BEAM LIFETIME IN THE ASTRID AND ASTRID2 SYNCHROTRON LIGHT SOURCES: EXCITATIONS AND VACUUM DEPENDENCES

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Abstract

The beam lifetime is a very important parameter for synchrotron light sources without top-up, and sometimes more important than the lowest possible vertical beam emittance. At the ASTRID [1] synchrotron light source, we have for many years routinely applied a phase modulation of the accelerating RF field, together with a vertical excitation of the beam at the first vertical betatron frequency. These two effects increase the beam lifetime from about 3 hours to around 100 hours at 150 mA. Lifetime measurements as function of modulation and excitation parameters will be presented. Additionally, measurements of the beam lifetime in ASTRID and ASTRID2 [2] as function of vacuum pressure will be presented.

INTRODUCTION

For synchrotron light sources without top-up the lifetime is a very important parameter. The varying thermal load on mirrors and other beam line and ring components makes it difficult to maintain a stable beam. Furthermore long lifetime gives a larger integrated photon yield, especially if refills take significant time. The ASTRID storage ring does not have a full energy electron injector, and the ring therefore needs ramping. Due to the thick septum the beam need time to cool between each accumulation from the microtron pre-injector. The total refill time is therefore quite long, typically ½ hour.

Most users on ASTRID have been more interested in a high flux, than in a small beam, i.e. they prefer a long lifetime over a small emittance. However this varies from beam line to beam line. Over the years the amount of vertical excitation (see later for details) has thus varied, as new beam lines have been build, and others have changed function.

Originally ASTRID was built as a dual purpose storage ring, capable of storing both heavy ions for atomic physics studies, and electrons for synchrotron radiation production. The capability of storing ions required a fairly large physical aperture and an Ultra High Vacuum (low 10^{-11} mB). These two qualities, together with the excitation techniques described below, have enabled us to increase the beam lifetime from the natural (Touschek) lifetime of ~3 h to about 100 h at 150 mA.

Over the years the vacuum in ASTRID has gradually been improving during electron storage, in particular after the mid 00'ies where ion operation ceased, and vacuum interventions became rare. This improved vacuum has allowed the beam lifetime to increase from about 35 h in the late 90'ies [3] to now about 80-100 h. As then, having a well-aligned orbit is still essential to achieve the long lifetimes.

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Table 1: Main ASTRID Parameters

Quantity	Value
Energy	580 MeV
Betatron tunes (h; v)	2.220; 2.630
Horizontal emittance	~140 nm
Design current	200 mA
Circumference	40.0 m
Damping times (h/v/l)	29/19/8 ms

BEAM LIFETIME WITH EXCITATIONS

At ASTRID, two types of techniques are used to improve the beam lifetime: An excitation of the beam at the first vertical betatron sideband, and a phase modulation of the RF master frequency. Figure 1 shows the beam lifetime as function of beam current for the four combinations of vertical excitation on and off, and RF phase modulation on and off. As can be seen, it is the vertical excitation which has the largest influence. The small dip in lifetime around 100 mA is because the RF phase modulation parameters were not completely optimized for all currents at the time of recording the data. Since we normally operate at higher currents, care is not always taken to optimize at the lower currents.

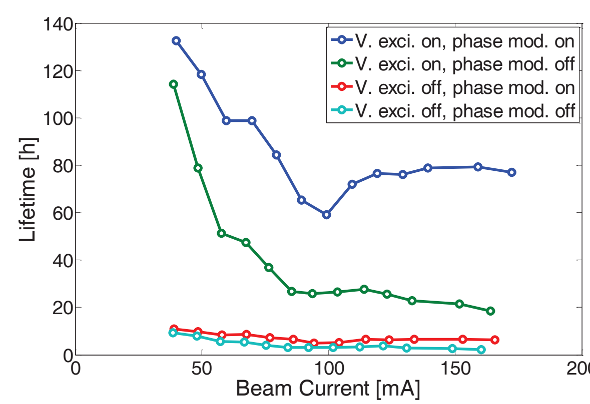

Figure 1: Beam lifetime as function of beam current with and without vertical excitation and RF phase modulation.

Vertical Excitation

The vertical excitation works by resonant excitation of the vertical betatron motion, which increases the vertical beam size, reducing the Touschek scattering. The output from a signal generator is fed to a vertical stripline

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through a 10 W, broadband amplifier. With a revolution frequency of 7.496 MHz and a fractional tune of 0.630 the excitation frequency is 4.62 MHz. In order to allow small variations in the (vertical) tune, FM modulation is used. The frequency deviation used is 60 kHz with a modulation frequency of 1 kHz. The modulation period has been chosen to be smaller than the damping time, resulting in a constant excitation. In order to keep the excitation stable, the (vertical) tune is continuously measured and corrected using the two quadrupole groups. Experimentally we have found that the beam is more stable, when correcting the tune instead of tracking the excitation frequency.

Figure 2 shows the beam lifetime as function of vertical excitation level (signal generator output). There is a steady increase in beam lifetime until a maximum is reached after which the lifetime quickly decreases, when overdriving the resonant excitation. The vertical emittance and thus the vertical beam size also vary with the excitation level. Even though a vertical excitation level of 1-2 dBm gives the highest beam lifetime, this is not the level we usual operate at. The operating level is a compromise between lifetime and photon yields through the (vertical) slits in the photon beam lines. The optimum of course varies from beam line to beam line. For the last many years we have been using a level of -3 dBm as the compromise.

By inserting a fast RF-switch between the signal generator and the amplifier, and turning the resonant excitation signal on and off in phase with the electron revolution frequency, the overdriving of the excitation can be used for killing selected bunches.

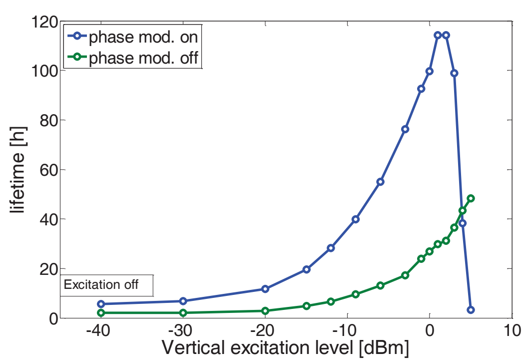

Figure 2: Beam lifetime as function of vertical excitation level with and without RF phase modulation.

RF Phase Modulation

At the 5th ESLS meeting in Lund 1997, Peter Kuske, BESSY reported that phase modulation of the acceleration RF field at a frequency of approximately three times the synchrotron frequency had led to an increase of the beam lifetime in BESSY I. Phase modulation of the RF master frequency was subsequently tried at ASTRID. An increase in beam lifetime was observed for all harmonics of the synchrotron frequency up to the 4th, with the third giving the best result at the time [3]. Experimentally it was found that the best results were obtained with a modulation frequency slightly below the synchrotron harmonic (small negative offset). The optimum modulation offset has always varied with beam current, see next section. Over the years we have regularly optimised the modulation parameters, especially the modulation offset. At some point the optimum harmonic also changed to be the second harmonic. The synchrotron frequency at the optimum cavity voltage (38 kV) is about 22 kHz. The improvement of beam lifetime with phase modulation is larger, the larger the beam current.

To our knowledge no theory explains all the details of the RF phase modulation. A theory [4] developed at our institute soon after our first use of phase modulation, suggests the lifetime improvement comes from a modification of the bunch density, lowering the density in the center of the bunch. The lower density implies a lower Touschek scattering, which improves lifetime.

PHASE MODULATION – PARAMETER DEPENDENCE

RF Phase Modulation Offset

Figure 3 shows the beam lifetime as function of phase modulation offset for a number of beam currents. The phase modulation is just below the 2nd harmonic of the synchrotron frequency. The optimum modulation offset is seen to shift closer to the harmonic (smaller offset) as the beam current decreases. Around and below ~100 mA the optimum offset is even not achieved in these scan. However, with a small offset the beam is more prone to sudden instabilities, and sudden large reductions in beam lifetime. We therefore aim to operate on the negative side of the optimum offset (i.e. with a slightly more negative offset).

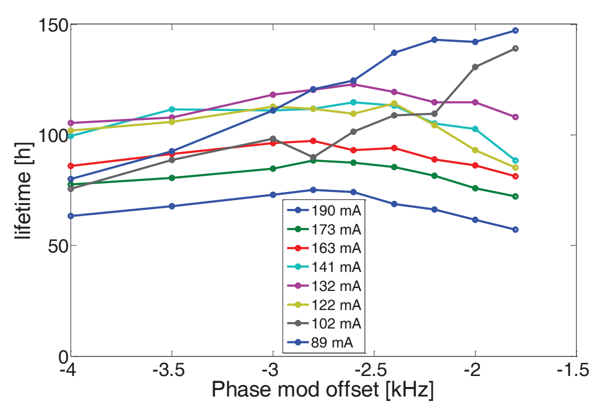

Figure 3: Beam lifetime as function of RF phase modulation offset for a number of beam current.

RF Phase Modulation Harmonic

Figure 4 shows the beam lifetime as function of modulation offset for RF phase modulation at the first 3 synchrotron harmonics. The second harmonic is clearly the better choice. However it should be mentioned that more work have been put into optimising other parameters (RF cavity voltages, phase modulation deviation) for the second harmonic that for harmonic 1 and 3. A completely global optimisation is in practice impossible.

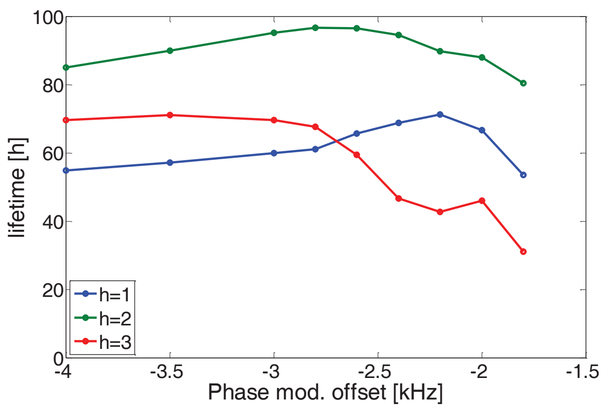

Figure 4: Beam lifetime as function of RF phase modulation offset for the first three synchrotron harmonics.

VACUUM DEPENDENCE

Operating at low beam energy (580 MeV), gas scattering is dominating, especially with the lifetime improving techniques described in the previous sections.

Figure 5 shows the beam lifetime as function of vacuum pressure, with data from both ASTRID and ASTRID2. The three lowest ASTRID pressure points were measured at 120 mA with all ion pumps on, some of the ion pumps on, and all of the ion pumps off. The higher pressure points are from start-up after a complete venting of the entire machine. The currents vary but were mostly rather low. The ASTRID2 points are from two commissioning days after a partial venting of the machine. The low pressure points are with low currents, whereas the high pressure points are with varying higher currents. The red (inverse) fit is a fit to the ASTRID data. It is clearly seen that to obtain a lifetime on the order of 100 h, a pressure in the low 10^{-11} mB is necessary.

ASTRID2 LIFETIME

ASTRID2, the new synchrotron light source in Aarhus presently being commissioned [2], has now been operated for about 1200 hours with an integrated stored current of 34 Ah. With a beam current of 65 mA, which routinely can be achieved in top-up mode, the natural lifetime is ~1 h. Even though it is not foreseen for user operation, applying a vertical excitation, like on ASTRID, can increase the lifetime to ~2 h. The average vacuum pressure is presently $\sim 3 \cdot 10^{-9}$ mB, and is improving with integrated beam current. The beam lifetime with vertical excitation is therefore expected to increase.

The RF cavity voltage has up till now been limited to about 45 kV due to insufficient cooling water. We expect more RF voltage will improve the natural beam lifetime, due to a higher momentum acceptance. To increase the momentum acceptance of the machine, the vacuum chambers are elliptical in the centers of the arc, where the dispersion is largest. Later this year a Landau cavity will be installed to further increase the lifetime [5].

Since ASTRID2 uses ASTRID as a full energy booster, top-up operation is possible. Compromises between lifetime and beam size is therefore not an issue, and beam lines which takes full advantage of the small emittance of ~10 nm can be build. Having a long lifetime is however still advantageous since each injection does imply a small perturbation to the stored beam. Another advantage of a long beam lifetime is the reduction of the produced ionizing radiation. For low-energy storage rings like ASTRID and ASTRID2, the ionizing radiation is caused only by electron loss, either due to beam lifetime or as losses during injection.

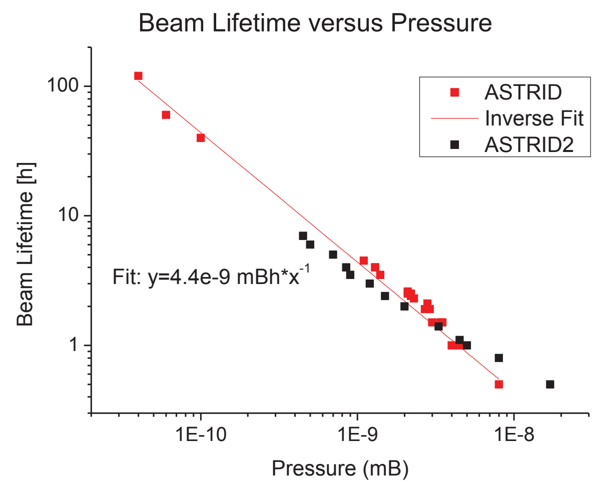

Figure 5: Beam lifetime as function of vacuum pressure.

REFERENCES

[1] S.P. Møller, "ASTRID – A Small Multi-purpose Storage Ring", EPAC'92, Berlin, p. 158 (1992); http://www.JACoW.org
[2] S.P. Møller, N. Hertel and J.S. Nielsen, "Status and very first commissioning of the ASTRID2 synchrotron light source", MOPEA003, these proceedings.
[3] J.S. Nielsen and S.P. Møller, "New developments at the ASTRID storage ring", EPAC'98, Stockholm, June 1998, WEP05F, p. 406 (1998); http://www.JACoW.org
[4] Yu. Senichev et al., "Increasing the life time of SR sources by RF phase modulation", EPAC'98, Stockholm, June 1998, THP23F, p. 1339 (1998); http://www.JACoW.org.
[5] Å. Andersson, M. Eriksson, M. Georgsson, "Landau cavities at Max II", EPAC'98, Stockholm, June 1998, THOA01A, p. 273 (1998); http://www.JACoW.org

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