USE OF PIEZOELECTRIC ACTUATOR TO FREQUENCY LOCK SUPERCONDUCTING QUARTER WAVE RESONATOR

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Abstract

The frequency control of the superconducting quarter wave resonator at Inter University Accelerator Centre (IUAC) is currently accomplished by mechanical and electronic tuners which are operated in the time scale in the range of a few seconds to a few microseconds. During operation, input RF power ≤ 100 W was required to control the resonator for a typical field of 3-5 MV/m for 6 watts of power dissipated in liquid helium. Though resonators are working fine at this power level, investigations are going on whether more reliable operation of the resonators is possible using a piezoelectric actuator to control the amplitude and phase of the accelerating fields. The piezoelectric tuner working in ~ milliseconds range with the dynamic phase control scheme will share a substantial load from the electronic tuner. In addition, in this new scheme, the resonator's phase lock loop will operate with lesser RF power than presently required. The test results of the piezoelectric tuner are presented in this paper.

INTRODUCTION

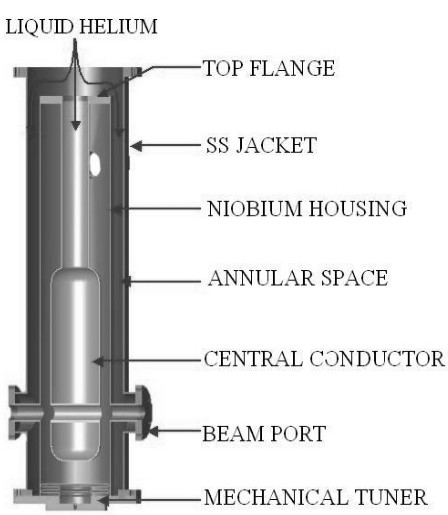

Figure 1: The schematic of the resonator and its mechanical tuner.

Presently, at IUAC, the commissioning of a superconducting (SC) linear accelerator (linac) based on niobium quarter wave coaxial resonator (QWR) is approaching completion [1,2]. The schematic of the resonator is shown in figure 1. The 15 UD Pelletron accelerator producing dc and bunched ion beam covering almost the entire periodic table, is used as the injector of the linac. Silicon and Oxygen beam from Pelletron accelerator has already been accelerated by the first accelerating module of linac and beam was delivered to conduct experiment.

The QWR of IUAC, is made from bulk niobium sheet and enclosed in a SS-jacket. Near the high voltage end of the central conductor, a pneumatically operated niobium bellows is placed to tune the resonator frequency. The complete resonator and the niobium bellow tuner are shown in figure 2 and 3.

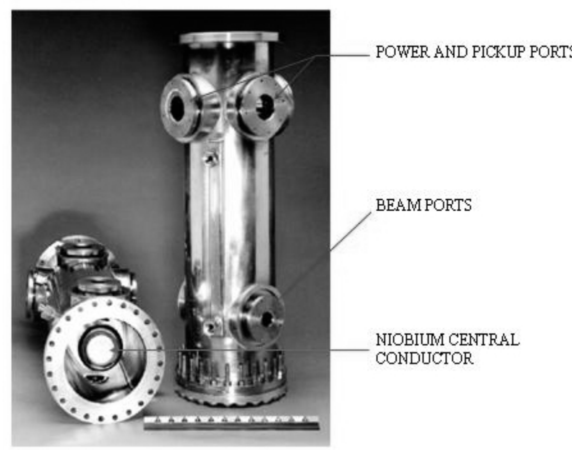

Figure 2: The photograph of two complete QWR.

The superconducting bulk niobium resonators have Quality factor in the range of 10^9. For IUAC QWR with resonance frequency of 97 MHz, the bandwidth of resonator is around 0.1 Hz. Vibration induced fluctuations of the frequency are of the order of a few tens of Hz in these resonators. The frequency fluctuations have got two components – one happens in slow time scale (seconds) and the other happens in faster (a few tens to hundreds of μsec) time scale.

To arrest the fast drifts of frequency, the effective bandwidth is increased by overcoupling the resonator with respect to the RF amplifier and the resonator is supplied with the additional reactive power. By flexing the niobium bellows acting as the mechanical tuner, the slow drift of the frequency is controlled. This helps to reduce the overall power requirement of the fast tuner to control the frequency jitter.

The two tuning mechanisms working simultaneously are able to lock the phase and amplitude of the resonators with respect to master oscillator and beam was accelerated through the linac. However, since helium gas is used to flex the bellows sitting at a very low temperature (~ 40-60 K), the gas line got chocked a few times by traces of moisture in the past during cold tests. In addition, the slow tuning mechanism requires continuous supply of high purity helium gas inside the SS-bellow, for its operation.

With the recent growing usage of piezoelectric crystal in the tuning mechanism of SC resonators, efforts are on to make the tuning mechanism more reliable and cost effective. The aim of the work is to study and develop a piezoelectric tuning mechanism with our existing fast tuning control scheme based on Dynamic Phase Control (DPC) [3] method for the phase locking of the resonator.

TEST OF PIEZOELECTRIC ACTUATOR AT ROOM TEMPERATURE AND COLD CONDITION

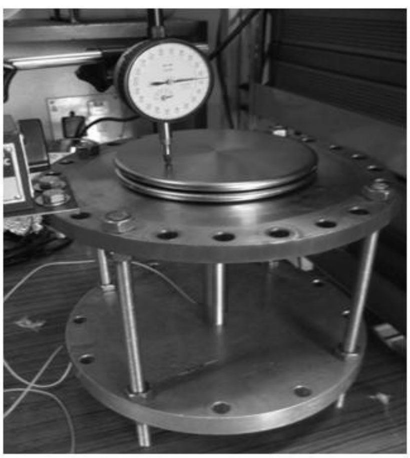

Figure 3: Measurement of the deflection of niobium bellows after powering the piezoelectric actuator.

Before connecting the niobium bellows loaded with piezoelectric tuner with the resonator, its effect on the niobium bellows was checked outside by measuring the deflection with dial gauge as shown in fig 3. One side of the piezoelectric is connected to the back of the niobium convolution of the tuner and the other side is clamped by fixing it on a aluminium flange. Biasing the piezoelectric actuator (Physik Instrumente (PI) make) [4] between -19 to 100 volts, the deflection measured by the dial gauge was 85 µm. The whole assembly shown in fig 3 was connected at the open end of a resonator (shown in figure 4) to test the performance at room temperature and cold condition. At room temperature, for a fixed distance between the top convolution of the slow tuner and the end of the central conductor, the frequency range of the resonator with full bias of the piezoelectric actuator (-19 to 100 Volts), was measured to be ~ 2.5 KHz. When the resonators were cold at 4.2 K, the frequency range had been reduced to 626 Hz. The hysteresis observed in the frequency change for increase and decrease of the bias voltage of the piezoelectric actuator is shown in figure 5.

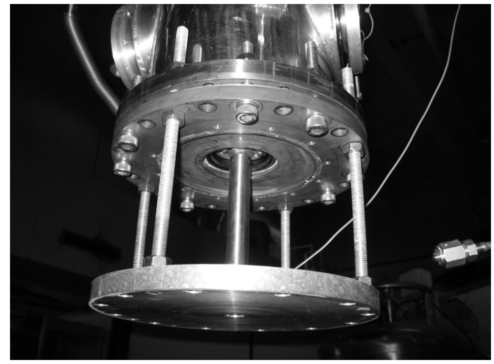

Figure 4: The mechanical tuner (hiding inside the resonator) along with the piezoelectric actuator prior to a cold test.

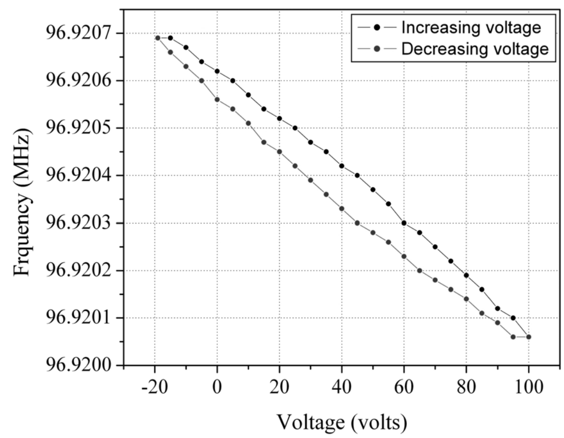

Figure 5: Hysteresis curve of the piezoelectric actuator.

CLOSED LOOP OPERATION OF PIEZOELECTRIC ACTUATOR TO PHASE LOCK A SC RESONATOR

To keep the superconducting resonator phase locked with reference to the master oscillator in the dynamic phase control loop, the piezoelectric voltage should vary with phase error of the resonator controller. To achieve this, a PI based control scheme has been planned. The aim of this control scheme is to compensate the frequency drift around central frequency of the resonator and eliminate the hysteresis effects. The block diagram for the closed loop control of the piezoelectric actuator with existing dynamic phase control based resonator controller is shown in figure 6. In the existing resonator control electronics, the phase error calibration is set for ~ 100mV for 0.1 degree of phase difference. The high voltage amplifier for the piezoelectric actuator has open loop DC gain of 15. Within this range, piezoelectric control will also work along with the fast tuner but only for the frequency jitter occurring in the time range of ~ 100 msec. To get the piezoelectric control work efficiently, during operation, the error signal is reduced electronically by a factor of 10. So, for a phase error signal of ~ 1000 mV (to have a phase stability of ± 0.5 degree), a voltage of 1.5 Volts will appear at the piezoelectric crystal and this will change the frequency of the resonator by 7.8 Hz. As the total bias voltage of the piezoelectric is ~ 120 volts, the change of 7.8 Hz/1.5 Volts will be sufficient to cover the entire frequency window of 40 – 100 Hz required for the resonators in different cryostats. The P-I control is designed with variable proportional gain of 0.01 to 2 and with variable time constant of 3 msec to 300msec. However, at the time of experiment, a time constant of ~ 100 msec is kept for the time response of the piezoelectric actuator. The block diagram of P-I control is given below in figure 7.

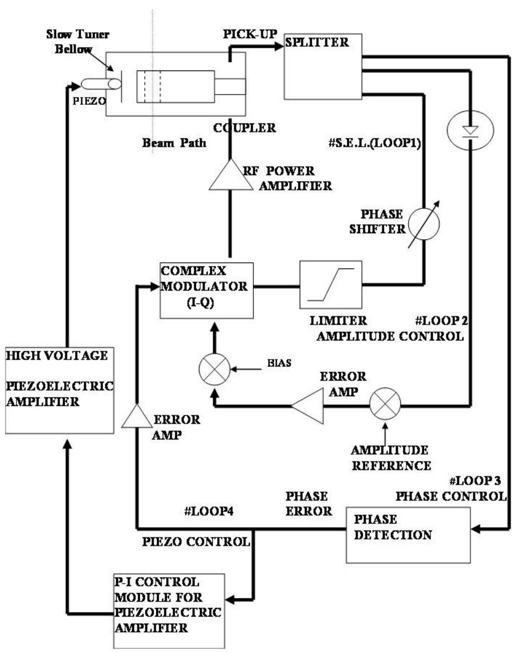

Figure 6: Block diagram of Piezoelectric close loop control scheme.

During the first test of a superconducting resonator in test cryostat along with the fast tuner and piezoelectric actuator acting as slow tuner, the overall locking mechanism worked very well. In this test, no mechanical arrangement for course tuning was available to tune the resonator frequency at 97.000 MHz. At a resonance frequency of 96.920 MHz, piezoelectric was kept at + 40 Volts to keep the phase error signal equal to zero by adjusting the reference of the P-I control. Then the control of phase and amplitude was put in close loop. It was observed that for both, large and small variation of resonance frequency from its central value, the piezoelectric voltage was kept on varying between a few volts to tens of volts. When the cryostat was banged to generate large vibrations, the resonator's frequency started fluctuating widely (>100 Hz), the controller drew lot of power (>250-300 watts) from RF amplifier and eventually the phase lock was broken. But within 5–10 seconds, the lock was recaptured with the help of piezoelectric tuner. During this extreme operation, the output from the high voltage amplifier to the piezoelectric actuator had gone up to a few tens of volts. The stability of the lock was observed for an hour at a moderate accelerating field of 2.2 MV/m. The amplitude and phase lock stabilities were measured to be 0.1% and ±0.4 degree respectively at this field level. The resonator was locked at 3.0 MV/m for a short duration, but due to lack of time, stability test at this field could not be accomplished for longer period.

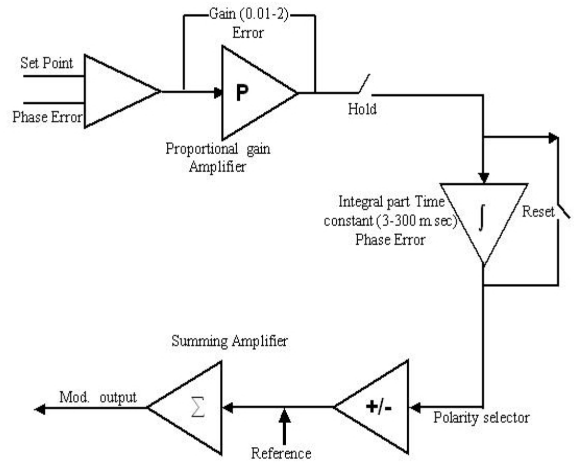

Figure 7: Block diagram of P-I control of piezoelectric actuator.

CONCLUSION

Piezoelectric actuator based control scheme was demonstrated successfully to lock the phase and amplitude of the superconducting resonators of IUAC. A mechanical tuning mechanism with the piezoelectric actuator is under construction and will be tested along with the piezoelectric and the fast tuner in future. The mechanical tuning scheme, if required, can be integrated in the closed loop. After successful test of the new tuning and locking mechanism, it will be implemented on the resonators in all the resonators of linac.

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REFERENCES

[1] S. Ghosh et al, Proc of tenth European Particle Accelerator Conference held during 23-27 June 2008 in Genoa Italy, page – 856.
[2] A. Roy, Proc. of this conference, TH202
[3] G. Joshi et al. Pramana, J. of Physics, Vol. 59, No.6, Dec 2002, page – 1035
[4] PI system product catalogue, http://www.pi.ws