OPTICAL BUNCH-BY-BUNCH BEAM DIAGNOSTIC SYSTEM IN KEK-PF

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Abstract

An optical bunch-by-bunch beam diagnostic system, which can detect oscillations of individual bunches in a multi-bunch operation, has been developed. The system is composed of a high-speed light shutter and an optical beam-oscillation detector. The shutter that consists of a pockels cell and polarizers can be opened or closed in a bunch spacing time (2ns in KEK-PF) and it can select a light pulse corresponding to a certain bunch in a bunch train. The beam oscillation detector can detect oscillations of the picked-out bunch with a spectral analysis method. The diagnostic system has been installed in KEK-PF Beamline-21, and observed vertical oscillation of individual bunches due to an instability in the multi-bunch operation.

1 INTRODUCTION

An analog switch method is usually adopted for a bunch-by-bunch beam diagnostic system. In the method, a pulse corresponding to a certain bunch in a pulse train from a beam monitor (a button type electrode is usually chosen) is selected by a fast electronic switch [1]. A bunch-by-bunch and turn-by-turn beam diagnostics with a digital memory system has also been developed [2]. However, ringing that commonly occurs in a fast electronics degraded the detection capability. Moreover, the electronic detection has an unavoidable problem that the BPMs detect not only the beam signal but also wake fields. To avoid these problems, we have adopted an optical beam detection method and developed an optical switch called a "high-speed light shutter"[3]. One of its merits is that the optical system is free from harmful effect caused by ringing, and has an excellent tolerance to electronic noise. Moreover, it is the most important strong point that the system is not affected by wake fields propagating in vacuum ducts. We have developed an optical bunch-by-bunch beam diagnostic system with the shutter, and have been observing vertical oscillation of individual bunches due to an instability in a multi-bunch operation in KEK-PF with the system.

2 OPTICAL BEAM DIAGNOSTIC SYSTEM

2.1 High-Speed Light Shutter

Basically, the shutter system is composed of a pair of polarization filters and a pockels cell [3]. The pockels cell (Fast-pulse Technology, 1044-FW) is placed between the polarization filters whose polarization angles are perpendicular to each other. The incident light can pass through the shut-ter while a high voltage pulse is applied to the cell because the cell rotates the polarization plane. Since the time response of the cell is fast enough, the operation speed of the shutter is mainly determined by the rise and fall time of the pulser. We have used the pulser whose output pulse has a width (FWHM) of 1.7 ns, which is shorter than the bunch spacing of 2 ns, and a height of 550 V. We operate the shutter with a repetition rate of $f_{shutter}$= 534 kHz which is one third of a revolution frequency (f_{rev}=1.60 MHz in the KEK-PF) because of the limitation of the repetition rate of the high voltage pulser (max. 600 kHz) and a reason described below.

2.2 Operation of High Speed Light Shutter

In order to observe the time structure of the shutter we made use of a photon counting method [4] and used a CW-laser (Spectra Physics, $\lambda = 488$ nm) as a light source. A block diagram of the shutter, including the optical setup, is shown in Fig. 1. To improve the polarization of the incident light on the cell we used a couple of polarizers. A signal generator generates a signal with a frequency equal to the RF acceleration frequency (f_{RF}=500 MHz in the KEK-PF). A divider generates a signal with a repetition frequency of $f_{rev}/3$. We used the divided signal as a trigger for the high voltage pulser. To eliminate electronic noise caused by the high voltage pulse, we carefully shielded the whole of the cell and cables that feed the pulse to the cell.

The light from the shutter passes through a pair of lenses. To eliminate stray light due to multiple scattering between optical devices, an iris diaphragm is set at the focal position of the first lens of the pair. The light from the lenses is attenuated by a neutral density filter (ND filter) and a slit, and detected by a microchannel-plate type photomultiplier (MCP-PMT, Hamamatsu Photonics, R3809U-52), which has an excellent time resolution (rise time of 0.15 ns, transit time spread of 25 ps). The output signal of the MCP-PMT is processed by a constant fraction discriminator (CFD, TENNELEC, TC454) to generate the start signal of the time-to-amplitude converter (TAC, ORTEC 467). On the other hand, a signal synchronized with the trigger for the pulser is used as a stop signal for the TAC. The output signals of the TAC are amplified and analyzed with a multichannel analyzer (MCA, Laboratory Equipment). An extinction ratio, which is defined as the ratio of intensity of singled-out light by the shutter to that of the leaked one, sensitively depends on a direction of an axis of the cell. Therefore, it is important to align the axis of the cell precisely with the direction of the light to operate the shutter system properly. To adjust the angle of the cell minutely

we mounted the cell on a triaxial goniometer and adjusted within $\sim 0.5°$ for all the directions.

The time structure of the shutter is shown in Fig. 2. The ordinate and the abscissa in the figure correspond to the counting rate of the photons and the time, respectively. FWHM of 1.0 ns and the extinction ratio of 800 are obtained. Because the bunch spacing of the KEK-PF is 2 ns, it is possible to single out light from one particular bunch in the multi-bunch operation with the shutter system.

We installed the shutter system in Beamline 21 (BL-21) in the KEK-PF and tried to pick out a light pulse from a certain bunch in the the multi-bunch operation. For the observation we used visible light component of SR from a bending section. In the experiment we used the RF signal of the KEK-PF as a signal source of the shutter system instead of the signal generator in Fig. 1. Figure 3 shows the time structure of the light passing through the shutter measured by the photon counting method. The three peaks in the figure show the count rates of the photons from 3 successive bunches. The count rate of the central peak, which corresponds to the picked-out bunch, is about 300 times as large as those of the others although the electron number in each bunch is almost equal; that is, the shutter system which has the extinction ratio of 300 is obtained. The ratio is about one third as compared to the experiment with CW-laser. One of the reasons is that the rotation of the polarization in the cell depends on the wavelength of the incident light; therefore, it is difficult to single out the SR as clearly as monochromatic light, like laser light, because the SR has a wide wavelength range. The other is that SR propagating in a direction with a certain angle from the median plane has elliptic poralization component and the polarizers cannot eliminate the elliptic polarization component completely.

2.3 Detection of Beam Oscillation of Individual Bunches

In order to detect vertical betatron oscillation of individual bunches in the bunch train, we have developed an optical betatron oscillation detection system which is composed of the high-speed light shutter and an optical betatron oscillation detector. A lens system is set behind the shutter and an image of the beam is put on a horizontal edge [5]. Because half of the image is cut off by the edge, the intensity of the light through the edge varies in response to the vertical motion of the beam. We used a photomultiplier tube (PMT, Hamamatsu Photonics, H2431-50) to measure the intensity. The change in amplitude of the signal selected by the shutter is analyzed with a spectrum analyzer (ADVANTEST, R3361D). Figure 4 shows a photograph of the beam diagnostic system in the beamline.

Because 280 in the 312 RF-buckets are filled in the multi-bunch operation in the KEK-PF, the contribution of leaked light pulses through the shutter during the closing time is not negligible even though the light shutter has the extinction ratio of 300. The spectral lines corresponding to the betatron oscillations of all bunches appear as side-
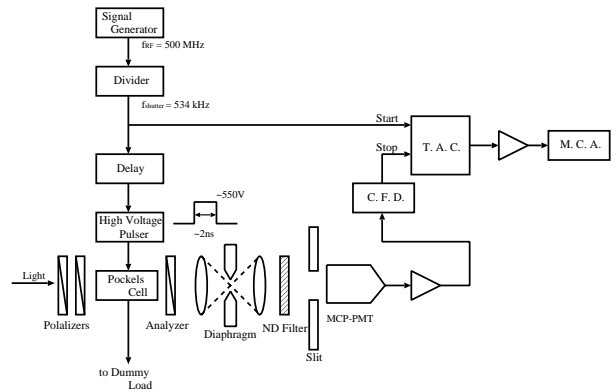

Figure 1: Block diagram, including the optical setup, of the high-speed light shutter.
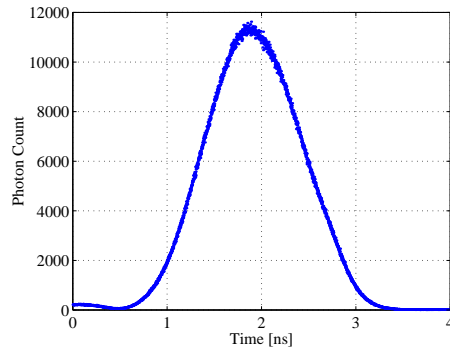

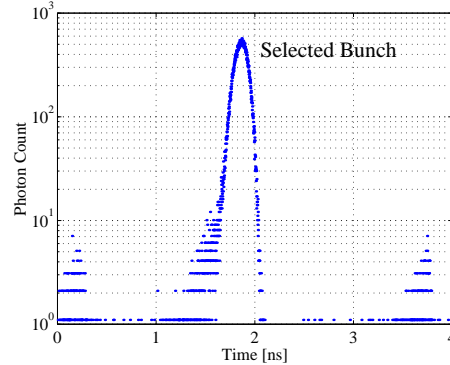Figure 2: Time structure of the singled-out light pulse from the CW-laser.

Figure 3: Time structure of the transmitted light. The SR of BL-21 in the KEK-PF at the multi-bunch mode was used as the light source.

bands of the harmonics of the revolution frequency. Meanwhile, those corresponding to the singled-out bunch appear on both sides of the harmonics of the shutter frequency. Therefore, we can distinguish the betatron oscillation of the selected bunch from the contributions of the other bunches by detecting the betatron sidebands (f_{obs}) of the spectral lines that are not harmonics of the revolution frequency (f_{rev}) but of the shutter frequency ($f_{shutter} = \frac{1}{3} f_{rev}$), i.e.,

$$f_{obs} = \frac{n}{3} f_{rev} \pm q f_{rev} \qquad \left(\frac{n}{3} \neq \text{integer} \right), \qquad (1)$$

where q is the decimal part of the vertical tune (0.29).

We have tried to observe a vertical instability observed in the multi-bunch condition in the KEK-PF with the system and the spectral method, and measured vertical tunes of individual bunches. The result shows that the vertical tunes depend on a position of bunches in a bunch train, and we were able to show that the phenomenon is caused by a modulation of ion density due to periodic passage of the bunch train. Detailed discussions are referred in Ref. [5].
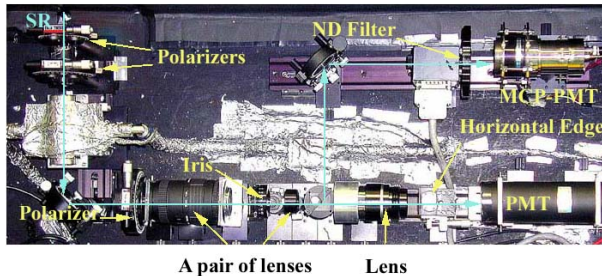

Figure 4: Photograph of the beam diagnostic system, including the high-speed light shutter, the photon counting system and the beam oscillation detection system.

3   SUMMARY AND DISCUSSION

We have developed an optical bunch-by-bunch beam diagnostic system which can detect betatron tunes of individual bunches in a multi-bunch condition in KEK-PF. We have adopted an optical method with an optical analog switch called "high-speed light shutter". The diagnostic system composed of the light shutter and an optical beam-oscillation detector can distinguish betatron oscillation of a selected bunch from contribution of the other bunches by a spectral method.

We can indicate some remarkable merits of the diagnostic system;

- A ringing, that usually occurs in electronic detection with button electrodes and causes a bad effect that each bunch-signal is affected by preceding bunches, does not occur in the optical system.
- It detects the beam signal only, in contrast to a button type electrode that detect not only the beam signal but also wake fields.
- It can be used for visible light, which can treat easily and safely in the atmosphere.
- In relation to above, most of optical devices that compose the system are not special-ordered but commercial ones.

The system also has a demerit; because we use an edge to detect the oscillation of the light in the diagnostic system, it is difficult to measure oscillation amplitude of the beam when that the amplitude is larger than a spot size on the edge. Now we plan to develop a new detection system using a fast-response position sensitive detector which has a good time response and good spatial resolution.

We built the detector on a beamline for a photon counting system that requires merely weak light; therefore, the intensity of light provided by the beamline was insufficient for the beam diagnostics in our present experiment and the S/N ratio of the measurement was unsatisfactory. We have improved the beamline to increase photon flux in the March 2001 and some adjustments for the beamline are now under way.

4   ACKNOWLEDGMENTS

5   REFERENCES

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