# Present Status and Upgrading Program of the Photon Factory Storage Ring

Hisashi Kobayakawa
National Laboratory for High Energy Physics
Oho, Tsukuba, Ibaraki 305, Japan

*Abstract*

The Photon Factory is a synchrotron-radiation research facility which has been in operation since 1982. The light source is a 2.5-GeV positron storage ring, which stores 360mA under routine operation. Beam injection takes place once a day from a 2.5-GeV linear accelerator. More than 2000 researchers use sixty experimental stations which cover the vacuum-ultra-violet (VUV) to hard X-ray wavelength range.

## I. INTRODUCTION

The Photon Factory is a user-based facility for synchrotron-radiation research at the National Laboratory for High Energy Physics (KEK). This facility includes a 2.5-GeV linear accelerator and a 2.5-GeV storage ring. The parameters of the storage ring and the linear accelerator are given in Table 1.

Table 1 Parameters of the Photon Factory linac and storage ring

| | |
|---|---|
| Injector Linac | |
| Energy | 2.5 GeV |
| Repetition | 25(50) pps |
| Peak current ($e^-/e^+$) | 50/10 mA |
| Pulse width | 1-1.5 ns |
| Positron Generating Linac | |
| Energy | 0.2 GeV |
| Peak electron current | 10 A |
| Conversion target | Ta, 2 rad. lengths |
| Positron energy | 0.25 GeV |
| Storage Ring | |
| Energy | 2.5 GeV achieved 3.0 GeV |
| Stored current | 360 mA achieved 520 mA |
| Circumference | 187 m |
| Radius of curvature | 8.66 m |
| Betatron tunes | 8.45 (hor), 3.30 (ver) |
| Horizontal emittance | 130 nmrad |
| RF frequency | 500 MHz |
| Harmonic number | 312 |
| Number of cavity | 4 |
| Radiation loss | 510 keV/turn |
| Vacuum pressure | $2 \times 10^{-10}$ Torr at 300 mA |
| Injection | 2.5 pps ($e^-$), 25 pps ($e^+$) |
| Time for injection | 2-10 min ($e^-$), 20 min ($e^+$) |

The storage ring has been operational since 1982. The major upgrades made on the storage ring have been: (1) low-emittance operation from 1987 in order to increase the brightness of synchrotron radiation, and (2) positron operation from 1988. Though significant increases in the brightness have been obtained after low-emittance operation, many difficulties have simultaneously arisen, such as an increase in beam instabilities and photon-beam drifting. Efforts have been made to stabilize the positron beam, and great progress has been achieved. Over the last several years, the facility has been operating at a high level of performance and reliability.

Twenty-three beamports have been equipped with beamlines. Sixty experimental stations are now operational; thirty-three of these are for X-ray studies, twenty-seven for VUV and soft X-rays and one for photon-beam position monitoring for diagnosis. Four beamlines were built by private companies. Six insertion-device beamlines have been operational (Fig. 1).

The number of users is about 2200, including more than 300 users from industries; 69% of the users are from universities, 7% from national laboratories, and 24% from industries. The number of proposals submitted every year is about 300; 48% of these involve solid state physics and material science, 23% chemistry and atomic or molecular sciences, 15% biology or biochemistry, and 6% for technology or industrial use.

An FEL-project using the Photon Factory storage ring is underway. This project involves FEL-research for developing the shorter wavelength region. A gain measurement at 177-nm is our present goal.

We are planning to increase the brightness of synchrotron radiation by reducing the beam emittance by a factor of 5. The new emittance will be 27 nmrad.

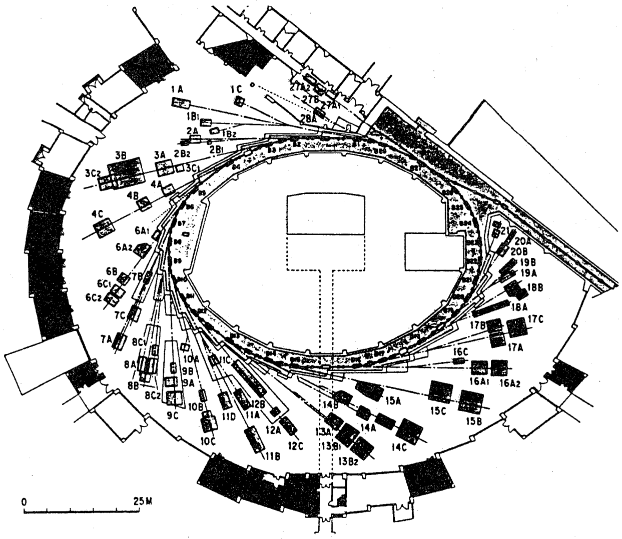

Fig. 1 Storage ring and experimental hall

## II. STORAGE RING OPERATION AND BEAM TIME STATISTICS

A summary of the operation times of the storage ring is given in Fig. 2. The operating beam of the storage ring comprises positrons. The initial stored current is 350-360 mA for user-runs and the beam lifetime is in excess of 60 hours at 300 mA. The average current is about 300 mA in 24-hour fill lengths. The injection rate of the positron beams is presently very high, 0.5-1.0 mA/sec, which has improved after several modifications made on the positron-generator system.

The product of the beam current and the lifetime ($I\tau$) is a good standard of the storage-ring performance. The value of 24 Amp·hr in 1991 is very large; we are presently maintaining it at around 20 Amp·hr (Fig. 3).

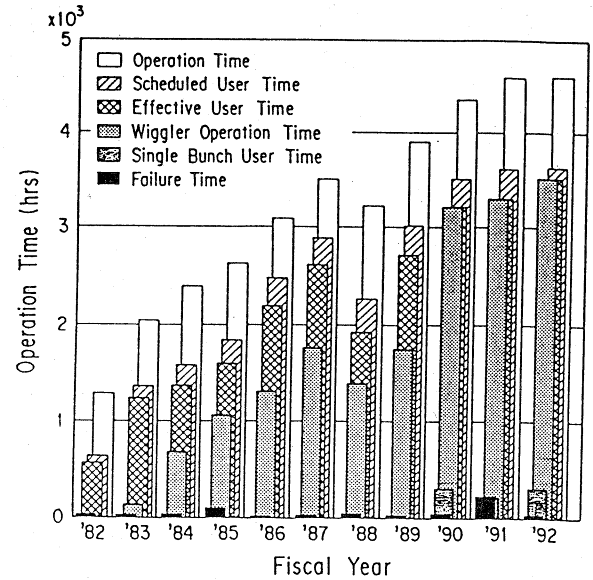


Fig. 2 Operation times of the storage ring.

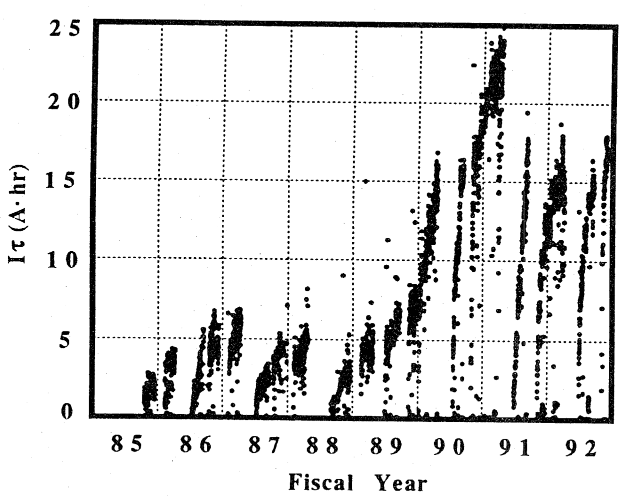


Fig. 3 A plot of $I\tau$

In fiscal year 1992, 301.7 hours were provided for single-bunch users. The beam lifetime at 50 mA is 10-20 hours, which is limited by the Touschek effect. The accumulation speed has typically been 0.08 mA/sec with a short-pulse positron beam having a peak current of 18 mA at a repetition rate of 25 Hz. Cleaning of the beams in the neighboring buckets routinely takes place after every beam injection. The ratio of the satellite bunch to the main one was kept below $10^{-5}$ by using the rf knock-out method and vertical scrapers at B04-B05.

The time-loss rate of the machine failure was very low, below 1% during fiscal year 1992, as shown in Fig. 4. The rather high failure rate during 1991 was due to a water leak into the storage-ring duct due to an accident. On December 16, 1991, during a beam test of the superconducting wiggler (BL-14) operating with 5-poles (5T), a water-cooled SR-absorber located just downstream of the wiggler melted due to high-power radiation. A large amount of water flowed into the ring duct. Although the interlock system worked completely well, and all of the isolation valves in the storage ring closed immediately within a second, 2/3 of the ring circumference was contaminated by water vapor. The broken absorber was made of stainless steel. This is an old mistake during the early days of the Photon Factory; the absorber was believed to have been replaced by one made of copper.

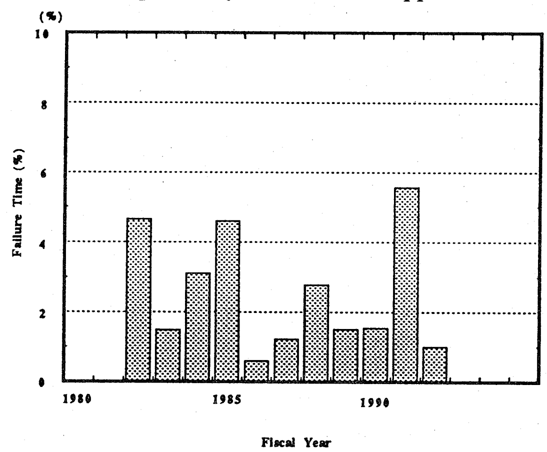


Fig. 4 Failure rate .

## III. INSERTION DEVICES

Insertion devices were installed into six straight sections of the storage ring. (1) The 119-pole undulator (U#02) at beamline-2 was upgraded in 1990. The magnet configuration was changed from the pure $SmCo_5$ type to a hybrid type comprising NdFeB magnets and vanadium permendur poles. Since the maximum value of the K-parameter increased from 1.7 to 2.3, U#02 can supply first-harmonic radiation at energies between 0.27 and 0.9 keV. This undulator was replaced by an optical klystron during the 1992-summer shutdown for a short-wavelength FEL study. The optical klystron has a special structure in that the magnet configuration can be switched back to that of the undulator. During the user-run, it can be operated completely under the undulator mode, including free-gap tuning. (2) The superconducting vertical wiggler (VW#14) at beamline-14 was upgraded in 1989. The new wiggler has five magnet poles with a maximum field strength of 5 T. The consumption of liquid helium is typically 0.12 l/h. It works as a wavelength shifter and provides X-rays with an energy of less than 100 keV. (3) A multipole wiggler/undulator (MPW#16) at beamline-16 supplies VUV to X-rays in the 0.03-70 keV energy range. MPW#16 was removed from the storage ring during the 1992-summer shutdown in order to replace its magnet pieces, since this wiggler had a problem in that the permanent-magnet pieces sometime came off during user-runs. The magnet array was reconstructed using new magnet pieces with a new holding system. The wiggler was reinstalled in January,1993. (4) An undulator of the four-array-revolver type at beamline-19 (Revolver#19) supplies VUV in the range 0.01-1.1 keV by the rotation of four undulators. (5) A multipole wiggler/undulator on beamline-13 (MPW#13) supplies VUV to X-rays in the 0.03-70 keV energy range. (6) The wiggler/undulator(EMPW#28) at beamline-28 supplies circularly polarized radiation of VUV to the X-ray range.

## IV. RESEARCH AND DEVELOPMENTS

### *A. Short-Wavelength FEL Project*

The FEL-project at the PF storage ring involves FEL research for developing a shorter wavelength region. A gain measurement at 177 nm is our present goal. For this project, we use the optical klystron at beamline-2. The time required for the FEL study is prepared in between user-runs, taking extra-runs of typically several days. The spectrum of spontaneous emission from the optical klystron was observed at a beam energy of 0.75 GeV by using a VUV spectrometer, the McPherson 225 1m-normal incidence type.[1]

### *B. Longitudinal Feedback System for the FEL study*

Under low-energy (0.75 GeV) operation for the FEL experiments, longitudinal coupled-bunch instabilities limit the beam current and quality. A longitudinal feedback system[2] was developed in order to realize stable 4-bunch operation for the FEL experiments. The system employs a bunch-by-bunch feedback scheme. The phase-oscillation signal of each bunch obtained from a button-type electrode is amplified and their phases are shifted by 90° in order to obtain energy-oscillation signals. A correction voltage is applied to each bunch through a feedback cavity in order to dampen the longitudinal oscillations. This cavity was installed in the straight section B04-05 during the 1992-summer shutdown.

### *C. Dynamic Aperture Measurement*

We are planning to reform the storage ring toward a low-emittance ring. The most serious issue in this plan is that the dynamic aperture will become small due to the strong sextupole fields. A computer simulation using an ideal machine model predicts that the dynamic aperture is still larger than the physical one. Since the real storage ring has various imperfections, we need to know the difference in the measured aperture and the computer-simulated one. The dynamic aperture of the PF ring can be varied with the octupole magnets which are presently employed to suppress transverse instabilities under routine operation. As the first step, we measured the apertures by varying the octupole strength[3], and compared the result with computer predictions. The procedure of the aperture measurement was to give a large kick to the circulating beam with a fast kicker magnet installed in B04-05 and then measure the amount of beam loss.

The experimental results show that the horizontal aperture was physically determined with no octupole excitation. The physical aperture at the scraper is about 30 mm, that is the duct size of VW#14. On the other hand, when the octupoles were excited, the measured apertures were dynamically limited because they depended on the octupole strength. Furthermore, the measured results agree with computer simulations (Fig. 5). However, no significant octupole dependence was observed in the vertical plane. This suggests that the vertical aperture is physically determined, even when the octupoles are strongly excited. The effective physical aperture estimated from the measurement at the scraper was about 8.0 mm.

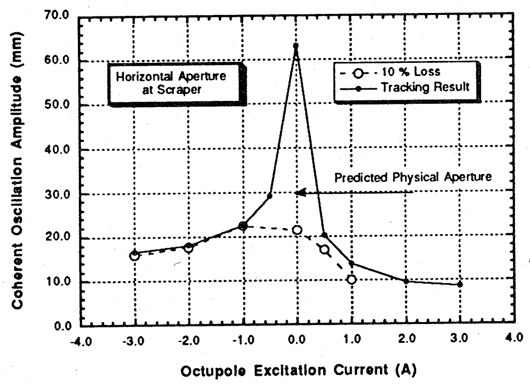


Fig. 5 Coherent oscillation amplitude in the horizontal plane at the scraper as a function of the octupole currents.

## V. PLAN FOR UPGRADING THE PF RING

The upgrade program of the PF storage ring is to reduce the beam emittance by a factor of 5, and increasing the brightness of synchrotron radiation by a factor of approximately 10. The present emittance is 130 nmrad; the new emittance will be 27 nmrad at 2.5 GeV. In this plan, we must add new quadrupole- and sextupole-magnets with a have smaller bore radius of 40 mm (the present bore radius is 55 mm); their side-yokes will be opened for the beamline ports. Since the bending magnets will not be changed, the source points and lines of the synchrotron light will also not be changed.

## VI. REFERENCES


1. H.Kitamura, *et al.*: private communication
2. S.Sakanaka, *et al.*: presented in this symposium
3. Y.Kobayashi, *et al.*: Proc. of the 1993 IEEE Particle Acc. Conf.