STUDIES OF BEAM LIFETIME IN INDUS-2 ELECTRON STORAGE RING

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Abstract

Indus-2 is an electron storage ring operating with 100mA beam current at beam energy 2GeV and is in use by beamline users. A longer beam lifetime is desired since it would allow higher integrated photon flux to be delivered for user's shifts. In this paper, we present a set of measurements performed at beam energy 2.0 GeV. We measured the beam lifetime as a function of current during beam current decay and vacuum pressure all around the circumference of the ring. These measurements helped us to estimate the contribution of various loss mechanisms such as Touschek, elastic and inelastic scattering etc. to the lifetime of the beam. Comparison with theory is also presented as well as an interpretation of each effect is made, which is useful for finding the limiting factor which governs the beam lifetime.

INTRODUCTION AND THEORY

The lifetime τ of an electron beam containing N particles is defined through its relative loss rate at a given time [1,2]:

$$\frac{1}{\tau} = -\frac{\left(dN/dt\right)}{N}$$

Indus-2 is an electron storage ring designed for 2.5GeV beam energy. The beam of energy 550MeV from booster synchrotron is injected and stored in Indus-2 and ramped to higher energy. During last six month the ring was operated at 100mA at beam energy 2GeV. In this paper we present the results of beam lifetime experiments carried out during March'10 to September'10.

Mainly three processes i.e. Gas scattering, Touschek scattering and Quantum lifetime decide beam lifetime in an electron storage ring [3]. For analysing stored beam current decay we considered Gas scattering and Touschek scattering effect and ignoring quantum lifetime because it does not contribute under normal conditions.

1. Gas scattering: There are essentially two processes in electron beam-gas interactions.

i) The elastic scattering on nuclei of gas atom

ii) The Inelastic scattering on nuclei of gas atom

The beam lifetime due to elastic scattering is given by

$$\frac{1}{\tau_{nuclei-el}} = \frac{2\pi r_e^2 KZ^2}{\gamma^2} \cdot \frac{\beta_{max}}{a^2} \cdot \langle \beta . P \rangle \qquad (1)$$

Where r_e: classical electron radius, Z: atomic number of the residual gas species, K: constant, γ : normalized energy,< β. P >: average of product of betatron amplitude function and vacuum pressure, a : limiting aperture and β_{max} : maximum betatron amplitude function of the ring.

The lifetime due to Inelastic scattering on nuclei also known as bremsstrahlung radiation emission is given by

$$\frac{1}{\tau_{nuclei-inel}} = \frac{4 r_e^2 KZ^2 \langle P \rangle}{137} \frac{4}{3} \ln\left(183 / Z^{1/3}\right) \left[\ln\left(1 / \Delta\varepsilon/\varepsilon\right) - \frac{5}{8} \right] \quad (2)$$

Where Δε/ε is the momentum acceptance. This process is practically independent of the electron beam energy.

2. Touscheck scattering:

The large angle coulomb scattering within the bunch contributes to the beam lifetime significantly. The Touscheck scattering half lifetime [4] is given by:

$$\frac{1}{(\tau_{1/2})_{Tous}} = \frac{\pi^{1/2} r_e^2 c N}{\gamma^2 (\Delta p_x)^3 \varepsilon_A V_B} F(\varepsilon_A) \qquad (3)$$

N: number of particles per bunch, V_B: bunch volume.

The total beam lifetime τ is define as:

$$\frac{1}{\tau} = \frac{1}{\tau_{nuclei-el}} + \frac{1}{\tau_{nuclei-inel}} + \frac{1}{(\tau_{1/2})_{Tous}(e-1)} \qquad (4)$$

RESULTS

Beam current 100 mA was stored in Indus-2 ring at beam energy 2GeV. The beam was left for its natural decay; time variation of average beam current and vacuum pressure was monitored. To compare the measured beam lifetime, theoretical estimation of vacuum and Touschek lifetime and total lifetime was carried out using formula 1-4. The parameters used in computations are given in Table 1. The measured beam current decay pattern taken in the month of March, June and September'10 is shown in figure1. This figure shows that beam current decay rate becoming slower with increase in running time of the ring. By energising two RF station with peak cavity gap voltage 375KV each, estimated quantum lifetime is more than 100 hours, which is significantly larger than the observed beam lifetime thus may not be a limiting factor so it was ignored in theoretical estimation of total beam lifetime. To understand the beam loss mechanism, peak cavity gap voltages and phases of operating RF stations were kept same so that Touschek lifetime is same in all these experiments.

Table 1: Parameters used in computation

Operating Tune ν_x ,ν_z	9.32, 6.14
Half aperture $_{\text{Horizontal, Vertical}}$ at injection	15, 6 mm
Half aperture $_{\text{Horizontal, Vertical}}$ at β_{max}	20.5, 12.5 mm
Horizontal, Vertical β_{max}	18.8, 15,5 m
Average β in $_{\text{Horizontal, Vertical}}$ plane	6.99, 5.73 m
Half aperture $_{\text{Horizontal}}$ at dispersion η_{max}	14mm
Residual gas atomic number (Z)	N_2
Horizontal beam emittance (m.rad)	8.46×10^{-8}
RF frequency	505.812 MHz

Vacuum pressures at 35 locations distributed over entire ring were monitored. Measured beam lifetime and average vacuum pressures at different stored beam current conditions during beam current decay is shown in figure2. This figure shows that, there is an improvement in beam lifetime and reduction in average vacuum pressure at different beam current from March to September'10.

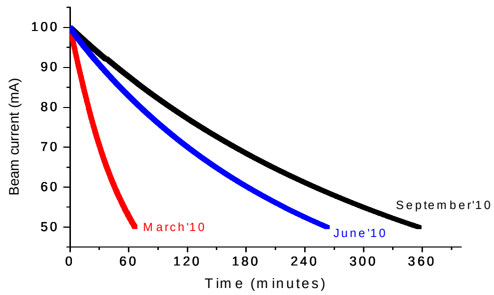

Figure 1: Improvement in beam current decay pattern

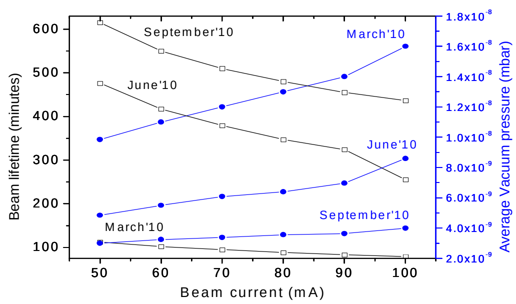

Figure 2: Average vacuum pressure and beam lifetime during beam current decay

With the existing vacuum pressures at 35 locations in the ring, a pressure profile along the beam path was generated. Using theoretical values of beta function of present operating lattice in horizontal and vertical plane, β_x.P and β_z.P was estimated. With the average values of β_x.P and β_z.P vacuum lifetime in horizontal and vertical plane at different stored beam current due to elastic scattering was estimated. From relation 2 with average pressure, vacuum lifetime due to inelastic scattering was estimated. Theoretical estimation of vacuum lifetime due to elastic and inelastic scattering is shown in figure 3. In this figure $\tau_{nuclei-el}$ is harmonic sum of vacuum lifetime in horizontal and vertical plane.

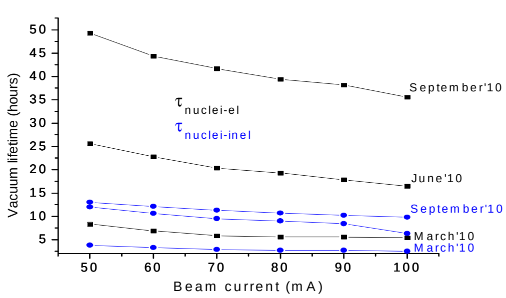

Figure 3: Theoretical estimation of vacuum lifetime due to elastic and inelastic scattering

The results show that, vacuum lifetime due to inelastic scattering of electron beam with the nuclei of residual gas atom is the limiting factor. Total vacuum lifetime was estimated by harmonic sum of vacuum lifetime due to elastic and inelastic scattering. By assuming all 291 RF buckets filled uniformly, 1% betatron coupling Touschek lifetime at different stored beam current was estimated. A theoretical estimate of Touschek and vacuum lifetime at different stored beam current is shown in figure 4.

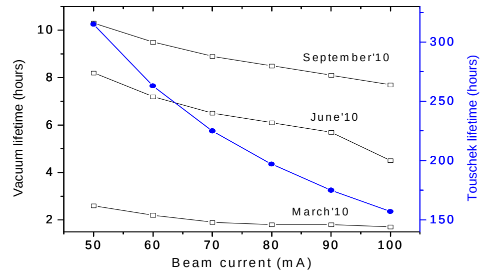

Figure 4: Theoretical vacuum and Touschek lifetime

The comparison of measured results with theoretical estimates is shown in figure 5. The results show that the gain in beam lifetime is due to the improvement in vacuum lifetime.

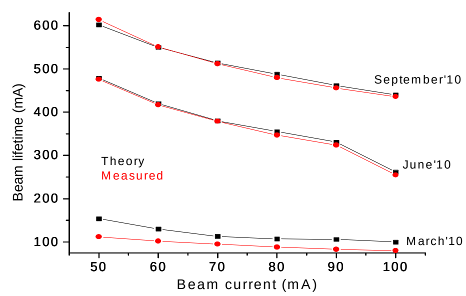

Figure 5: Comparison of measured lifetime with estimates

CONCLUSIONS

We tried to correlate the measured beam lifetime with theoretical estimates. Beam lifetime was estimated by assuming horizontal and vertical aperture15 and 6mm respectively necessary for beam injection and assuming RF acceptance (~0.7%) as a limiting factor for off momentum particle motion. Considering all 291 RF bucket uniformly filled with 1% betatron coupling the theoretical estimates are near to measured results. The results show that at present beam lifetime at 2GeV and 100mA is dominated by vacuum condition in the ring. Improvement in the vacuum will take place after repeated machine runs, in addition after closed orbit correction there will be increase in vacuum lifetime of the beam.

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