CURRENT STATUS OF A 1.2 GeV BOOSTER ELECTRON SYNCHROTRON AND IMPLEMENTATION FOR NUCLEAR STUDY AT TOHOKU UNIVERSITY

H. Hama, F. Hinode, O. Konno, A. Kurihara, A. Miyamoto, M. Mutoh, M. Nanao, M. Oyamada,
Y. Shibasaki, K. Shinto, S. Takahashi
Laboratory of Nuclear Science, Tohoku University, 1-2-1 Mikamine, Taihaku,
Sendai 982-0826, Japan

Abstract

A 1.2 GeV booster electron synchrotron (STB ring) with combined use of pulse-beam stretcher at Laboratory of Nuclear Science (LNS) [1], Tohoku University was constructed for study of nuclear physics, which is also supposed to be an injector for a planned future 3rd generation light source. Currently the STB ring is routinely operated with a booster-storage mode to supply high energy γ-rays for nuclear study produced via Bremsstrahlung using an internal target wire. Since finite range of a tagging counter array mounted in a bending section, the booster has to be also operated at another flat-top energy lower than 1.2 GeV to extend the γ-ray energy toward lower side. Because characteristics of the STB ring have not been well understood, various beam properties such as betatron tunes and instabilities are not completely controlled at the moment. In order to improve performance of the machine and to study the beam dynamics in a circular accelerator, fundamental properties of the STB ring is now being measured.

1 LNS ACCELERATOR COMPLEX

An injector S-band linac consisted with 19 accelerating structures provides multi-bunch beam with a long-pulse duration of 1 ~ 3 μs. The linac has been operated for multi-purpose use with high repetition rate up to 300 Hz, e.g., the lower energy beam than 50 MeV is able to branch off and often used for radioisotope production. Though the unloaded maximum energy is 300 MeV, an energy of 200 MeV is normally employed for the beam injection into the STB ring because of sufficient beam current. The beam energy is analyzed at a dispersive section in the transport line and selected to be within certain width (typically ± 1.5 %). Since there is an additional function of pulse-beam stretcher to the STB ring, the beam extraction system is also equipped. The quasi cw-beam extracted from the STB ring is transported to a couple of experimental stations.

2 THE STB RING

2.1 Basic Parameters

The STB ring constructed as a multipurpose synchrotron was commissioned in these years and has become routinely operational recently. At the moment there are two major tasks, i.e., a pulse-beam stretcher to produce the quasi cw-beam at the lower energy region from 150 to 200 MeV, and the booster-storage ring to supply internal 1.2 GeV beam. In this issue we mainly report on characteristics of the latter operation.

Table 1: Parameters and status of the STB ring

Lattice type	Chasman-Green
Superperiodicity	4
Circumference	49.7 m
Maximum energy	1.2 GeV
Injection energy	0.2 GeV (nominal)
Betatron tune	(3.24, 1.21) *)
Chromaticity	(~ -5.5, ~ -4.7)*)
RF frequency	500.14 MHz
RF voltage	140 kV
Harmonics	83
Natural emittance	170 nmrad (@ 1.2 GeV)
Momentum compaction α	0.0378
Dispersion	< 10 cm*)
x-y coupling coefficient	0.005*)
Beam current	< 20 mA*) (@ 1.2 GeV)
Lifetime	~ 10 min (@ 1.2 GeV)

*)Measured value

Main parameters and current status of the STB ring is summarized in Table 1. Lattice structure of the ring is the simplest double-bend achromat consisted of 4 cells, which is shown in Figure 1. Three dispersion-free straight sections are occupied by an injection septum, an RF cavity and a wire septum for slow extraction, and an extraction septum, respectively. Remaining one is reserved for future project. Unfortunately there has been no convenient room for nuclear experiments near by, the target wire for Bremsstrahlung γ-ray production was obliged to be installed in a dispersive section.

At the moment, the betatron tune has been chosen to be (3.24, 1.21) and the natural chromaticity was measured to be (-5.5, -4.7), which is not compensated yet because sextupoles are not equipped in the dispersive section. Fortunately we have not observed a beam loss due to the head-tail instability within a beam current of 20 mA. We have been considering to install thin sextupoles for future development of the machine with higher beam current operation. Beam lifetime has reached approximately 10 min at ~10 mA, which is surely dominated by the vacuum pressure and has been slowly getting better.

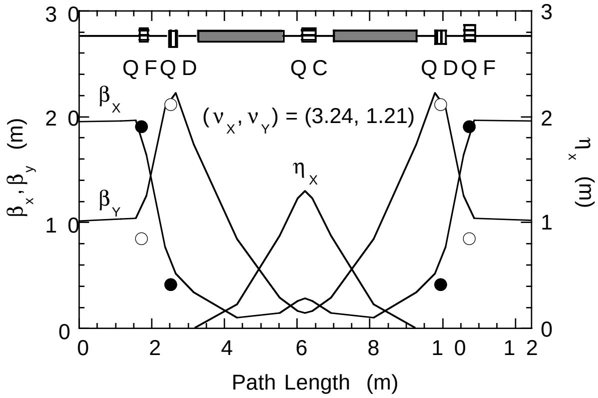

Figure 1: Lattice functions of the STB ring. Closed circle and open circle denote measured averaged horizontal and vertical betatron functions, respectively.

2.2 Beam Injection

The beam current from the linac beam is expected to be ~100 mA, and the long-pulse width of 1 µs is usually employed for the beam injection into the ring. However, because of the wakefield in the accelerating structure, the energy distribution in one beam-pulse is considerably broad, so that acceptable pulse width for the STB ring is supposed to be ~200 ns that is almost equivalent to the revolution time of the ring (166 ns). Indeed, the ring current at the injection is momentarily ~80 mA. Because of finite energy acceptance of the RF bucket (±1.2 % for 200 MeV) and the multi-bunch linac beam, the captured beam current is usually 20 ~ 30 mA.

Emittance of the linac beam in both planes has been measured to be about 300 nmrad, which seems to be sufficiently small to achieve better injection efficiency. Using 6 quadrupoles in the transport line, Twiss parameters, dispersion function and its slope at the injection point have been matched with those of the ring. Although certainty of the matching is not obvious, at present we have presumed the injection efficiency is governed by the longitudinal dynamics than the transverse one.

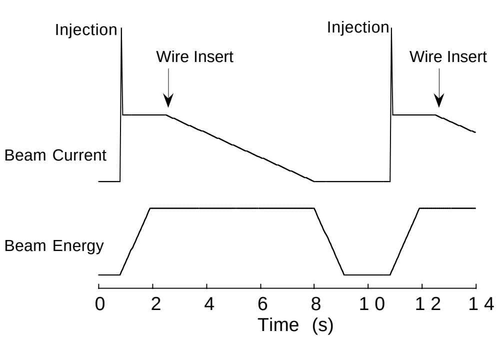

Figure 2: Temporal sequence for the experiment with the booster-storage mode of the STB ring.

2.3 Operation Scheme

Temporal sequence of the booster-storage mode operation is shown in Figure 2. Immediately after the beam injection, the energy ramping is started. It takes 1.1 s to accelerate the beam up to 1.2 GeV from 200 MeV, which is the maximum allowable speed of the power supply. Duration of the flat-top is on demand. In the Bremsstrahlung γ-ray experiment, the event rate is controlled by the position of the target wire, and it is normally restricted by counting rate of the tagging counter array. Accordingly stable accelerated beam current is crucial for such experiments. The intensity fluctuation of the 1.2 GeV beam has been suppressed within 10 % so far, which is certainly affected by operation of the injector linac.

3 TUNE MEASUREMENTS BY USING A STRIP-LINE

3.1 Measurement System

A strip-line type electrode installed in a straight section of the STB ring was designed so as to that intrinsic impedance of each strip-line should be 50 Ω. Tune measurements are performed by which two beam signals from strip-lines of diagonal position are fed into a 180° hybrid mixer and analyzed by a real time spectrum analyzer. Betatron oscillations are excited by applying external RF dipole field to another pair of diagonal strip-lines. White noise at a certain frequency range can be used as an RF knock-out field. Accordingly betatron tunes in both plane are able to be measured simultaneously.

3.2 Stability of Excitation Current

In a preliminary measurement after installing the system we have observed considerable periodic tune fluctuation as shown in Figure 3. Because the chromaticity is not corrected at all, the tune signals contain the synchrotron sidebands including many harmonics. In the measurement of Figure 3, the RF voltage was much reduced to make the betatron sidebands clear. It is obvious that the tunes, particularly the vertical one, beat with 50 Hz repetition rate that corresponds to the electricity line frequency. As the lattice functions shown in Figure 1, among 3 families of quadrupole, QF and QD dominate the horizontal and the vertical betatron functions, respectively, meanwhile QC controls the dispersion function. The vertical tune shift which must be mostly arisen by instability of QD magnetic field implies a current ripple having relative amplitude of ~10^{-3}. Although the horizontal tune shift seems to be smaller and different pattern from the vertical one, it may also indicates somewhat the current instability for QF. We are going to investigate source of the current ripple in the power supplies, which would be a serious problem to improve the machine performance and precise machine control for the study of the beam physics as well.

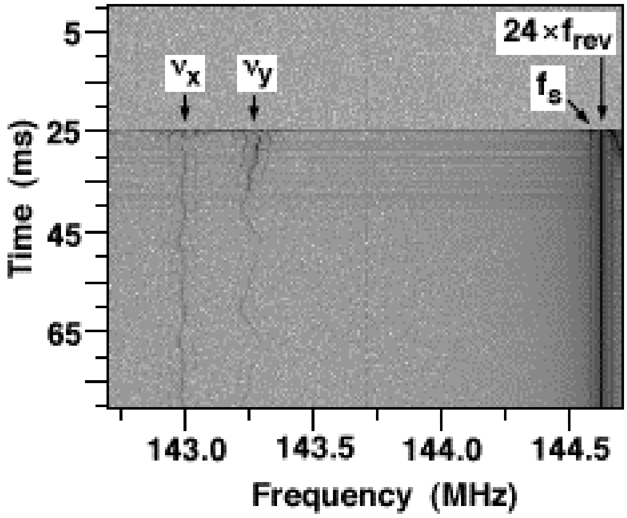

Figure 3: Tune fluctuation in a storage mode at the injection energy of 200 MeV. Betatron oscillations were excited by an external RF white noise at a frequency range of 1 ~ 2 MHz.

3.3 Tune Shift in Energy Ramping

At the present, we have employed a simple pattern for excitation of the magnetic fields in the energy ramping. All magnet currents are linearly increased, but the excitation slope of the quadrupoles are bit steeper than that of the dipoles because the beam loss occurred just after the ramping started when the quadrupoles were excited with same slope as the dipoles, which was probably caused by touching integer resonance. Figure 4 shows the tune shift in an early stage of the energy ramping.

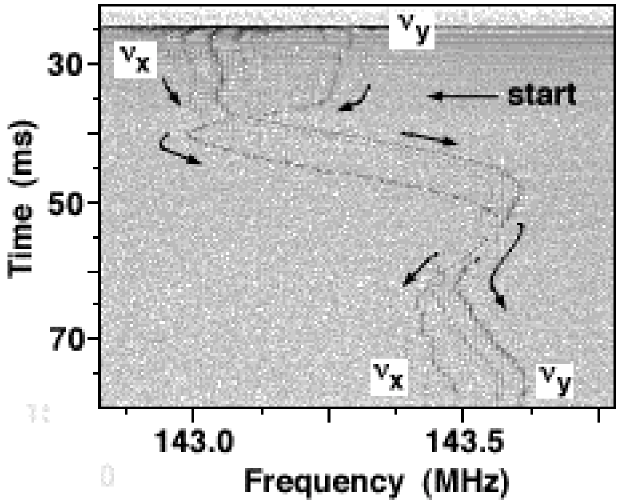

Figure 4: Tune shift in early stage of the energy ramping. The ramping is started at 10 ms after the beam injection.

Large tune shift is still seen after the ramping started. In addition it was found out that crossing of the tunes was also occurred. Specific feature is that the vertical tune is increased immediately and then decreased, meanwhile the horizontal one is getting decreased. Accordingly the tunes are crossing each other after a couple of ms. We have noticed a considerable beam loss occurred at 2 ~ 3 ms after the ramping started. This is certainly due to the difference resonance, in which the large horizontal betatron amplitude brought by the beam injection moves to the vertical betatron motion. An average horizontal betatron amplitude produced the beam injection is expected to be J = 7.2 mm mrad and the damping time is much longer (~2 sec). The vertical displacement at the location of QD would reach ~20 mm that is equivalent to the vacuum chamber height, if the horizontal amplitude is fully converted to the vertical one. A half of the beam intensity is possibly lost due to the difference resonance.

As showing in Figure 5, the coupled motion at the difference resonance can be clearly seen. From the minimum distance of the tunes, the coupling coefficient is deduced to be 0.005, which is rather small value. We presume this is due to small number of the quadrupoles and no sextupoles.

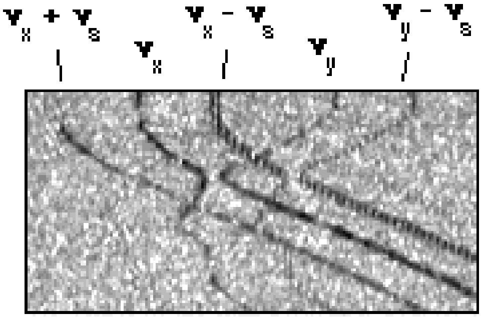

Figure 5: Observed coupled motion of the horizontal and the vertical betatron oscillations at $\nu_x - \nu_y = 2$.

4 SUMMARY

The STB ring is still commissioning stage. However characteristics of the ring has gradually become clear. Along with improvement of the stability of the power supplies, investigation of the tune shift in the energy ramping may be crucial for progress of the machine performance. Study of variation of actual magnetic field including effect of Eddy current in the ramping is under way.

REFERENCES

[1] F. Hinode, et. al., “Beam Commissioning of Stretcher-Booster Ring in Tohoku University”, Proc. 12th Symp. on Accelerator Science and Technology, RIKEN, Wako, Japan, September 1999, p177-179.