OBSERVATION OF TRANSVERSE INSTABILITY USING BUNCH-BY-BUNCH BEAM DIAGNOSTIC SYSTEM IN KEK-PF

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Abstract

Two types of bunch-by-bunch beam diagnostic systems, an optical and an electronic diagnostic one, have been developed. Each system has a high-speed analog switch which can be operated within a bunch spacing of 2ns and pick out a signal from one-bunch in multi-bunch operation. These systems were installed in the KEK-PF electron storage ring and the bunch-by-bunch detection of a vertical instability was observed.

1 INTRODUCTION

A bunch-by-bunch beam diagnostics is a powerful method for experiments of the accelerator physics, especially for studies considering a transient phenomena in which motion of bunches depends on the positions in the bunch train. To observe individual bunches in the bunch train independently, it is necessary to pick out a signal from one bunch in multi-bunch signals. We have developed two types of the bunch-by-bunch beam diagnostic systems: one is an optical method and the other is an electronic one. Each system has own analog switching system, namely, a high speed light shutter composed of optical devices and an electronic switch composed of a double balanced mixer. Because these systems can be operated within 2ns, which corresponds to a bunch spacing of the KEK-PF, it is possible to pick out one bunch signal in the multi-bunch mode.

In the KEK-PF, a vertical instability has been observed in the multi-bunch mode. The instability can be suppressed by exciting octupole magnets in routine operation for users, however, the origin of the phenomenon is not perfectly understood yet. We have installed the diagnostic systems in the KEK-PF and tried to observe the instability by using them.

2 OPTICAL DIAGNOSTIC SYSTEM

2.1 High-Speed Light Shutter

A schematic diagram of the high-speed light shutter [1] 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 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. A high voltage pulser (Kentech Instruments) generates pulses with a width (FWHM) of about 1.5ns, which is shorter than the bunch spacing, and a height of 550V. We operate the shutter with a repetition rate of 534kHz which corresponds to the frequency of 3-revolutions in the ring (1.60MHz/3=534kHz) considering the repetition limit of the pulser (600kHz).

We installed the shutter system in the beamline 21 and tried to pick out a light pulse from one bunch in the multi-bunch mode. The shutter was operated synchronized with the revolution of bunches by using an RF signal of the ring as a trigger source of the shutter. Figure 2 shows a time structure of the light passed through the shutter measured by a photon counting method. Three peaks in the figure 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 operation.

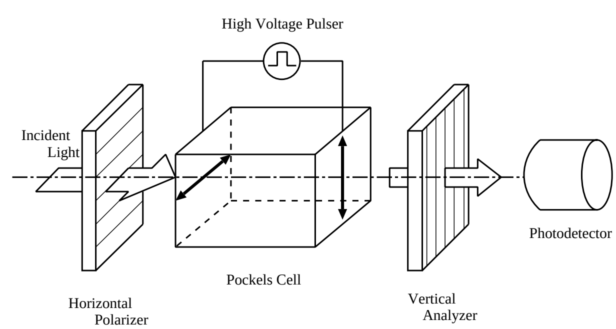

Figure 1: Schematic diagram of high-speed light shutter.

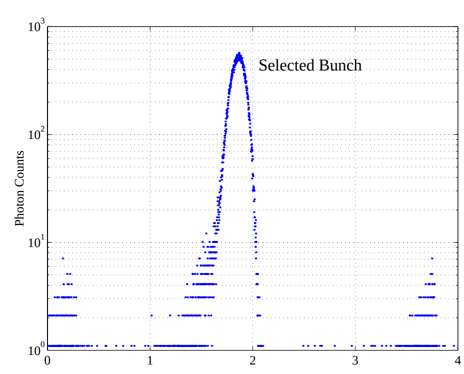

Figure 2: Time structure of light passed through shutter.

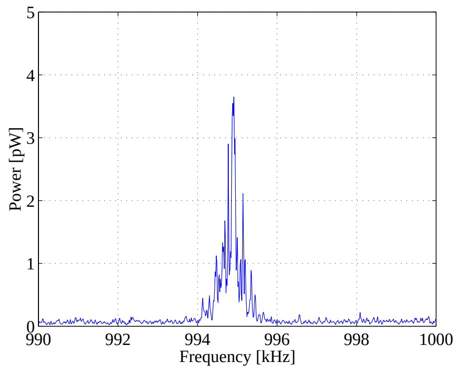

Figure 3: Spectrum corresponding to the betatron sideband ($f_{shutter} + f_{\beta y}$) of a selected bunch.

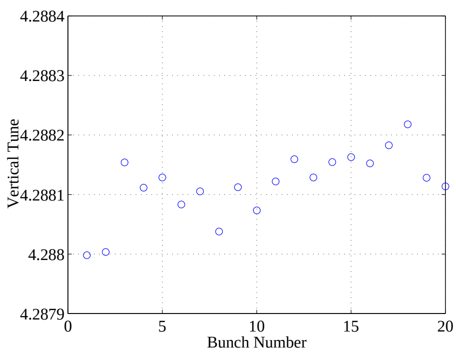

Figure 4: Optical detection of the vertical tune in the head of the bunch train.

2.2 *Detection of Bunch-by-Bunch Oscillation Using Optical Method*

The image of the beam is focused by a lens system set behind the shutter. Because the half of the image is cut off by a horizontal edge, intensity of light through the edge varies in response to the vertical motion of the beam. We use a light sensor (Hamamatsu Photonics, H6779) to measure the intensity. The change in the amplitude of the signal selected by the shutter is analyzed with a spectrum analyzer (ADVANTEST, R3361D).

Because the light shutter has an extinction ratio of 300 at the most, contribution of leaked light pulses through the shutter during the close timing is not negligible, the spectral lines corresponding to the betatron oscillations of all bunches appear on the both sides of harmonics of the revolution frequency. Meanwhile, those corresponding to the picked-out bunch appear on the both sides of harmonics of the shutter frequency. Therefore, we can distinguish the betatron oscillation of the selected bunch from contribution of the other bunches by detecting the betatron sidebands (f_{obs}) of the spectral lines that are non-harmonic of the revolution frequency (f_{rev}) but harmonic 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 tune (=0.28).

Betatron oscillation of bunches are detected in the multi-bunch mode (successive 280 bunches followed by 32 empty buckets) in which all bunches have almost equal intensity ($\sim$ 1.6 mA/Bunch) and total current of 450 mA. In order to observe the vertical instability, we turned off the octupole magnets that are usually excited to suppress the instability. Figure 3 shows the vertical betatron sideband around 995kHz (=534 kHz($\frac{1}{3} \times f_{rev}$)+455 kHz(0.28$\times f_{rev}$). The betatron oscillation of the picked-out bunch in the train was detected.

Figure 4 shows the vertical tune in the head of the bunch train observed by the optical system. It is clearly seen that the tune varies along the bunch train, and the mechanism is discussed in ref. [2] in detail.

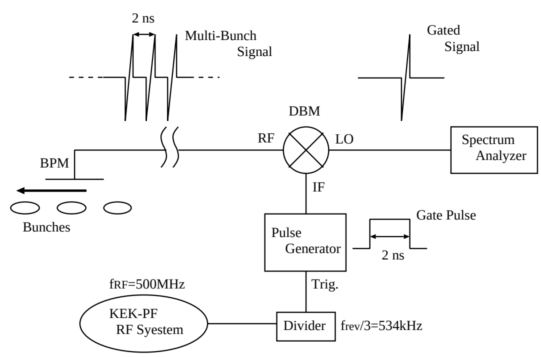

Figure 5: Block diagram of bunch-by-bunch diagnostic system using analog switch.

3 ELECTRONIC DIAGNOSTIC SYSTEM

3.1 *Electronic Analog Switch*

A block diagram of an electronic diagnostic system is shown in fig.5. The multi-bunch signal from a beam position monitor (BPM) and a pulse train which is synchronized to the revolution of bunches are multiplied by a double balanced mixer (DBM, R&K, M21). Because the pulse train has a width of 2ns which equals to the bunch spacing, we can pick out one bunch signal from the multi-bunch signal by adjusting the timing of the pulse train. Figure 6 and 7 shows the BPM signal without/with the gated pulse when the multi-bunch operation. It is clearly seen that one bunch signal is able to be picked out by the analog switch.

3.2 *Detection of Bunch-by-Bunch Oscillation Using Electronic Method*

As same as the case of the optical method, contribution of leaked pulses during the gate pulse is not active is not negligible because an isolation of the DBM is not enough in our experiment. We operated the pulse generator with the repetition rate of the frequency of $f_{shutter} = \frac{1}{3} f_{rev}$ as same as the light shutter, and detected the betatron oscillation of

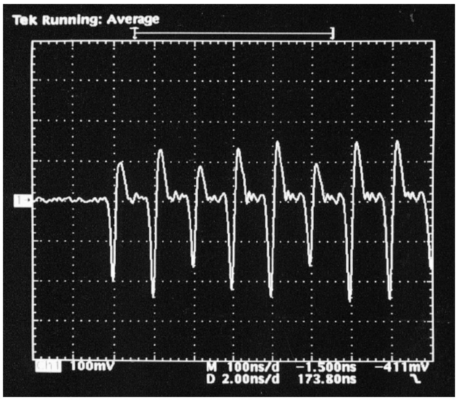

Figure 6: Multi-bunch signal without analog switch.

Figure 7: Multi-bunch signal with analog switch.

picked-out bunch by observing the frequency component as follows:

$$f_{obs} = f_{RF} + \frac{1}{3} f_{rev} + q f_{rev}. \qquad (2)$$

Betatron oscillation of bunches are detected in almost similar condition to the optical detection. Figure 8 shows the vertical betatron sideband around 500.08MHz (=500.1MHz(f_{RF})+534kHz($\frac{1}{3} f_{rev}$) +446kHz(0.28f_{rev}))

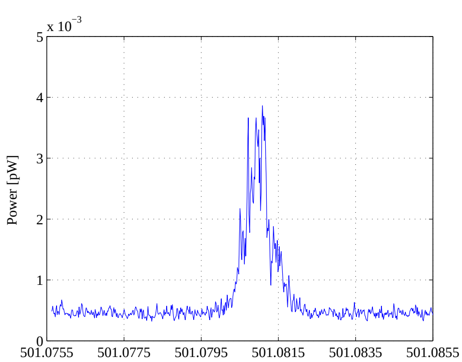

Figure 8: The spectrum corresponding to the betatron sideband ($f_{RF} + \frac{1}{3} f_{rev} + f_{\beta y}$).

although the vertical tune is slightly different from the case of the optical detection. The betatron oscillation of individual bunches can also be detected with the electronic method.

4 SUMMARY AND DISCUSSION

We have developed the optical/electronic bunch-by-bunch beam diagnostic system and tried to detect the vertical instability observed in the KEK-PF. Both of the two systems can pick out one bunch signal from the multi-bunch signal, and be detected the vertical betatron oscillation of individual bunches independently.

There are some problems in these diagnostic systems. Because the optical system uses the edge for detecting the spatial oscillation of the light, it is impossible to detect correctly the oscillation that has an amplitude larger than the spot size on the edge. In the electronic system, the picked-out signal can be disturbed by bunches which are ahead of the aimed bunch because of a ringing effect of the BPM itself. Moreover, the BPM signal is also disturbed by wake fields propagating in vacuum vessels because the BPM detects not only the beam signal but also the wake fields.

REFERENCES

[1] A. Mochihashi et al., "Bunch by Bunch Beam Diagnostics Using A Fast Light Shutter", APAC'98, KEK, Tsukuba, Japan, March 1998.

[2] T. Obina et al., In these proceedings.