A Test of 3-GeV Operation at the Photon Factory Storage Ring

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Abstract

During the fiscal years 1990-1991 the power supplies for the quadrupole magnets were reinforced to realize the 3-GeV operation at the Photon Factory Storage Ring (PF-Ring). In accelerator experiment, the 2.5-GeV positron beam with a current of 300 mA has been successfully accelerated up to 3 GeV without any beam loss, and the beam lifetime more than 40 hours has been obtained at 3 GeV. The 3-GeV operation of the PF-Ring is now ready for user experiments.

1. INTRODUCTION

The 2.5-GeV PF-Ring, a dedicated synchrotron radiation (SR) source, has been stably operated for a decade. At present the averaged current of stored positron beam is about 300 mA in the multi-bunch operation and the beam lifetime is more than 60 hours at a current of 300 mA. In addition, the single-bunch operation with a beam current of 30 mA has recently started for user experiments.

All the ring magnets and their power supplies except for those of some quadrupole magnets had already been prepared for the 3-GeV operation, as the ring was initially designed with a maximum energy of 3 GeV. On the other hand, the RF, vacuum and other systems of the PF-Ring had been greatly improved through a decade of operational experiences, so that the ring became possible to reach the beam energy of 3 GeV. Under these circumstances, the quadrupole power supplies without enough electric capacity to accelerate the 2.5-GeV beam up to 3 GeV were reinforced during the fiscal years 1990-1991. Thus it turned out that the ring can afford to supply much brighter hard x-ray for experimental users with almost the same amount of beam current as in the 2.5 GeV operation.

When the beam energy increases from 2.5 to 3 GeV, the critical energy of photons from bending magnets also increases from 4 to 7 keV, enabling brighter hard x-ray to become available. Another advantage of 3-GeV operation is that it will make a high current beam more stable since the beam instabilities are expected to become about two times weaker. On the other hand, the brightness in VUV and soft x-ray regions will slightly decrease since the natural emittance of the beam becomes about 40 percent larger. Furthermore, heat load on vacuum chambers and beamlines may cause some troubles at a high beam current, as synchrotron radiation power from bending magnets becomes doubled at 3 GeV. However, we have not yet encountered any heating trouble up to 300 mA. Table I shows a comparison between 2.5 GeV and 3 GeV. In this paper, we will report procedures for acceleration/deceleration between 2.5 and 3.0 GeV, measurement of orbit parameters, correction of tune shifts caused by wigglers, vertical orbit drift and so forth.

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Table I. A comparison between 2.5 and 3.0 GeV

	2.5GeV	3.0GeV	3.0GeV/2.5GeV
Betatron tunes (H/V)	8.45/3.30	8.45/3.30	
Momentum compaction	0.015	0.015	
Bending field	9.6 kG	11.6 kG	1.20
Natural emittance	125 nm·rad	180 nm·rad	1.44
Radiation loss per turn	399 keV	827 keV	2.07
Longitudinal damping	7.8 msec	4.5 msec	0.58
Transverse damping	3.9 msec	2.3 msec	0.58
Critical energy	4 keV	7 keV	1.73

2. PROCEDURES FOR ACCELERATION AND DECELERATION

Since the positron beam from the injector linac has a fixed energy of 2.5 GeV, it is necessary for the 3-GeV routine operation to accelerate the stored beam up to 3 GeV and then to decelerate the beam down to 2.5 GeV in order to save the injection time. In accelerator studies, we optimized the ramping currents of the magnets at every 0.1 GeV step between 2.5 and 3 GeV in both directions of acceleration and deceleration so as to make tune shifts and closed orbit distortions (CODs) as small as possible. It takes less than 10 minutes to accelerate or decelerate the stored beam without any beam loss. Before starting the 3-GeV operation, we first initialize all magnets by cyclically exciting the power supplies between the beam energies of 2.5 and 3 GeV in order to cancel the magnetic hysteresis effect. This procedure of initialization allows us to keep the tunes and CODs repeatable and then to stably accelerate and decelerate a high current beam between both energies.

2.1 Orbit parameters at 3 GeV

The orbit parameters at 3 GeV were adjusted to be the same as their designed values as far as possible. As a result, the horizontal and vertical tunes, and dispersion functions at both energies came into a good agreement within measurement errors. Beta functions at both energies also agreed well except for a slight difference of the vertical beta function around the long straight sections in the ring. The difference is due to a change of optics to save the current of a quadrupole family at 3 GeV. The measured beta functions [1] are shown in Fig. 1.

2.2 Correction of tune shifts caused by wigglers

The tune shifts due to the wigglers (VW#14, MPW#13, #16, and #28) with strong focusing effects were compensated by changing the excitation currents of quadrupole magnets near each wiggler [2]. As the focusing effect of a wiggler with a fixed field decreases in proportion to the inverse square of beam energy, the quadrupole correction strength Δk required must also decrease with the focusing effect. The Δk is written as

$$\Delta k = \Delta B' l / B\rho , \qquad (1)$$

where $B\rho$ is the magnetic rigidity, $\Delta B'$ the correction field gradient and l the length of quadrupole magnet. Since $B\rho$ is proportional to the beam energy, $\Delta B'$ must vary inversely as the beam energy. As field saturation in the quadrupole magnets is actually small, therefore, the correction currents to be supplied for the quadrupole magnets are almost inversely proportional to the beam energy. Figure 2 shows an example of the correction of tune shifts caused by the superconducting vertical wiggler, VW#14, that has the strongest focusing effect among all insertion devices in the PF-Ring. As seen in Fig. 2, it was found that only with the predicted values for correction currents the tune shifts were sufficiently compensated.

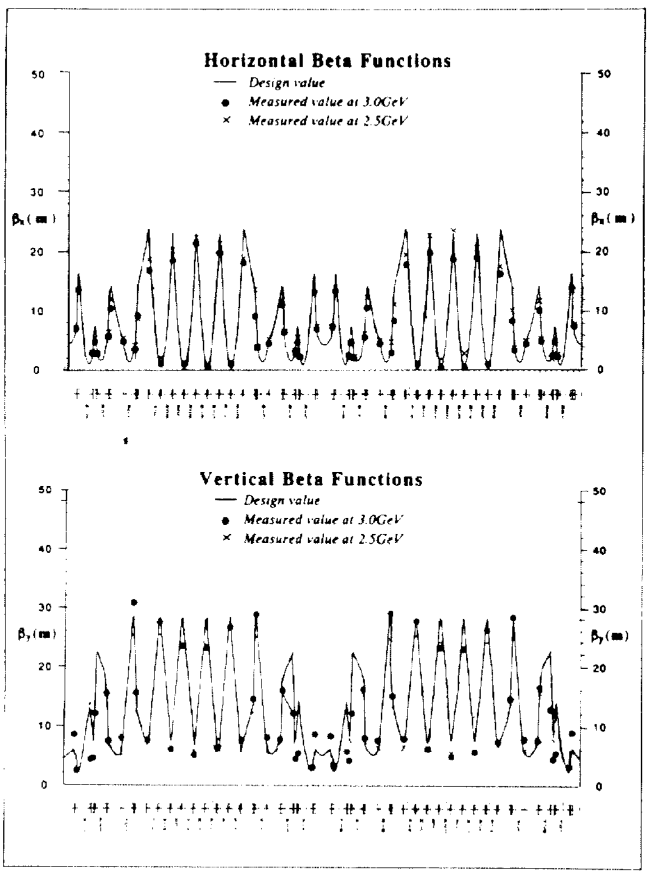

Figure 1. Measured beta functions. The closed circles and cross symbols indicate the beta functions measured at 3 GeV and at 2.5 GeV, respectively. The solid line shows the design value.

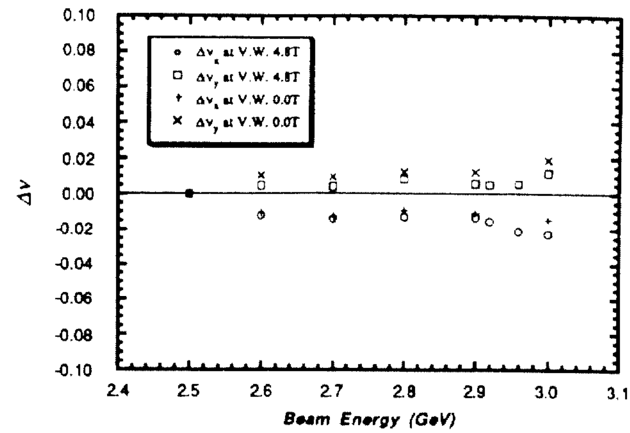

Figure 2. The tune shifts during acceleration. The open circles and squares represent the horizontal and vertical tune shifts with the superconducting vertical wiggler, V.W.#14, excited at 4.8 T. The plus and cross symbols are the tune shifts with the wiggler not excited. Correction data of quadrupole strength used to compensate for the tune shifts were calculated by a scaling law with respect to the beam energy.

3. SOME OPERATIONAL ASPECTS AT 3 GEV

3.1 Drift of vertical orbit after acceleration and its correction

After acceleration to 3 GeV, it was observed that the vertical orbit gradually drifted for several hours. Figure 3 shows the orbit drift generated during about 2 hours after acceleration completed. This vertical drift might be caused by the temperature rise of magnets though its origin has not yet been clarified. Using the digital feedback system (DFB) [3], however, we can suppress the orbit drift within an allowable limit, as also shown in Fig. 3.

3.2 Suppression of a Coupled-Bunch Instability

At the beam energy of 2.5 GeV, there appears a longitudinal coupled-bunch instability for a beam current more than 100 mA [4]. This instability is induced by RF cavities and one of the beam spectra observed appears at a frequency of 1151 MHz. Under the assumption that the growth rates of instabilities vary inversely as beam energy, beam instabilities are expected to be inversely proportional to the fourth power of beam energy because the radiation damping time is inversely proportional to the third power of beam energy. The threshold current of the longitudinal coupled-bunch instability at 3 GeV may therefore become about two times higher than at 2.5 GeV. We measured the threshold current of this instability as a function of beam energy. Its result is shown in Fig. 4. The solid line represents a curve fitted to a single power law, the energy dependence of which has not yet been explained well. At 3 GeV, we are free from the longitudinal coupled-bunch instability up to a beam current of about 270 mA, as seen in the figure.

Meanwhile, we have a troublesome instability at 2.5 GeV, a vertical coupled-bunch instability, whose origin has not yet been clarified. By exciting octupole magnets, however, it has almost been suppressed. This instability becomes weaker at 3 GeV but is still strong, so that we can not remove it completely.

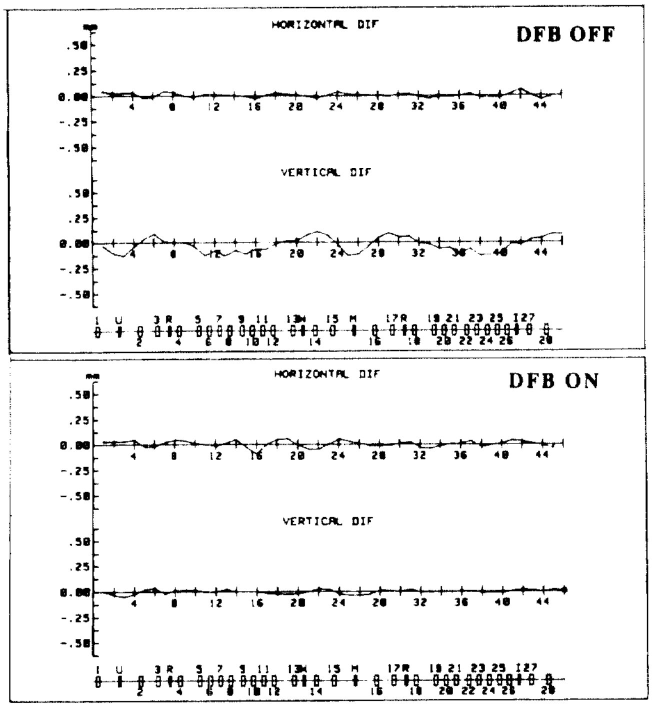

Figure 3. Vertical orbit drift along the ring measured about 2 hours after acceleration was completed; the upper is a case without DFB, and the lower a case with DFB. The system of DFB is capable of suppressing the orbit drift within an allowable limit.

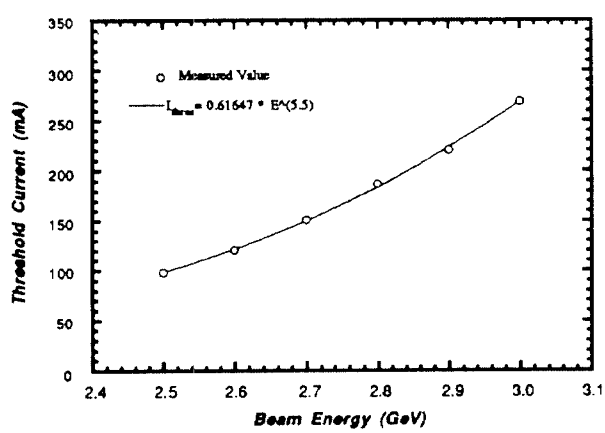

Figure 4. Threshold current of a longitudinal coupled-bunch instability as a function of the beam energy. The solid line represents a curve fitted to a single power law.

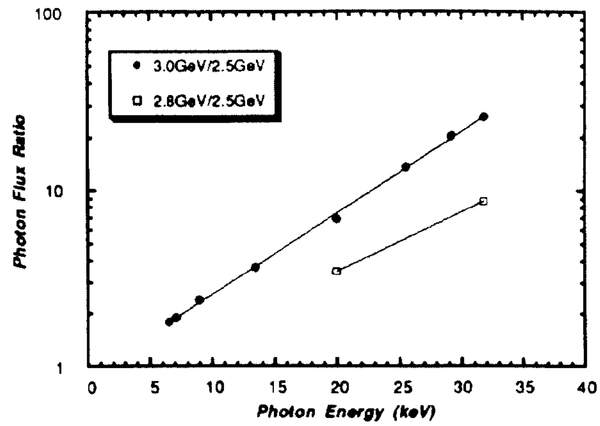

Figure 5. Ratio of photon fluxes at the beam energies of 2.5 and 3 GeV as a function of photon energy. Also shown in the figure is the ratio of photon fluxes at 2.5 and 2.8 GeV. The data were taken at the EXAFS beamline (BL10B).

3.3 Increase of Photon Flux

For the beam energy of 3 GeV it is expected that the synchrotron radiation flux increases in the photon energy range of more than several keV. The ratio of photon flux at 2.5 GeV to that at 3 GeV was measured at the EXAFS beamline (BL-10B) [5]. Figure 5 shows the ratio of photon fluxes normalized by the beam current. As shown in the figure, the photon flux indeed increased for the photon energy of more than several keV and it became about 20 times larger at 30 keV.

4. ACKNOWLEDGEMENT

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5. REFERENCES

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