PHASE LOCKING OF SUPERCONDUCTING QUARTER WAVE RESONATOR BY PIEZOELECTRIC ACTUATOR

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Abstract

The existing phase locking scheme of the quarter wave resonators(QWR) in the first operational module of the superconducting heavy ion linear accelerator of Inter University Accelerator Centre consists of a fast (electronic) and a slow time scale control. Presently, helium gas operated mechanical tuners are being used. They turn out to be complicated, somewhat unreliable and expensive for long term operation of the linac. In an alternate scheme to handle the slow time part of the phase control, the tuner plate is deflected by using a combination of a stepper motor for coarse adjustment and a piezoelectric actuator for fine adjustment of the frequency. During a recent cold test of a QWR the fundamental frequency of the QWR was brought to 97.000 MHz by the mechanical coarse tuner. The resonator was then locked at a field of 3.8 MV/m at 6 W of helium power and 40 W of forward power from the RF amplifier using the resonator controller along with the piezoelectric tuner.

INTRODUCTION

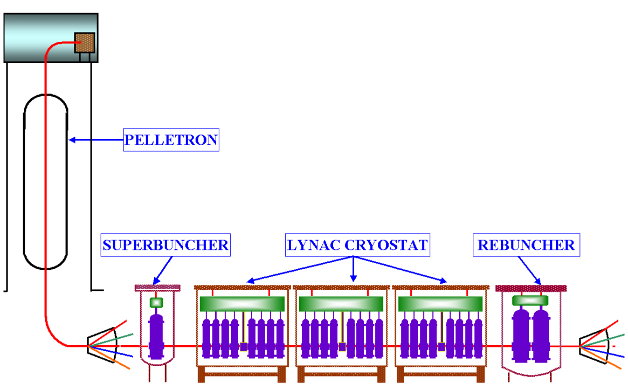

Figure 1: Schematic of IUAC Linac booster module.

The commissioning of superconducting linac boosters for increasing the energy of heavy ions from the Pelletron accelerator at Inter-University Accelerator Centre (IUAC), New Delhi is nearing completion. One module with eight cavities along with superbuncher consisting of single cavity and rebuncher consisting of two cavities have been operated for beam acceleration [1]. Accelerating fields of the resonators obtained in the linac cryostat are in the range of 3 –5 MV/m at 6 watts of dissipated power at critically coupled condition of the power coupler. The Linac control scheme [2] consists of a local RF control system for each individual resonator along with the RF Amplifier. The requirement of local RF control of the resonator is to keep the phase and amplitude of RF fields of the resonator constant with respect to the master oscillator. The fluctuation of resonant frequency acts as the main disturbance to the stabilization process. This fluctuation occurs in two time scales, the fast component occurs in a scale of less than a millisecond while the slow component occurs in tens of milliseconds to seconds range. In the fast tuner section, the resonator is made to operate in the self excited loop (SEL) [3]. Phase stabilisation with reference to the master oscillator is accomplished by adding a signal in quadrature with the loop signal which is controlled by the phase error between the self excited loop and the phase reference [4]. The slow-tuner control mechanism has been incorporated along with this fast tuner to keep the average of the resonator frequency same as that of the master clock.

SLOW TUNER MECHANISM FOR THE RESONATORS

The slow-tuner consists of a niobium bellows attached to the high voltage end of the resonator which can be moved by a few mm to tune the frequency of the resonators as shown in Figure 2. At present, a mass flow control for helium gas is being used to incorporate the movement of the niobium bellows by flexing SS bellows attached to the niobium bellows.

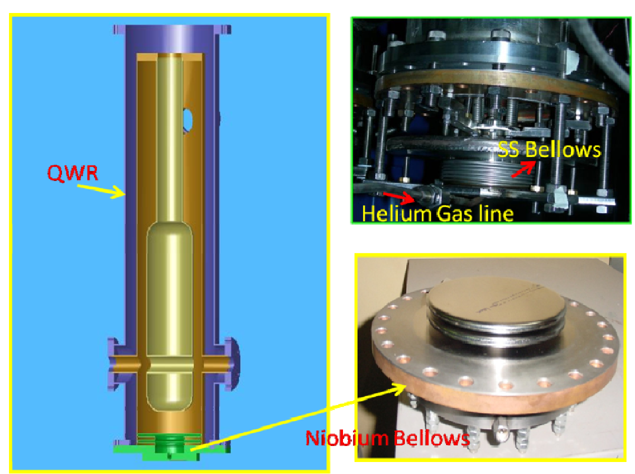

Figure: 2: Slow-tuner mechanism of IUAC QWR.

During operation, the slow-tuning scheme operates in a feedback loop to take care of the slow drifts in frequency and also to reduce the load on the fast tuner. Since this tuning mechanism uses a proportional helium gas flow through narrow tubes, the process takes place in the time scale of seconds. Hence the mechanical tuners are often being called as slow tuners and this operation requires continuous supply of high purity helium gas. Since helium gas flexes the bellows at liquid helium temperature, utmost care is required to avoid any possibility of conterminous choking the gas line. As an alternate plan to operate mechanical tuner, we have used a piezoelectric actuator directly coupled with the niobium bellows. This will be operated along with the electronic fast tuner.

TESTING OF PIEZOELECTRIC ACTUATOR BASED TUNER

The whole assembly of slow-tuner bellow along with piezoelectric actuator is connected to a QWR as shown below in Fig. 3.

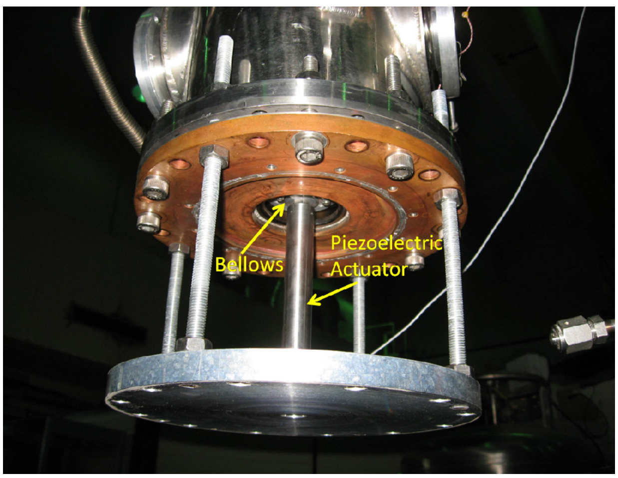

Figure 3: Slow-tuner with piezoelectric actuator.

The frequency of the resonator is tested with the slow-tuner and piezoelectric assembly by applying bias to the piezoelectric actuator at room temperature and also at liquid nitrogen temperature. The piezoelectric actuator of Physik Instrumente (PI) is used for this test. During an earlier test we successfully demonstrated the use of the same piezoelectric actuator in closed loop to keep the resonator phase and amplitude locked along with the fast tuner [5]. In that test, we had successfully demonstrated the piezoelectric actuator based control scheme for superconducting quarter wave resonators but were not able to lock the resonators at a higher field gradient for longer duration. In order to achieve this dynamics of the control scheme, some improvements are incorporated to make it more effective for phase locking the resonators at higher field gradient. In the same test, tuning frequency range of the piezoelectric actuator was found to be 626 Hz. Since this range was not always sufficient to bring the resonator to the master frequency of 97.000 MHz, a coarse tuning mechanism is needed to bring the resonators close to the required master oscillator frequency. In the newly developed movement mechanism explained in Fig. 4, the piezoelectric actuator is connected by a lever arm and a rotating shaft is connected from outside the cryostat to move the lever arm up/down. When the shaft is rotated either in clockwise or anti clockwise direction, the lever arm along with the piezoelectric actuator pushes or pulls the niobium bellows acting as the mechanical tuner and bringing the resonance frequency of the QWR nominally close to 97.000 MHz at liquid helium temperature.

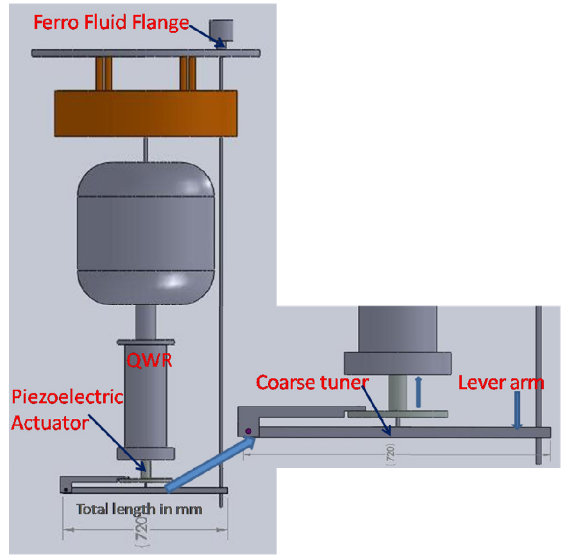

Figure 4: Design of the installed mechanical tuner with piezoelectric actuator.

Piezoelectric Actuator Assembly and Test Result of Coarse Tuner at Room Temp

First it was decided to test the tuning range of the mechanical coarse tuner at room temperature without powering the piezoelectric actuator. The piezoelectric actuator together with the mechanical fixture was mounted on a slow tuner bellow as shown in the Figure.5. The coarse tuning shaft was rotated clockwise from top to measure one end point for frequency range. Then the coarse tuning shaft was rotated anticlockwise from top to get the other extreme frequency range. The frequency range of the mechanical coarse tuner at room temp was measured to be 146.7 kHz. Then the piezoelectric actuator was powered with HV piezoelectric supply and the range of tuning by piezoelectric actuator alone was measured. The frequency range at room temperature was measured to be 4.05 KHz. The whole assembly is shown below in Fig. 5. The assembly was loaded in test cryostat to test phase locking performance of a superconducting cavity.

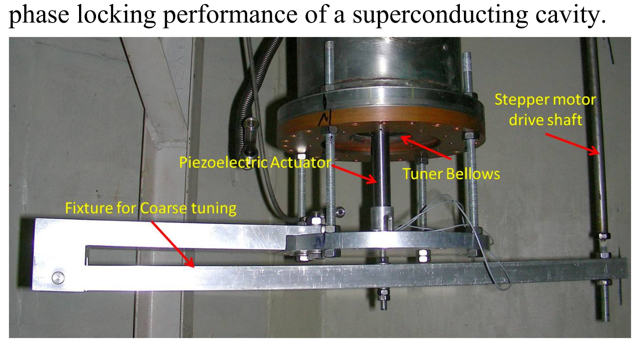

Figure 5: The coarse tuning arrangement with piezoelectric actuator.

PHASE LOCKING OF SC RESONATOR WITH MECHANICAL TUNER AND PIEZOELECTRIC ACTUATOR

To test the phase and amplitude stability of a superconducting resonator with piezoelectric actuator along with the mechanical coarse tuner, previous scheme of phase locking [5] was followed to optimize the electronics. The entire phase locking scheme is shown below in Figure 6.

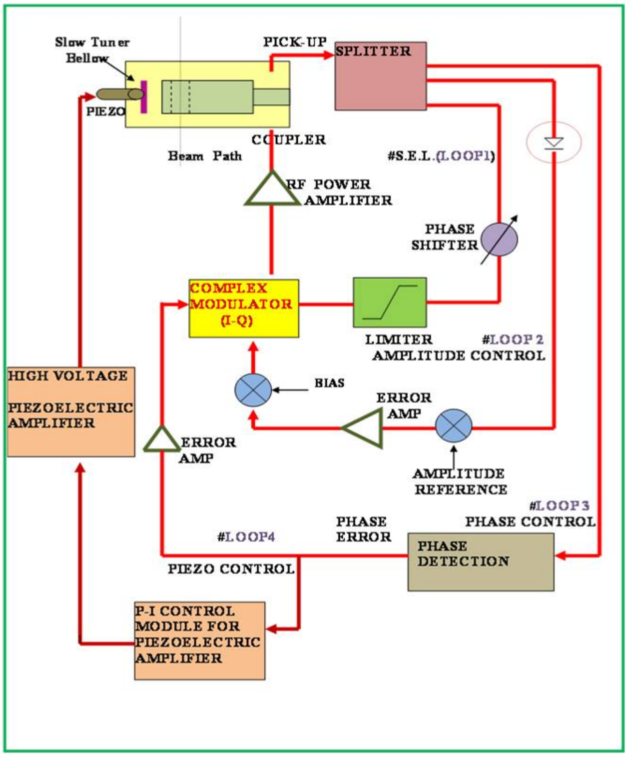

Figure 6: Block Diagram of the Closed Control loop.

Test Result without Coarse Tuner

The Resonator was set up at a moderate field of 3.25 MV/m with 60 Watt of Quiescent power from the RF amplifier with the drive coupler in over coupled mode. The amplitude of the superconducting resonator was locked with resonator controller. As the resonator frequency was found to be 97.048MHz, the frequency of the reference signal generator was changed to within 600 Hz of the resonator frequency with the tuning range of the piezoelectric tuner being 990Hz. The frequency of the resonator was made equal to the master frequency by adjusting the piezoelectric bias control reference value in the summing amplifier. The phase error signal was modified to feed the input of the piezoelectric PI control unit. The cavity was phase locked and the modified phase error was given to the input of P-I control unit. The output of the P-I control unit was given to the modulation input of the high voltage piezoelectric amplifier and the variable piezoelectric actuator voltage was able to control the slow drift of the resonator frequency successfully. The phase error observed was minimized by optimizing the time constant as ~ 100 msec. The lock was found to be quite stable and captured with a large disturbance in the cryostat caused by intentional banging.

Test Result with Coarse Tuner

With the same parameters as above conditions, the cavity was unlocked intentionally and the coarse tuner was operated to bring the frequency from 97.047884 MHz to 97.00350 MHz. After the coarse tuning the piezoelectric capacitance was discharged using a 100K resistor to avoid any voltage development across the piezoelectric element due to change of mechanical movement. Now piezoelectric actuator is biased to bring the frequency at 97.000MHz. The position of drive coupler of the resonator was fine tuned to minimize the power requirement at a given field level. The phase and amplitude of the cavity was locked at different field levels with the following parameters listed in Table 1 with piezoelectric actuator operating in closed loop. Stability of the lock was observed for more than an hour.

Table 1: Phase Locking Stability Specifications

Field Level	Phase Error	Amplitude Error	RF Amplifier Power (Max.)
3.84MV/m	0.15^0	0.03%	40 Watt
3.95MV/m	0.2^0	0.03 %	60 Watt

CONCLUSION

Piezoelectric actuator based control scheme along with the mechanical coarse tuner for superconducting quarter wave resonators is developed and tested successfully. The dynamics of this control scheme has been improved to make it more effective for locking the resonators at higher field gradient. With Stepper motor based coarse tuning and piezoelectric based fine tuning we will be able to use it for phase locking of superconducting QWRs in linac cryostat.

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REFERENCES

[1] A. Rai, et al, Proceddings of 14th International conference on SRF, Sept. 20-25 2009, Berlin, Germany.

[2] B.K.Sahu et al., Proceedings of Indian Particle Accelerator Conference 10-13 February 2009, RRCAT,Indore, India.

[3] J. R. Delayen, Ph. D. Thesis, California Institute of Technology, 1978

[4] G.Joshi, C.I.Sujo, B.K.Sahu, A. Pandey, A.Kumar B.P. and J.Karande, Paramana – Journal of Physics, Vol 59, No. 6, December 2002, page 1035-1040.

[5] B.K.Sahu, et al, Proceedings of Linac2008, Sep29-Oct3 2008, British Columbia, Canada.