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

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Abstract

Betatron oscillations of individual bunches in a multi-bunch mode operation have been observed using an optical bunch-by-bunch beam diagnostic system in the KEK-PF electron storage ring. Detection of bremsstrahlung gamma rays emitted by scattering between an electron beam and trapped ions has also been tried. Those experiments strongly suggest the existence of a transient ion trapping phenomenon, such as the Fast Beam-Ion Instability.

1. Introduction

In the KEK-PF electron storage ring, a vertical instability has been observed in a 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. A possible cause of the phenomenon seems to be an ion related effect, especially the phenomenon so-called the Fast Beam-Ion Instability (FBII)[1][2]. We have developed a bunch-by-bunch beam diagnostic system which can detect betatron oscillations of individual bunches in a bunch train, and tried to verify the dependence of the amplitudes or the frequencies of the betatron oscillations on the bunch position in the train in BL-21.

If ions are trapped in an electron beam, a scattering between electrons and ions occurs and consequently bremsstrahlung gamma rays are emitted. Since event rates of the gamma rays are proportional to the number of scattering centers, the rates show a number of trapped ions in the bunch train. We also have tried to detect the gamma rays with a Cherenkov counter.

2. Bunch-by-Bunch Beam Diagnostics

In order to pick out the synchrotron radiation pulse only from a particular bunch in a bunch train, we have developed a high-speed light shutter that can be opened or closed within 2 ns (corresponding to a bunch spacing in the KEK-PF)[3]. Operation of the shutter is synchronized with a revolution of bunches by using an RF signal as a source of a trigger for shutter operation. We operate the shutter with a repetition rate of f_{sh} = 534 kHz which corresponds to one third of the revolution frequency because of a repetition limit of a high voltage pulser which drives the shutter system.

The light through the shutter is focused on a vertical slit and detected by a photomultiplier tube (PMT, Hamamatsu Photonics, H6779). Vertical motion of the beam can be detected as amplitude variation of the output signal of the PMT because intensity of the light through the slit varies in response to the movement of the image of the beam on the slit. The change in the amplitude of the signal selected by the shutter is analyzed with a spectrum analyzer (ADVANTEST, R3361D).

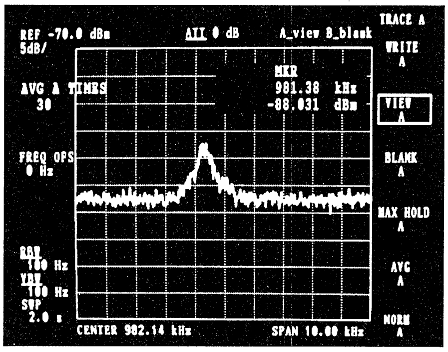

Fig.1 Betatron sideband of the 5th bunch in a bunch train.

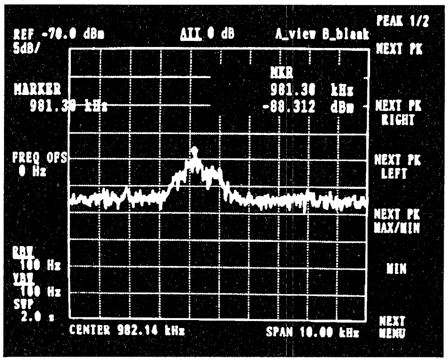

Fig.2 Betatron sideband of the 10th bunch in a bunch train.

Because the light shutter has an extinction ratio of 300 at the most, therefore, the contribution of leaked light pulses through the shutter during the close timing is not negligible, the spectral lines corresponding to the betatron oscillation 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 the contribution of the other bunches by detecting the betatron sidebands of a frequency that is not revolution-frequency-harmonic but shutter-frequency-harmonic.

3.Gamma Ray Counting

The bremsstrahlung gamma rays are emitted by a process of the scattering between the electron beam and the residual gas molecules or trapped ions, and the event rates are proportional to a number of the molecules and the ions. We have been developing gamma rays counting system with a Cherenkov counter. A PMT (Hamamatsu Photonics, R2083) is used because of its excellent time response (rise time of 0.7 ns). The Cherenkov detector is placed on a tangential direction of a beam orbit at a distance of 2.5m from the end of bending magnet, and shielded by lead blocks to exclude background events. A threshold level of a discriminator is adjusted to count only the bremsstrahlung gamma rays.

4.Results

4.1 Bunch-by-Bunch Detection of Betatron Oscillation

Betatron oscillations of bunches are detected in the multi-bunch mode (successive 280 bunches followed by 32 empty buckets) using the bunch-by-bunch beam diagnostic system. In order to detect the vertical instability, field strength of the octupole magnets was set at 33% of the normal value for routine operation. We also tried to detect the dependence of the instability on vacuum pressure by turning on/off the distribution ion pumps (DIPs). The average vacuum pressure around the ring changed from 4.2×10^{-8} Pa to 5.8×10^{-8} Pa when the DIPs were turned off. Figure 1 and 2 show the vertical betatron sidebands around 982 kHz (=448 kHz ($f_{\beta y}$) + 534 kHz (f_{sh})) of the 5th and 10th bunch with the DIPs OFF, respectively. Although the currents of these two bunches are much the same, not only these spectral powers but also the width are quite different. Spectral powers (the area of the spectrum) of bunches with the DIPs OFF at the total beam current of 350 mA are plotted in Fig.3-a and 3-b. Error bars represent ambiguity of the estimation of the background noise level. Because spectral powers depend on the bunch current, we also measured currents of individual bunches and normalized the spectral areas by them. The spectral power of bunches at the head of the bunch train are smaller than those at the tail as seen in these figures.

The spectral powers of leading 10 bunches with the DIPs ON are plotted in Fig.4. The total beam current was 365 mA with the DIPs ON, and other experimental conditions were the same as those with the DIPs OFF, except that the beam current was slightly large. That the instability grows along the bunch train and the growth rate is different with the DIPs ON/OFF suggests the close relation between the instability and ion related phenomena such as the FBII.

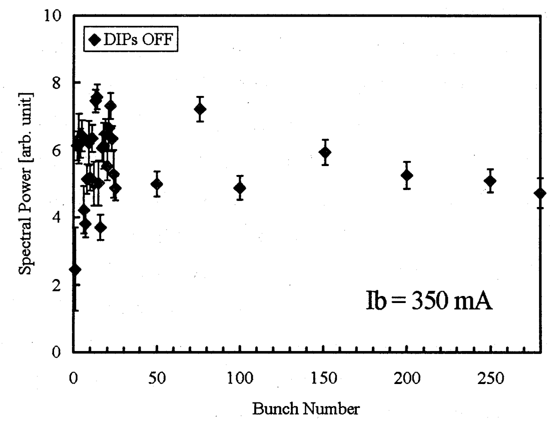

Fig.3-a Spectral powers of bunches with the DIPs OFF.

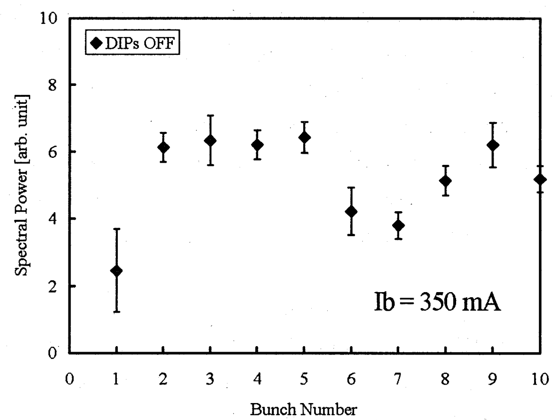

Fig.3-b Spectral powers of leading 10 bunches in Fig. 3-a.

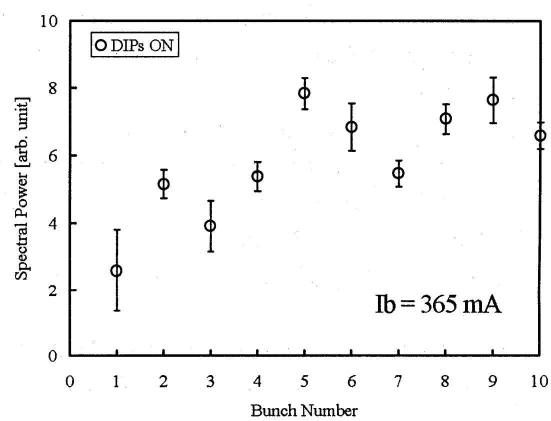

Fig.4 Spectral powers of leading 10 bunches with the DIPs ON.

4.2 Suppression of Vertical Instability

Because trapped ions oscillate stably around the beam, the ions could be cleared if the beam is excited with the ion frequency. We have also tried to clear the trapped ions by exciting the beam with an RF knockout (RFKO) method. Field strength of the octupole magnets was set at 33% of the normal value and the DIPs were turned on during the experiment. The beam signal from a BPM was analyzed with a spectrum analyzer (Hewlett Packard, 8562A). The vertical betatron sideband (= 448 kHz ($f_{\beta y}$) + 500.09 MHz (f_{RF})) without the RFKO is shown in Fig.5.

Figure 6 shows the spectrum when the beam was kicked diagonally (Two diagonal electrodes of the kicker with 4 striplines were excited.) with the frequency of f_{KO} = 748 kHz. The power of the vertical betatron sideband was suppressed about 3 dB, however, a small horizontal betatron sideband (= 640 kHz ($f_{\beta x}$) + 500.09 MHz (f_{RF}), corresponding to the middle peak in the figure.) was excited. We have also detected the bremsstrahlung gamma rays with and without the RFKO. Counting rates of the gamma rays were around 150 Hz with the RFKO and 210 Hz without the RFKO. The beam lifetime was increased from 40 hour to 48 hour by exciting the beam with the frequency of f_{KO}. Figure 7 shows the result when the RFKO power was set at 2 dB higher than that in Fig.6. The vertical instability was almost completely suppressed, and the counting rates of the gamma rays were around 190 Hz, which was higher than those at lower excitation power.

Because motions of the beam do not have the resonant frequency corresponding to f_{KO}, the result suggests that the trapped ions were cleared with excitation of the beam.

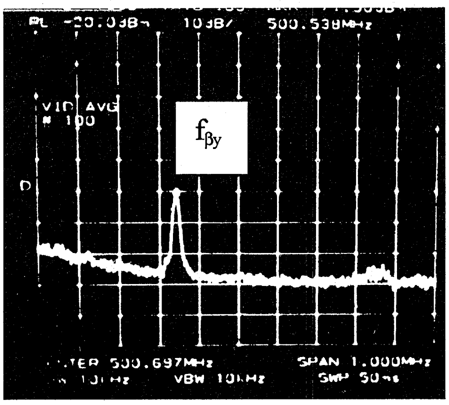

Fig.5 Vertical betatron sideband without RFKO. Center frequency = 500.697 MHz, Span = 1 MHz, Reference level = -20 dBm, 10dB/div.

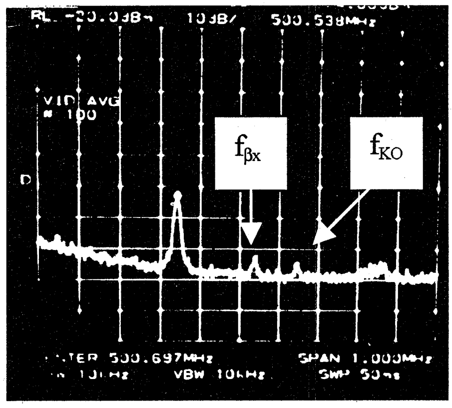

Fig.6 Betatron sidebands with RFKO.

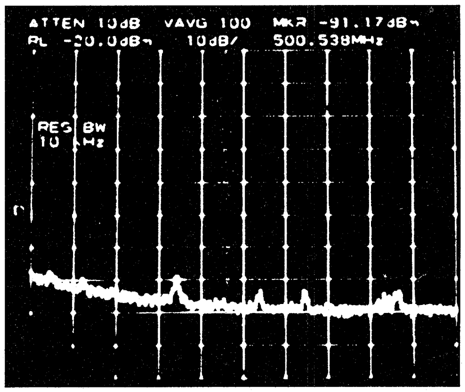

Fig.7 Betatron sidebands with RFKO that power is higher than above.

5.Summary

In the KEK-PF, a vertical instability has been observed in a multi-bunch mode. A bunch-by-bunch detection system of vertical betatron oscillation has been installed and the dependence of the oscillation amplitudes on the bunch position in the bunch train has been measured. The experiments show that the instability grows along the bunch train and depends on the vacuum condition.

When the beam was kicked diagonally at the ion frequency the vertical instability was suppressed and the counting rates of the bremsstrahlung gamma rays decreased. Because the kicked frequency did not correspond to the beam spectra, the experiment suggests that the trapped ions were cleared.

Further improvements are necessary for the bunch-by-bunch detection system of the betatron oscillations of a particular bunch, especially improvement of the sensitivity is essential. We are now developing a bunch-by-bunch bremsstrahlung gamma rays counting system with the Cherenkov counter, which would give information of trapped ions. Further theoretical approaches are also necessary for quantitative verification of those phenomena.

References

[1] T. O. Raubenheimer and F. Zimmermann, “Fast beam-ion instability. I. Linear theory and simulations”, Phys. Rev. E **52**, 5487 (1995).

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[3] A. Mochihashi, T. Kasuga, T. Obina, M. Tobiyama, “Bunch by Bunch Beam Diagnostics Using a Fast Light Shutter”, Proc. of the Asian Particle Accelerator Conference, Tsukuba (1998).