VOLTAGE CONTROL FOR THE 4-TH HARMONIC CAVITY IN HLS STORAGE RING*

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Abstract

A 4-th RF harmonic cavity is installed in the Hefei light source (HLS) storage ring to minimize the longitudinal instabilities and increase the Touschek lifetime. The cavity is monitored and controlled by an electronic module based upon analog signals. Both the cavity and the electronic module are manufactured in the Budker Institute of Nuclear Physics (BINP) of Russia. To more effectively vary or maintain the cavity voltage, we developed a digital PID feedback system based upon EPICS. This paper introduces this feedback system and presents some test and operation results.

INTRODUCTION

High harmonic cavities (HHCs) have been proposed and used in many synchrotron light source facilities [1–3]. HHCs are used for introducing Landau damping to control beam instabilities. They are also used to increase Touschek beam lifetime by stretching the beam bunch length. Due to its low energy — 800 MeV, the electron beam circulates in the Hefei light source (HLS) storage ring has strong coupled bunch instabilities, and the Touschek lifetime dominates the beam lifetime after the vacuum chamber is fully cleaned using the synchrotron radiation. To stabilize the beam and increase the beam lifetime , a 4-th harmonic RF cavity was installed in the storage ring during a major renovation [4].

The 4-th harmonic cavity was manufactured in the Budker Institute of Nuclear Physics (BINP) of Russia. Some main parameters of the cavity and the storage ring are listed in Table 1. This cavity can only work in passive mode, i.e.

Table 1: Main Parameters of the HLS-II Storage Ring [5]

Name	Value
Beam energy (MeV)	800
SR Circumference (m)	66.13
Fundamental RF Freq. (MHz)	204
Harmonic Number	45
HHC Resonance Freq. (MHz)	816
HHC Quality factor	5
Shunt impedance (MΩ)	2.5
HHC Operation mode	Passive

the electro-magnetic field in the cavity is generated by the electron beam of the storage ring, and the amplitude of the electric field, or the voltage across the cavity, can only be controlled by tuning the resonance condition of the cavity. The resonance condition can be adjusted by a tuning pole, which is driven by a servo motor system and controlled by an electronics module based upon analog signals. This module has an analog feedback loop which has been working reasonably well in controlling the cavity high voltage. However, due to the noisy nature of the measured voltage signal, the analog voltage feedback loop acts too frequently, leading to even noisier cavity voltages and damage of the motor system. To get a "cleaner" cavity voltage and protect the motor system, we develop a digital feedback system based upon the Experimental Physics and Industrial Control System (EPICS) and the analog electronics module.

This paper first gives an overview of the HHC control system, and then reports some test and operational results of the cavity voltage control using this system.

THE CAVITY CONTROL SYSTEM

A functional sketch of the HHC control system is illustrated in Fig. 1. An antenna is used to out-couple a small potion of the energy from the cavity. This energy signal is then feed to the control module to process the voltage across the HHC. The voltage signal, which is an analog DC signal, from the control module is measured by an analog-to-digital module in an Omron PLC. The digitalized voltage signal is then read by an AI record inside an EPICS input/output controller (IOC). The measured voltage signal is turn out

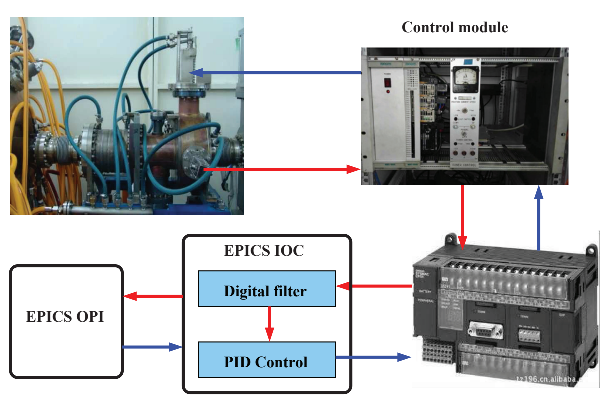

Figure 1: Overview of the voltage control system for the 4-th harmonic RF cavity.

to be very noisy, which puts serious impact on the voltage control. To eliminate this effect, a set of EPICS records are used to filter out the noise. A number of COMPRESS and AI records are employed to build up the digital filter. The filtered voltage signal is used as the input of a PID record. The

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PID record calculates the distance the motor need to move for maintaining the high voltage of the HHC at a particular setpoint. This distance value is then set to the control module to control the servo motor system and drive the tuning pole of the HHC.

A number of criteria are used to control the proportional, integral and derivative (PID) feedback. These criteria work as following:

- High and low limits of the beam current are used to control the PID feedback procedure. The feedback is active only when the beam current is between these two limits. Since the cavity voltage is a function of the beam current and tuning pole position, these limits can be used to avoid the voltage goes too high;
- High and low pole positions are also used as limits to active/de-active the feedback procedure;
- The feedback system only takes action when the measured voltage differs from the setpoint by a designated value — dV;
- A minimum delta time (MDT) is used to tell the feedback when to take action. The feedback record is processed only when the time between the last time the record was processed and the current time is larger than the designated MDT.

These criteria and the voltage setpoint can be monitor and controlled on EPICS operator interface (OPI) control panels.

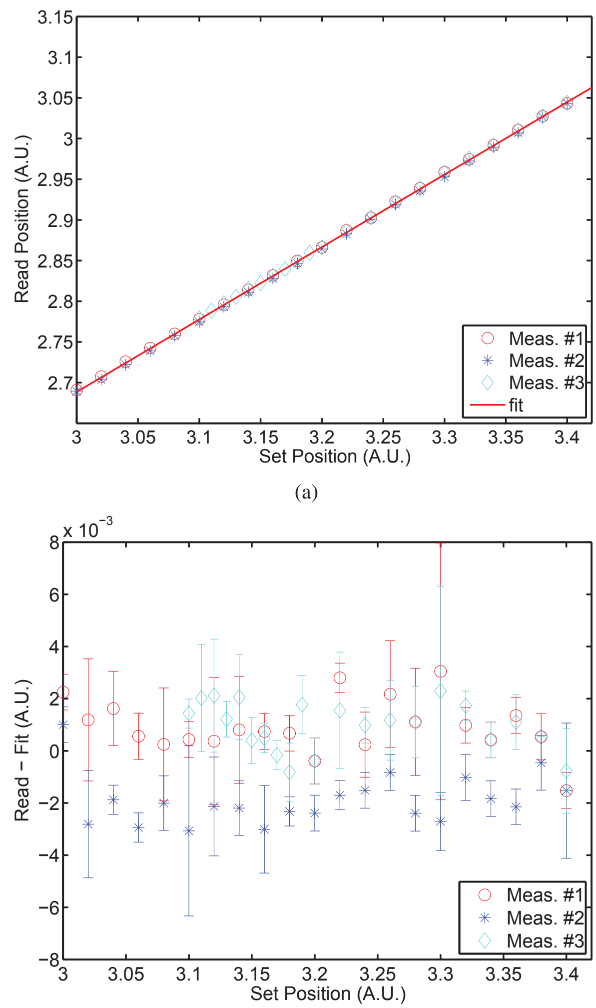
DETERMINING THE FEEDBACK PARAMETERS

In order to determine the PID parameters for the feedback loop, a number of tests, including the reproducibility of the tuning pole driven system and the relationship between the pole movement and the voltage change, are performed.

Reproductibility of the Tuning Pole Driving System

Two types of tests are performed to check the reproducibility of the pole driven system, which are pole position reproducibility and cavity voltage reproducibility, respectively. To check the pole position reproducibility, the pole is scanned in steps with no electron beam stored in the storage ring. The pole positions are measured during the scanning. Three scanning tests are performed and the results are plotted in Fig. 2 . These results indicate that the reproducibility of the pole driven system is within the measurement resolution, and good for controlling the cavity resonance condition.

When testing the voltage reproducibility, only a small amount of beam current, about 5 mA, is injected into the storage ring to avoid the high voltage of the HHC goes too high and damages the cavity. The high voltage of the HHC is measured while scanning the tuning pole. The results of 4 sets of measurements are plotted in Fig. 3. The pole is moved upwards in the 1st and 3rd measurements, and downwards in 2nd and 4-th measurements. The results show that the



(a)

(b)

Figure 2: The measured pole position vs its setpoint.

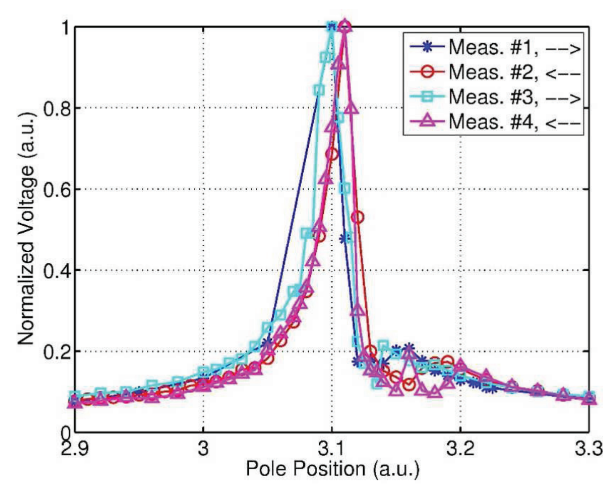


Figure 3: The high voltage of the HHC measured as a function of the tuning pole position.

resonance point is well reproduced when the pole moves in the same direction. There is a small difference of the resonance point for the pole moving in different directions due to some hysteresis effects. Since the cavity works far from the resonance point and the voltage is controlled by PID feedback during machine operation, this difference is durable.

Determining the PID Parameters

The PID parameters for the HHC voltage feedback loop are determined as following. First, the beam current of the storage ring is varied from 60 mA to 280 mA. At a number of selected beam currents, the tuning pole of the HHC is scanned to change the voltage across the HHC. The pole position, s, is linearly fit as a function of the HHC voltage. The slop, ds/dt, of the fit curve is used to determine the proportional term (K_P) of the feedback loop. One of the measurements measured at 240 mA is plotted in Fig. 4, and the measured slops for different beam currents are summarized in Table 2. The results indicate that the slops in the beam current range from 60 mA to 280 mA are within the range from -0.004 to -0.002. In reality, we select -0.0003, which is close to 1/10 of the mean value of the slops, as the K_P for the feedback loop. The integral K_I and derivative K_D parameters of the feedback loop are fine tuned to eliminate overshoot and avoid oscillation.

Table 2: Coefficients Measured at Different Beam Currents

Beam current (mA)	ds/dV
60	-0.003
120	-0.002
160	-0.003
200	-0.004
240	-0.004
280	-0.004

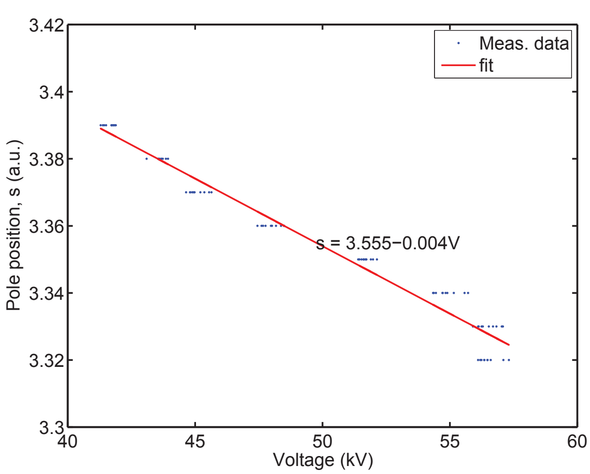


Figure 4: Pole position as a function of cavity voltage. The beam current is about 240 mA.

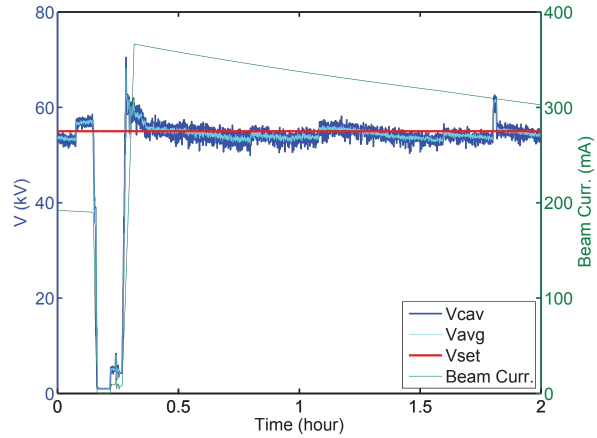


Figure 5: Pole position as a function of cavity voltage.

VOLTAGE CONTROL RESULTS

The HHC voltage control system has been used for varying and maintain the HHC voltage to/at designated values. At present time, the HLS storage ring works with a beam current in the range from 400 mA to 100 mA in decay mode, and 40 mA and 500 mA are set for the low and high current limits, respectively. The pole limits are set to 3.25 and 3.80, respectively, according to measurements to avoid damage to the cavity. During routine operation, the voltage setpoint is selected as 55 kV for minimizing the longitudinal oscillation and increasing the beam lifetime. 2 kV is selected as the voltage threshold, dV, which is about 4% of the setpoint value. Figure 5 shows the high voltage of the HHC in a period of two hours during light source operation. The figure indicates that the voltage feedback loop can effectively maintain the high voltage of the HHC around the voltage setpoint with a threshold of ±2 kV.

SUMMARY

A 4-th harmonic RF cavity was installed in the HLS storage ring to minimize the beam longitudinal instabilities and increase the Touschek lifetime. To effectively vary and maintain the cavity voltage to/at a designated value, a digital PID feedback loop is developed based upon EPICS. This feedback loop can effectively maintain the high voltage of the HHC around the voltage setpoint with a small threshold.

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