The Implementation and Open-loop Test of Analog VCO-PLL Control System in PEFP 13MHz RF Implanter**

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1. Introduction

In order to serve for creating special materials and biological applications in Proton Engineering Frontier Project (PEFP) laboratory, for ex., ion implantation in fabrication of semiconductor, surface hardening with ions, precision machining and membranes manufacture, a 13 MHz RF implanter was made and will be used for the heavy ion implantation experiment [1]. Due to various disturbances in environment, such as room temperature drift, water-flow impinging, the pump's vibration, the accelerating cavity normally cannot work at resonance peak of the frequency.

To keep it operating in stable, we are developing analog devices based VCO-PLL RF control system for this implanter. The RF system is continuously tracking the cavity resonance frequency‘s shift and always set the RF source frequency with the same value. The key design is using a PID compensator to realize cavity resonation peak lock-in and using internal mode method or lead-lag circuit to reject disturbance. [2] The design chiefly can be seen as a frequency tracking scheme to kept the cavity working on resonance. [3, 4]

In this paper, the block diagram of control system, the experimental setup, the cavity RF parameters test, and the device performance measurement in the open-loop were given.

2. The Structure of the Control System of Analog Devices VCO-PLL for the 13 MHZ RF Implanter

The structure of the analog devices based VCO-PLL control system illustrated as Fig.1. It is a close-loop tracking system with a PI compensator.

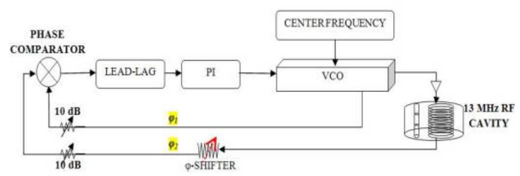

Fig. 1 Diagram of the frequency-tracking control

The VCO generated a varied RF frequency, which will depend on the feedback signal from phase comparator. The phase comparator receives two RF signals come from cavity and the RF source, compares their phase difference, and then output a DC signal proportional to this difference. When the cavity is working in the off-resonance due to disturbances, the detuning will make cavity works as a phase shifter, the phase difference between two feedback paths will drive the RF source tracking the cavity’s resonance frequency.

3. The Experimental Set-up of the Control System

Fig. 2 shows the experimental set-up of the control system to be used.

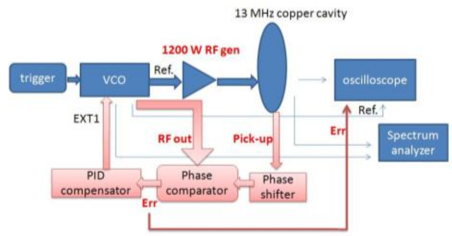

Fig. 2 The close-loop experimental set-up

We can see that it mainly includes 6 essential parts, (1) signal generator (VCO) and trigger, (2) power amplifier, (3) 13 MHz cavity, (4) and DC controlled phase shifter, (5) PID compensator circuit, (6) a phase comparator. And also it has some auxiliary parts. The compensator refers to PID controller and lead-lag or internal mode circuit, which are used for providing enough low frequency gain to suppress the noise fluctuation.

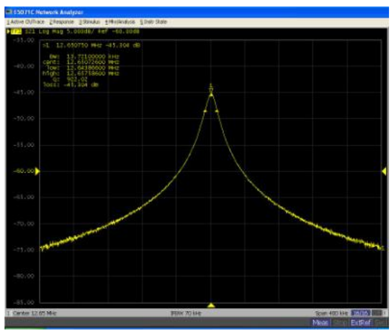

Fig. 3 13 MHz Cavity Resonation Curve

The phase comparator AD8302 is used for generating the error signal, so as to effectively provide feedback signal to the compensator. We use an Agilent E4438C and YoungSin YSR-25MH to drive the cavity, the power amplifier normally outputs 1200 W RF power to the coupler. The Fig. 3 shows the measurement results of frequency spectrum of the implanter’s cavity in the room temperature. The peak frequency is located at

13.6 MHz, and with a 3 dB half bandwidth 6.8 kHz which is correspond to 45 degree phase shift of the cavity. Fig.4 shows the control feature of the Mini-circuits JSPHS-16+ phase shifter, it can provide 180 degree phase shift for the feedback loop. The Fig.5 shows the transmission characteristics of the phase comparator. If we select the quiescent operation point which is located at 90 or 180 degree, the device will has very good linearity. The sensitivity of the phase is 10 mV/degree.

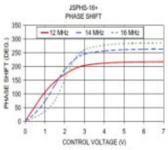

Fig. 4 DC controlled phase shifter

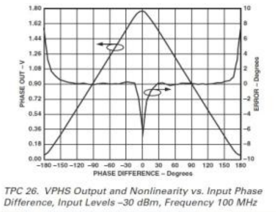

Fig. 5 10mV/degree phase comparator (the transmission curve)

We used an op-amp structure to implement the PI compensator and lead-lag; Fig. 6 is the circuit diagram of the PI compensator. Table 1 is the parameter set we used in this design.

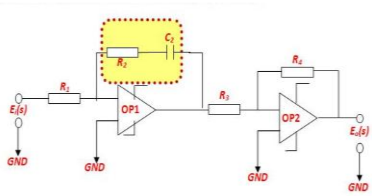

Fig. 6 The PI compensator Design

Table 1: The parameter settings of accelerator system

Item	value	unit	memo
R_1	2	kΩ	-
R_2	5	kΩ	Integrator
C_2	2.98	nF	Integrator
R_3	2	kΩ	-
R_4	382	Ω	-
K_p	0.4775	N/A	-
K_i	32028	N/A	-

The lead-lag circuit has a similar form with the PID compensator, here is not shown that.

4. The Results

We tested this set-up in open-loop case so far. The following Fig. 7 is the frequency peak of the RF picked-up signal from cavity's field probe. The Fig.8 is the input/output signals measured from the cavity during its operation. It consists of (from bottom to top) the reflected signal, forward signal, pick-up signal, and beam current measured by wire scanner. [1] Because the arc current in ion source is too small and the average signal of the wire scanner is not match when measuring, so we can see the beam current looks like very small (the first curve from top).

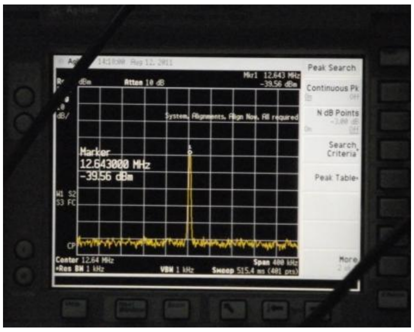

Fig. 7 The resonation peak of RF signal

Fig. 8 The picked-up signal from cavity (the second curve from top count)

5. Discussions

By open-loop test and prelimnary experiment, the fundamental control parameters for individual elements in the loop were obtained. Also the whole RF system can work well in pulsed mode. In the near future, we will realize cavity frequency peak lock-in in feedback case with a PID compensator, and try to sufficently remoce the loop noise, especially the 750 Hz heavy pump vibration disturbacnce.

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