MEASURING AND IMPROVING THE MOMENTUM ACCEPTANCE AND HORIZONTAL ACCEPTANCE AT MAX III

A. Hansson*, Å. Andersson, J. Breunlin, G. Skripka, E. Wallén
MAX IV Laboratory, Lund University, SE-22100 Lund, Sweden

Abstract

Lifetime measurements for varying horizontal scraper positions performed at different RF frequencies suggested a horizontal aperture restriction in the MAX III synchrotron light source. A combination of local orbit distortions and horizontal scraper measurements pinpointed the location of the horizontal aperture restriction to the center of the main cavity straight section. The aperture restriction was determined to be located 10.4 ± 0.3 mm from the beam center. The precise result was achieved by measurements and calculations of the Touschek lifetime as a function of the main cavity voltage. Realignment of the main cavity increased the average lattice momentum acceptance from 0.0116 ± 0.0003 to 0.0158 ± 0.0003 and the horizontal acceptance from $26 \pm 2 \times 10^{-6}$ m to larger than $44 \pm 2 \times 10^{-6}$ m. The increase in momentum acceptance increased the lifetime in MAX III by a factor of two.

INTRODUCTION

The lifetime in MAX III is shorter than envisaged when the ring was designed. The origin of the short lifetime is investigated in this paper and in Ref. [1]. In this paper the focus is on the momentum and horizontal acceptance.

A computer model of MAX III with fitted linear optics was developed for the characterization of the storage ring [2]. Additional response matrix measurements and fits, using the current operating settings of MAX III, were performed for the determination of the emittance [3]. The average of these recent fits forms the basis of the currently used model. An OPA [4] version of the model was used for the Touschek lifetime and momentum acceptance calculations in this paper.

HORIZONTAL APERTURE RESTRICTION

Figure 1 shows the horizontal aperture at the location of the horizontal scraper as a function of frequency change from the normal operating RF frequency at 99.925 MHz. The horizontal aperture at the location of the scraper is in this context the distance between the beam center and the horizontal scraper position where an effect on the lifetime starts to appear. Since the MAX III lifetime is Touschek limited and the vertical acceptance is small [1] the main effect on the lifetime from the horizontal scraper will appear when the momentum acceptance is affected. For the design

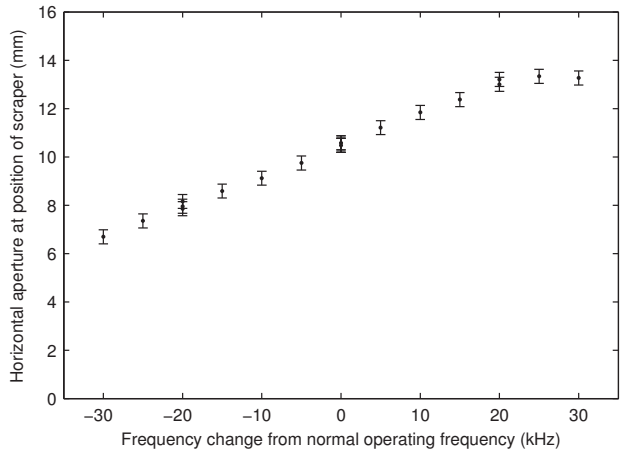

Figure 1: Distance between the beam center and the horizontal scraper position where an effect on the lifetime starts to appear as a function of RF frequency change.

apertures the horizontal scraper would, according to OPA calculations, start to affect the linear lattice momentum acceptance at 17.4 ± 0.1 mm from the beam center. The horizontal aperture as measured in Fig. 1 is clearly smaller. A dependency on the frequency can be observed. Decreasing the RF frequency will increase the electron energy (the momentum compaction factor is 0.0329) and, since all locations in MAX III have positive and nonzero dispersion, move the electron beam outwards. Increasing the RF frequency will move the electron beam towards the center of the storage ring. The frequency dependency in Fig. 1 suggests that a horizontal aperture restriction is located someplace on the outer side of the vacuum system. At around +20 kHz the horizontal aperture does not appear to increase any further when increasing the frequency. The measurements were performed at 108 ± 1 kV main cavity voltage and around this point the Touschek scattered electrons are lost because of the limiting RF momentum acceptance.

Figure 2 shows the horizontal beam position at the 16 beam position monitors in MAX III for four different orbits. One orbit is the normal operating orbit in MAX III and the other three have different orbit distortions around the main cavity straight section. The main cavity straight section starts at beam position monitor 14 and ends at beam position monitor 15. Figure 3 shows horizontal scraper measurements for the four different orbits from Fig. 2. The lifetime is measured as a function of the distance between the horizontal scraper and the beam center. The measurements were performed at a main cavity voltage of 108 ± 1

* anders.hansson@maxlab.lu.se

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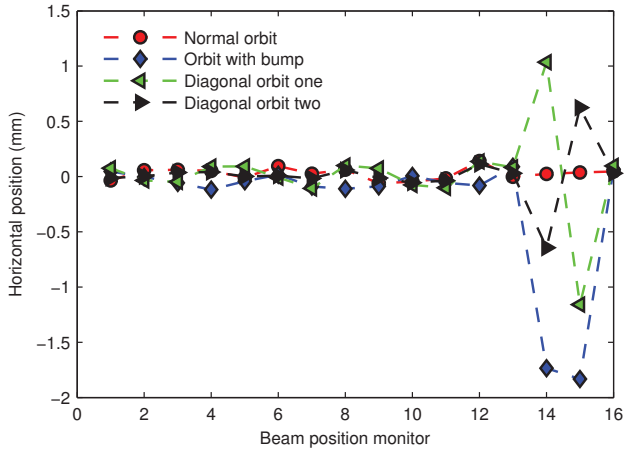

Figure 2: Horizontal beam position at the 16 beam position monitors in MAX III for four different orbits. The error of the measured beam position is estimated to be ± 0.05 mm.

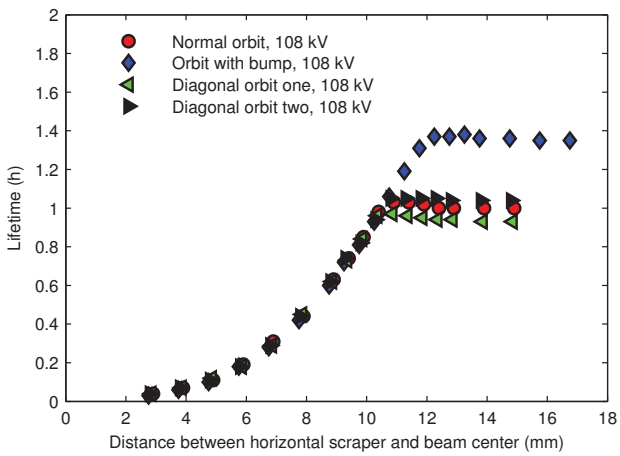

Figure 3: Horizontal scraper measurements for the four different orbits from Fig. 2. The error of the measured lifetime is estimated to be smaller than $\pm 0.3\%$. The uncertainty in the location of the beam center is estimated to be ± 0.2 mm.

kV. The scraper measurement corresponding to the orbit with the local bump (which moves the electron beam towards the inside of the ring) has a larger lifetime than the other three measurements when the horizontal scraper is far from the beam. The position at which the scraper starts to affect the lifetime is further away from the beam. This suggests that the horizontal aperture restriction is situated in the main cavity straight section and that it is located on the outer side of the vacuum system.

For the two diagonal orbits in Fig. 2 and 3 the scraper measurements show only small differences. This suggests that the aperture restriction is located close to the center of the main cavity straight section, where the diagonal orbits cross the normal orbit. Since diagonal orbit two gives a higher lifetime than diagonal orbit one the aperture restriction is likely located slightly upstream the center of the main cavity straight section. A main cavity absorber is located at this position.

Before the main cavity was moved, the alignment group verified the misalignment of the main cavity and concluded that the main cavity was placed roughly 5 mm too far towards the center of the ring. In the beginning of 2012 the main cavity was moved in total 4.5 ± 0.3 mm horizontally towards the outside of the ring in two steps. Figure 4 shows horizontal scraper measurements at 108 ± 1 kV main cavity voltage for the old, intermediate and new cavity position, and at 130 ± 1 kV for the new cavity position. For the measurements at the old and the intermediate cavity position there is a sharp edge in the scraper measurement when the horizontal scraper is moved towards the beam center and it abruptly limits the momentum acceptance instead of the cavity absorber. For the measurement at the new cavity position at 108 ± 1 kV the scraper measurement is noticeably softer, since the momentum acceptance is limited by the RF momentum acceptance until the scraper starts to influence it through the linear lattice momentum acceptance. For the measurement at 130 ± 1 kV the position where the horizontal scraper starts to limit the momentum acceptance is sharper again, which suggests there might be a new unknown restriction that limits the horizontal aperture.

MOMENTUM ACCEPTANCE AND HORIZONTAL ACCEPTANCE

Figure 5 shows the Touschek lifetime as a function of the main cavity voltage for the old, intermediate and new cavity position. The Touschek lifetime was obtained by subtracting the vacuum lifetime component (as determined in Ref. [1]) from the measured total lifetime at around 300 mA stored current. As long as the momentum acceptance is limited by the RF momentum acceptance, the Touschek lifetime will increase when the main cavity voltage increases. When the momentum acceptance is limited by the lattice momentum acceptance, increasing the main cavity voltage will decrease the Touschek lifetime since the bunch length is decreased (increasing the electron density and the probability of electron-electron scattering) while the momentum acceptance is not affected. During a transition region the momentum acceptance is limited by the RF momentum acceptance in parts of the ring and the lattice momentum acceptance in parts of the ring. The linear lattice momentum acceptance in MAX III does not vary much around the ring. For a fixed aperture restriction, the maximum value is around 15% larger that the minimum value and at most locations it is close to the average value. The transition region is thus a limited voltage span, and the location and appearance of it is largely determined by the average lattice momentum acceptance.

The lines in Fig. 5 correspond to calculations of the linear Touschek lifetime from OPA. The calculated lifetimes have been scaled by the scaling factor 2.7 determined in Ref. [1]. The best agreement with the measured lifetimes is for calculations where the cavity absorber is located 10.6 mm from the beam center for the old cavity position and

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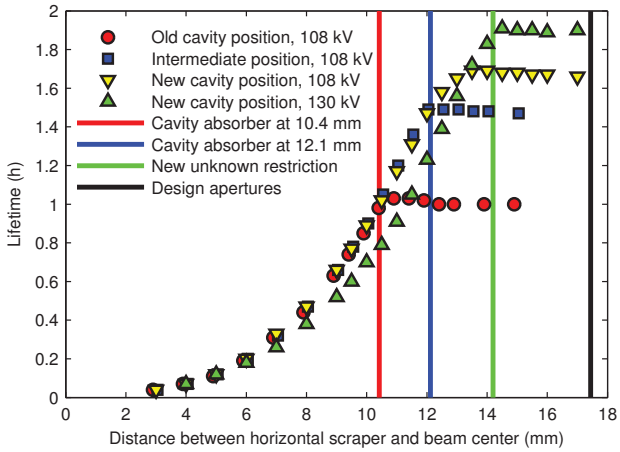

Figure 4: Horizontal scraper measurements for the old, intermediate and new cavity position. The error of the measured lifetime is estimated to be smaller than $\pm 0.3\%$. The uncertainty in the location of the beam center is estimated to be ± 0.2 mm.

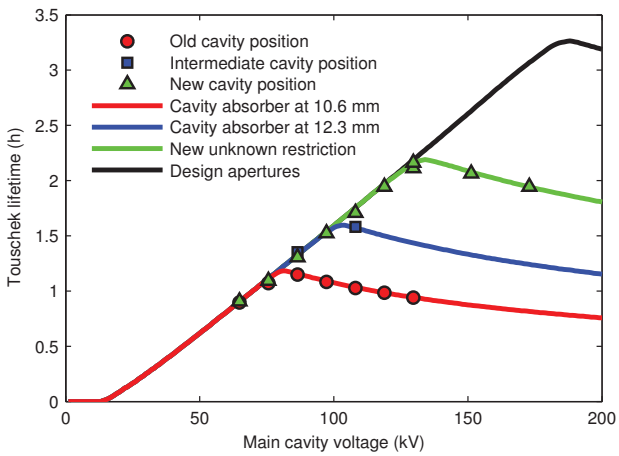

Figure 5: Measurements of the Touschek lifetime as a function of the main cavity voltage for the old, intermediate and new cavity position. The error of the measured Touschek lifetime is estimated to be $\pm 1\%$ or smaller.

12.3 mm from the beam center for the intermediate cavity position. For the new cavity position a new unknown restriction is suggested. If the restriction is assumed to be situated at the horizontal scraper, the best agreement is for calculations where the horizontal scraper position is 14.4 mm from the beam center. The calculations in Fig. 5 assume that the RF momentum acceptance is given by the main cavity only. The Landau cavities will however decrease the RF momentum acceptance by up to 3%. Taking this effect into account and including other error sources the cavity absorber is determined to be located 10.4 ± 0.3 mm and 12.1 ± 0.3 mm from the beam center for the old and intermediate cavity position. For the new cavity position the horizontal scraper starts to limit the lattice momentum acceptance 14.2 ± 0.3 mm from the beam center. The position, according to OPA calculations, where the horizontal scraper would start to influence the linear lattice momentum acceptance if the cavity absorber was located 10.4 mm or 12.1 mm from the beam center is marked in Fig. 4 together with the new restriction that corresponds to the horizontal scraper at 14.2 mm from the beam center.

It is unknown if the new restriction is a physical or dynamic aperture. The average lattice momentum acceptance of the new restriction is however known to have a value close to the average linear lattice momentum acceptance of the horizontal scraper when it is located 14.2 mm from the beam center.

As long as the main cavity voltage is high enough the momentum acceptance is determined by the lattice momentum acceptance. The average lattice momentum acceptance is 0.0116 ± 0.0003 for the old cavity position and 0.0135 ± 0.0003 for the intermediate cavity position. For the current operating settings in MAX III, the average lattice momentum acceptance is 0.0158 ± 0.0003, whereas the design average lattice momentum acceptance is 0.020.

The horizontal beta function at the location of the cavity absorber is 4.10 ± 0.06 m. The horizontal acceptance is thus $26 \pm 2 \times 10^{-6}$ m for the old cavity position and $36 \pm 2 \times 10^{-6}$ m for the intermediate cavity position. For the new restriction the value of the acceptance depends on where the restriction is located. For each position in the ring, a physical restriction can however not give a smaller average lattice momentum acceptance than the observed one. From this information a lowest possible value for the horizontal acceptance can be determined. For the current operating settings in MAX III, the horizontal acceptance is larger than $44 \pm 2 \times 10^{-6}$ m. The design value for the horizontal acceptance is 73×10^{-6} m and the design limiting horizontal aperture is the absorber downstream the dipole magnet.

Before moving the main cavity, the main cavity voltage was typically around 110 kV and the momentum acceptance was limited by the cavity absorber. For the new cavity position the main cavity voltage is kept around 130 kV, where the RF momentum acceptance and the lattice momentum acceptance is roughly equal, in order to give the maximum lifetime. This has increased the lifetime in MAX III by a factor of two.

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