# COMPLETION OF THE SUPERCONDUCTING HEAVY ION LINAC AT INTER-UNIVERSITY ACCELERATOR CENTRE

A. Rai, R. Ahuja, J. Antony, S. Babu, J. Chacko, G.K. Chaudhari, A. Chaudhary, T.S. Datta, R.N. Dutt, S. Ghosh, R. Joshi, D. Kanjilal, S. Kar, J. Karmakar, R. Kumar, M. Kumar, D.S. Mathuria, R. Mehta, K.K. Mistri, A. Pandey, P. Patra, P.N. Prakash, A. Roy, J. Sacharias, B.K. Sahu, A. Sarkar, S.S.K Sonti, S.K. Suman

Inter-University Accelerator Centre (IUAC), Aruna Asaf Ali Marg, New Delhi – 110067, India.

*Abstract*

The Superconducting heavy ion Linac at Inter-University Accelerator Centre (IUAC), New Delhi has been delivering high energy ion beams to users since 2008 [1, 2]. Initially the first accelerating module, housing eight Quarter Wave Resonators (QWRs), became operational together with the Superbuncher having one QWR and the Rebuncher having two QWRs. In subsequent years, the remaining two modules have also been installed and commissioned. The complete Linac was operated recently and several ion beams were delivered for scheduled experiments. The maximum energy gain was 8 MeV per charge state. Operational highlights include, successful operation of four resonators in the third module with Piezo based [3] mechanical tuning, implementation of remote phase locking of all the resonators in the three modules [4], development of a scheme for auto locking of resonators and testing of a capacitive pickup as a beam diagnostic element. Details will be presented vis-à-vis the problems encountered and the future course of action.

## INTRODUCTION

The Superconducting heavy ion Linac at IUAC is designed to have three accelerating modules each housing eight Quarter Wave Resonators, a Superbuncher module having one and a Rebuncher module having two QWRs respectively. Beam delivery from the Linac for scheduled experiments started with the commissioning of the first module together with the Superbuncher and the Rebuncher. In subsequent years the second and third accelerating modules have been installed and commissioned. The QWRs installed in the first module are among the first batch of twelve resonators that were designed and fabricated at Argonne National Laboratory (ANL) [5, 6]. The second and third modules house the QWRs which have been fabricated indigenously using the facilities developed at IUAC [7]. Initial tests of the indigenous resonators in the test cryostat yielded poor results. Several steps were taken to overcome the problem [8]. These included electropolishing (EP) to remove an additional ~50 µm of niobium material, optimization of the EP procedure followed at IUAC and improvements in the post EP surface cleaning techniques. Subsequently, there was a considerable improvement in the performance of the resonators and they were installed in the second and third Linac modules.

Meanwhile, a substantial effort was put in making the entire system more reliable and easy to operate with minimal human intervention. Several new developments were done in this regard. These include, successful implementation of piezo actuator based mechanical tuning, remote phase locking of resonators, successful testing of a scheme for auto locking of resonators, installation and initial tests of a capacitive pickup as a non interceptive beam diagnostic element and improvements in the existing gas based mechanical tuning system in the resonators.

## LINAC OPERATION

In the recent Linac operation, which extended for a period ~2 ½ months, several beam species from the 15 UD Pelletron accelerator [9] were accelerated through the three Linac modules and delivered for user experiments. A total of twenty two resonators (eight each in the first and the second modules and six in the third module) were available for the operation, out of which nineteen could be phase locked and used for beam acceleration. Table 1 lists the different beams, the energy from the Pelletron, the time widths achieved at the Linac entrance, the energy gain from the Linac and the total beam energy at the target. Resonators in Rebuncher, though fully operational were not used since there was no requirement from the users for time/energy bunched beams at the target. The beam acceleration was done with -10º phase offset in the resonators to achieve higher energy gain.

Table 1: Beams accelerated through Linac

| Beam species | Pelletron energy (MeV) | ΔT @ Linac entrance (ps) | Egain from LINAC (MeV) | Total energy (MeV) |
|---|---|---|---|---|
| $^{48}Ti^{14+}$ | 162 | ~204 | 108 | 270 |
| | 162 | ~185 | 95 | 257 |
| $^{30}Si^{12+}$ | 112 | ~132 | 84 | 196 |
| $^{28}Si^{11+}$ | 124 | ~143 | 65 | 189 |
| $^{28}Si^{8+}$ | 110 | ~225 | 50 | 160 |
| $^{30}Si^{12+}$ | 100 | ~260 | 80 | 180 |




ISBN 978-3-95450-143-4

### *Highlights*

In the present Linac operation, beam was accelerated through the complete system for the first time. This included nineteen resonators in the three accelerating modules and the Superbuncher resonator. The overall performance of the system was quite stable in the sense that only one or two cavities got unlocked in a period of twenty four hours and minimal monitoring was needed once the beam was tuned on the target. Some of the major highlights have been listed below:

**Successful operation of piezo tuner:** After the encouraging results obtained in several offline tests with the piezo actuator based mechanical tuning arrangement [3], it was installed in four resonators in the third Linac module. Figure 1 shows the third module with the piezo tuner installed along with its exploded view in the inset.

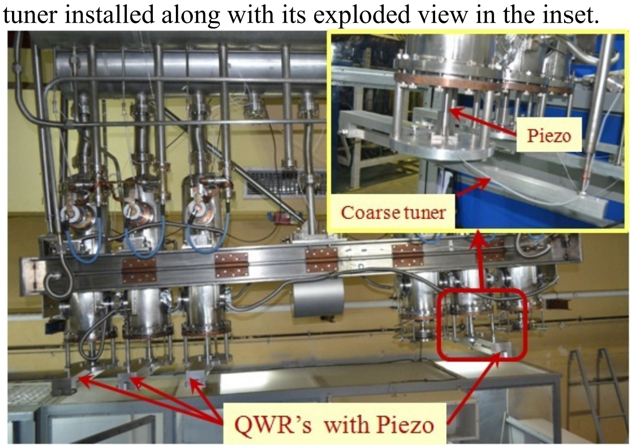


Figure 1: The third module with piezo tuner

During the operation, three out of four resonators could be phase locked and used for beam acceleration. The fourth resonator could not be used due to problems with its coarse tuning system. The performance of the piezo tuner was very satisfactory in that not only the phase locking process was easier as compared to the old helium gas based tuning system, but also the lock stability was greatly enhanced. Table 2 gives a comparison of the lock stability (measured in terms of the observed phase and amplitude jitters) for two cavities R33 and R36. R33 was phase locked with the helium gas based mechanical tuning system whereas R36 had the piezo for the mechanical tuner movement. Identical results were obtained with other cavities.

Table 2: Comparison of lock stabilities

| QWR | Field | Tuning | Phase jitter | Amp. jitter | RF power |
|---|---|---|---|---|---|
| R33 | 2.7 MV/m | Gas | 0.5° | 0.05% | 100-140 W |
| R36 | 3.7 MV/m | Piezo | 0.2° | 0.03% | 80-90 W |

**Remote phase locking of resonators:** The idea behind this development was to reduce the effort involved in running the system. The circuit [4] designed for this purpose uses MODBUS protocol over RS 485 interface. It works alongside the front panel controls of the mechanical tuner electronics and allows for a change in the resonance frequency of the resonator through CAMAC. After several rounds of initial tests it has now been implemented in all the Linac modules, the Superbuncher and the Rebuncher. During the Linac operation it worked satisfactorily and allowed the operator to phase lock the resonators from the control room. This helped in a smooth running of the system. It also led to substantial beam time savings.

### *Shortfalls*

**Low field levels in the second and third modules:** The average accelerating fields achieved in the second and third modules were 2.7 MV/m and 2.6 MV/m respectively @ 4 W of RF input power (load on the cryogenic system) which were quite low. Two possible reasons have been attributed to this poor performance. Firstly, the amount of niobium material removed from the RF surface in a few resonators (specially those which were installed in the Linac for the first time and have not been previously tested) through EP was not adequate and more EP is required to achieve the desired gradients. Secondly, the active RF surface of some resonators (specially those that have been previously tested and yielded better results) got contaminated and needs more cleaning. This could be simply an ultrasonic rinse followed by a high pressure rinse or a light etch followed by an ultrasonic and a high pressure rinse. A possible source of contamination might be the process of making the central conductor coaxial with the outer housing for all the resonators of both the modules. In this procedure [10] the gap between the central conductor and the outer hosing of the QWR was measured (Figure 2a) by inserting a micrometer at various points along the circumference. A special fixture was designed to push the central conductor (Figure 2b) in the appropriate directions to force it coaxial with the outer housing (Figure 2c).


(a) (b) (c)

Figure 2: Making the central conductor co-axial.

The aim of the whole exercise was to reduce the effect of microphonics in the resonator. Power spectrum measurements of the mechanical modes of the resonator done before and after the process indicated that the amplitude of the main mode was reduced by a factor of ~10.

**Heavy cryogenic load from a few resonators:** It was observed that when a few resonators (R25 & R28) in the second Linac module were phase locked during beam acceleration, there was a substantial increase in the heat load on the liquid helium system. Cryogenic load measurements indicated a heat load of ~105 W from a


ISBN 978-3-95450-143-4

single cavity (R25) operating at ~3 MV/m. It was thought that these resonators were getting severely loaded with field emission due to which the extra power going in to the liquid helium was being used up in generation of field emission electrons. Figure 3 shows results of X-ray measurements done in the vicinity of one of these resonators (R25). The results corroborate the field emission effect and it has been decided to give high pressure rinse to all the resonators to reduce field emission.

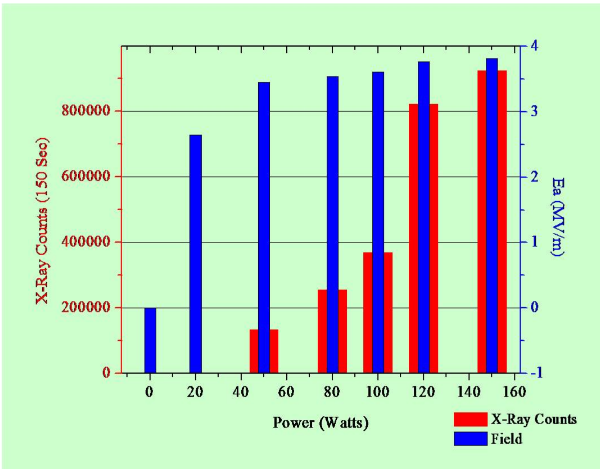


Figure 3: X-Ray measurements for R25 resonator.

## PLANNED IMPROVEMENTS

With the successful operation of the entire system the Superconducting Linac project at IUAC draws to a close. Efforts are now being made to improve the resonator performances and to make the operation smooth and operator friendly. A high pressure rinsing facility is being developed in a class 100 clean room for the final cleaning and assembly of the resonators. After the successful operation with piezo based tuning system, more piezo actuators have been procured for installation in all the resonators of the second and third modules. The electronics for the same is being developed in-house. Since the piezo cannot be installed in the first module due to space constraints inside the cryostat, these resonators will continue to operate with helium gas based tuning system. The existing array of proportional and solenoid valves in the pressure and vacuum circuits of the mechanical tuner bellow will be replaced with better quality proportional valves which have a nearly linear response over the whole operating range. These valves will now be operated in pulsed mode with suitable changes in the control electronics. Initial tests of the modified control electronics of the mechanical tuner, performed in the test cryostat, have yielded positive results [11]. More tests will be done to fine tune the electronics before it is implemented in the Linac.

To reduce human intervention in system operation, an auto phase locking technique is being developed wherein a digital circuit tracks the instantaneous resonance frequency of the resonator and operates the mechanical tuner accordingly to bring it close to the reference frequency. Thereafter the phase feedback is switched on automatically. After tuning the circuit in actual running conditions in the Linac the implementation work in the first module has been initiated.

The possibility of non interceptive beam energy measurements by using capacitive pickups is also being explored. For this purpose a custom designed probe (suitable for the beam currents and energies available at IUAC) has been procured together with the electronics for signal processing. This was installed in the Linac beam line and tested during the Linac operation. It qualified the first stage of tests. A reasonably clean signal could be achieved for beam currents of the order of ~3 nA. It also provided reliable information of the beam arrival phase. In the next step an identical probe will be mounted at a known distance from the first one and beam energy information will be extracted by setting up a Time of Flight (TOF) between the two devices. The TOF signal can also be used for the automation of the Linac tuning procedure.

## ACKNOLEDGEMENTS

The authors would like to acknowledge the help and support received from the Pelletron, RF Electronics, Vacuum, Beam transport, Electrical and Mechanical groups of IUAC. The help received from Mr. Akhil Jhingan with the data acquisition setup during the Linac operation is highly appreciated.

## REFERENCES

[1] S. Ghosh et. al., Physical Review Special Topic – Accelerator and Beams, 12, 040101 (2009).
[2] A. Rai et. al., Proc. of 14th International Conference on RF Superconductivity SRF 2009, September 20-25 2009, Berlin, Germany, page 244.
[3] B.K.Sahu et. al., Proc. of International Particle Accelerator Conference IPAC 2010, Kyoto Japan, page 2920.
[4] R.N.Dutt et. al., Proc. of Indian Particle Accelerator Conference InPAC 2011, Feb 15-18, 2011, New Delhi, India.
[5] K.W. Shepard, A.Roy and P.N.Potukuchi, Proc. of the 1997 Particle Accelerator Conference, May 12-16, 1997, Vancouver, BC, Canada, page 3072.
[6] P.N.Potukuchi, S. Ghosh and K.W. Shepard, Proc. of the 1999 Particle Accelerator Conference, New York, USA, page 952.
[7] P.N. Prakash, 14th International Conference on RF Superconductivity SRF 2009, September 20-25 2009, Berlin, Germany, page 502.
[8] A. Rai et. al, Proc. of Indian Particle Accelerator Conference InPAC 2011, Feb 15-18, 2011, New Delhi, India.
[9] D. Kanjilal et al, Nucl. Instr. And Meth. A328 (1993), 97-100.
[10] P. Patra et. al., to be published in the Proc. of Indian Particle Accelerator Conference InPAC 2013, Nov 19-22, 2013, Kolkata, India.
[11] A. Pandey et. al., Proc. of this Conference.


ISBN 978-3-95450-143-4