BEAM LIFETIMES IN THE ATF DAMPING RING

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Abstract

Electron beam lifetimes in the Accelerator Test Facility (ATF) damping ring are limited by elastic and inelastic beam-gas scattering as well as the Touschek effect, which, due to intrabeam scattering, transfers transverse into longitudinal momentum exceeding the momentum acceptance of the machine, thus leading to particle loss. Since the Touschek effect depends strongly on the vertical beam size, it can be utilized to determine the vertical beam emittance, thus providing a cross-check for data obtained by different methods, e. g. using the synchrotron radiation monitor. First results of beam lifetime studies and estimates of the vertical emittance are presented.

1 INTRODUCTION

Since all future Linear Colliders require very low emittance beams in order to achieve high luminosity, a prototype damping ring has been constructed at KEK to study the feasibility of the required beam parameters [1]. This ATF damping ring came into operation in early 1997, and its performance has been studied and improved since. In this paper the measurement of the electron beam lifetime is presented.

2 BEAM-GAS SCATTERING

In general, the beam lifetime can be limited by four different beam-gas scattering processes. First of all, the beam electrons interact with the nuclei of the residual gas such that they are scattered elastically (EN). This leads to particle loss if the electrons are scattered out of the transverse acceptance of the machine. Secondly, inelastic scattering off either the electrons (IE) or the nuclei (IN) of the residual gas occurs, leading to energy loss of the beam particle, which is lost if the energy loss exceeds the energy acceptance of the machine. Finally, elastic scattering of the beam particles off the gas electrons (EE) primarily leads to loss of particles because they exceed the energy acceptance of the ring.

With σ the total cross section of the beam-gas interaction and P the vacuum pressure, the beam-gas lifetime τ_{bg} can be written as [2]

$$\frac{1}{\tau_{bg}} = -\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}t} = 7.3\cdot 10^{28}\frac{\sigma}{\mathrm{m}^2}\frac{P}{\mathrm{Pa}}\,\mathrm{sec}^{-1}, \quad (1)$$

where N is the number of electrons in the beam.

As already mentioned, the total cross section σ of the beam-gas interaction can be written as the sum of four different cross sections,

$$\sigma = \sigma_{EN} + \sigma_{IE} + \sigma_{IN} + \sigma_{EE}. \quad (2)$$

The cross section for elastic scattering off the gas nuclei (EN) of charge $Z\cdot e$ can be written as [2]

$$\sigma_{EN} \approx \frac{2\pi r_0^2 Z^2}{\gamma^2}\frac{\langle\beta\rangle}{a^2/\beta_0}, \quad (3)$$

where r_0 is the classical electron radius, $\langle\beta\rangle$ is the average β-function around the ring, and a^2/β_0 is the radius a of the limiting aperture squared divided by the local β-function β_0. γ is the relativistic γ-factor.

The cross section for inelastic scattering of the beam electrons off the nuclei in the residual gas is [2]

$$\sigma_{IN} \approx \frac{16 r_0^2 Z^2}{411}\ln\frac{183}{Z^{\frac{1}{3}}}\left(\ln\frac{1}{\Delta E/E} - \frac{5}{8}\right) \quad (4)$$

where $\Delta E/E$ is the longitudinal acceptance.

The cross section for elastic scattering off the electrons of the residual gas (EE) reads [2]

$$\sigma_{EE} \approx \frac{2\pi r_0^2 Z}{\gamma}\frac{1}{\Delta E/E}, \quad (5)$$

while for inelastic scattering off the gas electrons (IE) it can be written as [2]

$$\sigma_{IE} \approx \frac{16 r_0^2 Z}{411}\left(\ln\frac{2.5\gamma}{\Delta E/E} - 1.4\right)\cdot \left(\ln\frac{1}{\Delta E/E} - \frac{5}{8}\right). \quad (6)$$

3 GAS DESORPTION

In the case of an electron storage ring like ATF, the vacuum pressure P is not simply a constant but depends strongly on the beam current I due to gas desorption induced by synchrotron radiation hitting the vacuum chamber. This process leads to a vacuum pressure which, in good approximation, depends linearly on the beam current [2],

$$P(I) = P_0 + k\cdot I, \quad (7)$$

where P_0 is the static vacuum pressure at zero beam current, while k is a constant. Figure 1 shows a measurement of the average vacuum pressure in the ATF damping ring as function of the beam current.

Together with equation 1, this leads to a beam lifetime which depends on the beam current itself. Therefore, the beam current cannot be described as a simple exponential decay as function of time anymore.

[0]Now at DESY, Hamburg, Germany

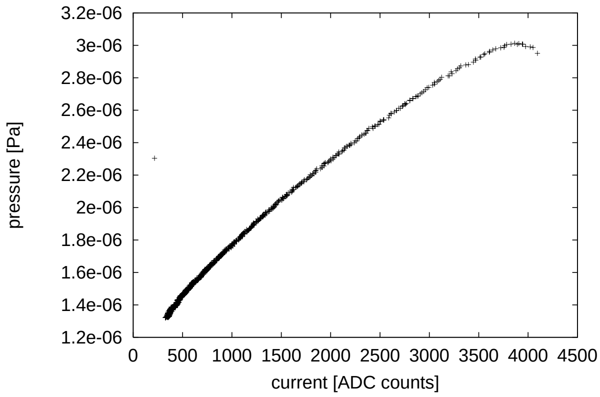

Figure 1: Measured average vacuum pressure in the ATF damping ring as function of the beam current.

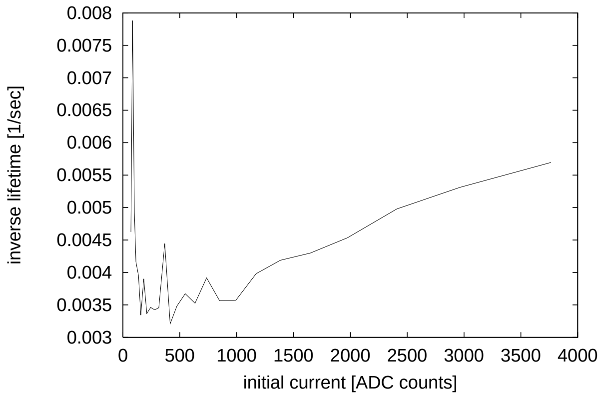

Figure 2: Inverse lifetime as function of the (initial) beam current in each interval.

4 RESULTS

To determine the beam lifetime in the ATF damping ring, the electron beam current and the vacuum pressure data have been taken simultaneously over periods of roughly 10 minutes each. Since the vacuum pressure depends linearly on the beam current, the beam lifetime as a function of the beam current reads

$$\begin{aligned} \frac{1}{\tau_{bg}(I)} &= -\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}t} \\ &= -\frac{1}{I}\frac{\mathrm{d}I}{\mathrm{d}t} \\ &= 7.3\cdot 10^{28}\frac{\sigma}{\mathrm{m}^2}\frac{P(I)}{\mathrm{Pa}}\,\mathrm{sec}^{-1} \\ &= 7.3\cdot 10^{28}\frac{\sigma}{\mathrm{m}^2}\frac{P_0+k\cdot I}{\mathrm{Pa}}\,\mathrm{sec}^{-1} \qquad (8) \end{aligned}$$

Here we assumed that the beam lifetime is purely determined by beam-gas scattering and not by such effects as intrabeam scattering, Touschek effect, etc.
As can be seen from equation 8, the inverse beam lifetime depends linearly on the beam current. Therefore each set of measured data was divided into several intervals of equal length. Each of these intervals was then fitted using an exponential function, and the resulting inverse beam lifetime within each interval was plotted versus the initial current of each interval. As an example, figure 2 shows the result of such an analysis. As can be seen from figure 2, the inverse lifetime indeed depends linearly on the (initial) beam current, while for very small beam currents the errors due to measurement noise dominate. For sufficiently large beam currents we have

$$\begin{aligned} \frac{1}{\tau_{bg}} &= 3.3\cdot 10^{-3}\,\mathrm{sec}^{-1} \\ &\quad +7.7\cdot 10^{-7}\cdot\frac{I}{\mathrm{ADC\,counts}}\,\mathrm{sec}^{-1}, \qquad (9) \end{aligned}$$

where the beam current I is given in ADC counts rather than in Amps.

From the pressure and beam current data, we get for the current dependent pressure

$$\begin{aligned} P(I) &= P_0 + k\cdot I \\ &= 1.33\cdot 10^{-6}\,\mathrm{Pa} + 5.43\cdot 10^{-10}\cdot \\ &\quad \frac{I}{\mathrm{ADC\,counts}}\,\mathrm{Pa}. \qquad (10) \end{aligned}$$

Inserting this into equation 8 and comparing this with equation 9 leads to

$$\begin{aligned} \frac{1}{\tau_{bg}} &= \left(9.7\cdot 10^{22} + 4.0\cdot 10^{19}\frac{I}{\mathrm{ADC\,counts}}\right) \\ &\quad \cdot\frac{\sigma}{\mathrm{m}^2}\mathrm{sec}^{-1} \qquad (11) \\ &= \left(3.3\cdot 10^{-3} + 7.7\cdot 10^{-7}\frac{I}{\mathrm{ADC\,counts}}\right) \\ &\quad \mathrm{sec}^{-1}. \qquad (12) \end{aligned}$$

Resolving both the expression for the offset and the slope for σ, we get $\sigma = 3.4\cdot 10^{-26}\,\mathrm{m}^{-2}$ and $\sigma = 1.9\cdot 10^{-26}\,\mathrm{m}^{-2}$, respectively. The discrepancy of a factor of about two between the two results might indicate an error in the pressure and/or the beam current measurement.
As can be seen from equation 9, the measured lifetime is shorter than 5 minutes, while the beam lifetime calculated from the cross sections for the IN, EE and IE process is larger than 10 minutes for the corresponding measured vacuum pressures [3]. Therefore, we can neglect these contributions here and assume that the beam lifetime is purely determined by the EN process. Resolving the expression for the EN cross section for the aperture, we get an aperture radius of about $a = 1\,\mathrm{mm}$ at a local β_0 of $10\,\mathrm{m}$.

5 REFERENCES

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