

Beam Lifetime in ELETTRA

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Abstract

The improvement in beam lifetime in ELETTRA during commissioning and initial operation is described. The results of measurements that have been carried out to determine the relative contributions of inelastic and elastic gas scattering and Touschek scattering are presented.

1. INTRODUCTION

Approximately 8 months since the first stored beam in ELETTRA [1] the ring is now operating routinely with a lifetime of 10 h at 100 mA at 2 GeV, after accumulating a total beam dose of 60 Ah. Commissioning began in October 1993 with the standard straight section vacuum chambers in place, which have an internal aperture of 80 mm (horiz.) x 56 mm (vert.). At that time only one sector (1/6th) of the ring had been baked-out (150°C) [2]. Since then a number of events have occurred that are relevant to the beam lifetime: i/ the remaining sectors of the ring have all been baked-out during various shutdown periods; ii/ three ID vacuum chambers have been installed with 20 mm internal vertical aperture; iii/ there have been several other interventions into the vacuum system to install a beam stopper, replace a photon absorber and repair some faulty r.f. shields.

In the following we present data about the improvement in lifetime during the commissioning and initial operation and attempt to understand the various contributing factors. We refer to the instantaneous decay rate $1/\tau = -(dI/I)/dt$, which according to theory is the sum of three main contributions:

$$\frac{1}{\tau} = \frac{1}{\tau_{inelastic}} + \frac{1}{\tau_{elastic}} + \frac{1}{\tau_{Touschek}}$$

which can be written as follows:

$$\frac{1}{\tau} = \left(a + \frac{b}{A^2} \right) (P_0 + P_1 I) + c I$$

where a , b and c are the inelastic, elastic and Touschek scattering terms respectively, P_0 is the base pressure, P_1 the gas desorption and A is the vacuum chamber limiting half-aperture.

2. MULTI-BUNCH

Most data have been taken under multibunch conditions at injection energy, that has varied between 1.0 and 1.18 GeV depending on linac performance. Fig. 1 shows a typical set of individual lifetime measurements taken during the second machine run (October 1993). The data were taken under slightly different conditions of tune, chromaticity, r.f. voltage, and fill uniformity which accounts for the variability in lifetime. The results are nevertheless well approximated by a linear relationship. The data from each run has been fitted in this way to extract the current dependent term. Fig. 2 shows

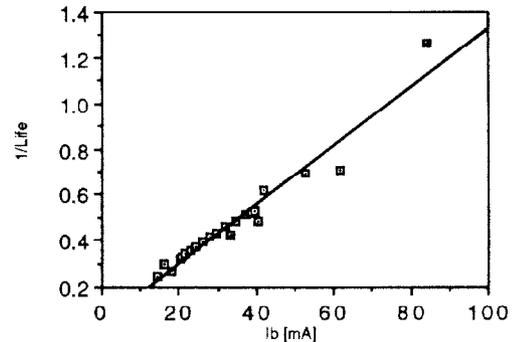


Figure 1. Decay rate (h^{-1}) as a function of beam current.

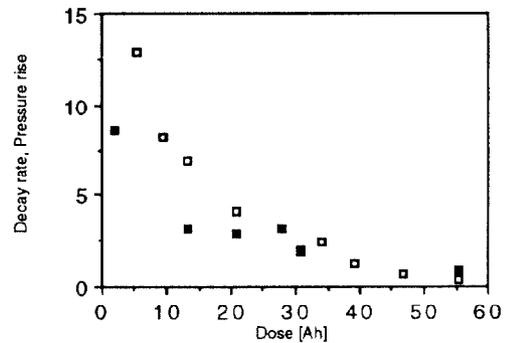


Figure 2. Decay rate ($\text{h}^{-1} \text{mA}^{-1} \times 10^3$), open squares, and pressure rise ($\text{nTorr mA}^{-1} \times 10^2$), solid squares, as a function of accumulated beam dose (Ah).

how this has improved during the first 8 months operation. The data are plotted as a function of total accumulated beam dose, irrespective of beam energy.

The marked improvement in lifetime - from 0.5 h (after about 2 Ah) to the present 15.7 h at 1.1 GeV - has resulted mainly from the reduction in gas desorption, as can be seen from the approximate correlation with measured gas desorption coefficient (P_1) shown in fig. 2. For the latter the pressure has been measured using the Penning gauges in 12 of the 24 bending magnets that are not affected by the synchrotron radiation emission [3]. A smaller contribution comes from the increase in Touschek lifetime as a result of the gradual increase in accelerating voltage. Initially one cavity was used with an accelerating voltage of 350 kV, but later this was increased to two and then three cavities, giving 1.05 MV total. Under present conditions the lifetime at 100 mA changes from 15.7 h to 6.7 h with an r.f. voltage reduced from 1.05 MV to 0.35 MV i.e. a difference in decay rate of $0.8 \cdot 10^{-3} \text{ h}^{-1} \text{mA}^{-1}$. Thus the influence of r.f. voltage is secondary to that due to the reduction of desorption.

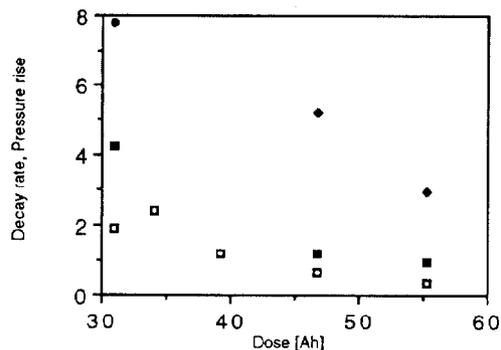


Figure 3. Decay rate ($\text{h}^{-1} \text{mA}^{-1} \times 10^3$) at 1.1 GeV, open squares, and 2 GeV, solid squares; pressure rise at 2 GeV ($\text{nTorr mA}^{-1} \times 10^2$), diamonds, as a function of beam dose.

Energy ramping was first achieved in January '94, after a dose of 27 Ah had already been accumulated at injection energy. Initially only small currents were ramped for test purposes. The first user shifts at 1.5 GeV and later 2 GeV were also initially with low current, and so the beam dose accumulated at high energy has been relatively small. Fig. 3 shows that the decay rate at 2 GeV has been about a factor 2.6 worse than at 1.1 GeV, largely as a result of the greater beam desorption, approximately 3.6 times higher than at 1.1 GeV. This is due partly to the increased photon flux, scaling linearly with energy, and the effects of thermal desorption due to heating of parts of the vacuum chamber. Figure 3 shows however that both the pressure and decay rate are improving rapidly with beam dose.

The present lifetime and measured pressure rise at 1.1 and 2 GeV are shown in figs. 4 and 5. The present operating conditions are with a gap in the bunch pattern of between 5 and 25 % which eliminates the effects of ion trapping such as low-frequency oscillations and variability in beam lifetime.

In view of the scarcity of the data, and the changing vacuum and r.f. system conditions, it is impossible to predict in detail the future lifetime performance. It is clear however that the lifetime is pressure dominated, and should be significantly better than at present by the time the specified dose of 100 Ah has been reached.

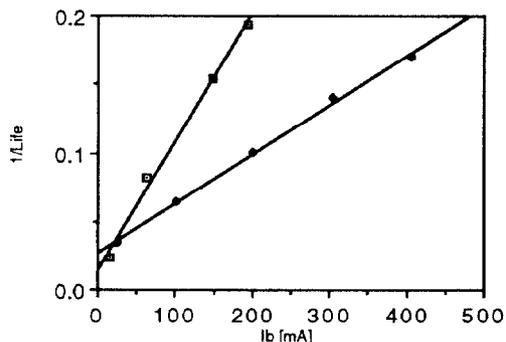


Figure 4. Decay rate at 1.1 GeV (lower) and 2 GeV (upper).

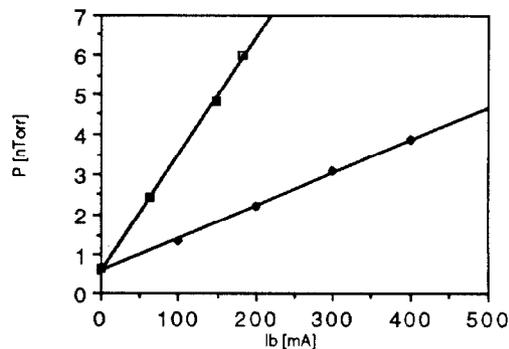


Figure 5. Average pressure rise with current at 1.1 GeV (lower) and 2 GeV (upper).

3. SINGLE BUNCH

Single bunch operation was commissioned in April 1994, giving for the first time the possibility to learn something about the separate contributions of gas scattering and Touschek lifetime. Fig. 6 shows the decay rate as a function of single bunch current at 1.1 GeV with two different accelerating voltages. Under these conditions the gas scattering lifetime can be neglected. It is clear from the non-linear dependence that the beam dimensions are not constant. The solid lines indicate the calculated Touschek lifetime

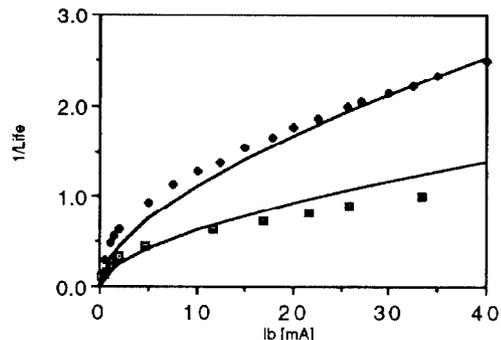


Figure 6. Decay rate in single bunch mode with r.f. voltages of 0.7 MV (upper) and 1.05 MV (lower) at 1.1 GeV

assuming nominal emittance ($2.1 \cdot 10^{-9}$ m rad) and with bunch lengthening determined by the microwave instability using the estimated broad-band impedance, $Z/n = 0.75 \Omega$ [4]. No reduction in broad-band impedance is taken into account for low currents, where the bunch length is smaller than the vacuum chamber radius. An emittance coupling factor of 3 % has been used to obtain a reasonable fit to the data. This is a reasonable value given the measured betatron coupling coefficient and vertical dispersion, and some expected increase in beam size due to intra-beam scattering [5]. It can be seen that the calculated variation of decay rate with current and the relative magnitude of the decay rate with the two voltages is in good agreement with the measured values.

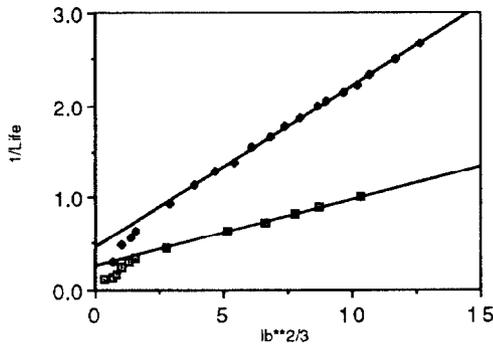


Figure 7. Data of fig. 6, plotted as a function of $I_b^{2/3}$.

Fig. 7 shows the measured data plotted against $I_b^{2/3}$. It can be seen that there is a linear relationship, consistent with bunch length increase as $I_b^{1/3}$, in agreement with the measured bunch length variation [5]. The same threshold can also be seen at about 2 mA.

It is interesting to note that with the same bunch current the lifetime in multibunch is larger than that in single bunch. For example, with 0.51 mA (1 mA) per bunch the single bunch lifetime is 7.4 h (4.2 h) whereas in multibunch it is 9.7 h (5.7 h). A similar discrepancy is apparent when comparing the calculated Touschek lifetime with the measured lifetime under multibunch conditions. For example, at 100 mA the calculated Touschek lifetime (using the same parameters as above) is 12.5 h, whereas the measured lifetime is 16 h. It appears therefore that some further bunch length increase is present in the multibunch case, possibly due to the longitudinal coupled bunch instabilities that have been observed.

4. ELASTIC SCATTERING

The storage ring is equipped with a set of horizontal and vertical scrapers at the end of an insertion device (dispersion free) straight section which have been used to determine the contribution to the lifetime of the Coulomb elastic scattering. Fig. 8 shows the results of a recent set of measurements as a function of vertical aperture ($A = \text{half-gap}$). It can be seen that there is a linear dependence of decay rate with $1/A^2$ as expected. Fig. 9 shows that the slope depends linearly on beam current.

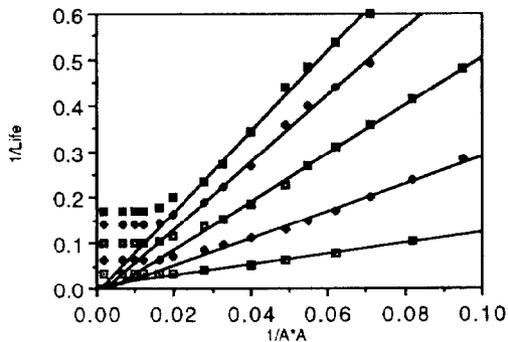


Figure 8. Decay rate as a function of $1/A^2$ at 25 mA (lowest), 100 mA, 200 mA, 300 mA and 400 mA (uppermost).

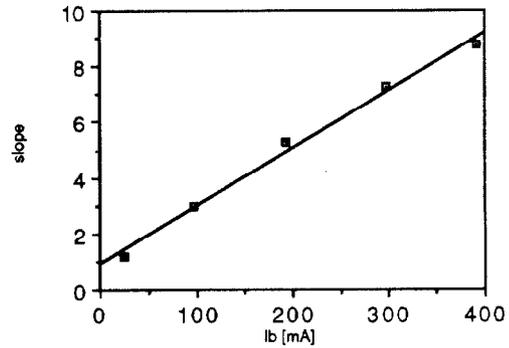


Figure 9. Variation of elastic scattering term ($\text{h}^{-1} \text{mm}^2$) with current.

From the fit we obtain a value $bP_1 = 0.021 \text{ h}^{-1} \text{mm}^2 \text{mA}^{-1}$. Using the measured value $P_1 = 8.1 \cdot 10^{-3} \text{ nTorr mA}^{-1}$ we then obtain $b = 2.6 \text{ h}^{-1} \text{nTorr}^{-1} \text{mm}^2$. Various measurements, including those carried out before introducing the narrow gap vessels, have given results consistent with this value. The intercept of the $1/\tau$ vs. $1/A^2$ graphs does not however give reliable information. A measurement has also been carried out at 2 GeV, which gave the result $b = 0.90 \text{ h}^{-1} \text{nTorr}^{-1} \text{mm}^2$, compared to a value of 0.79 that would be expected from the $1/\gamma^2$ scaling of the 1.1 GeV value. These values are however much larger than expected theoretically. The calculated value at 1.1 GeV is $1.3 \text{ h}^{-1} \text{mm}^2 \text{nTorr}^{-1}$, assuming N_2 as residual gas. However, the residual gas appears to be composed of 95 % Hydrogen [2], so the discrepancy, after taking into account the $Z(Z+1)$ dependence, is about a factor of 20. The results are nevertheless consistent with those reported elsewhere and are encouraging from the point of view of the future implementation of smaller aperture vacuum vessels. Even under present conditions a gap as small as $\pm 3 \text{ mm}$ gives a lifetime of 2.7 h at 100 mA; when the pressure reduces to 1 nTorr the lifetime with this gap would become nearly 10 h.

5. REFERENCES

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