# EFFECT OF A REDUCED VERTICAL APERTURE ON THE ESRF LIFETIME

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## *Abstract*

Touschek scattering makes a substantial contribution to the lifetime reduction, even in a high-energy light source like the 6 GeV ESRF. However, the installation of low gap vessels and the operation of in-vacuum undulators significantly enhance the elastic gas scattering lifetime contribution. In order to precisely estimate the impact of a reduced vertical acceptance on machine performance, a series of lifetime measurements has been carried out with varying a number of machine parameters (beam energy, integrated dose, current, transverse aperture). The analysis of the measurements is presented here.

## 1 INTRODUCTION

The ESRF is a 6 GeV third generation synchrotron radiation light source optimised for high brilliance radiation in the hard X-ray range. The emittances are 3.8 nm.rad in the horizontal plane and 25 pm.rad in the vertical plane (i.e. a 0.7 % coupling). The lifetime in multibunch mode (200 mA stored in 992 bunches) is 80 hours.

Among the processes that limit the beam lifetime in the ESRF, the main contributions are the following:

i) Touschek scattering of electrons inside the bunch induced by the increased density in the bunch volume.

ii) Elastic scattering on the residual gas atoms enhanced by the trend towards small gap undulator vacuum vessels.

In order to provide the longest lifetime, the filling pattern has evolved from a one-third filling mode (with equally spaced bunches and the remaining two-third of the ring being empty) to a uniform filling mode. This has led to a lifetime increase by a factor of 2, which shows that even for a high-energy machine, the Touschek lifetime has a strong impact on machine performance.

The vertical acceptance is dictated by either the 10 mm high, 5 m long Insertion Device vacuum vessels (CV5000) or by the gap of the 2 m long in-vacuum undulators (four are currently installed).

An additional aperture limitation can be induced when closing a vertical scraper. The analysis of the subsequent elastic gas scattering lifetime measurements is being used to assess the effects of a reduced aperture and model the lifetime.

## 2 VERTICAL ACCEPTANCE

The storage ring is equipped with a number of vertical scraper jaws (upper and lower) located at different vertical βs (Table 1) that can be individually closed.

Table 1: Vertical βs at scraper locations

| | C5 up | C5 low | C6 up | C6 low | C22 |
|---|---|---|---|---|---|
| $\beta_z$ (m) | 35.07 | 35.07 | 2.90 | 2.90 | 34.94 |

Measurements have been made at a low bunch current to minimise the contributions from the Touschek effect (100 mA stored in 992 bunches). The gap of the in-vacuum undulators was open. The lifetime evolution is recorded when closing the scraper jaw until the beam is lost. Raw lifetime measurements corrected from the intensity decay are shown in Fig. 1. Very different lifetimes are recorded for the same position of scraper jaws located at the same β. This is mainly caused by scraper alignment errors, since closed orbit deviations at scraper locations are too small to explain the discrepancy.

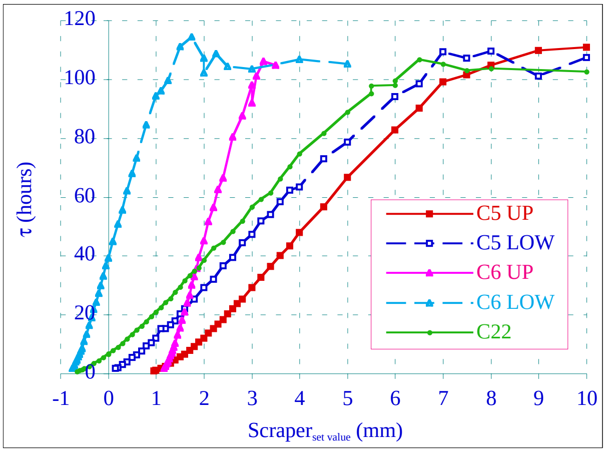

Figure 1: Lifetime as a function of scraper position

The analysis of measurements is based on the expected dependence of the elastic gas scattering lifetime $\tau_G$ on the vertical acceptance:

$$\frac{1}{\tau_G}=\frac{a}{A^2}=C_G\frac{1}{\gamma^2}\frac{\beta_A}{A^2}\sum_{atomj}\left[Z_j^2\sum_{gasi}\alpha_{ij}<\beta P_i>\right] \qquad (1)$$

$C_G$ is a constant

$\gamma$ is the energy in $mc^2$ units

A is the vertical half-aperture determined by the scraper

$\beta_A$ is the vertical β-function at the scraper location

$\tau_G$ also depends on the gas composition, which is defined by the residual pressures $P_i$, the atomic number $Z_j$ and the number of atoms $\alpha_{ij}$ of the different species.

The inverse lifetime evolution can be fitted to a linear law $\frac{1}{\tau_{meas}}=b+\frac{a}{A^2}$ where b accounts for vertical aperture independent lifetime contributions. The elastic loss rate is characterised by the coefficient *a*. An offset is introduced in the fitting parameters, to take into account scraper alignment errors so that $A=scraper_{set\_value}-offset$. As illustrated in Fig. 2, $\frac{1}{\tau_{meas}}$ deviates from the linear law at small $A^{-2}$ values (the inverse lifetime remains constant, indicating the presence of another aperture restriction) and at large $A^{-2}$ values (corresponding to the aperture region where the quantum lifetime takes over). Since the starting point of these two zones is somewhat blurred, all data corresponding to scraper positions larger than 5 mm or lifetimes below 3 hours are arbitrary removed. However, depending on the number of fitted data, the uncertainty on the loss rate *a* is in the 30 % range.

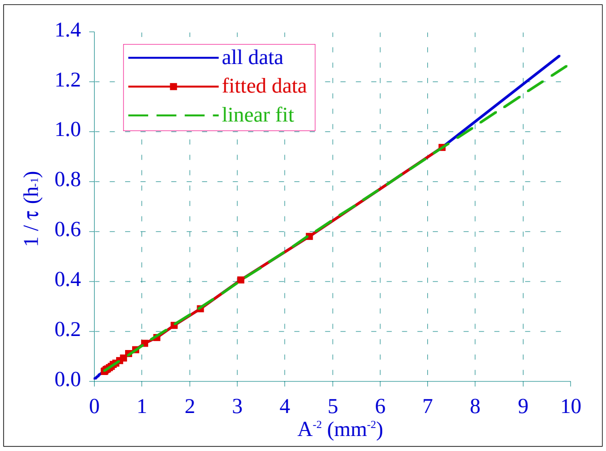

Figure 2: Fit of the inverse lifetime to a linear law

Once the set value of the scraper aperture is corrected by the offset, the real scraper positions can be transformed in apertures at the entrance of the ID vessels ($\beta_z$ = 5 m), using the scaling with the beta functions. As shown in Fig. 3, the lifetimes measured with the different scraper jaws are perfectly superimposed. The acceptance is defined as the point where the lifetime no longer increases with changing scraper positions. This saturation occurs for an aperture of ±2.8 mm at the entrance of CV5000 vessels instead of the theoretical beam stay clear of ±4 mm. This aperture restriction is likely due to machining and alignment errors.

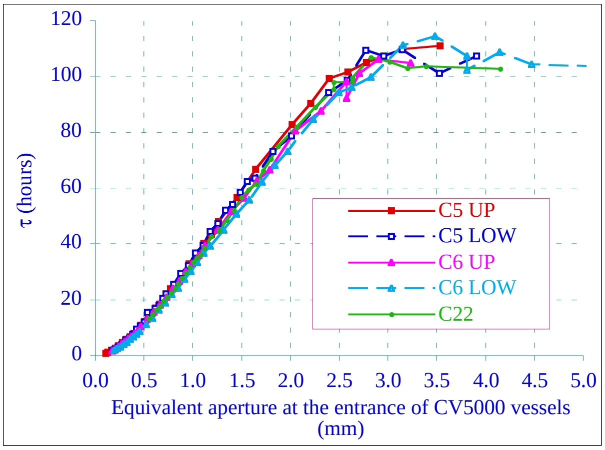

Figure 3: Lifetime evolution with real scraper apertures transferred to CV5000 vessels entrance

## 3 EFFECTS OF SMALL GAPS

Four in-vacuum undulators (1.6 m long in ID11 and 2 m long in ID9, ID22 and ID29) are presently installed in the ring. The gap can be scanned from the undulator open position (20 mm gap) down to a minimum gap of 2.1 mm. Figure 4 shows the corresponding reduction of lifetime at 6 and 4 GeV. Data were taken at 90 mA (HOM limitation at 4 GeV), at nominal coupling. For both energies, the lifetime starts to be affected for gaps below 6 mm. Therefore the operational gap for users is fixed at 6 mm.

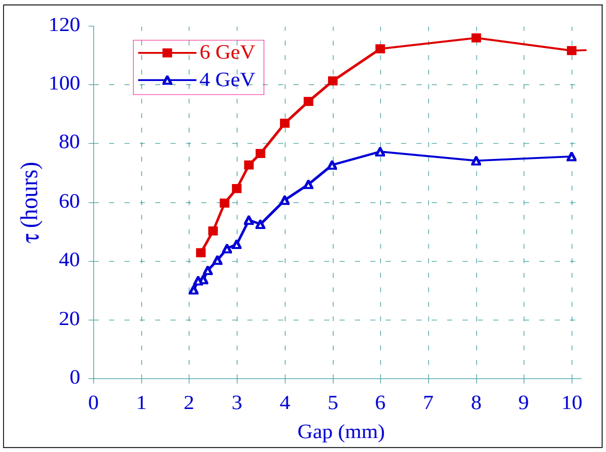

Figure 4: Lifetime evolution with in-vacuum undulator gap

## 4 ELASTIC SCATTERING LIFETIME EVOLUTION WITH MACHINE PARAMETERS

As indicated in Eq (1), the elastic scattering lifetime depends on a number of parameters:

### *4.1 Machine energy*

Measurements have been performed at nominal energy (6 GeV) and at reduced energies (4 and 3 GeV). The expected energy dependence (gas scattering lifetime varying like the inverse of the square of the energy) is not fully reproduced for the low energies (see Table 2). This is not understood yet.

Table 2:Loss rate dependence on energy

| Comparison 1 - 2 | $(\gamma_1/\gamma_2)^2$ | $(a_2/a_1)$ |
|---|---|---|
| 6 – 4 GeV | 2.38 | 2.6 |
| 4 – 3 GeV | 1.78 | 4.4 |

### *4.2 Pressure*

The pressure in the ring is expressed as $\overline{P} = P_0 + kI$, where $P_0$ refers to the pressure in the absence of beam and *k* is the gas desorption. The pressure variation is due to a conditioning effect (after venting of some parts of the ring) or to the varying beam current.

The mapping of the elastic gas scattering lifetime was performed using the C5 upper scraper jaw. Starting from 200 mA, the current was decreased by steps of 25 mA. The vertical emittance was artificially blown up to 160 pm (coupling of 4 %) to minimise the influence of the Touschek contribution. The loss rates (Table 3) are deduced from the fit of the inverse lifetimes to a linear law (Fig. 5).

Table 3: Elastic gas scattering loss rates

| I (mA) | a |
|---|---|
| 200 | 0.167 |
| 175 | 0.150 |
| 150 | 0.136 |
| 125 | 0.124 |
| 100 | 0.077 |
| 65 | 0.063 |

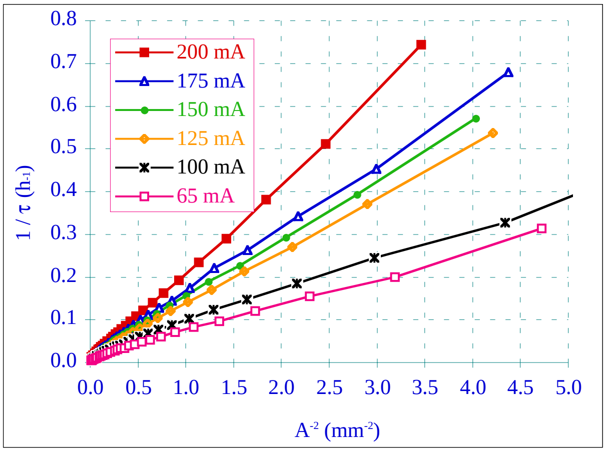

Figure 5: Mapping of the elastic gas scattering lifetime versus intensity

An equivalent pressure P can be reconstructed from the data processing and the elastic gas lifetime evolution given in Eq. (1). The comparison of the equivalent pressure (assuming a residual gas composition of 80 % $H_2$, 15 % CO and 5 % $CH_4$) and the measured pressure is shown in Fig. 6. There is a good agreement between modelling and measurements in the low intensity zone (the 10 % difference could easily be cancelled by a slight difference in the gas composition). But the jump of the reconstructed pressure above 100 mA is unexplained.

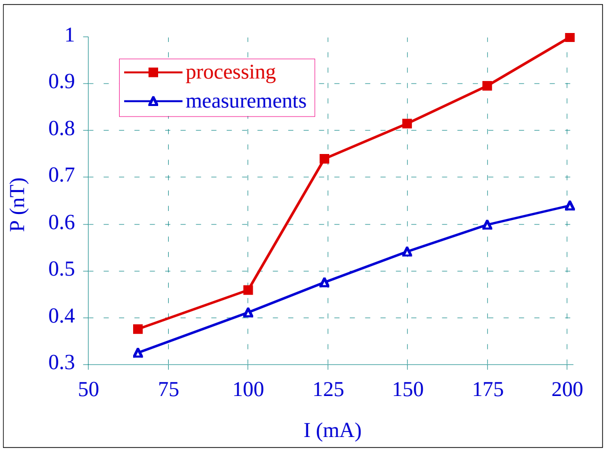

Figure 6: Measured and processed pressures

## 5 LIFETIME MODELLING

The total lifetime is determined by the elastic ($\tau_G$) and inelastic ($\tau_B$) scattering on the residual gas and scattering of electrons within the bunch ($\tau_T$). It can be expressed as:

$$\frac{1}{\tau}=\frac{1}{\tau_G}+\frac{1}{\tau_B}+\frac{1}{\tau_T} \qquad (2)$$

The different contributions as a function of intensity are evaluated as follows:

i) The elastic gas scattering lifetimes at the entrance of reduced vertical aperture vessels (10 mm CV5000 or in-vacuum undulators) is computed from the loss rates with using the $\sqrt{\beta}$ scaling of apertures.

$$\frac{1}{\tau_G}=\frac{\beta_{ID}}{\beta_{scraper}}\frac{a}{A_{ID}^2} \qquad (3)$$

ii) The Bremsstrahlung lifetime is computed from the pressure model and from the energy acceptance (1 2.5 % energy acceptance is assumed).

iii) The Touschek lifetime is deduced from (2) and from the law

$$\frac{1}{\tau_T}=c+dI^{\frac{2}{3}} \qquad (4)$$

with using the dependence of the Touschek lifetime on the intensity per bunch $I_{bunch}$ (Eq. 5) and the dependence of the bunch length on the intensity per bunch (Eq. 6):

$$\frac{1}{\tau_T}=C_T\frac{I_{bunch}}{\sigma_L(I_{bunch})} \qquad (5)$$

$$\left[\frac{\sigma_L(I_{bunch})}{\sigma_L(I_{bunch}=0)}\right]^3-\left[\frac{\sigma_L(I_{bunch})}{\sigma_L(I_{bunch}=0)}\right]=KI_{bunch} \qquad (6)$$

One can then (for given pressure and coupling conditions) estimate the impact of a reduced gap on the lifetime. As shown in Fig. 7, there is a good agreement between measured and predicted lifetime reduction.

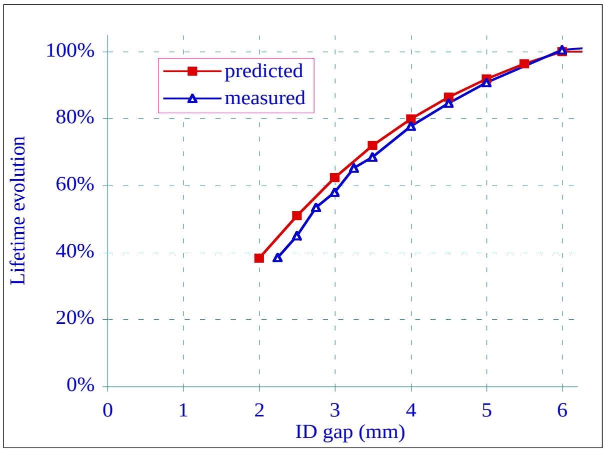

Figure 7: Lifetime reduction with gap

## 6 CONCLUSIONS

A consistent pressure modelling can be established from the measurement of the lifetime evolution as a function of vertical scraper position and beam current.

This modelling allows the impact of a further reduction of the vertical aperture to be estimated.