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Observation and mitigation of ion trapping in Indus-2

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Abstract. The presence of trapped ions in electron storage rings causes considerable degradation in the performances of the beam, such as increase in beam size, reduction in beam lifetime, shifting of betatron tune, beam instabilities etc. This paper discusses the effects of ion trapping and its mitigation in Indus-2 electron storage ring. Ion-induced instability generating partial beam loss is one of the main barriers in higher beam current accumulation in any electron storage ring. Though there are several techniques to clear the ions from the electron beam path, in Indus-2, it is addressed mainly by filling the storage ring in partial bunch filling pattern. In order to improve the electron beam performance and to mitigate the ion-related problem, a suitable bunch filling pattern has been determined. The theoretical prediction and the result of optimal bunch filling pattern are presented in this paper.

Keywords. Ion trapping; partial bunch filling; electron storage ring.

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1. Introduction

In an electron storage ring, positive ions are generated by beam gas collisions and these ions are trapped in the negative potential of the electron beam. The trapped ion increases the local pressure of the storage ring which reduces the beam lifetime. Under the influence of periodic force of the electron bunches separated by few nanoseconds, the positive ions make stable oscillations around the electron beam path. This phenomenon is known as ion trapping in storage ring. The presence of ions in the vacuum chamber causes the shift in betatron tune, emittance growth, beam loss through excitation of resonance and also instabilities due to the interaction of the electron beam with the population of the trapped ions. Hence it is important to reduce the ion density in the vicinity of electron beam. The ion accumulation and its impact on electron beam depend on the electron beam current, number of circulating electron bunches, transverse beam sizes and the mass of the ions. Several methods are used to control ion trapping in electron storage rings [1]. These include use of ion clearing electrodes, creation of gap in the bunch filling pattern, and resonant beam shaking etc. To avoid ion trapping, partial bunch filling method is adopted which is successfully applied in many electron storage rings such as ELETTRA, ESRF, KEK-PF, NSLS etc. In order to provide good brightness which in turn requires high stored beam current, there must be a mechanism to overcome ion trapping if any, in the storage ring. In this paper the conventional ion trapping and its removal are studied for Indus-2 using the technique of partial bunch filling pattern. Indus-2 is an electron storage ring of energy 2.5 GeV and is operational in round-the-clock mode for synchrotron radiation users with a beam current of more than 100 mA [2]. The electrons are injected into Indus-2 from the booster synchrotron at 550 MeV with a repetition rate of 1 Hz till the required beam current is accumulated. After the accumulation of the desired beam current, beam energy is ramped to its final energy of 2.5 GeV. Indus-2 ring consists of 16 dipole, 72 quadrupole and 32 sextupole magnets which are the main building blocks for circulating and storing the electron beam bunches. Apart from these magnets, there are 48 horizontal and 40 vertical steering magnets which are small dipole magnets used for correcting closed orbit distortion (COD) of the beam. For beam position monitoring, 56 beam position indicators (BPIs) are installed along the circumference of the ring. There are 4 radio frequency (RF) cavities operating at 505.8 MHz which are used for beam acceleration and also to replenish energy loss due to the emission of synchrotron radiation by the beam. The basic parameters of Indus-2 are listed in table 1.

2. Ion trapping

Some residual gas molecules remain inside the storage ring vacuum chamber even when the pressure is of the order of nTorr. The number density n of the gas molecules is expressed by the relation

$$p = n\,k\,T, \tag{1}$$

where k is the Boltzmann's constant, p is the pressure in Pascal and T is the temperature in K. So, with 1 nTorr pressure in the vacuum chamber, the molecular density of gas is 3.2×10^{13} m^{-3}. Normally, hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2),

Table 1. Parameters of Indus-2.

Energy	E	0.55–2.5 GeV
Current	I	300 mA (design)
Circumference	C	172.47 m
Bending radius	ρ	5.5 m
RF frequency	f	505.8 MHz
Harmonic number	h	291
Beam lifetime	τ	15 h @100 mA, 2.5 GeV
Betatron tune	ν_x/ν_z	9.27/6.15
Beam emittance	ε_x	130 nm rad
Betatron coupling		0.5%
β_x (max., min., average)		18.45, 1.35, 7.65 m
β_z (max., min., average)		14.7, 2.1, 6.24 m

methane (CH_4), nitrogen (N_2), and oxygen (O_2) are the gases present in the chamber in 1 nTorr vacuum range. The circulating electrons ionize the residual gas molecules present in the storage ring vacuum chamber by collision and thus ions are generated. The time taken for one electron in the beam to create one ion of any molecular species contained in the vacuum chamber is called ionization time of that molecular species. Total ionization time is the sum over all the gas species and is given by the following equation:

$$\tau_i = \frac{1}{d_m \sigma_{\rm i} c}, \quad \tau_{\rm tot} = \left(\sum_i \frac{1}{\tau_i} \right)^{-1}, \tag{2}$$

where d_m is the density of neutral molecules, $\sigma_{\rm i}$ is the ionization cross-section for gas molecules, c is the velocity of light, and τ_i is the ionization time of a molecular species.

In an electron storage ring with a typical pressure of 1 nTorr composed of H_2, CO and CO_2, the total ionization time is of the order of 1 s. The ion production rate is proportional to the beam current and the residual gas pressure in the ring and for singly ionized gas species, this rate is given by [3,4]

$$\frac{{\rm d}n_{\rm i}}{{\rm d}t} = d_m \sigma_{\rm i} c n_{\rm e}, \tag{3}$$

where $n_{\rm e}$ is the density of electrons and $n_{\rm i}$ is the density of ions.

A singly ionized ion can be doubly ionized by another collision with relativistic electrons and the ionization process may continue. Eventually, the ion density will reach an equilibrium state. The rate at which the singly ionized ions will be doubly ionized may be calculated using eq. (3) by substituting singly ionized density in place of molecular density and ionization cross-section of singly ionized ion in place of gas molecules. However, the cross-section of singly ionized ion will not be very different from that of gas molecules as they only differ by a factor $(Z-1)/Z$, where Z is the total number of electrons. For most gases this change in cross-section can be ignored to fist-order approximation.

A new term 'neutralization coefficient' is defined as follows and its value lies between 0 and 1.

$$\text{Neutralization coefficient; } \eta = \frac{\text{ion density}}{\text{electron density}}, \quad 0 < \eta < 1.$$

The electron beam in the storage ring consists of several bunches and the maximum number of bunches which can be filled in a given storage ring is governed by the harmonic number of the storage ring which is the ratio of the RF frequency to the revolution frequency. In Indus-2 the harmonic number is 291.

The line density of ions which is formed during the passage of electron beam is related as

$$\lambda_{\rm i} = \sigma_{\rm i} N_{\rm b} n p_{\rm i} / kT, \tag{4}$$

where $N_{\rm b}$ is the number of electrons per bunch, n is the number of bunches, $p_{\rm i}$ is the partial pressure of neutral molecules that become ion species 'i' when ionized, k is the Boltzmann constant and T is the temperature of the gas. This equation shows that ion density is proportional to the number of bunches and the electron population within the bunch of the storage ring.

3. Homogeneous bunch filling

The positive ions move with a thermal velocity which is very less compared to the velocity of light. Therefore, ions can be considered stationary with respect to the passing electron bunches. At each passage of the electron bunch, an ion of residual gas experiences transverse kick towards the bunch centre. As the electron bunches are equally spaced in a homogeneous filling, the ions may execute stable oscillations about the centre of the electron bunch centre. Ion motion obeys Hill's equation like the beam particles in a synchrotron [5]. Electron bunches act as focussing lens (thin lens) for the ions and bunch-to-bunch gap which are normally larger than the bunch length acts as a drift space.

The equation of motion of ions in vertical plane using thin lens approximation and for a homogeneous bunch filling pattern can be written as follows:

$$Y = MY_1, \tag{5}$$

where

$$Y = \begin{pmatrix} y \\ \dot{y} \end{pmatrix}, \quad Y_1 = \begin{pmatrix} y_1 \\ \dot{y}_1 \end{pmatrix} \quad \text{and} \quad M = \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ -k & 1 \end{pmatrix},$$

M the transfer matrix for a period (bunch (as a thin lens) + bunch gap) and k is the linear kick parameter defined as

$$k = \frac{2N_\mathrm{b} r_\mathrm{p}}{A\sigma_y(\sigma_x + \sigma_y)}, \tag{6}$$

where A is the atomic mass of the ion, L is the bunch-to-bunch gap, N_b is the number of particles in the electron bunch, r_p is the classical proton radius and $\sigma_{x,y}$ is the rms horizontal and vertical electron beam sizes.

The oscillations of the ions remain stable in the electron beam potential if the transfer matrix satisfies the following relation:

$$-2 \leq \mathrm{trace}\,(M) \leq 2. \tag{7}$$

The ions are trapped when their atomic mass exceeds a certain value known as critical mass (A_c). In other words, ions with atomic mass larger than the critical mass performs stable oscillations and hence are trapped in the potential well of the electron beam.

Using eq. (6),

$$\text{Critical mass; } A_{c\,x,y} = \frac{r_\mathrm{p} N C}{2n^2 \sigma_{x,y}\left(\sigma_x + \sigma_y\right)}, \tag{8}$$

where N is the total number of electrons in the beam, C is the circumference and n is the number of bunches.

As $\sigma_x > \sigma_y$, $A_{cy} > A_{cx}$. Hence, we study the electron beam ion interactions in vertical plane only. As the capture of ions proceeds, the electron beam undergoes neutralization and the condition of trapping changes. Consequently, the ions with atomic mass $A > (1-\eta)A_{c,y}$ will be trapped. As the ions found in the vacuum system of storage rings have maximum atomic number 44, critical mass above 44 will not allow the accumulation of ions in storage ring vacuum chamber. But in a storage ring of typical beam parameters with large number of bunches, critical mass appears to be smaller than unity. This envisages that all possible ions generated due to the residual gas species present at the vacuum level of 1 nTorr in the storage ring vacuum chamber will be trapped with homogeneous bunch filling.

From the stability condition (eq. (7)), the required length of the gap to prevent ion trapping is determined and is given by

$$L_{\text{gap}} > \frac{2\sigma_y(\sigma_x + \sigma_y)A}{r_{\text{p}} N_{\text{b}}}. \tag{9}$$

Taking CO as the dominant ion, for 100 mA beam current in the Indus-2 storage ring at 2.5 GeV and using eq. (9) a gap of nearly 10 RF buckets (6 m) between the bunches would be sufficient to prevent ion trapping. However, in this way only 29 buckets could be filled each with a separation of 10 RF buckets to avoid ion trapping. This will increase the required electron density in each electron bunch and may lead to various beam instabilities. The other more practical method is to make one long bunch train followed by a sufficiently large bunch gap.

The ion trapping phenomenon can also be explained using the ion oscillation frequency. Due to very small transverse velocity, the ions remain almost stationary at the place of their formation. When the next bunch arrives at the place of the ion, electron beam bunch pulls it towards the centre of the bunch. This process continues with consecutive moving bunches of electron beam setting up an oscillatory motion of the trapped ions. In other words, if ion oscillation frequency is smaller than the bunch arrival frequency, then the ions are trapped and are mathematically shown as [6,7],

$$4 f_{\text{ion}} \le \frac{c}{L_{\text{sep}}}, \tag{10}$$

where f_{ion} is the ion oscillation frequency and is given by

$$f_{(\text{ion})x,y} = \frac{c}{2\pi}\,\text{sqrt}\left[\frac{4N_{\text{b}} r_{\text{p}}}{3L_{\text{sep}}\sigma_{x,y}(\sigma_x + \sigma_y)A}\right], \tag{11}$$

where L_{sep} is the bunch-to-bunch gap.

In the actual electron storage ring, due to magnetic focussing structure the transverse beam size varies around its circumference. Thus, every ion has varying frequencies and can be stable in some regions of the ring and unstable in other parts of the ring.

4. Partial bunch filling

Leaving a number of consecutive RF buckets empty in the bunch filling pattern is effective and widely used in curbing the trapped ions in the storage ring. In this configuration, ion experiences a periodic attractive force of electron bunches and a drift where the electron bunches are absent. Such a repeated process amplifies the transverse ion oscillations and hence ions are ejected or lost. For gapped bunch train in a storage ring, the transfer matrix for a complete bunch train becomes [8]

$$M = \left[\begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix}\begin{pmatrix} 1 & 0 \\ -k & 1 \end{pmatrix}\right]^n \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix}^{h-n}, \tag{12}$$

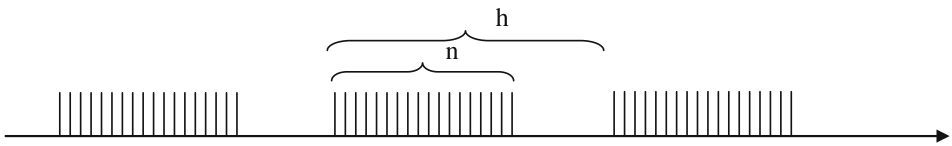

Figure 1. An illustration of the bunch train that shows a maximum possible h bunches out of which n bunches are filled with electrons and $h - n$ bunches are empty.

where the terms in square bracket represent the linear kick received by the ion due to consecutive n electron bunches and drifts received at the bunch-to-bunch spacing of length L. The electron beam filled with only n bunches have $h - n$ bunch gaps where h is the harmonic number, i.e., the maximum number of bunches stored in the storage ring. An illustration of the bunch train is shown in figure 1.

This matrix is too complex to determine the stability conditions in a simple analytical form. However, it is possible to find the same by numerical method where the stability condition $-2 \leq \mathrm{Tr}\,(M) \leq 2$ does not lead to a critical mass like in the case of homogeneous bunch filling.

5. Tune shift

The space charge of the accumulated ions causes shift in betatron frequency of the electron beam. The electron beam may drift towards resonance due to the shift of betatron tune and it may get wasted. Thus, the trapped ions impart additional focussing to the electron beam and the coherent tune shift due to the accumulated ions [1] is given by

$$\Delta v_{x,y} = \frac{r_{\mathrm{e}} d_{\mathrm{i}} \overline{\beta_{x,y}} C}{4\pi \gamma \sigma_{x,y}(\sigma_x + \sigma_y)}, \tag{13}$$

where r_{e} is the classical radius of the electron, γ is the relativistic factor, $\overline{\beta_{x,y}}$ is the average beta function $= C/2\pi v_{x,y}$, C is the circumference, $v_{\mathrm{x,y}}$ is the betatron tune and d_{i} is the density of ions.

This ion-induced tune shift is independent of its ion mass but it depends mainly on the density of the ions inside the ring vacuum chamber. Using the above equation and assuming a beam current of 100 mA at 2.5 GeV in Indus-2 with 1% neutralization coefficient, the calculated tune shifts are 0.0006 and 0.0023 in the horizontal and vertical planes, respectively. As σ_x is larger than σ_y, vertical tune shift will be more. Though the measurement of tune shift is important for studying ion trapping, the method still causes ambiguities as tune shift can also be produced by gradient errors and nonlinear elements in the ring other than the ion produced electric fields. Direct method of observing the ion trapping is to measure the high-energy bremsstrahlung produced by collisions between the electron beam and the residual gas molecules [9]. If ions are trapped in the beam there would be additional bremsstrahlung yield from electron and ion collisions.

6. Results and analysis

Considering the parameters of Indus-2 storage ring given in table 1, the calculated critical mass value is 0.05 for all 291 bunches filled uniformly at 100 mA stored beam current at an injection energy of 550 MeV. Thus, the linear model predicts all the ion species are trapped in this configuration. In figure 2, the trace of the transfer matrix of ion motion vs. different ion species is plotted for the ring filled with RF buckets and with a gap of 100 successive RF buckets for 100 mA beam current. This indicates that in uniform filling of all 291 bunches the trace of transfer matrix remains within the range of [−2, 2] and hence all possible ions perform stable oscillations. However, when a long gap is introduced between bunches, the trace of transfer matrix moves away from the zone of [−2, 2] and these ion species perform unstable motion and they are not trapped in the attractive electron beam potential.

The major species of residual gas in Indus-2 vacuum chamber are CO and H_2. Table 2 shows the percentage of residual gas present in Indus-2 measured using residual gas analyser. However, as the value of ionization cross-section for CO is larger than that of H_2 [10], CO^+ ions are dominant in the vacuum chamber. The ionization cross-section of each gas molecule can be described by the following relation:

$$\sigma_{\mathrm{i}} = 4\pi \left(\frac{\hbar}{m_{\mathrm{e}}C}\right)^2 \left\{M^2\left[\frac{1}{\beta^2}\ln\left(\frac{\beta^2}{1-\beta^2}\right) - 1\right] + \frac{C}{\beta^2}\right\}, \tag{14}$$

where M^2 and C are experimentally determined constants for different gas molecules, β is the speed of electron/speed of light. The ionization cross-section for Indus-2 at injection energy is estimated and tabulated in table 2.

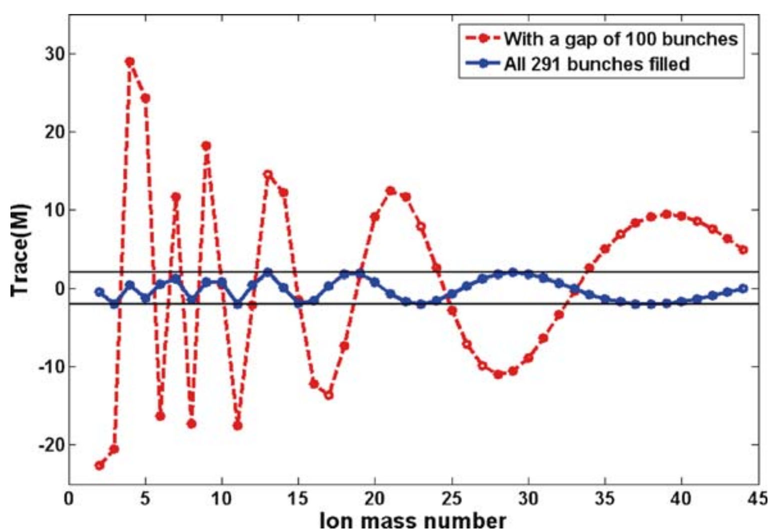

Figure 2. Trace of the transfer matrix of ion motion as a function of different ion species of mass upto 44[CO_2] for all filled 291 bunches (blue solid curve) and for a gap size of 100 consecutive bunches (red dash curve). Stable zone is between the two horizontal straight lines.

Table 2. Residual gas present in Indus-2 vacuum chamber, their ionization cross-sections and ion frequencies at 550 MeV.

Gas species	Mass no.	Weight fraction (%)	Ionization cross-section (10^{-22} m^2)	$f_{(\mathrm{ion})x}$ (MHz)	$f_{(\mathrm{ion})y}$ (MHz)
H_2	2	73	0.273	13.5	21.7
CO	28	24	1.553	3.6	5.8
O_2	32	2	1.744	3.4	5.4
CO_2	44	1	2.439	2.9	4.6

Using Indus-2 storage ring parameters listed in table 1 and eqs (10) and (11), the following results are obtained: $4f_{\mathrm{i},y[\mathrm{CO}^+]} = 23.2$ MHz, while $c/L_{\mathrm{sep}} = 500$ MHz. This implies $4f_{\mathrm{i}} \ll c/L_{\mathrm{sep}}$. So, ion like CO^+ is trapped in the potential well of electron bunches. The frequency with which ions oscillate around the circumference of the Indus-2 ring is shown in figure 3, when the stored beam current is 100 mA and distributed over all the 291 bunches equally at an injection energy of 550 MeV. The ion oscillation frequency in the horizontal and vertical planes for different ion species is tabulated in table 2. Here, it may be observed that all the ions oscillate with frequencies much less than the bunch arrival frequency in homogeneous filling pattern and hence are trapped in the electron beam.

Ions can also be ejected by shaking the electron beam near the resonant oscillation frequency of the ions [11]. The regular oscillation pattern of the ions changes considerably on shaking the beam and at the resonant oscillation frequency, ions are driven to larger amplitudes and hence move out of trapping potential. In Synchroton Radiation Research

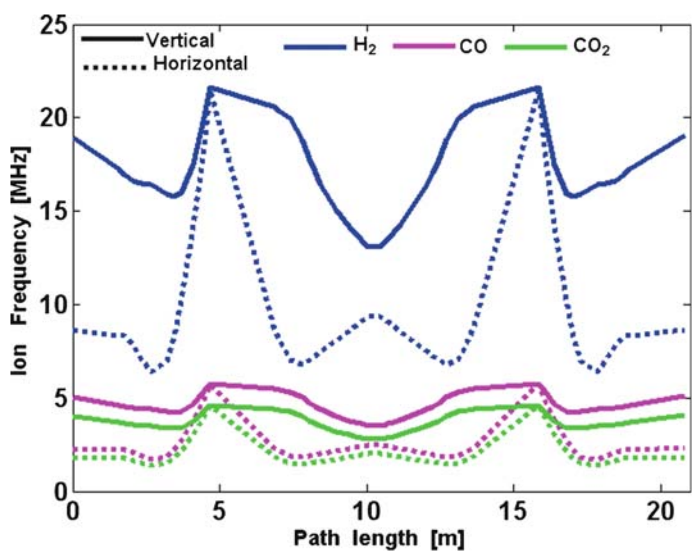

Figure 3. Variation of oscillation frequency of different ion species in both horizontal and vertical planes along the Indus-2 ring for one superperiod.

Centre (SRRC) this method is applied to overcome this ion-driven difficulty [12]. In Indus-2, this experiment was performed for CO ion and the loss of such resonant ion species was observed in vertical plane using real-time spectrum analyser. However, the required shaking amplitude was large and the beam obtained may create disturbances to the experimental users of synchrotron radiation. So, the shaking method is not adopted in Indus-2 to minimize the problem of ion trapping.

The stability of ions was investigated by considering uniform and partial bunch filling patterns [9]. Using eq. (12), the stability of different ion species vs. various gap sizes in the bunch train was estimated for a beam current of 20 mA at an injection energy of 550 MeV and is shown in figure 4. The graph shows stable and unstable bands for different ion species with respect to gaps in the filling pattern and the only region where trapping is really assured is shown at the extreme left side of the graph [15]. This explains that, when 291 bunches are filled, all the possible ion species are trapped. But as the gaps in filling pattern increase, more and more ion species become unstable. The graph shows that ion trapping becomes less with empty RF buckets and with a gap of 100–110 ($\sim$2/3rd filling), the Indus-2 ring is less affected by ion trapping effects. However, as the beam current increases the scenario of trapping condition vs. gap might change.

The stability conditions for various ion species were also studied for different beam currents up to 300 mA at injection energy and the possibility of ions becoming unstable as a function of various bunch gap sizes is shown in figure 5. This graph explains that, with 90% confidence, the ions are unstable for the entire beam current range for a gap size of 125 bunches and will not be trapped in the electron beam path. However, this analysis holds good for equal population in each bunch but, this may not be the situation in reality. So the minimum gap required in bunch train may be less than the above calculated value to avoid ion trapping. It may be observed here that the gap filling provides considerable improvement to the problem of ion trapping.

However, as the electron beam size varies with the position around the circumference of the ring, the trapping condition of ions also varies. Ions can be stable in some regions of the ring and unstable in other regions. The stability of ion species throughout the Indus-2 ring was estimated using various configurations of bunch train [13]. For this, the ring circumference was divided into small parts of 10 cm each and in each part, stability condition for a particular ion was checked. The ratio of the total area of the regions where the ions are trapped to the area of the ring was calculated for different bunch filling

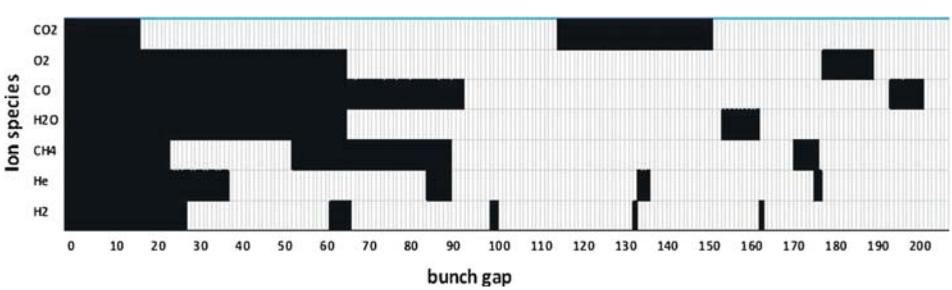

Figure 4. Stability of various ion species for different bunch gap sizes in Indus-2. Dark areas indicate the stability of ions.

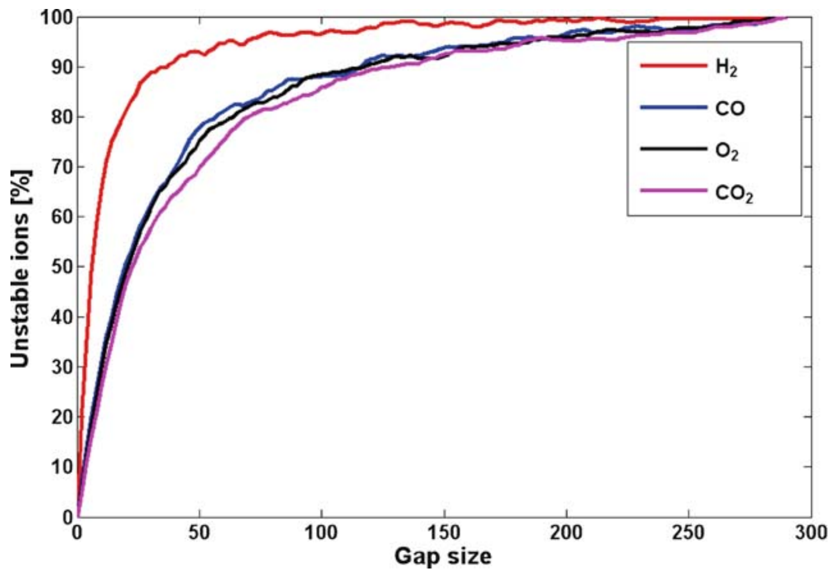

Figure 5. Percentage of unstable ions of various species for beam current up to 300 mA as a function of bunch gap size at 550 MeV in Indus-2.

patterns. The percentage of the region (with colour bar representation) where the CO ions are trapped in the ring is shown in figure 6. Thus, with the configuration of strings of electron bunches followed by strings of missing buckets, it was observed that the ring is surrounded by regions of stable and unstable ions. All other ion species also follow similar

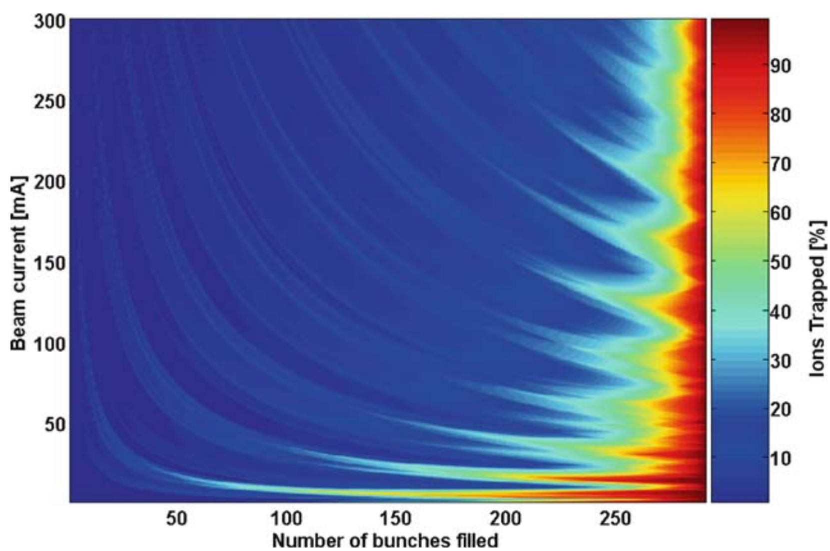

Figure 6. Region of ring circumference in percentage where the CO ions are trapped for different lengths of bunch train in the Indus-2 storage ring. The maximum length of the bunch train is 291.

trend and neglecting the divergence in the ionization cross-section, the operating condition of Indus-2 can be chosen from this graph in minimizing the effect of ion trapping. Looking at the graph it can be anticipated that in the Indus-2 storage ring, ion trapping takes place in less than 10% area if the ring was filled with 180 bunches and beam current of 100 mA or more.

7. Experimental observation

For a homogeneous bunch filling pattern, betatron tune measurement in both the planes was carried out in Indus-2 during beam accumulation at an injection energy of 550 MeV. The same tune measurement was also done with various length gaps in a single bunch train. The tunes are shown in a resonance diagram drawn upto fifth order and depicted in figure 7. Usually, lower-order resonances are more dangerous and should be avoided in an accelerator. Electron beam on resonance experiences an increase in betatron oscillation amplitude and loss of beam may occur. It is very clearly shown in figure 7 that vertical tune of the beam varies largely and may cross the resonance lines when the storage ring was filled with 291 and 250 bunches. However, when less number of bunches are filled, variations in betatron tune were found to be less and also stayed away from the resonance lines. As the beam size in vertical plane is smaller than that of the horizontal plane, the betatron tune shift in vertical plane is more and the tune measurement also supports the theory. From figure 7, it can be estimated that for 291 and 250 bunches filling in Indus-2 where ion trapping was ensured, the amount of tune shift in vertical plane was 0.012. But for 180 and 150 bunches filling, the tune shift was 0.002 which was very small compared

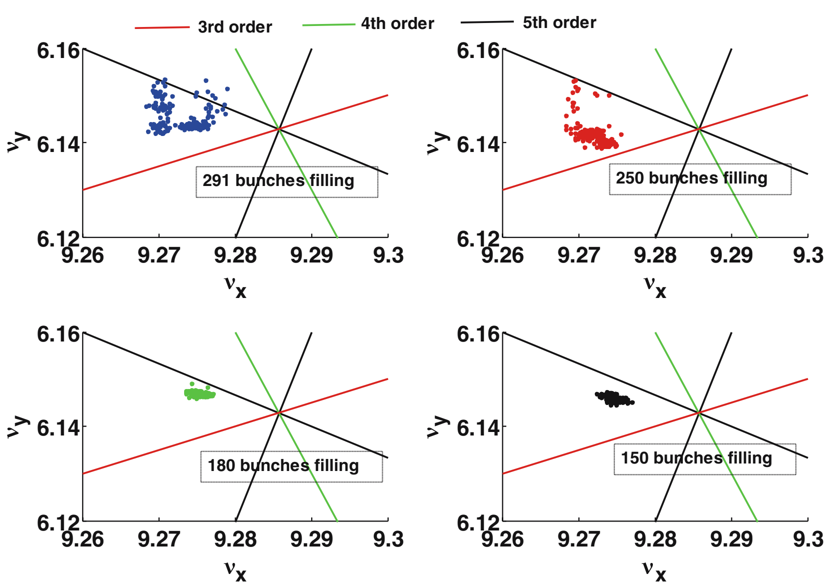

Figure 7. Variation of betatron tunes in both horizontal and vertical planes are illustrated in tune space for different bunch filling patterns in Indus-2.

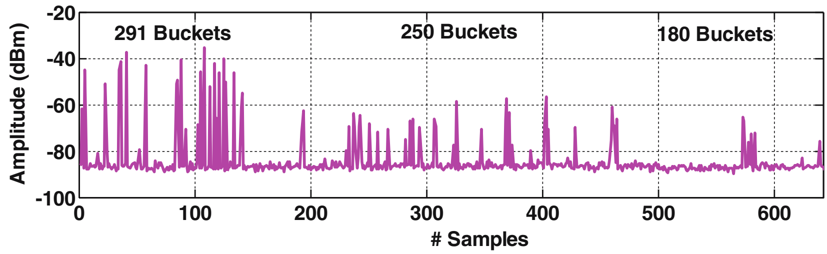

Figure 8. Amplitude variation of transverse coupled bunch instability in the vertical plane for different bunch filling patterns in Indus-2.

to the earlier cases. This observation leads to the conclusion that, as the length of the bunch train reduces, fewer ions are trapped in the electron beam potential.

When the ring was filled with 180 bunches, increase in beam accumulation rate by a margin of 50% was achieved. The beam current saturates at 150 mA in all 291 bunch-filling patterns whereas the saturation was observed at 220 mA in 180 bunches (2/3rd) filling. Also we have tried to accumulate the beam with 150 bunches which is half filling but in this case saturation was achieved at 180 mA which might be due to instabilities. The beam lifetime at injection energy was measured for homogeneous and partial bunch filling. It was observed that at injection energy the beam lifetime at 150 mA was 3 h 12 min and 5 h 40 min, respectively in 291 and 180 bunches filling. This shows that there was an increase of lifetime by 2 h when Indus-2 was filled with 180 buckets as compared to that of 291 buckets filling. These observations envisage the occurrence of trapped ions in homogeneous filling which are properly removed by selecting a partial bunch filling pattern. At present, Indus-2 is being regularly filled with 180 buckets that gives better performances.

The electron beam and the generated ions as a whole may also undergo coherent oscillations and they can increase the electron beam size and the beam loss. Ions trapped in the electron beam potential sometimes induce transverse instability in the beam and increase the beam size [14]. It was observed that in Indus-2 beam spot as seen on synchrotron light monitor (SLM) was shaking at high beam current in homogeneous filling mode. In order to understand the phenomena, the measurement of transverse coupled bunch mode excitation with the beam current of more than 100 mA was made. A large number of modes were seen to be excited but the mode number 290 was detected with higher amplitude in vertical plane. In horizontal plane there was no coupled bunch mode excitation. It was observed that there was a reduction in amplitude of the 290th coupled bunch mode in partial bunch filling pattern and the results are shown in figure 8. These measurements were taken between 130 to 150 mA for all the filling patterns and it was observed that the beam shaking phenomena seen on SLM for homogeneous filling were not noticed in partial filling.

8. Conclusions

The ion trapping mechanism is complicated and its effects cause serious problems in electron storage ring as it shifts betatron tune, increases the beam size, reduces the beam lifetime, generates beam instability and also degrades the quality of synchrotron radiation. The numerical analysis was carried out to study the stability of ions with respect to the number of bunches filled out from 291 bunches in Indus-2 storage ring. This reveals that a single long bunch gap is beneficial to curb the ion trapping phenomena and also smooth beam accumulation. It was experimentally seen that there was improvement in beam lifetime and accumulation rate with partial bunch filling of 180 buckets. It was also observed that the partial beam loss and saturation at high beam current were controlled in 2/3rd bunch filling which occur in 291 bunches filling. The growth of vertical beam instability was also attenuated with increasing gaps in the filling pattern.

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