BEAM LIFETIME MEASUREMENTS IN ELETTRA

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ABSTRACT

The beam lifetime in ELETTRA is dominated by Touschek scattering. In modifying the beam characteristics, i.e. the emittance coupling and the excitation level of longitudinal coupled bunch instabilities, the beam lifetime can be varied over a wide range and adjusted to the need of the users. Relaxed machine conditions correspond to a long lifetime with reduced beam quality, whereas a highly optimised machine goes in parallel with a reduced lifetime. Measurements of the beam lifetime in ELETTRA under various operating conditions were carried out in order to separate the relative contributions to the overall lifetime. A comparison with the theory is performed.

1 INTRODUCTION

ELETTRA has entered its third calendar year of operations [1] and is routinely delivering photons of very high brilliance -being a third generation light source- in the VUV to soft X-Ray region. For its users beam lifetime is an important issue that draws a particular attention due to ELETTRA's linac - storage ring energy mismatch whereby injection is performed at 1 GeV while the ring has to come to its operating energy (2 GeV) via energy ramping.

Some months after the start of the commissioning in autumn 1993 Touschek scattering had been already an important limiting factor [2]; now after two and a half years of operation and after accumulating a total dose of 1235 Ah, the beam lifetime is Touschek scattering dominated. Measurements of lifetime in single-bunch assuming nominal emittance and with bunch lengthening determined by the estimated (via bunch length measurement [3]) broad-band ring impedance, Z/n=0.75Ω are consistent with expectations (τ= 4 hours at 1 GeV and τ= 8.6 hours at 2 GeV with 0.85 mA per bunch). In the multi-bunch mode however lifetime can be significantly longer (τ=25 hours at 2 GeV and 250 mA in 346 bunches to be compared with the τ=10 hours predicted Touschek lifetime) due to blow up of the longitudinal phase space caused by longitudinal multi-bunch instabilities. The increased momentum spread leads to some degradation of the undulator spectral performance but in many cases the users prefer this operational mode i.e. long lifetimes. Controlling the longitudinal multibunch-instabilities by adjusting the temperatures of the cavities [4] and thus shifting away the dangerous higher order modes the predicted lifetimes and the expected spectral characteristics are obtained (see Fig. 2).

In the following we present data taken under various machine operating modes and settings. Thus measurements have been performed from 1 to 2 GeV, with various beam filling and emittance coupling.

Presenting and analysing the data we refer to the instantaneous decay rate 1/τ = -(dI/I)/dt, which is the sum of the elastic, inelastic and Touschek scattering decay rates and can be written as follows:

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

where a, b and c are the inelastic, elastic and Touschek scattering terms respectively, P_0 refers to the pressure in the absence of beam, P_1 is the gas desorption and A is the vacuum chamber limiting half aperture.

2 MULTI-BUNCH

All data presented for this operating mode are at 2 GeV and for the theoretical predictions always the nominal emittance (7 nm rad) is assumed which has been verified by beam profile measurements and by fitting the super-ESCA spectra. Figure 1 presents the product of beam current (mA) and lifetime (hours) showing three distinct sets of data taken for three different rms vertical dispersion values. For the upper set (squares and crosses) 10 and 6 mA in 12 bunches were used with measured rms vertical dispersion of 2.1 cm (corresponding to 2% coupling). For

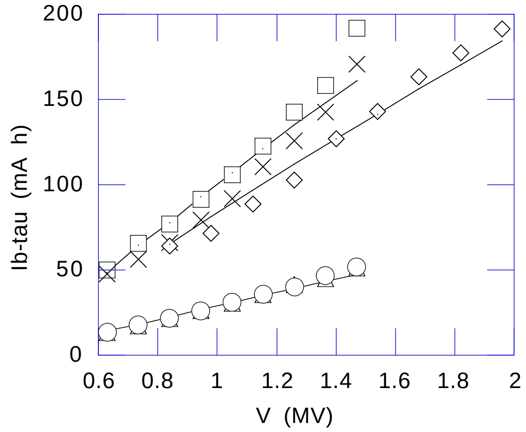

Figure 1. Product of beam current (mA) and lifetime (hours) at 2 GeV as a function of r.f. voltage for three different currents (10, 7 , 6 mA) and coupling (2%, 0.85%, 0.16%). The solid lines correspond to the prediction.

the middle set (diamonds) 7 mA in 15 bunches were used with measured rms vertical dispersion of 1.3 cm (0.85% coupling). For the lower set (circles and triangles) 10 and

6 mA in 12 buckets were used with a corrected rms vertical dispersion of 0.5 cm (0.16% coupling).

For the theoretical predictions the coupling has been extracted from the measured vertical dispersion (see section 3). We observe that the lifetime differs by about a factor of three between the two extremes of the coupling and a better agreement between the measured and the predicted values exist as the coupling becomes smaller.

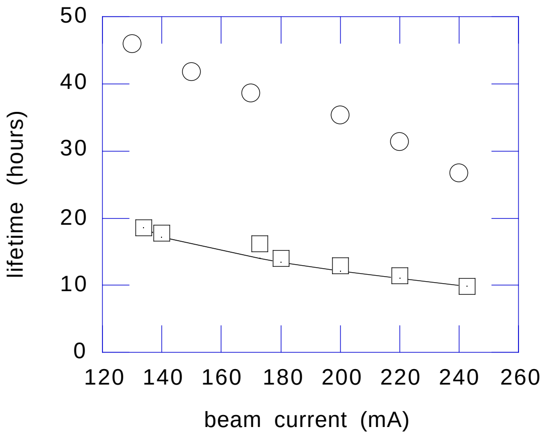

Figure 2. Lifetime as a function of beam current for the high lifetime mode (circles) and low lifetime i.e. instability free mode (squares) for 80% (i.e. 346 bucket) filling at 1.76 MV. Solid line is the prediction.

Figure 2 shows how the lifetime decreases when the machine operates with instability free settings. For the prediction again the nominal emittance was taken with a 0.35% coupling (i.e. 0.8 cm rms vertical dispersion measured). No turbulent bunch lengthening is included since in all cases the given currents are below threshold being in the range 1.1 to 1.3 mA/bunch for 1.76 to 0.84 MV given the nominal longitudinal impedance.

3 SINGLE BUNCH

In this case data have been taken at both 1 and 2 GeV and for different r.f. voltages. The nominal emittance and the indirect measured - via dispersion - emittance coupling were used for the predictions. Since here almost in all cases we are above the microwave threshold bunch lengthening has been included.

In Figure 3 the product of beam current (mA) and lifetime (hours) is shown as a function of the r.f. voltage for about 2 mA at 2 GeV. For the prediction a 0.35% coupling has been used.

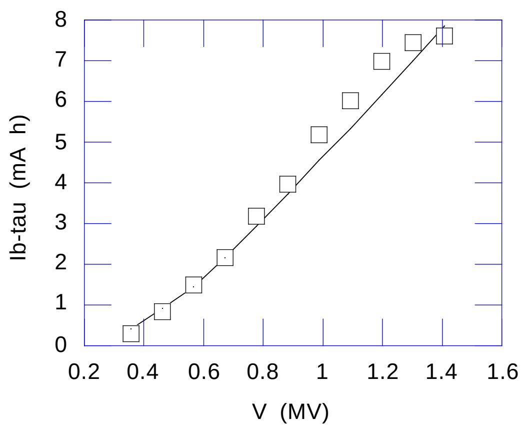

Figure 3. Product of beam current (mA) and lifetime (hours) at 2 GeV as a function of r.f. voltage for a single bunch current of about 2 mA. Solid line is the prediction.

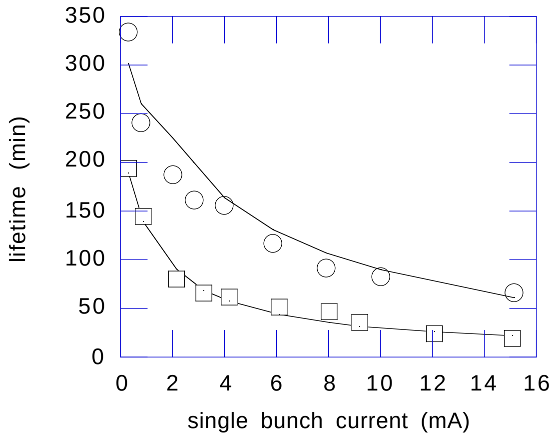

Figure 4. Beam lifetime at 1 GeV as a function of single bunch current for two different r.f. voltages (circles 1.76 MV and squares 0.84 MV). Solid line is the prediction.

Figures 4 and 5 show lifetime as a function of the beam current at 1 GeV (Fig. 4) and 2 GeV (Fig. 5) at two different r.f. voltages. Coupling at 1 GeV is 2% while at 2 GeV is 0.35%.

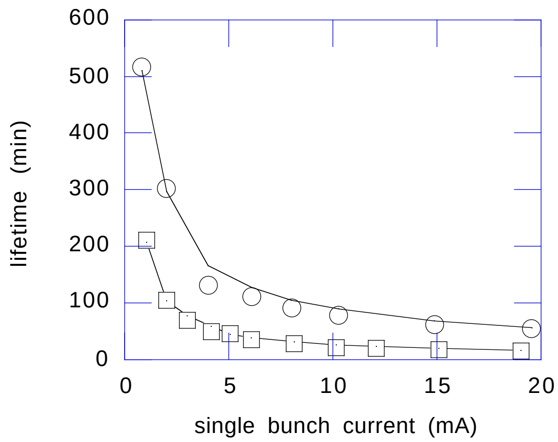

Figure 5. Beam lifetime at 2 GeV as a function of single bunch current for two different r.f. voltages (circles 1.76 MV and squares 0.84 MV). Solid line is the prediction.

In Figure 6 we show the product of beam current (mA) and lifetime (hours) at 2 GeV and 0.7 MV as a function of the measured rms vertical dispersion for bunch currents from 6 to 3 mA under different conditions of closed orbit and vertical dispersion correction. Each point was fitted by adjusting the coupling and a graph (Fig. 7) is obtained that shows the coupling as a function of rms vertical dispersion. The result is in a good agreement with the simulations [5].

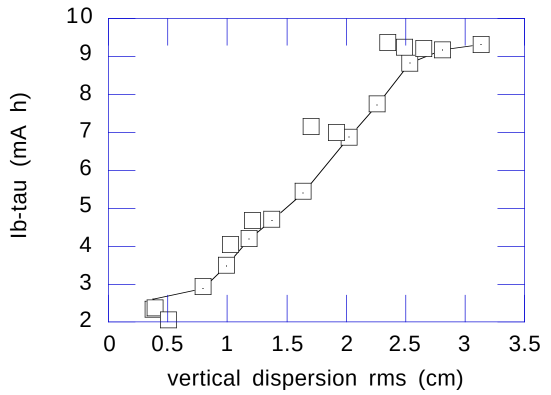

Figure 6. Product of beam current (mA) and lifetime (hours) at 2 GeV as a function of rms vertical dispersion for a single bunch currents between 3 and 6 mA. The solid line is the coupling fitted prediction.

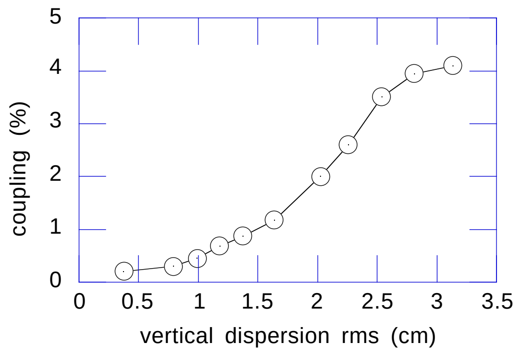

Figure 7. Relation between vertical dispersion and coupling obtained from the data in Figure 6.

4 GAS SCATTERING

From the linear fit in Fig. 8 the gas desorption constant is P_1=0.385 10^{-3} nTorr mA $^{-1}$. This is at least a factor of 20 lower than that reported eight months after the start of the commissioning [2]. Data at 2 GeV do not show an appreciable difference in average pressure which is 0.15 to 0.6 nTorr (250 mA 2 GeV) with peak value 1.5 nTorr at the light ports, therefore the same desorption constant is taken up to 2 GeV.

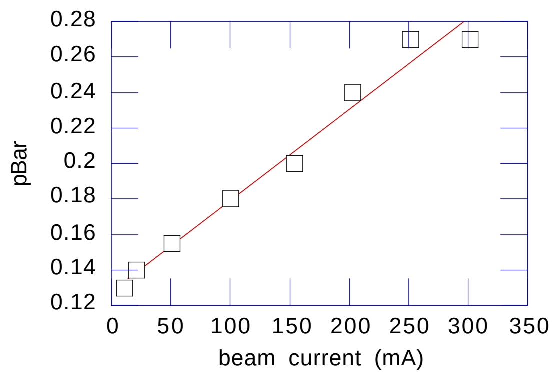

Figure 8. Ring pressure as a function of beam current at 1 GeV. The solid line is the linear fit to obtain the desorption P_1.

In Table 1 we show the calculated terms of the lifetime (hours) based on the desorption value found. The beam current was approx. 10 mA divided in 346 bunches (80% fill). For the prediction of the Touschek lifetime a 2 % emittance coupling was assumed. For the elastic and inelastic predictions we have assumed N_2 as residual gas.

Table 1

GeV	mA	τ_{elast}	τ_{inelst}	τ_{Tsch}	τ_{sum}	$\tau_{meas.}$
1.0	10.5	1084	1172	58	52.6	37.8
1.2	10.77	1562	1129	76	68	52.8
1.4	10.66	2126	1093	121	103	83
1.5	10.64	2441	1076	168	137	105.5
2.0	10.54	4339	996	539	323	158

As one can see from Table 1 the agreement is quite reasonable however the residual gas was reported [6] to be mainly composed of Hydrogen and this discrepancy has been also discussed in [2].

For the sake of completeness we estimate the a, b (and c) terms of the lifetime relation using the model (with A=7.5 mm) with the following results:

a (h^{-1} $nTorr^{-1}$)	b($h^{-1}nTorr^{-1}mm^{2}$)	c ($h^{-1}mA^{-1}$)
1 GeV: 8.5 10^{-3}	0.5	1.64 10^{-3}
2 GeV: 10 10^{-3}	0.12	1.76 10^{-4}

5 CONCLUSIONS

ELETTRA lifetime is Touschek scattering dominated. Very good agreement is obtained comparing with theory. However the gas lifetime is not consistent with the assumption of 95% hydrogen as residual gas [6]. Assuming N_2 the calculated at 2 GeV elastic scattering lifetime (b=0.12 $h^{-1}nTorr^{-1}mm^{2}$) is also a factor of eight lower than that extracted from recent scraper measurements.

REFERENCES

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[4] 'Improved Methods of Measuring and Curing MBIs in ELETTRA', by M. Svandrlik et al, these Proceedings.

[5] R. Nagaoka, graph presented at the ELETTRA MAC Meeting (October 1995).

[6] 'Exprerience with the ELETTRA Vacuum System during Commissioning', by J. Miertusova et al, EPAC 1994 Proceedings.