Commissioning of the SPring-8 Storage Ring

Haruo OHKUMA, Schin DATÉ, Keiko KUMAGAI, Mitsuhiro MASAKI, Takamasa MASUDA, Takeshi NAKAMURA, Jun-ichi OHNISHI, Takashi OHSHIMA, Taihei SHIMADA, Kouichi SOUTOME, Shiro TAKANO, Hitoshi TANAKA, Masaru TAKAO, Kazuhiro TAMURA, Koji TSUMAKI, and Noritaka KUMAGAI

Accelerator Division, SPring-8, Kamigori, Ako-gun, Hyogo 678-12, Japan

Abstract

In order to open the facility to synchrotron radiation users, the Spring-8 storage ring has been undergoing beam commissioning. The COD correction reduces the residue down to ~0.2 mm in terms of an rms. value in both horizontal and vertical planes. The beam lifetime of ~35 hours or more has been achieved at the beam current of ~20 mA and a beam dose of 11 Ah. Various machine parameters of the storage ring were tuned during the beam commissioning. The first stage of the beam commissioning will be completed at the end of September 1997.

1. Introduction

SPring-8 is the facility of a third generation synchrotron radiation source in the X-ray region. The accelerator system consists of an injector linac of 1.2 GeV, a booster synchrotron of 8 GeV and a storage ring of 8 GeV. It will be open to the users with ten beamlines since October 1997.

Beam commissioning of the injector linac was started on August 1996. Successively, beam commissioning of the booster synchrotron was started on December, and the storage ring was started since March 13th and the first stage of it was successfully completed by accumulating the electron beams of about 20 mA one month later. This quick tuning was mainly due to the high completion of hardware. Especially, the precision of magnet alignment was so high that no steering magnet was used to store the first beam in the ring. The major milestones during the storage ring beam commissioning are listed Table I.

Table I. Progress of Storage Ring Beam Commissioning

Date	Milestones
3/13	Start of SSBT tuning
3/13	**Start of storage ring beam commissioning**
3/14	Completion of first turn
3/25	Capture of electron beams in RF buckets
3/26	First observation of photon beams from a bending magnet
4/17	Stored current of 19.6 mA
	(lifetime ~3 hrs with ID gap fully opened)
5/14	Start of beamline commissioning (BL02B1 and BL47IN)
5/16	Operation with ID gap of 8 mm
5/17~6/15	Period of beam self-clearing on vacuum components
	(lifetime 14~15 hrs at ~18 mA)
6/16~18	Periodical inspection of storage ring by the STA
7/3	License by the STA for storage ring operation
	Start of experiments at two beamlines
7/12~8/24	Period of summer shut down

In this paper, tuning of the storage ring machine parameters, conditioning of the vacuum system with beam self-cleaning and so on, are described.

2. Injection

For beam injection into the storage ring four (three DC and one pulsed) septum magnets and four bump magnets are used. In the early stage of the commissioning the beam was injected directly onto the design orbit of the storage ring, and a one-turn trajectory was measured by using beam position monitors. Since the beam is injected 24.5mm inside from the design orbit and bump magnets cannot make this amplitude, steering magnets were used to make an auxiliary DC bump in the injection part.

To accumulate electrons in the storage ring, septum and bump magnet strengths were tuned with an off-axis injection scheme. The auxiliary DC bump was made in the injection part if necessary to reduce a coherent amplitude. We tried to find the best parameter set to make injection efficiency as high as possible. At present, the efficiency of 80-90% has been achieved in the following scheme: in a typical case the bump amplitude of 16.2mm is made with two bump magnets in the downstream of the injection point and 14.0mm is made with upstream two bump magnets, which means that the bump is not closed and has a discrepancy of 2.2mm at the injection point. The auxiliary DC bump is not made in this case.

Since we can select an arbitrary RF bucket among 2436 ones at each injection, the filling pattern in the storage ring can be controlled easily [1]. In an usual multi-bunch operation partial filling is adopted. In addition to the multi-bunch operation, single- and several-bunch operations were tested. At present, the maximum current per bunch is about 4mA, above which the vacuum deteriorates.

3. Tuning of RF system

There are three RF stations (named B,C and D) arranged around the ring. Each station has 1.0 MW klystron and 8 single cell cavities at a low betatron straight section.

In the beginning of the commissioning, the RF frequency is roughly fixed by fitting the initial phase of the synchrotron oscillation. After the COD well corrected, the RF frequency was fixed so as to minimize the 48th harmonics of the COD, which mainly comes from the dispersive distortion caused by the energy deviation.

In the early stage of the commissioning, we adjusted the phase of the RF stations to make the turn number of the beam longer and finally to capture it. The preferable phases of the B, C and D stations were -80°, -90° and 85°, respectively. The total accelerating voltage of 4 MV, which amounted to 12 MV. Later, the phases of the RF station were refined so as to maximize the synchrotron frequency [2]. The resultant phases of the B, C, and D stations were -104.5°, -96.7° and 85.0°, respectively. After fixing the phases, we calibrated the accelerating voltages of the RF cavities by measuring the dependence of the synchrotron frequency on the individual voltages.

4. Measurements of machine parameters

4.1 Optics

The lattice structure of the SPring-8 storage ring is of double-bend achromat type, and there are 48 straight sections where the dispersion vanishes. This straight section is used to install not only insertion devices but also septum magnets for injection or RF cavities.

During the commissioning period we studied three kinds of standard optics: "hybrid", "high-beta" and "high-tune" optics. In the "hybrid" optics, the horizontal betatron function β_x takes a large value (about 20m) and a small value (about 1m) alternately in the straight sections (Fig.1), while in the "high-beta" optics β_x takes a large value in all straight sections. The "high-tune" optics has a larger value of horizontal betatron tune compared with the "hybrid" optics. Design values of the emittance for "hybrid", "high-beta" and "high-tune" optics are 7, 7 and 5.5nmrad, respectively.

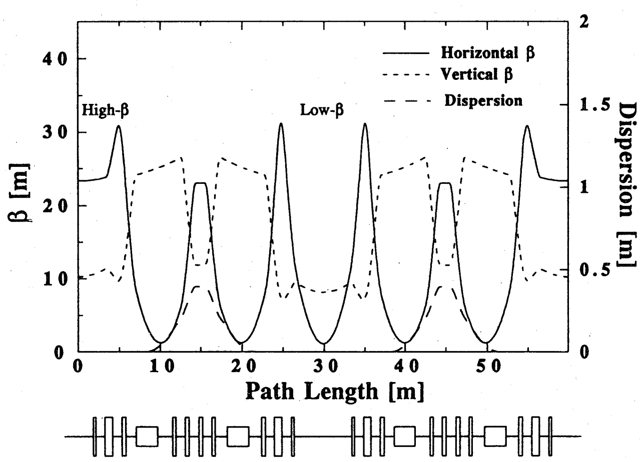

Fig. 1. Hybrid optics.

4.2 Betatron Tune

The betatron tune was measured with the RF knockout method, and it was found that measured values are always smaller than design values. Typical values are listed in Table II.

Table. II Typical value of the betatron tune.

	Hybrid		High-Beta		High-Tune	
	H	V	H	V	H	V
cal.	51.307	16.424	42.281	15.379	53.400	20.500
meas.	51.25	16.29	42.20	15.28	53.23	20.35

In these calculations of the tune, the following two effects are taken into account: (i) At the edge of bending magnets the beam passes about 12.5mm inside from the center. Then the beam feels constant non-linear fields and the tune is shifted. (ii) A steering magnet set near a quadrupole magnet affect its field and the effective length is reduced. The agreement between calculated and measured values were improved by taking account of these effects, but we still have some discrepancy shown above.

4.3 Dispersion

The dispersion function was deduced from beam positions measured at different RF frequencies. In Fig.2 we show the dispersion function of the "hybrid" optics after COD corrections. In this measurement the RF frequency was shifted by ±50Hz from the central value 508.579373MHz, and a design value of the momentum compaction factor was used. Residual dispersions in the vertical direction were found to be smaller than those in the horizontal direction.

In Fig.2 we can observe a global modulation of horizontal dispersion with 3 peaks. Because the ring has 48 cells and the horizontal betatron tune is around 51, this modulation shows that the component with harmonic number 51 remains in the horizontal residual dispersion. We observed modulation with 6 (=48-42) peaks in the high-beta optics and with 5 (=53-48) peaks in the "high-tune" optics.

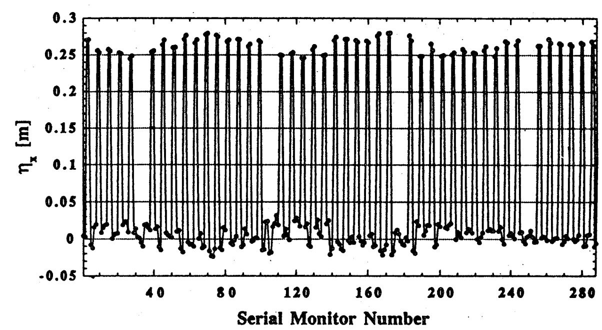

Fig. 2. Dispersion for hybrid optics.

4.4 Chromaticity

The linear chromaticity was deduced from betatron tunes measured at different RF frequencies. Typical values for the "hybrid" optics are as follows:

Table III Chromaticity for the hybrid optics.

	H	V
natural(cal.)	-116.86	-40.23
corrected(cal.)	-2.26	-0.63
measured	-0.93	+0.24

Both horizontal and vertical chromaticities are well corrected, but measured values are somewhat larger than calculated.

5. COD Correction

In the commissioning of the SPring-8 storage ring, the hybrid optics of which emittance is 7 nmrad was mainly used (see Fig. 1). Natural COD of this optics is small as mentioned above and rms values of the horizontal and vertical COD are respectively 1.7 and 2.4 mm. Owing to this small COD, even without any orbit correction, electron beams could be stored in the ring where both sextupoles and RF system are turned on. The COD was successfully corrected by using the best corrector method [3]. At present, the COD can be reduced down to ~0.2 mm in a rms value. By the COD correction, the horizontal dispersion is restored markedly and the vertical dispersion is corrected as well [4]. Figure 3 shows the horizontal COD distribution befor and after the correction.

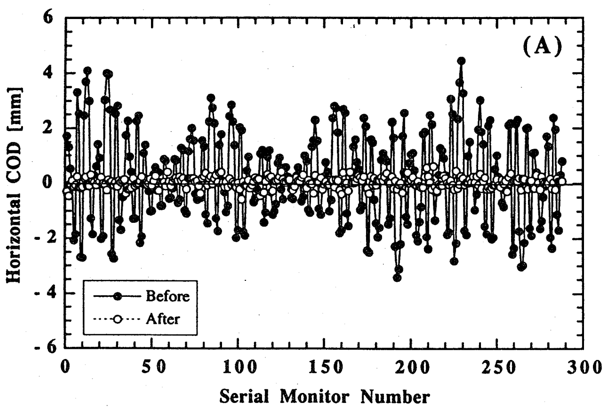

Fig. 3. Horizontal COD before and after the correction.

In respect to stability of the orbit, three kinds of orbit movement were observed but not cured yet. The first is a orbit drift of ~150 mm occurred after the stop of magnet power supplies and it continues for about two days from turning on the power supplies until the temperature of both magnets and girders reaches thermal equilibrium. The second is also the drift caused by a tidal movement and it will be mentioned later. The last is not a drift but the excitation of COD main harmonics, i.e., betatron tunes. Amplitudes of the harmonics slowly vary but an origin of this variation could not be clearly understood.

6. Vacuum condition and beam lifetime

The averaged pressure readings of the storage ring are $\leq 1\times10^{-8}$ Pa without electron beam, 5×10^{-7} Pa at a beam current of 18 mA. After a continuous cleaning by the synchrotron radiation, the pressure rise due to the photon induced desorption effect was significantly reduced [5].

An accumulated dose of 11Ah and a lifetime of 35 hours at 19 mA current were achieved after four months' operation. The gap of the insertion device has been closed down to 8 mm of the minimum gap of the standard in-vacuum type undulator of the SPring-8, the beam lifetime is reduced due to narrow gap of the insertion device. The relationship of the product of the beam current (I) and the lifetime (τ) versus the accumulated beam dose can be described by the following formula: $I\tau \sim 110 (\int I\,dt)^{0.65}$ mAh. The trend of the Iτ curve is determined by scattering of the electron beam by the photo-desorbed gas resident in the ring vacuum system.

7. An effect of the earth tide

A change in the electron beam closed orbit in a long time period has been observed by extracting oscillation modes in COD from data at a time and tracing them as sequences in time. To extract oscillations in a space of the betatron phase, the COD data are first normalized by square root of the betatron function, for which we have adopted designed values adjusted for observed tune. The normalized excursion is then decomposed into Fourier components. Powers of the zeroth and the 48th components which are extracted from horizontal COD data exhibited approximate but clear periodic change with a period of 24 hours. Figure 4 shows the change in the power of the horizontal zeroth component. Each dot corresponds to a set of the horizontal COD data. The periodic change is disturbed by jumps identified as changes in conditions of the beam operation. Also shown in the figure as a solid curve is the change of a potential of the tide-generating force due to motions of the sun and moon relative to a local frame fixed to SPring-8 site. The sign of the potential is chosen so that the smaller the potential, the higher the rising of the ground due to a reduction of the local gravitational acceleration directing to the center of the globe. The vertical scale is arbitral for the potential. It turned out that the phase of the change and relative depths of ravines in the sequence of data are well reproduced by the solid line. We therefore conclude that the periodic part of the change in the zeroth component is due to the change in the tide-generating force at the site of SPring-8. A decrease of 1×10^{-10} m in the power of a positive zeroth component corresponds to approximately 30 to 40 μm decrease of the radius of the electron beam relative to beam position monitors. According to Fig. 4, an expansion of the ring occurs at the same time when the ground rises due to the tidal deformation. If we assume an isotropic expansion of the globe, an expansion of 30 μm in the ring radius of 300 meters corresponds to a rise of the ground by 60 cm, which is a typical value for the earth tide.

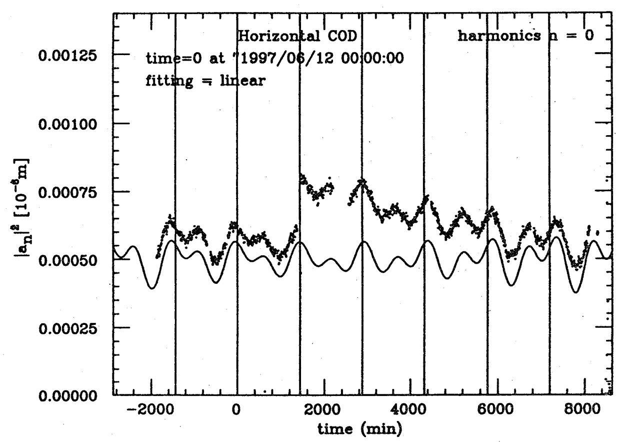

Fig. 4. The power of the zeroth Fourier component estimated from the COD (dot) and the potential of the tide-generating force (solid line).

8. Conclusion

The first stage of the beam commissioning of the Spring-8 storage ring was successfully progressed. User service mode will be started since October 1997. In parallel on this mode, further machine tuning will be made to upgrade performance of the storage ring.

References

[1] M. Takao, el al., in these proceedings.
[2] T. Ohshima, et al., in these proceedings.
[3] B. Autin, et al., CERN ISR-MA/73-17, CERN, Geneva, Switzerland, 1973.
[4] H. Tanaka, et al., in these proceedings.
[5] H. Ohkuma, et al., in these proceedings.