RF System for Bunch Lengthening*

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I. ABSTRACT

A harmonic cavity is used in the VUV ring to increase the Touschek lifetime and to help reduce peak current related instabilities. Phase locking servos for such a system normally require comparison of a Fourier component of the beam to a reference or information about the symmetry of the bunch. We have found it simpler to initially set the phase of the drive so that the center of the bunch is positioned at the zero crossing of the harmonic cavity voltage waveform. This phase relationship is then maintained by comparing the amplitude of the harmonic cavity field to the forward power, and adjusting the phase of the drive to keep the two powers equal. A system of this type has been operating in the VUV ring since October, 1993. It consists of a 52.88 MHz accelerating cavity and a 211.54 MHz bunch lengthening cavity providing increased lifetime over all operating currents.

II. INTRODUCTION

Bunch lengthening is achieved by reducing the slope of the accelerating voltage in the vicinity of the electron bunch. Operating with a lengthened bunch increases the Touschek lifetime by decreasing the density of the bunch. In addition to this increased lifetime, peak current effects such as the microwave instability and the head-tail instability can be reduced. Also, a spreading of synchrotron oscillation frequencies can provide Landau damping against coupled bunch instabilities. A. Hofmann[1] has described the RF conditions for a double RF system that yields optimum bunch lengthening. These conditions are given by:

$$V_T = V_1 \cos\phi_1 + kV_1 \cos(n\phi_n) = U_0 \qquad (1a)$$

$$\frac{\partial}{\partial \phi} V_T = -V_1 \sin\phi_1 - knV_1 \sin(n\phi_n) = 0 \qquad (1b)$$

$$\frac{\partial^2}{\partial \phi^2} V_T = -V_1 \cos\phi_1 - kn^2 V_1 \cos(n\phi_n) = 0 \qquad (1c)$$

Where V_1, ϕ_1 are the peak voltage and synchronous phase for the main RF system and $V_n = kV_1$, $n\phi_n$ are the peak voltage and synchronous phase for the harmonic RF system. All phases are measured from the peak of the waveform. For the VUV ring, the main RF system operates at 52.885 MHz with a peak voltage of 80 kV and the harmonic RF system operates at 211.54 MHz (n = 4). For this n and V_1 the above equations yield the optimum bunch lengthening parameters for the VUV ring:

$$\phi_1 = 78.7^\circ, \quad 4\phi_4 = -92.9^\circ$$
$$\textit{and} \quad k = 0.246 \quad \textit{or} \quad V_4 = kV_1 = 19.68\,kV$$

where ϕ_1, and ϕ_4 are measured in the 52 MHz frame.

III. PASSIVE SYSTEM

Initially, the harmonic cavity system was operated in a “passive” mode[2]. The transmission line to the cavity was shorted at a quarter wavelength from the base of the input loop and the voltage developed in the harmonic cavity was induced entirely by the beam.

The passive system provides added lifetime at high average currents where it is needed the most. But, as the current decreases, the voltage in the harmonic cavity also decreases causing the bunch to return to its normal length at low currents. This bunch length change creates a problem for those experimenters doing fluorescent lifetime experiments[3], since they have to measure and deconvolve the source shape as it changes. To reduce this bunch length change with current, a system which makes the cavity Q, R_{SH}, and δ functions of beam current could be implemented. This requires a variable coupling system which lowers the Q and thereby the shunt impedance of the cavity as stored current is increased. This was considered too costly and complex and for the VUV ring and R_{SH} was left as a constant.

A feedforward system was implemented which attempts to keep the magnitude of the harmonic cavity voltage constant as current changes. A signal proportional to the average beam current was conditioned and used to vary the cavity temperature. This changes the resonant frequency of the cavity and increases the magnitude of the cavity impedance at 211.54 MHz as I_b decreases. Therefore, the cavity voltage remains more constant as I_b changes. Unfortunately this also changes the phase of the impedance of the harmonic cavity as a function of beam current. Although this phase change is not desirable, the overall effect provided added lifetime at lower currents. The improvement in lifetime over a single cavity system is shown in figure 1.

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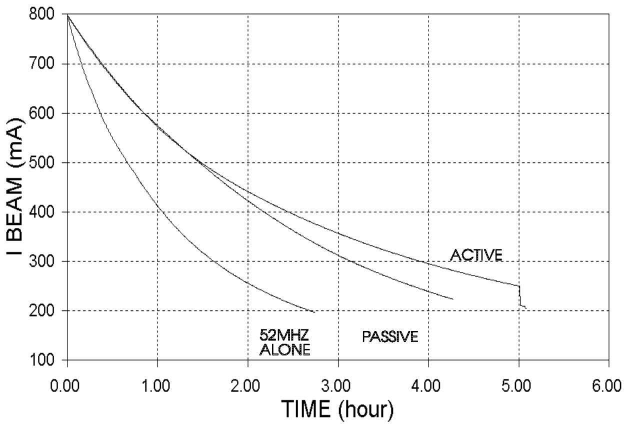

Figure 1 - Lifetime comparisons without the harmonic cavity with the harmonic cavity passive and with the harmonic cavity active.

IV. ACTIVE SYSTEM

The field in the harmonic cavity must be held constant in amplitude and phase to maintain the optimum bunch lengthening conditions . This requires tight phase and amplitude servo systems around both RF cavities to hold these conditions over an entire fill. A simple servo may be implemented if a conservative operating point is chosen. The system can still provide significant lifetime improvement without the need for a phase detection servo.

The operating point of the 211 MHz system is chosen so that the beam crosses the cavity gap on the rising slope of the RF waveform and that the net power given to the beam equals zero ($4\phi_4 = -\pi/2$). All other conditions remain the same as in the optimum case. The result of not operating at the optimum phase results in a bunch length for the VUV ring which is 80% of the optimum condition.

Such a system is shown in figure 3. The RF drive from a synthesizer serves as the reference for both systems. The 52 MHz system has standard NSLS detected amplitude and cavity tuning servo systems to compensate for beam loading. The 211 MHz system is set up with a detected amplitude loop keeping the forward power constant. With no beam, the transmitter drives the cavity at resonance through a near matched input loop. Therefore, there is little reverse power returning to the circulator which isolates the transmitter from the accelerating cavity. As beam is injected, the tuning loop compensates for the reactive beam load. Under ideal conditions the beam is maintained at the zero crossing of the RF waveform and the cavity power will always equal to the forward power from the transmitter.

Under actual conditions, the beam drifts from the zero crossing and the cavity power responds accordingly. The cavity power rises as $4\phi_4$ becomes more negative and drops as $4\phi_4$ becomes more positive. The difference signal between the forward and cavity power is used to create a slow servo loop which adjusts the harmonic cavity drive phase to keep the beam at $4\phi_4 = -\pi/2$. This keeps the two powers equal. The active bunch lengthening system provides added lifetime over the entire fill (figure 1) with minimal bunch length changes as a function of bunch current (figure 2) as measured using a stripline monitor[4].

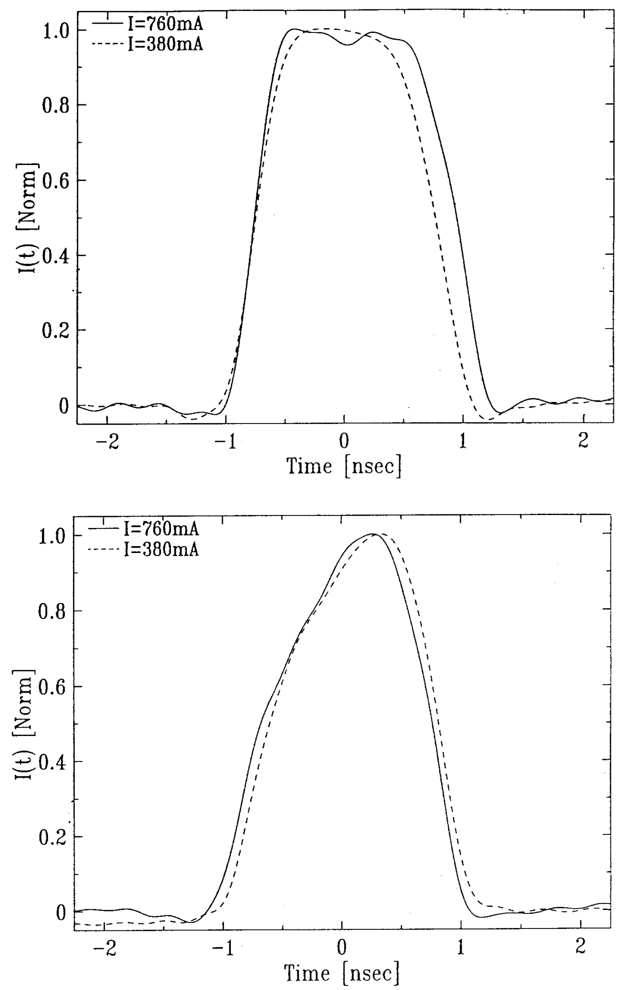

Figure 2 - Comparison of bunch shapes at 760 mA and 380 mA average current. Two different bunches are shown.

V. POWERED SYSTEM EXPERIENCE

The powered harmonic system has been operating reliably in a bunch lengthening mode for one year. The system has provided extended lifetime, and a stable longitudinal current distribution for the bunches in the VUV ring over the operating current range.

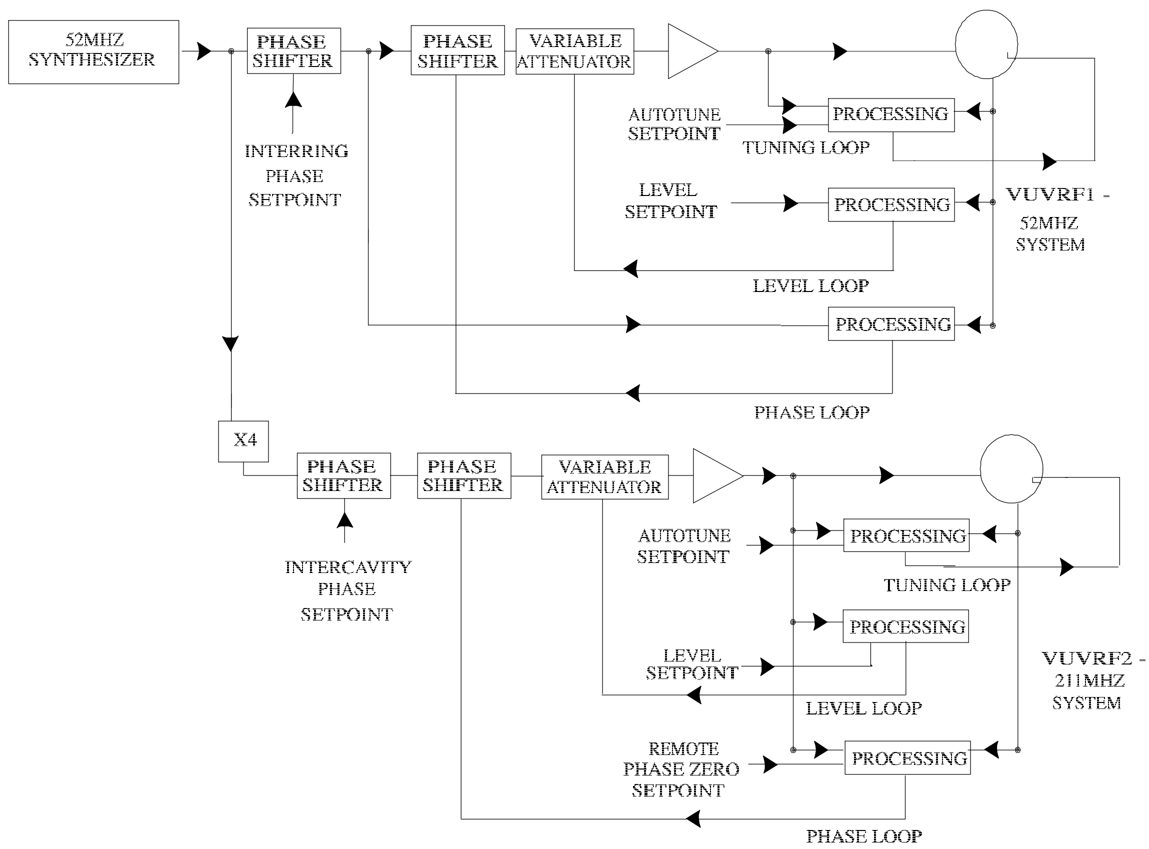

Figure 3 - Block diagram of the system.

During system commissioning it was noticed that the beam was more susceptible to audio frequency phase noise as the optimum bunch conditions were approached. A possible explanation for this is that the coherent synchrotron frequency is lowered and spread as the slope of the accelerating waveform is lessened causing increased coupling of power supply harmonics to the beam. Also, with the flat potential well created by the system, all potential well perturbations will be more noticeable.

Such is the case of a higher order mode (HOM) in the main cavity at 270 MHz. This HOM is at a rotation harmonic which is not an RF harmonic so it distorts the potential well differently for each bunch. This leads to a different shape for each bunch. Without the harmonic cavity, the differences in bunch shape due to this potential well distortion are barely noticeable . With the harmonic cavity in operation the distortion is clearly seen (fig 2). Due to both of these problems the harmonic cavity is currently operated at a lower voltage than the planned 19.68 kV. Priority will be given to removing the sources of power supply harmonic noise and to damp the mode at 270 MHz. Work will then proceed to obtain the necessary conditions for optimum bunch lengthening.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES

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