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Beam Diagnostics for Beam Commissioning of SPring-8 Synchrotron

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Abstract

The beam commissioning of the SPring-8 synchrotron was started on December 10, 1996 [1]. We achieved the first-turn of an electron beam at an energy of 1 GeV on the same day, the RF capture on December 11 and the acceleration at a beam energy of 8 GeV on December 16. From January to February 1997, fine tuning of the synchrotron was continued. The beam transport to the SPring-8 storage ring was achieved in March 1997. The beam monitors were used to measure the beam characteristics to decide the optimum parameters of the machine operation. In this paper, the status of the beam monitors and the beam diagnostics during the beam commissioning are reported.

1. Introduction

The SPring-8 synchrotron accelerates an electron beam or a positron beam from an energy of 1 GeV to 8 GeV at a repetition rate of 1 Hz [2]. Two types of the pulse length of the multi-bunched electron beam were used for the beam commissioning. At first, the bunch length of the electron beam was chosen to be 40 ns length for adjustment of the beam injection and for coarse tuning of the beam orbit to suppress the radiation dose around the synchrotron. Next, the beam of 1 μs bunch length was used for fine tuning of the beam orbit. Table 1 shows the beam monitors installed in the synchrotron and in the beam transport line from the synchrotron to the storage ring (SSBT). Most of the beam monitors were used for the beam commissioning.

Table 1. Beam monitors of synchrotron and SSBT

monitors	quantity
Fluorescent screen monitor	14
Beam position monitor (BPM)	80
Radiator	1
Beam loss monitor	5
High power RF knock-out (RF-KO 1)	1
Low power RF knock-out (RF-KO 2)	1
Strip line monitor	1
DC current-transformer (DCCT)	1
Fast current-transformer (FCT)	1
Synchrotron radiation monitor	1
Fluorescent screen monitor *	16
Strip line-type position monitor (SPM) *	2
Beam charge monitor *	1

* in the SSBT

2. Fluorescent Screen Monitor

2.1 Tuning of Injection Orbit

A single-turn injection with the on-axis technique is adopted as the standard injection method of the synchrotron. Two septum magnets and two kicker magnets are used for the beam injection from the linac. The beam positions and the beam profiles of the injection orbit and of the first-turn orbit in the synchrotron are observed by the fluorescent screen monitors. These monitors are divided into fixed-type and movable-type.

The fixed-type screen monitor is installed in front of every septum magnet. The fluorescent screens are fixed on the septum magnets across the designed orbit and have a rectangular hole around the orbit not to interrupt the beam. The injection orbit was adjusted that the beam passed through the center of the hole. Eight movable-type screen monitors are installed at the upstream side of the focusing quadrupole magnets in the synchrotron. The screens are leaned 45 degrees against the beam axis and are inserted in the beam duct using compressed air at the measurement. The area of each screen is 30 x 30 mm^2 for the beam. The fourth screen monitor is located at the downstream side of the injection kicker magnets and is used for tuning of the excitation current of the second septum magnet and two kicker magnets for the injection.

After adjusting the injection orbit, the first-turn and the multi-turn of the beam were confirmed at the energy of 1 GeV with DC operation. Then the dipole and the quadrupole magnets were excited and the sextupole and the correction magnets were not excited. The first-turn of the beam was confirmed by the third screen monitor, which was located at the upstream side from the injection point in the synchrotron. Figure 1 shows the beam profile on the third screen monitor at the first-turn of the beam. The beam energy from the linac was adjusted to 1 GeV by observing the beam position on eight movable-type screen monitors. At the screen monitors, the value of the dispersion function in the horizontal direction (η_x) is about 1 m. An average of the horizontal beam position of 1 mm on the eight screen monitors corresponds to a beam energy difference of 0.1 %.

2.2 Tuning of Extraction Orbit

Four bump, three kicker and four septum magnets are used for the beam extraction of the synchrotron. The fixed-type screen monitors are installed in front of every septum magnets and are used for tuning of the extraction orbit. The beam was extracted successfully without adjustment of the excitation current of the pulse magnets for the beam extraction. As the extracted beam orbit was tilted slightly in the vertical direction, a local bump orbit was made with the three vertical correction magnets that the tilt became negligibly small.

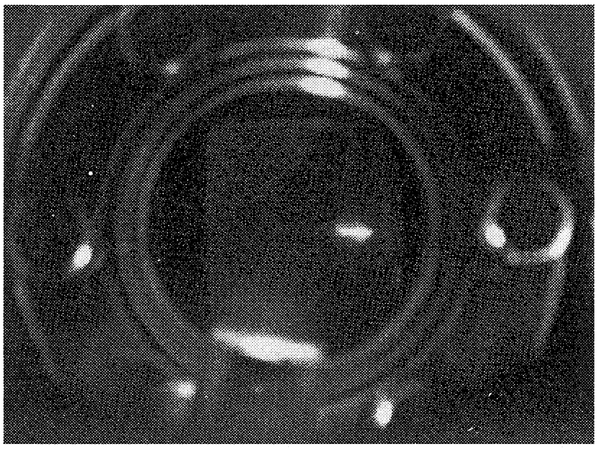

Fig.1 Beam profile on the fluorescent screen monitor after the first-turn of the beam.

3. Beam Current Monitors

The multi-turn of the beam and its lifetime were observed by a fast current-transformer (FCT). The FCT has a sensitivity of 2.5 V/A and a rise time of 500 ps. Figure 2 shows the waveform of first five turns of the beam observed by the FCT. The bunch length of the beam was 40 ns. The beam intensity in the synchrotron was measured by a DC current-transformer (DCCT), which has a bandwidth from DC to 4.2 kHz.

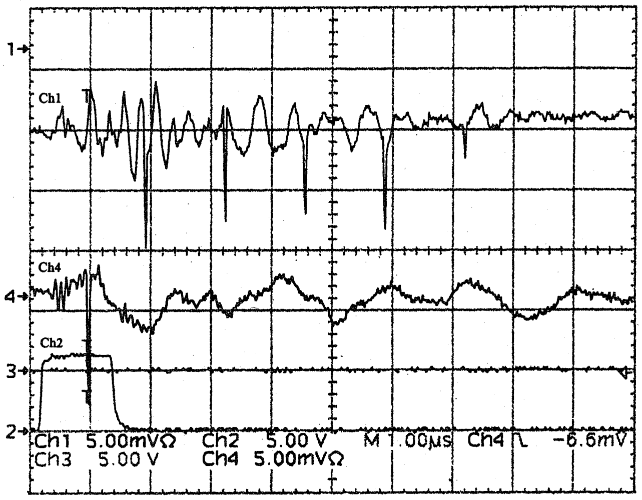

Fig.2 First five turns of the beam observed by the FCT. The waveform is shown at Ch1. Ch2 shows the waveform of the injection kicker magnet and Ch4 shows the waveform observed by the wall current monitor at the transport line from the linac.

4. Beam Position Monitor

4.1 Measurement of COD

The beam position monitors (BPMs) are located in front of every quadrupole magnets to measure closed orbit distortions (CODs) [3]. Each BPM has four button-type electrodes which are mounted on the wall of the vacuum chamber. The diameter of the electrodes are 18 mm. Output signals from the four electrodes are selected one after another by fast PIN-diode switches which are placed near the electrodes. These signals are detected by a heterodyne circuit at a monitor room for 20-BPMs. Four detection systems are used at the same time for 80-BPMs, and it is expected that the time of data taking of all the BPMs is less than 30 ms. The accuracy of calibration and the installation error of the BPMs are less than 0.1 mm and 0.3 mm, respectively.

After tuning of the RF capture of the injected electron beam at the energy of 1 GeV, the CODs were measured by the BPMs. It was confirmed that there was no time dependence on the COD by changing the timing of the BPM measurement. Next, the beam was accelerated from the energy of 1 GeV to 8 GeV and the COD was measured at 8 GeV. The power supplies for the dipole, the quadrupole and the sextupole magnets were excited with a trapezoidal current pattern at a repetition rate of 1 Hz. The RF accelerating-voltage was achieved by changing the RF phase between two klystrons [4]. The maximum CODs in the horizontal and in the vertical directions at the beam energy of 8 GeV without the COD correction were 2.53 mm and 2.92 mm, respectively.

4.2 COD Correction

The COD was corrected by the method based on a sensitivity matrix (Smatrix) [5]. The Smatrix represents the relation between the excitation current of each correction magnet and the variations of the beam positions measured at every BPMs. To correct the CODs, the excitation current of all the correction magnets are evaluated by the most effective corrector method using the measured Smatrix. As the result, the maximum CODs in the horizontal and in the vertical directions at the beam energy of 8 GeV are decreased to 2.22 mm and 1.40 mm, respectively. The route mean square of the horizontal and of the vertical CODs at the beam energy of 8 GeV are 0.47 mm and 0.38 mm, respectively.

5. Measurement of Betatron Tune

To measure the betatron tune, the beam is kicked out horizontally or vertically by the magnetic field which is generated from the knock-out electrodes in the beam duct. A certain frequency of the field is related to a fractional part of the betatron tune. Figure 3 shows the RF knock-out system. The knock-out electrode is a strip line-type and the length is 1 m. The impedance of each electrode is adjusted to 50 Ω. The maximum output power of the wide-band amplifier is 200 watts and the power is divided among four electrodes equally. To measure the vertical betatron tune, the beam is kicked out vertically with an RF phase shift of 180 degrees at the A-electrode and at the B-electrodes. At the horizontal betatron tune measurement, the beam is kicked out horizontally by switching over the RF phase of the B-electrode and of the D-electrode. The maximum strength of the magnetic field, which generated by the RF power of 200 W from the amplifier, is 7.1 x 10^{-6} T. It correspond to a kick angle of 4.3 x 10^{-6} rad at the beam energy of 1 GeV. When the resonance between the knock-out frequency and the betatron tune takes place, the amplitude of betatron oscillation is increased and the beam is lost on the beam duct. At the resonance points, the beam current is decreased to zero for about 10 ms and the knock-out frequency is decided using the DCCT. The relation between the knock-out frequency and the betatron tune is expressed as follows.

$$f_{\mathrm{knockout}} = f_{\mathrm{revolution}} \times (n \pm (\nu_{x,y} - \mathrm{Int}(\nu_{x,y})))$$

n : 0 or positive integer

$\nu_{x,y}$: horizontal or vertical betatron tune

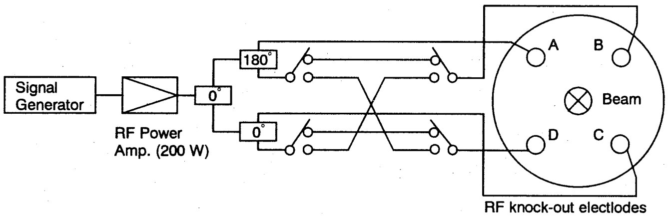

Fig.3 RF knock-out system for the measurement of the betatron tune.

To adjust the betatron tunes to the designed values, the excitation currents of the focusing and the defocusing quadrupole magnets were varied from the designed values. The horizontal and the vertical tune values were selected to 11.796 and 8.7833, respectively.

6. Beam Monitors of SSBT

The SSBT is the beam transport line from the synchrotron to the storage ring. The length of the SSBT is 310 m and the beam line of the storage ring is 9 m higher than that of the synchrotron. Sixteen fluorescent screen monitors were used to adjust the beam positions. The excitation currents of the dipole and the correction magnets were adjusted to the optimum values, that the beam passes through the center of the quadrupole magnets observing the beam positions on the screen monitors. If the beam does not pass the center of the quadrupole magnet, the beam position on the screen monitor moves when the excitation current of the quadrupole magnet is decreased from the present value. Two strip line-type position monitors (SPM) were installed at the end section of the SSBT to measure the stability of the beam position. The accuracy of calibration and the installation error of the SPMs are less than 0.1 mm and 0.5 mm, respectively. Figure 4 shows the result of the measurement of the beam positions at the SPMs. The stability and the repeatability of the beam position and of the beam angle between the SPMs are less than 0.1 mm and 0.1 mrad, respectively. It was confirmed that the beam loss in the SSBT was negligibly small with a beam charge monitor installed at the end of the SSBT and with the DCCT in the synchrotron.

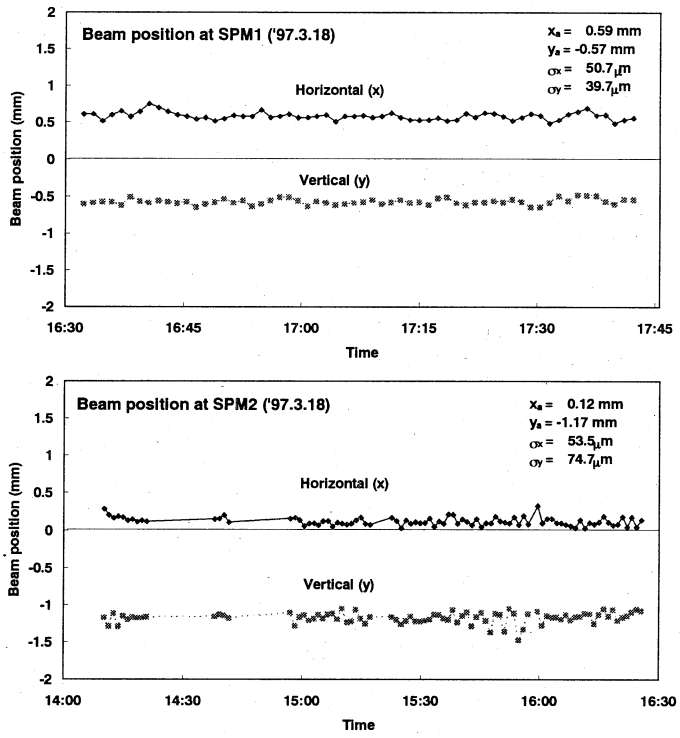

Fig.4 Beam positions at the strip line-type position monitors of SSBT.

7. Conclusion

The beam commissioning of the SPring-8 synchrotron was carried out successfully and the beam was supplied to the storage ring with good efficiency. The beam monitors were useful for the beam commissioning.

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