Beam Performance and Upgrades of the Storage Ring

Orbit Stability

Beam orbit stability is crucial for the generation of brilliant and stable photon beams for synchrotron radiation sources. Its realization is thus very important among various accelerator problems. Recently the beam orbit stability has been markedly improved and consequently orbit jumps by periodic orbit correction are being suppressed to a level where jumps are undetectable to users. This is due to the combination of the following four improvements. First is an improvement in current stabilizing circuits in the quadrupole magnet power supplies, which markedly reduce the current ripples and drifts. Second, with a reduction of horizontal orbit oscillation around 1Hz by the above improvement in current stabilizing circuits and an averaging of the beam position data on VME, the reproducibility of BPMs have been improved from several to about one micron in r.m.s. Therefore, any setting errors of correcting dipole magnets are drastically reduced in each orbit correction procedure. Third, to reduce errors due to the setting resolution of the correcting dipole magnet, air-core-type correcting dipole magnets with both high resolution and low hysteresis were installed. The twelve correcting dipole magnets in each plane are now used in routine user operation. Fourth, the correction algorithm was changed to utilize the good reproducibility of the BPMs, *i.e.*, the real orbit deviation is used as a correction target instead of the re-synthesized one making use of the Fourier harmonics of the orbit deviation. Figure 1 shows the amplitude changes of the betatron tune-harmonics (40th for horizontal and 18th for vertical) of COD for one day after the above improvements. The amplitude changes stay within 1μm and the orbit jump is small before and after the beam refilling. Before these improvements, the amplitude changes were about 5 μm for horizontal and about 3 μm for vertical. To achieve further orbit stability of sub-micron, a task force for orbit stability was organized and has been conducting overall improvement activities from a multilateral point of view.

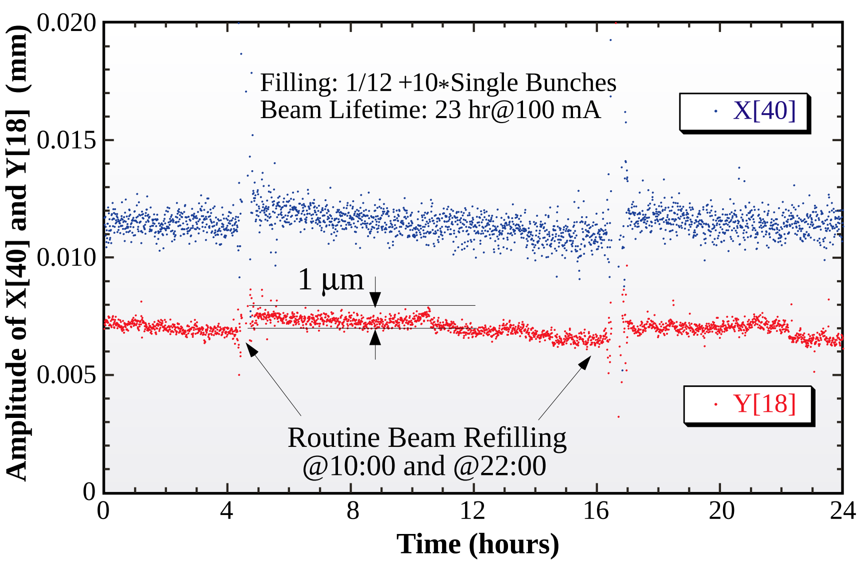

Fig. 1. Typical one-day orbit stability in a several bunch operation.

Electron Beam Emittance at User Operation

The lattice structure of the SPring-8 storage ring is a typical DBA configuration. This kind of configuration has an advantage in reducing electron beam emittance by extra radiation from insertion devices (IDs), because the ID radiation enhances the radiation damping but scarcely excites the betatron oscillation. At present, 22 IDs were installed in SPring-8 and are routinely employed in user operations. Most of them are in-vacuum types, the peak field of which is rather higher than an out-of-vacuum type. The above facts suggest us the possibility that the emittance reduction due to the ID radiation is not negligible. By using the ID parameters, we calculated dependence of the emittance on the extra radiation loss by IDs. We also measured the horizontal beam size variation by a visible light interferometer when ID gaps are closed to the minimum value one by one to estimate the emittance variation. Figure 2 shows the calculated horizontal emittance reduction ratio against the radiation loss increment by IDs together with the measured one. Here the horizontal axis stands for increment of the radiation loss by closing IDs. Both data agree well, as can be seen in Fig. 2. The horizontal emittance reduces as the radiation in the horizontal plane increases and it reaches ~5.3 nm•rad when all ID gaps are minimum. On the other hand, the vertical emittance is generated by six kinds of IDs with a horizontal magnetic field such as an elliptical multi-pole wiggler.

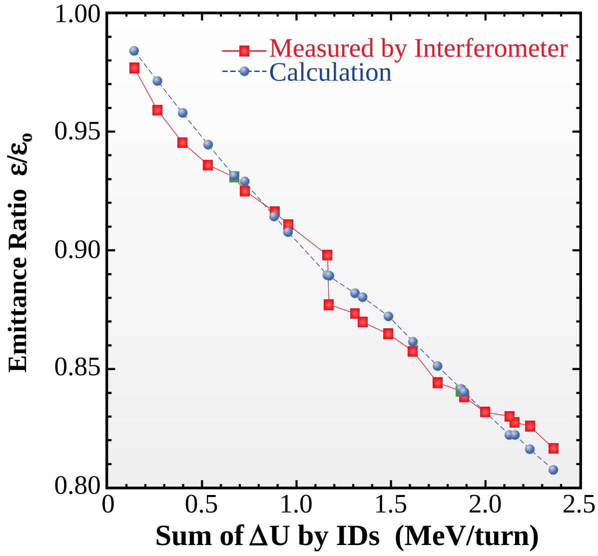

Fig. 2. Calculated emittance reduction rate against radiation loss by IDs as compared to measured value by interferometer, where ε: with IDs and ε_0: without IDs.

Accelerator Diagnostics Beamline

The accelerator diagnostics beamline #1 has a bending magnet light source, and wide band spectral availability including visible/UV light, and soft and hard X-rays is expected. The beamline consists of a front end in the accelerator tunnel, an optics hutch in the experiment hall, a visible light transport line transporting visible/UV light from the optics hutch to a dark room located in the experiment hall, and an X-ray transport line in the optics hutch. The visible light transport line was completed in 2000. Single bunch impurity has been measured by a gated photon counting method, which utilizes fast Pockels cells for switching light pulses, and the bunch length has been measured by a streak camera. The X-ray transport line (Fig. 3) was installed in 2001. It has a double crystal monochromator, which covers the energy range of 4 to 14 keV by Si(111) Bragg reflection. The monochromator crystals and their mechanisms can be moved off the beam axis in the monochromator vacuum chamber when use is made of white X-rays including both soft and hard X-rays. The X-ray transport line as well as the front end has no Be window, which would obstruct soft X-ray and visible/UV light and potentially distort the wavefront and degrade the quality of beam diagnostics such as the imaging resolution.

The precise measurement of the small vertical size of an electron beam is one of the most challenging subjects of the accelerator beam diagnostics of low emittance synchrotron radiation sources. The resolution of electron beam imaging is significantly improved by utilizing synchrotron radiation in shorter wavelength regions. X-ray imaging observation of the electron beam using a single phase zone plate is in preparation at the X-ray transport line. A monochromatic X-ray is selected by the double crystal monochromator. The magnification factor of the zone plate is about 0.3, and an X-ray zooming tube will be used as a detector to compensate for demagnification.

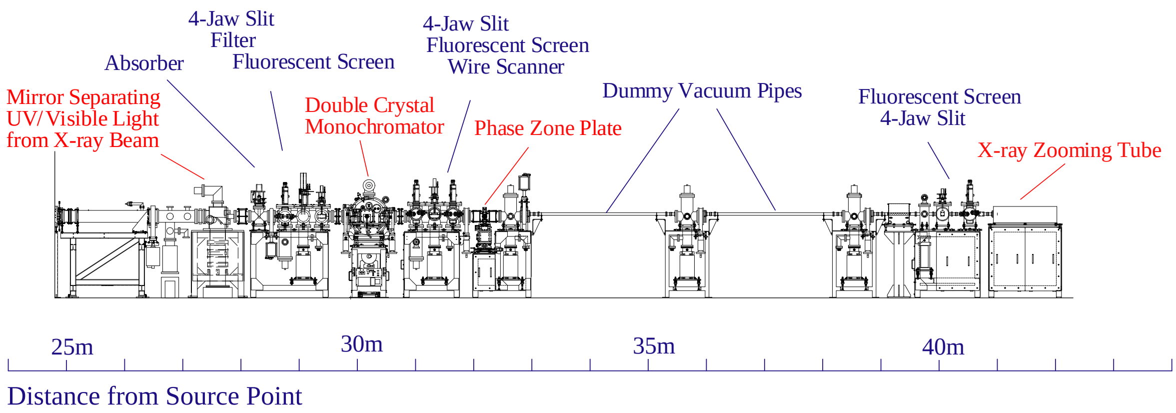

Fig. 3. X-ray transport line of accelerator beam diagnostics beamline #1.

The R&D of accelerator components and new types of light sources are other major research subjects. In the X-ray transport line, there are two dummy vacuum pipes of approximately 2 m length, which will be replaced by an apparatus for the specific purposes of R&D. For example, the study of the effects of synchrotron radiation on cooling water in vacuum components such as absorbers is in progress. Production of γ-ray photons with energy of the order of 10 MeV is in preparation, which utilizes the backward Compton scattering of the far infrared laser photons injected to the storage ring.

Other Research and Developments Activities

The following research and development activities were performed:

- Analysis of beam instability and bunch-by-bunch feedback test.
- Beam loss analysis in the injection process and installation of new injection septum magnets to realize a top-up operation.
- Test of low energy operation at the booster synchrotron and the storage ring.

Developments and Upgrades of Linac

Accelerator Stabilization

An energy compression system (ECS), which was completed in 2000, achieved remarkable beam performances improvements as follows:

• The energy spread of the 40 ns beam was compressed from 3.5% to 1.4% at the beam current of 350 mA. Consequently, the injection current into the synchrotron was increased about five times without decrease the injection efficiency.

• The energy fluctuation of the 1 ns beam at a beam charge of 1.9 nC was reduced from 0.06% rms to 0.02% rms as illustrated in Fig. 4.

• The injection rate into the New SUBARU storage ring – 1.5 GeV synchrotron radiation source for VUV region – reached more than 90% and maintained this during one operation cycle of three- or four-weeks.

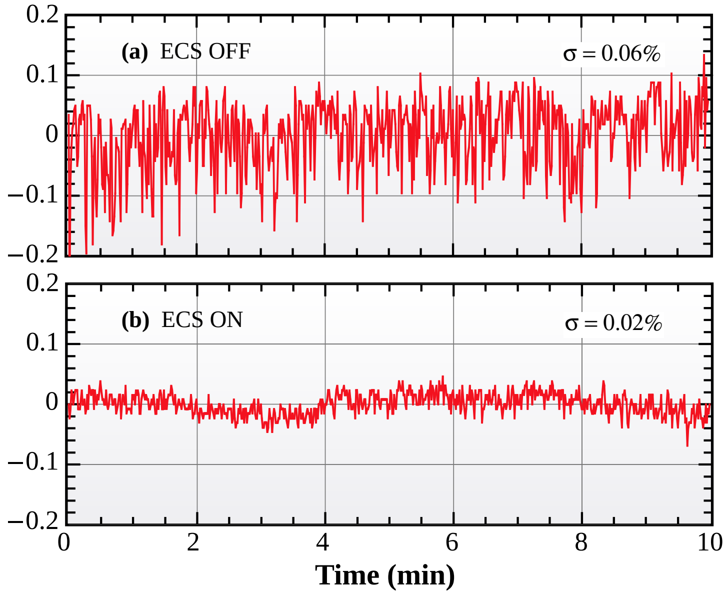

Fig. 4. ECS reduced the energy fluctuations of 1 ns beams at 1.9 nC.

Uniform Bunch Current at Several Bunch Operations

In the several bunch operations of the storage ring, each bunch current is equalized at the injection to the storage ring by adjusting manually the current of the linac gun. The current can be changed by modifying the voltage of the grid pulser, or by inserting an iris in front of the gun. Though a change in the accelerating charge results in a change of the beam loading which leads to a change in the beam energy, an ECS works to stabilize the beam energy extracted from the linac. The stored bunch current of the storage ring is measured by the monitoring signal amplitude from a button pickup using an oscilloscope which monitors the trigger delays. The typical deviation of the bunch current to the mean value is less than 3%.

Development of RF-gun

We introduced a new 0.3 TW laser system for the RF-gun in order to stabilize the laser power and make the laser pulse width variable. It has a power stability of about 3% and the pulse width can be selected from 1 to 19 ps. The vacuum system was also reinforced, with the result that the dark current from the cathode plane was reduced to 1/10 of its previous value.

A preliminary experiment presented the minimum normalized beam emittance of 6 πmm•mrad at a beam charge of 0.3 nC/bunch. Figure 5 shows a photograph of the RF-gun experimental setup.

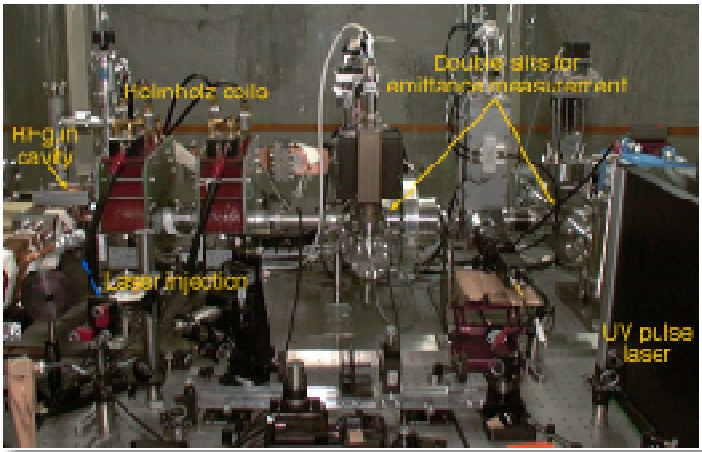

Fig. 5. RF-gun experimental setup on an optical bench.

Upgrades of RF Timing System

Improvements of the Timing System of the Booster Synchrotron

The timing system of the synchrotron receives a 508.58 MHz RF reference signal and a 1-cycle signal at a rate of 1 Hz from the RF station of the storage ring and regenerates many timing signals such as a gun trigger, pulse magnet triggers and ramping patterns. We improved the timing system of the synchrotron to give it better stability and flexibility. In the SPring-8 RF timing system, a phase-locked-loop (PLL) feedback, using the signal returned in the same optic fiber reflected by the mirror located at the end point was applied for phase stabilization. PLL feedback was already adopted most of the entire signal-transmission line between the RF station of the storage ring and the RF low power system of the synchrotron. A lso, the phase control part in the RF low power system was stabilized by PLLs. In 2001, a PLL feedback was introduced in the remaining part of the signal-transmission line. As a result, the fluctuation in the RF phase between the synchrotron and the storage ring is less than 0.3 degree. The fluctuation in the RF phase between the linac and the synchrotron has been remarkably improved. The measured time jitter of a gun trigger to the RF signal is 18 ps in r.m.s. This improvement results in benefits to other advanced operations of the synchrotron, for example, storing an electron beam for longer than 1 second, changing the injection cycle from 1 Hz to a slower frequency to increase the RF knock-out operation period and ejecting the low energy beam during ramping up.

Development of the New RF Synchronization System between the Linac and Circular Accelerators

A new synchronization system for two different RFs was introduced. A 508.58 MHz RF is used in both the booster synchrotron and the storage ring, and the linac uses a 2856 MHz independent RF. The phase between the 508.58 and 2856 MHz RFs was not locked. In the new synchronization method, the pre-trigger signal triggers a 2856 MHz RF generator, which consists of an arbitrary waveform generator and a frequency multiplier. The time width generating the 2856 MHz RF is about 290 µs. The RF for a linac is generated by the RF of a circular accelerator. The uniqueness of this method is that an RF for a linac is not continuously generated but pulsing. The RF generator apparatus for a linac is simple and can be applied to any combination of two RFs. With this new method, beam intensity from the linac was kept almost constant even with higher peak current, and the shift of the beam energy center became smaller than that when an independent synthesizer is used. The block diagram is shown in Fig. 6. The energy stability was not only almost constant but also fell to 0.015% and beam quality was remarkably improved.

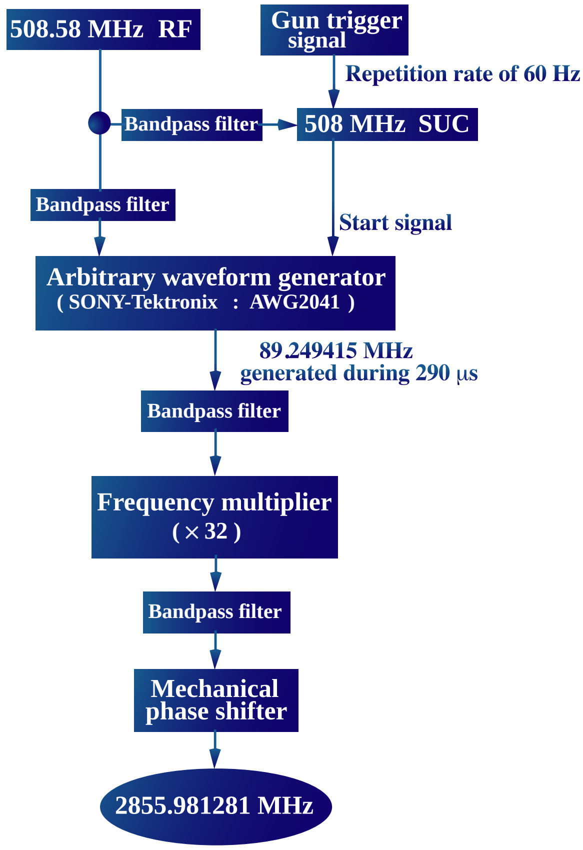

Fig. 6. Block diagram of the new synchronization method between the 508.58 MHz and 2856 MHz RFs.

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