OPERATIONAL EXPERIENCE WITH MULTI-BUNCH FEEDBACK AT THE ADVANCED LIGHT SOURCE

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1 INTRODUCTION

All third-generation light sources suffer from multi-bunch longitudinal and transverse instabilities, the most troublesome (from the viewpoint of the user) being in the longitudinal plane. Different facilities have developed different strategies to deal with this problem. At the ESRF only one-third of the circumference is filled, giving higher bunch currents, and the longitudinal instability is damped by the bunch-to-bunch spread in their synchrotron frequencies (Landau damping) created by beam-loading.[1] At ELETTRA the high-Q higher-order-modes (HOMs) in the RF cavities, that drive the instability, are individually shifted in frequency (by changing the RF cavity temperatures), to values where their impedance no longer contributes to the driving term of the instability.[2] These “passive” approaches are very sensitive to the particular “tune” of the storage ring and, in practice, do not fully suppress the instability. At the Advanced Light Source (ALS) we have adopted a different approach ... the motion of each bunch is monitored and a feedback kick is applied to that bunch to minimize it’s motion. This “active” system is relatively insensitive to the storage ring tune, and has been successfully implemented in both the transverse[3] and longitudinal[4] planes. In this paper we describe the efficacy of the feedback systems, and describe some unexpected heating effects that arise as a result of the high peak currents that occur when the feedback systems are in operation.

2 THE EFFECTS OF COUPLED-BUNCH INSTABILITIES

Coupled-bunch instabilities in the ALS arise through the interaction of the electron bunches with the impedance of the vacuum chamber, especially the HOMs in the RF cavities. The result of these instabilities is a standing wave pattern of displacements - either transverse displacement or longitudinal phase, around the circumference (described by the mode number), that oscillate at the betatron or synchrotron frequencies, respectively. Without feedback we have observed that the coherent motion generated by the instabilities rapidly decohere, such that the instability manifests itself as an increase in transverse emittance and energy spread. The most dramatic consequence of these effects is the five-fold (or more) increase in Touschek lifetime when operating without feedback, which accompanies the degradation in beam quality.

At the ALS transverse instabilities are not observed until the longitudinal feedback system is turned on. Then we observe emittance increase in the vertical plane, as shown in figure 1. The horizontal emittance is relatively insensitive to multi-bunch instabilities. Only the most demanding experiments on the ALS are sensitive to emittance blow-up at these levels. Conversely, increase in energy spread has significant effects on almost all experiments.

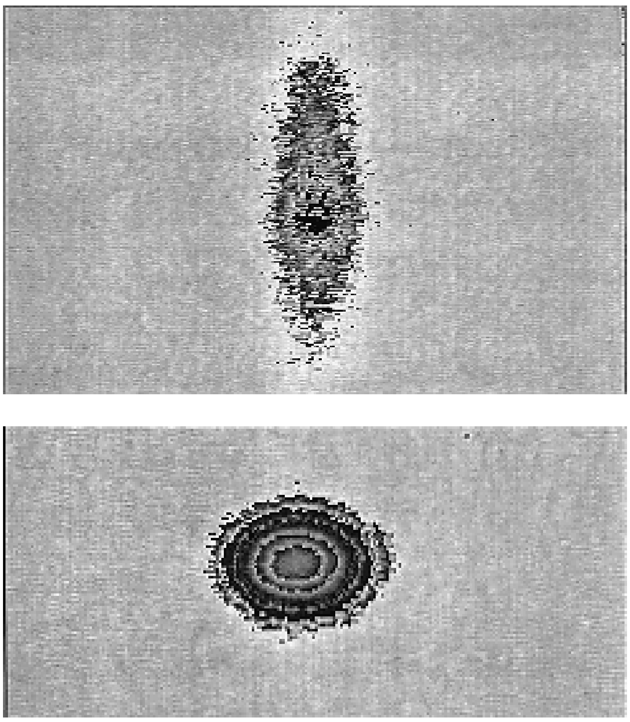

Figure 1. Vertical beam blow-up caused by the transverse coupled-bunch instability. The Lower picture shows the instability suppressed by feedback.

In the ALS we observe the relative energy spread, σ_E/E, increase from it’s expected value of 8×10^{-4} to 3.2×10^{-3}, i.e., an increase of a factor of 4. For bend-magnet beamlines this manifests itself in an increase in the horizontal beam-size through the equation

$$\sigma_X = \mathrm{sqrt}[\beta_x \varepsilon_x + (\eta\ \sigma_E/E)^2] \qquad (1)$$

where σ is the beam-size, β is the amplitude function, ε is the beam emittance, and η is the dispersion function (which is finite at all the bend magnet source points). For example, the horizontal source size at the X.2 and X.3 bend-magnet beamlines increases from 95 µm to 306 µm due solely to the increase in energy spread described above.

For undulator beamlines the result of energy spread is spectral line-width broadening:

$$\delta\lambda/\lambda = 2\sigma_E/E. \qquad (2)$$

In the U5.0 undulators (which have 89 periods), the natural line-width of the first harmonic is 0.48% RMS, to be compared with line broadening due to energy oscillations of 0.64%. The situation gets progressively worse as we look at higher harmonics, where the natural line-width reduces linearly with the harmonic number. Figure 2 shows the spectral characteristics of the 5th harmonic of the U5.0) undulator spectrum, with and without the feedback systems operational. Analysis of the high energy side of the spectral distribution (which is insensitive to emittance effects), shows that the data is consistent with a relative beam energy spread of 8×10^{-4}.

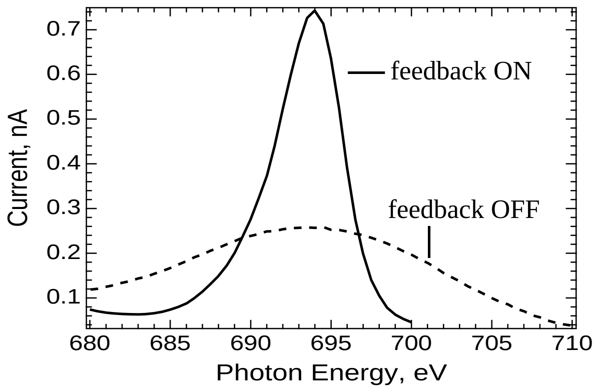

Figure 2. Spectrum of the 5th haronic of the U5.0 undulator, measured on beamline 7.0.

With all feedback systems operational the ALS beam parameters have been measured to be:

$$\varepsilon_x = 4 \times 10^{-9} \text{ m-rad} \qquad (3)$$

$$\varepsilon_y < 1 \times 10^{-10} \text{ m-rad} \qquad (4)$$

$$\sigma_E/E = 8 \times 10^{-4} \qquad (5)$$

3 BEAM LIFETIME

Even when the multi-bunch feedback systems are off, the ALS beam lifetime is predominantly determined by Touschek scattering. Hence, when we turn feedback on we expect a reduction in lifetime inversely proportional to the increase in bunch density. That this is the case is shown in figure 3, where the beam lifetime is plotted against bunch current, and the theoretical curve (calculated by ZAP) is based on other measured parameters. For example, the RF acceptance is measured from the synchrotron frequency. The agreement between measurement and theory is remarkably good.

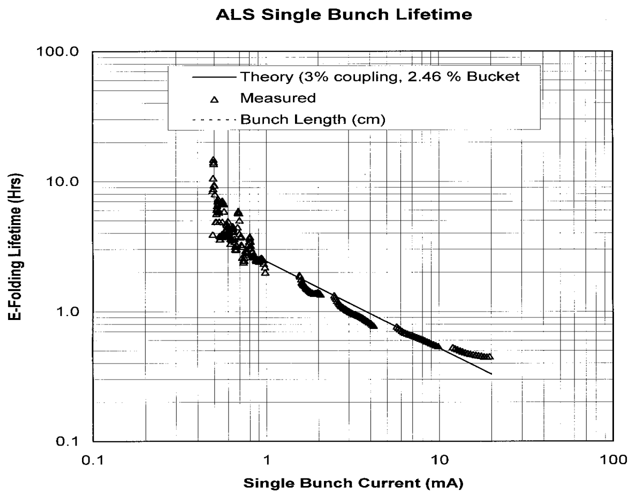

Figure 3. Beam lifetime as a function of the single bunch current.

4 COMPONENT HEATING ASSOCIATED WITH HIGH PEAK CURRENTS

One unpleasant surprise associated with the high peak currents created when the feedback systems are on, manifested itself in April 1995, when part of a bellows liner melted! Figure 4 shows an electron's view of the offending "finger", which kept the facility off the air for more than two weeks. In the ALS storage ring, 1 mA in a single bunch has a charge of 0.67 nC in a bunch length (sigma) of 15 ps, giving a peak current of 45 amperes. At the time of failure we were testing the feedback system with 350 mA in 56 bunches. Such melting implies temperatures well in excess of 1000°C, requiring power transfer from the beam at least one order of magnitude greater than expected from image currents induced by the electron beam. Two hypotheses quickly emerged to explain the source of the extra power[5]. The first recognizes that most of the induced current flows in only a thin, ≈ 3 µm thick "skin depth", and that the surface of the material used in the bellows liner has a roughness of ≈ 1 µm. This surface roughness will significantly increase the impedance seen by the induced currents. The second hypothesis assumes that a small, low-Q cavity is created in part of the bellows as a result of differential expansion across the liner. Power is then resonantly extracted from the beam by this cavity. Evidence for the latter effect has been observed in a special diagnostic bellows assembly that is equipped with an infra-red pyrometer and E- and B-field RF probes. The resonance behavior was eliminated when the design was modified to straighten any longitudinal curvature of the liner, however, an underlying temperature increase, that varies quadratically with the current, was still present at a value much higher than expected. Empirically we find that, with the feedback systems on, the liner temperature varies as:

$$\Delta T(°C) = 4.3 \times 10^5 \times I^2 / N_b \quad (6)$$

where I is the average current in Amps, and Nb is the number of bunches.

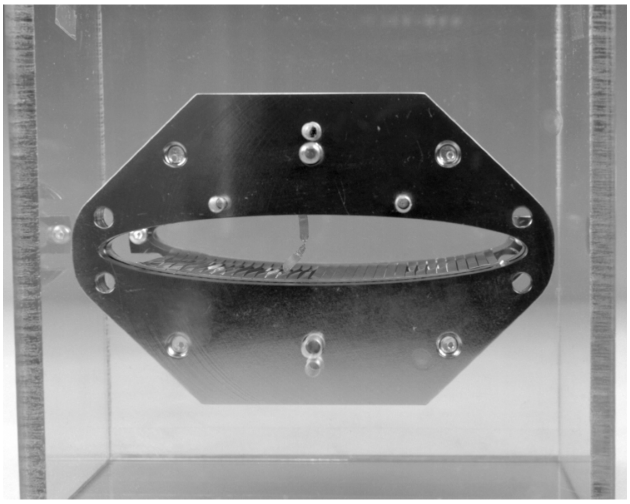

Figure 4. Beam's eye view of the broken bellows lines after it was removed from the storage ring.

A polished version of the liner will be installed in the diagnostic bellows assembly early this summer to quantify the surface roughness hypothesis. In the meantime, acceptable temperature increases are maintained by running high currents in many bunches. For example, 400 mA in 320 bunches (the nominal operating mode), gives ΔT = 215 °C, and no deleterious effects are observed.

Another area of the storage ring that gets uncomfortably hot in the presence of high peak currents are the ends of the ceramic tubes that form the vacuum envelope for the fast injection-magnets. Thermocouples reveal that the heating is localized at the ends of the tubes, and again the possible sources of power are high resistance and the resonant behavior of the bellows that relieve stresses at the junction between the ceramic tubes and the more robust section of aluminum to which they are attached. The remedy in this case was to force air cool the tubes.

5 SUMMARY

With the successful commissioning of the longitudinal and transverse coupled-bunch feedback systems at the ALS, the nominal operating parameters of the storage-ring beam (emittance, bunch length, etc.) have been met at the full current of 400 mA. The expected beneficial effects for both undulator and bend-magnet beamline users have been demonstrated. Unexpected component heating due to high peak- and average-currents have been parameterized, and operational constraints have been implemented to reduce the effects to acceptable levels.

6 ACKNOWLEDGMENTS

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8 REFERENCES

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