. The electron is filled in 280 consecutive bunches and 32 bunches are remained empty to avoid a strong instability due to the ion trapping. Even with the partial filling, weak transverse instability which is also assumed to be the ion instability occurs at a high current as 450 mA. The transverse instability could completely be cured by using the transverse bunch-by-bunch feedback system during the user operation. As shown in Fig. 4(a), only the vertical betatron sidebands were observed previously. However, after the reconstruction, the horizontal betatron sidebands are observed instead of the vertical sidebands.

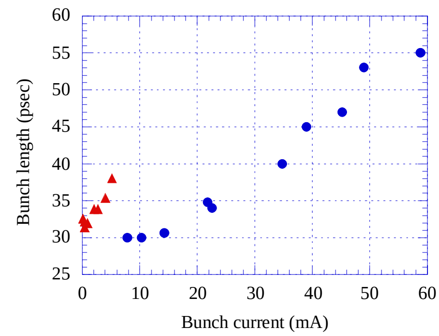

Figure 5: Comparison of the bunch lengthening before (triangle) and after (circle) the reconstruction.

The betatron tunes for the both directions are changed from (ν_x, ν_y) = (9.60, 4.28) to (9.60, 5.28), so the fractional tunes have the same values. An experimental study and an analysis of the transverse instability are continued [6].

Figure 5 shows a comparison of the bunch lengthening before and after the reconstruction. Previously the bunch lengthening was observed at the very low bunch current. Now the threshold of the bunch lengthening has been moved above 10 mA. This is a result of the reinforcement of RF shield in the beam ducts. As the bunch is effectively shortened at the practical current, the beam lifetime of the single bunch operation which is limited by the Touschek lifetime becomes one-third of the previous value.

SUMMARY

The reconstruction of the storage ring for the straight-sections upgrade was completed in 2005. After the successful recommissioning, the recovery of the beam lifetime has proceeded as expected. To exploit the reinforced straight sections, beamlines using new undulator technologies will be constructed. First of all, the short-gap mini-pole undulator is already being operated as a new x-ray source.

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