OBSERVATION OF VERTICAL INSTABILITY IN UVSOR ELECTRON STORAGE RING

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Abstract

An ion-related vertical instability of the UVSOR electron storage ring was observed in a multibunch mode with empty buckets (a bunch gap). In contrast to a shorter bunch train, it was clearly seen that vertical tune had step-like changes with decrease of a beam current in a longer train. The step-like change in the tune seems to be caused by sudden change in condition of stability of trapped ions. Change in amplitude of the vertical betatron oscillation along a bunch train was also observed with a bunch-by-bunch beam diagnostic system. The structure of the amplitude seems to have relation to modulation of the ion density along the train.

1 INTRODUCTION

In the UVSOR electron storage ring, a vertical instability has been observed in a multibunch mode, in which a series of bunches (a bunch train) followed by a series of empty buckets (a bunch gap) is stored in the ring. The instability is very weak enough to neglect influence on users of synchrotron radiation, however, it is observed by pickup electrodes with spectrum analyzer. The instability depends on the condition of the vacuum in the ring; namely, the instability is clearly observed under poor vacuum conditions and becomes weak in good vacuum conditions. The dependence implies that the phenomenon is ion-related, however, the origin of the phenomenon has not been sufficiently understood yet. To verify the origin of the instability, we have observed dependence of a vertical betatron oscillation frequency (vertical tune) on a beam current in the multibunch mode. Experiments of bunch-by-bunch beam diagnostics that can detect betatron oscillations of individual bunches in the bunch train have also been performed.

2 EXPERIMENTS

2.1 Change in Vertical Tune on Beam Current

We have observed dependence of the vertical tune on the beam current in two kinds of multibunch modes with a pickup electrode and a spectrum analyzer (Rhode & Schwartz, FSEB30). Because a vertical spontaneous oscillation has been observed in a multibunch mode in which a series of 12 bunches (a bunch train) followed by a series of 4 empty buckets (a bunch gap) are stored, we measured the vertical tune by observing the spontaneous oscillation in the multibunch mode, not using the RF-KO method. In the experiment, the vertical tune was measured above

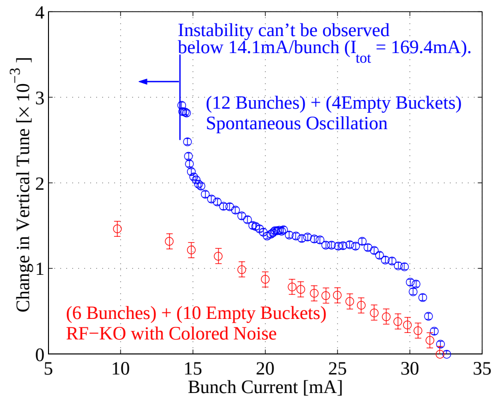

Figure 1: Dependence of the vertical tune on the beam current in two kind of multibunch modes. Blue and red circles correspond to the results for the 12 and 6 bunches, respectively.

169.4mA because the spontaneous oscillation was not able to be observed below the beam current. Blue circles in fig. 1 show change in the vertical tunes with decrease of the beam current in the multibunch mode. The ordinate of the figure corresponds to the measured tune shifts from the tune of the highest beam current in the experiment. To emphasize phenomena in the multibunch condition, we subtracted current dependence of the vertical tune caused by a wake field that causes head-tail instability[1] and a tune shift caused by the space charge effect[1]. From an analysis of the longitudinal impedance from bunch lengthening in the UVSOR[2] and a theoretical value of the tune shift caused by the space charge effect, we have concluded that the bunch current dependence of the vertical tune caused by these two effects is -3.3×10^{-5}/mA. As seen in the figure, the change in the tune due to the change in the beam current remains after the subtraction, and especially, it is clearly seen that the tune has step-like changes around the bunch current of 15 and 30 mA. Such sudden changes of the vertical tunes around these bunch currents were always observed in a series of the experiments.

We have also observed the dependence in other multibunch mode in which a series of 6 bunches followed by a series of 10 empty buckets are stored. Because no spontaneous oscillation was observed with the shorter bunch train, we measured the vertical tune by using the RF-KO method with a colored noise source. Red circles in the fig. 1 show change in the vertical tunes with the decrease of the beam current for the shorter bunch train. As seen in the figure, the tune doesn't have the sudden changes in contrast to the case of the 12 bunches.

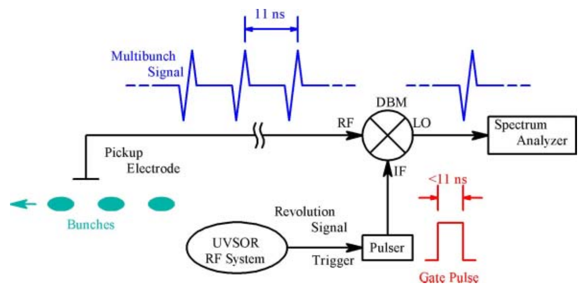

Figure 2: Block diagram of bunch-by-bunch diagnostic system using an electronic analog switch.

2.2 *Bunch-by-Bunch Beam Diagnostics*

A block diagram of a bunch-by-bunch beam diagnostic system with an electronic analog switch is shown in fig. 2. The multibunch signal from a pickup electrode and a pulse train which is synchronized to the revolution of bunches are multiplied by a double balanced mixer (DBM, R&K, M21CC). Because the pulse train has a width of shorter than the bunch spacing time (11ns in the UVSOR), we can pick out one bunch signal from the multibunch signal by adjusting the timing of the pulse train. We have observed frequency spectra of the picked out signal with the spectrum analyzer. Spectral power of an revolution frequency (we observed the revolution frequency ($f_{rev} = 5.6$ MHz) which is an upper sideband of an RF frequency ($f_{RF} = 90.1$ MHz)) when one particular bunch in the bunch train is selected is about 100 times as large as the spectral power when one empty bucket is selected, therefore contribution of leaked pulses through the analog switch during the gate-off time is about 1% to the selected pulse.

By using the analog switch, we have observed the vertical spontaneous oscillation for individual bunches in a multibunch mode in which a series of 12 bunches followed by a series of 4 empty buckets are stored. In the experiment we have observed the spectrum of the revolution frequency ($f_{RF} + f_{rev} = 95.7$ MHz) and its vertical betatron upper sideband ($f_{RF} + f_{rev} + f_y = 98.2$ MHz) simultaneously. Figure 3 and 4 show the frequency spectra of the revolution frequency and a vertical betatron oscillation frequency for the 1st and the 6th bunch in the bunch train. As seen these figures, it is clearly seen that the spectral power of the vertical betatron sidebands for these two bunches is very different although the power of the carrier frequency, that depends on the intensity of the selected bunch, is almost the same. Moreover, the frequency peak of the 6th bunch in the fig. 4 seems to have higher frequency than the 1st bunch. To analyze amplitude of the betatron oscillation we estimated the peak power of the betatron oscillation spectrum P_{fy} of the individual bunches. Because the peak power depends not only on the amplitude of the oscillation of the bunch but also on the bunch intensity, it is necessary to normalize the power with the intensity. To estimate the intensity of the individual bunches we analysed the peak power P_{car} of the revolution spectrum $f_{RF} + f_{rev}$ that is a carrier frequency of the betatron sideband. After the estimation we normalized P_{fy} with P_{car} and determine $\sqrt{\frac{P_{fy}}{P_{car}}}$ as the amplitude. Figure 5 shows the amplitudes as a function of the bunch position in the train for the same multibunch mode but different total beam currents. The amplitude of the bunch that has the largest amplitude is defined as unity in the figure. As seen in the figure, the amplitudes are large in the head and the tail of the train and small in the middle of the train. We have also analyzed the vertical tune for the individual bunches for the experiments. Figure 6 shows change in the tunes along the bunch train for the same conditions as in the fig. 5. Some structure of the vertical tunes along the bunch train can hardly be seen clearly because of error bars that come from a S/N ratio of the frequency spectrum and a resolution of the spectrum analyzer.

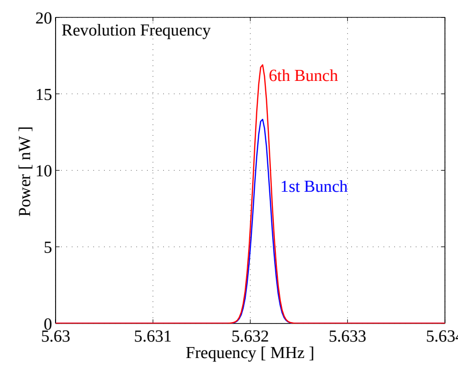

Figure 3: The frequency spectra of the revolution frequency of the 1st and the 6th bunch in the bunch train.

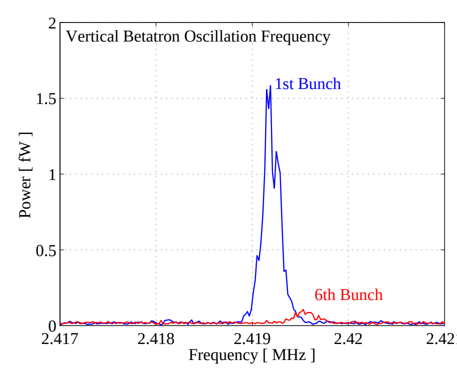

Figure 4: The frequency spectra of the vertical betatron frequency of the 1st and the 6th bunch in the bunch train.

3 DISCUSSION AND SUMMARY

3.1 *Change in Vertical Tune on Beam Current*

The step-like changes in the vertical tune on the beam current in a multibunch mode with 12 bunches in fig. 1

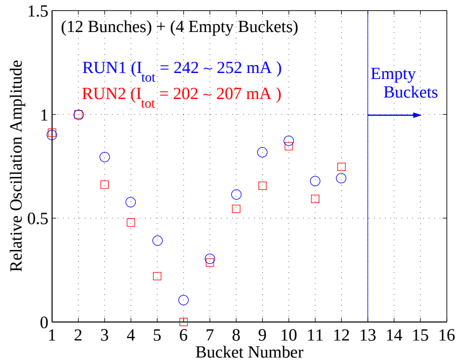

Figure 5: The oscillation amplitudes of individual bunches along a bunch train with 12 bunches.

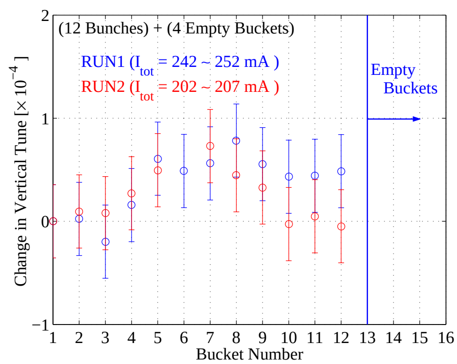

Figure 6: The change in the tunes along a 12-bunch train.

seem to be explained by an ion related effect[3][4]. According to the classical theory of the ion trapping, an electric field by the ions trapped by the electron beam could increase the tune, and the change in the tune is proportional to the ion density. Because a trapping condition of the ions depends not only on configuration of the bunch train but also on a beam size, the condition differs at different positions in the ring under the same configuration of the bunch train. We calculated a ratio of the total area of regions where ions are trapped to the area of the whole UVSOR-ring in two configurations of the bunch train that is the same in the experiments in fig. 1. Figure 7 shows the ratios of the two configurations of the bunch train. In the calculation[5], ion species of CO^+ and CO^{2+} are assumed because CO is the main component of the residual gas molecules in the UVSOR-ring. As seen in these figures, the ratio has sudden changes around the bunch current of 15 mA in CO^+ and 30 mA in CO^{2+} in 12-bunch train; on the other hand the step-like changes in the vertical tune can be seen around the same bunch currents in the experiments with 12-bunch train. Therefore, it is supposed that the change in the tune observed in the multibunch mode with 12-bunch train is caused by the sudden change in the trapping condition of the residual gas ions. On the other hand, such sudden change in the tune was not observed in 6-bunch train although a step-like change around the bunch current of 25 mA in CO^{2+} is predicted in the calculation. We speculate that this would be because that in shorter bunch train the ion density around the beam orbit would be lower than in longer bunch train due to a bunch gap although the ions are trapped stably. Not only more experiments for the phenomenon but also computer simulation are needed to verify the cause of the disagreement. Experiments for other configuration of the bunch train are needed, too.

3.2 Bunch-by-Bunch Beam Diagnostics

The structure of the oscillation amplitude along the bunch train in fig. 5 seems to have relation to modulation of the ion density along the train discussed in [5][6]. In the calculation of the modulation of the density of CO^+ and CO^{2+} ions for the experiments in fig. 5, it is predicted that the density becomes higher in the head and the tail of the bunch train and lower in the middle of the train. This suggests that the beam in the head and the tail of the train would be strongly affected by the ion-related effect compared to that in the middle of the train. More precise measurements, especially for the tune measurements, are needed to quantitative discussion for this phenomenon.

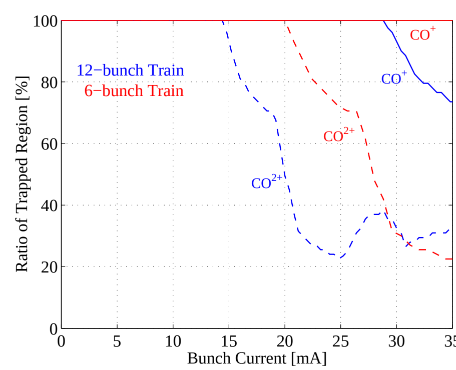

Figure 7: The ratios of the area of the regions where the CO^+ and CO^{2+} ions are trapped to the area of the whole ring for 12- and 6-bunch trains.

4 REFERENCES

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