SINGLE BUNCH PURITY DURING SPRING-8 STORAGE RING TOP-UP OPERATION

K. Tamura, T. Aoki, JASRI/SPring-8, 1-1-1 Kouto, Mikazuki, Sayo, Hyogo, 679-5198, Japan

Abstract

Top-up operation of the SPring-8 storage ring has been started since May 2004. Top-up injection is repeated every minute at several-bunch mode operation to keep the stored beam current at 99mA. To supply a stable and highly purified pulse light, it is an important subject to keep bunch purity less than 10^{-9} level during the top-up operation. A gated photon counting system for single bunch purity measurement that utilizes a fast light shutter system and current status of the bunch purity during the top-up operation are presented.

1 INTORODUCTION

To make use of pulse characteristics of synchrotron radiation, the SPring-8 storage ring has been operated at many kinds of filling modes, in which several singlets or trains of bunches are located at equal intervals. At these filling modes, so-called several-bunch modes, some time-resolved experiments demand the bunch impurity of less than 10^{-9}. Top-up operation has been started since May 2004 [1]. Very low current of 30~40 μA is injected every minute, and the stored beam current is kept at 99mA. To satisfy the demands of the bunch purity during the top-up operation, we need a reliable bunched beam cleaning system that can supply stably the purified single bunch beam for a long period and the bunch purity monitor with a high sensitivity.

At the SPring-8, a highly purified single bunch beam has been produced with an RF-knockout (RF-KO) system in the booster synchrotron and injected into the storage ring [2]. With the RF-KO, the impurity of less than 10^{-9} has been constantly achieved [3]. In addition to the RF-KO, development of a beam deflector system to improve the bunch purity is underway [4]. The beam deflector eliminates unwanted grid emission current from an electron gun. When it operates successfully, the linac will be able to supply a highly purified single bunch beam into the booster synchrotron.

Measurement of the bunch purity of the SPring-8 storage ring has been done by a gated photon counting system, which operates in the visible light range. Performance of the bunch purity monitor of the SPring-8 will be explained in section 2. In section 3, present status of the bunch purity during the top-up operation will be shown.

2 BUNCH PURITY MONITOR

The bunch purity monitor has been installed at the accelerator diagnosis beamline #1 (BL38B2), which has a bending magnet light source. The monitor consists of a fast light shutter system that operates in visible light region and a photon counting system that uses a micro-channel-plate type photo-multiplier tube (MCP-PMT) as a photon detector [5].

Although the photon counting method is known as the method with an excellent dynamic range, it takes a long measuring time to realize its dynamic range. Furthermore, even if we have taken enough measuring time, the sensitivity of the impurity is limited to around 10^{-6} level because of noises due to the structure of the MCP-PMT.

In order to realize the sensitivity of the impurity of less than 10^{-9} in shorter time, we have developed a light shutter system that can pick out a particular light pulse from a synchrotron light pulse train. When we adjust the timing of the shutter to be opened to a satellite bunch adjacent to the main bunch, we can decrease the contrast between the light pulse from the satellite bunch and that from the main bunch.

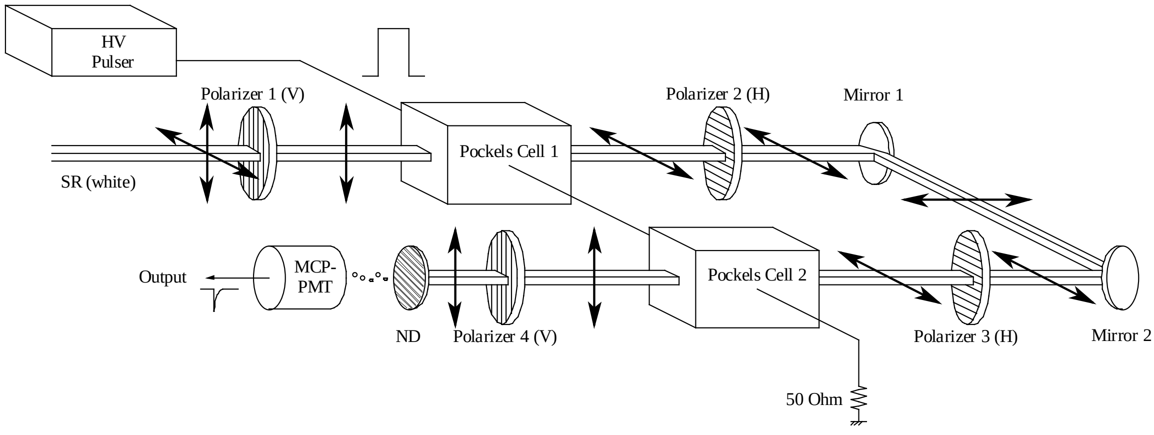

Figure 1: Schematic drawing of the SPring-8 bunch purity monitor.

Basic components of the light shutter are two polarizers whose polarization angles are perpendicular to each other, a fast Pockels cell placed between the polarizers, and a high voltage pulser that drives the Pockels cell. Two-set of the light shutter are used for the SPring-8 bunch purity monitor as shown in Fig. 1.

Performance of the light shutter is expressed by the extinction ratio and the time response. The extinction ratio is defined as the contrast between the intensity of transmitted light with the light shutter opened and that with the shutter closed. Transmission efficiency of the light shutter depends on the wavelength of the light and the applied voltage to the Pockels cell. Since we use white light in visible region, we are concerned about the total efficiency of transmission. In our case, the light shutter shows the maximum transmission efficiency at the applied voltage of around 1.5 kV, and the extinction ratio becomes maximum value. As reported before [5], the extinction ratio of a light shutter system is about 200. To improve the extinction ratio, we have arranged two light shutter systems in tandem as shown in Fig. 1. The time response of a high voltage pulser and the characteristics of the transmission line of high voltage pulses dominate the time response of the shutter. We have used the pulser with a pulse height of 1.5 kV, rise/fall time of 1 ns, pulse width of 6~10 ns (variable). The pulser can operate at 209 kHz, which is equal to the revolution frequency of the SPring-8 storage ring. The Pockels cell (Fastpulse Technology, N1072) is designed to match the 50 Ω coaxial line system.

2.1 Extinction Ratio of Light Shutter

The extinction ratio is defined as the intensity ratio of transmitted light with the shutter opened with respect to leaked light with the shutter closed. Using the synchrotron radiation, we determined the extinction ratio as follows.

At the SPring-8, a 1 ns beam from the linac has been purified by the RF-KO of the booster synchrotron. When we turn off the RF-KO, we can store a single bunch beam accompanied with satellite bunches due to the grid emission of the electron gun. Adjusting the operational timing of the light shutter to one of the satellite bunches, we can determine the extinction ratio by comparing the intensities of the light pulse from the satellite bunch at the time of opening and closing the shutter.

Turning off the RF-KO, we stored a single bunch beam of 1.1 mA. Figure 2 (a) is the time spectrum of light pulses measured with the light shutter closed (measuring time: 1000 s). Horizontal axis shows the bucket number, 0 means the bucket where the main bunch is stored, -1 and +1 represent the buckets that locate before and behind the 0th bucket, respectively. The RF acceleration frequency of the SPring-8 storage ring is 508.58 MHz, and an interval of buckets corresponds to about 2 ns. Vertical axis shows the number of counts by the photon counting method. Counting rate of each bucket corresponds to the intensity of light pulse. In this case, counting rates of the satellite bunches in +1st and -1st buckets were 0.09 and 0.06 cps, respectively. Since the light shutter was kept closed in this measurement, the shutter did not modify the intensities of light pulses. The contrasts between light pulse from main bunch and those from the satellite bunches are equal to the bunch impurities. Counting rate of the main bunch was 3.2 kcps, and the bunch impurities of +1st and -1st bucket were 3×10^{-5} and 2×10^{-5}, respectively.

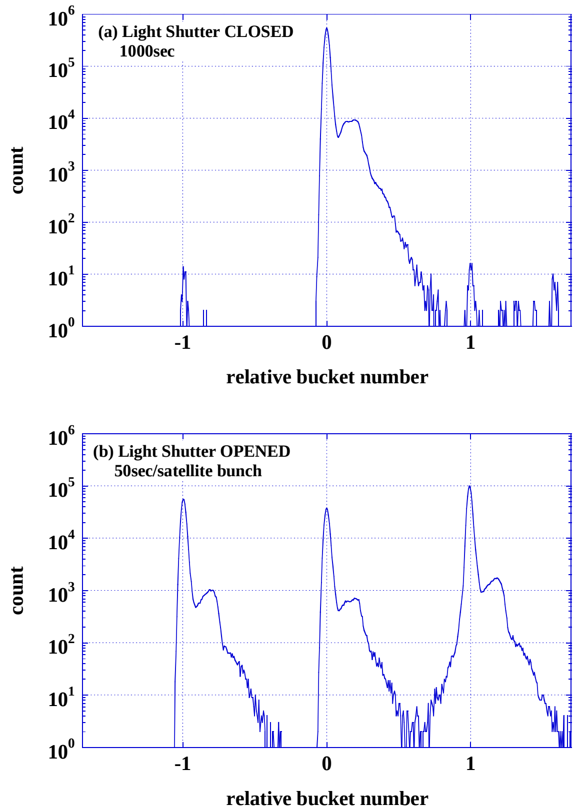

Figure 2: Time spectra of the light pulses measured (a) with the light shutter closed and (b) with the light shutter opened.

Figure 2 (b) is the time spectrum with the light shutter opened successively measured after the measurement of the spectrum in Fig. 2 (a). The spectrum was obtained by combining two spectra measured with adjusting the operational timing of the light shutter to +1st or -1st bucket. Measuring time of each spectrum was 50 s. As a data of the main bunch in Fig. 2 (b), we displayed the data of the main bunch measured with the light shutter opened at +1st bucket. Opening the light shutter at +1st or –1st bucket, counting rates of the satellite bunches in +1st and -1st bucket are increased up to 11 and 7 kcps, respectively, which are greater than that of the main bunch.

The magnifications of counting rates show that the extinction ratio of the order of 10^5 has been achieved.

2.2 Performance of Bunch Purity Monitor

We stored a single bunch beam of 1 mA with the RF-KO, and measured the time spectrum of the beam with the light shutter opened at +1 or -1st bucket. Figure 3 shows the result. The time spectrum is also combined spectrum of two measurements (measuring time: 500s per satellite bunch). Counting rate of the main bunch was 2.7 kcps.

We could not detect any photons at -1st bucket. This corresponds to the impurity of less than 2×10^{-11} as compared with main bunch of 1mA. We can conclude that no electron exists at -1st bucket because the number of electrons in main bunch is 3×10^{10}. On the other hand, there appeared about hundred events at +1st bucket. We could not have distinguished the events whether they originated from electrons or noises of the measurement system yet. Supposing these events are not the noises but the photons from the electrons, the bunch impurity at +1st bucket is 7×10^{-10}. This corresponds to the existence of about twenty electrons at most. The sensitivities of the monitor are 2×10^{-11} or less at -1st bucket, and 7×10^{-10} at +1st bucket.

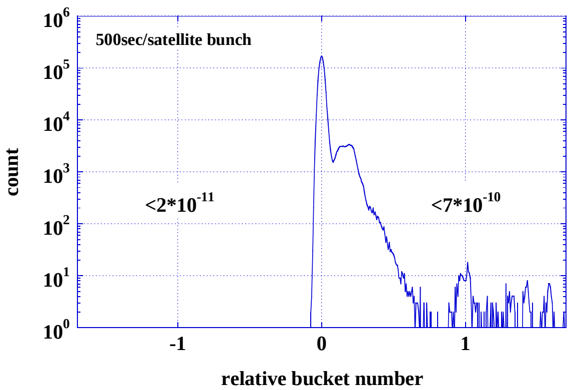

Figure 3: Time spectrum of the single bunch beam injected with the RF-KO of the booster synchrotron.

3 BUNCH PURITY DURING TOP-UP OPERATION

Since May 2004, top-up operation of the SPring-8 has been started. In the top-up operation at several-bunch modes, a purified single bunch beam with a small current of 30~40 μA is injected every minute. To verify the performance of the top-up operation, we observed time variation of bunch impurity.

From 9th to 16th June, the SPring-8 was operated with the filling mode of 2/21-filling + 18 isolated bunches. Thanks to the top-up operation, bunch current of every isolated bunch was kept at about 1.5mA. We continuously measured the impurity at +1st bucket just behind a particular isolated bunch, and found that small growth of the impurity occurred. The result is shown in Fig 4. As mentioned before, we have not eliminated the effect of noise of measuring system, and the sensitivity of the impurity measurement has been limited to 7×10^{-10} at +1st bucket. We supposed all events at +1st bucket were originated from the electrons, and expressed the upper-limit of the impurity in Fig 4. Error bars represent the statistical error.

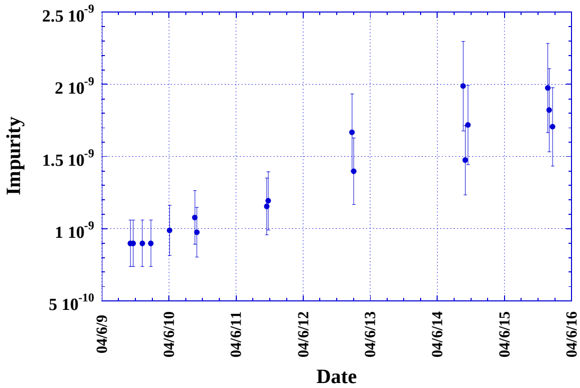

Figure 4: Growth of the bunch impurity during the top-up operation.

The bunch impurity increased from 9×10^{-10} up to 2×10^{-9} during one week top-up operation. Since the bunch current of the isolated bunch is 1.5 mA (4.5×10^{10} electrons), the number of electrons at +1st bucket increased from 40 up to 90. In this period, the number of top-up injections and total injected current into this isolated bunch was 480 and 15.5 mA, respectively.

4 SUMMARY

The SPring-8 bunch purity monitor that utilizes the fast light shutter system with the extinction ratio of 10^5 has been in operation. The sensitivities of the monitor are 2×10^{-11} or less at -1st bucket, and 7×10^{-10} at +1st bucket. The bunch impurity during the top-up operation was measured for one week and small degradation of the bunch impurity of the order of 10^{-9} was observed.

ACKNOWLEDGEMENT

The authors wish to express their appreciation to Dr. N. Kumagai, Dr. H. Ohkuma, Dr. S. Takano, Dr. H. Tanaka and H. Yonehara of JASRI for their valuable discussions.

REFERENCES

[1] H. Tanaka et al., "Top-up Operation at SPring-8 – Towards Maximizing the Potential of a 3rd Generation Light Source ", presented at EPAC'04.
[2] H. Suzuki et al., Nucl. Instr. And Meth. A, 444 (2000) 515-533.
[3] T. Aoki et al., PAC'03, Portland, May 2003, p.2551.
[4] T. Kobayashi et al., " Dark Current Reduction System for SPring-8 Linac", presented at EPAC'04.
[5] K. Tamura, the 12th Symp. on Acc. Sci. and Tech., Wako, Saitama, Japan, 1999, pp.546-548.