

### 3. PF-AR Upgrading Project

#### 3-1. Outline of the Project

The PF-AR was originally constructed as a booster of the TRISTAN electron-positron collider, and had been partially used as an X-ray source. The ring was converted into a dedicated pulse X-ray source after completion of the TRISTAN experiments. However, because the ring was not designed as a light source, there are several problems: a short beam lifetime caused by insufficient vacuum system performance, low reliability due to superannuation of the machine components, inability of closed-orbit control due to a lack of reliability of the beam-position monitor (BPM) system, an insufficient number of beamlines, an unsatisfactory beam current limited by the RF system, etc. In order to solve some of them, we decided to improve the vacuum system and the BPM system within the annual budget of KEK from the beginning of 1999, and began to manufacture the new vacuum ducts made of OFHC copper with newly designed BPM electrodes. In the meantime, the Government approved a supplementary budget for the PF-AR upgrading project in December, 1999. The following are the main improvements based on the budget. Vertical steering magnets to improve the orbit control capability and quadrupole and sextupole magnets newly designed not to interfere with SR beamlines were manufactured. The power supplies for the steering magnets were all renewed, power supplies for the new quadrupole magnets were built and the control system of the power supplies for magnets will be completely renewed in the upgrading project. In order to enhance the pumping speed of the vacuum system, we arranged distributed ion pumps (DIP), sputter ion pumps (SIP), titanium sublimation pumps (TSP) and non-evaporable getter pumps (NEG) around the ring. We also arranged vacuum gauges every 5 m to monitor the vacuum pressure. The control system will be changed from the present NORDAL

system to the EPICS, which is successfully used in the KEKB control system. A beamline and an in-vacuum-type insertion device were designed and manufactured. Since the budget was limited, we decided to reuse the present APS cavities (only the HOM dummy loads of which will be reinforced) and the injection system, including the injection-beam transport line.

#### 3-2. Magnet System

Field measurements of the new quadrupole (QM), sextupole and vertical steering magnets were carried out using the rotating coil systems [1]. First, the excitation curves of these magnets were measured. The results agreed well with the predictive values. Figure 1 shows an excitation curve of the integrated field gradient ( $B'l$ ) for the QMs. Next, an end correction for the QMs was carried out in order to ensure a good magnetic field region. The end-shims, which are made from the same materials as the magnet yolk, were attached to both edges of the magnet poles. Since the 12-pole field component was dominant, we tried to reduce this component using the end-shims. The current dependence

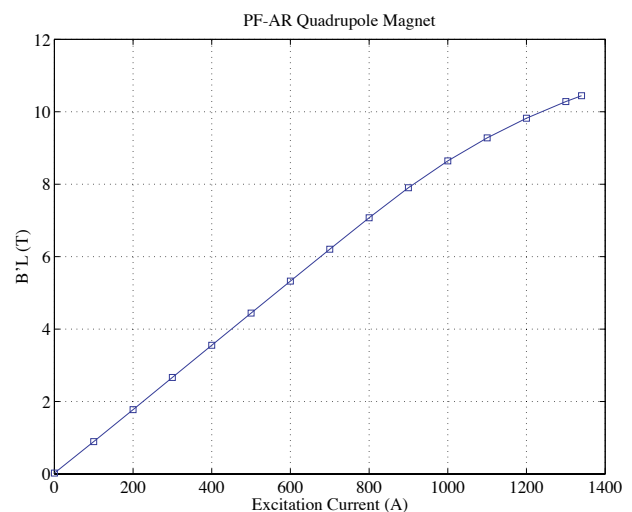


Figure 1. Excitation curve of the integrated field gradient ( $B'l$ ) for a new quadrupole magnet with a wide aperture.

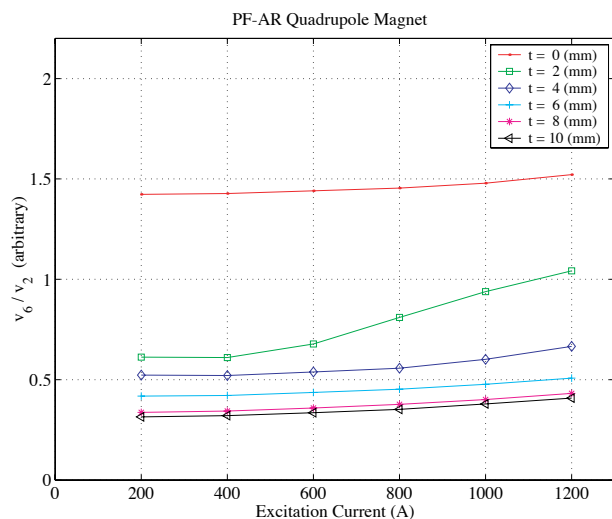


Figure 2.

Current dependence of the 12-pole component measured at several thicknesses of the end-shims. The vertical axis shows the ratio ( $V_6/V_2$ ) of 12-pole component for the quadrupole component, which was measured using a tangential coil.



Figure 3.

Photograph of the bipolar power supplies installed in the east power supply building.

of the 12-pole one, which is shown in Fig. 2, was measured at several thicknesses of the end-shims. It was reduced by about 1/5 using an end-shim of 10 mm thickness.

Two power supplies (20 V-1340 A) for new QMs with a wide aperture, which were installed to avoid

interference with the new ID beamlines (NW12, NW14), were fabricated. The 140 bipolar power supplies (50 V-10 A) for both the horizontal and vertical steering magnets were also fabricated to obtain further stabilization of the orbit. Figure 3 shows a photograph of the bipolar power supplies installed in the east power-supply building. The interfaces of all power supplies were exchanged from CAMAC to ARCNet, which was connected to the EPICS system.

A survey and an alignment of the bending and quadrupole magnets were carried out before the installation of new vacuum ducts.

#### Reference

- [1] Y. Kobayashi et al., *Proceedings of 10th Symposium on Accelerator Science and Technology*, (1995) 121

#### 3-3. RF System

Six APS-type (Alternating Periodic Structure type) cavities are used to provide a total rf voltage of about 15 MV. These cavities are housed in the east (two cavities) and west (four cavities) straight sections. Each rf station is driven by a 1-MW klystron, where the east station is operated with half the power of the west station.

In order to stabilize the cooling-water temperature for the cavities, which is important to avoid any cavity-induced beam instabilities, a temperature-stabilization system was constructed in FY1997. This system comprises chillers, heat exchangers, and a control system. It can stabilize the water temperature by exchanging the heat between input water and cold water, where the cold water is provided by chillers. Using this system, we can independently set the water temperature for each cavity, as well as stabilize the temperature. This function is useful to look for an optimum condition for the storage ring operations.

During the present reconstruction, the following upgrades are underway: i) replacement of the present 1-kW higher-order-mode (HOM) loads to new 3-kW ones, ii) improvement in the crowbar circuit of the klystron power supply, iii) replacement of the control software to an EPICS-based one, and iv) replacement of some of the old components. These upgrades will be useful to achieve higher beam currents.

### 3-4. Vacuum System

For the upgraded PF-AR, the existing beam chamber, vacuum pumps and vacuum gauges will be renovated.

The beam chambers around the entire circumference should be replaced by new ones, except for the RF cavities, insertion devices and some beam diagnostics equipment. New chambers for the arc sections have been designed. These consist of two parts: with a beam-position monitor (BPM) and the others. The parts are assembled with bellows after calibration of the BPM. The total number of arc-chambers is 56. The production of certain parts and bellows was finished in FY1999. The rest were man-

ufactured, and all 56 arc-chambers were fabricated. Also, the beam chambers necessary in straight sections were designed and manufactured. All new chambers were prepared in FY2000. Removal work of the existing chambers started at the end of February, 2001, and two arc-chambers were installed on a trial basis.

The pumping speed of the ring should be greatly increased to improve the beam lifetime. Titanium sublimation pumps (TSP), distributed ion pumps (DIP) and sputter ion pumps (SIP) will be used as the main pumps. These pumps were newly prepared with controller power supplies, and the DIPs were installed in the arc-chambers. A cold cathode gauge (CCG) was adopted for measuring the ring pressure. The CCG usually has convenience and ease of operation, but is required in the ring to operate precisely in the  $10^{-7}$  Pa range, or lower. A new controller power supply was developed, and the gauge performance was examined by comparing with an ion gauge calibrated against a spinning rotor gauge. The calibration factor was then determined. The result was satisfactory, as shown in Fig. 4.

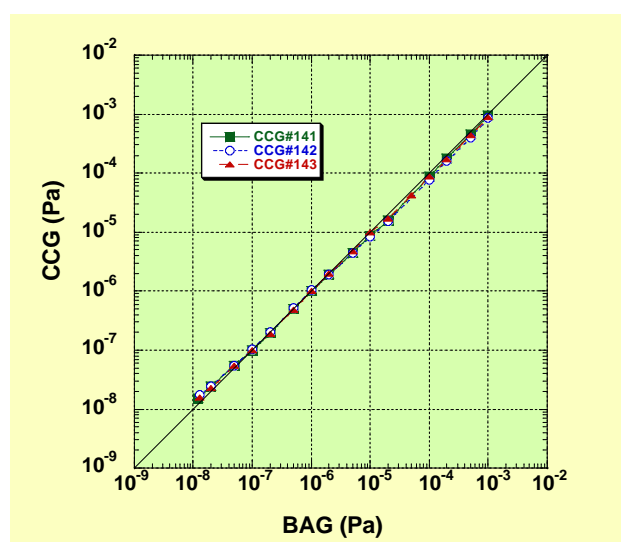


Figure 4. Calibration curve of the CCG compared with a BA gauge.

### 3-5. Monitor System

Accompanying the upgrading project of the PF-AR, the beam-position-monitor (BPM) system has been partly renewed in order to precisely measure the electron-beam orbit and to stabilize the beam position using feedback. Owing to a replacement of all vacuum ducts, new pickup units with four-button electrodes have been manufactured. A cross-sectional view of the pickup unit is shown in Fig. 5. Four feed-throughs were attached to the copper duct by flanges. Each BPM unit is fixed to an end of the quadrupole magnet.

The 56 BPMs in the normal-section part of the PF-AR had to be calibrated prior to assembling with the bending part of the vacuum ducts. The sensitiv-

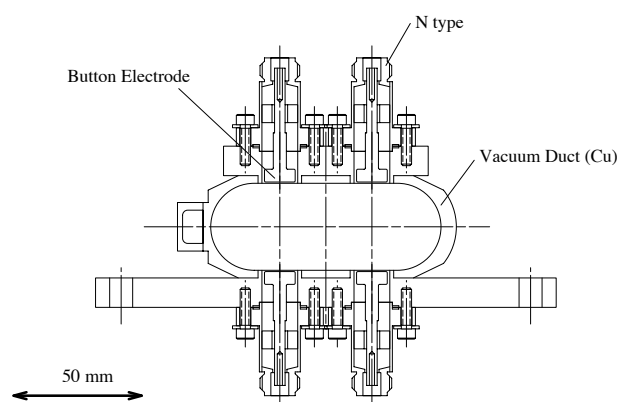


Figure 5.  
Cross-sectional view of the pickup unit.

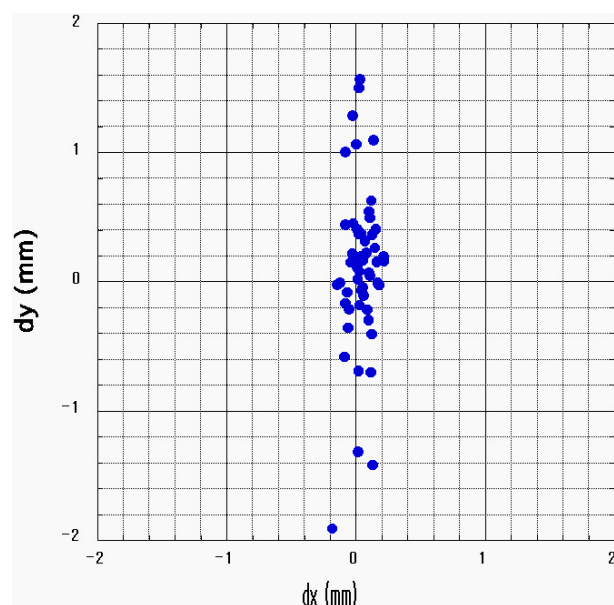


Figure 6.  
Distribution of the electrical center offsets.

ity of the BPM had been simulated before the calibration by using the Boundary Element Method, and only the electrical offsets of the BPM have been measured with an overall accuracy of about  $100\ \mu\text{m}$  at a calibration bench using a coaxially strung metallic wire. Figure 6 shows the distribution of the measured electrical-center offsets for new BPM pickup units. The horizontal and vertical electrical offsets of each BPM are represented as one closed circle in this figure. Most measured offsets are less than  $700\ \mu\text{m}$  in the vertical direction, and less than  $200\ \mu\text{m}$  in the horizontal direction. This is in good agreement

with simulated results considering the difference in the sensitivities between both directions. There are several BPM units with large ( $> 1\ \text{mm}$ ) offsets; we found these offsets to result from the unequal distances between the four button electrodes and the inner surface of the vacuum duct by a simulation. These measured offsets will be stored on a computer and used to calculate the beam position.

### 3-6. Control System

A renewal of the control system based on EPICS (Experimental Physics and Industrial Control System) is under way. In order to minimize the loads and costs of the replacement, the device interface layer under CAMAC modules are not being changed. The existing CAMAC serial highways connect the control building and four sub-control buildings. For controlling the RF, the beam monitor, vacuum and beam transport, input/output controllers (IOCs) act as a host controller of each serial highway, and also act as a channel access server of the EPICS. To control of the magnet power supplies, we adopt the ARCNet system because of its advantage of easy operation and much functionality developed for the KEKB control system. A new server workstation (HP K900) started operation, which is used to develop software and to operate the PF-AR.

### 3-7. Insertion Devices

An in-vacuum undulator (period length of 4 cm and number of periods of 90) has been designed and constructed as an X-ray source for a new beamline (NW2) in the PF-AR. In this beamline, the use of X-rays in the range from 5 to 25 keV will be major for XAFS experiments. In order to cover this energy region by the fundamental to 5th harmonics, we need to adopt a period length as short as 4 cm,

although the beam energy in the PF-AR is as high as 6.0 (or 6.5) GeV. All magnet arrays of the undulator are brought into the vacuum of the PF-AR, since the undulator field having such period lengths as the present case (4 cm) is successfully achieved by the in-vacuum configuration, as proved by the preceding in-vacuum type undulator U#NE3 in the PF-AR.

As a spectral performance, this undulator is required to have two modes: 1) a mode for high brilliance for conventional XAFS experiments, and 2) a mode for relatively wide bandwidth (some 10% as relative bandwidth) for the dispersive XAFS experiments. A spectrum with a wider bandwidth is obtained by magnetic tapering, which can be achieved by making a difference (say, up to 1 or 2 mm) between gaps in the entrance and exit of the magnet array. Switching from the wide-bandwidth mode (tapering mode) to the high-brilliance mode must be made completely without any error. For this purpose, we have developed a new-type gap-driving mechanism, which uses a differential-gear system.

Magnetic commissioning is under way and will be followed by vacuum commissioning in the summer



Figure 7.  
In-vacuum undulator U#NW2 under magnetic adjustment.

of 2001 (Fig. 7). Calculated spectra are shown for the high-brilliance mode (Fig. 8) and for the tapering mode (Fig. 9), respectively.

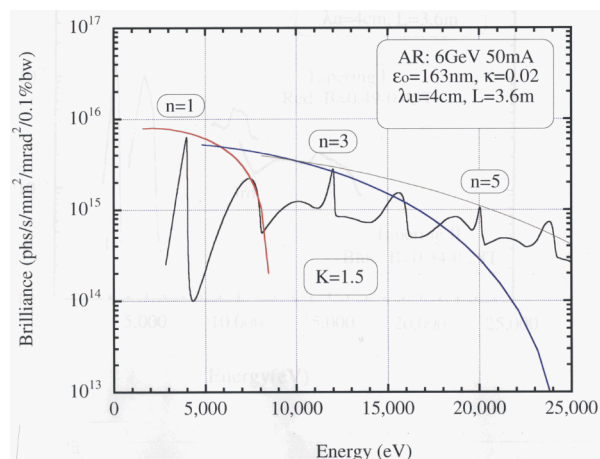


Figure 8.  
a) Calculated spectrum given in the case of  $K = 1.5$ . The parameters are given in the figure. The curves with the harmonic numbers  $n$  represent the loci of the peak of each harmonic.

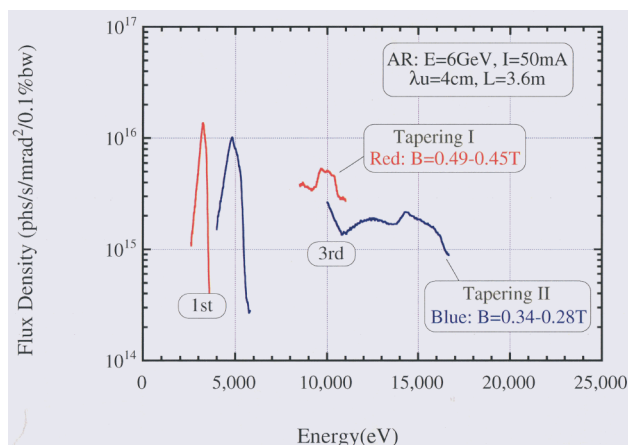


Figure 9.  
Spectra for the tapering mode. Two cases of magnetic tapering are shown: 1) case I, where a peak magnetic field of 0.49 T at the entrance gradually decreases to 0.45 T at the exit of the undulator, and 2) case II with the magnetic field from 0.34 T to 0.28 T.