OBSERVATION OF ION INDUCED EFFECTS AND THEIR IMPACT ON THE PERFORMANCE OF THE MLS ELECTRON STORAGE RING*

J. Feikes[@], M. v. Hartrott, G. Wüstefeld, HZB[†], Berlin, Germany
A. Hoehl, R. Klein, C. Koschitzki, G. Ulm, PTB, Berlin, Germany

Abstract

The Metrology Light Source (MLS) [1] is in user operation since 2008 at operating energies ranging from 105 MeV up to 630 MeV and with multi bunch currents up to 200 mA. At the injection energy of 105 MeV as soon as the beam current exceeds a few mA, the beam is strongly blown up in all three spatial dimensions and strong oscillations at very different spectral frequencies can be observed. These effects are caused by the interaction of beam charge with ions present and their strength and characteristic time scales depend on several machine parameters. As ion effects can strongly deteriorate the performance of the MLS, we report on first investigations.

ION INDUCED CURRENT LIMITS

The MLS has been designed and built by BESSY [2] according to the specifications of its owner, the Physikalisch-Technische Bundesanstalt (PTB). Since 2008 running in routine operation, the MLS has a wide range of operating modes and parameter settings as shown in Table 1.

To accumulate higher operating currents, several combined measures to suppress ion related effects have to be taken [3] as applying

- a clearing voltage of -2000 V at four dedicated clearing electrodes
- a clearing voltage of -300 V at four BPM stations, misused for that purpose
- beam shaking at a transverse tune.

An example is shown in Fig. 1, where accumulation starts without any ion suppression while clearing voltages and beam shaking excitation are added step by step. The reason could be a blow-up of the beam size with increasing beam current, its strength depending on the ion density. Once the beam size is so large that it hits the physical aperture, accumulation stops.

SOURCE SIZE MEASUREMENTS

The beam dimensions at the low injection energy are determined by two effects: intra beam scattering and ion trapping. Both effects strongly couple. As the operating conditions depend sensitively on the source sizes these were measured as function of several machine parameters.

An optical imaging system was used, installed at a bending magnet. The synchrotron radiation emitted from the electron beam in the centre of the bending magnet

Table 1: Machine and operating parameters of MLS

Circumference	48 m
Revolution time	160 ns
Injection energy	105 MeV
Operational energy	105 MeV to 630 MeV
Beam current	1 pA to 200 mA
Accumulation rate	1/5 Hz
Injected current	4 mA / single shot
Momentum compaction factor	10^{-4} to 3×10^{-2}
Damping times at injection	3 s longitudinal 5 s transverse
Peak vacuum pressure after a total accumulated dosis I * T = 500 A h	< 10^{-9} mbar at 150 mA beam current
Vertical aperture Horizontal aperture	28 mm full height 24 mm full width

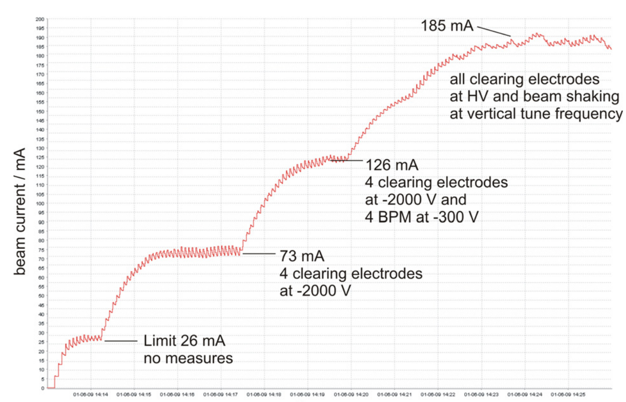

Figure 1: Current limits caused by beam ion interaction. While accumulating without any ion suppression the beam current saturates at low currents (26 mA). With each additional countermeasure applied the saturation current increases.

* Work funded by Physikalisch-Technische Bundesanstalt
@ joerg.feikes@helmholtz-berlin.de
† By the merger with the former Hahn-Meitner-Institut (HMI), BESSY became part of the new Helmholtz-Zentrum Berlin für Materialien und Energie (HZB)

is focused by an achromatic lens system onto a CDD camera.

The display of the imaging system has been calibrated thus allowing for the absolute measurement of the beam size.

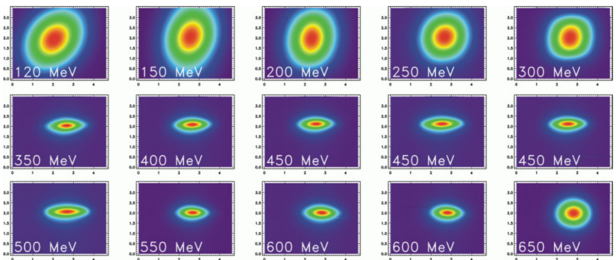

Figure 2: Beam images of a 100 mA beam taken on the ramp. Above 600 MeV coupling is enhanced by raising a squew quadrupole to improve Touschek lifetime.

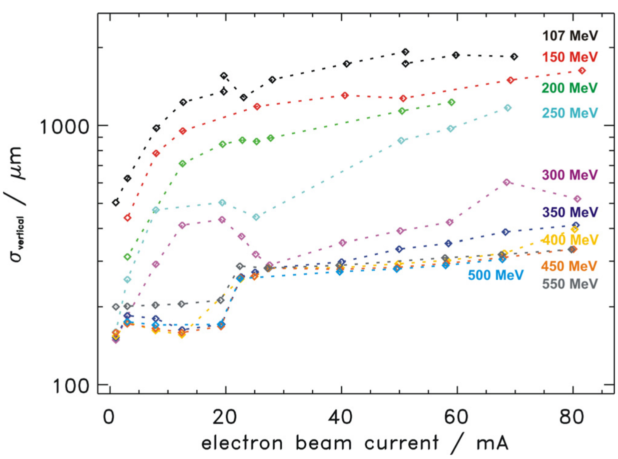

Figure 3: Vertical beam size (1σ = rms) as function of the electron beam current at different beam energies (logarithmic scale).

The vertical beam sizes shown in Fig. 3 have been recorded from an on line evaluation of source point images. Each point of the displayed curve at the different specified energies in reality has been obtained in a ramp up cycle at constant ring current. The beam optics at the different energies on the ramp is kept fixed by appropriate scaling of all magnet power supply currents.

As predicted [2], a strong beam blow up due to strong intra beam scattering at energies below 350 MeV is observed. Only due to this strong beam blow up at injection energy, it is possible to store the desired operating current at a reasonable lifetime (~1 h at 100 mA), because it improves Touschek lifetime by the enlarged bunch volume. The strong increase of the source sizes at currents below 30 mA and energy around 300 MeV is not expected.

DEPENDENCY ON COUPLING

The source sizes depend on optical coupling. As the coupling element on the ramp also properly scale with the beam energy, the beam sizes shown Fig. 3 represent equivalent coupling condition. But it is observed that ion interactions change the behaviour expected from linear optics.

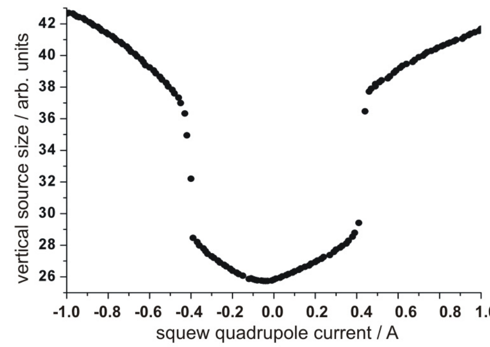

Figure 4: Vertical source size as function of the squew quadrupole current at a small value of the momentum compaction factor and at 630 MeV (clearing voltage on).

Figure 4 shows an example of a frequently observed phenomenon. While scanning the current of a squew quadrupole from -1.5 A to 1.5 A, at a certain negative value the source size shrinks instantly by about 30 % and restores at a certain positive value. At low momentum compaction values this effect is enhanced. In order to further analyze this coupling behaviour a refined plot of the source size ratio as function of the squew quadrupole current, based on a relation given in [4], is shown in Fig. 5. A parabolic behaviour around the minimum is expected from linear optics and was observed at BESSYII but is not seen here, showing again that other factors are determining the source size.

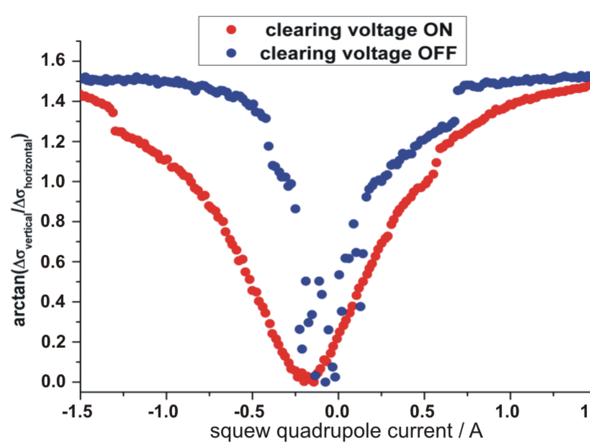

Figure 5: Measured at 630 MeV and 109 mA beam current the arctan($\Delta\sigma_{vertical}/\Delta\sigma_{horizontal}$) verses squew quadrupole current is plotted with and without clearing voltage applied. Δσ are the changes of the source size due to the change of the quadrupole current.

A demodulated 500 MHz beam signal from a strip line pick up usually shows a low frequency oscillation even at small beam currents. At injection energy its frequency is about 16 Hz and at 630 MeV about 70 Hz. This oscillation obviously is an ion-related instability either in the horizontal or longitudinal plane (there is considerable dispersion at the strip line). When the clearing voltage is off, during the squew quadrupole scan, this instability changes its time structure at the point of sudden size shrinking. At low optical coupling the Fourier spectrum is broad and the signal looks quite irregular on a spectrum analyzer. Above it becomes a strong and pure harmonic oscillation with a frequency depending on the coupling value and becomes very sensitive on the beam current. With clearing voltage on, there is no such effect. The instability mechanism behind this observations is still unknown

TUNE SIGNALS

Simple models predict an incoherent tune shift ΔQ_{inc} proportional to the electron current I and the ion density d_{ion}:

$$\Delta Q_{inc} \sim I \cdot d_{ion}$$

It was tried to measure the ion neutralization factor in such a way, but it results that it is not sufficient to measure just a shift of a peak of a tune signal. Figure 6 shows some tune signals as function of the beam current at constant external excitation. A transition of broad to sharp signals at 10 mA is accompanied by almost vanishing signal amplitude The direction of tune shift with current reverses sometimes. At higher currents, there are only small tune shifts and the behaviour is more systematic. We think what is observed at the pick up is a mixture of beam-induced and ion- plasma-induced signals screened by the ion cloud around the pick up. In attempts to extract a pure electron beam signal several carrier frequencies were tried (inclusive mirror modes). Introduction of a bunch gap does not improve either. The data are still not coherent enough to be used directly but we made the experience that with continuing beam scrubbing many ion related effects diminish. But even at a much better vacuum conditions we do not expect them to become negligible.

SUMMARY

Ion related effects are very important for the beam dynamic in the MLS and crucial for the ability to accumulated the desired operating currents and are therefore target of investigation.

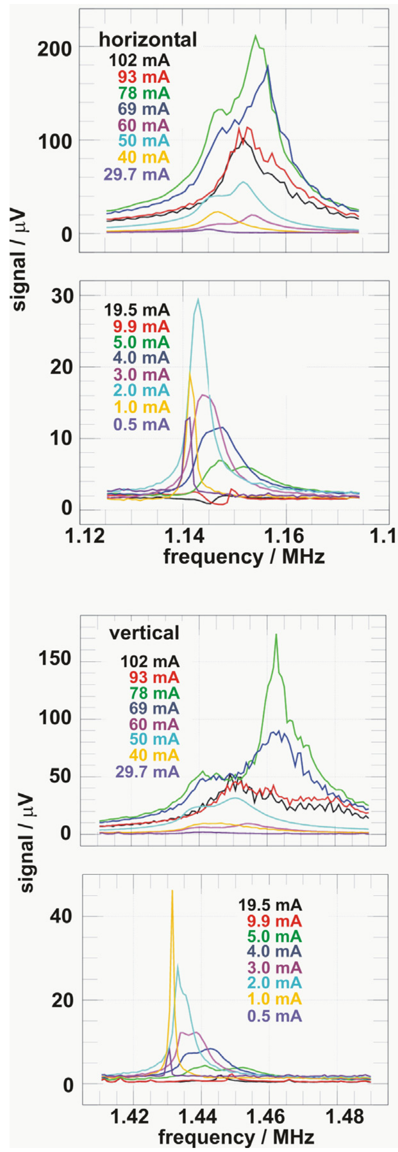

Figure 6: Transverse tune signals as function of the beam current at 630 MeV. Top: horizontal, bottom: vertical tune line; the beam current is coded by different colours.

REFERENCES

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