BEAM LIFETIME AND BEAM BRIGHTNESS IN ALS*

C. Kim, A. Jackson, and A. Warwick, Lawrence Berkeley Laboratory, Berkeley, CA 94720

Beam lifetime in ALS is dominated by the Touschek scattering. Measurements of lifetime in single-bunch mode with estimates of bunch dimensions obtained from undulator radiation data are consistent with expectations (t=1.8 hours at 1.25 mA per bunch). However, the lifetime is significantly longer in multi-bunch mode (t=11 hours at 400 mA per 320 bunches). This discrepancy has been traced to an increase in the momentum spread and bunch length in the beam caused by longitudinal coupled-bunch motions driven by higher-order modes in the rf cavities. The increased momentum spread leads to a significant degradation in the undulator spectral performance. Feedback stabilization of the coupled-bunch motion improves the spectral characteristics of the undulator beam at the expense of beam lifetime. We observe an increase of ~200% in beam lifetime by operating at the betatron coupling resonance.

I. INTRODUCTION

Photon beams with unprecedented spectral brightness from undulators and wigglers are the trademark of the third generation synchrotron radiation sources, such as the Lawrence Berkeley Laboratory's Advanced Light Source (ALS) [1]. Short bunch length, low emittance electron beams are essential for the undulators and wigglers to generate spectral brightness higher than 10^{19} photons /s-mm^2-mrad^2-0.1% bandwidth.

In order to realize the short bunch length low emittance beam, the lattice was designed to have a very strong focusing and a small momentum compaction factor. Longitudinal [2] and transverse [3] rf feedback stabilization was designed to prevent electron bunches from loosing their brightness as a result of various instabilities.

In these storage rings, the beam lifetime is dominated by the large angle intra-beam scattering called Touschek scattering[4]. In this process, transverse momentum is transferred to the longitudinal momentum whereby the particles are lost from the longitudinal momentum acceptance. Measurement of beam lifetime is an indirect way of measuring the brightness of the beam because the lifetime becomes shorter as the electron beam density increases.

The ALS storage ring has been serving the user community without the rf feedback stabilization for some time. Without this stabilization, the longitudinal coupled bunch instabilities grow first and saturate at some larger values of energy spread and longer bunch length. The resulting larger energy spread actually stabilized the transverse instabilities.

The ALS lattice and beam parameters are summarized in Table I. We have been operating at the nominal energy of 1.5 GeV with the beam current up to 400 mA and at the ramped energy of 1.9 GeV with the beam current up to 260 mA.

These parameters were experimentally confirmed: the momentum compaction factor was calculated from the measured synchrotron frequency as a function of the cavity voltage; beam emittance and the energy spread were measured at the diagnostics beamline [5].

Table I.. ALS Electron Storage Ring Parameters

Circumference [m]		196.8
Nominal Energy (GeV)		1.5
Revolution Freq. [MHz]		1.52
Harmonic Number		328
Betatron Tune	Horizontal	14.28
	Vertical	8.19
Synchrotron Freq. (kHz)	1.5 GeV	11.5
Momentum Compaction		0.0016
Natural Chromaticity	Horizontal	-24.6
	Vertical	-27.3
Natural Emittance (m-rad)	1.5 GeV	3.4 x 10^{-9}
	1.9 GeV	5.5 x 10^{-9}
Natural Energy Spread (σ_E/E)	1.5 GeV	6.5 x 10^{-4}
	1.9 GeV	8.3 x 10^{-4}
Natural Bunch Length (σ_l mm)	1.5 GeV	3.7
	1.9 GeV	4.7
Radiation Loss (keV/turn)	1.5 GeV	91.5
Radiation Damping at 1.5 GeV [msec]	Horizontal	15.3
	Vertical	21.5
	Energy	13.5

II. LIFETIME MEASUREMENTS

Lifetime in the ALS electron storage ring was measured by measuring the stored current, I(t), using a DC current transformer and using the definition, $\tau(t) = I(t)/(dI(t)/dt)$. Measured lifetime depended on beam energy, bunch current and the number of bunches stored. Measured beam lifetimes at 1.5 GeV are plotted in Figure 1 against stored electron current per bunch for single, 240, and 320 bunches. The rf multi-bunch feedback system was turned off at the time of measurements.

Calculated Touschek lifetimes using the ZAP code [6] are shown in solid lines for different bunch lengths in Figure 1.

For the single bunch mode, the measured lifetime at low current asymptotically approaches the calculated Touschek lifetime for the natural bunch length of 3.7 mm. However, at higher current, the measured lifetime is considerably longer than the expected Touschek lifetime for

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the same bunch length indicating bunch lengthening increased energy spread.

Also, longer beam lifetimes were observed for a given beam current per bunch when the number of bunches stored in the storage ring is increased as shown in Figure 1.

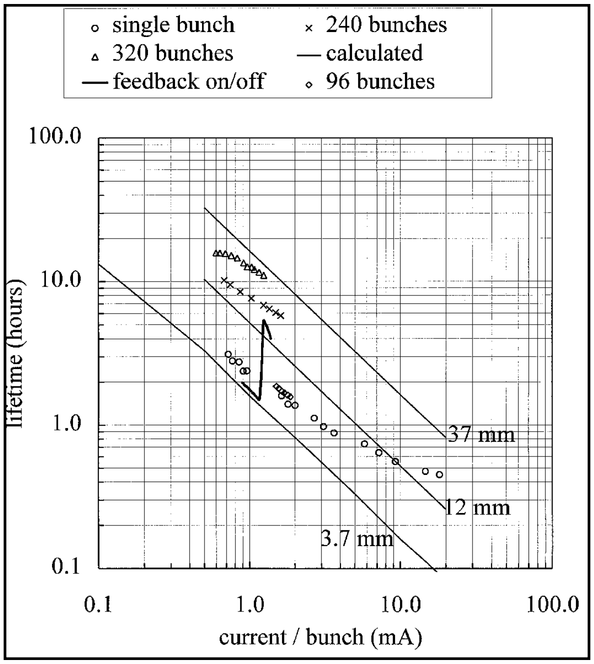

Figure 1: Measured beam lifetimes at 1.5 GeV are plotted against stored electron current per bunch in the ALS Storage ring. Theoretically expected Touschek scattering times at the given bunch lengths are shown in solid lines.

Lifetimes were also measured for 1.9 GeV beam for single and 320 bunch fills. They are plotted in Figure 2 against current per bunch. The rf multibunch feedback system was turned off at the time of measurement.

Calculated Touschek lifetimes are shown in solid lines for three different bunch lengths in Figure 2. The measured lifetime at 1.9 GeV agrees very well with the calculated Touschek time. Significantly less bunch lengthening and energy spread are apparent.

III. SPECTRAL INTENSITY MEASUREMENTS

The effects of the longitudinal beam feedback stabilization on beam lifetime and on the spectral intensity of the ALS undulator Beamline 7.0 were studied. At the time of this study, a prototype of the longitudinal feedback system was able to control up to 84 bunches. The transverse feedback system was not ready. The lifetime is already close to the theoretical minimum with 84 bunches pattern as shown in Figure 1. That would mean that there is no room for further decrease in beam lifetime with the feedback.

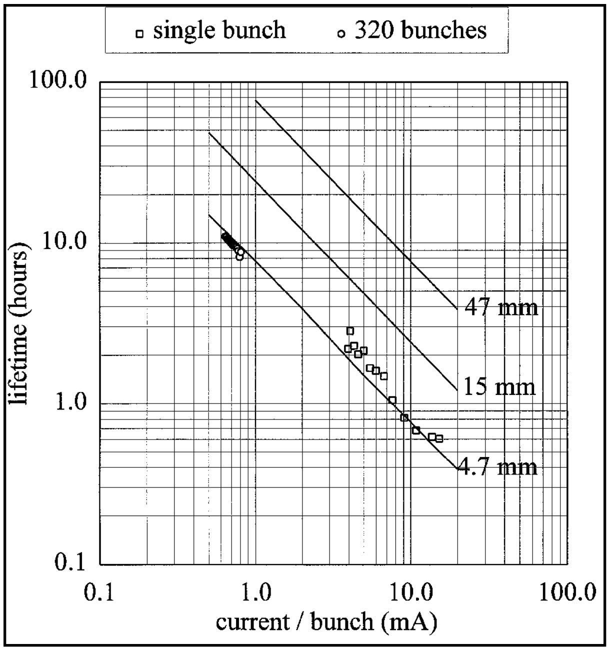

Figure 2: Measured beam lifetimes at 1.9 GeV are plotted against stored electron current per bunch in the ALS Storage ring. Theoretically expected Touschek scattering times at the given bunch lengths are shown in solid lines.

The feedback system was turned on and the storage ring and was filled with 84 bunches up to 2 mA per bunch. When the beam decayed to about 96 mA, the feedback system was turned off. The spectral intensity of the fifth harmonic of the undulator beam at Beamline 7.0 was measured before and after the feedback was turned off. The results are shown in Figure 3. The line with of about 0.7 % with the feedback on is somewhat larger then single bunch spectrum of 0.5 % at a similar current per bunch. The line showed a double peak when the feedback was turned off. The beam lifetime changed from 5.5 hours to 1.5 hours when the feedback was turned off. Both the broader line width and longer lifetime with the feedback came to us as a suprise at first. It is most likely that when the longitudinal feedback system was turned on the transverse feedback system was turned off. Some transverse instabilities apparently were excited which increased the vertical beam size and the lifetime.

This situation, however, has since been shown to be atypical. Usually, the beam lifetime decreases (as expected) when the longitudinal feedback is turned on.

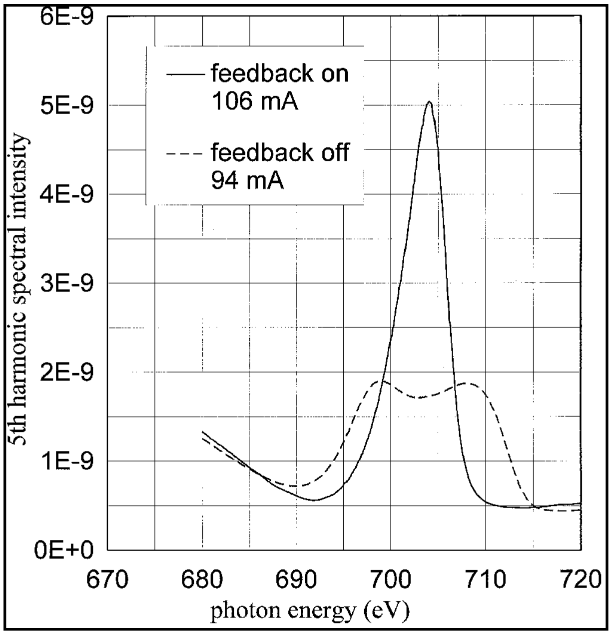

Figure 3: Measured spectral intensity of the fifth harmonic of the photon beam at ALS BL 7.0, with and without feedback.

IV. BUNCH LENGTH MEASUREMENTS

Electron bunch length in the ALS Storage Ring was measured by three methods: measuring the longitudinal structure of the bunch using a streak camera [7], measuring the photon beam pulse duration using a fast photo diode and a sampling scope [5], and measuring the pulse duration using a button-shaped beam position monitor (BPM). The results are consistent. The BPM data is presented here.

A 10 mm button-shaped beam position monitor (IDBPM Sector 4) and the Tektronix CSA803 sampling scope with a 20 GHz bandwidth sampling head were used [8]. The effects of the finite button size and the cable length are subtracted from the measured data by quadratically subtracting a calibrated number. The results are plotted in Figure 4 against the bunch current.

Best fit for the data is of the form $3.7 + 1.04 * I^{0.56}$. Best fit for the data for I > 10 mA is proportional to $I^{0.36}$. These lines are also plotted in Figure 4. Pure microwave turbulent blow-up is expected to give a $I^{(1/3)}$ dependence for currents above certain threshold [9]. Other effects, such as the potential well distortion and a special frequency dependence of the longitudinal impedance, alter the functional dependence.

VII. CONCLUSIONS

We conclude that the beam lifetime in ALS is dominated by the Touschek scattering. We observed significantly shorter lifetimes and brighter spectral intensities as expected for high beam current operations with both the longitudinal and the transverse feedback systems turned on. It is expected that ALS will deliver its full design beam brightness when both the longitudinal and transverse feedback systems become available. Cavity conditions such as the tuner position and the temperature changes the frequencies of the higher order modes and the growth rates of the transverse and longitudinal instabilities and the bunch lengthening characteristics.

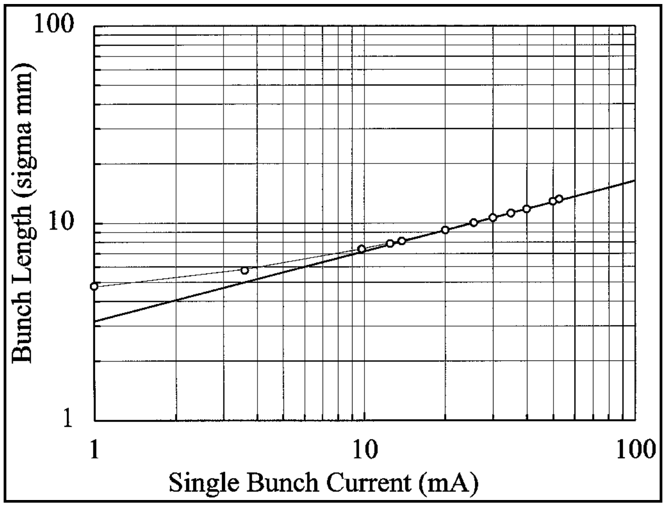

Figure 4: Measured bunch lengths are plotted against the stored electron beam current in the single bunch mode of operation at 1.5 GeV.

VIII. ACKNOWLEDGMENTS

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IX. REFERENCES

[1] See, for instance, A. Jackson, Proceedings of the IEEE Particle Accelerator Conference, May 6-9, 1991.
[2] J. Fox, et. al., in these proceedings.
[3] W. Berry, J. Byrd, J. Corlett, J. Johnson, G. Lambertson, and J.Fox, in these proceedings.
[4] See, for example, J. LeDuff, *Nucl. Instrum.* Methods A239, 83(1985).
[5] J. M. Byrd and J. N. Corlett, in these proceedings.
[6] M. S.. Zisman, S. Chattopadhyay, and J. J. Bisognano, LBL report, LBL-21270, UC-28 (1986).
[7] T. Renner Private communications.
[8] This beam position monitor system has been developed by J. Hinkson for controlling the beam in the insertion device.
[9] G. Vignola, B. Craft, and S. Chattopadhyay, LBL ESG Tech Note-23, December 1985.