The Study of the Trapped Ion Effects in the SRRC Storage Ring

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Abstract

Ions produced from the residual gas can be trapped by the electron beam and limit the performance of the electron storage ring. During the commissioning of the SRRC storage ring, features of the ion trapping showed up. In this paper effects of the trapped ions in the SRRC storage ring were investigated in several aspects.

I: Introduction

The SRRC storage ring is a 1.3 Gev electron storage ring. During the early commissioning stage spontaneous vertical coherent oscillation has been observed. This coherent oscillation limits the quality of the synchrotron light. It was found that the tune of this coherent oscillation shifts with the beam current and could be cured by leaving a big empty gap in the filling bunches[1]. This effect is suspected coming from the ions and it motivates the study of the trapped ion effects on the storage ring

Ions are produced from the residual gas. For the SRRC storage ring the vacuum pressure rise is around 2 ntorr at the beam current of 200mA when the accumulated beam dose of 50 Ah. The main compositions of the residual gas are H_2 and CO, in which H_2 takes about 93.3% and CO about 4.4%. The residual gas composition in the SRRC storage ring is shown in table 1. Since the ionization rate for the CO molecule is much larger than that for H_2, the trapped ions in the ring are mostly H_2 and CO.

H_2	CH_4	H_2O	CO	CO_2
93.3%	0.5%	0.5%	4.4%	1.2%

Table 1: Residual gas composition in the SRRC storage ring.

The ion has the possibility to be trapped by the electron beam and results in the two beam instability[2], if the ion mass is larger than the critical mass $A_{c\ x/y}$ [3,4] for the horizontal and vertical planes respectively

$$A_{c\ x/y} = \frac{N_e r_p}{n}\frac{\pi R}{n\ \sigma_{x/y}(\sigma_x+\sigma_y)} \qquad (1)$$

in which n is the number of stored bunches, σ_x/σ_y is the horizontal/vertical beam size, N_e the number of the stored electrons, r_p the classical proton radius and R the average radius of the ring. At present user run the maximum beam current is 200mA and the number of filling bunches is around 100 to 120 in the SRRC storage ring. The beam size for the vertical and the horizontal close to 100 µm and 250 µm respectively. These operation parameters obtain a critical mass of 0.4 or less. It implies all of the molecules in the ring do have the possibility to be trapped by the electron.

When the ion is trapped it will deteriorate the performance of the electron beam and the quality of the synchrotron light[5~12]. A series of experiment were done to investigate the trapped ion effect on the tune. The behavior of coherent oscillation is also studied. Effects of the chromaticity, gaps of the electron bunches and cleaning electrode on the ions were also investigated.

II: Experimental Results

a): Coherent Oscillation

There are many sources which can cause coherent oscillation. While ion trapping is one of the suspicious origin[5]. In SRRC storage ring coherent oscillation can produce the fluctuation of the normalized synchrotron intensity at the experimental station larger by 3%, which is much beyond the requirement. There are two ways to avoid the coherent oscillation at SRRC. One is to leave the filling pattern with a big empty gap and the other is to tune the sextupoles to get strong enough chromaticity. The harmonic number for the SRRC storage ring is 200. At zero chromaticity and 250mA if the empty gap is larger than 120, no horizontal and vertical coherent oscillation are found. If the empty gap is less than 120, the coherent oscillation will show up. Then the larger chromaticity is used to cure this oscillation. It is found that the smaller the empty gap the bigger the chromaticity is needed. For the most severe one, i.e. no empty gap filling, the chromaticity needed is around +6.5 at 250mA.

From design parameters and equation (1) if the empty gap is 140 and the beam current 250mA then the critical mass will be slightly larger than H_2. That means H_2 will escape from the trapping. The estimated empty gap of 140

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is very close to the no coherent oscillation limit of 120. The discrepancy could come from the number of the electrons per bunch is not uniformly distributed in reality and the design parameters are slightly different from the real ones. This result implies H_2 play an important role in the coherent oscillation phenomenon.

One of the features of the coherent oscillation is that it has current limit below which the oscillation disappears. It is found that the bigger empty gap has smaller current limit. It is also found that when the beam current is reduced the tune spread and the amplitude of the coherent oscillation peak are getting smaller too.

To obtain more information of the coherent oscillation one filling pattern, which is easy to trap ions, was injected and the sextupoles were tuned to get strong enough chromaticity to cure this oscillation at the beginning. Then the pressure of the fifth and the sixth superperiods of the ring were increased steps by steps. It is found the vertical coherent oscillation peak shows up first and the horizontal peak appears latter at the higher pressure. Figure 1 shows this behavior at different pressures. As shown in figure 1 the vertical peak begins to be excited when the local pressure in the fifth and sixth superperiods are increased up to around 12 ntorr. As the local pressure increases up to about 16 ntorr there are strong horizontal and vertical oscillation peaks. The reason why the vertical peak is easier to be excited than the horizontal one can be understood from the interaction force which is inverse proportional to the beam size. Since the vertical beam size is smaller than the horizontal, it is easier to accumulate ions and the vertical coherent oscillation is then easier to be excited. When the pressure is increased high enough the horizontal coherent oscillation will also be excited too. This results show the ions could drive coherent oscillations not only at lower chromaticity but also at the higher chromaticity as the pressure is high enough.

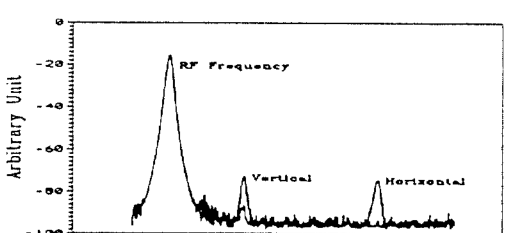

Figure 1: The coherent oscillation at different pressures.

b): Tune Dependence

The leading space charge force of the ions on the electron beam is equivalent to a quadrupole lens. Hence it will introduce tune shifts according to

$$\Delta\nu_y = \frac{r_e}{\gamma} \oint ds \frac{d_i \beta_y(s)}{(1+\sigma_y/\sigma_x)} \qquad (2)$$

in which β_y is the vertical beta function, d_i the density of the trapped ions, r_e the classical electron radius, σ_x/σ_y the horizontal/vertical beam size and γ is 2544 for the SRRC storage ring. Equation (2) is valid only for the vertical. If the horizontal one is considered then the vertical beta replaced by the horizontal beta and the horizontal and vertical beam size need to be interchanged. As the number of trapped ions is getting larger, effect of the focusing quadrupole become bigger and the larger tune will then be expected. The smaller empty gap in the filling pattern is easier to accumulate ions[7~11]. Previous result of smaller empty gap requiring stronger chromaticity seems to support this fact. In order to have a clear picture, the tune measurement at different gaps was done. The measurement was from 250mA to 50mA and figure 2 shows the results for the vertical plane at around 200mA and 1.5 ntorr. From figure 2 the tune shift becomes evidently as the empty gap is reduced to 20, which implies the ion effects is series. The behavior at different current is similar to what figure 2 shows horizontally and vertically. From these results it is obvious that bigger enough empty gap could avoid the ion trapping phenomenon in the SRRC storage ring. This results is consistent with the expectation. From figure 2 the vertical tune shift between 20 empty gap and the ion trapping less evident one is estimated to be 0.001. For the averaged vertical beta of the ring of 5.77m, the density difference of the trapped ions for 0.001 tune shift is $1.8\times10^{12}m^{-3}$.

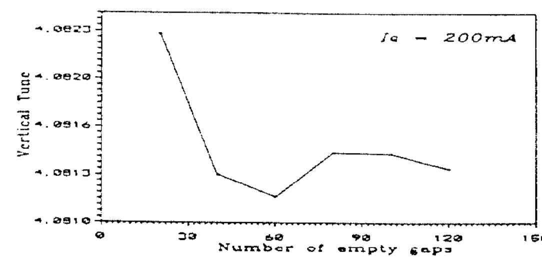

Figure 2: The vertical tune verse empty gaps at 200mA.

From the experimental data it is also found the horizontal tune increases as the increasing of beam current. This is due to accumulate more ions with higher current. While the vertical tune is found to be decreasing as the beam current increased. Since there are many instability sources which have contribution to the tune such as impedance[12], their effects on the tune need to be distinguished from the ions. It is also found that there is additional coherent oscillation peak as the empty gap bigger than 60. This is suspected from the competition of other instability sources.

c): Cleaning Electrode

From the above experimental results the SRRC storage ring has the trapped ion effect in the routine operation pressure when the empty gap is not bigger enough. This effect will give some limitation on the ring performance. In order to reduce the ion effects, simplified DC cleaning electrodes are used and tested. Two plates of the stripline electrode of length 15cm at the straight section, down stream to the fifth superperiod, and a button of one BPM in the sixth superperiod are used for this propose. A approximated no empty gap filling pattern was used to test the cleaning electrode effect. It is found the electrode will effectively clean the ions and give 0.0002 reduction in the vertical tune at 240mA and 1.7 ntorr. Figure 3 shows this effect in the frequency domain. The horizontal tune shift due to this cleaning process is not so obvious at this pressure. If the local pressure increased up to around 22 ntorr the effect of the ion cleaning becomes obvious and the tune will be reduced by 0.005 and 0.0015 horizontally and vertically by the electrode.

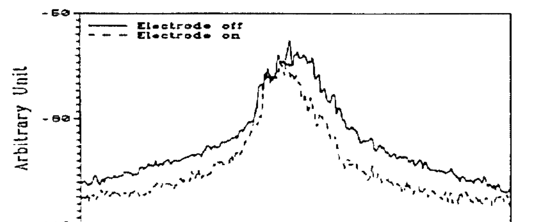

Figure 3: Vertical tune spectrum in frequency domain with and without cleaning electrode.

III: Discussion and Conclusion

From the experimental results it can be concluded that the ion trapping phenomenon in the SRRC storage ring can be improved by a big enough empty gap in the filling pattern. If the empty gap is bigger than 120 no horizontal and vertical coherent oscillation are found with zero chromaticity. On the other hand when the empty gap is not big enough then the coherent oscillation will show up and vertical coherent oscillation is easier to be excited than the horizontal. One of the features of the coherent oscillation is that it has threshold current limit bellow which the oscillation disappears. The vertical current limit is smaller than the horizontal for the vertical coherent oscillation is easier to be excited. At higher pressure the coherent oscillation peak is enlarged for both planes. The strong chromaticity is able to cure the coherent oscillation with the smaller empty gap requires the larger chromaticity. This is due to more accumulated ions for the smaller empty gap. For the most sever case, i.e. the one with no empty gap, the chromaticity needed is up to +6.5 at 250mA.

When the empty gap is reduced to 20 the tune shift is obvious at the routine operation pressure. The vertical tune shift produced by the effective quadrupole of ions for 20 empty gap comparing with to the ion trapping is less evident one is around 0.001 at 200mA. Cleaning electrode could effectively clean part of the ions and gives 0.0002 reduction in the vertical tune at 240mA. For the SRRC storage ring 0.001 tune shift seems a big one. The problem concerned is not only the tune shift but also the instability produced by the ions. Since the cleaning electrode could only reduce the vertical tune by 0.0002 at the approximated no gap one, the function of this simplified electrodes seem not adequate when the ring is operated with the small empty gap or no empty gap one.

It is also found that the H_2 molecule could play an important role in the trapped ion effects such as transverse coherent oscillation. From the linear model estimation the critical mass can be increased to be above H_2 by tuning the number of filling bunches. This estimated value of the empty gap is 140 compared with the experimental result of 120. The discrepancy could come from the number of electrons was not uniformly distributed per bunch in the experiment and the approximated model is used. It is also worthy to notice that CO as well as molecules with other weight can be trapped also. They should have some contribution in the trapped ion effects.

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