ION-RELATED PHENOMENON IN UVSOR ELECTRON STORAGE RING

A. Mochihashi, M. Katoh, M. Hosaka, K. Hayashi, J. Yamazaki,
Institute for Molecular Science, 38 Nishigo-Naka Myodaiji, Okazaki 444-8585, Japan

Abstract

A vertical tune shift depending on a beam current was observed in the UVSOR electron storage ring. The vertical tune increased as decrease in the beam current, and the slope of the tune shift depended on the condition of the vacuum in the ring. Such change in the vertical tune was explained by change in stability condition of trapped ions on the beam current. The experimental results in multibunch condition are discussed with computer simulation based on a theoretical model.

INTRODUCTION

In the UVSOR electron storage ring, a coherent oscillation of electron bunches in vertical direction has been observed in a multibunch operation, 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 oscillation amplitude is small enough to neglect influence on users experiments of the synchrotron radiation, however, it can be observed by pickup electrodes with a spectrum analyzer. The oscillation depends on the condition of the vacuum in the ring; namely, the oscillation is clearly observed under poor vacuum conditions and becomes weak in good vacuum conditions. The dependence implies that the phenomenon is caused by ion-trapping[1, 2]. We have measured the betatron tune under different conditions of the vacuum, and found that the vertical betatron tune (vertical tune) increases as the pressure increases. We have also observed change in the vertical tune on the beam current, and found that the vertical tune gradually increases as the beam current decreases. From these experimental results, we have discussed that such change in the vertical tune on the beam current is also ion-related; namely, a neutralization factor, that is defined as the ratio of the ion density in the beam to the circulating electron density, increases as decrease in the beam current. We have tried to discuss the dependence of the neutralization factor on the beam current with tracking calculation for the ions. The changes in the vertical tune on the beam current from the tracking calculations are estimated and compared with the experimental results.

OBSERVATION

Change in Vacuum Condition

We observed dependence of the vertical tune on the vacuum conditions in the UVSOR-ring. We changed the vacuum conditions by turning off distributed ion pumps (DIPs) and sputtering ion pumps (IPs) and measured the vertical tune. In a series of the experiments, we performed the measurement with a multibunch condition in which a series of 12 bunches followed by 4 empty buckets are stored in the ring. To measure the vertical tune, we used the RF-KO method with a band-limited noise source (colored noise source) and analyzed beam signals from a pickup electrode by a spectrum analyzer (Rhode & Schwartz, FSEB30). Figure 1 shows the setup of the tune measurement. We used the colored noise source which generates the noise signal whose center frequency is $f_{noise} = 850$ kHz and frequency spread is $\Delta f = \pm 120$ kHz. To adjust the noise band to the betatron frequency f_β we performed a method of frequency modulation by using a double balanced mixer (R&K, M21CC). By adjusting frequency of the signal from the signal generator (Hewlett Packard, 8657A) to $f_{rev} + f_\beta - f_{noise}$ and mixing it with the signal from the noise source we generated the colored noise whose center frequency is $f_{rev} + f_\beta$ with the frequency spread of $\pm\Delta f$. Figure 2 shows beam spectra that correspond to the vertical betatron sidebands in response to the colored noise signal that includes frequency-component of the vertical tune. A blue peak in Fig. 2 corresponds to the beam spectrum under the usual vacuum conditions (at the averaged pressure of $P_{av} = 48$ nPa and the total beam current of $I_{total} = 45.5$ mA) and a red one corresponds to the spectrum when all the DIPs and IPs were turned off (at $P_{av} = 110$ nPa and $I_{total} = 41.0$ mA), respectively. Although the beam currents for these two beam spectra were almost the same, those peak frequencies are different, as clearly seen in the figure. In order to determine the tunes, we calculated the first-order moments of the spectra. Figure 3 shows that the tunes changed when the averaged vacuum pressure was intentionally changed. From Fig. 3, it is clearly seen that the vertical tune increases with increase in the vacuum pressure, especially when all the DIPs and several IPs were turned off (14 IPs are settled in the ring, and 4 IPs were switched off in the experiment).

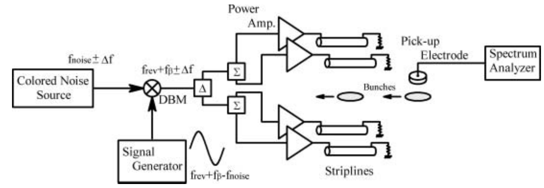

Figure 1: Schematic diagram of the tune measurement system.

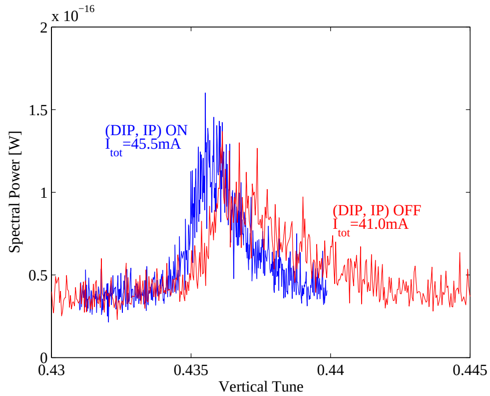

Figure 2: The frequency spectra of the vertical tune when the normal vacuum condition (blue), and both the DIPs and IPs were turned off (red).

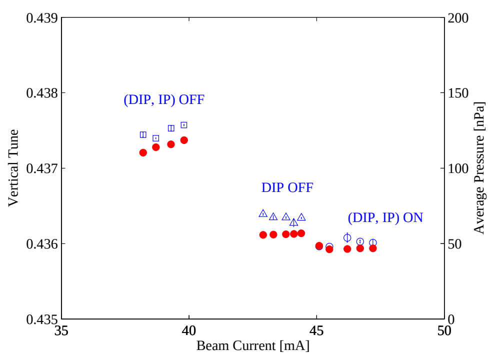

Figure 3: The change in the vertical tune and the averaged pressure when the ion pumps were intentionally turned off. Empty and filled marks correspond to the change in the vertical tune and the average pressure, respectively.

Change in Beam Current

We observed dependence of the vertical tune on the beam current in the multibunch condition (12 bunches + 4 empty buckets) without changing the vacuum conditions intentionally. Figure 4 shows the measured tune shifts from the tunes of the highest beam current in each experiment. Red and blue circles in Fig. 4 represent the results in the multibunch condition but in different vacuum condition. Blue triangles in Fig. 4 represent the results for the horizontal tune in Exp. 2. For comparison measured tune shift in single bunch operation is shown in Fig. 4. Figure 5 shows the change in the averaged pressure in the ring during each experiment. The pressure in the Exp. 2 of the 12-bunch train was higher than in the Exp. 1; this is because we installed a new vacuum chamber in a beamline between these two experiments. As seen in Fig. 4 and 5 the dependence of the tune on the beam current tends to become larger when the vacuum pressure is higher, as seen in the Exp. 1 and 2 in Fig. 4 and 5. On the other hand, the dependence in the singlebunch condition was much smaller than in the multibunch conditions although the bunch current in the singlebunch and the multibunch conditions were the same. The fact that the change in the horizontal tune in Exp. 2 is very small compared to that in the vertical tune also indicates that the change in the vertical tune in the multibunch condition is caused by the ion-related phenomenon.

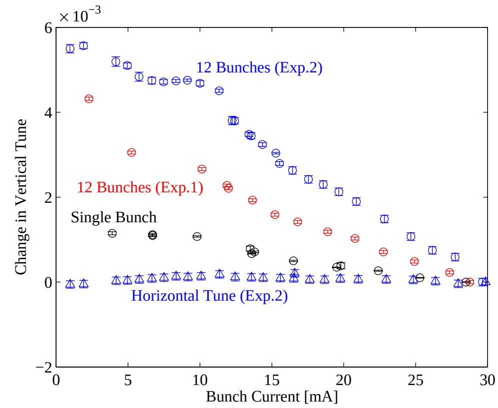

Figure 4: Dependence of the vertical tune on the beam current in the multibunch condition but in different vacuum condition, and the singlebunch condition. Blue triangles correspond to the change in the horizontal tune in Exp. 2.

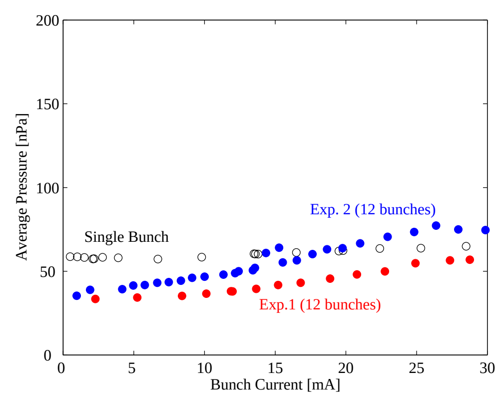

Figure 5: The average vacuum pressure for each experiment in Fig. 4.

DISCUSSION

Vertical tune shift $\Delta\nu_y$ due to the trapped ions is written as[2]

$$\Delta\nu_y = \frac{r_e E_0}{2\pi E}\lambda_e \eta \int_C \frac{\beta_y(s)}{\sigma_y(s)\,(\sigma_x(s)+\sigma_y(s))} ds, \qquad (1)$$

where r_e the classical electron radius, E_0 the rest mass of the electron, E the total energy of the electron, λ_e the averaged line density of the electrons, η the neutralization factor, $\beta_y(s)$ the vertical betatron function and $\sigma_{x,y}(s)$ the horizontal/vertical beam size, respectively. In Eq. (1) the tune shift is proportional to the line density of the electron λ_e; namely, the tune decreases as the beam current decreases.

For the Exp. 1 and 2 in Fig. 4, however, the vertical tune increases with decrease in the beam current just contrary to the prospect from Eq. (1). One of causes of the disagreement is that the neutralization factor η might strongly depend on the beam current; namely, in Fig. 4 the neutralization factor could increase largely as the beam current decreases. We have estimated theoretically the dependence of the neutralization factor on the beam current by evaluating a capture rate α of the ions as a ratio of the number of the trapped ions to total number of the created ions. To evaluate the capture rate, we have performed a tracking calculation of motion of the individual ions that are affected by the attractive force of the continuous passage of the bunch train. In the calculation, we assume CO^+ ions because CO is one of the main component of residual gas in the UVSOR-ring. Figure 6 shows with contour map the capture rate for different bunch current at each position in one superperiod of the UVSOR-ring. As seen in the figure, the capture rates gradually increase as the bunch current decreases in all the positions and saturate below 10mA/bunch.

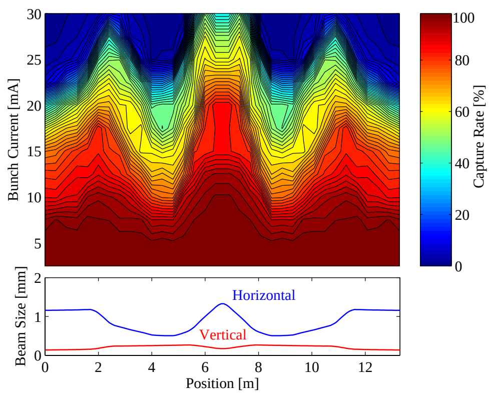

Figure 6: The capture rate for different bunch current in the multibunch condition at each position in one superperiod of the UVSOR-ring.

With the capture rate α, the equilibrium neutralization factor η is written as $\eta = \frac{D_0}{D_e}\alpha$, where D_0 and D_e are the CO gas density and the electron density in the beam, respectively. With the measured pressure in Fig. 5 and the capture rate that is averaged over the whole UVSOR-ring, we have estimated the dependence of the vertical tune on the beam current for Exp. 1 and Exp. 2 in Fig. 4 from Eq. (1). The experimental results and the theoretical calculations are shown in Fig. 7. To discuss the ion-related effect clearly, we have subtracted the change in the vertical tune on the beam current in the single bunch condition from the experimental results of the multibunch condition; it is supposed that the change in the vertical tune in the single bunch condition is mainly caused by the wake field that could cause the strong head-tail instability[3]. On the other hand, to estimate the theoretical value of the change in the vertical tune, we have estimated partial pressure of the CO gas from the average vacuum pressure in Fig. 5 by using the quadrupole mass filter settled in the UVSOR-ring. In the theoretical calculation in Fig. 7, the partial pressure of the CO gas is used as the gas density D_0 in Eq. (1). As seen in the figure, the results of the tracking calculations reproduce qualitatively the experiments, namely, the vertical tunes gradually increase with decrease in the beam current, and moreover, the magnitude of the change in the vertical tune agrees quantitatively with the experimental results in $\Delta\nu_y \sim 10^{-3}$. In the region where the bunch current is lower than 15mA, the agreement between the experiments and the tracking becomes as not good as in the higher bunch current. We have a speculation that this disagreement comes from the effect of other ions that have smaller A/Z ratio than CO^+; the critical mass[2] in the multibunch condition becomes smaller than $A/Z = 16$ below the bunch current of around 15mA. It is supposed that the main candidates of such ions come from dissociation of CO^+ ions because of the multiple ionization process; for example, C^+ and O^+. In Eq. (1) and the calculation in Fig. 7 it is assumed that spatial distribution of the ion cloud is identical with the beam size; however, in general, the size of the ion cloud could differ in different beam current. To consider the change in the ion cloud size and the ion density on the beam current is also the next subject.

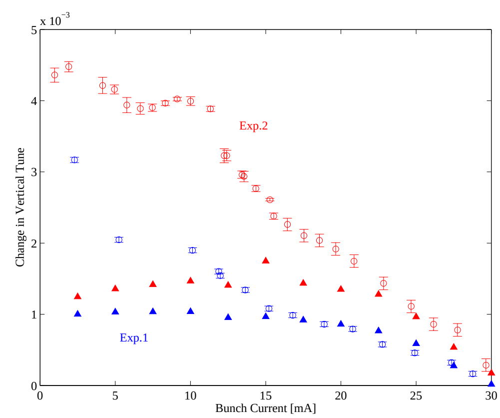

Figure 7: The experimental results and tracking calculations of the change in the vertical tunes. Empty and filled circles correspond to the experiments and the tracking caculations, respectively.

REFERENCES

[1] R. D. Kohaupt, DESY Interner Bericht No. H1-71/2, 1971 (unpublished).

[2] Y. Baconnier, G. Brianti, CERN Internal Report No. CERN/SPS/80-2 (DI), 1980 (unpublished).

[3] A. Chao, *Physics of Collective Beam Instabilities in High Energy Accelerators,*, (Wiley-Interscience Publications, New York, 1993).

[4] P. A. Readhead, Can. J. Phys. **47**, 2449 (1969).