BEAM LIFETIMES AND FILLING SCHEMES FOR SYNCHROTRON RADIATION SOURCE INDUS-2

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Abstract

Indus-2, a synchrotron radiation source at a nominal energy of 2 GeV will have an injection energy of 700 MeV. The source will be operated in different filling modes to satisfy the beam users requirements. For avoiding the trapping of ions, it will be necessary to operate the ring in a partial filling mode. As the synchrotron and the storage ring have different RF frequencies, a scheme to fill any desired filling pattern is discussed. The beam lifetime at the injection energy is important for filling the required current. Beam lifetimes at different energies for the proposed filling patterns are discussed.

1 INTRODUCTION

The synchrotron radiation source Indus-2 will have the injection energy of 700 MeV. A beam of 700 MeV electrons extracted from the synchrotron will be injected into Indus-2. Indus-2 has been designed to operate at a nominal energy of 2 GeV with a peak energy of 2.5 GeV to satisfy the requirements of the x-ray user community in India. In order to produce required flux and brightness of the synchrotron radiation at this energy, the design current is 300 mA. For the natural bunch volume, the lifetime is few minutes. But due to intrabeam scattering and single bunch effects the bunch volume increases giving rise to an increase in beam lifetime. Estimations of these effects are thus important to ensure that the lifetime at the injection energy will be adequate so as to fill the required current in the ring.

There can be a continuous loss of electrons of the beam due to various processes. The scattering of one electron by another electron within a bunch or by the residual gas can kick the electron out of the machine acceptance (which can be longitudinal or transverse) and thus it is lost. The beam current slowly decreases due to this continuous loss and the time during which the beam current decreases to 1/e of its initial value is defined as beam lifetime. The two main processes contributing to the beam lifetime are the Touscheck scattering and gas scattering.

The molecules of residual gases inside the vacuum chamber are ionised by the collision with electron bunches circulating in the ring. Under certain conditions these ions can be trapped inside the passage of the electron bunches and cause space charge built up, causing tune shift and tune spread of the electron beam and increasing the local pressure in the ring affecting the beam lifetime. The trapping of ions reduces when the periodicity of kicking is reduced. This can be done by introducing a gap between bunches in the same manner as introducing the stop bandwidth in the presence of quadrupole gradient errors. Ion trapping esti-

mates for Indus-2 envisage that ions starting from the lowest mass number will be trapped if all the 291 buckets will be filled and filling of 194 consecutive buckets and leaving 97 empty buckets will reduce ion trapping.

Thus it has been decided to fill 194 consecutive buckets leaving a gap of 97 empty buckets to overcome the ion trapping. There may also be a requirement from synchrotron radiation users to fill a single bunch or symmetric 3 bunches in the ring for some special kind of experiments. The RF frequency of the synchrotron is 31.613 MHz and two out of three bunches are extracted from the synchrotron and will be injected into Indus-2 having a RF frequency of 505.812 MHz. The filling scheme is proposed so as to fill any required filling pattern in Indus-2. The beam lifetime estimates in different filling patterns are described.

2 SINGLE BUNCH EFFECTS

The parameters of Indus-2 given in Table 1 have been used for the estimates. For the ring broadband impedance of 2 Ω, the ring average current of 300 mA in 291 buckets (1.031 mA/bunch) and in 194 buckets (1.546 mA/bunch) at 700 MeV is above the microwave instability threshold. Thus, there will be an increase in the momentum spread associated with bunch lengthening due to potential well distortion and microwave instability. The single bunch estimates predict [1] that a maximum current of 8.8 mA can be stored in a single bunch at 700 MeV. Thus it has been decided to have a design current of 8 mA for operating the ring in single bunch. Figures 1 and 2 show the increase in the bunch length and energy spread as a function of energy in the different filling patterns. In multibunch filling modes, bunch lengthening and increase in energy spread is significant upto 1.1 GeV but in case of single bunch filling with 8 mA it is pronounced upto very high energies and one can observe even a slight bunch shortening after 2 GeV.

Another single bunch effect is the intrabeam scattering where small angle Coulomb scattering within a bunch causes diffusion of the particles, leading to an increase of emittance. This effect has to be added to the radiation damping and the quantum excitation, that defines the natural emittance, in order to find the new equilibrium emittance. A betatron coupling of 1% has been assumed. Calculations of bunch lengthening, widening and increase in emittance have been done using the code ZAP [2]. Figure 3 shows an increase in horizontal emittance in different filling modes. In the energy range 0.7-1.3 GeV there is an increase in the beam emittance due to intrabeam scattering and above this range there is no growth in the natural emittance.

Table 1: **Parameters of Indus-2**

Circumference (m)	172.4743
Ring average current (mA)	300
Injection energy (MeV)	700
Energy loss per turn (keV)	2.06
Natural beam emittance(ϵ_x)(m.rad)	4.55×10^{-9}
Coupling factor	0.01
Energy spread	2.168×10^{-4}
Damping times (τ_x, τ_y, τ_l)(msec)	343,334,165
Momentum compaction	0.005157
Typical tune point	9.2,5.2
Lattice averaged $< \beta_{x,y} >$ (m)	7.934, 7.856
Maximum $\beta_{x,y}$ (m)	21.2, 18.74
RF frequency (MHz)	505.812
Harmonic number	291
Effective beam pipe radius (cm)	2.22
Broadband impedance $|Z/n|$ (Ω)	2
Pressure in the ring (nTorr)	1

Figure 2: Bunch widening
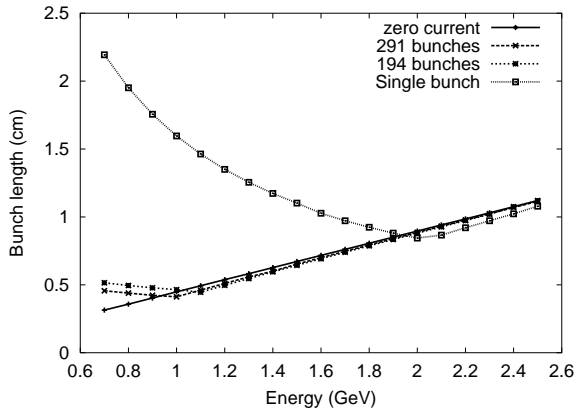

Figure 3: Emittance blow up

Figure 1: Bunch lengthening

3   BEAM LIFETIME

The beam lifetime is defined as the intensity at which the beam intensity is reduced by a factor 1/e. The total beam lifetime is the harmonic sum of Touscheck, vacuum and quantum lifetimes. The care has been taken in choosing the transverse and longitudinal apertures in Indus-2 to have a large quantum lifetime. The lifetime at the injection energy is governed mainly by Touscheck scattering and at higher energies by vacuum.

With the single bunch parameters as obtained by single bunch effects described in section 2 and the dynamic apertures of ± 15 mm in the x-plane and ± 8 mm in the vertical plane have been used for the lifetime estimates. These dynamic apertures are obtained after incorporating all the multipole errors. A minimum dynamic aperture of ± 13 mm is required to carry out the injection process in the horizontal plane [3]. As the RF voltage is ramped during energy ramping so as to keep the synchrotron tune constant, the corresponding bucket half heights have been consid-
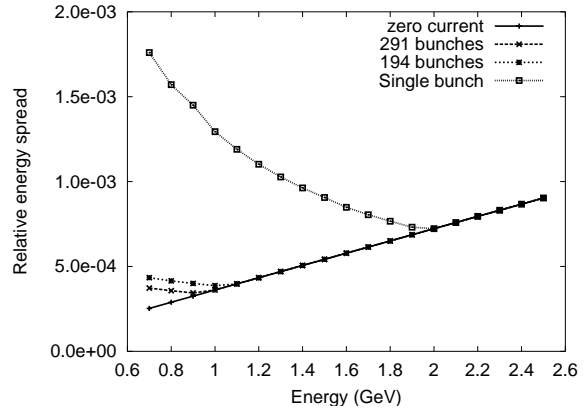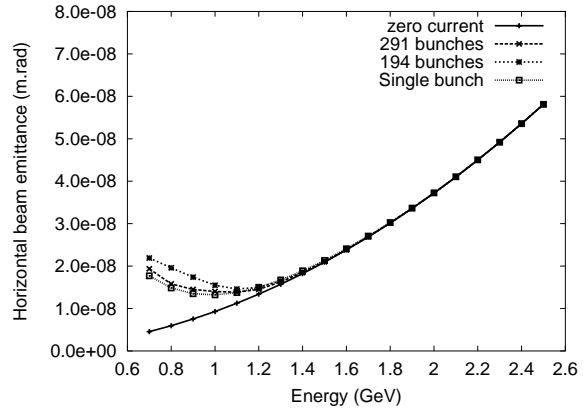
ered for vacuum lifetime estimates. The vacuum lifetimes have been estimated for 1 nTorr pressure of N_2 equivalent gas. The vacuum lifetime is taken as a harmonic sum of the vacuum lifetimes in the horizontal and the vertical planes. The contributions of the Touschek and vacuum lifetimes to the total lifetimes at different energies are shown in Figure 4 for the case of 2/3 filling of the ring (194 buckets). The beam lifetimes at different energies in various filling modes are given in Figure 5.
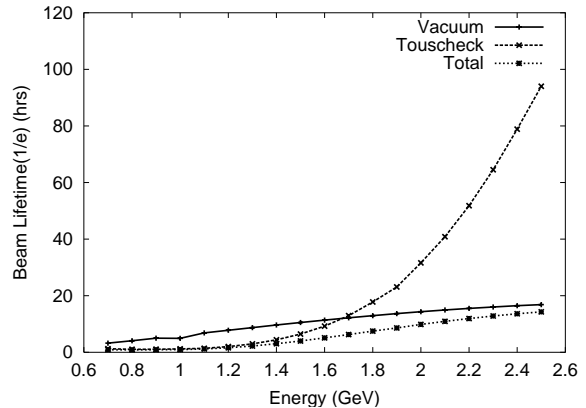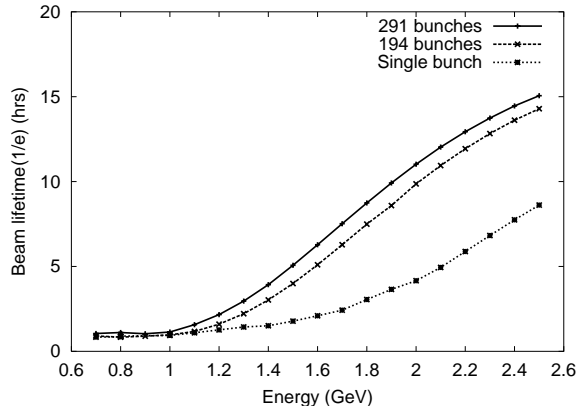

Figure 4: Lifetime contributions

Figure 5: Beam lifetimes in different filling patterns

4 SCHEMES OF FILLING OF BUCKETS

The synchrotron operates at 31.613 MHz RF frequency. This frequency is 3 times the revolution frequency of the synchrotron thus there are 3 buckets in the synchrotron. With the injection method followed in the synchotron, all the three buckets are filled giving 3 circulating bunches [4]. Out of these three bunches only two can be extracted due to rise time of the extraction kicker. Indus-2 will have RF frequency of 505.812 MHz and 291 buckets. The following scheme is proposed for filling any desired buckets in Indus-2 using two extracted bunches from the synchrotron.

- Indus-2 RF frequency (f_{I-2}) = 16 × synchrotron RF frequency (f_{syn})
- Revolution frequency of Indus-2 = $f_{I-2}/291$
- Revolution frequency of synchrotron = $f_{syn}/3$
- If N_{I-2} and N_{syn} are the number of revolutions of Indus-2 and synchrotron respectively, then :
  $N_{I-2} \times (291/f_{I-2}) = N_{syn} \times (3/f_{syn})$
  $N_{I-2} \times 97 = N_{syn} \times 16$
  This implies that when an electron makes 97 revolutions in the synchrotron, an electron in Indus-2 will make 16 revolutions. So, the coincidence time is 97 $\times 3/f_{syn}$ = 9.205 μsec.
- For T^{RF}_{syn} and T^{rev}_{I-2} as the synchrotron RF time period and revolution time for Indus-2 respectively, the following relations can be written for integers n,m and k:

  n T^{RF}_{syn} = n(16/291) T^{rev}_{I-2}
  n × (16/291) T^{rev}_{I-2} = m T^{rev}_{I-2} + (k/291) T^{rev}_{I-2}
  n = (291 × m + k) / 16
  When m=5k, n=91k which is integer for any value of k. So, advancing by i × 91 every time, i^{th} bucket can be filled.

If extraction from the synchrotron will be locked with the coincidence time pulse and RF's of the synchrotron and Indus-2 will be locked with each other, the two extracted bunches can fill the 1st and 17th bucket of Indus-2 every time (1-2 Hz).

To selectively fill the consecutive buckets of Indus-2, the synchrotron RF periods after the first extraction can be counted. The extraction delay after the first coincidence pulse should be varied as 0 × 91, 1 × 91, 2 × 91,·····(h-b-16) × 91 RF periods of the synchrotron on the subsequent extractions, where h is the harmonic number and b is number of gaps in the buckets. After first filling upto h-b, the counter should be set back to zero and the same logic should be repeated to fill more current in the buckets till the required current is filled.

To fill the single bucket, a single bunch can be extracted from the synchrotron by adjusting the extraction kicker delay. The extraction will be carried out when the extraction energy is reached and the coincidence occurs. Thus, every time the same bucket will be filled if no additional delay is given. The same logic can be used for filling of say 3 symmetric buckets by adjusting the delays as 0 × 91, 96 × 91 and 183 × 91 synchrotron periods. The maximum delay necessary in order to fill all the 291 buckets will be 290 × 91 synchrotron periods, i.e. 835 μsec.

5 CONCLUSIONS

Indus-2 synchrotron radiation source will be operated in different filling modes. To avoid the ion trapping problem, it is proposed to fill two third of the ring continuously by leaving a gap of one third ring. There can be a request from the synchrotron radiation users to fill the ring in a single bunch or few bunches mode. As Indus-2 will be operating at 505.812 MHz and the synchrotron at 31.613 MHz, a scheme is proposed to count the number of synchrotron RF periods after the first extraction and adjust the necessary delay at every injection. This logic will make it possible to fill any desired filling pattern in Indus-2. The beam lifetimes estimates under different filling conditions ensure that the lifetime of nearly one hour will be available at the injection energy which will be sufficient for accumulating 300 mA current in multibunch and 8 mA in single bunch operation. At peak energy the beam lifetime will be governed by the vacuum lifetime and it will be nearly 14 hours with two third of ring filled and nearly 9 hours with a single bunch at 8 mA.

REFERENCES

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