IMPROVEMENT OF THE PNEUMATIC FREQUENCY TUNER OF THE SUPERCONDUCTING RESONATORS AT IUAC

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Abstract

The existing phase locking scheme of the quarter wave resonators (QWR) used in superconducting linear accelerator of Inter University Accelerator Centre (IUAC) consists of a fast (electronic) and a slow time (pneumatic) control. Presently, helium gas operated mechanical tuners are being used to phase lock the resonators against the master oscillator (MO) frequency and different ion beams have been accelerated and delivered to conduct experiments. The present pneumatic frequency tuner has two limitations: (a) no proportional flow control in vacuum condition (b) large hysteresis problem in the proportional valve responsible for gas flow control. Due to these limitations, the system becomes non-linear and the response time is very slow (~sec). Using the existing system, phase locking of a resonator becomes delicate and time consuming. In addition, it was found to be difficult to implement auto phase locking mechanism on the resonator. To overcome these problems and to improve the dynamics of the existing tuner, a new pneumatic tuning system has been adopted. Details of the existing tuning mechanism and the modified tuning system along with the test results will be presented in the paper.

INTRODUCTION

To augment the energy of the ions from the existing Pelletron accelerator at IUAC, a 97MHz Superconducting (SC) Linear Accelerator (LINAC) [1] consisting of five cryostats having 27 QWR was installed and made operational [2]. The schematic diagram of Pelletron LINAC system is shown in Fig. 1.

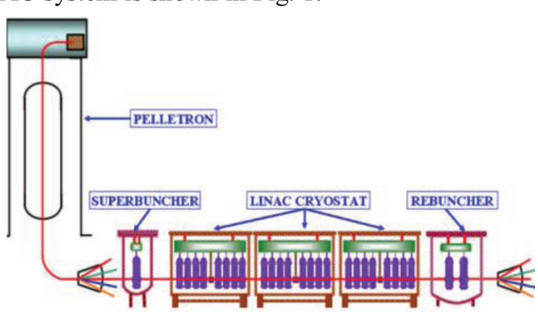

Fig. 1: Schematic diagram of Pelletron LINAC system.

The QWR used in SC LINAC need to be phase locked against the MO frequency for beam acceleration. It is difficult to make the frequencies of all the operational cavities equal to the MO, so there is need of frequency tuner. The phase lock is achieved by dynamic phase control method [3]. In this method, the fast frequency fluctuation is controlled by I-Q modulator, whereas the slow frequency fluctuation is controlled by operation of mechanical tuner. In this scheme, niobium bellows mounted at the high voltage end of QWR are flexed (pressurized and evacuated) by helium gas to change the capacitance and hence the frequency of QWRs. The diagram of QWR with pneumatic frequency tuner is shown in the Fig. 2.

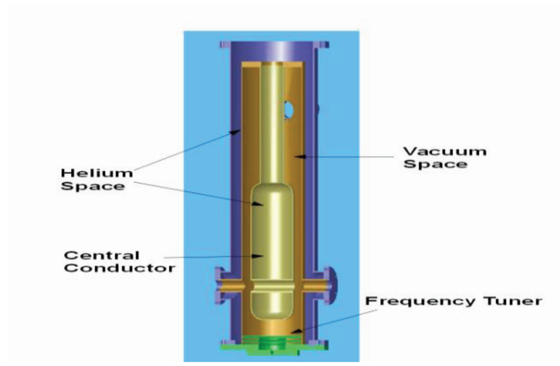

Fig. 2: The diagram of QWR with slow tuner bellow.

Recently, in some of the cavities, piezo tuners.[4] have been installed and tested successfully. It has been planned to install the piezo tuners in LINAC cryostat # 2 and 3. Helium gas operated pneumatic tuner will be continued in the cavities of LINAC cryostat #1 because piezo tuners can't be installed into it due to space constraint in LINAC cryostat # 1. In order to improve the dynamics of the pneumatic frequency tuner and to make the system faster and reliable, an improved pneumatic frequency tuner [5] has been planned, fabricated and tested successfully in the test cryostat.

EXISTING PNEUMATIC FREQUENCY TUNER SYSTEM

In the existing pneumatic frequency tuner design, there is one proportional valve in the pressure line and one ON / OFF valve in the vacuum line. In both the lines, flow restrictors allowing helium gas flow up to 900cc/min at a pressure gradient of 7psi are present. In addition, a line having fixed leak rate of 60cc/min at a pressure gradient of 7psi between pressure manifold and vacuum line is also present. The pneumatic frequency tuner controller module, gets the error signals from resonator controller and pressure transducer. It processes these signals and supplies the control voltage to the pneumatic valve assembly. The valves regulate the flow of helium gas into slow tuner bellow and thus the frequency of the cavity is tuned. While tuning the cavity frequency, it takes some time for the pneumatic frequency tuner system to bring

ISBN 978-3-95450-143-4

the cavity frequency to that of the MO. There is hysteresis problem in the pneumatic valves as these operate on dc voltage. Also, the flow control in pressure and vacuum conditions are not similar, resulting in non-linearity problems in tuning the cavity frequency. So an improvement to make the system more linear, faster and reliable was felt necessary. Schematic diagram of the pneumatic frequency tuner system is shown in Fig. 3.

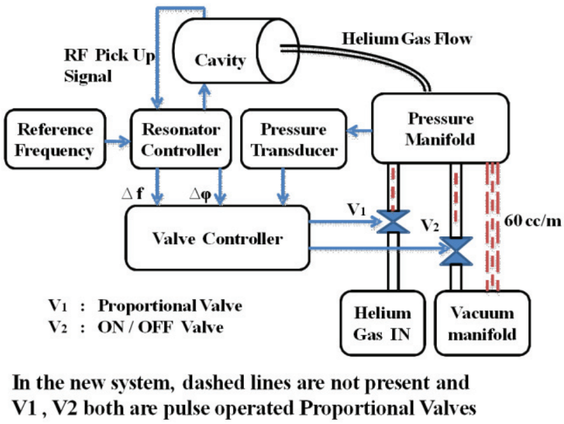

Fig. 3: Schematic diagram of the pneumatic frequency tuner system.

IMPROVED PNEUMATIC FREQUENCY TUNER SYSTEM

In the new design, modifications in the mechanical assembly and control system have been done.

Mechanical Assembly

(a) Flow restrictors have been removed to improve system response time (b) Fixed leak rate of 60cc/min has been removed. (c) The valves V_1 and V_2 as shown in the figure. 3 have been replaced by two identical proportional valves that can be operated in pulsed mode also.

Control System

(a)DC valve control scheme has been changed to Pulse Width Modulation (PWM) control scheme (b)The time constant and the gain of the control system has been changed accordingly.

PWM Control Scheme

Pulse-width modulation uses a rectangular pulse wave whose pulse width is modulated resulting in the variation of the average value of the waveform. If we consider a pulse waveform f(t) with a low value y_{min}, a high value y_{max} and a duty cycle D, the average value of the waveform is given by:

$$\bar{y} = \frac{1}{T}\int_0^T f(t).dt \tag{1}$$

As f(t) is a pulse wave, its value is y_{max} for $0 < t < D.T$ and y_{min} for $D.T < t < T$. The above expression then becomes then becomes:

$$\bar{y} = \frac{1}{T}\left(\int_0^{DT} y_{max}.dt + \int_{DT}^{T} y_{min}.dt\right)$$

$$\bar{y} = \frac{D.T.y_{max} + T(1-D)\,y_{min}}{T}$$

$$\bar{y} = D.y_{max} + (1-D)\,y_{min} \tag{2}$$

If we consider $y_{min} = 0$, the above expression becomes

$$\bar{y} = D.y_{max} \tag{3}$$

From this, it is obvious that the average value of the signal is directly dependent on the duty cycle D.

In modified controller at IUAC, valves are controlled by a 10 V rectangular pulses of fixed frequency 20 Hz with variable duty cycle from 5% to 95%. This limit on duty cycle ensures a continuous leak path. Picture of the modified slow tuner is shown in Fig. 4.

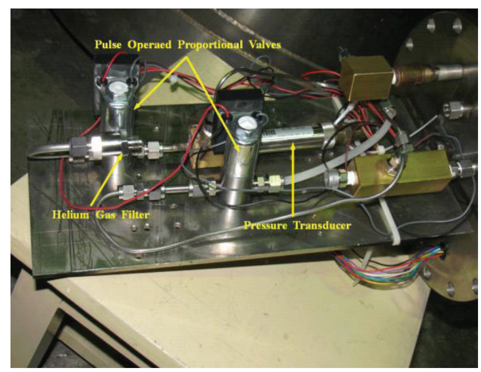

Fig. 4: Modified pneumatic frequency tuner.

ANALYSIS

The flow and response characteristics have been measured with the improved and faster pneumatic frequency tuner. From the measurement, the required gain and time constant of the system has been calculated for the optimal settings of the control loop operation. Accordingly the electronics has been modified. A dedicated PWM for the new proportional valves has been developed and integrated in the system.

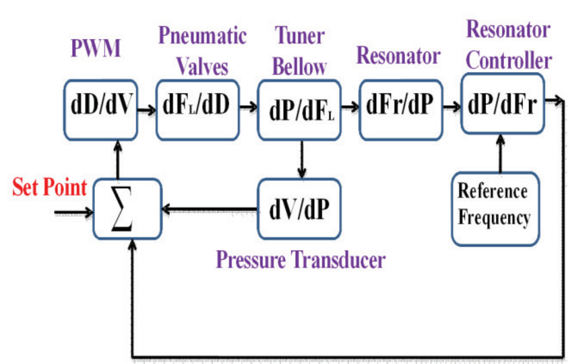

Fig. 5: Transfer Characteristics of modified pneumatic frequency tuner system.

The transfer characteristics of the modified pneumatic frequency tuner system are shown in the Fig. 5. Here, D is the duty cycle of the PWM of pneumatic controller, V is the error signal, F_L is the helium flow rate, P is the pressure inside tuner bellow and Fr represents the frequency of the cavity. In this feedback loop, any change in the phase/frequency of the cavity, results in the change in feedback voltage. This prompts to change the duty cycle and thus the flow of the helium gas is regulated, thereby regulating the frequency of the cavity.

TEST RESULTS

The modified slow tuner has been tested for its stability. The PWM introduced in the control circuit is found to be linear and stable. The graph is shown in Fig. 6.

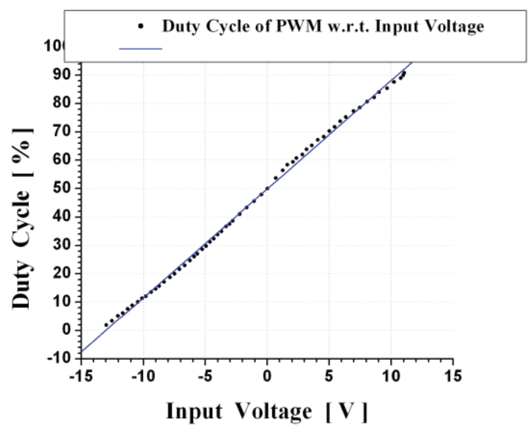

Fig. 6: Response of Pulse Width Modulator.

Using the PWM technique, the system is almost free of hysteresis problem as shown in Fig. 7. Both the results shown in Fig. 6 and 7 ensure a linear control of the frequency/phase of a SC QWR governed by the improved tuning mechanism.

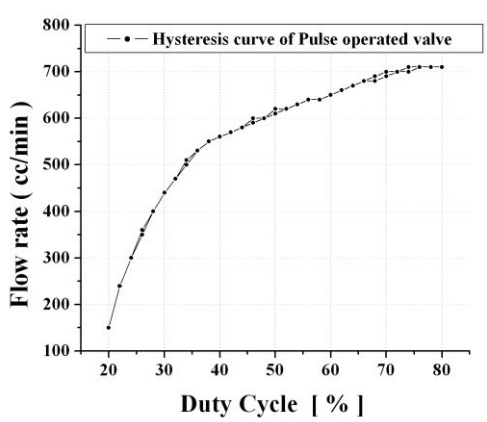

Fig. 7: Response of Valve in Pulse Mod.

The change of frequency of QWR by pressurizing and evacuating the tuner bellow using existing pneumatic frequency tuner as well as the modified pneumatic frequency tuner is shown in Fig. 8. The graph clearly shows that the improved pneumatic frequency tuner is able to change the frequency of the QWR in comparatively less time.

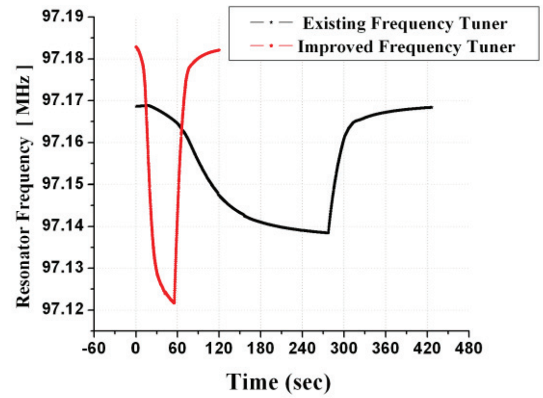

Fig. 8: Change of frequency of QWR by pressurizing and evacuating the tuner bellow.

In the test cryostat, SC QWR operating at 97.014 MHz was tested with this modified pneumatic frequency tuner system. The resonator was phase locked @ Ea = 3.3MV/m. During the test, amplitude and phase errors were 10mV and 100 mV respectively. In the locked condition the reference frequency was intentionally changed by 100Hz. The time taken by the improved frequency tuner to capture the lock was measured to be 50ms.The power requirement was low and the system seemed to be more stable.

CONCLUSION

The improved pneumatic frequency tuner has been tested successfully. This tuner has proved its linearity, faster response and reliability. Overall RF power required for control is found to be reduced using this improved design.

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ISBN 978-3-95450-143-4