First beam acceleration with niobium-based superconducting linear accelerator at NSC

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The 15 UD Pelletron of Nuclear Science Centre is capable of accelerating ions having mass up to 40 amu above Coulomb barrier. To augment the beam energy above Coulomb barrier for mass up to 100 amu, a booster Superconducting Linear Accelerator (Linac) is being developed[1] and currently undergoing tests for regular operation. The Linac will consist of one superbuncher (SB) cryostat consisting of a single Quarter Wave Resonator (QWR) cavity, three Linac cryostats, each consisting of eight QWRs and a superconducting solenoid as focussing device and a rebuncher cryostat consisting of two QWRs. The energy of the heavy ions expected from the Linac would be double that currently obtained from the Pelletron.

The subsystems for the linac are resonators, cryostats, cryogenic distribution system, RF instrumentation, beam transport and diagnostic devices. The accelerator augmentation programme of NSC has emphasized construction of as many components in India as possible by utilizing the available human resources with appropriate training. The lack of expertise in the area of design, fabrication and testing of superconducting resonators was bridged through a joint collaboration with Argonne National Laboratory (ANL), USA, where the world's first superconducting heavy ion linac booster with split-ring resonators was installed.

The booster linac consists of an independently phased array of short resonant QWR structures for achieving a relatively broad velocity acceptance. A variety of ions can be accelerated using these structures. Acceleration of various charge-to-mass ratios is achieved by properly adjusting the rf phase of each cavity in the array. Since the QWRs are independently powered and phased, the system provides accelerated particles even if a few units fail. Use of superconducting structures reduces the requirement of rf power by many orders of magnitude leading to a significant reduction of cost of sophisticated rf electronics. This type of booster linac provides a cost-effective way to increase the energy of ion beams from tandem accelerators preserving the high beam quality, energy variability and operational flexibility. The modularity, lower cost per megavolt and better energy efficiency are some of the major attractive features of this accelerating system.

The accelerating structure of Linac is a superconducting niobium QWR as shown in Figure 1. The QWR cavity chosen as the accelerating element for the NSC linac is made of niobium operating at a frequency of 97 MHz. The first prototype resonator was built and successfully tested in collaboration with ANL. Fabrication of another 12 QWRs at ANL followed that. The fabrication of more resonators at ANL was halted due to the US Govt sanctions in 1999. After gaining expertise from ANL through collaborative research, it was decided to fabricate the remaining resonators indigenously.

Since the resonator material, niobium, becomes superconducting below 9.2 K, it is necessary to cool the resonators below this temperature. This is done with liquid helium and the resonators are housed in cryostats operating at a pressure of $\sim 10^{-8}$ mbar. The cryostats and the cryo distribution system has been designed and fabricated indigenously. The 400 W RF amplifiers were designed in house and the resonator controllers were developed in collaboration with Electronics Division, BARC. For the indigenous fabrication of resonators

Figure 1. Indigenous niobium quarter wave resonator.

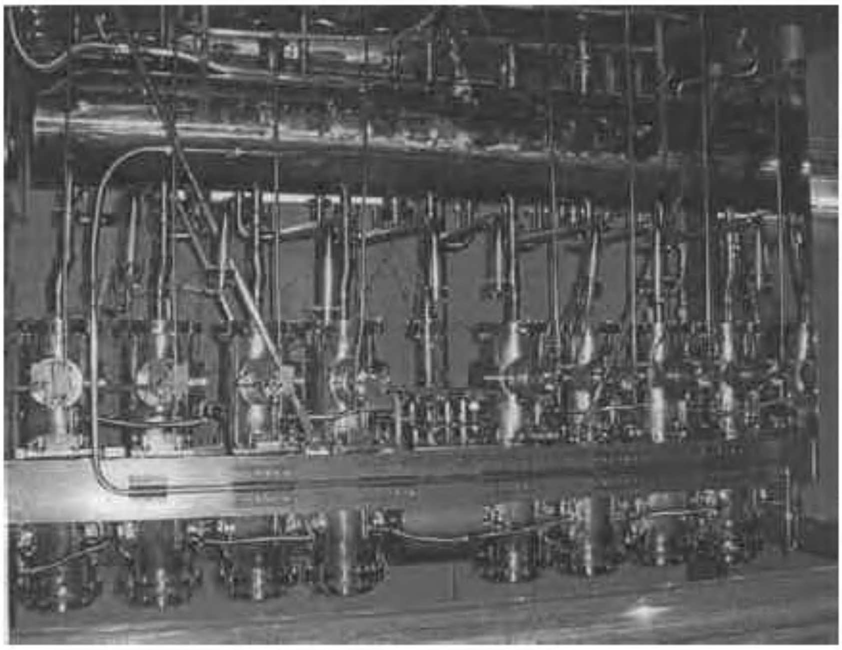

Figure 2. Eight QWR cavities and a superconducting solenoid in the first Linac cryostat.

several new facilities were established, e.g. Electron Beam Welding facility, Surface preparation laboratory, High Vacuum furnace.

Initially a number of off-line tests were performed for resonators in Superbuncher and Linac cryostat. In the past, the performance of the superbuncher with beam had been tested several times. Presently eight QWRs, out of which one resonator was indigenously fabricated at NSC, has been installed and aligned in the first Linac cryostat (Figure 2).

In the recent beam test, five out of eight resonators worked and they were locked to the same frequency from master oscillator along with the superbuncher. Due to the prolonged exposure of the resonators in the atmosphere, only a modest field of 1–2 MV/m was achieved for all the resonators. Acceleration and stability tests were successfully conducted. During previous cold tests, resonators in Linac cryostat had performed satisfactorily at 3–4 MV/m. This was the first beam test with the full system of Multiharmonic buncher, High energy sweeper, Phase detector, Superbuncher and the resonators in the first Linac cryostat, phase locked together.

During on-line test, a dc beam of $^{28}Si^{7+}$ at 90 MeV energy from the Pelletron was prebunched to a time width (Full width at half maximum) of ~1.5 ns by the Multiharmonic buncher (MHB). The post tandem High-energy sweeper (HES) then removed dark currents from the bunched beam. This bunched beam was injected into one resonator placed before the Linac acting as superbuncher. After optimizing the phase and amplitude of the superbuncher, the time width of the beam bunch was measured to be 360 ps at the entrance of Linac with the help of a cooled surface barrier detector. This time-width includes the intrinsic time resolution of the detector. In a separate experiment with dc beam, the intrinsic time resolution from a cooled ΔE–E telescope set-up was measured to be 285 ps FWHM. Assuming that both detectors contribute equally, the time resolution of the individual detector is ~200 ps. Consequently the intrinsic time width of the bunched beam after correcting for the detector resolution is ~300 ps.

The beam from the superbuncher was then injected into the resonators of the Linac cryostat. The RF phase of the first resonator was adjusted in such a way that the centroid of the beam enters at a phase of –70° with respect to zero cross-over of positive slope of the sinusoidal accelerating voltage into the first gap of the resonator. In this way, one by one, all the remaining five resonators were turned on, locked with the master oscillator and their phase synchronized to accelerate the beam. The energy of the beam was measured at the second scattering chamber at the exit of the Linac cryostat. The total energy gain at the exit of Linac was measured to be 5.8 MeV. The transmission of the beam through Linac was close to 100%.

1. Roy, A., *Curr. Sci.*, 1999, **76**, 149.

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