A SYSTEM FOR AUTOMATIC LOCKING OF RESONATORS OF LINAC AT IUAC

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Abstract

The superconducting LINAC booster of IUAC consists of five cryostats housing a total of 27 Niobium quarter wave resonators (QWRs). The QWRs are phase locked against the master oscillator at a frequency of 97 MHz. Frequency tuning of the resonator prior to phase locking is done by a Helium gas based mechanical tuner (slow tuner). The frequency tuning and phase locking is done from the control room consoles. To make LINAC operation smoother, automation of phase locking of the resonator has been done. A detailed about the automation system and its implementation in LINAC have been presented in this paper.

INTRODUCTION

The 27 QWRs of IUAC LINAC distributed in five modules (one in superbuncher, eight each in three accelerating modules and two in rebuncher) are independently phase locked with the Master Oscillator (MO) during the operation[1] [2]. The phase and amplitude locking of the resonators is based on dynamic phase control method along with additional control for the mechanical tuner. For slow frequency and phase variations, the Helium gas based tuner has been implemented in the first LINAC cryostat. The tuner is also responsible for frequency tuning prior to phase locking. The tuner bellows and the resonator are shown in Fig 1.

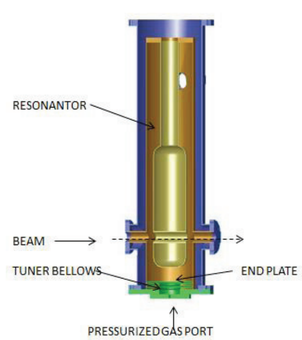

Figure 1: The resonator and the slow tuner.

As shown in the Figure 1, the slow tuner consists of a Niobium bellows that forms a capacitive gap with the central conductor of the resonator. The expansion and contraction of the bellows, which is a function the gas pressure inside it, defines the resonant frequency of the cavity. The pressure in the tuner bellows is maintained using valves V1 and valve V2 as shown in figure 2. When the resonator frequency is different from the MO frequency, the opening of the valves is changed to compensate for the shift. Earlier this was being done manually. The operation was done remotely from control room using a combination of analog and digital techniques. The automation using digital technique is described in [3]. A mechanism for automatic operation of the valves is worked out for smooth LINAC operation.

DESCRIPTION

Dynamics of the Tuner

The digital compensator is required to compensate for the time response characteristics of the tuner system in the feedback mode. The identification of the time response has been done experimentally by applying a voltage step to the valve drive. The result is shown in figure 2. A first order open loop response of the bellows and valve system with a comparatively low dead time can be seen.

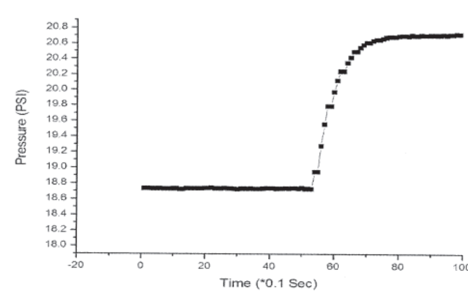

Figure 2: Time response of the pneumatic system.

This response can be mathematically expressed as follows:

$$G(s) = \frac{K}{\tau s + 1}$$

Where K is the steady state gain and τ is the time constant of the system. τ in the gas valve system is of the order of one second. This type of response can be easily corrected with a PID compensator. A digital feedback system offers several advantages with large time constant systems.

ISBN 978-3-95450-139-7

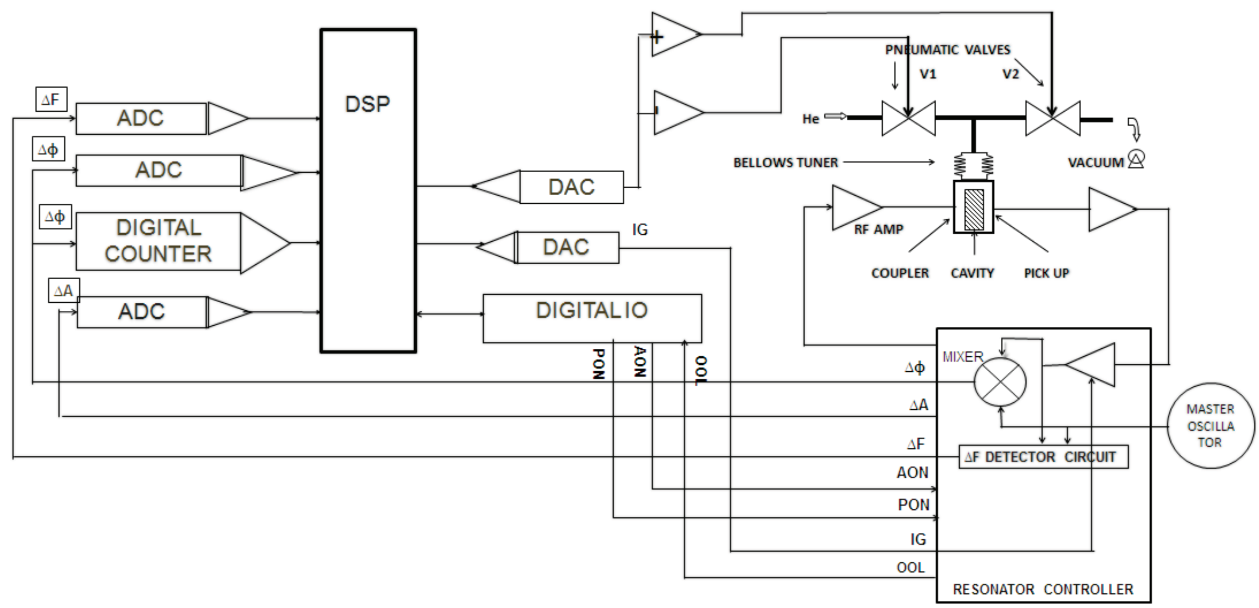

Figure 3: Block Diagram of the system implementation.

Resonator control system

The control system along with the implementation is shown in figure 3. The resonator controller of IUAC works on a dynamic phase control scheme [4] [5] [6]. The resonator controller is responsible for stabilizing the phase and amplitude of RF signal. The proportional valves along-with the pressure and vacuum lines forms the mechanical assembly for the control of slow tuner bellows.

Automation Implementation

A simplified block diagram of the automation scheme is shown in figure 4.

In the loop diagram is shown in figure 4, the digital compensator block implemented by a CPU runs the DSP algorithms for phase and frequency locking. The compensator implements a PID transfer function of the form-

$$G(s) = K_p + K_d s + \frac{K_i}{s}$$

Where Kp, Ki and Kd are proportional, integral and derivative gains.

Operation of the Digital Control Loop

In the unlocked state the phase error (E_ϕ) consists of the beat frequency between generated from the resonator pick up and the MO. This beat frequency is applied to a gated digital frequency counter to measure the frequency error (E_f). E_f is used as the error input to the digital compensator. The output of the digital compensator drives the tuner valves. The feedback action causes the resonant frequency of the cavity to move towards that of the MO. When E_f becomes very low, the phase feedback is switched on in the resonator controller and the resonator phase is locked. The resonator controller phase is locked by raising the PON line.

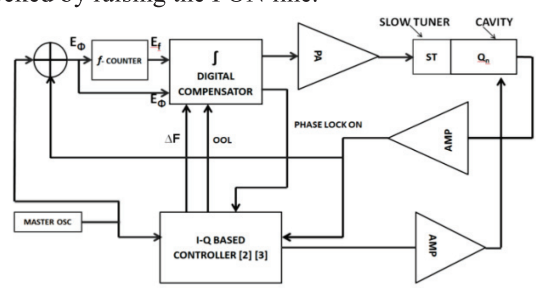

Figure 4: Control loop diagram.

Once in the locked state, the resonator controller takes care of the phase stabilization. The tuner loop of figure 4 in this state is switched to take input from phase error (E_ϕ) instead of E_f. This makes the control to take care of the slow drift of the resonator frequency along with main phase stabilization loop.

The complete automation scheme is shown in figure 3 where all the signals required for locking are shown. The system first does the amplitude locking by minimizing the amplitude error and automatically raising the AON line. This is followed by the phase locking process described in the previous paragraph.

If during operation, the resonator controller gets unlocked, the resonator controller raises the out of lock (OOL) signal. This signal is read by the digital controller as shown in figure 3 and figure 4 and is immediately responded to by disabling the PON line and going back to the frequency mode.

Although a frequency counter based frequency measurement provides good stability and accuracy, in cases of an overshoot cycle in the loop, it fails to provide the direction of the frequency error. To correct this problem, the counter is replaced by the ΔF signal coming

ISBN 978-3-95450-139-7

from the resonator controller for frequency errors below 1.5 kHz.

The threshold frequency and phase values for mode switching depends upon the coupling and the actual Q of the resonator. Typical values of E_f for enabling phase loop are less than 20 Hz.

The code in the processor is written to initially sample the frequency counter and later on the phase error ADC at the sampling frequency. The algorithm is run regularly and the output to the DAC for each sample is generated. The switching mechanism for switching between frequency and phase modes is programmed. A calibration mode is provided to calibrate the PID gains, the thresholds and other parameters.

Control Interface (Local and Remote)

The manual local control of the slow tuner valves V1 and V2 is required for testing and conditioning of the the slow tuner system. Pump and purge operations are frequently carried out for conditioning of the system. Figure 5 shows the control and coordination system. To enable these tasks, switches for forcing extreme valve positions of full vacuum and full pressure are provided. Also for manually changing the resonant frequency, shaft encoder is provided. The shaft encoder and the switch systems are interfaced to a GUI based control CPU which controls the automation DSP system via an interface link.

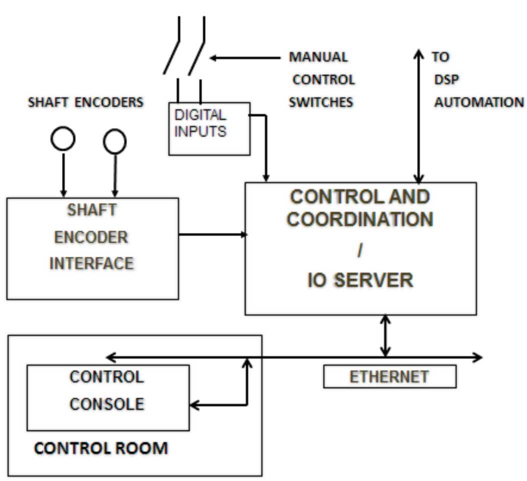

Figure 5: Control and coordination.

For remote control from the IUAC control room, the control CPU provides client server link to the main control room clients. The control CPU is provided with a Ethernet link for the purpose.

Calibration

Calibration of the system requires the tuning of the Proportional and dynamic time constants of the controller. It also requires programming of thresholds at different stages of the automation process. Particularly important are P,I and D gains, the phase mode to frequency mode threshold and frequency to phase mode threshold. The calibration facility is provided by the control CPU when it sends calibration related commands to the DSP controller working in the calibration mode.

HARDWARE

An 80188 based CPU has been used with ADC and DAC for the implementation of the DSP System. A digital counter with adjustable thresholds is interfaced for frequency measurement. Communication and control interface has been implemented with help of a serial interface for communicating with a controller CPU. The controller CPU is connected to the main control system via an Ethernet interface using a client server interface protocol. The control and coordination CPU has been implemented based upon an Intel based standard platform which supports a strong GUI and a stable network server interface for remote communication. The system has been provided with shaft encoder for local and manual control as required. Local and remote operations are supported. The hardware is assembled as a 19” rack-mount unit.

SOFTWARE

The automation process routine flowcharted in figure 6 is a sequence of following tasks-.

1. Look at the amplitude error and adjust IG until it is minimum.
2. Switch on amplitude locking on main controller.
3. Drive pneumatic valves V1 and V2 to Minimize ΔF.
4. When the ΔF is very small, switch on the main PLL by raising the PON line.
5. Watch OOL signal regularly. If it fails, unlock the phase lock PLL and go back to frequency mode.

The software consists of the process routines for automation, local control and remote control from the control room.

The closed loop for the frequency approach and slow phase control is implemented as described in the description section. The inputs are read according to the stage of the automation process and the valves are driven accordingly.

Shaft encoders and switches are interfaced to provide manual control of the valve positions.

A remote control interface is implemented using the IUAC client server control system protocol. The standard protocol used at IUAC is used for compatibility reasons. The control commands are communicated by the control room to the control and coordination CPU and are passed on to the automation system as required. A server is used for the purpose.

ISBN 978-3-95450-139-7

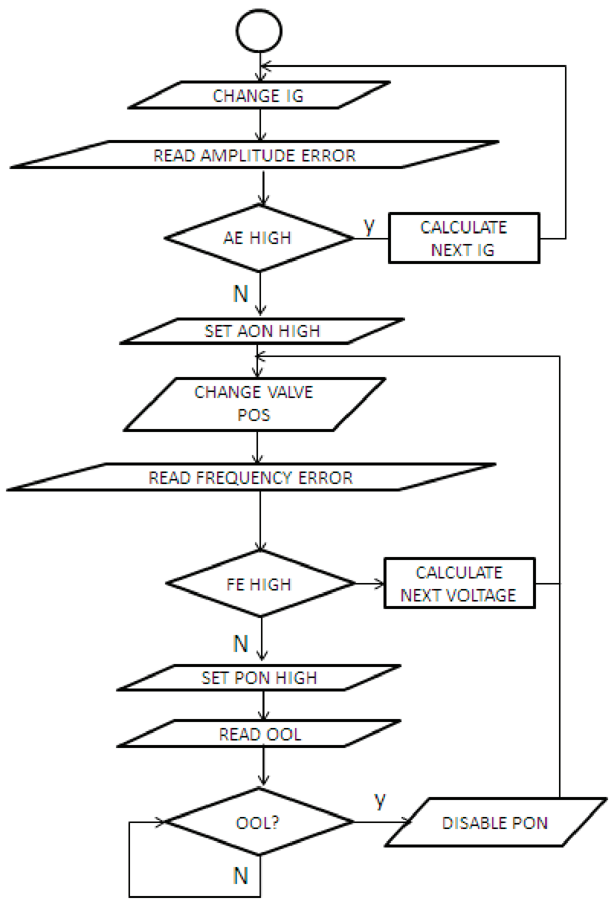

Figure 6: Flowchart of Automation.

RESULTS

The system has been tested on a few resonators of LINAC cryostat 1 and is being implemented on the resonators of LINAC cryostat 1. The auto-locking system works reliably and no failures in locking have been observed. Phase error measured in the locked state is low. Auto locking has been successful done upto a resonator field of 4.5 MV/m at IUAC which is one of the highest at IUAC.

FUTURE PLANS

Support for different actuator systems for frequency tuning is underway. Near future design modifications are taken up for piezo electric frequency tuners and pulse width modulator (pwm) based gas valves. Resonators in some cryostats in the system are already being upgraded to piezo electric frequency tuners [7]. PWM gas valves instead of DC have also been tested and slated for change[8]. Modifications in driver stage and software are being designed and implemented for these changes.

ACKNOWLEDGEMENTS

Sincere acknowledgements are due for the group members and colleagues working with me for the project. Help from Mr. Siddharth Gulati of NSIT, Delhi and Mr. Naveen Sisodia of IIT, Delhi is highly acknowledged. I am also thankful to our former director, Dr A.Roy for encouragement.

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ISBN 978-3-95450-139-7