Effects of Vertical Aperture on Beam Lifetime at the Advanced Photon Source (APS) Storage Ring*

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Abstract

When a positron's energy deviation δE/E exceeds the rf acceptance, or when it receives an angular kick for the betatron motion that exceeds some limiting admittance, the positron will be lost. The main contributions to the total beam lifetime come from single Coulomb and Touschek scattering. In this report we investigate the dependence of the residual gas pressure and the vertical aperture of the Advanced Photon Source storage ring on the total beam lifetime. We present results of calculating the total beam lifetime as a function of vertical aperture for varying average ring pressure, beam current, and coupling coefficient.

I. Introduction

The vertical aperture and pressure enter the lifetime calculation through the single Coulomb scattering. In particular, the variation in vertical aperture is due to elastic scattering on nucleii. The Touschek lifetime numbers do not vary with vertical aperture and are read from the table in Ref. [1]. The total beam lifetime is calculated and plotted as a function of the vertical aperture.

The so-called SPEAR scaling calculation is also included. Experimental observations [2] at the SPEAR storage ring seem to suggest that, for short bunches with rms bunch length σ_l smaller than the beam pipe radius b, the effective longitudinal broadband impedance seen by the beam at frequencies beyond $\omega_c = c/b$ (c being the speed of light) is scaled down by a factor of $(\sigma_l/b)^{1.68}$. This phenomenological power law is referred to as the "SPEAR scaling law."

II. Method of Calculation

The single Coulomb scattering lifetime for a pressure of 1 nTorr, T, is calculated for a range of vertical apertures. Included are elastic and inelastic scattering on nucleii and electrons. The vertical aperture is taken from 1 mm to 20 mm, in 1-mm increments. The highest value of the vertical aperture corresponds to the aperture in the insertion straight sections. The vertical aperture values and the corresponding single-Coulomb scattering lifetime values are used to obtain the single-Coulomb scattering lifetime as a function of the assumed pressure from the formula

$$\tau_{gas} = \frac{T}{P} \qquad (1)$$

where P is the assumed pressure in nTorr. The single-Coulomb scattering lifetime and Touschek lifetime are inserted into the following equation

$$\frac{1}{\tau_{total}} = \frac{1}{\tau_{gas}} + \frac{1}{\tau_{Touschek}} . \qquad (2)$$

in order to obtain the total beam lifetime.

The Touschek lifetime is calculated for the APS storage ring, by use of the code ZAP [3]. For the SPEAR scaling calculations, one needs to find the rms value of the lenghtened bunch, σ_l, and its corresponding rms momentum spread, σ_p. Once these numbers are obtained from Option 2 of the ZAP code, they are input into the Touschek scattering routine of ZAP. The results are used in the present work.

In each case, the calculated rms minimum bunch length σ_l is 0.58 cm and the corresponding rms momentum spread σ_p is 0.96×10^{-3}. In the case of SPEAR scaling, σ_l and σ_p increase, respectively, to 0.89 cm and 1.48×10^{-3} for 5.22 mA current, and, respectively, to 1.51 cm and 2.50×10^{-3} for 10.44 mA current.

III. Analysis of Results

Each plot shows the total beam lifetime, as a function of vertical aperture, for pressures of 1 nTorr, 2 nTorr, 3 nTorr, and 4 nTorr; for currents of 1 mA, 5.22 mA, and 10.44 mA; and for 10% and 1% coupling. The total beam lifetime for 10.44-mA current and 1% coupling is not shown. In this case, the current is too high and the coupling too low to obtain interesting results. The bucket height is assumed to be ± 2%. As may be seen in Figs. 1 through 5, the beam lifetime decreases with increasing current and decreasing coupling. In the case of SPEAR scaling, holding the coupling fixed and increasing the current will not appreciably change the lifetime. This may be seen by comparing Fig. 6 with Fig. 8 and Fig. 7 with Fig. 9.

Each of these graphs also shows a vertical bar, at the total beam lifetime of 10 hours. This is the minimum allowed lifetime for optimum APS storage-ring operation. Clearly, lifetimes below 10 hours for given vertical apertures are too low. Such vertical apertures are to be avoided. Therefore, this method may predict what kinds of bunches may be sustained at what apertures by estimating the aperture for which a given bunch will operate at exactly 10 hours. For the APS storage ring we consider three phases [4]: the commissioning phase, for which the vertical aperture is 40.7 mm, Phase I, for which the vertical aperture is 12 mm, and Phase II, for which the vertical aperture is 8 mm. According to the APS list of parame-

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ters [5], the maximum circulating current for a single bunch is 5 mA.

From Figs. 1-9 it is immediately seen that a 0.58-cm bunch will not be sustained under 4-nTorr pressure at all, and a 0.58-cm, 5-mA bunch cannot be sustained under a pressure of 3 nTorr either (Figs. 3 and 4). For SPEAR scaling, both 0.89-cm and 1.51-cm bunches having 10% coupling can be sustained under 3-nTorr pressure in the insertion straight sections (Figs. 6 and 8), while the 0.89-cm bunch with 10% coupling can also be sustained under this pressure in Phase I (Fig. 6).

For the pressures of 1 nTorr and 2 nTorr and 10% coupling, the 0.58-cm bunches, as well as the SPEAR-scaled 0.89-cm and 1.51-cm bunches, are sustained for vertical apertures of all three phases. Moreover, for the lowest pressure (1 nTorr), only the 0.58-cm bunches with 5-mA current and 1% coupling are not sustained (Fig. 4).

As can be expected, the 0.58-cm bunches with the best lifetimes are those with 1-mA current and 10% coupling. As Fig. 1 shows, they can be sustained in the ring environment of 1-, 2- and 3-nTorr pressure for all three phases. Figure 2 shows that the 1-mA current bunches with 1% coupling also do well; however, at 3 nTorr they cannot be sustained in Phase II. On the other hand, the 0.58-cm, 10-mA bunches do rather poorly. From Fig. 5 it is seen that only bunches having 10% coupling are sustained at 1-nTorr pressure. Longer bunches stand a better chance under these conditions.

IV. ACKNOWLEDGEMENT

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V. REFERENCES

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[2] Chao, A. W., "Coherent Instabilities of a Relativistic Bunched Beam," *Physics of High Energy Particle Accelerators*, SLAC Summer School 1982, AIP Conf. Proc. No. 105, 1983, p. 353.

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[4] "7-GeV Advanced Photon Source Conceptual Design Report," ANL-87-15, April 1987.

[5] *Ibid*, Appendix A.

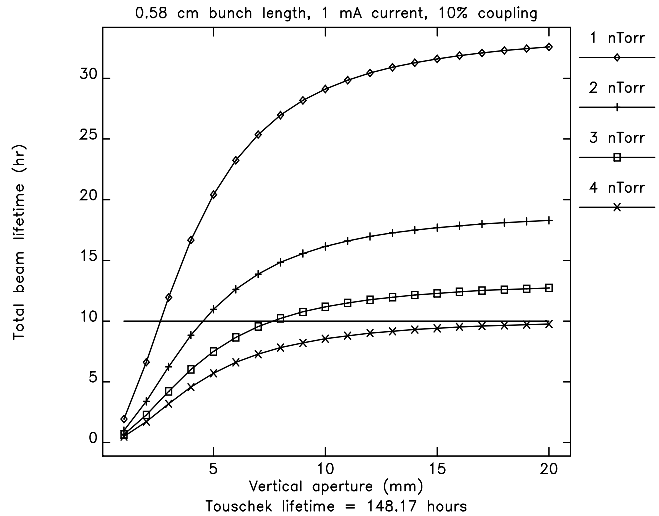
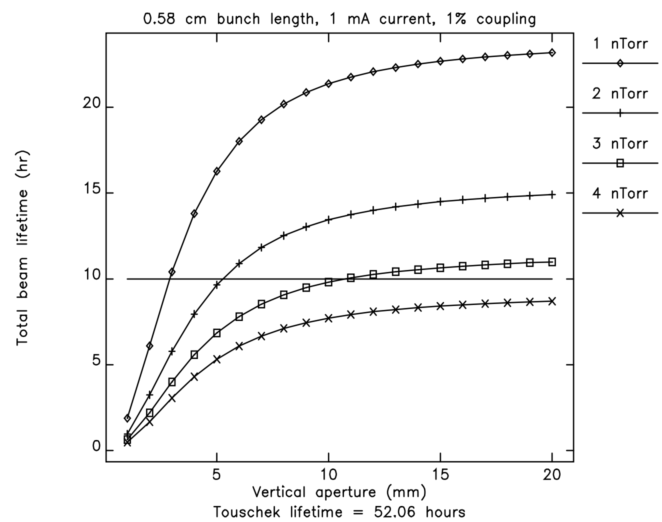


Figure 1



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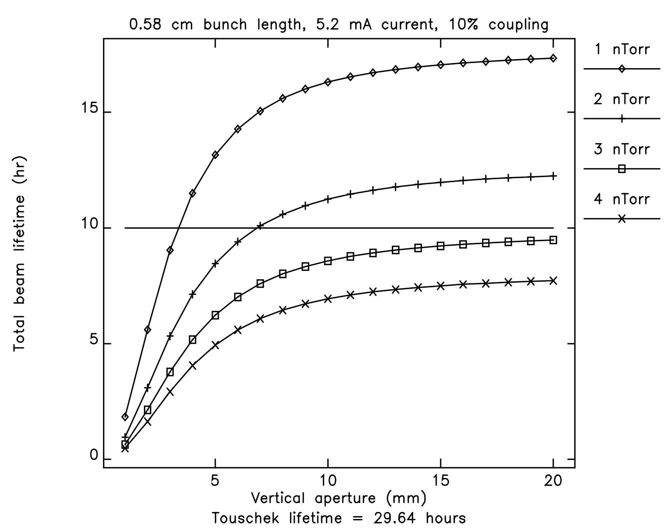

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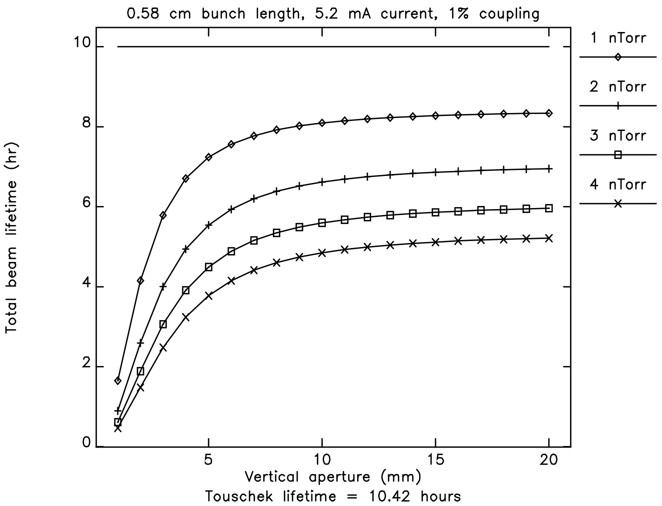

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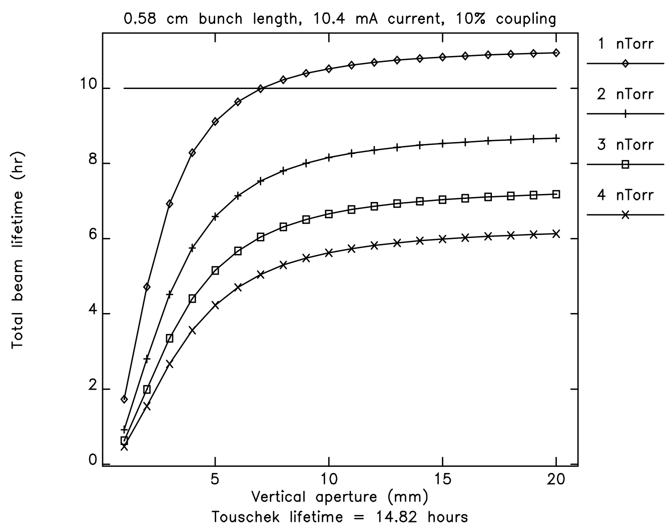

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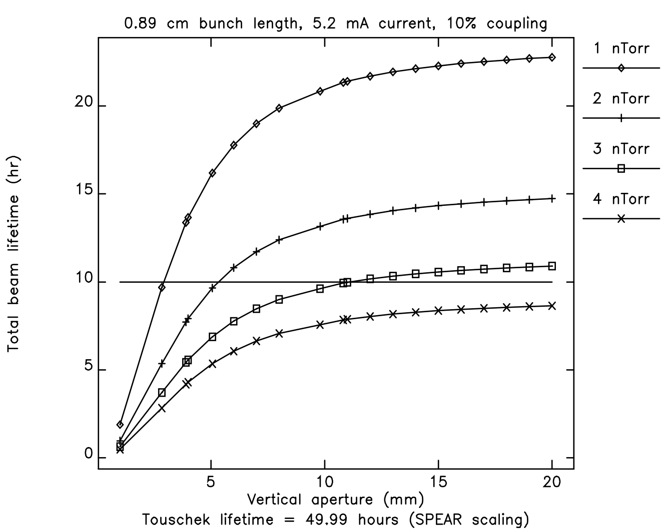

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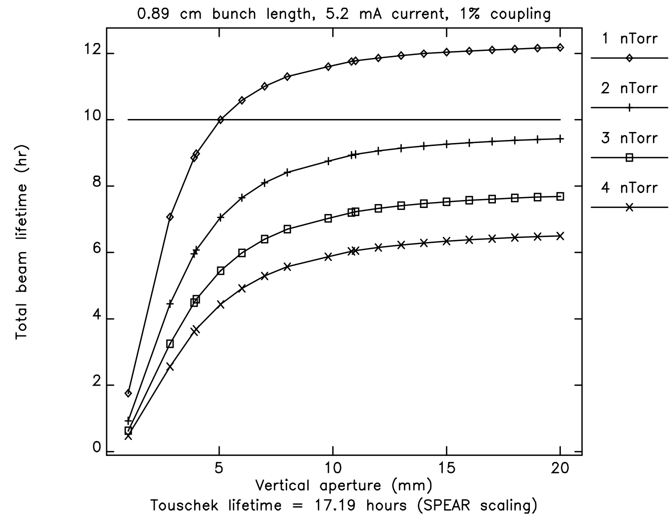

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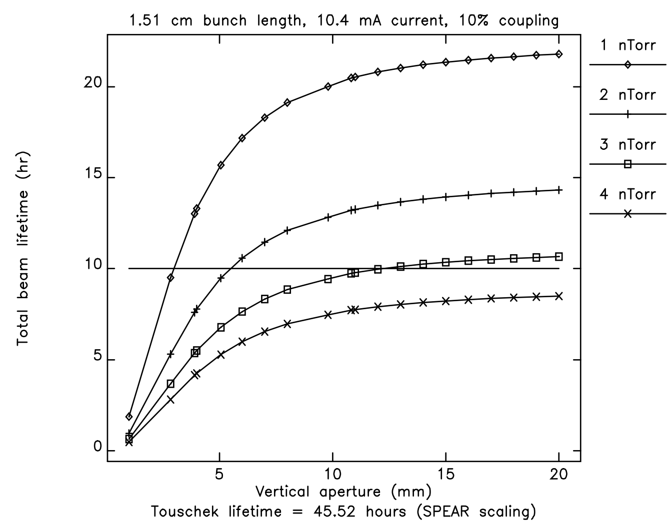

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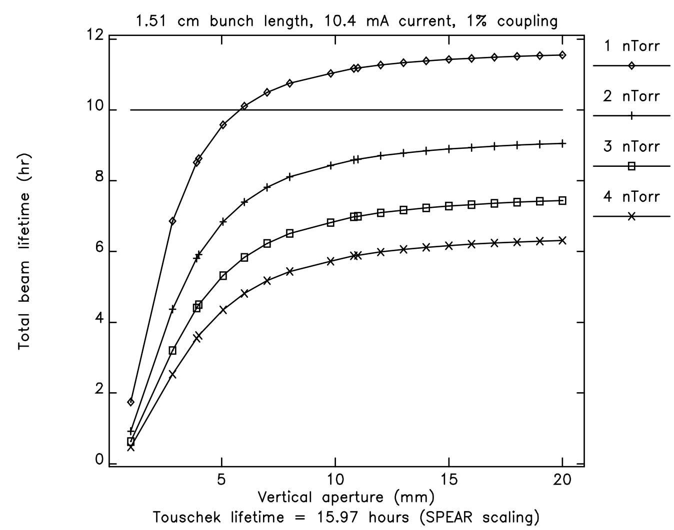

Figure 9