ION-RELATED PHENOMENON IN UVSOR/UVSOR-II ELECTRON STORAGE RING

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Abstract

A vertical betatron tune shift depending on beam current under multibunch condition was observed in the UVSOR storage ring. Vertical tune increased as beam current decreased, and the slope of the tune shift depended on the condition of the vacuum in the ring. Such a change in vertical tune was explained by a change in the number of trapped ions, that arises from the change in the stability condition of trapped ions with the beam current. Based on a theoretical model that gives density of the trapped ions the experimental results were discussed via analytic and tracking calculations with the effect not only of the gas molecules but also of the dissociated ions. Precise tune measurement has been also performed in the UVSOR-II storage ring in single-bunch condition. A design of vacuum pressure measurement system via detecting residual gas fluorescence is also mentioned.

INTRODUCTION

In UVSOR electron storage ring, we have measured betatron tune under different conditions of vacuum, and found that vertical tune increases with pressure. We have also observed a change in vertical tune with beam current, and found that vertical tune gradually increases as beam current decreases[1]. From these experimental results, we have discussed that such a change in vertical tune with beam current is ion-related; namely, a neutralization factor defined as a ratio of the ion density in the beam to circulating electron density increases as beam current decreases. We have used a new model[1] that shows the dependence of the neutralization factor by introducing a capture rate of the generated ions that is defined as the ratio of the number of the trapped ions to total number of the generated ions. To estimate the capture rate, we have used both an analytic method based on the linearized classical theory of ion trapping[3, 4] and tracking calculation for the ions. The change in neutralization factor with beam current is estimated both by the analytic method and by tracking calculations, and change in the vertical tune with beam current is also estimated and compared with the experimental results. In quest of the ion-related phenomenon, precise tune measurement has been also performed in upgraded UVSOR storage ring (UVSOR-II)[2] in single-bunch condition. Dependence of the betatron tune on the beam current has noteworthy structure especially when the beam current is very small; tracking calculation based on the model gives a speculation that the structure is also ion-related. Precise measurement of vacuum pressure on the beam orbit, which is quite difficult on real accelerators, is a key issue not only of the ion-related phenomenon but also basic beam diagnostic and lifetime problem of the electron storage ring. Development of vacuum pressure measurement system via detecting residual gas fluorescence is now under way.

The basic parameters of UVSOR and UVSOR-II storage ring for the experiments of the ion-related phenomenon are summarized in Table 1.

Table 1: Basic parameters of UVSOR/UVSOR-II ring for experiments of ion-related phenomenon.

Parameters	UVSOR	UVSOR-II
Beam energy	750 MeV	750 MeV
Ring circumference	53.2 m	53.2 m
RF frequency	90.1 MHz	90.1 MHz
Harmonic number	16	16
Betatron tune	3.16/1.43	3.75/3.20
Beam emittance	165 nm-rad	60 nm-rad

MULTIBUNCH CONDITION IN UVSOR

We observed the dependence of vertical tune on the vacuum condition 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 by the RF-KO method with colored noise signal[1]. Beam signal was detected by a button-type pickup electrode and the beam spectrum was observed by a spectrum analyzer. We were able to perform precise tune measurement that had typical error of $\sim 10^{-4}$ by analyzing the beam spectrum excited by the noise RF-KO. In a series of experiments, we performed the measurement under a multibunch condition in which a series of 12 bunches followed by 4 empty buckets were stored in the ring. Figures 1(a) and 1(b) show that the tunes changed when the averaged vacuum pressure was changed. We also observed the dependence of the vertical tune on beam current under the multibunch condition in different two vacuum conditions: at a low vacuum pressure (Exp.1) and at a high vacuum pressure (Exp.2). Figure 2 shows the change in average pressure in the ring during each experiment. Figure 3 shows change in betatron tunes in multibunch and single-bunch condition on the beam current. As seen in

Fig. 3, under the multibunch conditions the dependence of vertical tune on beam current tends to become larger with increasing the vacuum pressure. The slope in the single-bunch condition seems to come from a wake field that causes strong head-tail instability[5]; from the experiment the slope is estimated to be $\sim -5 \times 10^{-5}$/mA that is small campared to the slope in the multibunch conditon. The weak dependence in the single-bunch condition and that of horizontal tune in the multibunch condition implies the change in the vertical tune is caused by ion-trapping phenomenon. According to the ion-trapping theory[3, 4],

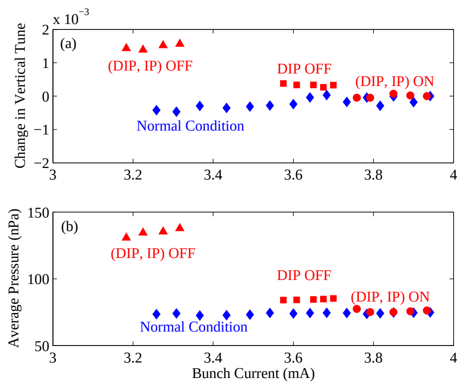

Figure 1: (Upper) (a) Change in the vertical tune when vacuum pumps were intentionally turned off (red marks) and when the normal vacuum condition (blue marks). (Lower) (b) Change in average pressure when the pumps were turned off.

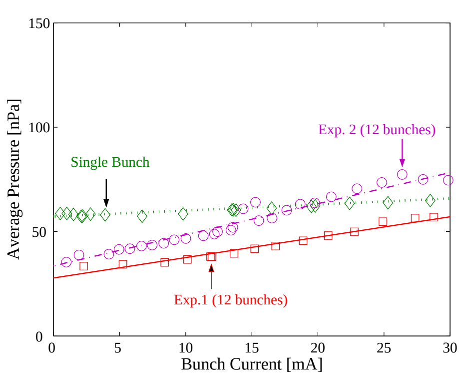

Figure 2: Averaged vacuum pressure for Exp.1, Exp.2 and single-bunch condition.

vertical tune shift $\Delta\nu_y$ due to the ions is written as

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

where r_e, E_0, E are the classical electron radius, rest mass of the electron and total energy of the electron, β_y and $\sigma_{x,y}$ are vertical betatron function and horizontal/vertical beam size, λ_e and η are the line density of the electron in the ring and the neutralization factor of the trapped ions. In Eq. (1)

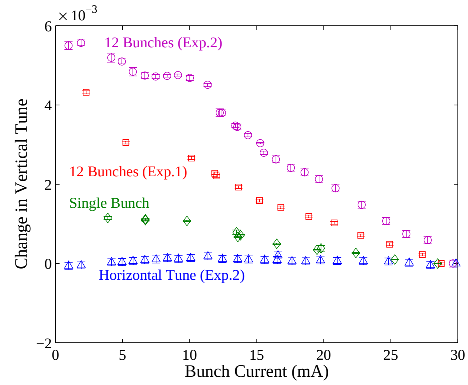

Figure 3: Dependence of tune on beam current in vacuum conditions in Fig. 2.

an approximation that the transverse size of trapped ion-cloud is equal to the transverse beam size is adopted. From Eq. (1), vertical tune is proportional to the line density of the electron. Thus, it decreases as beam current decreases. However, experiments say that the vertical tune increases with the beam current decreases. This contradiction suggests that the neutralization factor of trapped ions increases rapidly as beam current decreases; namely, the number of trapped ions increases as beam current decreases. We have estimated theoretically the dependence of neutralization factor on beam current by evaluating capture rate of ions[1] both by an analytic method based on the classical theory of ion trapping[3, 4] and by tracking method. In the calculation we assume CO^+ as a main ion species because from the ion-trapping theory it is supposed that CO^+ ions are mainly trapped by the beam in the beam current region shown in Fig. 3[1]. In the calculation we considered not only effects of CO^+ ions but also effects from C^+ and O^+ which come from multiple ionization of CO^+. We also considered change in partial pressure of CO gas on the beam current during the experiment. Figure 4(a) and 4(b) show results of the tracking and analytic calculations for Exp.1 and 2 with experimental results. In the figures, the slope of the vertical tune in the single-bunch condition is subtracted from the multibunch data. The tracking calculations considering CO^+, C^+ and O^+ ions agree with the experiments qualitatively. However, they overestimate the change in vertical tune at a bunch current of less than $\sim$15mA. It is supposed that the overestimation comes from the multiple ionization cross section of CO assumed in the calculation[1], that is difficult to estimate properly. The analytic calculations also tend to overestimate the change in vertical tune; this is because effect of dynamic aperture of the ions is not considered in the analytic calculation but is only considered the stability condition of the ions.

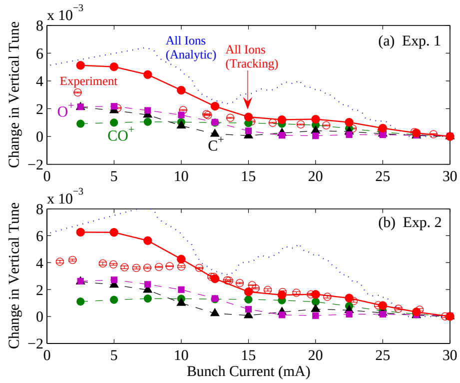

Figure 4: Experimental results (red empty circles), tracking results(filled marks) and analytic calculations (blue broken curve) of change in vertical tune for (upper) (a) Exp.1 and (lower) (b) Exp.2.

SINGLE-BUNCH CONDITION IN UVSOR-II

Precise tune measurement has been also performed in the UVSOR-II storage ring in single-bunch condition. Figure 5(a) shows the measured vertical tune shifts from the maximum tune value in each measurement. On the whole, the vertical tune tends to decrease when the beam current increases; this slope seems to come from a wake field that causes strong head-tail instability[5]. Overlapping with the slope, however, there seems to be some structure in smaller beam current region; around 3mA there seems to be a broad peak and in very small current ($<$ 1mA) there seems to be also another steep peak. We have estimated numerically change in vertical tune on the beam current caused by the ion-related phenomenon in single-bunch condition in UVSOR-II. In the estimation, we have calculated both change in the capture rate of the ions and the change in transverse ion-cloud size on the beam current by tracking the ion motion; from the capture rate and the transverse ion-cloud size, we have estimated the vertical tune shift with the linearized ion-trapping theory[3, 4]. The caculations are shown in Fig. 5(b). In the calculations we have assumed H_2^+ and CO^+ as ion species, and the ratio of the partial pressure is assumed to be P_{H_2} : P_{CO} =10:1 that is typical ratio measured by quadrupole mass filter in UVSOR-II. The pressure P_{CO} is assumed to be 10nPa that agrees with typical value from vacuum gauges settled in the ring in the same order of magnitude. As seen in Fig. 5(b), the calculation of the vertical tune shift has characteristic structure, especially in smaller beam current. The tune shift has two separated peaks; a sharp peak that is around 0.3mA and caused by trapped H_2^+ ions, and broad one that is around 3mA and caused by trapped CO^+ ions. It seems that the two-peak structure in the calculation is identical with the experimental results even though the experimental results contain not only the ion-related tune shift but also the slope from the wake field; from analytical calculation[5] the slope from the wake is estimated to be about -1×10^{-5}/mA. The difference between each experiment in Fig. 4(a) also implies that the ion-related phenomenon causes the structure of the vertical tune on the beam current.

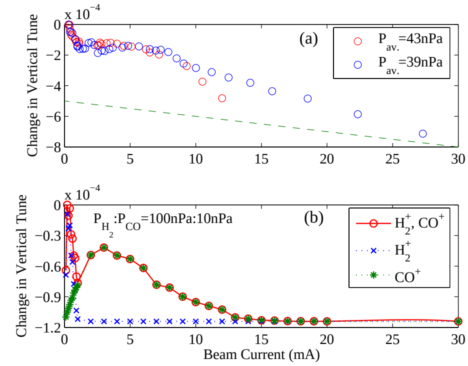

Figure 5: (Upper) (a) Experimental results of change in vertical tune in single-bunch condition in UVSOR-II in different vacuum pressure conditions. Broken line corresponds to the estimation of the wake field effect. (Lower) (b) Tracking calculation of change in vertical tune in single-bunch condition from H_2^+ and CO^+ ions.

DEVELOPMENT OF GAS FLUORESCENCE DETECTION SYSTEM

Precise measurement of vacuum pressure on the beam orbit which is quite difficult on real accelerators is a key issue not only for the ion-related phenomenon but also for basic beam diagnostic problem of the electron storage ring. Now we are developing a system that can measure number of residual gas molecules on the beam orbit by detecting fluorescence light from the residual gas molecules; the molecules which are excited by the scattering with the high energy electron relax again and emit fluorescence light that has characteristic wavelength. Vacuum pressure measurement by detecting intensity of fluorescence light under various vacuum conditions in the storage ring is now considered, and the detection system is planning to be installed in UVSOR-II in this summer.

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REFERENCES

[1] A. Mochihashi *et. al.*, Jpn. J. Appl. Phys. **44** (2005) 430.

[2] M. Katoh, *et. al.*, AIP Conf. Proc. **705**, p. 49 (2003).

[3] R. D. Kohaupt: DESY Interner Bericht No. H1-71/2 (1971).

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

[5] A. Chao, *Physics of Collective Beam Instability in High Energy Accelerators* (Wiley-Interscience, USA, 1993) p.185.