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TRANSIENT BEAM LOADING IN THE ALS HARMONIC RF SYSTEM*

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Abstract

We report on the commissioning of a higher harmonic radiofrequency system at the Advanced Light Source, designed to improve the beam lifetime. We have achieved an increase above a factor of two in our best results up to now. Transient beam loading of the harmonic cavities, due to the unequal fill patterns, creates the greatest limitations on lifetime improvement. We also describe several interesting effects on the operation of the longitudinal and transverse multibunch feedback systems.

1 INTRODUCTION

Higher harmonic cavities have been proposed and tested (references can be found in [1]) as a means of improving the beam lifetime by stretching the bunch and decreasing the charge density, thus reducing the Touschek scattering which is particularly important for storage rings, such as the Advanced Light Source (ALS), with moderately low beam energy and small transverse beam size.

To this end, in May 1999 we installed a third harmonic RF system on the ALS storage ring consisting of 5 single-cell copper 1.5 GHz cavities. The details of the cavity design and fabrication are described in [1]. The cavity parameters are summarized in Table 1.

Table 1: ALS harmonic cavity parameters

Frequency	1.499 GHz
max voltage/cell	125 kV
bore diameter	5 cm
R/Q	80.4
meas. Q	21000
meas. R_s	1.69 MΩ
number of cells	5
power/cell	4.6 kW

Prior to operation with the harmonic cavities, the beam lifetime at full current was about four hours, depending on the beam energy (1.5 or 1.9 GeV) and the transverse emittance coupling. The primary aim of the harmonic system is to increase the Touschek-dominated lifetime up to a factor of three.

We operate the cavities in a passive mode where all of their voltage is induced by the beam. The beam current has Fourier components at multiples of the RF frequency.

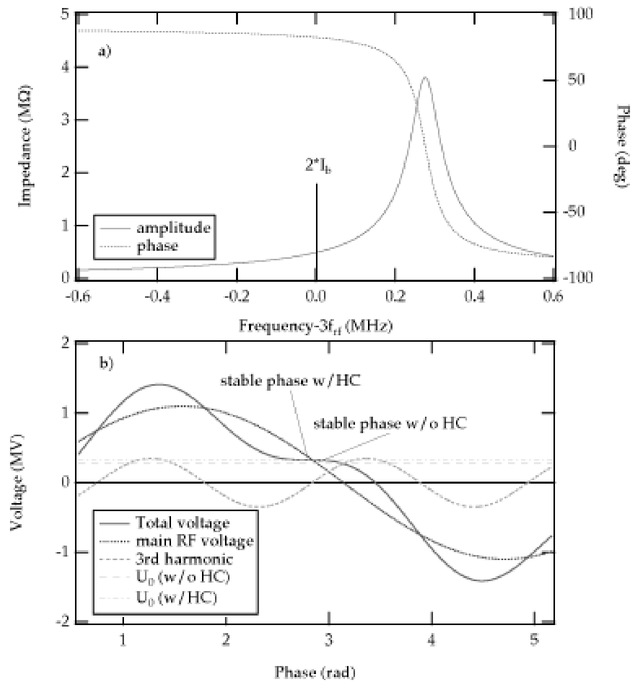

Figure 1. a) Tuning of the harmonic cavity fundamental mode for reaching optimum bunch lengthening voltage and phase. b) Total voltage from main and harmonic RF cavities.

In the ALS case, we use the third harmonic component at 1.499 GHz to drive the fundamental mode of each cavity. When this mode is driven as shown in Fig.1a, it induces a voltage almost 90 degrees out of phase with respect to the beam. This harmonic voltage tends to cancel the gradient of the main RF voltage and longitudinally defocus the beam (Fig.1b). This lowers the longitudinal charge density in the bunch and ultimately increases the lifetime. The cavity can also be tuned below the beam harmonic, thus generating a voltage which adds to the main RF gradient and shortens the bunch.

2 OPERATIONAL CONSIDERATIONS

The ALS storage ring is usually operated at an energy of 1.9 GeV and the maximum current of 400 mA can be distributed in up to 328 bunches. To satisfy the requirements of the experimental users, we leave a gap of about 20% in the fill pattern. Both longitudinal and transverse multibunch feedback systems (LFB and TFB) are used to control coupled bunch instabilities.

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Because the fundamental mode of the harmonic cavities can drive these instabilities, it is important to properly tune them when operating in either bunch lengthening or shortening mode, or when they are in the so called "parked" positions at ±1.5 or ±2.5 rotation harmonics away from 3 times the RF frequency f_{RF}.

In bunch lengthening mode the cavity is initially tuned at zero beam current between $3 \times f_{RF}$ and the next rotation harmonic, which in the ALS is 1.5 MHz above. At high beam current the cavity is slowly tuned inside this frequency range until the lifetime is optimized. The cavities not used to lengthen the bunch are left in their parked position; we try to tune them symmetrically with respect to the third harmonic frequency to balance their effect on the longitudinal instabilities.

To tune and characterize the modes in each cavity, we used the signal spectrum from a weakly coupled probe while circulating a single bunch in the ring. Our goal was, using a combination of our two tuners, to tune the fundamental mode to either a bunch lengthening or parked position and simultaneously tune the first monopole HOM (TM011) in between rotation harmonics in order to minimize its impact on the beam stability. Other HOMs are damped by a ferrite load. By fitting an impedance to the spectra it is possible to calculate both the resonant frequency and Q to fair accuracy.

3 EXPERIMENTAL RESULTS

Our diagnostics for measuring the effects of the harmonic cavities were a dual-axis synchroscan streak camera (SC), a DCCT current monitor, to measure the lifetime, and a spectrum analyzer for examining the beam signals coming from the LFB pickups.

All the measurements shown in this paper were made at 1.9 GeV with stable beam, except where indicated. This is important since the lifetime in the ALS depends strongly on the effective beam dimensions and the effect of the harmonic cavities is better understood when the beam is stable.

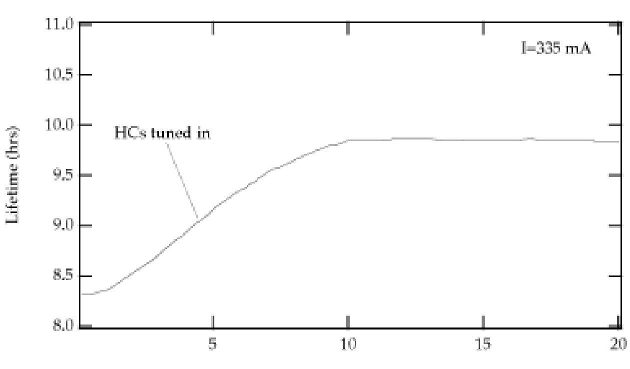

Figure 2. Lifetime increase as 4 harmonic cavities are tuned from $0.5*f_{rev}$ to $0.35*f_{rev}$ above the third harmonic at a current of 335 mA.

Shown in Fig.2 is a plot of the lifetime vs. time measured in a 2.5% gap fill pattern as the harmonic cavities are tuned from their initial position towards resonance, thus increasing the harmonic voltage.

The beam current is 335 MA and the lifetime at this current with the cavities parked is 4.5 h. This indicates a factor of two lifetime increase in this fill pattern.

Figure 3 shows SC images for the short gap fill pattern, used in the accelerator physics studies, and the 17% gap fill used for normal operations. The vertical axis is the fast sweep, showing the length of each bunch, and the horizontal axis is the slow time sweep of about a single turn.

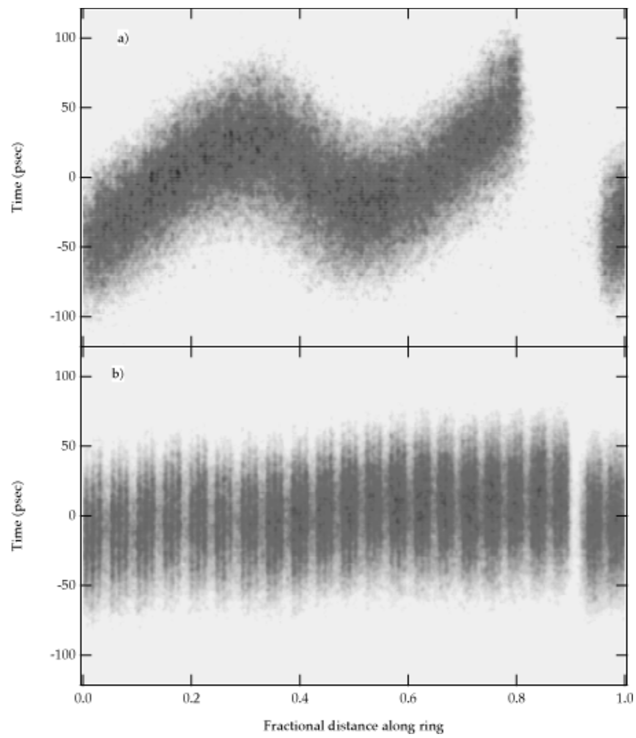

Figure 3. Streak camera image of the longitudinal bunch distribution. a) 17% gap. b) 2.5% gap.

Shown in Fig.4 is the variation of the relative synchronous position and bunch length of each bunch as extracted from Fig.3. For the larger gap, there is a large variation in the relative phase and bunch length. This is due to transient beam loading and is discussed in detail later on.

We also observed a large detuning of the synchrotron frequency as we varied the voltage in the cavities. Shown in Fig.5 is the amplitude of a longitudinal beam transfer function made with 3 cavities in lengthening mode and 2 parked, measured with the small gap fill pattern. In this measurement the cavities were left at a fixed tuning of $+0.5\ f_{rev}$ and only the beam current was changed. As the current increases, the synchrotron frequency decreases and the width of the response increases. We believe this increase corresponds to an increase in spread of the synchrotron frequencies within the bunch.

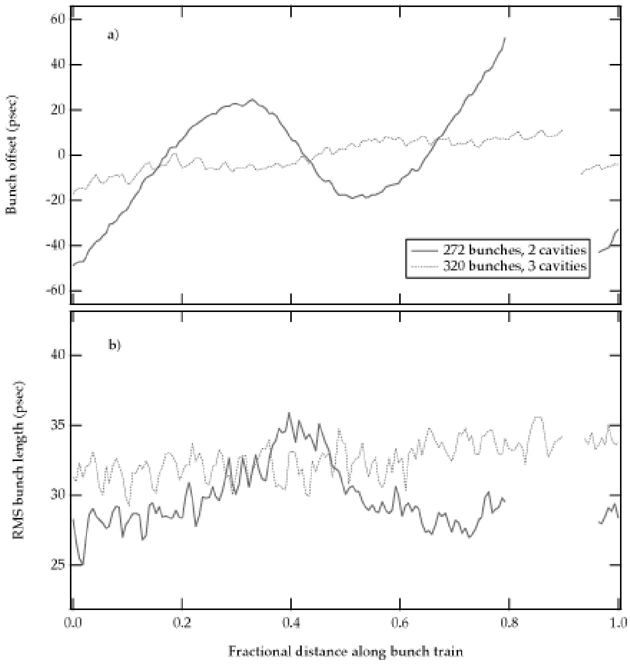

Figure 4. Longitudinal beam offset (a) and bunch length (b) along the bunch train.

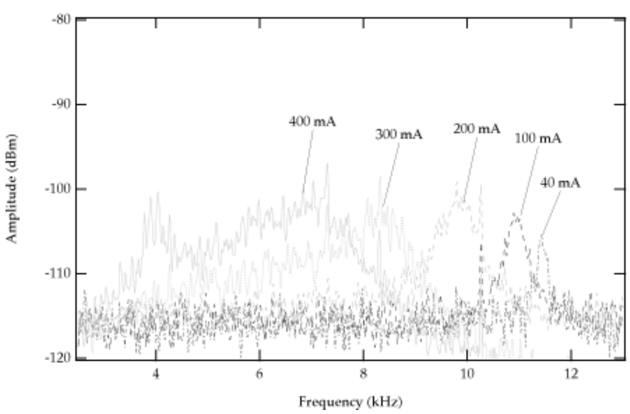

Figure 5. Synchrotron frequency response of 3 cavities with a 2.5% gap.

Since the harmonic voltage is generated only by the beam, rapid variations in the beam current cause variations in the induced voltage. This results in a variation of the harmonic voltage, and consequently of the bunch lengthening, along the bunch train as shown in Fig.4b.

For studying the effects of different gap sizes, we developed a tracking simulation which includes the longitudinal motion of the beam and the voltage and phase of the main and harmonic RF cavities [2].

The results reported in Fig.6 show an 80 degree harmonic phase shift and a 25% variation in the voltage amplitude along the bunch train. Since the optimum harmonic phase is near 90 degrees, only the bunches in the middle of the train are significantly lengthened. Analogous simulations, performed for a narrow gap, give a much reduced transient.

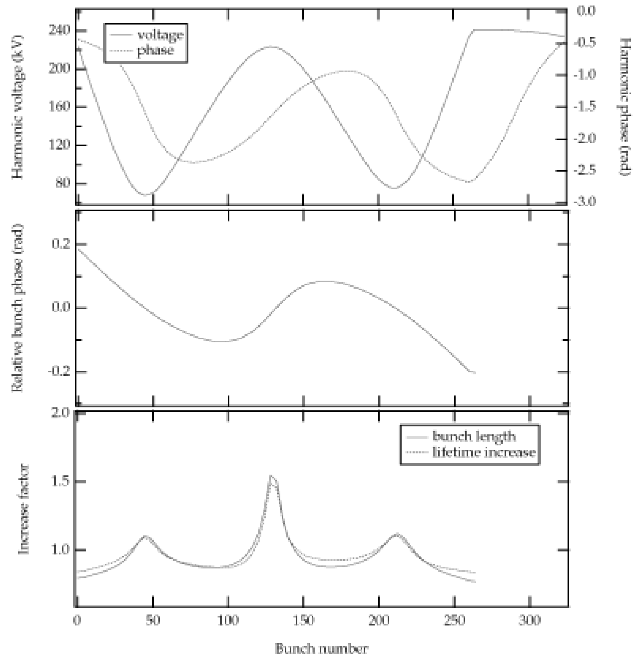

Figure 6. Calculated transients for a 17% gap and two cavities tuned to bunch lengthening. a) Harmonic voltage and phase. b) Relative stable phase. c) Bunch length and lifetime increase.

We believe these transients to be a severe limitation on the lifetime improvement achievable using passive cavities. Possible cures, currently under evaluation, are to operate with reduced gaps, tailor the fill pattern to compensate for the transient or drive the cavities from an external power source

4 CONCLUSIONS

We have commissioned five third harmonic cavities for bunch lengthening at the ALS. We have observed lifetime increases of more than a factor of two, when operating with a shorter gap in the fill. However, the increase during user operations has been limited to about 50%, mainly due to the transient beam loading effects caused by the 17-22% gap in the fill pattern

REFERENCES

[1] J. Byrd, et al., “Design of a Higher Harmonic RF system for the Advanced Light Source”, NIM-A 439,15 (2000).

[2] R. Siemann, “Computer Models of Instabilities in Electron Storage Rings” *in The Physics of Particle Accelerators*, AIP Conf. Proc. 127, 431 (1993).