Measurement of Single Bunch Impurity in SPring-8 Storage Ring using a Light Shutter System

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Abstract

A light shutter system which operates in the visible light region has been developed. The light shutter has the rise/fall time of less than 1 ns, flat top of 1.1ns and extinction ratio of larger than 200. These values are enough to pick out the light pulse from a particular bunch in a bunch train at the SPring-8 storage ring. By applying the light shutter to a photon counting system for the measurement of the bunch impurity, the detection rate of photons from satellite bunches was increased more than by the two order. A satellite bunch of the impurity of 10^{-9} level was successfully detected.

1 Introduction

When the SPring-8 storage ring is operated in the single- or the several-bunch mode, some time-resolved experiments demand the bunch impurity of less than 10^{-6}. The bunch impurity is defined as the ratio of the number of electrons in a satellite bunch to that in the main bunch. In an electron storage ring, synchrotron radiation (SR) is emitted as light pulses. The contrast between the light pulse from a satellite bunch and that from the main bunch is proportional to the bunch impurity. We can obtain the bunch impurity by measuring the contrast of the light pulses. A photon counting method is widely used for the bunch impurity measurement [1]. In the method, SR is attenuated and detected as a photon. The detection timing of the photon with respect to the timing signal which synchronized to the bunch revolution is analyzed in digitally. An excellent dynamic range can be easily obtained when a large number of events are collected. This method, however, takes a long measuring time to obtain the contrast of the light pulses of larger than 10^6 because it collects the events one by one. This situation will be eased by use of a light shutter [2] which cuts the light pulse from the main bunch but passes the light pulse from the satellite bunch. The light shutter decreases the contrast of the light pulses and enables us to measure the bunch impurity quickly or precisely.

Table 1: Main parameters of the SPring-8 storage ring.

Energy	E	8	GeV
Circumference	C	1436	m
Radio frequency	f_{rf}	508.58	MHz
Harmonic number	h	2436	
Revolution frequency	f_{rev}	209	kHz

We have developed a light shutter system which consists of a fast Pockels cell, two polarizers and a high voltage pulser. We measured the characteristics of the light shutter, such as the time profile and extinction ratio, and applied it to the bunch impurity measurement. In section 2, the principle of a light shutter system is briefly explained. Experimental setup is shown in section 3. Characterization of the light shutter and the application of it to the bunch impurity measurement are described in section 4 and 5. Related parameters of the SPring-8 storage ring are listed in Table 1.

2 Light Shutter System

The light shutter makes use of the linear electrooptical effect of birefringent crystals, known as Pockels effect. The effect results in rotating the plane of polarization of the linearly polarized light propagating through a crystal as a response to an applied voltage.

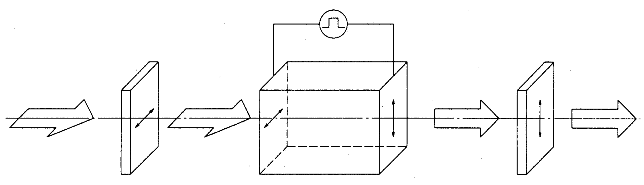

Fig. 1 Conceptual drawing of the light shutter system.

The light shutter system consists of two polarizers whose polarization angles are perpendicular to each other and a fast Pockels cell placed between the polarizer [3]. As shown in Fig. 1, when a certain voltage is applied to the cell, the cell rotates the plane of polarization of the incident light. The transmitted light from the cell can pass through the second polarizer, i.e., the shutter is opened. While no voltage is applied, the plane of polarization of the incident light is unchanged and the light can not pass through the second polarizer, i.e., the shutter is closed. We can operate this system as a light shutter by applying high voltage square pulses to the cell.

We have used a two-crystal type Pockels cell (Fastpulse Technology, N1072FW). The material of the crystals is DKDP (KD_2PO_4). The pulser (Kentech Instruments, HMP1 Pulse Generator) can operate up to 220 kHz which covers the revolution frequency of the SPring-8 storage ring. The height and rise/fall time of the output pulses are 650V and less than 1ns, respectively.

The performance of the light shutter is dominated by the time response and extinction ratio. In order to transmit the high voltage pulses with first rise/fall time, the cell 1072 is designed to match the 50-Ohm coaxial line system. The extinction ratio is defined as the contrast between the intensity of the transmitted light with the light shutter opened and that with the shutter closed. Precise alignment of the cell with respect to the path of the incident light is necessary to obtain high extinction ratio. The cell is aligned with a precise three-axial rotational stage which the cell is mounted on.

3 Experimental Setup

We installed the light shutter system into the photon counting system in the temporal photon beam extraction line where the visible-light component in SR from a bending magnet have been used for the beam diagnostics. Not only the bunch impurity measurement, but the vertical beam size measurement with a Young's interferometer [4] and the bunch length measurement with a streak camera system have been also performed there.

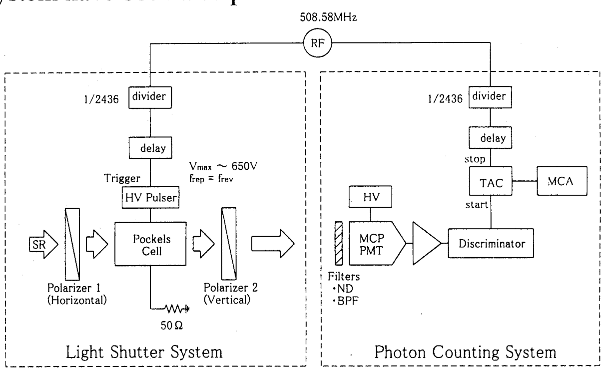

Fig. 2 Block diagram of the photon counting system for the bunch impurity measurement and the light shutter system.

A Block diagram of the photon counting system is shown in Fig.2 together with the light shutter system. SR is reduced by ND filters down to the level of one photon detection per hundred revolutions of a bunch and detected by a micro-channel-plate type photomultiplier tube (MCP-PMT, Hamamatsu Photonics, R3809U-52). The pulses from the MCP-PMT are input to a fast timing discriminator (EG&G ORTEC, 9307). The discriminator produces the timing pulses which synchronize the detection timing of photons. The time intervals between the pulses output from the discriminator and the timing signals synchronized to the bunch revolution are converted to the pulse heights by a time-to-amplitude converter (TAC, EG&G ORTEC 567). The distribution of pulse heights is analyzed with a multi channel analyzer (SEIKO EG&G MCA7700-010).

In order to synchronize the operation of the light shutter with the bunch revolution, the high voltage pulser is externally triggered by the timing signal generated using the signal of RF system of the SPring-8 storage ring. The output timing of the pulses, i.e., the timing of the light shutter to be opened, can be adjusted by changing the delay of the external trigger pulse.

4 Characterization of Light Shutter System

The time response and extinction ratio of the light shutter were measured with the photon counting system. We used the visible part (wavelength range 400~650 nm) in SR for the measurement of the time profile. Changing the trigger timing of the light shutter to be opened by 250 ps step, we measured the change of the intensity of the light pulse from a particular bunch in a bunch train. Figure 3 shows the time profile of the light shutter. The ordinate is expressed by the extinction ratio. The light shutter opens/closes within 1 ns which is shorter than a bunch spacing of the SPring-8 storage ring (about 2ns). The ringing of the profile which appears after closing the shutter is due to the undershoot of the high voltage pulses.

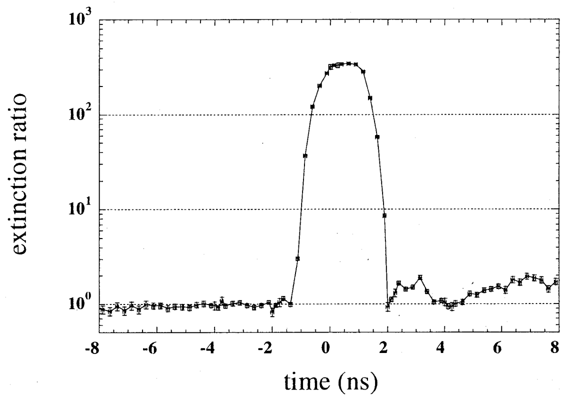

Fig. 3 Time profile of the light shutter.

We also investigated the dependence of the extinction ratio on the wavelength range of the incident light. We measured the extinction ratio at the wavelength of 441 nm, 488 nm and 532 nm (bandwidth 10 nm in FWHM). The extinction ratio became worse as the wavelength became shorter (620 @532 nm –> 156 @441 nm). This is due to the effect of insufficient collimation of the incident light. If the path of the incident light is not parallel to the optical axis of the crystal in the cell, the plane of polarization will be somewhat changed even if no voltage is applied to the cell. This effect gets severer and makes the extinction ratio worse as the wavelength became shorter. Typically, the extinction ratio for the wavelength range of 400~650 nm is larger than 200. As summarized in Table.2, the performance of the light shutter is enough for extraction of the light pulse from a particular bunch in a bunch train.

Table 2: Main parameters of the light shutter.

Rise time (10-90 %)	0.9	ns
Flat top	1.1	ns
Fall time (90-10 %)	0.8	ns
Extinction ratio	> 200	
Repetition frequency	209	kHz

5 Application to Bunch Impurity Measurement

5.1 Performance of Bunch Impurity Measurement System

The Performance of the bunch impurity measurement system with the light shutter was confirmed as follows. We stored the single bunch beam the purity of which was made worse than that of usual single bunch beam of the SPring-8 storage ring by the two or three order. We measured the detection rates of photons from four satellite bunches before and behind the main bunch with the light shutter and those without the shutter. Since the light shutter opens for only one bucket in a revolution period of the electron beam, the detection rate was measured by adjusting the timing of the shutter to be opened to one of four satellite bunches. The same measurement was repeated for each satellite bunch.

By comparing the detection rate with the light shutter to that without the shutter, we determined the magnification of the detection rate of photons.

Figure 4 (a) is the time spectrum of the light pulses measured without the light shutter (measuring time: 1000s). We recognize three satellite bunches in –2nd, -1st and +1st buckets but not in +2nd bucket. The sensitivity of the impurity measurement at +2nd bucket is limited to 7×10^{-7} (statistical error of 99% level) by the noises due to the structure of the MCP-PMT. Figure 4 (b) is the time spectrum successively measured with the light shutter after the measurement of the spectrum in Fig. 4 (a). The spectrum was obtained by combining four spectra. Each spectrum was measured for one of four satellite bunches selected by the light shutter. The measuring time was 250s per satellite bunch. The data of the main bunch is expressed by the average of four measurements. It is found that the contrast between the light pulses is weakened more than by the two order. We confirmed that the detection rate of photons is enhanced by about 200 by the light shutter.

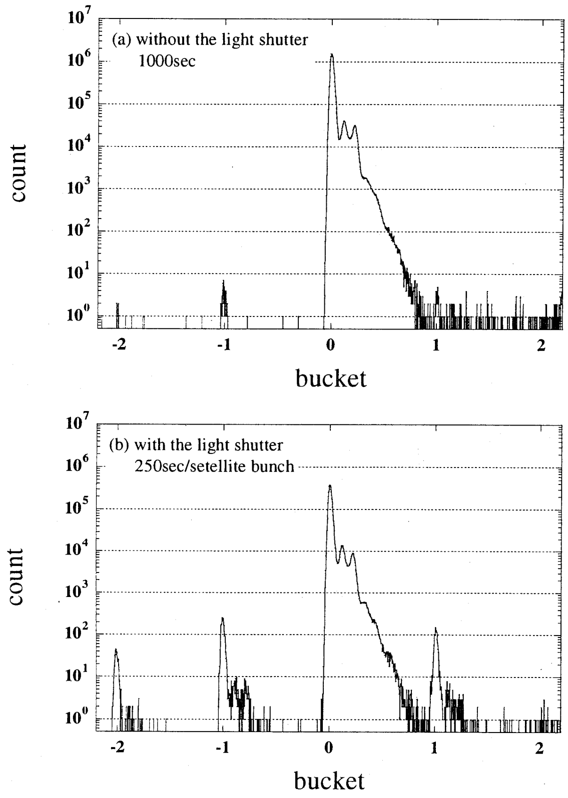

Fig. 4 Time spectra of the light pulses measured (a) without the light shutter and (b) with the light shutter.

5.2 Bunch Impurity Measurement

We stored the single bunch beam with the usual purity and evaluated the sensitivity of the measurement of the single bunch impurity with the light shutter. The time spectrum of the light pulses measured with the shutter is shown in Fig. 5. It is also the combined spectrum of four measurements (measuring time: 500s per satellite bunch). Considering the magnification of the detection rate, the impurities of two satellite bunches in $\pm$1st buckets correspond to $6 \sim 7\times10^{-8}$. In –2nd bucket, we recognize a satellite bunch of the impurity of 7×10^{-9}.

In +2nd bucket, we can not find a satellite bunch at more than noise level of 5×10^{-9} (statistical error of 99% level). It is consistent with the sensitivity without the shutter mentioned in sub-section 5.1. Therefore, we can evaluate a satellite bunch of the impurity of above 4×10^{-9} with respect to the main bunch of 1mA for measuring time of 1000s.

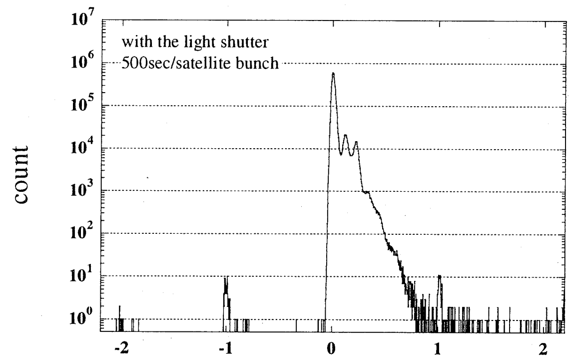

Fig. 5 Time spectrum of the light pulses measured with the light shutter.

6 Summary

In order to improve the sensitivity of the impurity measurement, we developed the light shutter system which opens/closes within the bunch spacing and operates up to 220 kHz. In the measurement of the single bunch impurity, the light shutter well emphasized the intensity of the light pulses from the satellite bunches by about 200. We detected a satellite bunch of the impurity of 10^{-9} level successfully. By use of the light shutter system, the sensitivity of the impurity measurement has been improved to 4×10^{-9} for measuring time of 1000 s.

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