BEAM LIFETIME STUDIES IN DAΦNE

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Abstract

The beam lifetime of the DAFNE Φ-factory is strongly dominated by the Touschek effect. An analysis of its dependence on machine parameters has been done in order to improve machine performance. Measurements taken in different conditions are here presented and compared with simulations. The agreement is quite satisfactory when taking into account the measured bunch length, the machine coupling, and the estimated dynamic aperture.

1 INTRODUCTION

Two experiments, KLOE and DEAR, are taking data on the DAΦNE Φ-factory [1]. During KLOE data taking the average DAΦNE luminosity is a large fraction (70%) of the peak one even if the beam lifetime is quite short. The lifetime of the two beams ranges between 15 and 30 min, the luminosity is mantained close to the peak value all the time by frequent beam refills (every 10-15min), while KLOE data acquisition is kept on.

A further step to increase average luminosity necessarily requires dedicated work to improve beam lifetime. In fact, as it will be described below, tuning the machine to increase peak luminosity generally has a side effect of reducing lifetime. A short beamlifetime is also related to a high machine background in the detectors. The different actions adopted to reduce the background level are described in [2].

DAΦNE beam lifetime is determined by the single Touschek scattering and by the interaction with gas molecules (scattering and bremsstrahlung). Among the two effects the Touschek is the dominant one, due to the relatively low energy and the very good vacuum.

2 BEAM LIFETIME CALCULATIONS

To calculate the beam lifetime for DAFNE the computer code LEDA [3] has been modified in order to take into account the actual shape of the vacuum chamber and the limit due to the dynamic aperture [4].

Touschek effect is an elastic scattering of two particles within a bunch. The two emerging particles suffer the same change of the relative momentum devlation ε, one gains and the other loses.

Lifetime is calculated according to the formula given by H. Bruck[5]:

$$\frac{1}{\tau}=\frac{\sqrt{\pi}\, r_o^2 c N}{\gamma^3 \sigma'_x \varepsilon^2 (4\pi)^{\frac{3}{2}} \sigma_l \sigma_x \sigma_y} C(u_{min}) \qquad (1)$$

where: r_0 classical electron radius, c velocity of light, γ electron energy in units of rest mass, N number of electrons per bunch, $(4\pi)^{3/2}\,\sigma_l\,\sigma_x\,\sigma_y$ bunch volume,

$$\sigma_x' = \sqrt{\varepsilon/\beta_x + \sigma_p^2 \left(D_x' + D_x\,\alpha_x/\beta_x\right)^2}$$

and $C(u_{min})$ is a slowly varying function of $u_{min} = \left(\varepsilon/(\gamma\sigma_x')\right)$. ε is the maximum accepted value for the relative momentum deviation. It is the minimum between RF acceptance and momentum acceptance due to transverse aperture (physical or dynamic).

At each azimuth s_i along the ring the following quantity is calculated:

$$H(s_i) = \gamma_i D_i^2 + 2\alpha_i D_i D'^2_i + \beta_i D'^2_i . \qquad (2)$$

The maximum horizontal displacement in a position s_j for a particle which has got a relative momentum deviation change ε_i in s_i is:

$$x_j = \varepsilon_i \left[\sqrt{H_i}\, B_j + \left| D_j \right| \right] \qquad (3)$$

The limiting value for ε_i is obtained by equating x_j to the physical half-aperture in that position A_x^j and taking the minimum all over the ring:

$$\varepsilon_i = min_j \left\{ \frac{A_x^j}{\sqrt{H_i \beta_i} + \left| D_j \right|} \right\} \qquad (4)$$

The minimum between ε_i and ε_{RF} is used to calculate at s_i the value of 1/τ which is then averaged over the ring. To take into account dynamic aperture, a value for the aperture limit at different energies is given in input, at a fixed azimuth, assuming it scales as square root of β_x along the ring.

The total beam lifetime is calculated taking into account quantum lifetime, Touschek scattering, elastic and inelastic gas scattering.

The DAFNE parameters used to calculate the beam lifetime for a typical configuration are listed in Table 1 and the different contributions to the total lifetime are shown in Table 2. This calculation is performed using the vacuum chamber aperture without including dynamic aperture limitation.

Table 1: Parameters used for lifetime calculations

E = 510 MeV	V_{RF} =120KV
ε = 0.94 mm mrad	ε_{RF} = 6.0 10^{-3}
α_c = .030	σ_l = 2.2 10^{-2} m
U_0 = 9.2 KeV	I_{bunch} = 15 mA
σ_p nat = 4.0 10^{-4}	κ = 2.0 10^{-3}

Table 2: Different contributions to DAFNE lifetime

Quantum lifetime	$1.7\ 10^{35}$ s
Gas bremsstrahlung	$1.08\ 10^{5}$ s
Gas scattering	$1.01\ 10^{5}$ s
Touschek	2567 s
Total	2447 s

A value of gas pressure of $T10^{-9}$ torr is assumed, in practice the average vacuum is well below this value. Anyway the beam gas contribution is much smaller than the Touschek, due to the low energy of the ring and to the very small value of the vertical emittance. In fact τ is proportional to γ^3 and σ_y (see (1)).

2.1 Lifetime limitations

In practice the measured lifetime is smaller than the calculated one and therefore the factors that could give a lifetime reduction have been studied. The main possible limitations are: closed orbit, coupling configuration and dynamic aperture.

Closed orbit is not included in the calculations and could reduce the effective aperture. After correction the closed orbit is displaced by means of orbit bumps along the ring to check that it is not affecting beam lifetime. This is specially useful in the interaction regions where, due to crossing angle at the interaction point, the two beams travel off axis.

Coupling is measured from the ratio R ($R = \sigma_y/\ \sigma_x$) at synchrotron light monitor (SLM). The resolution of the SLM could affect this measurement and the difference between the coupling measured at the SLM and its value around the ring might explain a discrepancy in the measured and calculated lifetime. Coupling is corrected down to very small values by using antisolenoids to compensate the strong effect of KLOE solenoid and then by adjusting eight skew quadrupoles in each ring.

A dynamic aperture smaller than the vacuum chamber could explain the short lifetime. In fact lifetime is very sensitive to sextupole settings and betatron tunes. DAΦNE is a small machine with two low β interaction regions and therefore has strong chromaticity correcting sextupoles.

Beam measurements have shown the presence of a strong nonlinear term in the field of the wigglers [6]. This nonlinear term gives a large tune shift on amplitude and a reduction of the dynamic aperture. Octupole magnets have been recently installed to compensate this effect, preliminary results are presented at this conference [7].

3 MEASUREMENTS

In order to understand the beam lifetime behaviour different kinds of measurements have been performed. Only measurements performed with positrons are shown because with electrons the ion trapping effect makes the interpretation of the data less clear. For electrons beam lifetime is longer due to larger coupling and longer bunches.

3.1 τ versus Beam Current

It is important to know the dependence of τ on the current in order to correctly normalize measurements done at different currents. As shown in (1) Touschek lifetime is inversely proportional to current. For the operating currents the bunch length is in the anomalous lenghtening regime [8] and its length is proportional to $I^{1/3}$. As a consequence lifetime is proportional to $I^{-2/3}$.

Beam lifetime τ as a function of current, in the DEAR configuration, at a coupling $\kappa = 3.4\ 10^{-3}$ is shown in Fig. 1: triangles are measured points and the line is a fit with $I^{-2/3}$.

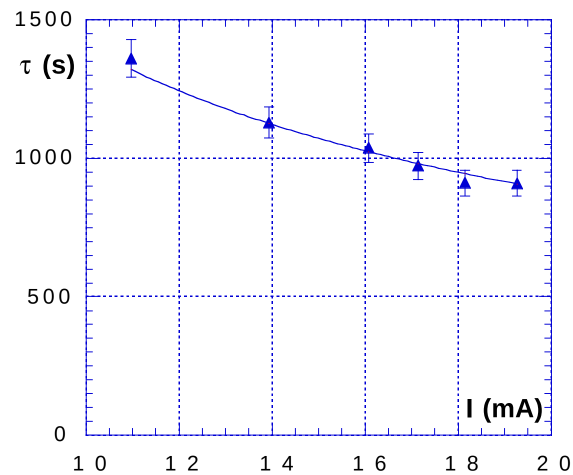

Figure 1: Measued lifetime versus current fitted with $\tau \propto I^{-2/3}$.

3.2 Lifetime versus skew quadrupole current

From (1) a linear behaviour of τ versus the vertical beam size σ_y is expected. We vary machine coupling by changing the current of a skew quad and measure the ratio R at the SLM. We use the ratio R instead of σ_y because it is less sensitive to the intensity of the beam image (the horizontal beam size is constant during the measurement because the coupling is very small).

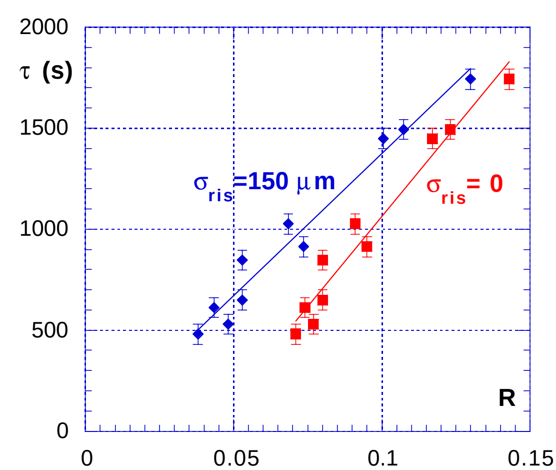

Figure 2: τ vs. R with and without SLM resolution.

The squares in Fig. 2 show the beam lifetime versus R for a single bunch in the KLOE collision configuration at currents of 10 mA. The points are fitted with a straight line. Due to the effect of the resolution of the SLM the line does not cross zero. Data are corrected by subtracting quadratically the SLM resolution in order to have a line crossing through zero. The horizontal beam size is σ_x = 2.4 mm, and therefore the minimum measured value of R = .075 corresponds to a resolution σ_{ris} = 150 µm and a vertical size σ_y = 108 µm.

3.3 τ versus RF Voltage

The RF energy acceptance increases with the square root of the RF voltage. Touschek lifetime increases with the square of the energy acceptance (neglecting the function $C(u_{min})$ nearly constant in our case) and therefore it should increase linearly with the voltage if there were no other limitations due to physical and dynamical aperture. A dynamic aperture limitation at 7 σ_x has been estimated by inserting a scraper to intercept the beam and an energy limitation of .5% has been observed when changing the energy by means of RF frequency. The measured (April 01) behaviour of lifetime as a function of RF voltage is shown in Fig. 3 (dots) and compared with calculations. The solid line is the lifetime calculated taking into account the vacuum chamber aperture (larger than 10 σ_x all over the ring), and the measured bunch length. A coupling value of $\kappa = 2.3\ 10^{-3}$ has been used instead of $\kappa = 4.5\ 10^{-3}$, given by the SLM, due to the fact that the beam size is smaller than the SLM resolution. Such a low coupling value is measured by the luminosity scans made (at low current) by varying the vertical position of one of the beams at the crossing point. From this scan a value of $\Sigma = \sqrt{\sigma_{y+}^2 + \sigma_{y-}^2} = 11\mu m$ has been obtained. The dashed line, which fits the data, assumes a dynamic aperture limitation at 7 σ_x and an energy limitation of .5%.

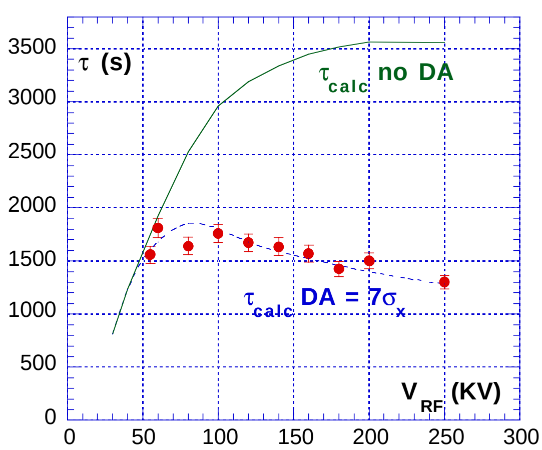

Figure3: τ vs. V_{RF}, I = 10 mA, $\kappa = 2.3\ 10^{-3}$.

This plot shows a strong reduction of lifetime due to dynamic aperture limitations.

On the KLOE optics machine coupling has been continously reduced in order to increase the luminosity. The vertical β_y at the IP has been reduced from .06 m to .03m. This change has improved the luminosity at the expense of increased chromaticity and sextupole strengths which could reduce the dynamic aperture. Luminosity has increased from 2.0 $10^{31}cm^{-2}s^{-1}$ (Apr 01) to 5.1 $10^{31}cm^{-2}s^{-1}$.

Recent measurements (May 02) on the KLOE optics (see Fig. 4) show a smaller lifetime. The measurements have been performed for two different values of R and scaled at the same value of $\kappa = 1.8\ 10^{-3}$ taking into account SLM resolution. The Σ measured by luminosity scans is Σ = 7.9 µm and corresponds to a lower coupling $\kappa = 1.1\ 10^{-3}$.

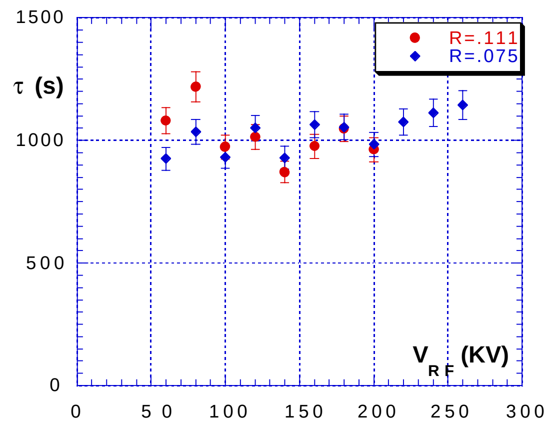

Figure 4: τ vs. V_{RF} at 10mA and $\kappa = 1.8\ 10^{-3}$ taking into account the SLM resolution.

4 CONCLUSIONS

The measured beam lifetimes are in reasonable agreement with calculations when taking into account dynamic aperture, measured bunch length and coupling. Very small coupling and strong nonlinearities give a quite short lifetime. A chance to improve the lifetime will come from the present work dedicated to study machine nonlinearity and increase the dynamic aperture.

5 REFERENCES

[1] M. Zobov et al., “Luminosity Performance of DAFNE”, This Conference.

[2] M. Boscolo et al., “Simulations and measurements of the Touschek Background at DAFNE”, This Conference.

[3] G. Vignola., “LEDA code,” private communication.

[4] S. Guiducci., “Beam Lifetime in DAFNE”, DAFNE Technical Note L-12, February 1993.

[5] H. Bruck, “Accelerateurs Circulaires de Particules”, Presse Universitaires de France, 1966.

[6] C. Milardi et al., “Effects of nonlinear terms in the wiggler magnets at DAFNE”, PAC 2001, Chicago, USA, 2001.

[7] C. Vaccarezza et al., “Preliminary Results of DAFNE Operation with Octupoles”, This Conference.