BUNCH BY BUNCH BEAM DIAGNOSTICS USING A FAST LIGHT SHUTTER

A. Mochihashi, Univ. of Tsukuba, Tsukuba, 305-0006, Japan
T. Kasuga, T. Obina, M. Tobiyama, KEK, Tsukuba, 305-0801, Japan

Abstract

A bunch-by-bunch beam diagnostic system which consists of a high speed light shutter and an optical beam detector has been developed. Since the open/close time of the shutter is comparable to a bunch spacing of 2 ns, it is capable of picking out the light pulses from a particular bunch in a bunch train. The selected pulses can be analyzed with conventional optical beam diagnostic methods in order to measure beam properties of the individual bunch. The system was installed in KEK-PF and bunch-by-bunch tune measurement was tried.

1 INTRODUCTION

Optical methods in the beam diagnostics are powerful for electron storage rings, and many attempts to measure beam parameters such as transverse/longitudinal beam distributions and betatron/synchrotron motions and to determine beam-induced wake fields in vacuum vessels have been made using the methods[1][2]. If we are able to pick out the light pulses only from a particular bunch in a bunch train, bunch-by-bunch beam diagnostics which are quite essential for modern accelerators become easy[3]. Such a beam diagnostic system will be a strong tool for the experimental verification of beam instabilities which depend on the bunch position in the bunch train such as the Fast Beam-Ion Instability (FBII).

A high speed light shutter that operates within the bunch spacing is necessary for such optical beam diagnostics. Since the bunch spacing of KEK-PF is 2 ns in the multi-bunch mode, the shutter has to be opened or closed within 2 ns. We have been developing such a high speed light shutter and making experiments to detect the betatron oscillation of an individual bunch in the train of bunches using it.

2 HIGH SPEED LIGHT SHUTTER

A schematic diagram of the high speed light shutter is shown in Fig.1. A pockels cell (Fastpulse Technology, 1044-FW) is placed between polarization filters whose polarization angles are perpendicular to each other. The incident light can pass through the shutter while a high voltage pulse is applied to the cell because the cell rotates the polarization plane of the light. Since the time response of the cell is fast enough, the operation speed of the shutter is determined by the rise/fall time of the pulser.

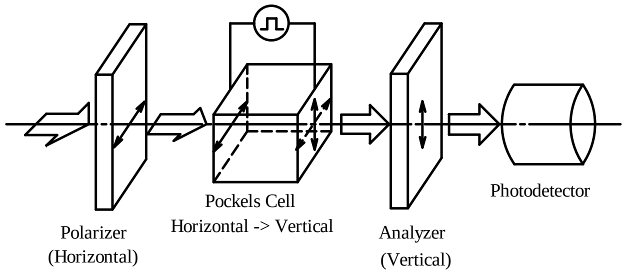

Figure: 1 Schematic diagram of high speed light shutter.

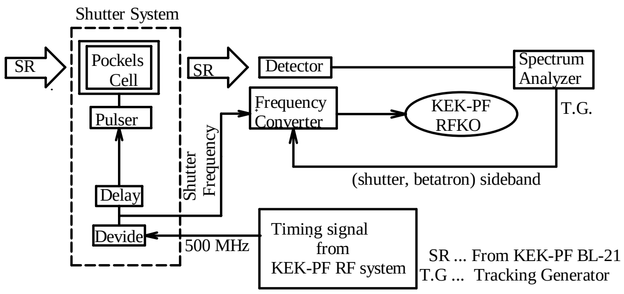

Figure: 2 Block diagram of bunch-by-bunch betatron oscillation detection system.

The pulser (Kentech Instruments) generates pulses with a width (FWHM) of about 1.5 ns, which is shorter than the bunch spacing of KEK-PF (2 ns), and a height of 550 V. We operated the shutter with a repetition rate of 534 kHz which corresponds to the frequency of 3-revolutions in KEK-PF (1.60 MHz / 3 = 534 kHz) considering a repetition limit of the pulser (600 kHz).

3 DETECTION OF BUNCH-BY-BUNCH BETATRON OSCILLATION USING OPTICAL METHOD

The block diagram of the optical bunch-by-bunch betatron oscillation detection system is shown in Fig.2. The shutter is triggered by a timing pulse from a divider, which generates the signal synchronized to the 3-revolutions (534 kHz) of a bunch dividing the RF signal (500 MHz) by 312 (harmonics number) and 3 (revolutions). The light pulses passed through the shutter are detected by an avalanche photodiode (APD, Hamamatsu Photonics, R2381) or a photomultiplier (PMT, Hamamatsu Photonics, H6779). The light through the shutter is focused on a photodetector using a lens with a focal length of 100 mm. If the image is focused on the edge of the sensing area of the detector, the amplitude of the output signal varies with the betatron oscillation because the image moves with the transverse motion of the bunch. The change in the amplitude of the signal picked-out by the shutter was detected with a spectrum analyzer (ADVANTEST, R3361D). Since the maximum extinction ratio (the intensity of light passed through the opened shutter / that leaked out the closed shutter) is about 300 as described in the following section and the number of bunches in the bunch train is 250, a contribution of uncalled-for bunches is larger than (or comparable to) that of the picked-out bunch. In order to detect the betatron oscillation only of the picked-out bunch, we made use of spectrum analysis. The spectral lines corresponding to the betatron oscillation of the bunch train appear on the both sides of harmonics of the revolution frequency f_{rev}. Meanwhile, those corresponding to the picked-out bunch appear on the both sides of harmonics of the shutter frequency f_{sh} (= f_{rev} / 3). Therefore, if we find betatron sidebands on the side of the frequencies which are harmonics of f_{sh} and non-harmonics of f_{rev}, they are spectral lines corresponding to the betatron oscillation of the picked-out bunch.

We excited the betatron oscillation using the RFKO (RF knockout) method, since no spontaneous oscillation was observed. In order to synthesize the RFKO frequency, the output signal of the tracking generator of the spectrum analyzer tuned at a betatron sideband of f_{sh} (=f_{rev} / 3) and the sinusoidal wave with the frequency f_{sh} synchronized to the shutter operation were mixed with a double balanced mixer (DBM) and filtered out. We were able to observe the betatron sidebands of the shutter frequency f_{sh} exciting the betatron sideband of the revolution frequency f_{rev} in this manner.

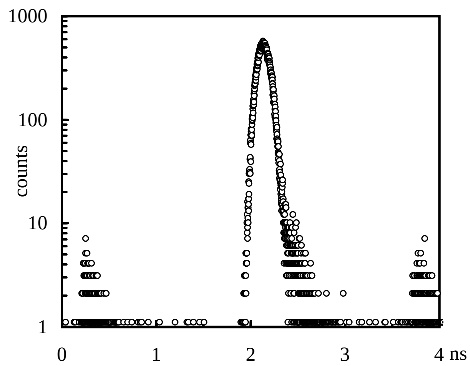

Figure: 3 Time structure of light passed through shutter.

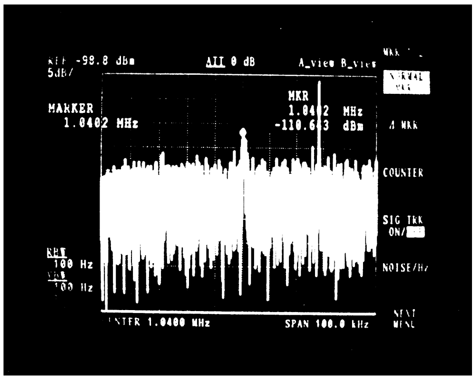

Figure: 4 Betatron sideband of the picked-out bunch. Middle peak corresponds to $f_{\beta y}+f_{sh}$. Right-side peak corresponds to $2f_{sh}$.

4 RESULTS

4.1 High Speed Light Shutter

We installed the shutter in BL-21 and observed the time structure of the light passed through the shutter using the photon counting method in the multi-bunch mode. The result is shown in Fig.3. In the figure, 3 peaks show count rates of photons from successive 3 bunches. The count rate of the central peak, which corresponds to the picked-out bunch, is about 300 times as large as those of others although an electron number in each bunch is almost equal. The fact shows the shutter works properly, namely, it is capable of picking out a particular bunch in the bunch train in the multi-bunch mode.

4.2 Bunch-by-Bunch Detection of Betatron Oscillation

Bunch-by-bunch tune measurement was tried also in BL-21. Fig.4 is the result of the experiment with the APD when the betatron oscillation was excited by the RFKO method. The middle peak in the figure corresponds to the vertical betatron upper sideband (1034 kHz = 500 kHz ($f_{\beta y}$= (ν_y –3) f_{rev}) + 534 kHz (f_{sh})) of the shutter frequency, and the peak on the right corresponds to $2f_{sh}$ (= 1069 kHz). The betatron oscillation of the picked-out bunch in the bunch train was detected in this manner.

We also tried to observe the dependence of the betatron oscillation on the bunch position using the PMT because the sensitivity of the APD is not sufficient for this purpose. A bunch train with 250 bunches and a total current of 400 mA was stored and betatron sidebands of bunches were observed with the RFKO method. In the experiment, several bunches were lost due to over-excitation of the RFKO and the train was split into 4 bunch trains. Fig.5 and 6 show the betatron sidebands of the 1st and 70th bunch in the 4th bunch train at 1005.4 kHz (= 471 kHz ($f_{\beta y}$) + 534 kHz (f_{sh})) and 1004.4 kHz (=

470 kHz (f_{β_y}) + 534 kHz (f_{sh})), respectively. The spectra of these two bunches are slightly shifted each other as seen in these figures. The tunes (the peak frequency of spectra) of several bunches in the 1st and 4th bunch train are plotted in Fig.7. A bunch current of each bunch was 1.3~1.9 mA. Influence of a deviation of bunch currents on the tune measurement is negligible because the beam current dependence on the tune is $-2*10^{-4}$ /mA[4]. The tunes of the head bunches are slightly larger than those of the rears, that is consistent with the data measured at KEK-AR[5]. Since the experiment was preliminary and the origin of the phenomenon is not known, more systematic investigation is necessary.

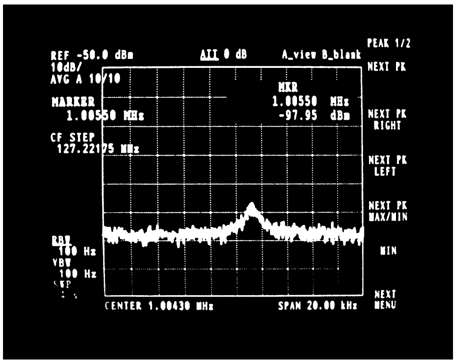

Figure: 5 ($f_{\beta_y}+f_{sh}$) of #1 bunch in 4th bunch train.

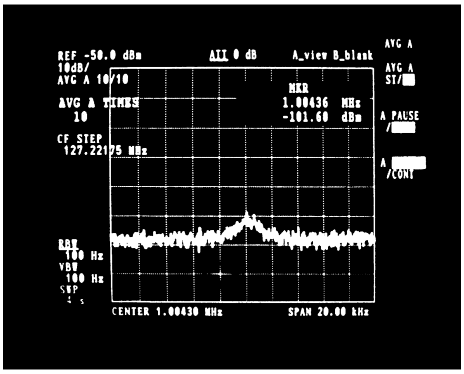

Figure: 6 ($f_{\beta_y}+f_{sh}$) of #70 bunch in 4th bunch train.

5 SUMMARY

The high speed light shutter which can operate within the bunch spacing of 2 ns was developed. The shutter was capable of picking out the light pulse from a particular bunch in a bunch train. By detecting the spatial oscillation of the picked-out light, the bunch-by-bunch betatron oscillation was detected. The experimental result was consistent with the data measured at KEK-AR.

Some improvements are necessary for quantitative bunch-by-bunch tune measurement, namely, optimization of the spectral sensitivities of the shutter and the detector, and improvement of the extinction rate

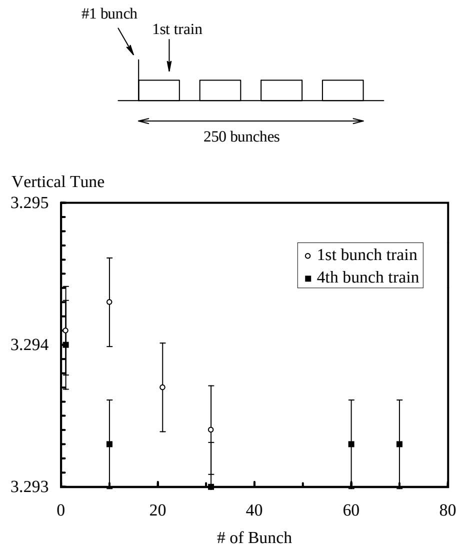

Figure: 7 Tunes of several bunches in the 1st and 4th bunch train. Error bars represent FWHM of spectral peaks.

of the shutter. Also systematic investigation of the tune dependence on the bunch position in a bunch train is a future subject. The bunch-by-bunch beam diagnostics using the shutter will be a strong tool for the experimental verification of beam instabilities.

6 REFERENCES

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