Transactions of the Korean Nuclear Society Autumn Meeting
PyeongChang, Korea, October 25-26, 2007

Resonant Frequency Shift Monitoring Method for PEFP Linac Cavity

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1. Introduction

A 20-MeV proton linac which consists of an ion source, 3-MeV RFQ and 4-tank DTL is developed in KAERI site as a front part of the 100-MeV PEFP (Proton Engineering Frontier Project) linac [1]. For the stable and efficient acceleration of the proton beam, the resonant frequency of the linac cavity should be well matched to the high power RF driving frequency, which requires a resonant control system such as RCCS (resonant control cooling system). To control the resonant frequency of the accelerating cavity, we should monitor the resonant frequency, which can be changed from various reasons including thermal drift of ambient temperature. We have studied two different schemes for monitoring the resonant frequency shift during the operation of the accelerator. Both of the methods based on the RF field profile during the pulse operation. One way is using a rising part and the other is decay part of the RF pulse in the cavity. From the test by using a dummy cavity with known resonant frequency shift, we found that the decay part of the RF pulse gives more exact result. We present the details of the resonant frequency shift observation methods and test results in this paper.

2. Methods and Results

2.1 Fundamental Theory

The non-linear dynamics of a single RF cavity can be represented by the state-space equation like following,

$$\frac{d}{dt}\begin{bmatrix} V_I \\ V_Q \end{bmatrix} = \begin{bmatrix} -\omega_{1/2} & -\Delta\omega \\ \Delta\omega & -\omega_{1/2} \end{bmatrix}\begin{bmatrix} V_I \\ V_Q \end{bmatrix} + \frac{\omega_{RF}}{2}\frac{R}{Q}\begin{bmatrix} I_I \\ I_Q \end{bmatrix}$$

where V_I, V_Q are I/Q component of a cavity field, $\omega_{1/2} = \omega_{RF}/2Q$ is the half width of the resonance, $\Delta\omega = \omega_0 - \omega_{RF}$ is the cavity detuning, and I_I, I_Q are I/Q components of the forward RF current. This equation can be derived from the second-order differential equation for a driven RLC circuit. If the RF cavity is driven by a pulsed input of RF power, the cavity field builds up and reaches the steady state. The cavity field builds following the above equation. From the ringing part of the cavity field, we can find the cavity detuning by using the above equation. Right after tuning off the driving RF power, the cavity field amplitude decays exponentially with a time constant which is proportional to the loaded Q of cavity and the cavity field phase ramps with ramp rate which is proportional to the resonant frequency shift. Therefore we can find the resonant frequency shift by measuring the RF field profile in the cavity in decay part and fitting the curve with a line.

2.2 Experimental Setup

To test the frequency shift monitoring method, we use a dummy cavity with known frequency shift of 100 kHz.

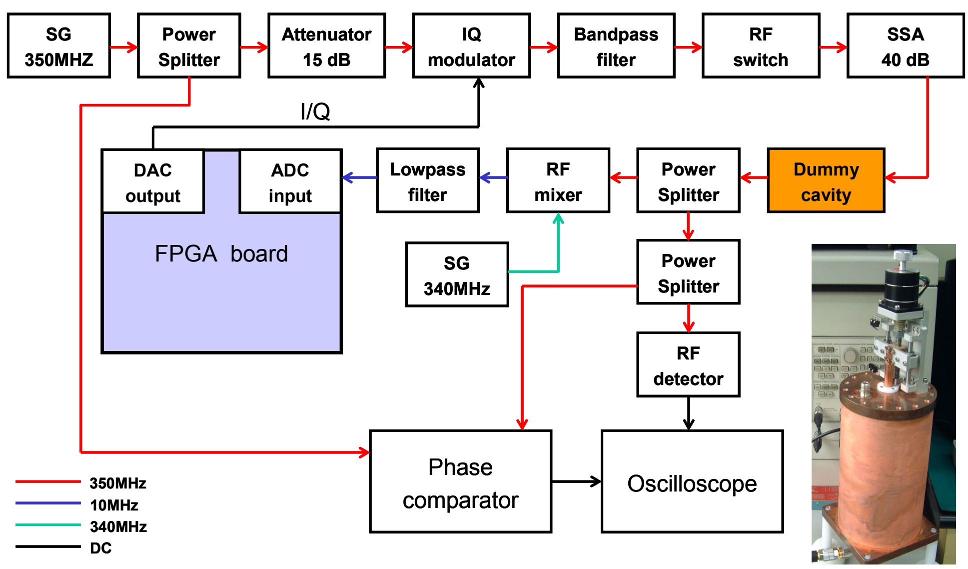

Figure 1. Schematic of the experimental setup for frequency shift measurement

The dummy cavity has a resonant frequency of about 350 MHz, which is same as PEFP linac frequency and motorized frequency tuner. The experimental setup is shown in Figure 1 schematically [2]. The 350 MHz cavity field signal is proved and down-converted to 10 MHz by mixing the signal with 340 MHz LO signal and converted to digital values with 14-bit 40 MHz ADC, then recorded. One of merits of this method is that the frequency shift can be monitored with the on-line processing during the experiment.

2.3 Measurement Results and Discussions

First we detuned the dummy cavity to about ±100 kHz using a network analyzer and then applied pulsed RF power to the cavity and measured the field profile. Figure 2 shows the measured cavity field profile for pulse test. To obtain the frequency shift from rising part of the profile, we used a least square method. In addition the frequency shift was obtained using the decay part of the same profile by linear fitting as shown in Figure 3. The test results are summarized in Table 1. As can be seen from the table 1, the two methods make results reasonably well matched with measured values with a network analyzer. In addition the decay part gives slightly better results than rising part. This is because the method using rising part requires steady-state values which are not necessary in decay part calculation.

3. Conclusion

We have studied two different schemes for monitoring the resonant frequency shift during the operation of the accelerator. Both of the methods based on the RF field profile during the pulse operation. One way is using a rising part and the other is decay part of the RF pulse in the cavity. From the test by using a dummy cavity with known resonant frequency shift, we found that the decay part of the RF pulse gives more exact result. These methods can be applied during the high power test of the accelerator and the frequency shift data can be used as an input signal for the cavity resonance control system such RCCS.

4. Acknowledgements

This work was supported by the 21C Frontier R&D program of Korea Ministry of Science and Technology.

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[2] H. S. Kim, H. J. Kwon, K. T. Seol, I. S. Hong, Y. G. Song, D. I. Kim and Y. S. Cho, “Development of the PEFP Low Level RF Control System”, in Proceedings of PAC 2007, Albuquerque, USA, 2007

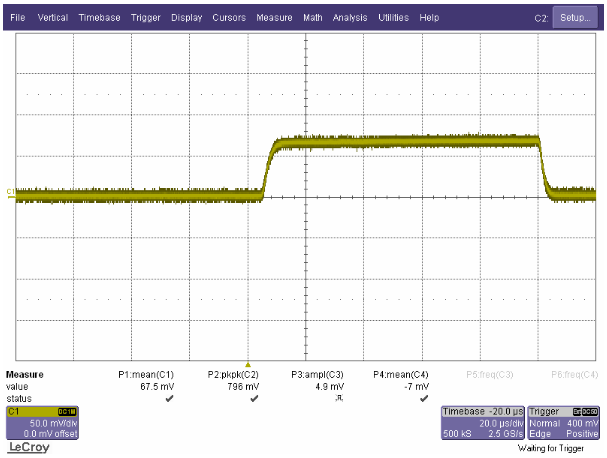

Figure 2. Cavity field profile during RF pulse test

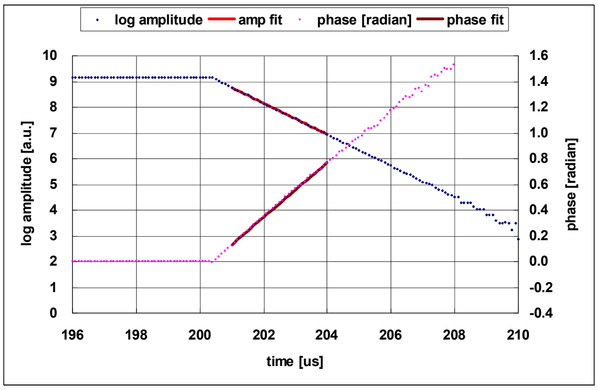

Figure 3a. Linear fitting for the decay part of cavity field (Resonant frequency is above the RF driving frequency)

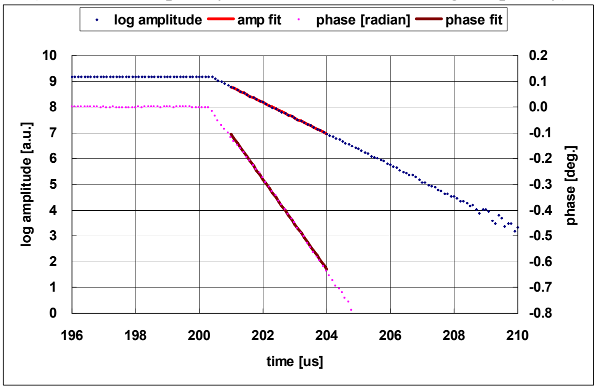

Figure 3b. Linear fitting for the decay part of cavity field (Resonant frequency is below the RF driving frequency)

Table 1. Summary of the detuning measurements

freq. shift	network analyzer	rising part	decay part
below res.	-99.5 kHz	-84.7 kHz	-89.8 kHz
above res.	+100.0 kHz	+103.4 kHz	+104.2 kHz
on res.	0 kHz	-8.7 kHz	+3.6 kHz