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BEAM DIAGNOSTIC INSTRUMENTATION IN THE PHOTON FACTORY STORAGE RING

T. Katsura, H. Nakagawa and S. Shibata

National Laboratory for High Energy Physics
Oho-machi, Ibaraki-ken, 305 Japan

Summary

The Photon Factory storage ring is expected to provide researchers with a stable and flexible synchrotron radiation source. To meet their various needs, the machine is required to undergo changes in the optics[1] It must be equipped with a beam monitoring system which can provide precise and sufficient information of the machine parameters.

The function of the beam monitoring system is composed of several means: beam position monitors current monitors, tune measuring system, profile monitors and others. The beam position monitor system consists of 45 electrostatic position monitors and provides closed orbit measurements. Position information is also given by some other independent means, that is by using synchrotron radiation itself at several beam channels. The bunch structure will also be observed with a fast synchrotron radiation detector. Beam profiles are observed by screen monitors for the initial operation and by use of synchrotron radiation. Beam current is measured in two different terms. A DCCT gives the average current, while a toroidal transformer gives the fast current component to be compared with the amount of current transported from the injector linac. The tuning parameters are measured by a coherent excitation system which not only provides the betatron frequencies but also works as an active oscillation damping tool.

The beam transport and injection system is equipped with several means to measure beam emittance and dispersion so as to confine the beam within a desired momentum spread before it reaches the storage ring. The function of the monitoring system also is to provide the central control operator with beam positions, intensity, and profiles.

2. Beam Monitors for the Ring

2-1 Beam Position Monitors

Beam positions must be measured with an accuracy of 0.1 mm to make the closed orbit correction effective. There will be four position monitors every betatron period in correlation with the correcting element. A total of 45 electrostatic position monitors will be installed around the ring circumference. Each of them measures both horizontal and vertical beam position.

A position monitor has six disc shaped electrodes and built directly into the Q-vacuum chamber and situated near the quadrupole[2] This type of position monitor is chosen mainly by the following reasons:

(i) The over-all dimension has to be small to make the inner wall of chamber smooth and the RF losses small enough.

(ii) This type of electrode is easier to manufacture with the required tight tolerances than other types such as electromagnetic loop, or strip line.

The signal will be induced by a bunch current of order 8 A for its duration of 130 ps every 2 ns when an average current of 500 mA in 312 bunches is assumed. The transverse position sensitivity on the central orbit is about 4%/mm for both vertical and horizontal directions. This implies that the system including the electronics must have resolution better than 0.4 % for the required accuracy. The response of the monitor is shown in Fig. 1. The linear range is limitted to the central region. Non-linearities corrected by the computer program.

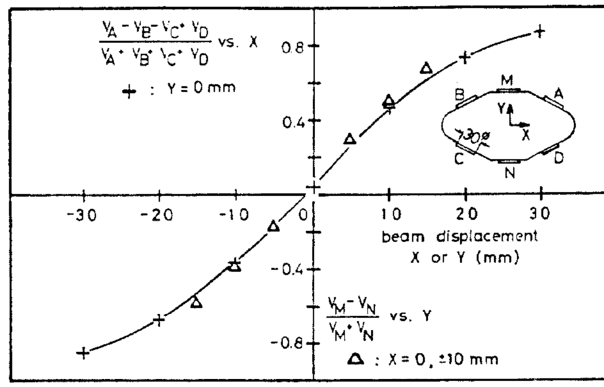

Fig. 1 Sensitivity of six-electrode position monitor. For a displacement in the x-axis, the beam position is given in terms of electrode signal V's as $\Delta x = S_x(x,y)(V_A-V_B-V_C+V_D)/(V_A+V_B+V_C+V_D)$ where $S_x(x,y)$ is the position sensitivity at the point concerned. Along the x-axis, $S_x(0,0) = 4\times10^{-2}$/mm for y=0(+). The y sensitivity S_y is measured along three lines parallel to y axis: y=0, ±10(Δ). All three give almost the same value of $S_y(0,0) = 4.63\times10^{-2}$/mm.

Beam analog signals are derived using coaxial relay switches, attenuators and amplifiers with detectors before DC signal will be transmitted to an A/D convertor which are conneted to the computer link. Six electrode signals of each position monitor are multiplexed with a coaxial relay onto one coaxial cable to outside the tunnel. The attenuators in front of the head amplifiers are programmable to maintain electrode signal levels within the range of the processing electronics and to cover a dynamic range from 10^5 up to 6×10^9 particles per bunch. The head amplifier has a mixer with a local oscillator followed by IF amplifying stages to obtain a gain of about 100 dB altogether.

Calibration of each position monitor involves (1) finding a standard point as the origin of a physical coordinate system which will be used with respect to the quadrupole magnet and (2) one-to-one mapping between the physical coordinates and the coordinates calculated by using the electrode signals.

To guarantee the physical cooridnates, each position monitor will be firmly mounted on a pair of precisely machined arms to lessen its lateral movement with respect to a corresponding axis of quadrupole magnet.

Calibration data for a position monitor are obtained as a chart like in Fig. 2 which shows the coordinates calculated by using electrode signals corresponding to the physical coordinates. A beam position falling within a grid of 5mm × 5mm will be

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obtained by linear interpolation based on the parameter expression of the mesh.

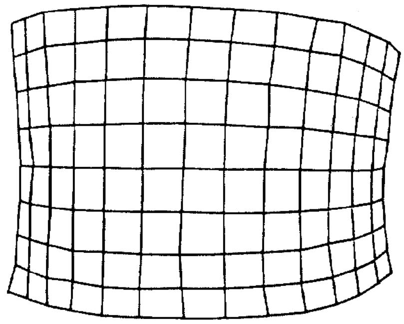

Fig. 2 Calibration map of position monitor with 5mm × 5mm grids covering 65mm × 40mm area.

2-2 Beam Monitors Using the Synchrotron Radiation

The quality of the stored beam reflects upon the extracted synchrotron radiation. Observation of the radiation will provide many useful informations about the electron beam in the ring. There are many synchrotron radiation ports, one of which are completely available for monitoring use.

VUV vertical beam position monitor

A pair of photoemissive horizontal ribbons will be installed to measure beam positions independently of the electrostatic position monitors. As the synchrotron radiation has its intricsic angular divergence, it is possible to tell if the beam traverses in the middle of the pair of ribbons by comparing signals between the two[3]

Fig. 3 shows the position sensitivity measured with a pair of tungsten ribbons exposed to synchrotron radiation from a 380 MeV storage ring at 1 m away from the source point.

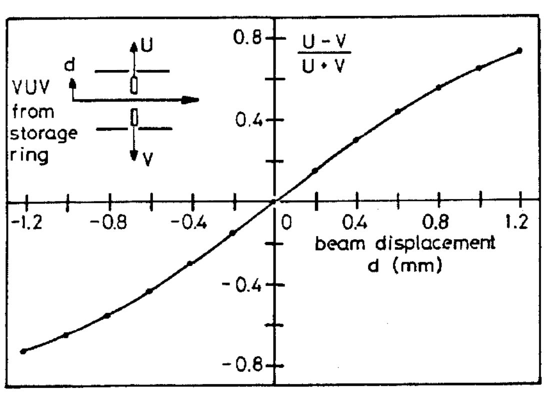

Fig. 3 VUV beam position monitor with two tungsten ribbons 3 mm wide and 4 mm apart placed in an ultra high vacuum chamber.

Position information will be transmitted to the control room for fine tuning of the electron beam. This will guarantee to make the extracted radiation very stable.

X-ray position monitor

In an X-ray channel, X-ray position will be measured by using an ionization chamber with two triangle electrodes on which ions are collected. The difference between the two signals from the electrodes will give position of X-ray beam. Fig. 4 shows the position sensitivity of this type of monitor which is exposed to X-rays from an X-ray generator with a Cu target.

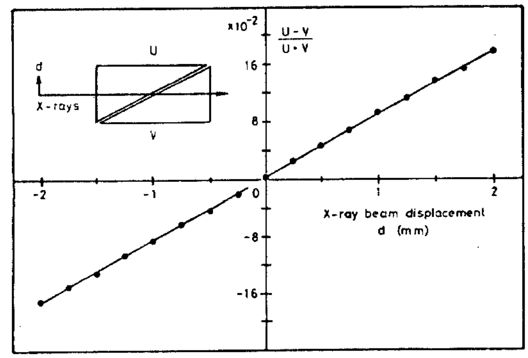

Fig. 4 X-ray beam position monitor with two triangle collectors 20mm wide and 50mm long in an air ionization chamber of which height is 60 mm. Across the chamber, a voltage of 5.2 kV is applied to collect positive ions.

Beam profile monitor

For measuring the profile of the stored beam there will be a mirror which allows the observation of the synchrotron light through a TV camera.

The vertical beam size, of which measurement is difficult other wise, can be measured by forming an image of the beam cross-section. However, the resolution will be limited by a diffraction limit because of the small angular spread of the synchrotron radiation. Therefore, X-ray region must be used. As a candiate of such detectors, an ionization chamber with a multiwire collection plane has been tested with a narrow X-ray beam and proved to have good resolution.

2-3 Beam Current Sensors

DC current transformer

An average beam current transformer will be installed in the ring with a ceramic break on the chamber. The scheme is a combination of a magnetic modulator and an active L/R integrator[4]. The transformer measures the beam current up to 500 mA with linearity errors less than 0.2 % and down to 5 mA which is set by the ripple of power supply. The current reading stays within 5×10^{-5}/cm for different beam location within the aperture of 190 mm and varies about 0.2 mAT/°C due to temperature. The frequency response remains the same for two different input currents of 60 mA and 200 mA and has a pass-band of DC to 500 Hz.

Fast current monitor

To compare the injected beam current with that coming through the beam transport line, an ordinary toroidal current transformer is installed in the ring and it has a freuqency response from 3kHz to 3MHz.

2-4 Transverse deflector and pick-ups for tune measurement

The beam tuning system includes a set of devices to measure the non-integral part q of the betatron number. The system must at least cover a frequency range from 160 kHz to 800 kHz to measure the value of q falling in either $0.1<q<0.5$ or $0.9>q>0.5$. We employ a combination of magnetic deflector and pick-up electrodes[5]

Fig. 5 shows a schematic diagram of the system.

Two pairs of pick-up electrodes are installed to observe horizontal and vertical oscillations independently. The deflector is made of a set of four rods which are placed on a cylindrical surface one at the middle of each quadrant with the axis parallel to the beam. Each rod, of which length is 50 cm and inductance 0.5μH, is driven by an 100 W RF generator.

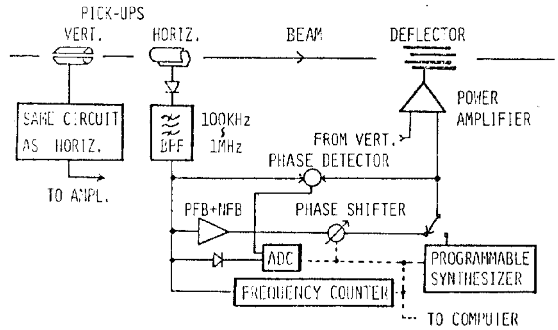

Fig. 5 Tune measurement system with four rod deflector and beam ossillation pick-ups connected each other by a circuit which detects the resonance frequency and phase relation.

Operation of the whole system will be made in three modes.

(i) External exitation mode: The beam will be given a forced oscillation by turning on the synthesizer. With a constant current supplied by the synthesizer, the amplitude and phase of the transverse beam oscillation will be obtained as a function of frequency. The amplitude will be kept smaller than 0.1 mm.

(ii) Self-excitation mode: The loop of the system is now closed by disconnecting the external source. Fine adjustment of the phase shifter causes the system to oscillate by itself. The beam oscillation amplitude is controlled by a circuit composed of both positive and negative feedbacks[6]. At large amplitudes, the circuit allows the negative feedback to take over the positive feedback which is limited to increase. The value of q is accurately obtained by counting the frequency of self-oscillation f_q and using the relation

$$q = Nf_q/f_{RF}$$

where N=312 is the harmonic number and f_{RF} the RF frequency.

(iii) Oscillation damping mode: With the negative feedback only turned on, the system can damp the beam transverse oscillation.

3. Beam Monitors in the Beam Transport Line

The beam monitoring system for the transport line consists of beam position monitors, current monitors, secondary emission profile monitors (SEM) and beam slits.

Signals from all the monitors will be fed to the monitor computer located in the storage ring control room. Because of difficulty of access to inside the tunnel due to high radiation, all the mechanical movements of SEMs and slits are thoroughly remote-controlled from the console.

3-1 Beam position electrodes

Eight sets of electrostatic position monitors will be installed to measure both vertical and horizontal position. A set of position monitor is made up of two pairs of electrodes. One pair of electrodes to measure horizontal beam position is made of a cylinder cut into two equal parts by a vertical plane crossing the axis. The other pair for the vertical position measurement has the same structure but the cylinder is rotated by 90 degrees about the axis. Its position sensitivity is 2.5%/mm.

3-2 Beam current monitor

Conventional beam current transformers are placed at the same locations as the position monitors. A transformer is made of a core wound with thin high-permeability tapes.

In order to observe the linac beam of which duration is 1 μsec and rise time about 0.1 μsec, the bandwidth of the transformer is required to be from 3 kHz to 3 MHz.

The output signals from transformer windings are fed directly into coaxial transmission lines and connected to a signal processor which consists of sample-and-hold circuits and a multiplexer.

3-3 Eenrgy Analyzer

The electron current in the ring is very sensitive to the energy of the beam delivered by the injector linac. The energy spread of beam must be kept constant during transportation.

The energy analyzer is composed of an energy defining slit and SEM profile monitors which are installed in the region of high horizontal dispersion. The beam spread due to the dispersion η is given by $\eta\Delta p/p$ where $\Delta p/p$ is momentum spread. Assuming η = 9 m and $\Delta p/p$ = 0.2%, the beam size will be 36 mm. The energy spread is observed by measuring the beam size with the SEMs and can be trimmed by the slit. The energy defining slit is made of water cooled copper blocks which are remote-controlled to move in and out of the beam. The SEMs are also used to give the beam profiles and transverse emittance ellipse.

Each SEM consists of 64 horizontal and 32 vertical wires which are made of gold plated tungsten 100 μm in diameter and spaced 1.0 mm apart. By shifting the wire assembly with a step smaller than the wire spacing, it is possible to improve the resolution.

Assuming that we have a secondary emission efficiency of about 4% and a beam size of 2 mm, each wire will collect a charge of about 20 pC. The output signal of each wire will be stored in an individual sample-and-hold circuit. These stored signals are then serially multiplexed and sent to the computer.

References

1. Y. Kamiya and M. Kihara
   Nucl. Instr. and Meth. 177, 65 (1980).
2. T. Katsura and S. Shibata
   "Beam Position Monitor for the Photon Factory Storage Ring", KEK-79-27, November 1979.
3. Herman Winick
   IEEE Nucl. Sci., 26, 3798 (1979).
4. F.C. Williams and S.W. Noble
   Proc. IEEE 97 Part II, 445 (1950).
5. J.L. Pellegrin,
   SPEAR-190,: PEP-120 Aug., 1975,
6. R. Bossart and V. Rossi
   SPS/ABM/RB/jf,
   SPS Improvement Report No. 156,
   Jan., 1979.