Status Report of SPring-8

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Abstract

The beam commissioning of SPring-8 was started since 13 March 1997 and was successfully completed with the beam performance far beyond the target specification. The user operation was started since October 1997. Presently 18 beamlines were operated in the user service mode, 9 beam lines are in commissioning mode and 12 beam lines are under construction. The two new transport lines of L3 and L4 (New SUBARU line) were installed in the linac, and the service of 1GeV electron beam was started as a parasite mode of the linac since the autumn of 1998. In this conference, the status of the SPring-8 accelerator facility is reported.

Machine Operation

The SPring-8 was operated by two or three week mode as 1 cycle without any big trouble since the beam commissioning. Figure 1 is the operation statistics for the last three years. The total operation time was 8293.6 hours. 5578.2 hours (67.3%) were used by users and 175.8 hours (2.1%) were lost due to the failures of machine (0.7%), beam line (1.1%) and utilities(0.3%). The remaining 2539.6 hours (30.6%) were used for the tuning&study of accelerators (linac, synchrotron, storage ring and beam lines) and for the commissioning of new photon beam lines.

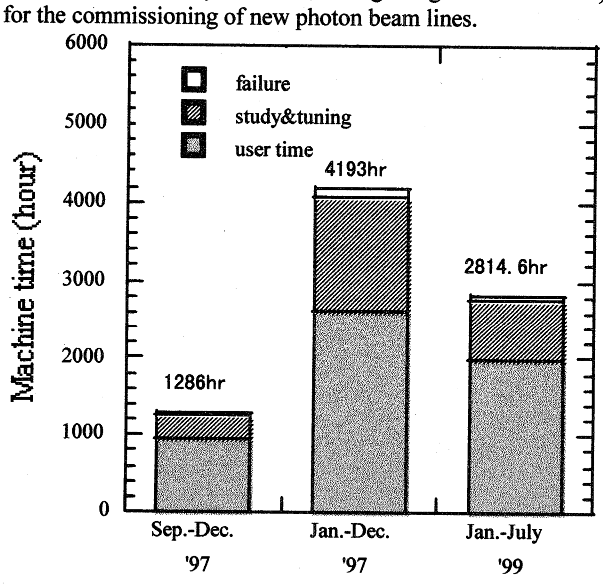

Fig.1 Operation statistic since 1997

53.5 % of the total user time was operated by multibunch mode, as full-filling mode or 2/3 filling mode. The full-filling mode was used for the user time operation before the first half of 1998. At present, the 2/3-filling mode is being used for the user operation to eliminate an emittance growth due to an ion-trapping effect. The remaining time (46.5%) was operated by several bunch mode, such as a 21-bunch mode(21 equally spaced 3 or 7 bunches train), 10-bunches + partially filling and so on. The filling pattern can be changed easily by a timing system which selects an arbitrary rf bucket among 2436 at each injection. In the several bunch mode, 0.5 or 1mA/bunch are stored and an impurity level of less than 10^{-6} are being routinely achieved in the user time operation. The maximum current per bunch of about 16 mA was achieved without any beam instability in a machine study. The bunch current was limited by decreasing of vacuum pressure due to the heating of bellows port.

Beam Performance of Storage Ring

Since the beam commissioning of the storage ring in March 1997, the machine performance, such as orbit stability, emittance, coupling etc., has been investigated in detail. Table 1 shows the achieved beam performance and the design values of the storage ring specifications.

Table 1 Beam performance of SPring-8 Storage Ring

	designed value	achieved value
Energy	8GeV	8GeV
Stored current		
multi /single	100mA/5mA	100mA/16mA
Bunch length (σ_l)*	35/- psec	35/100psec
Tunes (vx,vy)	51.22/16.16	51.16/16.31
Chromaticities (ξx,ξy)	0/0	3.21/3.93
Emittance	6.99nmrad	6.8±0.5nmrad
Coupling ratio	≤ 10%	≤0.06%
Energy spread	0.0011	≤0.001
Life time		
100mA (full fill)	24hr	80hr
1mA (single bunch)		6hr
Impurity (user time)		$\leq 10^{-7}$
COD		
horizontal (rms)		≤ 0.1mm
vertical (rms)		≤ 0.1mm
Orbit stability (rms)	10% of $\sigma_{x,y}$	a few μm
Dispersion at ID		
horizontal (rms)	0cm	1.4cm
vertical (rms)	0cm	0.4cm

* these values were estimated and measured at a rf voltage of 12MV

beam life time and bunch length

In the 2/3 filling mode (0.043mA/bunch), the total beam life time is about 55 hours at 100mA. This life time is determined not only by the dynamic vacuum pressure but also by Touschek effect even in multibunch mode. In this 2/3-filling mode, the gas scattering life time and the Touschek life time is 140 hours and 120 hours, respectively. In the full filling mode, the beam life time is about 80 hours at 100mA, whose life time is significantly longer than that of the 2/3-filling mode at same intensity. It seems that the electron beam size is grown by an instability due to an ion-trapping effect. In the single bunch mode, the life time decreases rapidly with the bunch current as shown in fig.2. The life time is about 6 hours at 1mA/bunch and is shorter than 2hours at 5mA/bunch.

The dependence of the life time on the bunch current is mainly contributed by the Touschek effect. In the SPring-8 storage ring, the bunch length at low current was good consistent with a design value of 36psec. But the bunch length measured by a streak camera increases rapidly with the bunch current as shown in fig.2. And the bunch length at a high current of 12mA/bunch becomes 2.5 times longer than that at the low current. The increase was good consistent with the simulation result on bunch lengthening due to the inductive impedance of vacuum elements.

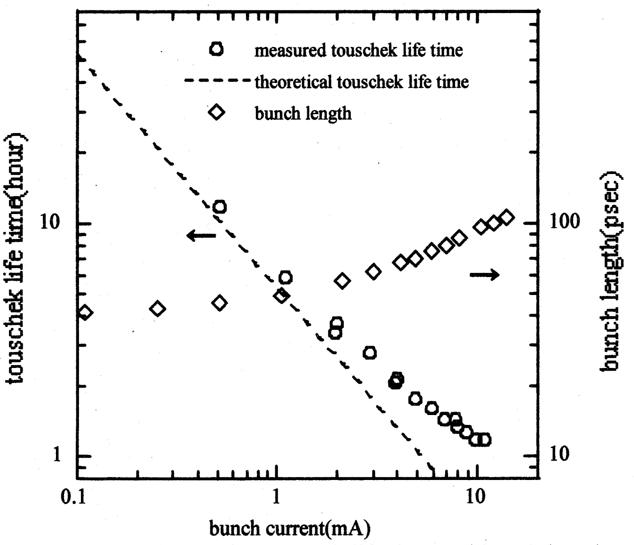

Figure 2. Dependence of Touscheck life time and bunch length on beam current.

horizontal emittance and extremely small vertical emitance

The horizontal emittance was estimated from a horizontal beam size and a beta function at the position of the size measurement. The horizontal beam size was measured from the relation between the electron loss rate and the amplitude of injection bump orbit with a half-sine shape of 8μsec width and by assuming the transverse distribution of electron beam as gauss-distribution. The measured horizontal emittance was 6.8±0.5nmrad. The vertical emittance depends on the coupling between the horizontal and vertical betatron oscillations. The coupling ratio was estimated from the following measurements,

1. Coupling measurement from mode frequencies

The operation point(ν_x,ν_y) of the SPring-8 storage ring is (51.16,16.32). The betatron coupling is mainly induced by the difference resonance of ν_x-ν_y=35. The width on the difference resonance in single resonance approximation is estimated from the relation between the unperturbed tunes and the measured ones around the neighboring of the resonance. The coupling ratio, calculated by using the measured width(of less than 0.005) and the distance from the difference resonance, is about 0.06% in the normal operation point (ν_x=51.16,ν_y=16.32).

2. coupling dependence of Touschek Lifetime

The Touschek lifetime has a large sensitivity to the coupling ratio in the single bunch mode of SPring-8 storage ring. The 0th order dependence of Touschek life time (τ_T) on the coupling ratio (κ) is given by following equation,

$$\tau_T = c\times\sigma_x \times\sigma_y\times\sigma_l = A\times\sigma_l\times\sqrt{\kappa}/(1+\kappa),$$

where σ_x is the bunch width, σ_y the bunch height and σ_l the bunch length, and A is a constant. The constant A was calibrated by using the relation between the Touschek life time and the coupling ratio estimated from the measurements of coherent oscillation[1]. In this coherent oscillation method, we can't observe directly the oscillation corresponding to coupling ratio of less than 1% due to the position resolution of our beam position monitor. At present, the minimum coupling ratio is estimated to be around 0.04% from the life time of about 3 hours measured at the operation point of (51.11,16.32) at 1mA/bunch ,

3. Measurement of visibility by interferometer

The visibility for visible light from a bending magnet gives directly the vertical electron beam size. Now, the visibility measurements are underway. As a preliminary result, the coupling ratio of 0.1%. as a upper limit was obtained at the normal operation (51.16,16.32).

The coupling ratio of the storage ring is extremely low without the correction of skew components and vertical dispersion due to a good magnet alignment method[2], a good calibration of beam position monitor[3] and a suitable COD correction.

Orbit stability

In the third generation synchrotron radiation source, the stability of electron beam orbit is one of the most important performance to achieve a highly brilliant photon beam. In the construction and fabrication of SPring-8 storage ring, the effect of perturbation sources to induce the orbit movement were designed as week as possible. The digital feedback system was developed to still more stabilize the electron orbit. The system corrects the cod components corresponding to the betatron tune harmonics and its satellite ones in horizontal and vertical directions at interval of one minute. The obtained beam stability is 0.8μm in rms for the 51th betatron tune harmonics in horizontal cod and 0.5μm in rms for the 16th harmonics in vertical cod.

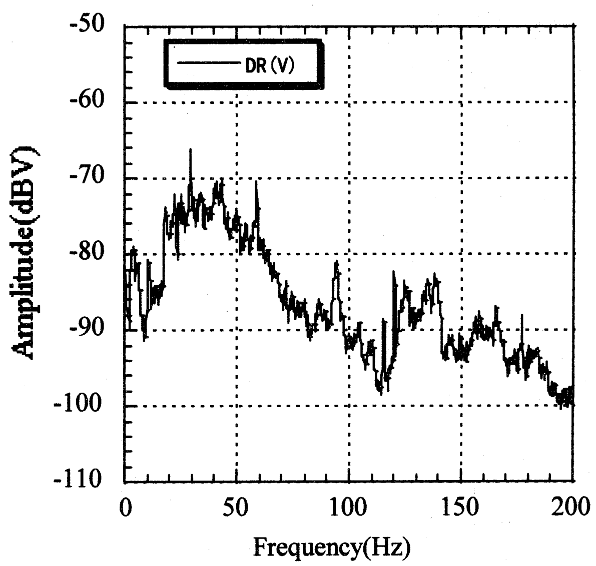

Figure 3. Fast vibration of electron orbit in vertical plane. The amplitude at 30 Hz corresponds to a few micron.

Now, a fast vibration of the electron orbit is being investigated in detail Figure 3 shows the vibration in vertical plane. The maximum amplitude is within a few micron in horizontal and vertical directions, respectively. This vibration are being induced by water pumps of cooling system and pressure fluctuation of water to make magnets and vacuum chambers cool.

A change of the circumference, which is observed as a 0th harmonics in the horizontal cod, induces an energy shift in electron beam. The 0th component was, therefore, corrected by adjusting the rf frequency within 0.3μm in rms. These two feedback system are now routinely used in user operation.

Recent Developments and Upgrades

linac

Operation of the linac was started in 1996, and the beam operation began on August 1, 1996. The cumulative usage hours of klystrons and the high voltage power supplies are about 13000 hours. The klystron had operated without any big trouble up to today. The energy stability of the linac beam has been studied in detail and improved by reducing the rf power and phase drifts due to the stabilization of the temperature fluctuation of the atmosphere and cooling water in the klystron gallery. In addition, in January 1999, a chicane was installed in the downstream of the last accelerator guide to monitor the injection energy of electron beams into the synchrotron. After these improvements, the beam current and the beam energy at the beam transport line was stabilized within ±0.7% (1σ) and ±0.1% (1σ), respectively.

To make the two kinds of beam pulse widths from a requirement of the user operation mode of the storagr ring: 1nsec at a beam current of 2A for single/several bunch operation and 40nsec at a beam current of 200mA for multibunch operation. The electron gun assembly was replaced from a Y796 cathode assembly for high intensity use to a Y845 assembly to generate more stable beam.

The new beam lines of L3 and L4 were installed in the summer of 1998. The L3 beam transport line transfers an electron beam of 1.2GeV to an experimental hall for the beam physics. On the other hand, L4 beam line supplies an electron beams of 1GeV to a New SUBARU storage ring, whose ring is a 1.5GeV synchrotron/storage ring built by the Himeji Institute of Technology for their synchrotron radiation use. The commissionings were started in the autumn of 1998 and the service of 1GeV electron beam to the New SUBARU ring was carried out as a parasite mode of the linac operation.

As other developments, there are following projects. A stable compact pulse modulator for 80MW klystron used a 40MHz inverter high voltage power supply was developed as a next-generation modulator and is now being tested. Also, a photocathode rf gun of single cell was assembled in a test stand and high-power up to 18MW was fed into the cavity. The maximum electric-field gradient of 127MV/m was achieved on the cathode. The photoelectrons by irradiation of UV laser was extracted in the spring of 1999 and the beam test is in progress.

synchrotron

Single bunch beam was formed by rf knockout (rf-KO) at the injection porch of the synchrotron. Tuning of the rf-KO system has been intensively carried out since the beam commissioning of December 1996. The installation of a high power rf-KO system and the increase in the time interval of the injection porch were performed to improve the purity of the single bunch beam in the storage ring. Consequently, an impurity level of less than 2×10^{-8} was achieved as a lowest value in the single bunch operation of the storage ring.

The synchrotron has been controlled by five DEC workstations running Open VMS and 14VMEs since the commissioning. However, due to the future needs and the transparent operation of the SPring-8 accelerator facility, the synchrotron control system was reintegrated by replacing all CPU boards with HP9000/743rt boards and by installing a new control software based on the same architecture of the storage ring. Consequently, the parameter change of the synchrotron's equipment has become still more quick and still more simple. The new control system has been operating successfully since January 1999.

Storage ring

The following improvements and developments were carried out;

-to make the coupling ratio as low as possible, 24 skew quadrupole magnets were installed to correct the skew components and the vertical dispersion function.

-to improve the orbit stability, the temperature fluctuation of cooling water in magnet and vacuum systems was stabilized within 0.3 degree by replacing a response curve of the control logic in cooling system from a step response to a continuous one.

-to make the loss time due to a failure of power supply as short as possible, a super magnet power supply, which can be replaced commonly for all of main quadrupole and sextupole magnets power supplies, was developed and installed in the magnet power station.

-to supply a stable photon beams for users, the fourth rf station will be completed in this year. Due to this installation, a sufficient rf-voltage can be supplied to the electron beam, even though all of Insertion Device are operated with full specification.

-to investigate the performance of the electron beam and perform R&D on accelerator components, a beam diagnostic's beam line (BL38B2) is under construction.

-to install a top-up operation, injection septum magnets with high magnetic performance were developed. This top-up operation injects continuously electron beams without kicking the circulating beam in the storage ring. Therefore, this operation can improve effectively the shortening of the beam life time due to Touschek effect in the several bunch mode

As other project, the installation of a 30m long straight section, in the storage ring, the production of high energy γ ray by a Compton back scattering of laser and R&D on the production of high intensity slow positron beam by using a supper conducting wiggler magnet of 10 Tesla are in progress.

Conclusion

The SPring-8 was operated without any big trouble since the beam commissioning. The total operation time was about 8300 hours. About 5600 hours was used for users. The beam performance of SPring-8 is being now achieved far beyond the designed specification due to the intensive machine study and the machine improvement. Upgrades in brightness and orbit stabilization are in progress to provide state-of- the art x-ray and electron beams for all users.

Acknowledgment

This work is a culmination of the efforts of all members of the SPring-8 Accelerator Division.

References

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