BUNCHED BEAM CLEANING SYSTEM OF SPRING-8 BOOSTER SYNCHROTRON

T. Aoki, K. Fukami, N. Hosoda, T. Ohshima, M. Shoji, K. Tamura, H. Yonehara
JASRI/SPring-8, Mikazuki, Sayo-gun, Hyogo 679-5198, Japan

Abstract

In order to fill an aimed radio frequency (rf) bucket with an electron beam in the storage ring at SPring-8, the bunched beam cleaning system which we call RF knockout (RF-KO) system is installed in the booster synchrotron. The time width of the beam from the linac operated with 2856MHz rf is 1nsec for single-bunch beam operation. The beam is distributed not only in a single rf bucket of the booster synchrotron operated with 508.58MHz rf but also in other rf buckets. The energy of injected beam is increased from 1GeV to 8GeV. The RF-KO system is operated at minimum beam energy of 1GeV because the required knockout power is reduced. The bunched beam in the satellite rf buckets are coherently shaken by the electromagnetic field produced by four RF-KO electrodes in the vacuum chamber. As the amplitude of betatron oscillation increase, the beam soon begins to collide with a beam duct and is lost. The single-bunch beam injected into the targeted rf bucket is effectively kept alive on the zero-crossing point of RF-KO waveform with a precise timing system. The beam intensity of satellite rf buckets in the storage ring was measured with a photon counting method and determined to be 10^{-9} less than that of the main rf bucket.

INTRODUCTION

SPring-8 is a synchrotron radiation facility composed of a 1GeV linac, a booster synchrotron, and an 8GeV storage ring. The booster synchrotron operated with 508.58MHz rf is designed to accelerate an electron beam from 1GeV to 8GeV with a repetition rate of 1Hz. The time width of the beam from the linac operated with 2856MHz rf can be selected as 40nsec for multi-bunch filling and as 1nsec for several-bunch filling into the storage ring. Although eight-pulse beam can be injected per one cycle from the linac, usually only one-pulse beam is injected. At the several-bunch filling mode, the beam of 1nsec is distributed not only in a single rf bucket of the booster but also in other rf buckets. Most of the beam in satellite rf buckets are dark current from the electron gun and the accelerator columns of the linac. It is necessary to suppress or to remove the beam in satellite rf buckets for high purity bunch formation in the storage ring.

At the high energy of 8GeV, it is hard to remove the satellite bunches in the storage ring. We think it is easy to remove the satellite bunches in the booster at low energy and to make any beam-filling pattern with high purity bunches into the storage ring. Beam cleaning in the booster is done by RF-knockout (RF-KO) system which kicks the beam in satellite bunches with electromagnetic force at low energy [1]. Figure 1 shows the beam energy

pattern of the booster. The pattern can be changed easily by operation window software. The flat-bottom period of 250msec is decided for eight-pulse beam injection that is the maximum number of beam-pulse accepted in the booster. To keep the beam cleaning duration more than 100msec for the latest eighth-pulse beam, the flat-bottom of 250msec is needed.
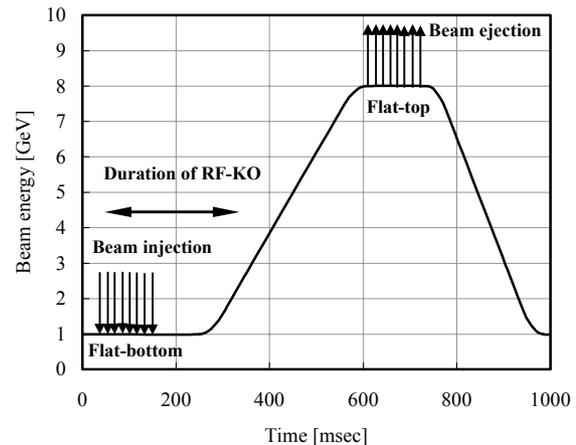

Figure 1: Beam energy pattern of booster and timing of beam injection and ejection. RF-KO system is operated at flat-bottom period.

RF-KO SYSTEM

The RF-KO system consists of a low-level system, a high-power system, and a beam-kicker. Figure 2 shows the block diagram of the RF-KO system. To remove the beam in the satellite rf buckets effectively, the sine-wave signal resonate with vertical betatron oscillation is used for beam-kick.

Not to affect the main bunch, RF-KO signal must be zero output at the instant of main bunch passing through the beam-kicker. Zero-crossing points of rectangle-wave, rise and fall of the wave-form, is adjusted to keep the main bunch alive. The rectangle-wave is generated by the arbitrary waveform generator with external clock of 508.58MHz. The frequency of the rectangle-wave is four times the revolution frequency of the booster that makes eight zero-crossing points at the rf buckets for eight-pulse beam injection. The RF-KO waveform is produced by multiplying the sine-wave and the rectangle-wave together.
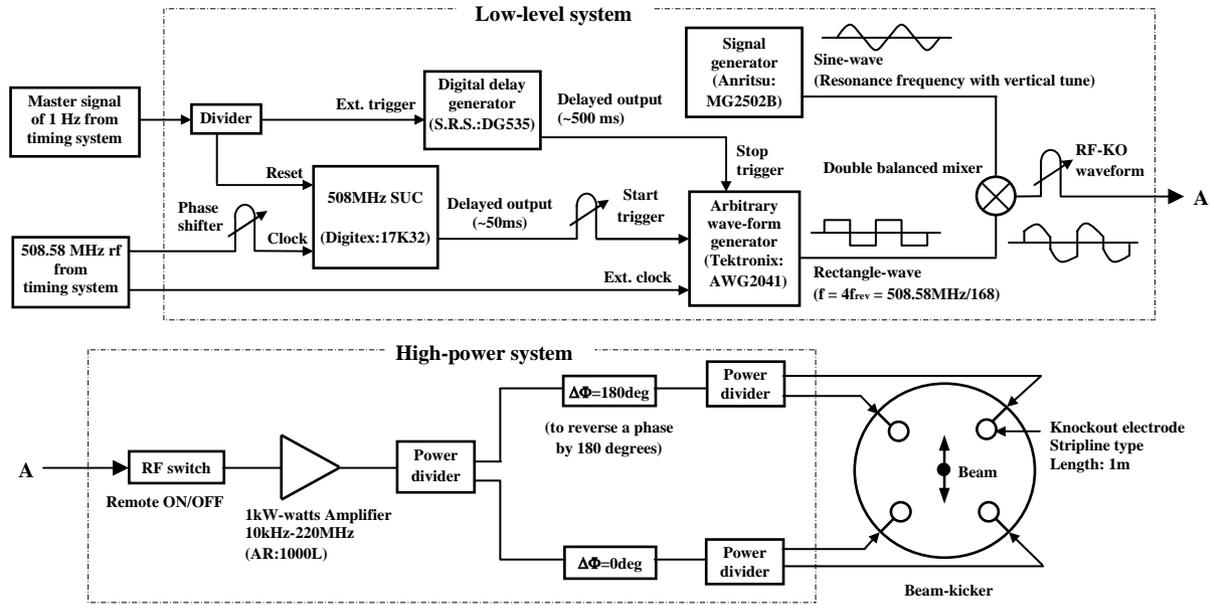
Figure 2: Block diagram of RF-KO system

The RF-KO waveform was produced only by the arbitrary wave-form generator in the old system. The vertical betatron tune was adjusted to the RF-KO signal because the variation of the RF-KO frequency was limited. We improve the system to combine the sine-wave with the rectangle-wave by using a double balanced mixer. The RF-KO frequency can be adjusted more accurately on the resonance frequency. This method also simplifies the machine tuning for the beam cleaning.

The RF-KO signal is amplified by a 1kW-output amplifier and is divided into four electrodes of the beam-kicker. The Beam-kicker is composed of four 1m-long electrodes installed in a cylindrical vacuum chamber. Arrangement of four electrodes in the vacuum chamber is rotated 45 degree from orthogonal position. Phase of the signal to the upper two electrodes are reversed 180 degree to kick the beam in vertical direction. The beam-kicker is installed in the booster where the vertical betatron function is large enough for effective beam kick. The signals passed through the electrodes are attenuated 30dB and are observed by oscilloscope for monitoring of the system condition.

BETATRON TUNE MEASUREMENT

It is important to measure the betatron tune accurately at the flat-bottom period. The RF-KO electrodes are used both as a beam-shaker for tune measurement. The low-level signal output of RF-KO is switched to random-noise generator for the beam-shake. Connection between the RF-KO high-power system and the electrodes are changed correspond with the direction of betatron tune. The time variation of the betatron frequency is measured by real-time spectrum analyzer (Tektronix: 3056). The RF-KO frequency, which resonates with vertical tune, is determined by this measurement.

Figure 3 shows the time variation of the vertical betatron tune. The fluctuation of the tune in the flat-bottom period is about 0.015, and it is mainly caused by the current ripple of the magnet power supplies. The vertical betatron tune must be adjusted in constant value for effective beam kick. The excitation current pattern of the quadrupole magnets are corrected to fix the betatron tune in constant value.
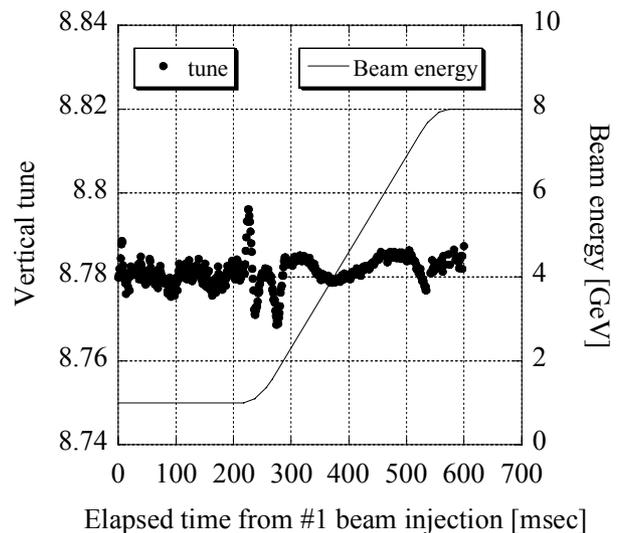

Figure 3: Time variation of vertical betatron tune.

TUNING FOR BEAM CLEANING

On the machine tuning for the beam cleaning, it is important to adjust the timing of RF-KO signal and RF-KO frequency. The zero-crossing point of the RFKO

signal is set on the main rf bucket by using phase shifter. In case that the zero-crossing point is synchronized with the main bunch, no beam loss is observed on an averaged beam current measured by DCCT.

For the fine tuning of RF-KO frequency, beam is shaken by the beam-shaker with continuous sine-wave. A frequency that grows up the beam loss is set directly as the RF-KO frequency. Due to the betatron tune dependence on beam charge density, the vertical tune of 40nsec beam is higher about 0.002 than that of 1nsec beam in the same averaged beam current. The charge density per bunch of the 40nsec beam is about 1/20 less than that of the 1nsec beam. It is hard to measure the vertical tune of the satellite bunches, so we use the tune value of 40nsec beam as the RF-KO frequency.

The single-bunch impurity is measured by using the visible synchrotron light at the accelerator diagnostics beam-line I (BL38B2) in the storage ring. Photon counting method with a fast light shutter system is used [2]. The fast light shutter system consists of Pockels cells, polarizers and a high voltage pulser. The fast light shutter extracts a light pulse from a particular bunch in the storage ring. The bunch impurity can be decided by the extinction ratio of the light shutter (typically 10^5). The latest result of the impurity measurement is less than 2×10^{-11} and less than 1×10^{-9} before and after the main rf bucket, respectively. The results of both are the measurement limit of this system.

We measure the bunch impurities of the satellite rf buckets adjacent to the main rf bucket as a function of the acceleration voltage of the booster. Figure 4 shows the dependence of the bunch impurities on the acceleration voltage at the flat-bottom period. The increase of the acceleration voltage decreases the bunch impurity exponentially. Now, we are investigating the mechanism of this relation.

CONCLUSION

To make the high purity bunches in the SPring-8 storage ring, the beam cleaning system was installed in the booster synchrotron. It was confirmed that the high purity bunched beam was formed efficiently in the booster by removing the satellite bunches at low beam energy of 1GeV. Another advantage of the beam cleaning system in the booster was the ability to make any beam-filling pattern in the storage ring with high purity bunches. Several-bunch filling pattern into the storage ring has been successfully operated, and the beam-line users are satisfying the bunch purity.
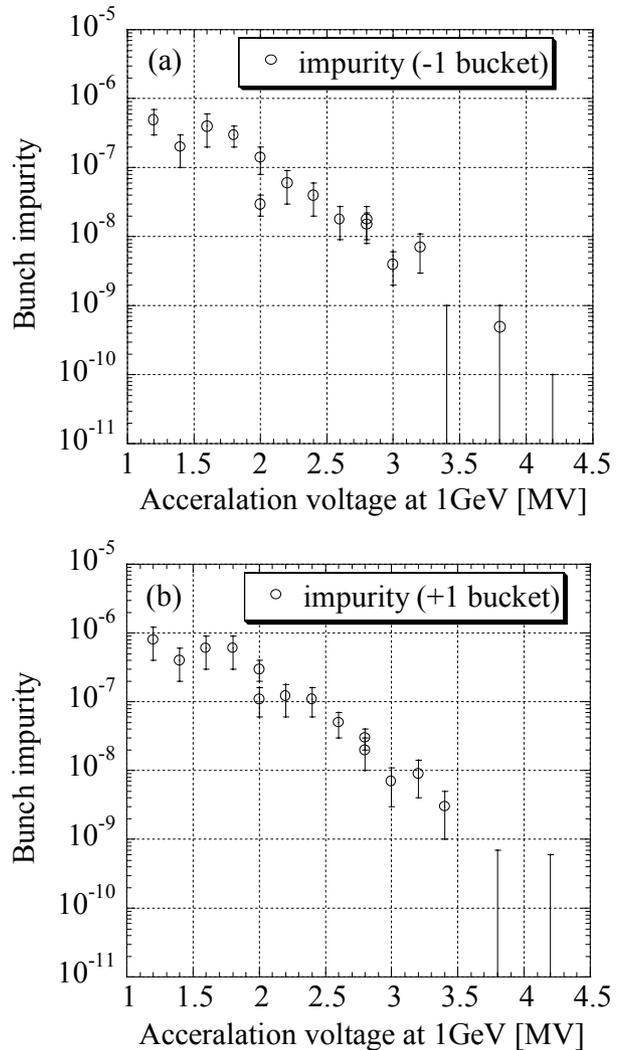

Figure 4: Relation between the acceleration voltage of the booster and the bunch impurity. Upper (a) is -1st bucket and lower (b) is +1st bucket, which are just before and after the main rf bucket, respectively. The bucket spacing is about 2nsec.

REFERENCES

[1] H. Suzuki et al., Nucl. Instr. and Meth. A 444 (2000) 515-533

[2] K. Tamura, Proc. of the 12th symp. on Acc. Sci. and Tech., (1999) p546-548