BUNCH LENGTHENING CONTROL USING THE FOURTH HARMONIC CAVITY IN THE VUV RING*

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Abstract

A harmonic cavity in a synchrotron storage ring may be used to change the shape of the bucket potential. Adjustment of the amplitude and phase of the harmonic component to flatten the slope of the waveform at the synchronous voltage will lengthen a stored bunch, thus extending the Touschek lifetime that is limiting the performance of the VUV ring. Beam induced 211 MHz power in a fourth harmonic cavity was used to check feasibility of this concept. The data obtained during UV studies at the NSLS will be summarized.

Introduction

Peak currents of over 1.1 amperes have been stored in the VUV ring at the NSLS. To improve lifetime and obtain higher currents, the bunch length has to be increased. A prototype cavity has been installed in the ring for this purpose. Its resonant frequency is four times that of the 52.88 megahertz main accelerator cavity. The gap voltage required is a fourth of the nominal 10 kilovolts in the main cavity.

Tests of the concept were performed using the self induced voltage of the fourth harmonic cavity. The results were quite favorable.

To make corrections over a larger range of beam current the cavity should be driven by a separate RF power source. This system has been installed and preliminary tests have been made. Instabilities have been encountered when there is more than 100 milliamperes of stored beam. There is a serious cross coupling of power between the cavities caused by the beam.

Cavity

The installed cavity is a pillbox cavity tuned to 211 MHz with a mechanically driven loop tuner. The Q is in excess of 10 K due to copper plating. The structure, however, is made of stainless steel with very poor heat transfer characteristics. With beam passing through its gap, any loss of control of the beam will heat the cavity causing its resonant frequency to go down. When not in use, a mechanically driven plunger shorts out the gap to prevent coupling to the beam.

Presently a new cavity is being fabricated. See Figure 1. Since it is all copper, its thermal stability will be much improved.

Self-Excitation Mode

Normal acceleration would dictate that the beam would be located on the negative slope of the beam. For debunching the beam should be center at the zero crossover on the positive slopes of the RF waveform. This is the Robinson unstable side of the cavity phase. The circulating beam can self induce field in the gap of the 4th harmonic cavity. By detuning the cavity (increasing frequency) the beam location can approach the necessary induced phase if the beam magnitude is sufficient.

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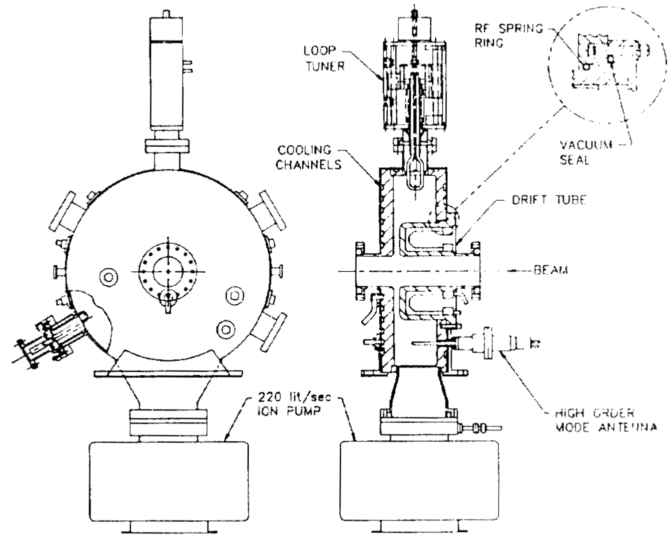


FIG. 1 RF CAVITY ASSEMBLY

The fundamental cavity at 52.88 MHz is phase and amplitude stabilized by a mechanical tuning element; the feedback loop circuits not shown. It is set for Robinson damping of synchrotron oscillations as in the usual mode of operation without the harmonic cavity. The harmonic cavity was mechanically tuned. The main cavity was set at its nominal value of 77 kilovolt gap (27 kilovolts). The fourth harmonic cavity was coupled to a transmission line terminated in a matched load.

Several reference waveforms were used to measure the relative phase between the accelerating voltages in each cavity with respect to the bunch position and with respect to one another. The power input to the fundamental cavity was measured by a calibrated pickup loop sensing the amplitude in the cavity.

The amplitude of the voltage in the harmonic cavity was interpreted from the power coupled to the load. A cavity shunt resistance was obtained by tuning the cavity for maximum power output out of the beam at cavity resonance gave the value 150 kilohms for the effective shunt resistance. This value was cross checked by an RF measurement of the cavity Q and an approximate calculation of the capacitive loading in the cavity. It was further checked experimentally by measuring the shift in the synchronous phase position with respect to the voltage in the fundamental cavity. Agreement was within 30 percent.

Now varying the resonant frequency of the harmonic cavity changed both the amplitude and the phase of the harmonic component. Beam injection was started. Initially the cavity voltage had to be set at resonance to observe cavity field. As beam intensity was increased the cavity was detuned so that the required 90° phase shift could be approached. Bunch length was measured by observing the synchrotron radiation pulse emitted by the bunch with a photodiode and a sampling oscilloscope. The lowering of synchrotron frequency was also observed as the beam spread.

With five bunches filled and 2.7 kW in the fundamental cavity there was sufficient average beam current to sustain power in the harmonic cavity, and maintain the detuning angle close to 90 degrees. A rapid increase of the bunch length was observed above 600 watts in the harmonic cavity. More notable was the evolution of the synchrotron radiation pulse shape from a Gaussian toward a trapezoidal shape. A fast run through cavity power in excess of 1000 watts showed a true flat-top pulse. As the cavity heated the resonant frequency shifted and stability was lost. From the nominal bunch length of 0.7 nanoseconds (FWHM) the bunch lengthened to 1 nanosecond at 400 watts in the harmonic cavity. With 800 watts and 690 mA the width was 1.5 nanoseconds. When the power was 1000 watts a rectangular shape was observed.

Studies with 211 MHz RF PA

The low level RF is obtained from the 52.88 MHz system as shown in Fig. 2. It is multiplied by 4 to obtain a synchronized 211 MHz signal. With further amplification, 5 kilowatt of excitation power is available. A fast phase servo having a variable BW up to 8 kilohertz attempts to lock the harmonic cavity phase to a reference (see Fig. 3). The reference used was either a filter signal derived from a pickup electrode or a signal taken from the main cavity and multiplied by four. A motor driven tuner was used to tune out the reactive part of the beam thus attempting to match the transmitter. Ideally, the transmitter only has to supply the real I^2R power loss of the cavity. If the beam ideally passes at the zero crossover their is only a reactive component which can be tuned out.

Due to the poor heat conduction of the cavity, any excursion of the beam will cause thermal runaway since the detuned cavity will drift toward resonance causing further induced power. The response time of the tuner servo is too slow to completely eliminate this problem. Disconnecting the servo and manually driving the tuner produced best results. Difficulties were encountered in the harmonic phase servo from pick-up. Some of the sources of pick-up have been corrected. Even with these problems we have been able to debunch the beam of up to 100 milliamperes. Above this current threshold we have not been able to overcome a beam instability (See Fig. 4). The synchrotron phase would jump by ± 10° in the main cavity. This was produced by a movement of ± 40° in the harmonic cavity. The beam was either receiving or giving power to the harmonic cavity. Since the power supplied to the beam by the main cavity was either decreasing or increasing, the synchronous phase had to move.

Conclusions

We have demonstrated that a fourth harmonic cavity can indeed debunch the beam, but when we attempt to supply the cavity field by an independent power source, instabilities result.

Further development will be made on the phase servo and tuner motor while we wait for construction of the new harmonic cavity.

Acknowledgement

We would like to thank Jonathan Wachtel for his efforts on this project when he was at the NSLS. He had done most of the theoretical work on debunching and participated in the studies. Extensive use of his writeup of results have been used in this paper.

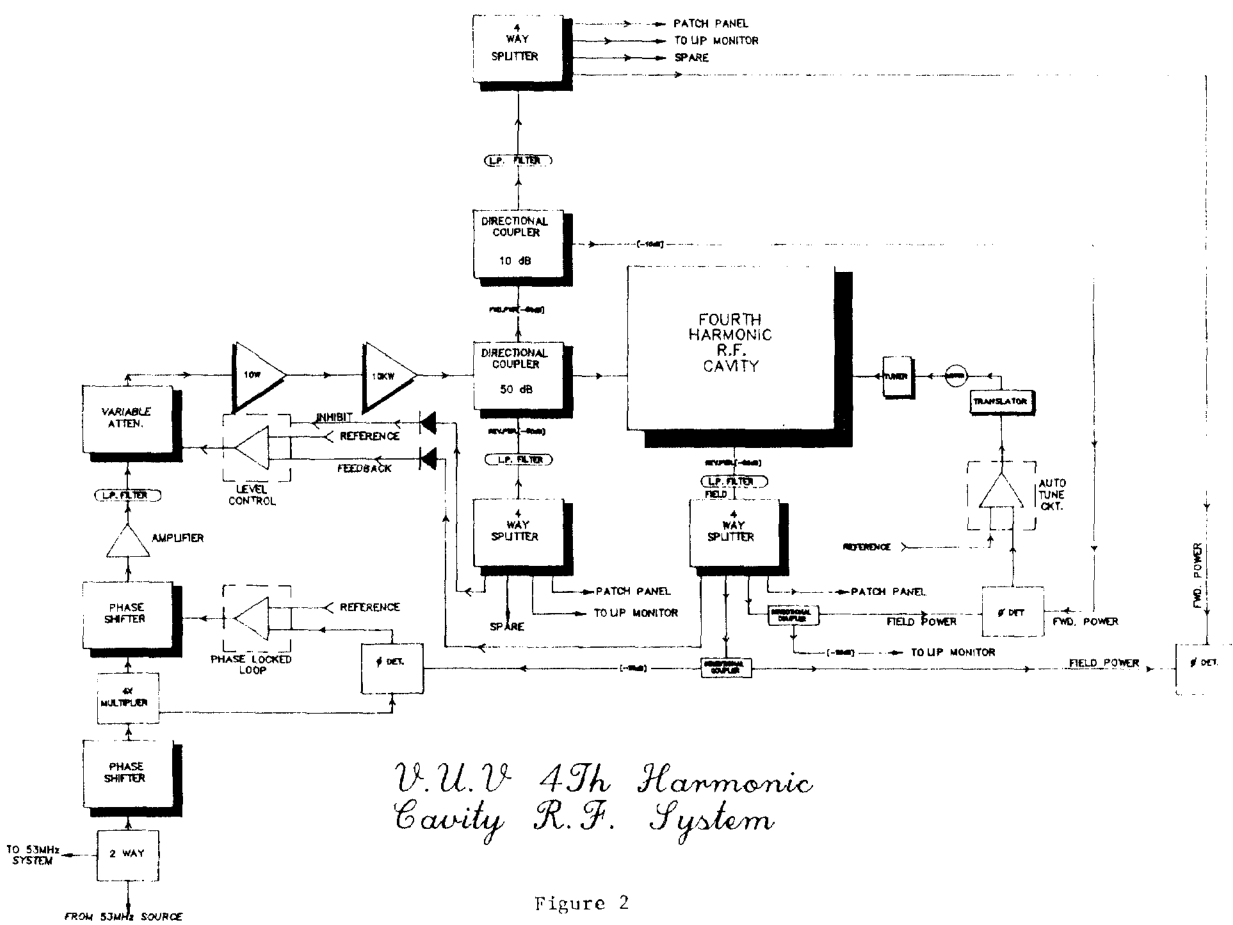
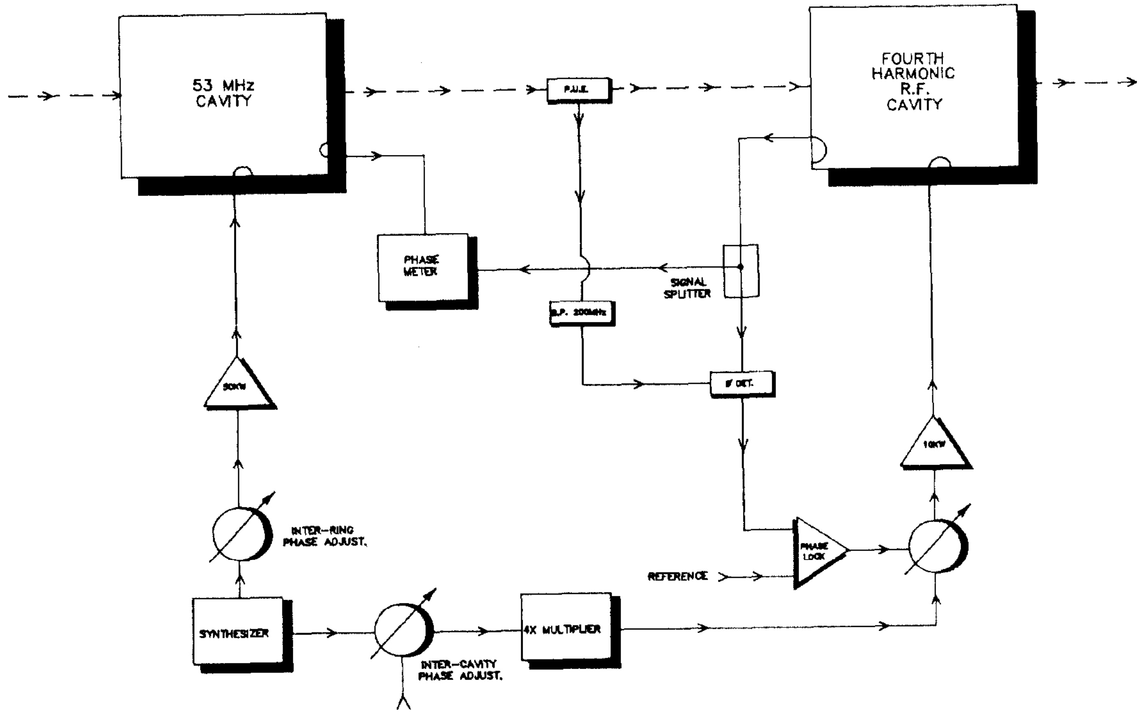


Figure 2



*4Th Harmonic Cavity
Phase Control*

Figure 3

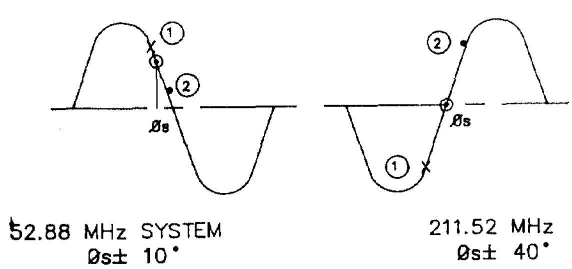


Figure 4