3 PF-AR

3-1 Summary of Machine Operations

The operation statistics for FY2004 are summarized in Table 1. The total operation time was 4857 hours, and the failure time 98.5 hours. The total operation time is now comparable to that of the PF ring. The failure rate is still about 4 times larger than that of the PF ring, but has improved greatly over recent years.

The RF acceleration system was composed of 4 cavities in the west long straight section and 2 cavities in the east long straight section by the end of June 2004. As reported in the last issue, we have plans to install new undulators for the NW14 beamline in the west straight section in FY 2005 and 2006. In order to make room for them, we evacuated two cavities from the west straight section during the summer 2004 shutdown. As also reported in the last issue, the #3 cavity in the west straight section became out of order after a vacuum accident and never recovered in FY2004. The #4 cavity and one of the spare cavities were moved to the east straight section whereas the #3 cavity was withdrawn. Corresponding to the move of the cavities, the low level RF system also had to be modified. Although we had been forced to operate the PF-AR with only five cavities from April 2003, we were finally able to restore the 6th cavity to the RF system in September 2004. In addition, we also refitted the power supplies for the klystrons in the same period. Although the RF system was largely modified in the summer, the PF-AR restarted smoothly in October.

Table 1 Operation statistics of PF-AR in FY2004.

Operation Time	4857.0 h	
SR Experiment	3941.5 h	81.2%
Beam Development	733.5 h	15.1%
Failure	98.5 h	2.0%
Miscellaneous	83.5 h	1.7%

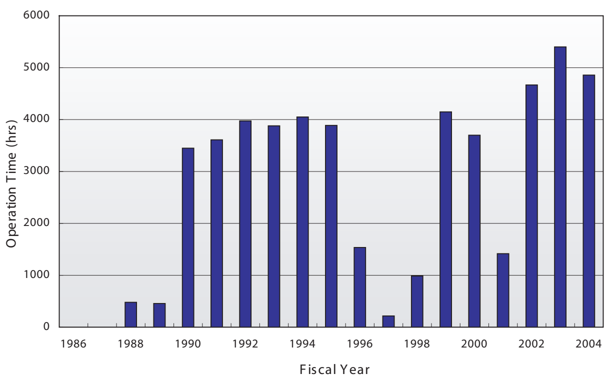

Figure 1
Operation time history of the PF-AR.

The PF-AR was injected twice a day as a rule, however, it was injected three times a day for about 3 months from October due to a large decrease in beam lifetime after modifications to the vacuum system during the summer shutdown. The initial beam current of 60 mA was unchanged throughout the year.

As reported in the last issue, a new standard operation mode (two-bunch operation at 5 GeV) for medical applications was established. However, no operation for medical applications was performed in FY2004. For the 6.5 GeV operation, the present value of the emittance (290 nm·rad) is not satisfactory. We have been making efforts to find a stable operating point that gives the optimum emittance of 160 nm·rad. We still have many things to try in order to establish a standard operating point that is adequate for user runs. A novel injection scheme using a pulsed quadrupole magnet was successfully tried. This method is described in detail in a separate section.

3-2 Research and Development

Transferring two cavities from west to east section

New undulators are planned for the latter half of the west RF section. In order to make space, we transferred two cavities from the west to the east RF section during the summer of 2004. The change in the cavity layout is shown in Fig. 2. The cavities were transported along the ring tunnel using rollers (see Fig. 3). At the same time, the problem cavity (W-3) was replaced with a spare one. These works were accompanied by changes in other parts of the RF system, such as in the waveguide network and in the control system. The modified RF system was commissioned successfully in October 2004.

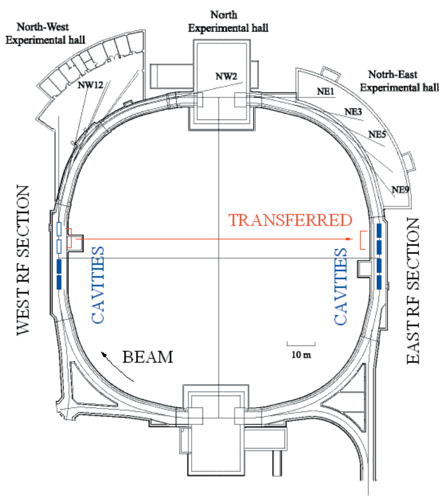

Figure 2
Layout of the cavities in the PF-AR tunnel. Two cavities were transferred from the west to the east rf section.

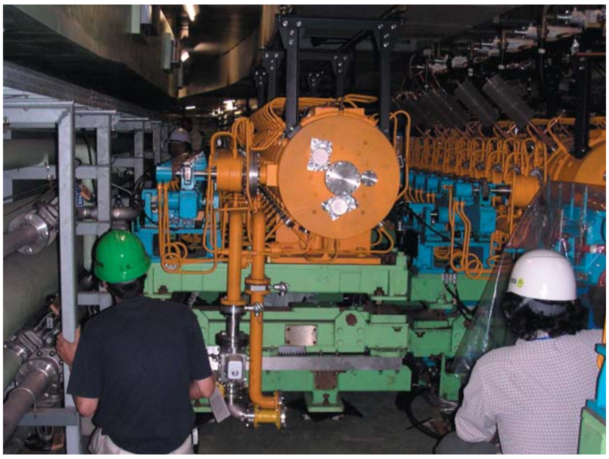

Figure 3
Transporting a cavity in the PF-AR tunnel.

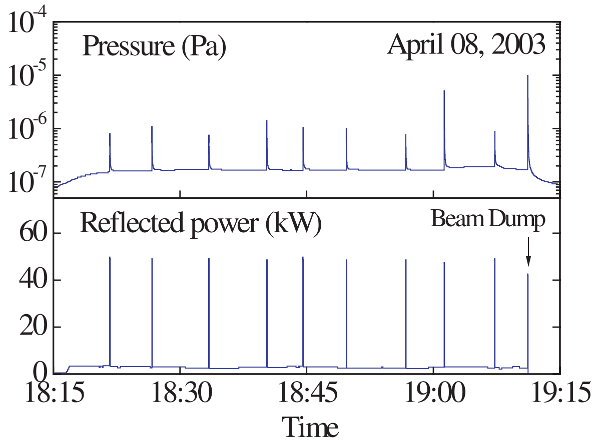

Figure 4
Vacuum pressure in cavity W-3 and reflected power from two cavities (W-3 and W-4) during the trouble. The beam energy was ramped at 18:16 with a beam current of 15 mA. The rf voltage was 16 MV with 6 cavities.

Efforts to repair the damaged cavity W-3

Six alternating-periodic-structure (APS) cavities, having eleven accelerating cells and ten coupling cells, are used for beam acceleration. As described in the previous report [1], one of the cavities (W-3) experienced serious problems in April 2003. The cavity could be operated with RF power of up to 190 kW/cavity, but frequent trips occurred under normal beam operations [2]. These trips happened following a vacuum leak in a neighboring cavity (W-1), and were due to spikes of reflected power from the cavity accompanied by sudden pressure rises, as shown in Fig. 4. Strangely, these trips occurred under beam operations at 6.5 GeV, but did not occur at an injection energy of 3 GeV. Due to limited time to fix this problem, we suspended operation of this cavity from April 2003 to June 2004.

Every time we had a scheduled shutdown, we made efforts to recover the problem cavity. These efforts included: (i) replacement of old ion pumps and some tuning plungers, (ii) inspection of the inside of the cavity using a fiber scope, (iii) fine tuning of an accelerating $\pi/2$ mode, (iv) replacement of an input coupler, and (v) inspection of higher-order-mode (HOM) couplers. Despite such efforts, the cavity did not recover at all.

Further investigations under beam operations revealed that the trouble was closely related to the irradiation of synchrotron radiation (SR) on the cavity wall. When we imposed a vertical closed-orbit bump having an angle of more than 0.3 mrad in a bending magnet upstream of the west cavities, trips in the problem cavity consistently disappeared. We should also point out the following observations: (1) upstream of the problem cavity W-3 there were two other cavities which are irradiated more strongly by the SR without problems, and (2) cavity W-3 worked well prior to the leak at the neighboring cavity. From these facts, we consider that some defects must have existed in cavity W-3 before the leak, and that these defects were activated by the leak. Then, the irradiation of the SR onto these defects triggered discharges under beam operation conditions. To confirm the above assumptions, we plan to investigate the inside of the problem cavity.

Because the PF-AR was originally designed as a booster for the TRISTAN main ring, there are currently no SR masks for the cavities, however, we plan to install them in the near future. Due to the long length (3.4 m) of the cavities, some of the masks should be made removable, due to their narrow apertures (19 mm at minimum).

References

[1] *Photon Factory Activity Report 2003,* **21A** (2004) 108.
[2] S. Sakanaka, K. Ebihara, S. Isagawa, M. Izawa, T. Kageyama, T. Kasuga, H. Nakanishi, M. Ono, H. Sakai, T. Takahashi, K. Umemori and S. Yoshimoto, *Proc of the PAC.*, (2005).

Progress of beam injection using a single pulsed quadrupole magnet

During the summer shutdown in 2004, we installed a single pulsed quadrupole (PQ) magnet into the PF-AR. Machine studies were carried out from the autumn shift, and beam injection using the new magnet was successfully conducted. Fig. 5 shows the location of the PQ-magnet installed in the PF-AR, and Fig. 6 a photograph of the actual magnet. A strip-line type beam kicker was originally installed at this location, and was relocated to the south symmetric point (see Fig. 5).

During the machine study, the excitation timing of the pulsed quadrupole magnet was firstly adjusted using the signal of the current transformer, as shown in Fig. 7. Once the timing was fixed, beam injection could easily be conducted using the PQ-magnet. Next, the COD (closed orbit distortion) was corrected to make the stored beam pass through the center of the magnet. The oscil-

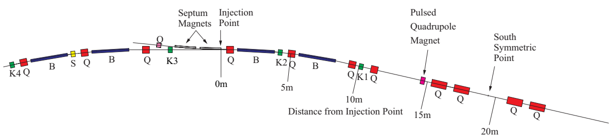

Figure 5
The location of the pulsed quadrupole magnet.

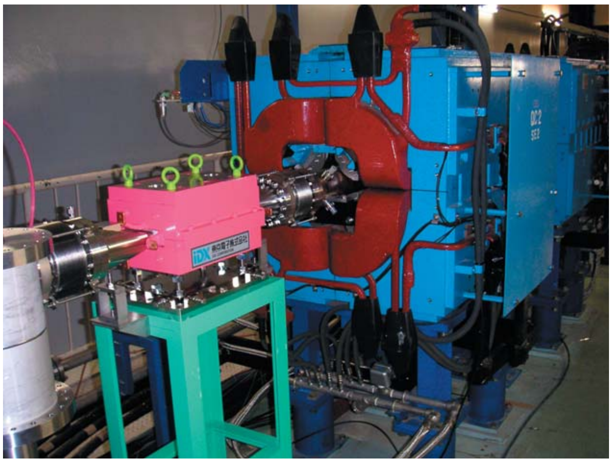

Figure 6
The pulsed quadrupole magnet (the lovely pink magnet) installed in the PF-AR.

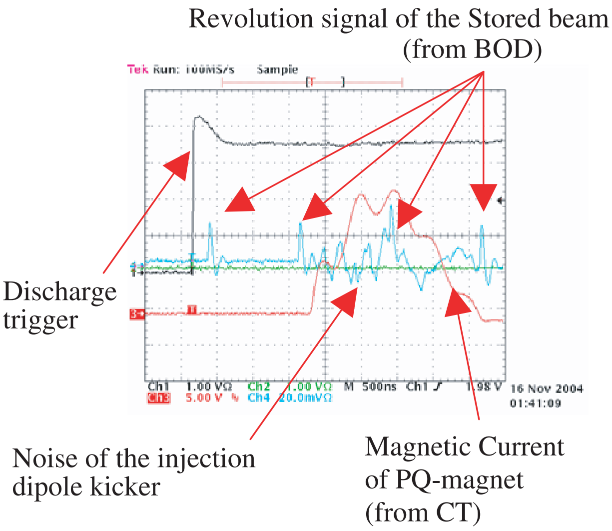

Figure 7
The excitation timing of the pulsed quadrupole magnet.

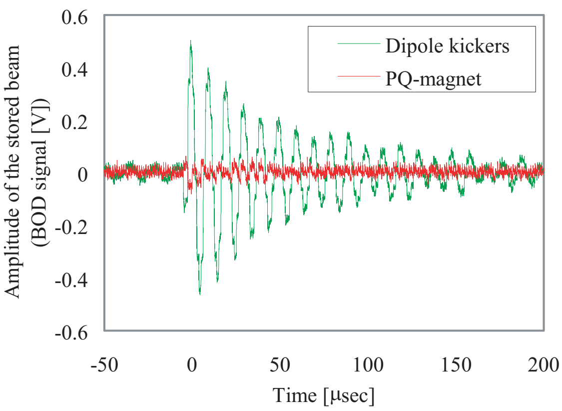

Figure 8
Oscillation of the stored beam.

lation of the stored beam excited by the PQ-magnet is compared to that excited by the dipole kickers in Fig. 8, and the beam profile of the injected beam and the stored beam using the two systems are shown in Fig. 9. As can be seen from these figures, while a large oscillation is observed for the conventional injection system, very little oscillation of the stored beam is observed for the

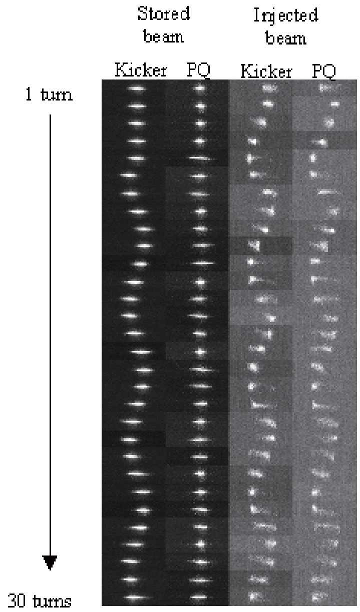

Figure 9 Beam profile.

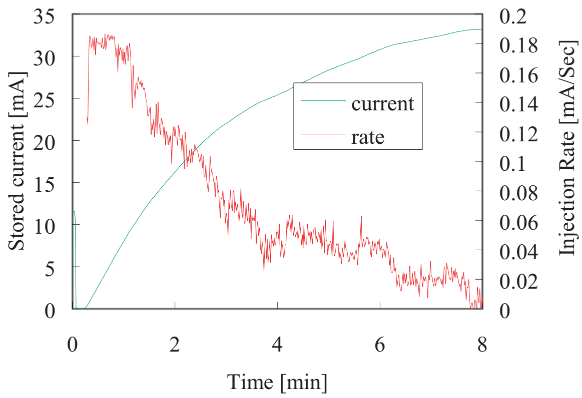

Figure 10
Injection history with the PQ magnet.

PQ-magnet system. We note that, in order to improve the injection rate for the usual injection system with the dipole kickers, a kicker jump (an intentional leakage of the closed bump) is inevitable and is one of the reasons for the large oscillation of the stored beam. On the other hand, the blink of the stored beam with the PQ-magnet is the quadrupole-mode oscillation excited by the PQ-magnet. However, if we can install another pulsed quadrupole magnet upstream of the injection point, we may be able to cancel the quadrupole-mode oscillation. The typical trend of the beam injection rate and the stored beam current using the PQ-magnet is shown in Fig. 10.

In single-bunch mode, a maximum stored current of 65 mA has been achieved with the usual injection system using the dipole kickers. However, we have never realized a beam current of more than 50 mA using the PQ-magnet. It is well known that the beam instability problem is very severe in the PF-AR. It is said that the dipole oscillation of the stored beam excited by the injection dipole kickers may raise the beam instability, deteriorate the beam injection rate, and finally determine the maximum stored current for the usual injection system with the dipole kickers. For the PQ-magnet, however, a dipole oscillation of the stored beam has not been observed. Thus, the mechanism (or the type of the beam instability) which restricts the maximum stored current may be different from that with the usual injection system with dipole kickers. Investigating this mechanism will be the subject of future machine studies.

In four-bunch mode, we succeeded in storing a beam current of more than 90 mA using the PQ magnet injection system.

Two new in-vacuum type undulators for the PF-AR

For the past few years the non-equilibrium dynamics project has been underway at the 6.5 GeV PF-AR [1], and to support the project we are planning to modify the RF sections of the PF-AR to create empty straight sections for insertion devices, and to construct a new beamline AR-NW14. Two of the four RF cavities in the west RF section are to be moved to the east section, where there are already two operating cavities (see Fig. 11). In the new straight sections we plan to construct and install two new in-vacuum type X-ray undulators (U#NW14-36 and U#NW14-20) for beamline AR-NW14 in the most downstream section and the second-lowest section.

In the construction of these undulators, we have employed the same in-vacuum technology [2] used already for several of the PF-AR undulators, and adopted a pure Halbach type magnet arrangement with period lengths λ_u=36 mm for U#NW14-36 and λ_u=20 mm for U#NW14-20. The numbers of periods were chosen to be N=80 for U#NW14-36 and N=75 for U#NW14-20. For U#NW14-36 the period length was chosen to cover the photon energy region of 5-25 keV under 6.5 GeV operation using up to the fifth-order harmonics (see Fig. 12.) For U#NW14-20 the period length was chosen for the first harmonic to cover the energy region of 13-18 keV under the same conditions. Fig. 13 shows how the spectrum from U#NW14-20 depends on the magnet gap.

For the magnet material we have selected an Nd-Fe-B alloy with a remanent field of B_r=12.0 kG and a coercivity of iHc=28 kOe (NEOMAX35VH, NEOMAX Co. Ltd.), for its excellent magnetic performance and endurance against the high temperatures reached during baking. Magnet blocks made of the porous alloy are coated with a 5-μm layer of TiN to create a vacuum-tight seal, embedded in an oxygen-free copper holder, and attached to a pair of aluminium magnet-mounting beams.

Magnetic measurements and adjustments are now underway for U#NW14-36, which will be installed in the PF-AR during summer 2005 following vacuum commissioning. The installation and commissioning of U#NW14-20 will be carried out in 2006.

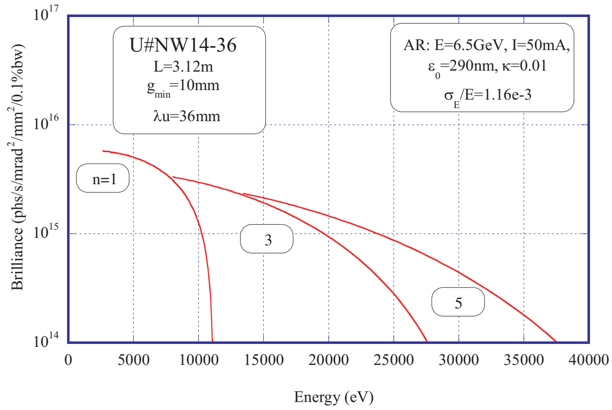

Figure 12
Spectra of the radiation from U#NW14-36. Brilliance of the first, third and fifth harmonics are shown.

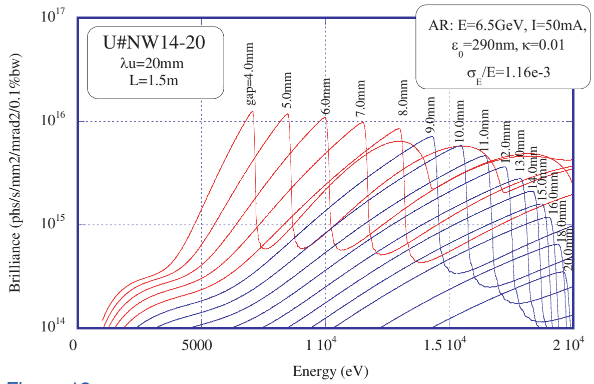

Figure 13
Spectra of the radiation from U#NW14-20. The first harmonic covers an energy region from 13 to 18 keV as the magnet gap is changed from 8 mm to 14 mm.

Figure 11
Modification of the west RF section in the PF-AR.

References

[1] *Photon Factory Activity Report 2003*, **21A** (2004) 66.
Photon Factory Activity Report 2004, **22A** (2005) 83.

[2] S.Yamamoto, K. Tsuchiya and T. Shioya, *AIP Conf. Proc.*, **705** (2004) 235.