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PHOTON FACTORY : STATUS OF STORAGE RING

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Introduction

The 2.5 GeV electron storage ring of the Photon Factory is a dedicated synchrotron radiation source[1] The first beam was stored at the design energy on March 11, 1982. Experiments with synchrotron radiation was started in June. During this year, efforts have been devoted to investigation of the properties of the storage ring. Then, the stored beam currents were increased and the beam lifetime was improved.

In February 1983, a superconducting vertical wiggler of 5 Tesla and a permanent magnet undulator have been successfully come into operation. The spectra of emitted radiation were measured.

General description

The Photon Factory complex consists of a 2.5 GeV linac, a 2.5 GeV storage ring and an experimental area, as shown in Fig. 1. Although the nominal operating energy is 2.5 GeV, the magnet system which is composed of 28 bending magnets and 58 quadrupoles is capable of raising energy up to 3 GeV by ramping after the beam is stacked. The injection is carried out in the multi-turn injection scheme in which a pulse of electron beam as long as 1 μs is injected while the revolution time is 624 ns. The injection rate is 1 Hz.

The four 500 MHz rf cavities are situated in the straight section of zero momentum dispersion. Each cell is rated to dissipate 30 kW of rf power, which is fed by two 180 kW klystrons.

As for the beam diagnostic elements, there are a photoelectron detector and a DC current transformer to measure the stored beam current, 46 button type position monitors, photo-diode arrays to measure the profile using the synchrotron radiation, a TV profile monitor and a betatron tune measuring system using a magnetic deflector.

Pumping system consists of 52 sputter ion pumps (128 ℓ/s), the distributed ion pumps (DIPs) within the 28 bending magnets, 50 titanium getter pumps and 6 roughing pumping stations. The wire electrode is stretched along the chamber wall in the bending magnet for argon discharge cleaning.

Out of 24 possible exit ports of synchrotron radiation, seven beam lines have been operating, and two lines (BL1 and BL4) are now in preparation. Each line is split into three or four branch lines, to each of which an experimental station is attached. Details of the beam line design is described in Ref. 2.

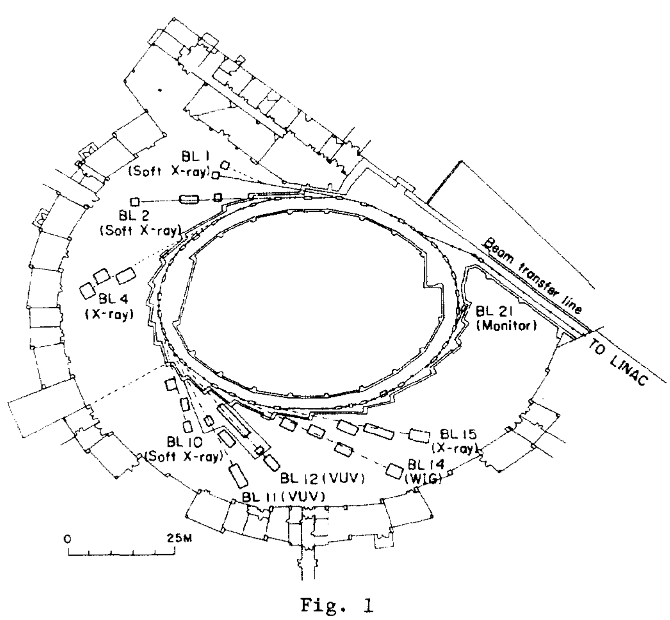

Fig. 1

The vertical wiggler with the maximum field of 6 Tesla is located in a medium straight section. The maximum offset of the beam from the central orbit is 10 mm. The critical wavelength is 0.5 A at 2.5 GeV. A 60-period permanent magnet ($SmCo_5$/Fe) undulator with total length of 3.7 m is located in a long straight section. The pitch of the period is 60 mm, the gap can be changed from 20 to 80 mm and the field strength is 3 kG with gap of 27 mm.

Operating experience

Table 1 gives the breakdown of operating time during the fiscal year 1982. Machine time of 674 hours has been devoted to users in total operation time of 1301 hours.

Table 1

Run	2	3	4
Date	June 2 ∿ July 17	Oct. 21 ∿ Dec. 10	Jan. 13 ∿ March 5
Total operating time (hr)	407	274	630
User's machine time (hr)	185	121	368
Percentage of user's time	45.3	44.1	58.4
Percentage of machine failure in user's time	12.4	10.9	9.2

The storage ring is routinely operated at 2.5 GeV. The beam current has been increased from 6 mA in the first commissioning up to the record of 250 mA. This current level, however, was not allowed because of a heating problem. Usually the initial stored beam current is limited to 160 mA.

The lifetime of stored electron beams is affected mainly by the residual gas pressure. During the June-July run, the beam lifetime was still short due to enormous outgassing from chamber walls in the presence of high stored beam currents. As indicated in Fig. 2, however, the beam-cleaning effect by synchrotron radiation was effective, and the pressure with beams has been improved with increasing the integrated beam current. At the end of the run, the beam lifetime of 30 minutes was attainable at the beam current of 100 mA, where the residual pressure was 1×10^{-7} Torr. During the summer shutdown, both a bakeout at 150°C for 2 days and an argon discharge cleaning for 3 hours were performed. With these procedures, the beam-cleaning effect was accelerated, and thereafter the lifetime has been steadily improved as the residual pressure decreases.

We have experienced, however, that the lifetime of stored electron beams sometimes decreases faster than expected, or even drops suddenly to half of its previous level. This phenomenon occurred more frequently when DIPs are working. It could be cured by applying negative potential of several hundred volts to argon discharge cleaning electrodes. Consequently, the

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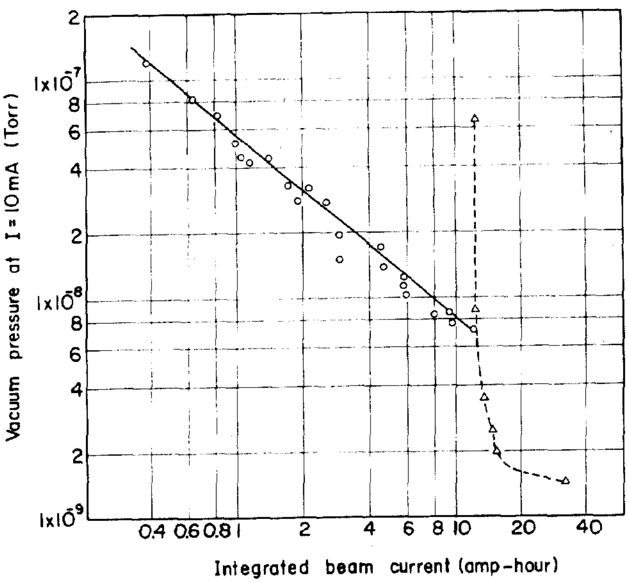


Fig. 2

lifetime of electron beams has been improved considerably and has become reproducible. By these means, we can achieve the lifetime of 3.5 hours at the stored beam current of 100 mA. The residual pressure is 4×10^{-9} Torr. Fig. 3 shows how the lifetime behaves with the stored beam current in different situations.

The injection is scheduled once per 4 hours, during which the stored current decays down to approximately 50 mA. The charge rate is typically 1 mA/sec, and a typical filling time is of the order of 10 minutes with half the time being taken up by evacuating the experimental hall and tuning up the linear accelerator injector.

On February 15, 1983, the superconducting vertical wiggler successfully came into operation with the magnetic field of 5 Tesla. The spectrum of synchrotron radiation was measured. The closed orbit during the excitation of the wiggler could be kept within 1 mm by adjusting the current of auxiliary power supplies. A change in the betatron tune was measured to be 0.06 in the horizontal plane and -0.05 in the vertical plane. No tune correction was necessary for the operation of the storage ring.

The undulator has been in operation from February 22, 1983. No significant effect was observed on the

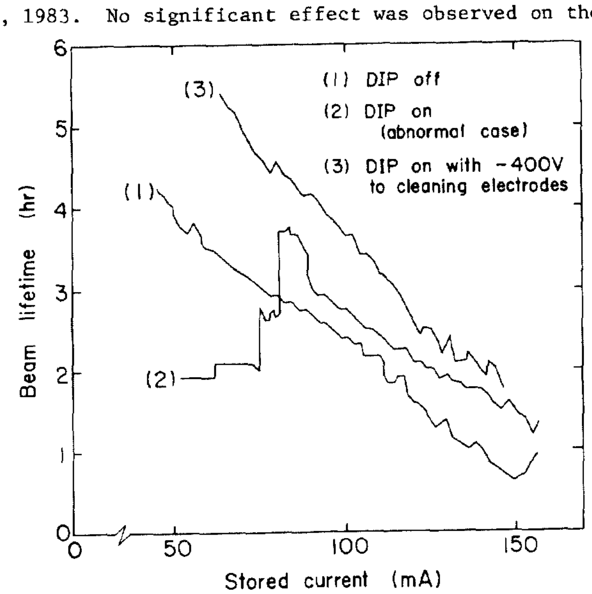


Fig. 3

storage ring operation. The K-value was changed from 0.4 to 1.7 by changing the magnet gap. The radiation spectrum was taken by measuring photoelectrons from helium, and the first interference peak at 380 eV and several peaks of higher orders were observed with the K-value of 1.7 which is achieved with the magnet gap of 28 mm.

Results of accelerator studies

1. Lattice parameters

Lattice parameters have been measured to check the effect of unavoidable errors in the magnet system. In view of the fabrication tolerances and the accuracy of measuring the beam position and the tune, agreement with designed values was quite satisfactory (within 10%).

2. Control of the closed orbit

Stability of the closed orbit is important for the synchrotron radiation sources. Observed uncorrected distortions were ±6 mm in the horizontal plane and ±4 mm in the vertical plane. By using 28 horizontal and 42 vertical orbit correctors, we achieved the orbit correction within ±1 mm in the horizontal plane and ±0.5 mm in the vertical plane, after three iteration processes. In the case of the horizontal plane, the rf frequency was included as an adjusting parameter. It is interesting that the optimum rf frequency was correlated with ambient temperature, which indicates the corresponding deformation of the storage ring enclosure.

To insure the reproducibility of the orbit, we usually initialize the magnet system in prior to the routine operation, and eliminate error fields to be produced due to hysteresis effects. For the same reason, we have operated the storage ring with the fixed operating point (5.26, 4.17) through the course of 2- to 3-month running period.

3. Resonances

Resonance mapping measurements have shown the existence of synchrobetatron sidebands of fundamental lattice resonances. We have observed the sidebands of the integer resonance $\nu_y - m\nu_s = 4$ for $m \leq 4$, where the beam grows in the vertical direction and is lost. Other higher sidebands have not been observed. There have also been observed the first and second sidebands of the half-integral resonance ($2\nu_x + m\nu_s = 11$, $m = 1,2$) and the first sidebands of the third order resonance ($3\nu_x \pm \nu_s = 16$), which give the horizontal blow-up to the beam. At the first sidebands of the coupling resonance $\nu_x - \nu_y \pm \nu_s = 0$, the beam enlarges just as observed at $\nu_x = \nu_y$.

4. Coupled bunch instabilities

Both horizontal and longitudinal coupled bunch instabilities have been observed. The frequency spectrum of a signal from the position monitor peaked at frequencies,

$$f^{\pm}_{n,\mu} = nBf_r \pm (\mu f_r + f_{\beta,s}),$$

for all positive integral value of n

with B being a number of bunches (312), f_s the synchrotron oscillation frequency (56 kHz), f_β the frequency corresponding to the fractional part of the betatron tune and f_r the revolution frequency. The observed mode number μ was 268 for the horizontal oscillation and 161 for the longitudinal oscillation.

For the standard operating point, the frequency $f^{-}_{n=3,\mu=268} = 1070.3$ MHz is close to a cavity resonant frequency of a TM111-like mode, whose transverse coupling impedance $R_\perp = 27$ MΩ/m is the largest among TM1ℓm-like modes. The tune dependence of the threshold current of the horizontal instability are shown in Fig. 4. The narrow tune dependence of threshold current is consistent with high Q-values of the TM111-like mode

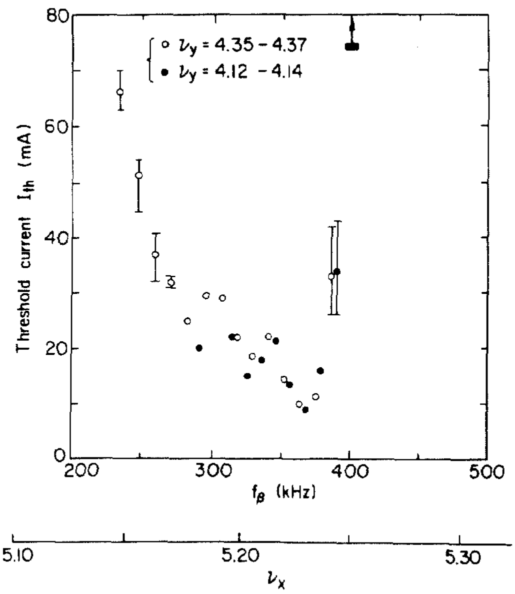


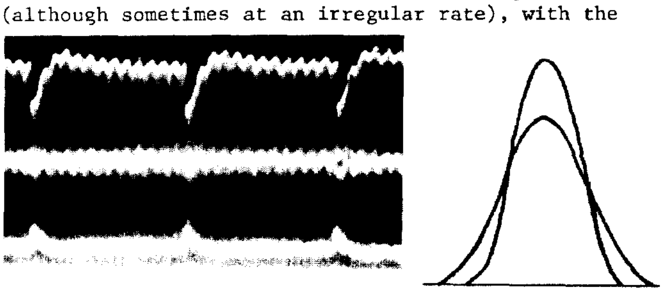
Fig. 4

(Q = 40,000) and the fact that the resonant frequencies are in agreement within 100 kHz for four cavities. It is curious that the horizontal blow-up occurs only when some "triggers" like the injection kickers or the rf knock-out can be allowed to exist. Beams can survive for a long time in the unstable region shown in Fig. 4, if the tune is shifted there after the injection was achieved with the stable operating point.

For the longitudinal oscillations, the frequency $f^{+}_{n=1,\mu=161}$ = 758.228 MHz is again close to a resonant frequency of a TM011-like mode in the cavities, whose longitudinal coupling impedance R_{sh} = 3.0 MΩ is the largest among the higher order modes. The observed f_r-dependence of the threshold current is consistent with measured resonant frequencies of four cavities. It is remarkable that the amplitude of the oscillation grows with beam current but saturates at several tens mA, and begins to be modulated with a frequency of about 200 Hz. The modulated oscillation manifests itself as a broadening of the resonant frequency spectrum on a spectrum analyzer and, more clearly, as the oscillation of the horizontal beam profile.

5. Vertical instabilities

We have observed the vertical instabilities both during injection and storage. During storage, the beam bursts vertically to a large size, but the coherent signal at the vertical betatron frequency is not detectable. As shown in Fig. 5, blow-up is observed like a notch in the signal from the profile monitor. The vertical growth stays within the storage ring aperture and is not associated with beam loss. Then the beam damps back to a small size with a time constant comparable with the radiation damping time. This intermittent oscillation appears almost regularly (although sometimes at an irregular rate), with the



(20 ms/div)

Fig. 5

frequency which varies linearly with stored current. The frequency also depends on the gross vacuum pressure: the blow-up grows less frequently under the good vacuum conditions. The instability may be independent of betatron tune over a wide range.

We have sometimes experienced the cases in which no notch was observed throughout the whole storage cycle. At present it is hypothesized that ions trapped inside the electron beam give rise to the instability, although the mechanism has not been fully understood.

The vertical blow-up has also been observed during injection, which limits accumulation more than 50 to 100 mA. It should be noted that the instability does not occur when DIPs are switched off.

6. Variation of beam size with current

As indicated in Fig. 6, the beam size grows with stored beam current. These values correspond to the "stationary" beam sizes which must be superimposed by the modulated or the intermittent oscillations for the real beam, as described before. We have not yet been able to identify any particular mechanism of blow-up, but it is a problem to be solved urgently.

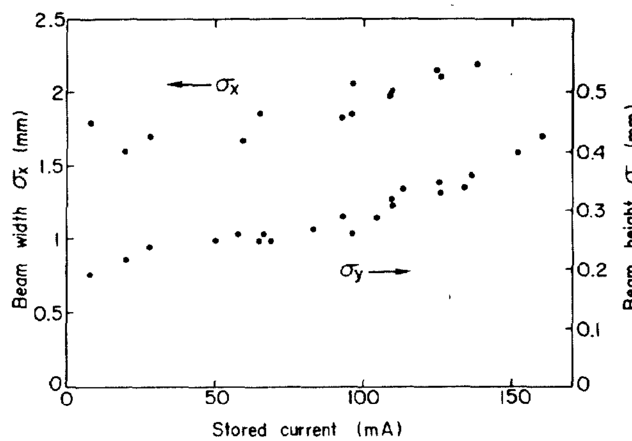


Fig. 6

Future improvement

1. Damping antenna which will reduce the coupling impedances by two order of magnitude are being developed to suppress the coupled bunch instabilities. Octupole magnets will be installed as one of the means to cure the instabilities.
2. Realisation of the single bunch mode will be pursued for two reasons: firstly to realize synchrotron radiation experiments on relaxation phenomena and secondly to eliminate the ion effects by leaving a small gap in the circumferential filling.
3. Preparations for the positron storage, which can be free from complicated ion effects, will be promoted to make it possible within a year.

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