DEVELOPMENT AND OPERATIONAL ASPECTS OF Nb QWR BASED HEAVY ION LINAC SYSTEM AT IUAC DELHI

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Abstract

The superconducting linac of IUAC consists of five cryostats containing 27 niobium quarter wave resonators. Since last few years, energized ion beams from linac are being delivered routinely for scheduled experiments. In a recently concluded linac operation, all the resonators installed in the five cryostats were used in the acceleration and delivery of the ion beam on the target with an energy gain of 8 MeV/q and a time width of ~ 180 ps. Recently, an improved mechanical damping mechanism has been implemented and piezo actuator based tuning mechanism have replaced the gas based tuner of most of the resonators. Other new developments e.g. automatic phase locking of the resonators and auto beam tuning of the complete linac are being currently pursued.

INTRODUCTION

The project of superconducting (SC) linac of Inter University Accelerator Centre (IUAC) started in collaboration with Argonne National Laboratory (ANL) and first twelve quarter wave resonators (QWR) along with the prototype resonators were built at ANL [1]. Subsequently, the facilities to build SC QWR were developed at IUAC and the remaining resonators were fabricated in-house [2]. In figure 1, a schematic of the linac at IUAC is shown.

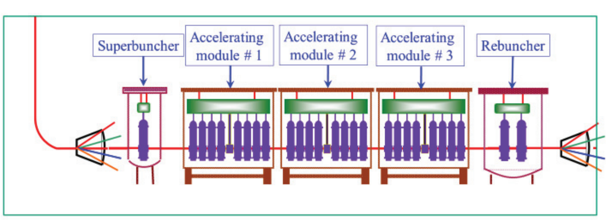

Figure 1: The schematic of SC linac of IUAC.

During the initial period of linac operation (2004-2007), multiple problems were faced. The major problems were to generate higher accelerating fields ($\geq$ 4 MV/m) and to phase lock the resonators at those fields with nominal RF power (~100-120 W). Due to the large stored energy in our QWR and presence of ambient microphonics in the cryostat, the power requirement to lock the resonators at higher fields has gone up to ~300 W, which caused serious operational problems in the past [3]. To tackle these problems, the buffer volume of liquid Helium at the top of the resonators was increased [3], SS-balls were used as the vibrational damper [4], and the non-coaxiality of the central conductor with respect to the outer niobium cylinder was corrected. Recently, piezo actuator has been used as the mechanical tuner [5]. The piezo-tuner seems to be a marvellous tool not only to correct the slow frequency drift more efficiently than the existing gas based tuner but also to damp the vibration of the mechanical tuner bellows reducing a particular mode of microphonics. All the recent improvements along with the latest results during the last linac operation are presented in this paper.

REMAINING FEW HURDLES IN LINAC OPERATION

During the last linac operation, out of 22 accelerating QWRs, the number of resonators achieving accelerating fields (at 6 W helium power) above 4 MV/m, between 3-4 MV/m, between 2-3MV/m and < 2 MV/m are 3, 15, 2 and 2 respectively. To improve the accelerating fields of the resonators, conventional routine procedures are applied on them. The QWRs have undergone more number of electropolishing cycles than usually required, their RF surfaces are cleaned with 18MΩ-cm de-ionized water in an ultrasonic cleaner and they are subjected to couple of hours of helium conditioning in addition to RF pulse conditioning.

Since last few years, efforts are dedicated to bridge the gap between the electric field achieved during Q-measurement at 6 W of helium power and during phase locking [6] of the SC resonator. The major reason behind the inability to phase lock a SC resonator with $\leq$ 120 watts (up to 120 W was proved to be safe for our system in long term operation) is the requirement of large stored energy [$0.11 J/(MV/m)^2$] and the presence of large amount of microphonic vibration coupled to the resonator. The vibration present in the cryostat ambience can contribute to different modes of vibration in the resonator, e.g. (a) the central conductor of the resonator can act as a pendulum and start vibrating at its own natural frequency of ~ 60 Hz, (b) the slow tuner bellows can vibrate at a frequency of ~ 30 Hz, (c) the thin sheet of all parts of the niobium resonator can vibrate at a frequency of a few Hz due to pressure fluctuation of liquid helium etc. In addition, some other higher order cryogenic excitation modes may also be present. All these vibration will contribute to an overall jitter in the central frequency of the resonator which subsequently requires more RF power to maintain the stable phase/amplitude lock. Our intention is to reduce the frequency jitter to the maximum possible extent.

Reduction of Vibrational Mode Contributed by the Central Conductor

To reduce the vibrational mode resonating at ~ 60 Hz, the co-axiality of the central conductor (CC) with respect to the niobium housing of all the resonators were checked and corrected [7]. Then an improved vibration damping mechanism has been adopted in all the indigenous QWRs built in-house. The details are given in the following:

Co-axiality of the central conductor with respect to the outer cylinder of the resonator

The central conductor (CC) which is not co-axial with respect to the outer cylinder produces larger frequency jitter as compared to the fully co-axial CC requiring more RF power (> 150 W) to stabilize the phase and amplitude of a SC QWR. In some of our QWRs, the deviation from co-axiality was measured between 2 to 5 mm at their open ends. To measure the effect of the co-axiality of the CC, the resonator, operated in self excited loop (SEL), was coupled to a fixed amount of external vibration. The Fast Fourier Transformation (FFT) of the frequency difference signal (Δf) between the resonator and a stable reference signal was obtained from the cavity resonance monitor and measured by the spectrum analyser (HP35670A). Figure 2 shows the large amount of reduction of the amplitude of vibration of a niobium resonator before and after making the central conductor more co-axial (from 5 mm to ±0.5mm).

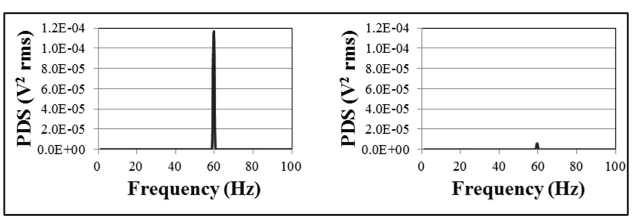

Figure 2: Fundamental mode of vibration in a resonator before (left) and after (right) making the central conductor more co-axial.

Experiments to improve the efficiency of the vibration damper by using SS-balls

In the past, the optimum number and diameter of the SS balls as vibration damper [4] were determined on the resonators fabricated in collaboration with ANL. Later, it was noticed that the surface finish of the inside portion of the end cap of the central conductor (where the SS-ball as vibrational damper rests) fabricated at ANL and the indigenously fabricated ones at IUAC were not identical. Therefore the mass, number and diameter of the SS balls required for efficient vibration damping needed to be optimized. So a new series of experiments at room temperature have been conducted to optimize the number and diameter of the SS balls for the indigenously built resonators. In the similar type of experiments [4], a constant vibration is coupled to the niobium resonator kept at room temperature and highly polished SS-balls with diameter varying from 1 mm to 12 mm were inserted inside the central conductor. In every occasion, the amplitude of fundamental vibration of the mode (~ 60 Hz) contributed from the oscillation of the central conductor is recorded. The optimum number and diameter necessary to efficiently damp this mode of vibration are found to be 35 and 8 mm respectively. The different modes of vibration from 0 to 100 Hz without and with the SS ball is shown in figure 3 which shows a drastic reduction of the vibrational mode around 60 Hz with the vibrational damper.

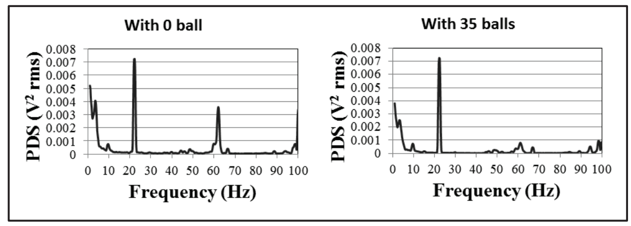

Figure 3: Damping of the vibrational mode of the resonator at liquid helium temperature originating from the oscillation of central conductor.

Piezo-Actuator as the Mechanical Tuner and the Reduction in the Vibrational Mode Contributed by the Bellows Tuner

The phase and amplitude lock of the SC QWR at IUAC is achieved with the help of electronic control and mechanical tuner. The slow drift of the resonance frequency is corrected by the mechanical tuner by using pure helium gas to flex the Niobium tuner bellows. As the response time of the helium based gas tuner was large (in second), a time lag between the resonant frequency deviation and its stabilization exists. This gives rise to a time dependent slow drift in the resonance frequency. The electronic control is implemented not only to stabilize the RF field against the microphonics but also to control this slow drift. In order to improve the dynamics of the existing control, an alternate scheme using piezoelectric actuator based tuner has been developed, tested and finally implemented on all the resonators in the 2^{nd} and 3^{rd} accelerating modules. The control scheme for piezoelectric actuator based control is designed to compensate the slow frequency drift around central frequency of the resonator and also to damp the low frequency eigen-mode excitations during operation. This reduces a substantial load from the dynamic phase control scheme. The output of the integral and Positive Position Feedback (PPF) controllers are combined to drive the piezoelectric actuator. There are several advantages of the piezo tuner over the gas based tuner as listed in the following:

(a) The integral part of the piezo-controller corrects the slow drift of the resonance frequency in faster time scale (in 100 millisecond range).

ISBN 978-3-95450-142-7

(b) The rigid structure of the piezo actuator acts as a vibration damper using the PPF control in the region of mechanical eigen mode frequencies of interest (figure 4).
(c) Piezo actuator based tuning mechanism doesn't need helium gas, so system becomes less expensive and simple for operation.

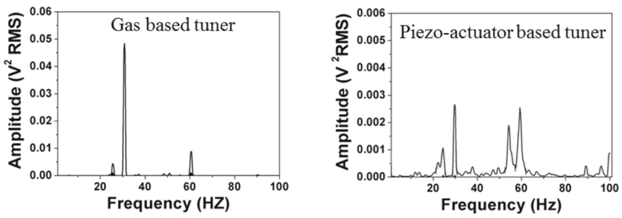

Figure 4: Microphonics damping by the Piezo actuator.

In the recent concluding test of SC linac, all 14 resonators with Piezo tuner had performed very well.

RESULTS OF RECENT BEAM ACCELERATION THROUGH LINAC

The SC linac of IUAC became operational with a single accelerating module in 2007 and accelerated ion beams were being delivered for scheduled experiments since 2008. Subsequently the remaining two accelerating modules were added and all the three modules including the superbuncher and rebuncher are now operational. However, the last accelerating module is still short of two resonators which will be installed soon. In the recent beam acceleration through linac, the fourteen resonators of linac-2 and 3 were equipped with improved vibrational damping mechanism, new piezo actuator based tuner and were made more co-axial (± 0.5mm). During this linac operation, for the first time at IUAC, all the QWRs installed in Superbuncher (SB), three accelerating modules and the Rebuncher (RB) took part in beam acceleration. The maximum energy gain from 22 accelerating resonators was measured to be ~ 8 MeV/q. The beam species along with the energy gain etc. are given in table-1.

Table 1: The beam species accelerated through Pelletron and SC linac

Beam species	Pelletron energy (MeV)	ΔT obtained by SB (ps)	Egain from LINAC (MeV)	Total energy (MeV)	ΔT obtained by RB (ps)
$^{48}Ti^{14+}$	162	160	113	275	185
$^{31}Si^{12+}$	130	117	91	221	RB not operated

FUTURE PLAN

Though the Piezo actuator based tuner worked successfully on all the QWRs of second and third module, due to space problem, the similar system couldn't be implemented on the QWRs in the first accelerating module.

To improve the dynamics of its gas based tuner system, an improved gas flow control system based on Pulse Width Modulator [8] is being developed and successfully tested on a few QWRs. This system will be implemented on all the QWRs of module-1 in near future.

An auto phase locking mechanism is tested successfully on a few SC resonators. It will be implemented in future on all the QWRs.

A couple of capacitive pick-up (CPU) will be installed at the exit of linac to measure the energy of the ion beam by 'time of flight' (TOF) technique. The TOF signal will be used to auto-energy tune the resonators in all three accelerating modules by adjusting the accelerating phases.

CONCLUSION

The superconducting linear accelerator of IUAC has been delivering ion beams since 2008. Recently the last remaining accelerating module with six resonators took part in the beam acceleration along with the other cryostats of linac. The total energy gain from linac and the final time width at target location was measured to be ~ 8 MeV/q and 185 ps respectively. After installing another two resonators in linac-3, improving the accelerating fields of some of the QWRs and phase locking them at the same fields obtained at 6 W of helium power, it is expected to improve the energy gain of the linac upto 12 MeV/q. Simultaneously, efforts are dedicated to improve the operational aspects of the linac to imrove the piezo actuator based tuner system, auto locking of the SC resonator and auto-energy tuning of the beam through linac using capacitive pick-up.

ACKNOWLEDGEMENT

The author would like to acknowledge the help received from the staff members of Pelletron group, beam transport group, RF & electronics group, MG-1 and MG-2 groups. The authors would like to thank Dr. Gopal Joshi, Electronic division, BARC, Mumbai for his help and support.

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