Beam Lifetime Investigations at BESSY

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Abstract

Lifetime measurements are reported for different operating conditions of the BESSY I storage ring. These experiments have been performed in an attempt to identify the relative contributions of different lifetime limiting processes as a basis for lifetime optimisation. Broadening of the beam using white noise excitation has proved to be a helpful tool to obtain quantitative information on the relative strength of the contributions due to gas scattering and the Touschek effect.

Introduction

For a synchrotron radiation source used as a tool in the field of fundamental and applied research, besides brilliance, source stability and up-time, the beam lifetime is an important figure of merit. In the present paper we describe measurements and calculations to determine the relative importance of the different lifetime limiting processes of the BESSY storage ring under the typical conditions of high brilliance operation [1]. This information is also helpful in the planning of a reasonable and cost effective component replacement and improvement program, which is under way at BESSY, to keep the machine running at high performance for the next decade after the first ten years of very successful user's operation.

For an electron machine in the energy range around 1 GeV the most important processes affecting the lifetime are i) Coulomb scattering between the electrons and the gas molecules in the vacuum chamber, ii) scattering between individual electrons in a bunch (Touschek effect) and iii) interaction of the electrons with the ion cloud captured by the beam. Assuming that these processes are statistically independent, the total loss rate is $1/\tau_{tot} = 1/\tau_{Coul} + 1/\tau_T + 1/\tau_{ion}$.

Measurements

We have measured the lifetime as a function of beam current for various operation modes, which are possible using the two rf-systems of the BESSY-ring, a 500 MHz (h = 104) system and a 62.4 MHz (h = 13) system. As can be seen in Fig. 1, the lifetimes observed with the 62.4 MHz rf-system in single bunch and multi bunch operation follow the same power law, $\tau \sim I^{-a}$ with a = 0.52. In the normal high brilliance user operation mode (500 MHz rf-system, partial filling of the storage ring with N ≅ 64 buckets) the lifetime shows roughly the same characteristic for higher single bunch currents, whereas at lower currents a slightly stronger dependence is observed.

If all 104 buckets of the 500 MHz rf-system are filled, the current dependence of the lifetime is less pronounced (a = 0.2) with the same current dependence as observed at low currents in single bunch operation with the 500 MHz system. For single bunch currents above 7 mA, however, the decrease in beam lifetime with increasing current is much stronger (a = 0.85).

Some features of these observations can be explained qualitatively by ion effects: if no filling gap is used, ion trapping is most effective and the transverse beam size is enlarged, which leads to a longer Touschek lifetime. When operating the ring with a filling gap a significant fraction of the ions can leave the capture potential. This ion clearing effect is particularly strong in single bunch operation with the 500 MHz rf-system above the clearing threshold of about 7 mA. Practically no difference is observed in the lifetime between single bunch and

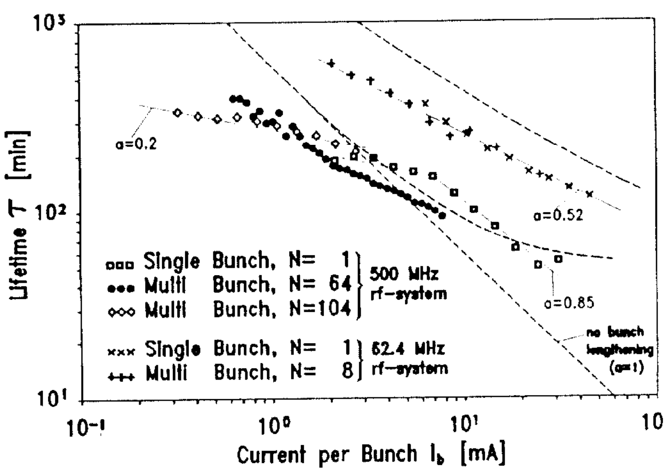

Figure 1: Beam lifetime measured for different operation modes as function of the current per bunch. N = number of buckets filled with electrons. The dotted lines show the theoretical Touschek lifetime taking bunchlengthening with a broadband impedance of Z/n = 7 Ω and ΔE/E = 1% into account.

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multi bunch operation (N = 8) with the 62.4 MHz rf-system in Fig. 1, which indicates that there is not much variation in the ion behaviour of the two operation modes.

The situation changes when the lifetimes of the single bunch and multi bunch mode with the 500 MHz rf-system are compared. The obvious difference of the current dependence must be attributed to a different ion trapping behaviour of the single bunch mode which shows the strongest current dependence (a = 0.85) above the trapping threshold around 7 mA. However, the maximum value a = 1 is not reached, which could be expected in the limit of zero bunchlengthening, when the Touschek effect dominates the lifetime and other contributions can be neglected.

For the user operation mode (500 MHz rf-system, N = 64) it is most interesting to get quantitative information on the relative contributions from Coulomb-scattering and from the Touschek effect. The observed lifetime τ_{exp} in the partial filling mode as function of the stored current is shown in fig. 2 (circles). The rhomboidal symbols denote the Coulomb lifetime τ_{Coul} and the triangles the Touschek lifetime extracted from the data of fig. 3. As can be seen, the Coulomb scattering process dominates the loss rate at smaller beam current, whereas both lifetime limiting processes are comparable at higher currents.

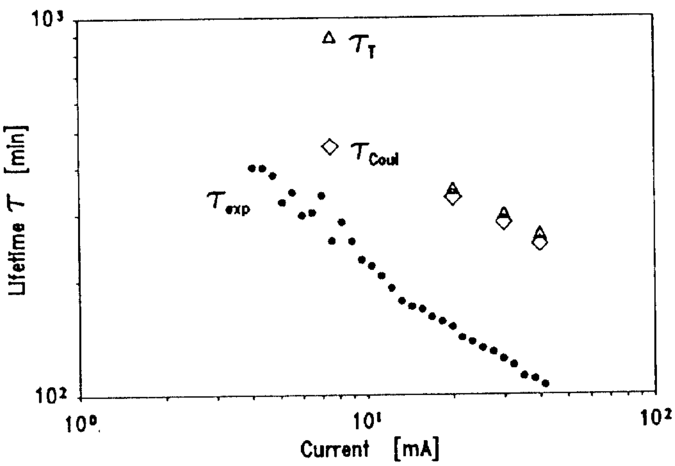

Figure 2: Beam lifetime τ_{exp} measured in the multibunch user operation mode. The data for the Coulomb lifetime τ_{Coul} and the Touschek lifetime τ_T are extracted from Fig. 3

Utilizing white noise excitation, the vertical beam size σ_z has been varied for different stored currents resulting in a strong lifetime enhancement with increasing beam size up to approximately $\sigma_z = 1mm$ (fig. 3). A further beam size enlargement has a negligible effect on the beam lifetime, which may be attributed to a strong increase of the Touschek lifetime

$$\tau_T \propto \frac{\left(\frac{\Delta E}{E}\right)^3 \sigma_x \sigma_y \sigma_s}{I_b} \qquad (1)$$

and a correspondingly small contribution to the total loss rate. This justifies to take the saturation values for the beam lifetimes in fig. 3 as an approximation for the Coulomb scattering lifetime only (triangles in fig. 2). Assuming furthermore that the loss rate due to Coulomb scattering is independent of the beam size, the values obtained for τ_{Coul} may be used to extract τ_T using $1/\tau_{exp} = 1/\tau_{Coul} + 1/\tau_T$, where τ_{exp} corresponds to the experimental values from fig. 3 without beam excitation.

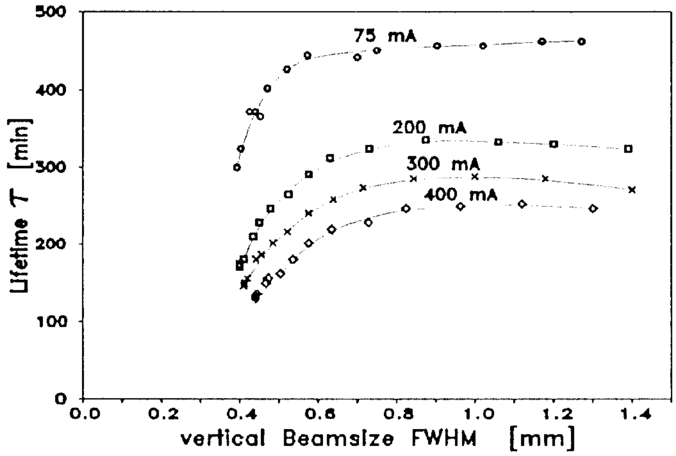

Figure 3: Beam lifetime in the multi bunch mode (500 MHz rf-system, N = 64) as a function of vertical beam size σ_z

Possible improvements

The measurements and the extracted data show that an improvement of the lifetime may be obtained by i) improving the vacuum conditions at large beta values as indicated by Wiedemann [2] due to $\tau_{Coul} \propto 1/ < p \cdot \beta >$ ii) reduction of the Touschek loss rate by an improvement of the energy acceptance as given in the above expression for τ_T.

Concerning the gas scattering process, the dominant contribution is expected to be concentrated on the inner dipole magnet vacuum chambers of the BESSY TBA structure due to an increased pressure caused by synchrotron radiation induced desorption and large beta values. A new and simple vacuum chamber was constructed, taking advantage of simple forming techniques and utilizing NEG pumps which are integrated in the vacuum chamber.

To determine the limiting energy acceptance we measured the lifetime of the stored beam as function of the 500 MHz cavity voltage (fig.4). The strong increase of the lifetime corresponds roughly with $\tau_T \propto (\Delta E/E)^3$, up to a saturation value, which is approximately obtained at 250 KV. The comparison with the theoretical energy acceptance curve (full drawn line) results in an energy acceptance of 1%. The saturation indicates that the energy acceptance is transversely limited. A detailed analysis of the non-linear dynamics for off momentum particles indeed demonstrates a limitation of the transverse energy acceptance to about 0.8% due to an unsymmetrical sextupole scheme in the ring [3]. Therefore symmetrized correction schemes have been worked out to improve the energy acceptance.

Another way to overcome the Touschek effect induced life-

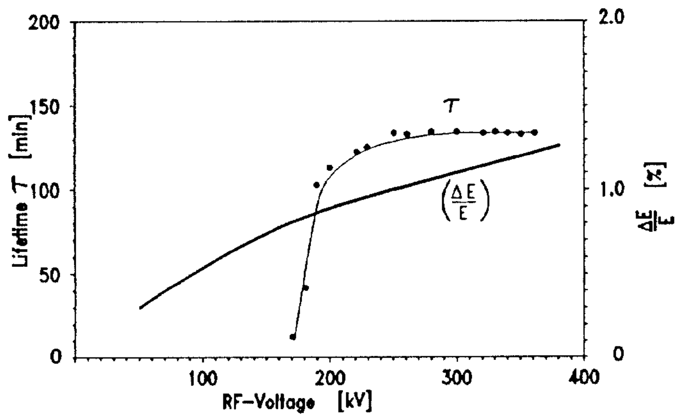

Figure 4: Measured beam lifetime τ and theoretical longitudinal energy acceptance as a function of the cavity voltage for operation with the 500 MHz (N = 62, I $\approx$ 300 mA) rf-system.

time limitation is to increase the bunch volume by lengthening the bunches with a higher harmonic cavity, provided that the time structure of the beam is not a concern. This method has been applied successfully at the NSLS-VUV ring. First experiments at BESSY to improve the lifetime using the existing double rf-system have shown, that longitudinal oscillations which are always excited at high currents in multibunch operation [4] play an important role in the loss process. Further studies are necessary to understand this mechanism.

Conclusion

Lifetime measurements under different operation conditions of the BESSY I storage ring have shown that Touschek and Coulomb scattering loss rates are comparable at high intensities in the low emittance user operation mode. Broadening of the beam using white noise excitation proved to be a helpful tool to obtain quantitative information on the relative strength of the contributions from beam-gas interaction and the Touschek effect. The results also indicate that the energy acceptance of the machine is transversely limited. Symmetrisation of the sextupole compensation scheme and bunch lengthening using a higher harmonic cavity are promising countermeasures to overcome this limitation.

Acknowledgements

We would like to thank W. Anders, T. Westphal, and the machine group for assistence in the single bunch measurements. Helpful discussions with P. Kuske are gratefully acknowledged.

References

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