HEAVY ION LINAC BOOSTER AT IUAC, NEW DELHI

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Abstract

The first module of the booster superconducting linear accelerator that will have a total of three modules, each having 8 quarter wave coaxial line bulk Nb resonators, has been commissioned at IUAC. During initial operation of the first linac module, energy gain was found to be much lower due to various problems which are now identified and solved. After acceleration through the linac module and subsequent re-bunching using superconducting Rebuncher, 158 MeV Silicon beam having pulse width of 400 ps was delivered to conduct nuclear physics experiments. The other two linac cryostats and the required 16 resonators to be installed in those two cryostats are in the final stage of fabrication. Work has also progressed on a high current injector that would act as an alternate source of heavy ions for the super conducting Linac.

INTRODUCTION

Currently the programmes for addition of superconducting linac boosters for increasing the energy of heavy ions from the Pelletron accelerator at Inter-University Accelerator Centre (IUAC), New Delhi is nearing completion. The accelerating structures for the linac is a quarter wave cavity resonators (QWR) made of bulk Niobium operating at 97 MHz and optimised for β = 0.08 [1]. One module with eight cavities have been operated for beam acceleration and several problems faced with the drive coupler, slow tuner have been sorted out. A very novel method was found to reduce the microphonic noise in the cavity, which reduced the power required to amplitude and phase lock the cavities. Fields of the resonators obtained in the linac cryostat are in the range of 3 –5 MV/m at 6 watts of dissipated power at critically coupled condition of the power coupler. Fabrication of 15 more resonators for the next two modules is progressing according to schedule in the in-house resonator fabrication facility. In addition to the resonator production, several ANL built resonators have been repaired. It is also planned to design, develop and prototype a suitable low beta resonator around β = 0.045 for the high current injector.

IUAC has also agreed to build two β = 0.22, 325 MHz Single Spoke Resonators for the proton driver linac project of Fermi National Accelerator Lab (FNAL), USA. The resonators will be built at IUAC, and the final processing and testing will be carried out at FNAL.

QUARTER WAVE RESONATOR

The Quarter Wave resonator is a coaxial structure operating in the TEM mode with beam accelerating gaps in a direction perpendicular to the symmetry axis. The QWR incorporates a few distinctive features viz., a pneumatic slow-tuner in the form of a niobium bellow provides a tuning range of approximately 100 kHz, substantially larger than in any working quarter wave resonators; the Nb cavity being jacketed by a stainless steel shell joined to the Nb cavity through explosively bonded Nb-SS transition flanges. A picture of completed QWR along with the Nb slow tuner bellows is given in Fig. 1.

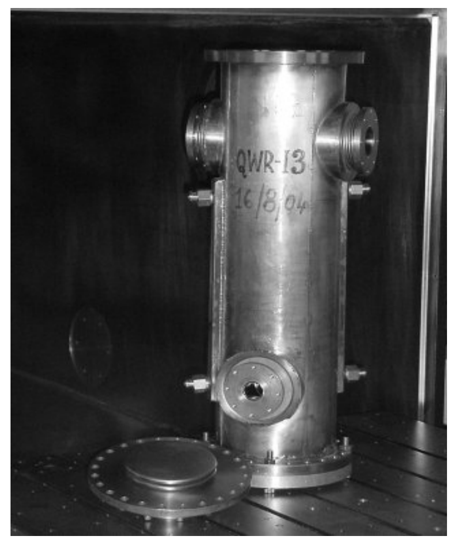

Figure 1: Indigenously built niobium quarter wave resonator with slow tuner bellows at IUAC.

The prototype QWR and twelve more resonators were fabricated in ANL and out of these, 8 resonators are used in the first linac module.

In order to fabricate the resonators in house, a Superconducting Resonator Fabrication Facility (SuRFF) has been set up and is fully functional. It consists of a 15 kW Electron Beam Welding machine, an automated Surface Preparation Laboratory for electro-polishing the cavities, a High Vacuum Furnace, and a dedicated test cryostat set-up.

Production of the superconducting niobium quarter wave resonators for the second and third linac modules has progressed sufficiently and nearing completion. There have been some problems faced in completing the (technically difficult) closure welds (the weld joining the top flange with the niobium housing as shown in Fig. 3) although several bare niobium resonators have been successfully welded and are ready for the stainless steel outer jacketing. After all the electropolishing was over, welding of the major sub-assemblies began for completing the bare niobium resonators. This work was done systematically to ensure that the RF resonance frequency scatter was kept to a minimum. The length of the Central Conductor primarily decides the RF frequency, therefore a single resonator was initially completed and its frequency was measured. Based on this data the Central Conductor length of two more resonators was adjusted and they were completed and their frequencies were measured. The Central Conductor length was further fine tuned and the remaining twelve resonators were completed. Although this took longer than if we had finished all the resonators together, it helped in achieving the desired RF frequency in most cases. Fabrication of the niobium mechanical Tuner Bellows began as the electropolishing work on the major resonator sub-assemblies neared completion. The tuner is mounted at the open end of the resonator. In order to determine the open-end length of the housing for providing appropriate capacitive loading and therefore the required tuning range from the tuner, we have decided to complete one tuner bellow assembly. This work is presently nearing completion. Simultaneously several components for the remaining tuner bellows have been machined and formed, and are being electron beam welded.

The stainless steel outer jackets (helium vessel) have been fabricated and electropolished (at a commercial vendor). They have been cut into two halves for the clamp shell assembly. Other items for the outer jackets, such as the top domes, CF flanges and pre-cool channels have also been fabricated. The measured Q curve for the first cavity fabricated at IUAC is presented in Fig. 2.

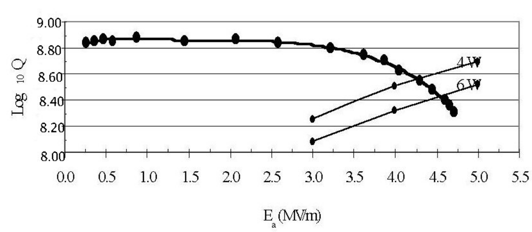

Figure 2: QWR-I1 cold test performance.

Repair Work on Existing QWRs

In addition to resonator fabrication for the linac modules several critical repair jobs have also been undertaken. On several of the ANL built QWRs the transition assemblies, in which welded ss bellows were used, leaked when the resonators were loaded in the cryostat and filled with liquid/gas helium. This problem had not been encountered during the prototype resonator testing. The design of both the coupling and beam port transition flange assemblies were changed and formed stainless steel bellows are now being used. The leaking assemblies on several cavities have been successfully repaired by machining them out and replacing with the modified design.

Reduction of Microphonics Frequency Jitters

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 high RF power caused melting of insulation of RF power cable, excessive heating of drive coupler and increased cryogenic losses. To reduce the requirement of RF power, a novel technique of damping the mechanical mode of the resonator by inserting stainless steel balls of suitable diameter inside the central conductor (Fig. 3) of the QWR has been adopted.

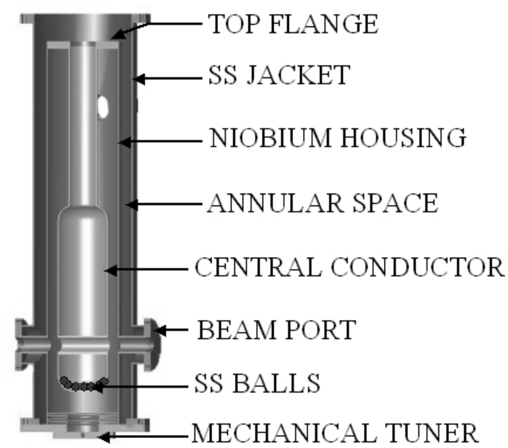

Figure 3. Schematic for the damping of vibrations of central conductor through stainless steel balls.

The dynamic friction between the balls and the niobium surface damps the vibration of the central conductor excited due to coupling of the mechanical mode to ambient noise. The frequency jitter of the QWR was measured at superconducting temperature without/with SS balls with the help of a cavity resonance monitor in phase lock loop and a reduction of microphonics by a factor of ≥ 2 has been recorded with balls as damper. During phase and amplitude locking, a remarkable reduction of input RF power of about 50% (Fig. 4) has been achieved to lock the resonator [2].

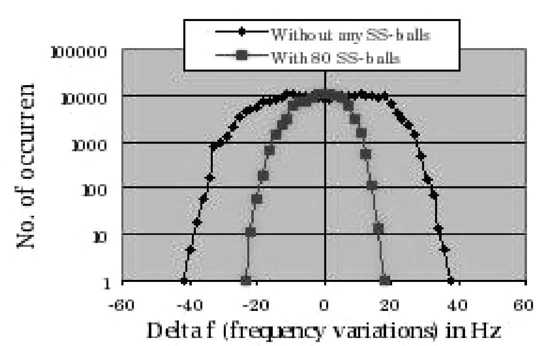

Figure 4. Damping in frequency jitter with ss balls in central conductor of resonator.

Modifications for Improvement f Liquid Helium Cooling Efficiency

In our old design, at the top of the resonator, there used to be a flat flange (SS) with a 40 mm diameter bellows through which liquid helium enters into the resonator from helium vessel. Just below this flange, about 15 mm down, the resonator's niobium flange, which carries maximum current when the QWR is energised, is located.

To avoid trapping of bubbles at SS flat flange on the top of the resonator, the flat flange was replaced by a hemispherical structure. With these modifications, a number of cold tests were performed on different resonators in linac cryostat and improved electric fields comparable to the results in the test cryostat were obtained.

New Drive Coupler

The Quarter Wave Resonators (QWR's) required nearly 300 Watts of RF power to generate field of ~4 MV/m in over coupled mode. Due to this high power requirement, in our first few tests, we found that the insulator of RF power cables were melting and a thin layer of material was deposited on to the cold surface of cavities. A detailed analysis of this thin film was done using Energy Dispersive X-Ray Analysis (EDX) at Solid State Physics Laboratory, Delhi. This showed Zn (96.5%)/Cu (2.49%) in atomic % as main peaks. The rack and pinion were made of brass and the excessive heating during powering of the cavities might have caused the coating. To eliminate any possibility of metal coating on niobium surface during the operation of the resonators in future, three new types of the drive coupler were fabricated. In the most successful design (Fig. 5), the rack and pinion made by brass was moved outside the resonator. During several off-line tests of the resonators with the new drive couplers, no coating was observed on niobium surface or on the inside portion of the drive coupler.

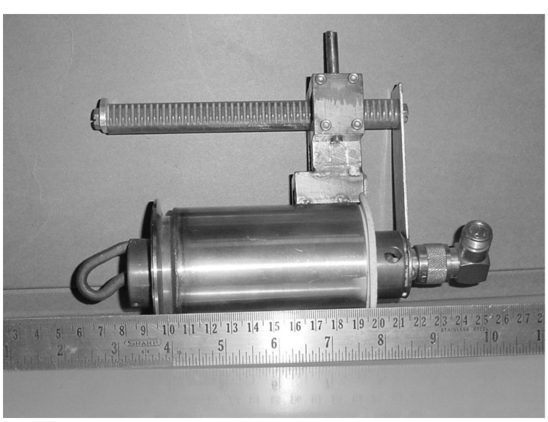

Figure 5. The final design of the power coupler

Slow Tuner

During last few cold tests the original slow tuner bellows were observed to start leaking from welding joints. Though these leaks could be repaired, we decided to re-design the whole system of movement of the slow tuner. In new design, He gas is introduced in an stainless steel bellows and through a mechanical attachment linear motion is transferred to niobium bellows (Fig. 6). The new design was successfully tested in test and linac cryostat for frequency range and response measurements. Now the new arrangement has replaced the old one in all the resonators of superbuncher, linac and rebuncher cryostat.

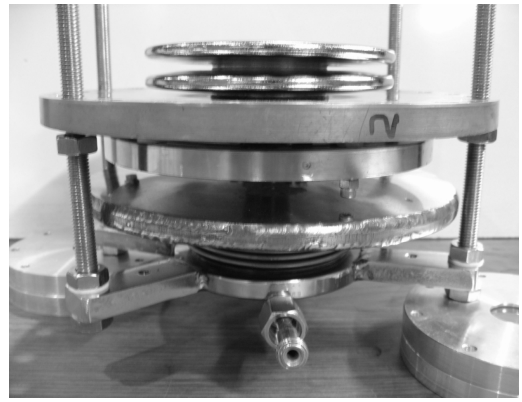

Figure 6. The mechanical tuner connected with the SS-bellow along with the gas line.

Rebuncher

Two Quarter Wave Resonators (QWR) having accelerating field up to ~3.5 MV/m each have been installed in rebuncher cryostat. One of these resonators was fabricated in-house at IUAC. The rebuncher cryostat along with these resonators are shown in Fig. 7.

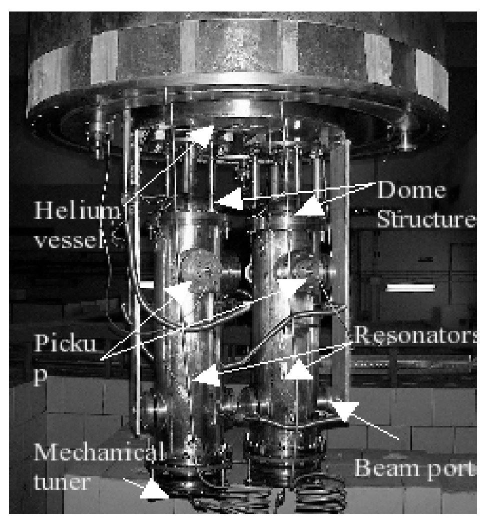

Figure 7. Two resonators (QWR) installed in rebuncher cryostat prior to cold test.

ON-LINE TEST OF LINAC

After carrying out cold tests of the resonators in test cryostat, eight resonators and a superconducting solenoid has been installed and aligned in the first linac cryostat.

Initial off-line tests of the resonators in linac were carried out to understand the cool down times and check the field levels in the resonators.

Finally, dc and pulsed beam were accelerated through resonators in Linac cryostat. Three runs with ^{28}Si beam from the Pelletron have been successfully carried out. The beam bunching system of IUAC consists of a pre-tandem multiharmonic buncher (MHB) [3] and a post tandem high-energy sweeper (HES) [4]. A phase detector has been placed after analyser magnet of the Pelletron to sense the phase of the beam bunch. The bunched beam was transported to the superbuncher located about 25 metres downstream from the phase detector. The point of time focus of the superbuncher is ~ 9 metres from it and coincides with the entrance point of the first linac cryostat.

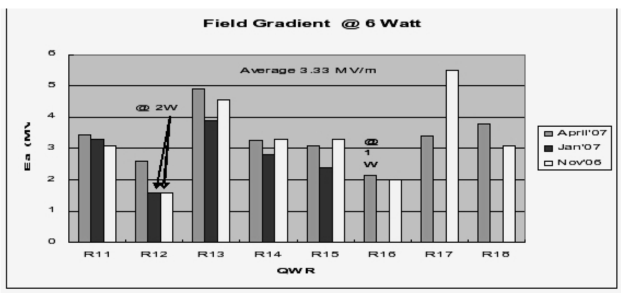

Figure 8. Field gradient achieved by 8 resonators on 3 on-line tests.

During these tests, the resonators could be maintained in phase locked condition for several hours. The field levels in the first test were quite low (1-2 MV/m) although field levels > 4 MV/m have been reached in previous tests [5]. The cause for the low field levels was coating of the resonator surface from overheated brass rack and pinion arrangement for movement of the RF coupler drive. The coupler design has been changed to avoid exposure of the brass portion to inside of the resonator. After these modifications, two runs of the linac with Si beam were performed. In these runs the field levels > 3 MV/m were maintained and the field levels were locked for 3-4 days for experiments to be done with the accelerated ions. The transmission of the beam through linac was close to 100%. The result of the accelerating field gradient of the linac resonators is shown in Fig. 8.

Towards the end of last year, all the modifications in the resonator accessories were tested and the resonators in SB, linac and RB cryostats, were made ready for beam acceleration. In November 2007, 130 MeV ^{28}Si^{+10} beam from Tandem was initially pre-bunched by the Multiharmonic buncher with the dark current removed by the high energy sweeper and a time width of ~ 1.1 ns was obtained at the entrance of the SB resonator. By carefully adjusting the phase and amplitude of the superbuncher resonator, a time width of ~ 250 ps had been measured at the entrance of linac cryostat with the help of a cooled thin (50 µm) surface barrier detector. The beam of 250 ps was then injected into the seven resonators of linac cryostat and a total energy gain of about 28 MeV was measured from all the resonators of linac cryostat by another thick surface barrier detector (300 µm) installed at the exit of linac. The energy spectrum of the beam from the Pelletron and after every resonator in linac is shown in Fig. 9.

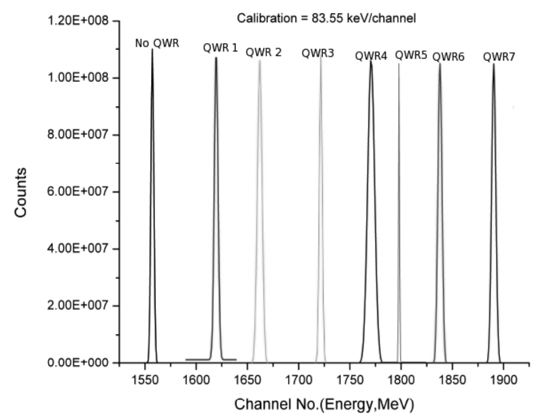

Figure 9. The energy spectrum of the beam from the Pelletron and after turning on the seven resonators one by one in linac cryostat.

The beam was then transported up to the rebuncher which was located at about 14 meters down the line from the first linac cryostat. With the help of the switcher magnet, beam was further tuned up to the location of an experimental scattering chamber, at about 13 meters from the rebuncher cryostat. A pair of thick (300 µm) and thin surface (40 µm) barrier detectors cooled to subzero temperature were installed in the scattering chamber to measure the energy and time width of the beam bunch.

By optimizing the reference phase of a single resonator of the RB cryostat and then by changing the amplitude of the accelerating field, a time width of the beam bunch measured by the detector at the scattering chamber could be compressed from 1.1 ns to ~400 ps (shown in Fig. 10). A nominal accelerating field of ~ 1.7 MV/m was found to be adequate from a single resonator of the rebuncher cryostat to re-bunch the beam at the experimental chamber. Due to shortage of time towards the end of the experiment, not much effort could be devoted to further reduce the time width. But with a more systematic approach to vary the bunching field of the rebuncher in smaller steps and proper adjustment of the nuclear electronics, the time width of the beam bunch could be matched with the value obtained at the entrance of linac by the SB.

In December 2007, 100 MeV ^{16}O^{+8} beam from Pelletron, pre-bunched by MHB and low energy chopper, a time width of ~1.0 ns was injected into SB. The resonator in SB had produced a time width of ~160 ps at linac entrance and finally after acceleration by seven resonators in linac, a total energy of 120 MeV was obtained at the exit of linac. The average field obtained from the resonators was ~ 3 MV/m from beam energy calibration. This beam was then re-bunched by a resonator in RBC and a time width of ~ 500 ps with 120 MeV was delivered at the experimental chamber. The beam was then used for about a week by an experimental group to study fusion-fission reaction dynamics using neutron multiplicity measurement.

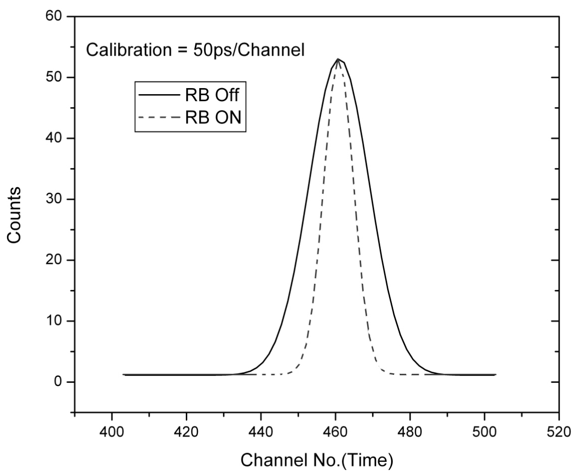

Figure 10. Beam pulse width with the rebuncher cavity on and off.

The operation of the one third of the complete linac with superbuncher, a single linac cryostat and rebuncher has thus been demonstrated and it is planned to deliver the linac beam to the user on a routine basis. The fabrication of the second and third linac modules with sixteen resonators are going on in full swing. These modules are expected to be installed in the beam line by the end of this year.

Two Nb Single Spoke Resonators operating at 325 MHz, β=0.22, is under fabrication at IUAC using in-house facilities for electon beam welding and electropolishing for the Proton Driver Linac of a High Intensity Neutrino Source at Fermi National Accelerator Laboratory, USA as a collaborative program. The resonators are designed by Fermilab.

In the high current injector project to provide an alternate injector to the superconducting linac, the high Tc superconductor based ECR source PKDELIS[6] parameters have been optimised and a prototype RFQ operating at 48.5 MHz has been fabricated and cold tested using bead-pull technique.

ACKNOWLEDGMENT

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