# SUPERCONDUCTING LINAC AND ASSOCIATED DEVELOPMENTS AT IUAC DELHI

A. Roy, Inter-University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi – 110067, India

*Abstract*

A superconducting linear accelerator system has been developed as a booster of heavy ion beams available from the existing 15UD Pelletron accelerator. Two linac modules having eight niobium quarter wave resonators (QWRs) each have been installed and are fully operational for regular scheduled experiments. The third module is being added to the system. A new high current injector has been planned to couple to the superconducting linac. For this a high temperature superconducting electron cyclotron resonance ion source (HTS-ECRIS) was designed, fabricated and installed successfully. A radio frequency quadrupole (RFQ) accelerator is being developed for accelerating accelerate ions from the ECR (A/Q ~ 6) to an energy to of about 180 keV/A. The beams will then be accelerated further by drift tube linacs (DTL) to the required velocity to inject them to the existing superconducting linac booster. Prototypes of both these have been tested for power and thermal studies. Details of these developments and associated systems are presented in this paper.

## INTRODUCTION

A superconducting linac boosters for increasing the energy of heavy ions from the Pelletron accelerator at Inter-University Accelerator Centre (IUAC), New Delhi is in operation for the past four years [1,2,3]. Heavy ions from the 15 UD Pelletron Accelerator have been accelerated through two modules, each with eight Nb quarter wave cavity resonators and used for many experiments in Nuclear Physics and Materials Science. The third module is in the process of installation and testing. The layout of the accelerator is shown in figure 1.

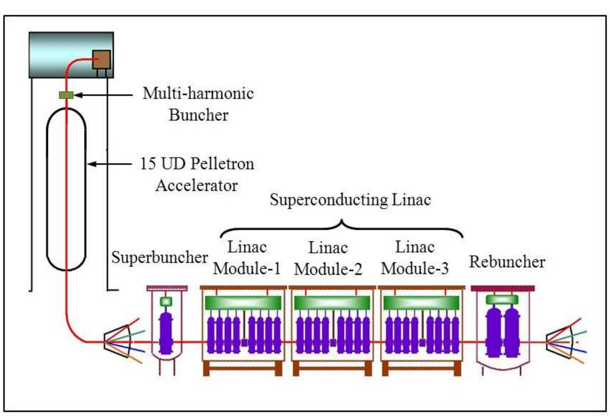


Figure 1: Sketch of the Pelletron – Linac accelerator system at IUAC, New Delhi.

Improvements were made in cooling the drive couplers of the resonators and an alternate frequency tuning mechanism based on piezo tuners has been developed. The novel method of reducing the microphonic noise in the cavity using steel balls to reduce the power required to amplitude and phase lock the cavities has been improved further. Automation of the phase tuning of the resonators was successfully tested out.

The High Current Injector planned to increase the ion flux has been designed and prototype of a suitable low beta Nb resonator with $\beta = 0.05$ has been fabricated. Prototypes of room temperature radio frequency quadrupole and drift tube linac have been built and tested for design validation.

IUAC is fabricating two $\beta = 0.22$, 325 MHz Single Spoke Resonators for the Project X of Fermi National Accelerator Lab (FNAL), USA. Several single cell 1.3 GHz TESLA type cavities and a 5-Cell cavity have been built in collaboration with RRCAT, Indore.

## SUPERCONDUCTING LINAC

The complete linear accelerator (Linac) of Inter University Accelerator Centre (IUAC) will consist of five cryostats, the first one acting as superbuncher (SB) consists of a single quarter wave resonator (QWR), the next three linac cryomodules house eight QWRs each, and the last one has two QWRs used as rebuncher (RB).

In recent past, with the help of superbuncher, the first linac accelerating module and the rebuncher, Pelletron ion beams from $^{12}C$ to $^{107}Ag$ were further accelerated and delivered to conduct experiments in Nuclear Physics and Material Science. In 2011 another eight niobium resonators were installed in the linac cryostat-2 and a couple of off-line cold tests were conducted followed by beam acceleration through linac without the last accelerating module. During the beam acceleration, all sixteen resonators of cryostat 1 and 2 took part along with the single resonator operated each in superbuncher and rebuncher cryostat. During this entire period of beam acceleration extending for more than a month, three different beam species: $^{19}F$, $^{28}Si$ and $^{31}P$ were accelerated and beam was delivered in the beam line of HYRA (Hybrid Recoil mass Analyzer) and NAND (National Array of Neutron Detectors). The results of the beam acceleration, in brief, are given in Table 1.

Copyright © 2012 by the respective authors — cc Creative Commons Attribution 3.0 (CC BY 3.0)


ISBN 978-3-95450-122-9

Table 1: The Beam Species and Their Total Energies Delivered for Experiments

| Beam | Pell. energy (MeV) | Linac energy gain (MeV) | Total energy (MeV) |
|---|---|---|---|
| $^{19}F^{+7}$ | 100 | 37 | 137 |
| $^{28}Si^{+11}$ | 130 | 60 | 190 |
| $^{31}P^{+11}$ | 130 | 56 | 186 |

To increase the performance of the accelerating fields and hence the energy gain of the ion beam from the linac, several steps are adopted and they are listed in the following:

A warm water ultrasonic rinsing facility was installed for the final rinsing of the resonator before installation in the linac cryostat. It is observed that warm water ultrasonic rinsing reduces the field emission and helps to improve the accelerating fields of the niobium resonators.

A separate cooling arrangement for the power coupler of the resonator is designed and fabricated for the drive couplers of the resonators being installed in the linac cryostat-3. A Cu cold finger cooled to LN2 temperature is connected to the drive coupler as shown in figure 2. The coupler could then handle up to 400 watts without overheating and the temperature on the coupler remained below 268 K. This will allow operation of the resonator at higher rf power and increase the accelerating field,

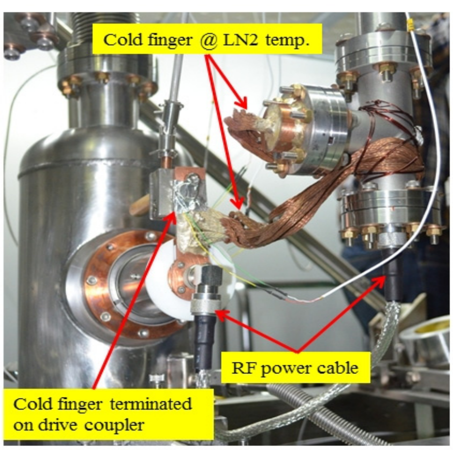


Figure 2: The additional cooling arrangement of the drive coupler at LN2 temperature.

To make the Linac operation smooth and trouble free, automatic locking of the resonators (when they go out of phase lock occasionally) without any human intervention has been taken up and some substantial progress is also achieved. In the next beam acceleration cycle, the auto tuning mechanism on linac resonators will be implemented.

In order to bring flexibility in the phase tuning of the resonators, a computer code has been developed to calculate the optimum phase at which the ion bunch would be injected in to each resonator in the linac. The programme varies the phase for each resonator at random to achieve the optimum time bunch at the target position. The results have been validated with beam during operation of the linac.

At present, the installation work of the remaining eight resonators in the last accelerating module (number-3 in figure 1) of linac is going on. After that, a couple of offline cold tests are planned to validate the performances of the resonators installed in linac-3. After the successful off-line testing of linac, the operation of the complete linac and the delivery of the ion beam for scheduled experiments are expected to start within a few months.

### *Reduction of Microphonics*

During early on-line beam tests of linac, high RF power of about 300 watts was required to lock the resonators in over-coupled mode due to presence of microphonics. The requirement of RF power was successfully reduced by a novel technique of damping the mechanical mode of the resonator by inserting stainless steel balls of suitable diameter inside the central conductor of the QWR[4]. Further improvements were made in the reduction of the frequency jitters by experiments with combination of different diameters of the steel balls.

### *Piezo Tuner*

The frequency fluctuations of the resonators are controlled by a feedback control for the fast components and the slow components by a mechanical tuner operated using helium gas. It was observed that often the forward rf power required by the feedback control system was rather high. To reduce the average power and to improve the dynamics of control mechanism, an alternate fast tuning mechanism has been tried out successfully and presently being implemented on all the resonators of the last accelerating module of linac. In this scheme, the tuner plate is deflected initially by a mechanical course tuner operated by a stepper motor driven shaft from outside and once the mean frequency is achieved, the control is handed over to the Piezo tuner controller (figure 3).

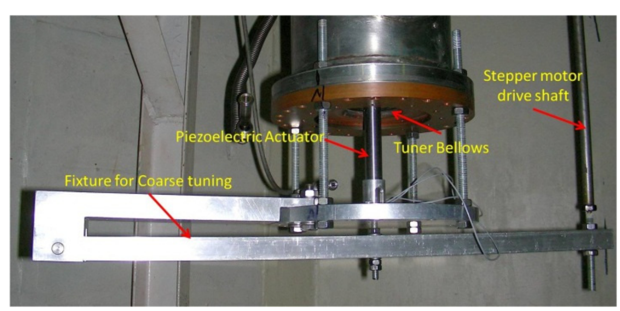


Figure 3: Detail of the piezo-actuator and its accessories connected at the bottom end of a resonator.

The piezoelectric actuator works in closed loop along with existing resonator control scheme to phase lock the

Copyright © 2012 by the respective authors — cc Creative Commons Attribution 3.0 (CC BY 3.0)

resonator. The response time for the Piezo to correct the frequency deviation is of the order of tens of milli second. During this short time, the deviation in frequency is very small and the extra power supplied by the amplifier is of negligible amount. Consequently the average power required by the resonator is negligible so the overall power requirement gets reduced substantially. During a recent test, a resonator could be phase locked at 3.6 MV/m field level with forward power of 100 W using the piezo tuner [5].

## CRYOGENIC SYSTEM

The liquid helium cooling needs of RF accelerator cavities were being met by an existing piston based LHe plant. This plant was commissioned in 1996 and has been running since then to take care of the cooling needs of the stand alone resonator testing or actual beam delivery through the resonators to the users. Over last couple of years the plants performance has deteriorated because of non availability of proper spares and other wear and tear issues. At present the maximum tested heat load capacity of this machine is ~280W. So keeping in mind the running of existing facility and also the future expansion in cryogenic activities a new LHe plant of higher capacity (LINDE Cryotechnique,750W) has been commissioned recently. The machine has been tested for a maximum load of 950W @ 4.4K (with $LN_2$), 500W @4.4K (without $LN_2$) and maximum liquefaction capacity is 225 l/h (with $LN_2$). This plant has some more features built in so that cool down and continuous operation of LINAC becomes easier. These are (i) availability of 10K gas @ 3 g/s for initial cryostat cool down, (ii) return cold gas from distribution system can be routed to the low pressure stream of the cold box at 3 different positions depending on the temperature of the stream and (iii) automation features for non-stop operation.


Figure 4 : New Liquid Helium Plant with the central dewar in beam hall.

The new LHe plant has recently been connected to the existing distribution system at Valve Box-4 near rebuncher cryostat with the addition of a new LHe distribution line. Also to automate the distribution side all the inlet and outlet valves to the 5 cryostats has been automated. The inlet valve flow coefficient $C_v$ has also been changed to incorporate the new flow scenario.

## HIGH CURRENT INJECTOR

The High Current Injector (HCI) would consist of an Electron Cyclotron Resonance (ECR) ion source followed by a Radio Frequency Quadrupole (RFQ), six sections of Drift Tube Linac (DTL) and one low beta module with eight superconducting QWRs.

### *ECR Source*

The 18 GHz High Temperature Superconducting ECR Ion Source, PKDELIS [6] will be used for delivering multiply charged ions (A/q ~ 6) covering a wide mass range (up to $^{238}$U) with beam intensities much higher than those available from the Pelletron. The beams extracted from the ion source will be further accelerated using a high voltage platform and subsequent acceleration will done using room temperature RFQ and DTL. The emittance of different ion beams extracted from the ECR source were measured and the measurements showed clearly a mass and charge state dependence with highest emittance for the lightest ions. The energy spread of various ions was determined by measuring the plasma potentials of the source for different ion species as a function of different source parameters. The plasma potential was found to play a significant role in determining the longitudinal focussing and transport of the beam through the HCI.

### *Beam Transport*

The Beam Transport System (BTS) for High Current Injector (HCI) from ECR source in BH-III to LINAC in BH-II has been thoroughly exercised using CODES Trace 3D, GICOSY, TRANSPORT and TRACK. Both transverse and longitudinal optics were considered so that good beam matching was maintained btween different HCI components and also with the superconducting linac. The layout based on the calculated optics has been finalised. The technical specifications of the magnets are being determined for placing the order for magnet fabrication. The high voltage deck for the ECR has been designed and order has been placed with a local vendor for fabrication.

Copyright © 2012 by the respective authors — cc Creative Commons Attribution 3.0 (CC BY 3.0)

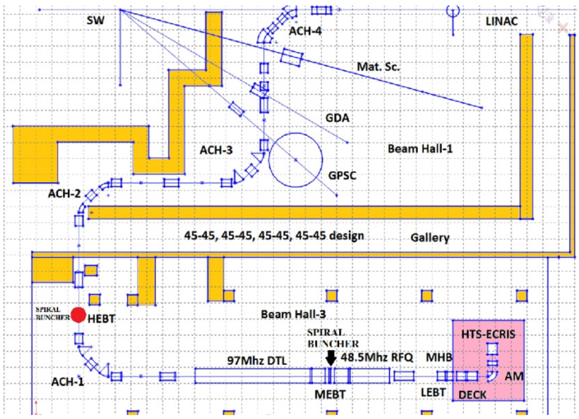


Figure 5: Plan of the layout of the high current injector for the linac.

## *Radio Frequency Quadrupole*

A prototype of four-rod RFQ with operating frequency of 48.5MHz is designed and constructed as an accelerator section of High Current Injector (HCI) system to accelerate ions with A/q of 6 from 8keV/A to 180keV/A. Last year the high power tests for the prototype RFQ were completed. Various problems seen in the original model were corrected and satisfactorily solved. Based on the lessons learned, the final RFQ design was finalised, drawings made and is now under actual fabrication.

One of the major issues was the overheating of the base plate. The original model had a stainless steel base plate which was copper plated. The base plate was found to be hot at several places near the walls. A new base plate of copper was again manufactured and it was found that this solved the problem of localised heating. It was also found that the input and output flanges were also getting warm, but were within tolerable limits.

Some problems with the high power RF amplifier was also observed, especially unexpected tripping of the amplifier, even when there was no reflected power from the RFQ cavity. This was traced to high reflections from the high power section to the driver amplifier due to shifts in the frequency response at higher powers. A tuning of the high power section at high output power solved this issue.


Figure 6: Test set up for the prototype radio frequency quadrupole.

The final RFQ cavity mechanical design and drawings were completed, keeping in mind the lessons learnt from the prototype. Additional cooling options on the side and end flanges have been provided. The chamber has been fabricated at Bangalore, leak tested at IUAC and has been copper plated at RRCAT. The welding and surface finishes have been maintained at a higher standard compared to the prototype as they were found to be the limiting factor earlier in the surface treatment and plating.

The vanes, base plate and vane holders have been finalised, and is under fabrication at vendor's site in Ahmedabad.

## *Drift Tube Linac*

The specification of the drift tube linac, which will operate at 97 MHz, is given in the Table 2.

Table 2: Specification of Six Tanks of the Drift Tune Linac

| Tank # | Cells | Length (cm) | $E_{out}$ (MeV/u) |
|---|---|---|---|
| 1 | 11 | 38.5 | 0.32 |
| 2 | 13 | 73.4 | 0.55 |
| 3 | 13 | 94.4 | 0.85 |
| 4 | 11 | 86.5 | 1.15 |
| 5 | 11 | 99.2 | 1.46 |
| 6 | 9 | 81.6 | 1.80 |

Complete design validation has been done on a full scale prototype DTL resonator. Low level RF tests using bead pull technique were carried out. These tests validated the design frequency and electric field profile along the beam axis.

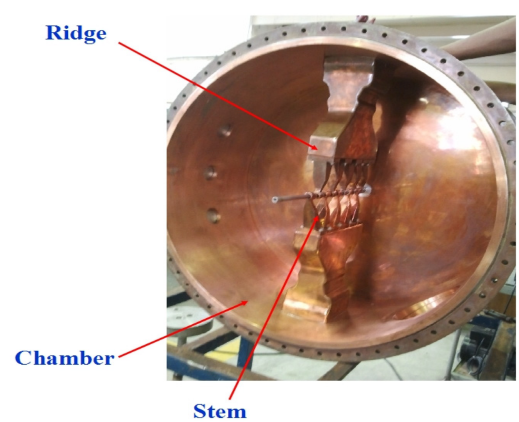


Figure 7: Prototype Drift Tube Linac with 11 gap sections.

Prototype resonator has been tested up to 6 kW input power. Total duration of high power test was ~ 100 hrs. Frequency and temperature variation has been measured. These tests have validated the complete resonator design parameters, power coupler and efficiency of water

Copyright © 2012 by the respective authors — cc Creative Commons Attribution 3.0 (CC BY 3.0)

ISBN 978-3-95450-122-9

cooling. Design modification is on to further improve the cooling efficiency near ridge base.

### *Low Beta Resonator*

In order to provide flexibility in the beam injection from the HCI to the Linac, a superconducting module containing eight quarter wave resonators with $\beta = 0.05$ at 97 MHz has been designed. A prototype QWR has been fabricated and validated with bead-pull tests and is shown in figure 8 .

(a) (b)

Figure 8: (a) Niobium outer housing (left) and central co-axial conductor (right), (b) low beta resonator complete with the outer SS vessel.

This module with low beta resonators will also be able to match the velocities of an wider range of heavy ions from the Pelletron to the superconducting linac [7].

## OTHER RESONATORS

In addition to in-house projects, two niobium single spoke resonators ($\beta$=0.22, f=325 MHz) for Project-X at Fermi National Lab, USA are in the final stage of fabrication. Four 1.3 GHz Tesla-type single cell niobium cavity have been fabricated in collaboration with RRCAT, Indore and tested at Fermilab. Two of the single cell cavities reached 35 MV/m and 40 MV/m in cold tests at 2 K. A multi-cell Tesla type cavity is also being fabricated in collaboration with RRCAT, Indore.

## ACKNOWLEDGEMENT

The work from IUAC reported here is on behalf of all the members of the Linac, Resonator Fabrication, Cryogenics and High Current Injector groups of Inter-University Accelerator Centre.

## REFERENCE

[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 (SRF2009), p – 244.
[3] S.Ghosh et al, Proc. of 12th International conference on Heavy Ion Accelerator Technology (HIAT2012).
[4] S.Ghosh, P.N.Patra, B.K.Sahu, A.Rai, G.K.Chaudhuri, A.Pandey, D.Kanjilal and A.Roy, Physical Review STAB 10 (2007) 042002.
[5] B.K.Sahu et al. In this proceedings, contribution TUPB033.
[6] D.Kanjilal, G.Rodrigues, P.Kumar, A.Mandal, A. Roy, C.Bieth, S.Kantas and P.Sortais, Rev. Sci. Instr. Vol 77, (2006) 03A317.
[7] Prakash N. Potukuchi et al , In this proceedings, contribution TUPB049.

Copyright © 2012 by the respective authors — cc Creative Commons Attribution 3.0 (CC BY 3.0)


ISBN 978-3-95450-122-9