OPERATIONAL EXPERIENCE WITH THE IUAC LINAC

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Abstract

The superconducting heavy ion LINAC at the Inter University Accelerator Centre (IUAC) is designed to have three accelerating modules, each housing eight Niobium Quarter Wave Resonators (QWR), a superbuncher housing a single QWR and a rebuncher housing two QWR's. Presently one accelerating module, the superbuncher and the rebuncher are operational. The other two modules are in an advanced stage of fabrication. In a recent operation several ion beams (from ^{12}C to ^{107}Ag) from the 15 UD Pelletron were further accelerated through the first LINAC module and delivered for scheduled experiments. The energy gain from the LINAC, which was primarily dictated by the requirements of the experiment, was in the range of 2.5–3.5 MeV per charge state. The time widths achieved at the LINAC entrance and at the target locations were of the order of 200 and 350ps respectively. Details of the operational experience, results, problems encountered and the improvements that are being planned, have been presented in the paper.

INTRODUCTION

The Superconducting booster LINAC at IUAC [1] when fully operational, with all the three accelerating modules each having eight Quarter Wave Resonators (QWR), will accelerate heavy ion beams up to mass ~100 above the coulomb barrier. This limit is presently exceeded only up to mass ~50 with the ion beams accelerated from the 15 UD Pelletron accelerator [2]. Figure 1 shows a schematic of the full Tandem-LINAC system at IUAC.

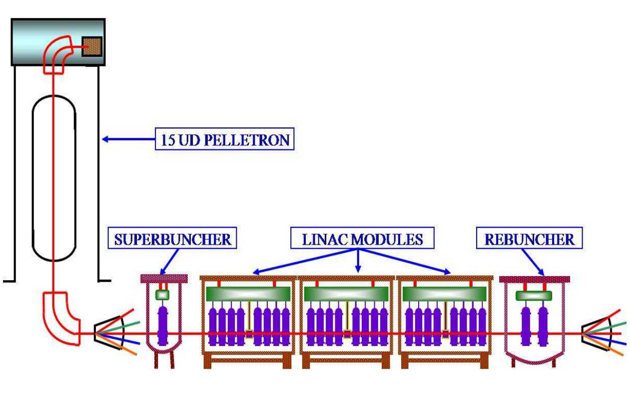

Figure 1: The Tandem-LINAC system at IUAC.

The first batch of twelve Stainless Steel (SS) jacketed Niobium QWR's for the LINAC have been designed and fabricated in collaboration with the Argonne National Laboratory (ANL) [3,4]. A superconducting resonator fabrication facility has thereafter been setup for the in house Resonator fabrication [5]. Figure 2 shows an IUAC QWR along with its schematic.

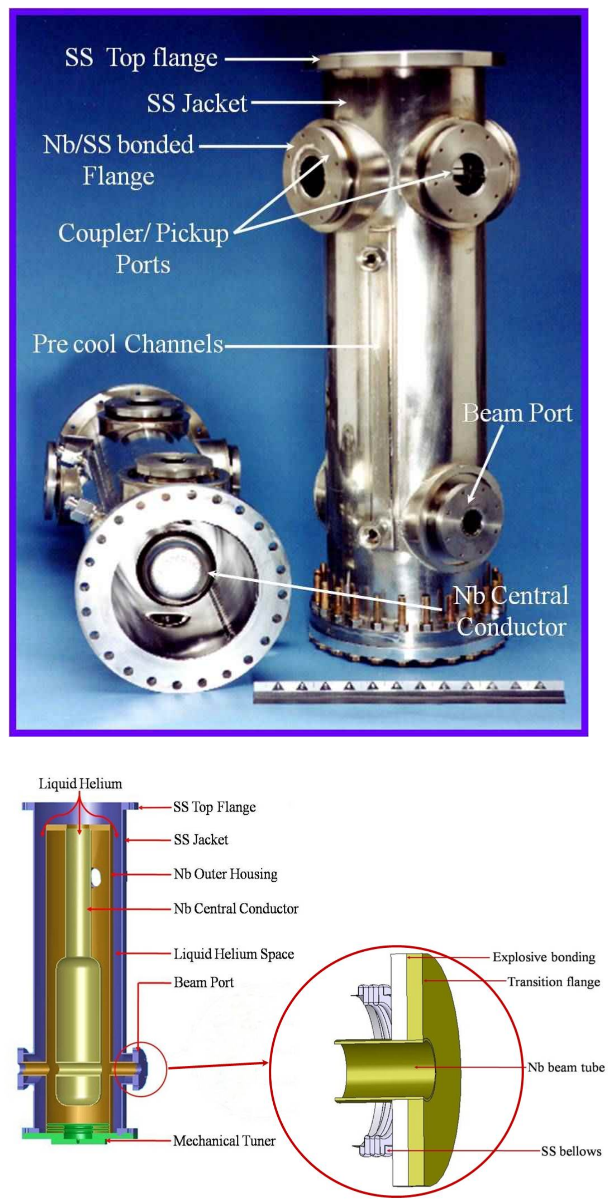

Figure 2: The Niobium QWR.

Operational tests of the first accelerating module together with the Superbuncher (SB) and the Rebuncher (RB) had started a few years ago. However a number of problems faced during the initial operation [1, 6], prevented the smooth running of the LINAC. These included low values of accelerating fields achieved in the LINAC cryostat, high power requirements for the phase control of the superconducting cavities in LINAC, helium leaks from the edge welded bellows of the coupling ports of the QWR etc. Continuous efforts have been made ever since to sort out the problems. These have led to several design modifications in the existing system as well as evolution of some novel techniques. Some of the major modifications [1] include changes in the design of the power coupler, improvement in the cooling mechanism of the cavities in the LINAC cryostat, modifications in the mechanical tuner assembly etc. In addition, an ingenious method for the reduction of the mechanical vibrations in the cavities has been developed and implemented [7]. This has led to a substantial reduction in the forward power required for the phase control of the cavities during operation. Regular tests, both with and without beam, have also been carried out to test the validity of the changes made and for any further optimization if required. Consequently, the first LINAC module (Figure 3), is now ready for beam acceleration. Various beams have been delivered for scheduled experiments that extended for a month.

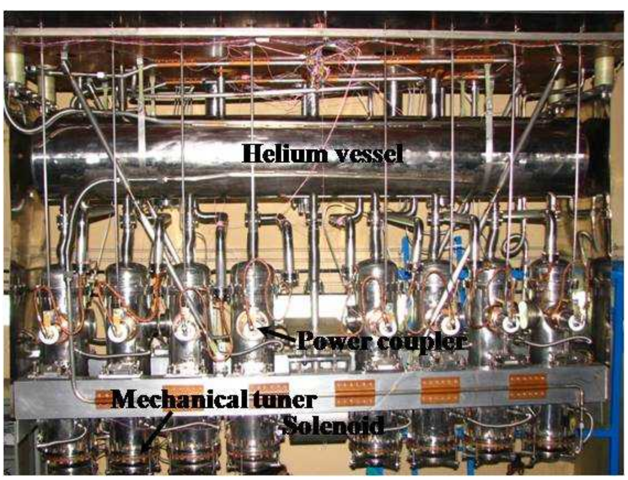

Figure 3: The First LINAC module ready for operation.

THE LINAC OPERATION

During the past few years several cold tests of the first LINAC module were carried out. Beam acceleration was also demonstrated on few occasions and the accelerated beams were delivered for experiments. These were short runs aimed to test the system performance rather than to conduct scheduled experiments. The last operation was however dedicated for this purpose only. A variety of ion beams were accelerated and delivered for user experiments. It was for the first time that all the eight LINAC cavities were operational and took part in beam acceleration. Table 1 lists the different beams, the energy gains (both from the Tandem and the LINAC) and the time widths at the entrance of the superbuncher, the LINAC and at the target location. Rebunching with a time waist at the target was done in only few of the experiments. In the others the rebuncher cavity was not operated.

Table 1: Ion Beams Accelerated Through LINAC

Beam	Energy from Tandem (MeV)	ΔT MHB (ns)	ΔT SB (ps)	Energy gain LINAC (MeV)	ΔT (RB) Target (ps)
$^{12}C^{+6}$	87	0.95	250	19.2	OFF
$^{16}O^{+8}$	100	0.95	163	18	342
$^{18}O^{+8}$	100	0.96	182	20	378
$^{19}F^{+9}$	115	1.08	190	25.8	354
$^{28}Si^{+11}$	130	1.2	182	37.5	OFF
$^{48}Ti^{+14}$	162	1.68	176	51.2	OFF
$^{107}Ag^{+21}$	225	1.7	232	74.6	OFF

Tuning of the LINAC was done in three steps. DC ion beam from the source was first chopped (to ~ 40ns width) and then bunched by the pre-tandem Multi Harmonic Buncher (MHB) [8] to time widths of ~ 1.0-1.7ns. The ion bunches were further compressed by the superconducting buncher to ~ 160-250ps at the entrance of the first accelerating module (the time widths quoted are inclusive of the intrinsic detector resolution ~100ps). The LINAC cavities were then powered one at a time and phase locked with the master clock (operating at 97MHz). Phase locking of the IUAC cavities is done using the dynamic phase control technique [9] which is implemented by means of a resonator control module [10]. Beam acceleration was done with a phase offset of -20° for phase focussing. For some beams, where the timing requirements at the target were not stringent and the primary concern was the beam energy, acceleration was done with a phase offset of -10° to achieve a higher energy gain. Finally the rebuncher cavity was tuned by monitoring the beam energy and time width at the experimental chamber. Timing and energy measurements in the pre and post LINAC sections were done by scattering the ion beams with a gold foil and then detecting them with Silicon Surface Barrier Detectors mounted in these areas.

Problems Encountered During Operation

The major problems faced during the operation have been described below:

Q drop of the Superbuncher cavity: Prior to the beam acceleration through LINAC, the single resonator of the superbuncher was conditioned through the multipacting barrier and phase locked at an accelerating field of 1.46

MV/m with a forward power of 15 W from the amplifier. The lock was stable for a period of ~ 8-9 hours after which it was observed that the field in the cavity had collapsed and the lock was broken. This was clearly not the case of re-appearance of multipacting, as initially thought, since the pickup signal from the cavity was constantly increasing on increasing the input power. There was a significant drop in the Q of the cavity (from an initial value of ~3×10^8 to ~5×10^6) because the level of the pickup signal was much lower than before for the same input power into the cavity. The reason for the Q drop was not fully understood. There were doubts that some portions of the superconducting surface got heated up due to trapping of the boiled off helium gas and that this has led to the deterioration in the cavity performance. The liquid helium flow to the cryostat was therefore stopped and the cavity was warmed up to 24K. This was done to remove any trapped gas. When the cavity became superconducting again its performance was regained and thereafter it operated smoothly throughout the entire experimental cycle.

Failure of one of the two Rebuncher cavities: The rebuncher cryostat, shown in Figure 4, of the IUAC LINAC houses two QWR's.

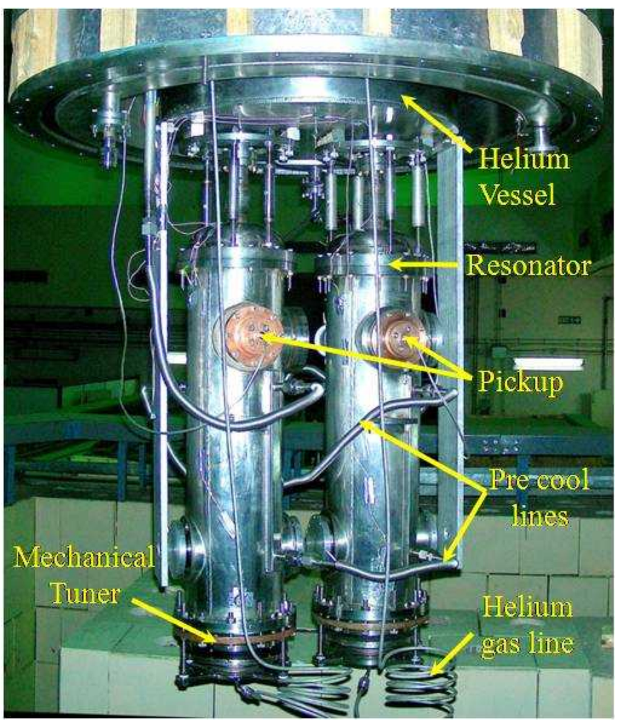

Figure 4: The Rebuncher Cryostat.

During the offline test of the system, prior to beam acceleration, both these cavities could be conditioned through the multipacting barrier. Thereafter high power pulsed RF conditioning was done for both of them and they were phase locked at moderate field levels. The phase locks for both the cavities were switched off after a period of ~ 6 hours, when it was noticed that the average forward power for locking had increased to ~150W. This was just a precautionary measure to avoid any damage to the power cables of the cavities. However, all subsequent attempts to phase lock the second rebuncher cavity (RB2) were unsuccessful though the first cavity (RB1) could be locked again at the same field level with the same forward power. In fact RB2 could not be phase locked even at very low accelerating field levels and even with the maximum value of the coupling coefficient that could be achieved with the variable power coupler. Measurements done with the reflected power from the cavity indicated that the fault was with the power line, as it was no longer possible to achieve an impedance matching between the amplifier output and the cavity input as seen through the variable transformer. This problem however, did not affect the LINAC operation as the rebunching could be successfully done with the single operational cavity in the rebuncher.

In addition, there were some minor problems like instabilities in the phase lock of some of the LINAC cavities, shifts in the time spectrum of the bunched beam from the Multi Harmonic Buncher (this was particularly true with the ^{107}Ag beam) etc. These could however be sorted out easily by taking proper corrective measures. This included optimization of the coupling coefficients and reduction in the field levels of the unstable cavities and minor modifications in the phase locking electronics of the Multi Harmonic Buncher.

Planned Improvements

Based on the experiences of the last few tests, several improvements have been planned in the system. The aim is not only to improve the overall system performance but to also make the operation easier and more streamlined. A few of these have been described in the following subsections:

System automation and remote operation: This includes automation of the power coupler movement with provisions of position read back and development of the necessary infrastructure for the remote phase locking of the cavities. An automated coupler movement will enable the operator sitting in the control room to precisely set the coupling coefficients for the different cavities prior to locking. This setting is being presently done manually from the cryostat top.

The phase locking of the cavities is presently done through CAMAC except for the initial adjustments of the mechanical tuner in order to bring the resonance frequency of the cavity close to the operational frequency of 97 MHz. The mechanical tuner for the IUAC QWR, Figure 5, consists of a Niobium bellows which provides a capacitive loading to the cavity. The bellows is deflected by pressurizing it with helium gas causing a change in the resonance frequency of the cavity. The helium pressure inside the bellow is controlled by a set of valves one of which is an open/close type while the other is a proportional flow control type [11]. The control voltage to these valves is provided by an electronic module, which is a proportional integral (PI) controller. This is interfaced with the resonator control module. While phase locking the cavities the resonant frequency is brought close to 97

MHz (within ~10-15 Hz) by manually adjusting the valve voltages from the front panel of the tuner control module. Thereafter the lock is switched ON and the deflection of the tuner bellow is controlled in accordance with the instantaneous phase and frequency error signals generated from the resonator controller. A new circuit has been designed to bypass the front panel controls of the tuner controller and have a remote control of the valve voltages. After successful Initial tests, incorporation of the circuit into the existing system is now being done. The phase locking operation would then be fully remote controlled.

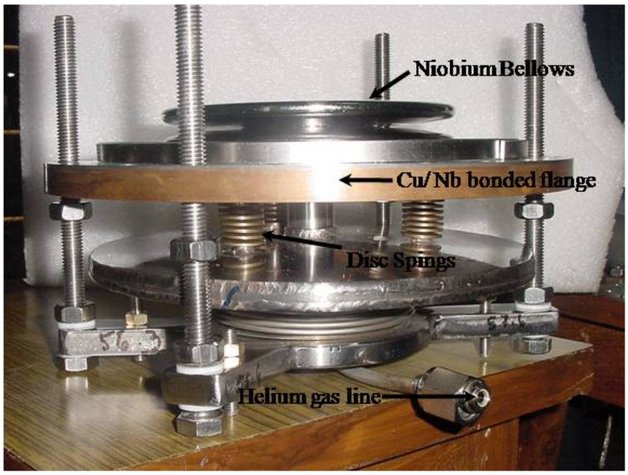

Figure 5: The mechanical tuner bellows.

Use of Piezo tuner for phase locking: The phase control of the IUAC QWR is currently done by a combination of an electronic tuner based on the dynamic phase control scheme and a mechanical tuner operated by gas pressure. The electronic tuner works in the time scale ranging from ~100 µs to ~ 10ms and controls the phase jitter due to fast mechanical vibrations picked up from the ambience. It has a control window that is approximately equal to the loaded bandwidth of the cavity. The mechanical tuner on the other hand operates in the time scale of several seconds and controls the slow drifts in the resonance frequency, which are primarily due to helium pressure fluctuations. This scheme has worked successfully with the cavities in the first module. However, the average power requirements for stable operation have been high and in the range of ~150 W at 6W of input power into helium. Another drawback of the present control scheme is the requirement of pure helium gas which proves to be expensive in long operations. An alternate scheme for phase control is therefore being developed, where in the mechanical tuner movement would be done using a combination a stepper motor for coarse frequency adjustments and a piezo for fine tuning. The piezo tuner which has a response time of ~100ms will act as a bridge between the fast electronic tuning and the slow mechanical tuning. It is therefore expected to reduce the average power required for stable operation. Use of stepper motor would avoid the requirement of helium gas. Initial tests with the piezo based tuning mechanism were done in the test cryostat [12]. The piezo tuner was interfaced with the fast tuner using a PI controller. The results were encouraging and a cavity could be successfully phase locked at a moderate field level ~3.0 MV/m. In a parallel development a fixture has been designed for the coarse tuning with a stepper motor. This has to be now interfaced with the fast tuner after which the whole phase control system comprising of the fast tuner, the piezo tuner and the coarse mechanical tuner can be incorporated in the LINAC modules 2 and 3.

Besides these, several other modifications have been planned and some of them have already been incorporated. These include design changes in the outer SS jacket of the cavities, that have been fabricated in house. In these a dome shaped structure is now an integral part of the jacket (Figure 6a).

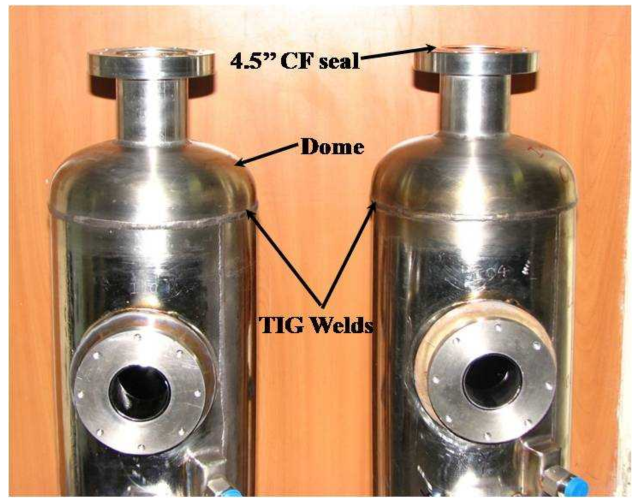

Figure 6a: Design change in the cavities.

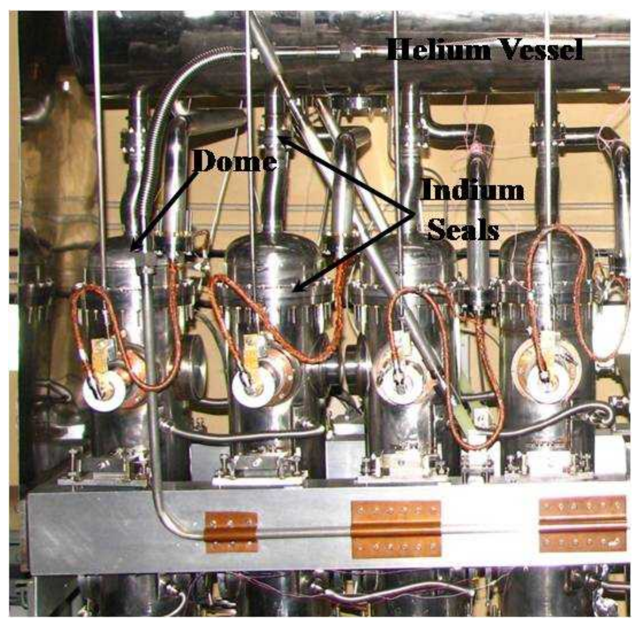

Figure 6b: The Present Configuration of QWR's in a module.

Earlier this dome was a separate entity attached to the cavity as well as to helium vessel of the cryostat with an

Indium seal (Figure 6b). This prevented the baking of the cavities to a temperature beyond 90° C for the fear of melting the Indium. In the present design the use of Indium has been completely avoided by welding the dome to the SS jacket of the cavity and providing a ConFlat sealing with the helium vessel. This will allow the cavities to be baked at a higher temperature of ~120°C, that is reported to improve the Q slope [13]. Another major design change has been done in the second and the third cryostats themselves, where arrangements have been made for forced cooling of the cavities with liquid helium. This is different from the first LINAC cryostat where the cooling was done through gravity feed. This improvement is expected to allow a much faster cool down of the cavities, thereby reducing the risk of occurrence of Q disease.

For the ease of operation, it has been planned to use a time of flight setup in the post LINAC section for energy measurements. This will be a non interruptive method of energy measurement that will use the beam pickup of two spiral resonant cavities already installed in this area. It will allow an online monitoring of the beam energy, without the need to put a scattering foil and use a surface barrier detector, as is being done presently.

CONCLUSIONS

A considerable time and effort have been spent in understanding the various problems that arose at different points of time and then solving them. This has led to a delay in the completion of the whole project. However, in retrospect the entire troubleshooting exercise has been a quite useful one in the sense that not only it has provided a valuable insight into the system behaviour, but also has given the confidence to proceed with the installation and commissioning remaining two modules. The second and the third LINAC cryostats are currently in the final stages of fabrication. The cavities and the associated accessories for the two cryostats are ready and their installation will be started shortly. Cold tests of the two modules are planned towards the end of this year and it is expected that beam acceleration from the full LINAC will begin by the spring of the next year.

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