PIEZOELECTRIC ACTUATOR BASED PHASE LOCKING SYSTEM FOR IUAC LINAC

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Abstract

The linac of IUAC consists of five cryostats having a superbuncher(SB), three accelerating modules, having eight quarter wave resonators (QWR) each, and a rebuncher(RB). At present SB, two accelerating modules and RB are operational and testing of the last linac module is being carried out. In the operational linac modules the phase locking is achieved by a combination of fast I-Q based electronic tuner and helium gas flow based mechanical tuner. Microphonics measurement on the resonators confirms the presence of low frequency vibrations along with main mechanical mode of the resonator. The existing gas flow based mechanical tuner working in the time scale of seconds can't arrest these vibrations, In a parallel development we have tested a piezoelectric actuator based fast tuner operating in the time scale of milli seconds. The test results showed that the piezoelectric based tuner can arrest all low frequency vibrations and reduce a substantial load from the electronic tuner to improve the dynamics of the phase locking scheme. The implementation of this scheme along with test result is presented in this paper.

INTRODUCTION

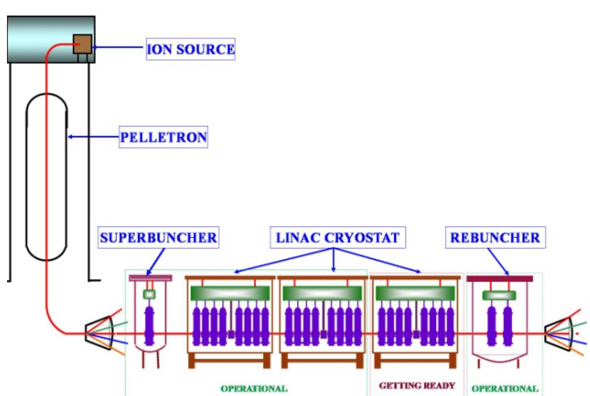

Figure 1: The schematic of IUAC linac.

At Present, the first two accelerating modules of IUAC superconducting (SC) linear accelerator (linac) are operational with superbuncher and rebuncher to provide accelerated heavy ion beams to conduct experiments in nuclear physics and materials science [1]. The third linac module is almost ready for beam acceleration. Each module has eight SC niobium Quarter Wave Resonators (QWR) operating at a resonance frequency of 97MHz and are independently phase locked with the master oscillator. The phase locking of the SC QWR consists of fast I-Q based dynamic phase control along with the helium gas flow based mechanical tuner [2]. The vibration related fluctuations around master frequency (microphonics) are mainly controlled by the fast I-Q based electronic tuner and the slow drifts of the central frequency are arrested by closed loop helium gas flow based mechanical tuner, to reduce the load on the electronic tuner. The gas flow based tuner operates in the time scale of seconds. Thus it can control frequency drifts less than a Hz. All the faster component of frequency jitter put an extra load on the electronic tuning mechanism of the resonator. An alternate piezoelectric actuator based tuner along with stepper motor based coarse tuner is successfully developed and tested with one of the QWRs in the test cryostat [3].

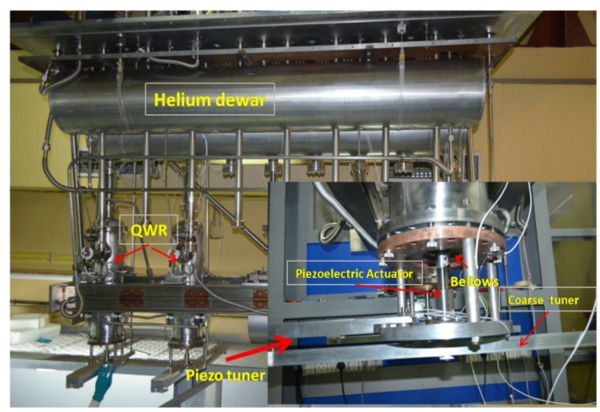

Figure 2: The piezoelectric actuator based mechanical tuner in third linac cryo module along with close view.

The stepper motor based coarse tuner brings frequency close to the master frequency and then the control is given to the piezoelectric actuator based tuner. The piezoelectric tuner operates in the time scale of tens of milli seconds and thus takes considerable load away from the fast tuner to reduce the average power during operation. After the successful operation of piezoelectric based tuner in test cryostat it is decided to optimise the tuner performance for linac operation and the new piezoelectric actuator based mechanical tuners are installed in two of the resonators in third linac module. The control scheme is tested with conditions similar to actual operation.

ISBN 978-3-95450-122-9

MEASUREMENT OF MICROPHONICS OF QWRS DURING LINAC OPERATION

External vibrations caused by vacuum pumps and pressure changes of the helium bath are coupled to the resonator and they may excite any natural resonance frequency associated with this resonator. This phenomenon produces to a jitter in the resonance frequency of a resonator and known as microphonics. The amount and nature of microphonics will determine the achievable field stability and also the required amount of control to be shared between electronic tuner and piezoelectric based mechanical tuner. To reduce this frequency jitter by damping the main mechanical mode an unique vibration damper using ordinary SS balls have been used in our resonators with great success[4]. Microphonics measurements have been performed on the resonators of first and second linac module cooled at liquid helium temperature in the closed loop cryogenic operational mode. Existing resonator control electronics used to lock the cavity field to an external master oscillator with the help of self-excited loop (SEL) and separate feedback loops to lock both the phase and amplitude of the resonator. The control electronics have been used to stabilize the phase and amplitude of the accelerating field of a superconducting resonator using RF power from the 400 Watt RF amplifier.

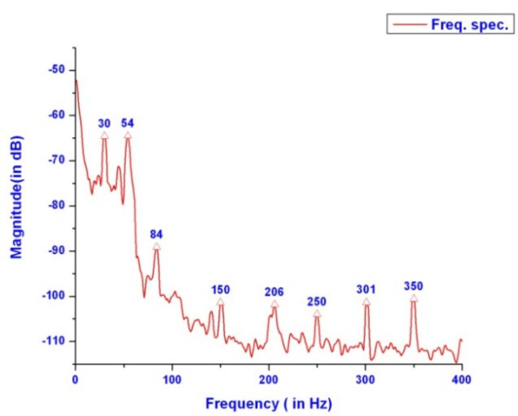

Figure 3: All the resonant modes of the resonator in linac cryostat.

The probability for cavity eigen frequency shift due to microphonics is measured using Agilent signal analyser model 35670A. The total frequency spectrum of the vibrations a resonator is shown in figure 3. It is observed from figure 3 that most of the microphonics is caused by internal mechanical resonances in the frequency range of 1Hz to 100Hz where as higher order modes up to 400 Hz are also present with much reduced amplitude. The main mechanical mode of the resonator is 54 Hz in this resonator and around 60 Hz in most of the resonators. During measurement of microphonics some low frequency vibration less than 30 Hz is also observed in some of the resonators.

CHARACTERISATION OF PIEZOELECTRIC ACTUATOR BASED MECHANICAL TUNER FOR OPERATION

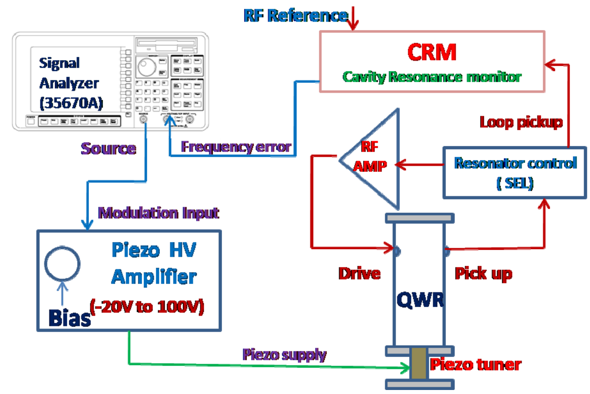

Figure 4: Set up for measurement of frequency response or piezoelectric based mechanical tuner.

The dynamics of the piezoelectric actuator based tuner is optimised to implement on the resonators of the linac cryostat after proper characterisation of the overall system with the piezoelectric mechanical tuner. The dynamic characteristics of the final piezoelectric actuator with attached bellows for the resonator are studied extensively at cold temperature using SEL to understand the different resonant modes of the system. Figure.4 shows the set-up for the measurement of the transfer function between the piezoelectric amplifier input and the frequency range of the resonator around the mean centre frequency. To measure the frequency response of the piezoelectric actuator based mechanical system a periodic chirp signal from the source of the signal analyser in the frequency range of 1 to 400 Hz.

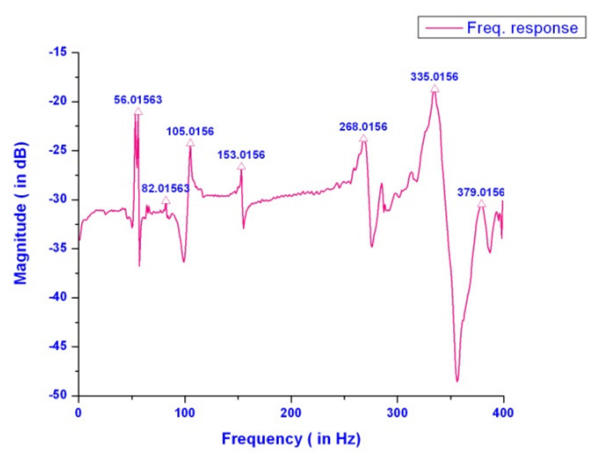

Figure 5: Frequency response of the piezoelectric tuner.

Since the periodic chirp provides an equal amount of energy at all the frequencies within the span, the measurement covers all the resonant modes of the system. The same resonant modes are also verified by using swept sine analysis of the analyser. The various resonant modes are shown in Figure. 5. The DC bias of the piezoelectric amplifier is varied to obtain the transfer function. The first resonant mode is found to be the main mechanical mode of the resonator. The response time of the system is also studied by applying a step function of 10 msec. Based on the results we have concluded that the closed loop system can be safely operated around 10 msec.

CLOSED LOOP OPERATION OF PIEZOELECTRIC ACTUATOR TO PHASE LOCK LINAC RESONATOR

The superconducting resonator frequency is first brought close to the master oscillator by operating the coarse tuner. The piezoelectric bias voltage is kept at a mid voltage range to have maximum closed loop dynamic range in both the direction. The Resonator is first phase locked using the dynamic phase control loop. The phase error of the resonator controller is processed in a dedicated PI based control to compensate the frequency drift around the central frequency of the resonator and to 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.

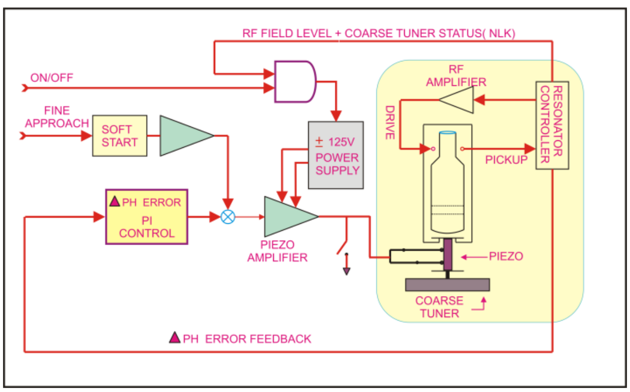

Figure 6: Block diagram of Piezoelectric close loop control scheme.

The electronics for the closed loop control is designed in house. The control consists of a high voltage amplifier along with P-I based closed loop control and necessary safety interlocks. In the existing resonator control electronics, the phase error calibration is set for ~ 5mV for 1 Hz change in frequency whereas the high voltage amplifier for the piezoelectric actuator need to supply ~125mv to correct 1Hz frequency drift from the master. Hence the DC gain of the loop was decided and 3 dB bandwidth of the control loop was optimised at 16 Hz with unity gain at 32 Hz. The total phase margin for control was 80 degree. During the test, the overall locking performance was found to be satisfactory. The proportional gain and integration time constant was optimised to have a correction of +/- 80 Hz variation in the central frequency within 12 milli second time scale. The stability of the lock was found to be good and the average power for locking was reduced drastically with piezoelectric actuator taking away a substantial load from the fast tuner. It was observed that for both, large and small variation of resonance frequency from its central value, the piezoelectric voltage was kept on varying at the same rate to correct the variation. When a large mechanical vibration was coupled intentionally with the resonator the resonator's frequency started fluctuating widely (~160 Hz), but the controller was able to hold the lock with increase in forward power momentarily. The total range of the piezoelectric actuator based tuner is found to be 990 Hz along with coarse tuner range of 42 kHz for this particular set of resonator and mechanical tuner. The stability of the lock was observed for a few hours at an accelerating field of 3.8 MV/m. The amplitude and phase lock stabilities were measured to be 0.1% and ±0.2 degree respectively at this field level.

CONCLUSION

Piezoelectric actuator based control scheme is successfully implemented in a resonator in third linac cryostat. It is found to improve the phase locking performance. The mechanical coarse tuning mechanism with the piezoelectric actuator also performed well and we are in the process of replacing the ferrofluid based coarse movement with linear motion feed through for ease of coarse operation. We are planning to use piezoelectric based tuners in four of the resonators installed in linac-3 along with existing gas flow based tuners in the other four to have detailed operational statistics. Piezoelectric tuners will be installed on all the other linac resonators in place of gas operated mechanical tuners.

ACKNOWLEDGEMENT

Authors would like to acknowledge the help and cooperation received from the cryogenic group and resonator fabrication group of IUAC. The authors acknowledge the technical help and suggestion received from Mr. Gopal Joshi and S. Khole of Electronics Division, BARC during testing.

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