STUDY OF ION TRAPPING PHENOMENA IN INDUS-2 STORAGE RING

Saroj Jena#, A. D Ghodke and Gurnam Singh
IOAPDD, Raja Ramanna Centre for Advanced Technology, Indore-452013

Abstract

Electron beam in a synchrotron or storage ring ionizes the residual gas molecules present inside its vacuum chamber. These positive ions are trapped in the negative potential well of electron beam and limit the performance of the electron storage ring. During the commissioning of the Indus-2 storage ring, some features have shown up which may be related to ion trapping. In many storage rings, introduction of one long bunch gap in the stored beams has been found to be very effective in avoiding problems caused by ions. In this paper we discuss the phenomenon of ion trapping and its possible cure by optimization of the bunch gaps in Indus-2 storage ring. A suitable bunch-filling pattern with a single long gap appears suitable for Indus-2.

INTRODUCTION

The circulating electron beam collides with residual gas molecules in the storage ring vacuum chamber and thus positive ions are produced. These ions get trapped in the negative potential well of electron bunches and this phenomena is called ion trapping [1]. These accumulated ions are detrimental to the electron beam performance and they can result in beam lifetime reduction, emittance growth, tune shift and sometime even beam instabilities. There are standard ways to reduce the ion density, such as use of ion clearing electrodes, gap in bunch filling and use of positrons etc. Here bunch filling pattern is discussed, which works efficiently in storage rings across the world. In this method beam injection is performed in a way that leaves a desired number of consecutive RF buckets empty. The positive ions experience attractive force from the electron bunches and drift apart as they encounter empty buckets around the ring circumference. For an optimally chosen gap length, the transverse ion oscillation amplitude amplifies and the ions are lost from the beam path. This gap length depends on several factors such as beam current, transverse beam sizes and mass of the ions generated etc. During the Indus-2 operation, it is sometimes observed that the stored beam lifetime drops by few hours below a certain beam current and this phenomenon couldn't be explained by any of machine parameters that affects beam lifetime. This above occurrence may be caused by ion trapping.

THEORY

Ion motion obeys Hill's equation similar to theory of betatron oscillation in a circular accelerator. Electron bunches represents focusing lens and bunch-to-bunch gap as a drift space for the ions. As the bunch length of electron beam is much smaller than the gap between the successive bunches, this allows us to use thin lens approximation for the focusing effect of electron bunch. The focusing strength of the electron bunch can be written as [2]

$$a_{x,y} = -\frac{2\, N_e r_p\, c}{A\, \sigma_{x,y}(\sigma_x+\sigma_y)} \qquad \text{…………… (1)}$$

Where N_e is the number of electrons per bunch, r_p the classical proton radius, c the velocity of light, A the atomic mass number of ion and σ_x and σ_y the rms horizontal and vertical beam sizes respectively. In the case of uniformly distributed electron bunches, the effect of an electron bunch on ions can be described by an equivalent lattice of N_b,FO focusing cells. Here F and O represent the focusing kicks by electron bunch and drift space between bunches, respectively and N_b is the number of bunches in the ring. Transverse displacement of an ion is affected by electron bunch and can be expressed as follows

$$\begin{pmatrix} y \\ \dot{y} \end{pmatrix} = \begin{pmatrix} 1 & t_{rf} \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ a & 1 \end{pmatrix}\begin{pmatrix} y_0 \\ \dot{y}_0 \end{pmatrix} = \mathrm{M}\begin{pmatrix} y_0 \\ \dot{y}_0 \end{pmatrix} \qquad \text{………. (2)}$$

Where t_{rf} is the bunch spacing ($1 / f_{rf}$). The above equation is written for vertical plane and for horizontal plane y is replaced by x. The stability criterion for the motion of the ions can then be derived in a similar way as the formalism used in electron accelerator optics which is$|Tr(M)| \leq 2$. This relation defines a critical mass A_c and ion masses $A > A_c$ have the stable motion, i.e those ions are trapped in the beam path

$$A_{c\,x,y} = \frac{r_p\, N\, C}{2\, N_b{}^2\, \sigma_{x,y}(\sigma_x+\sigma_y)} \qquad \text{……… (3)}$$

Where N is the total number of electrons in the ring. Since usually horizontal beam size is larger than that of vertical one, the vertical stability criterion is more stringent and thus only considered here. Considering parameters of Indus-2 storage ring the calculated critical mass value comes out 0.05 for all the 291 bunches filled uniformly and 100mA stored beam current at injection energy of 550MeV. Thus the linear model predicts in this configuration, all the ion species will be trapped. In figure 1, the stability of ions vs. different ion species is plotted for all 291 bunches and 200 bunches filled uniformly for 100mA beam current. This indicates that when a long gap is introduced between bunches; some of the ion species becomes unstable and they are not trapped.

#s_jena@rrcat.gov.in

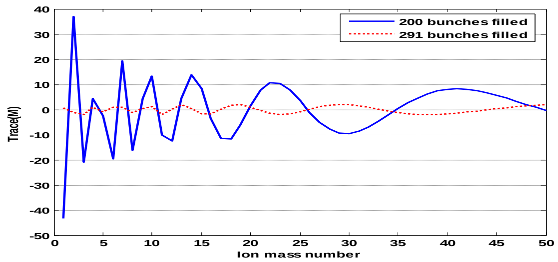

Figure 1: Stability of ions verses different ion species.

EFFECT OF MISSING BUNCHES

For the string of bunches followed by string of missing bunches the transformation matrix of a complete train can be written as [3]

$$M = \left[\begin{pmatrix} 1 & t_{rf} \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ a & 1 \end{pmatrix}\right]^{N_b}\begin{pmatrix} 1 & t_{rf} \\ 0 & 1 \end{pmatrix}^{h-\mathrm{N_b}} \quad \ldots\ldots (4)$$

Where h is the harmonic number, i.e maximum number of bunches in a storage ring and N_b is the number of successive filled bunches. Ion motion becomes unstable if the condition $|Tr(M)| \geq 2$ is satisfied. The above matrix equation can be solved numerically. The stability of different ion species which are normally encountered in an electron storage ring are plotted against various gap sizes in the bunch train for a beam current of 100mA at injection energy and is shown in the figure 2. This shows that when the 291 bunches are filled; all the ions are trapped in the beam path. In Indus-2, 100mA beam current was successfully stored with all 291 bunches which seems to contradict the theory. But the above analysis does not include the density of ions that build up in the vacuum chamber during the process of ionization. This figure also indicates the number of trapped ions diminishes as the gap in the bunch train increases. It was observed in Indus-2 that the threshold beam current at which beam accumulation stopped in the case of uniform filling was less than that, when it was filled with some bunch gaps in the filling pattern which implies that, this phenomenon may be due to the problem of ion trapping. It was also observed that the beam accumulation rate was more with partial bunch filling, rather than the uniform bunch filling.

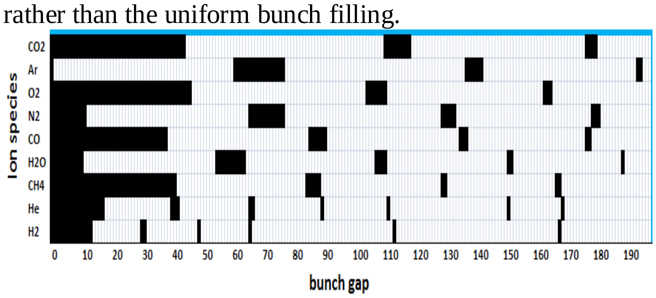

Figure 2: Stability of ion mass vs bunch gap at 100mA beam current.

The stability conditions for various ions are studied for different beam currents up to 300mA at injection energy and the ion instability verses bunch gap size is plotted in figure 3. This graph shows that none of the ions will be trapped for the entire beam current range with 90% confidence for a gap size of 145 bunches. This analysis holds good only for uniform bunch current with the linear theory of ion optics but in reality all bunches may not be filled with equal population. Hence ions, which are trapped in uniform bunch filling case, may not be trapped in real situation**.** So the minimum gap required in bunch train may be less than the above calculated value to avoid the ion trapping.

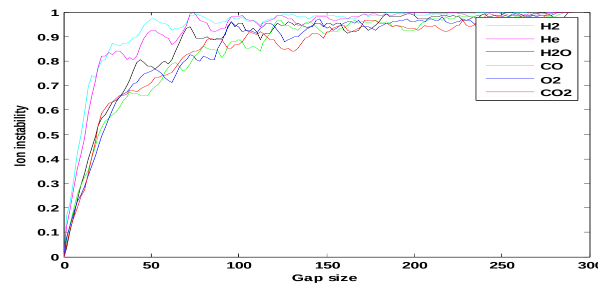

Figure 3: Instability of ions for beam current upto 300mA at 550MeV.

CONCLUSION

The above results are based on simulation and are to be verified by experimentally in Indus-2 storage ring. In our further study, non-linear effects of the electron bunch will be considered. Furthermore it is shown that large gap in the bunch train can significantly improve the machine performance by reducing the ion density. But the large gap will result in lifetime reduction as the beam population per bunch increases for the same beam current. Moderate positive chromaticity can reduce the transverse oscillation amplitude that grows due to the trapping of ions. Hence a combination of less chromaticity and big gap or vice versa will be exercised to avoid trapping of ions. The present understanding of ion trapping is incomplete and needs many more experimental investigations to get a complete picture on this phenomenon.

REFERENCES

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