DEVELOPMENT OF QUARTER WAVE RESONATORS

Amit Roy
Inter University Accelerator Centre, Aruna Asaf Ali Marg
P.O.Box 10502, New Delhi - 110 067, India

Abstract

The accelerating structure for the superconducting linac booster for the 15 UD Pelletron at IUAC is a Nb QWR cavity, designed and fabricated as a joint collaboration between IUAC and ANL, USA. Initial cavities required for the first linac module were fabricated at ANL. For fabrication of cavities required for future modules a Superconducting Resonator Fabrication Facility has been set up at IUAC. Three quarter wave resonator (QWR) cavities have been fabricated and fifteen more resonators for the second and third linac modules are in advanced stage of completion. This facility has allowed us to undertake repairs on some of the resonators which sprung leaks. First experiment with the accelerated Si beam through the first linac module having eight resonators along with a superconducting solenoid have been conducted recently.

INTRODUCTION

The Pelletron accelerator at IUAC 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 structure is being installed[1]. The first Linac module consisting of eight Niobium Quarter Wave Resonators (QWR) optimized for IUAC Pelletron and a solenoid as focussing device, has been installed at IUAC. The QWR was designed and fabricated as a joint collaboration between IUAC and Argonne National Laboratory (ANL), USA[2]. The other elements of the Linac which have been installed are a superbuncher (SB) cryostat consisting of a single QWR and a rebuncher cryostat consisting of two QWRs.

A Multiharmonic Buncher has been installed and tested as the pre-buncher before the Pelletron. The bunch width delivered by this buncher is ~ 1-2 ns[3]. One superconducting QWR cavity has been installed after the Pelletron and operated as the Superbuncher delivering <150 ps pulsed beams for injection into one Linac module with eight resonators. Cryogenics facilities consisting of a 600 W liquid helium plant, LN2 plant, several large cryostats to house the cavities are fully functional and the cryogen distribution lines have been installed to supply cryogen to superbuncher and superconducting linear accelerator modules[4]. The cavity resonators for the 2nd and 3rd modules are being fabricated in house and a full fledged superconducting resonator fabrication facility has been established consisting of Electron Beam Welding machine, High Vacuum furnace and a Surface Preparation Laboratory. Major effort has been expended also in areas of beam transport and rf electronics required to operate this linac. Most of the required hardware has been built indigenously.

QUARTER WAVE CAVITY 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 central conductor is shaped with two different diameters to reduce the effective length of the cavity by capacitive loading. This helps in reducing the frequency jitter and thus in the control of the cavity. The resonator is formed entirely of niobium and is closely jacketed in a vessel of stainless steel which contains the liquid helium. A small amount of niobium-stainless steel bonded composite material is used to provide welding transitions where beam and coupling ports penetrate the stainless steel jacket. A novel 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. A picture of completed QWR along with the Nb slow tuner bellows is given in figure 1.

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

The pnematic drive for the slow tuner bellows has been further modified with the experience of running the cavities in the linac cryostat.

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 the off-line tests, all the resonators have exceeded the minimum design goal of 3 MV/m with 4 watts of input power. The best performance achieved was 5.0 MV/m at 4 watts of input power. In the on-line tests the performance has been slightly worse compared to the off-line tests, but the field levels exceeded 3 MV/m at 4 W.

In order to fabricate the resonators in house, a Superconducting Resonator Fabrication Facility (SuRFF) at Inter-University Accelerator Centre (IUAC) 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.

Initially, a single QWR was successfully constructed and tested using this facility and then installed in the first module of the IUAC linac. Two more QWRs have been fabricated and the performance of the resonators were checked using the test facility, consistng of a test cryostat and associated equipment that include the RF electronics for powering the cavity, the thermometry for temperature monitoring and the vacuum system controller. The process for fabrication of fifteen resonators for the second and third linac modules have made good progress and is expected to finish by middle of 2007[5]. The measured Q curve for the first cavity is presented in figure 2.

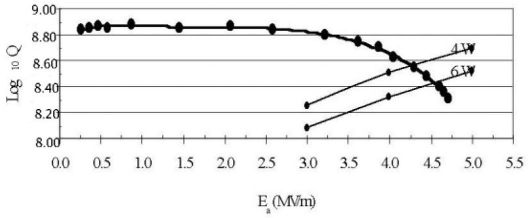


Figure 2: QWR-I1 cold test performance.

Repair Work on Existing QWRs

In addition to resonator fabrication for the linac modules several critical repair jobs have also been undertaken. For example, in the IUAC resonator the transition from the inner niobium housing to the outer stainless steel jacket is provided through niobium-stainless steel explosively bonded flange and edge welded stainless steel bellows. On several of the ANL built QWRs these assemblies 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. In order to avoid problems on future resonators we have modified the design of both the coupling and beam port transition flange assemblies using formed stainless steel bellows procured from a local vendor. Several transition flange assemblies have been fabricated, thermally cycled and pressure tested. The leaking assemblies on several cavities have been successfully repaired by machining them out and replacing with the modified design.

RF POWER & CONTROL

The amplitude and phase of the resonator were maintained constant with respect to the master reference using a resonator control module based on the principle of dynamic phase control, designed in collaboration with Electronics division, BARC, Mumbai. It is found that the control module can stabilize the phase of the super conducting resonator up to 0.5 degree accuracy and amplitude with accuracy of 1%. A Slow -tuner is used to bring the frequency of the resonator close to the master frequency and stabilize it there. The resonators are powered using a 400Watt, 97 MHz RF amplifier designed in house and tested with an RF circulator and load at the output to take care of the reflected power. The technology is transferred to M/s BEL, Bangalore for production of initially required ten amplifiers and the rest of the required units are being produced at IUAC.

The clock distribution system has been designed and developed to provide the master reference to the Linac and its subsystems which includes a multi harmonic buncher, High energy sweeper and phase detector. The circuit uses 6.0625 MHz as the fundamental frequency generated using a crystal oscillator specially made at M/s BEL, Bangalore and the other frequencies are generated by frequency multiplication. The clock distribution system is now being used with the Linac control. A phase meter input module has been developed which mixes the RF signal phase to be measured with some offset RF frequency within a few kHz and then extracts the AF signal for phase meter input.

Reduction of Microphonics frquency jitters

During on-line beam tests of niobium superconducting quarter wave resonators (QWR), it has been observed that due to presence of microphonics in the ambience of linac, rf power of about 300 watts is required to lock the resonators in over-coupled mode. The high rf power causes several operational problems like melting of insulation of RF power cable; excessive heating of drive coupler leading to other associated problems 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 (figure 3) of the QWR has been adopted.

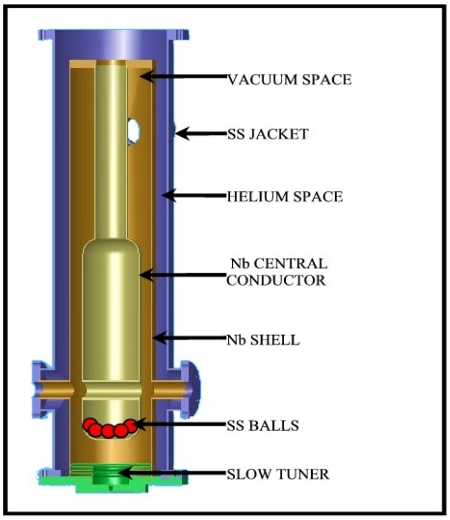


Figure 3. Schematic for the damping of vibrations of central conductor through stainless steel balls.

Due to dynamic friction between the balls and the niobium surface, the amplitude of the vibration of the central conductor excited by the mechanical mode has been reduced drastically. Microphonics measurement on

QWR at superconducting temperature has been performed without/with SS balls with the help of cavity resonance monitor in phase lock loop and a reduction of microphonics by a factor of 3 has been recorded with balls as damper. During phase and amplitude locking, a remarkable reduction of input rf power of about 50% (figure 4) has been achieved to lock the resonator[6].

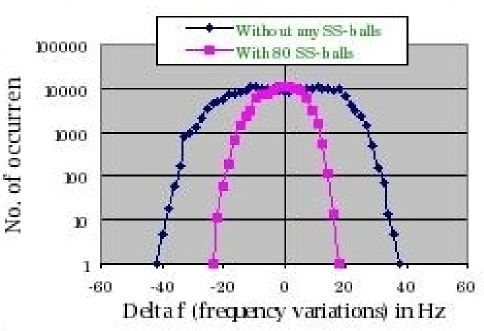


Figure 4. Damping in frequecy jitter with ss balls in central conductor of resonator.

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. The resonator assembly with a superconducting solenoid mounted on the support bars suspended from the top plate of the cryostat module is shown in figure 5. 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.

Figure 5. Eight resonators and a solenoid in first linac module ready to be loaded for a cold test.

Finally, dc and pulsed beam were accelerated through resonators in Linac cryostat. Three runs with ^{28}Si beam from the Pelletron have been succesfully carried out. The beam bunching system of IUAC consists of a pre-tandem multiharmonic buncher (MHB) and a post tandem high-energy sweeper (HES). 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.

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. 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 and to provide better cooling through liquid nitrogen. 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 energy gain is shown in figure 6.

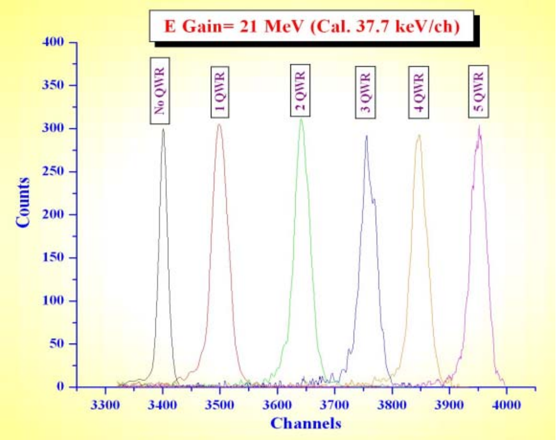


Figure 6. Energy gain by Si beam as resonators get turned on one by one.

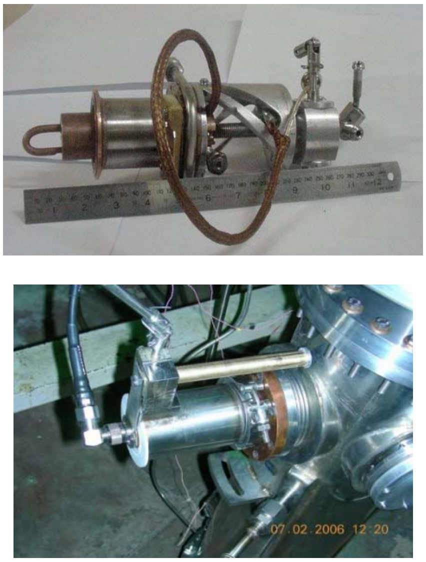
MODIFICATIONS

New Drive Coupler

To change the coupling strength and couple the RF power into cavities we had a drive coupler based on rack and pinion design to facilitate linear motion of the loop. 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. Two new designs of drive coupler were made to replace the rack and pinion and to also incorporate LN_2 cooling. Salient features of one of the new drive probes(figure 7a) are:

1) The movement of drive probe is done using worm and worm wheel.
2) Liquid nitrogen cooled central conductor and outer conductor.

In the second design (figure 7b), the rack and pinion is kept outside of the cavity so that there is no chance of contamination.



(a)

(b)

Figure 7(a), (b) . Two different new drive couplers which avoids brass components inside and can be cooled with liquid nitrogen.

The performance of the new drive couplers were checked in cold tests in the test cryostat. High power pulse conditioning was done for long duration (4-5 hrs). Cavity was then locked at 2.2 MV/m @ 150-170 watts of input power for nearly 18 hrs. With successful completion of the tests it was decided to replace all old drives with the new design. To increase the coupling range a rotational motion was incorporated in one of the designs along with linear motion through a spiral groove. This enables the loop to have a linear travel of ~70 mm and 70 deg rotation.

Slow Tuner & Top Flange

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 in introduced in an stainless steel bellows and through a mechanical attachment linear motion is transferred to niobium bellows. The new design was successfully tested in STC for frequency range and response measurements. The new assembly is shown in figure 8.

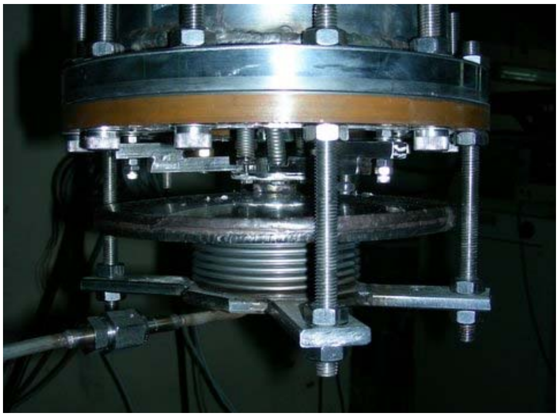


Figure 8. New slow tuner bellows with ss pneumatic tuner mechanism.

The SS top flange of the resonator is flat and clearance between this flange and top niobium surface is about 1/2 inch. During boiling of liquid helium bubbles may get trapped in this region and reduce the cooling of the top flange. To overcome this, a hat like structure having slope for movement of bubbles and as well as a buffer volume is developed. The modified top flange is shown in figure 9. This hat structure gives two fold advantage, one it provides a buffer volume for LHe, secondly it does not allow bubble to be trapped, thus localized heating / insufficient cooling problem is removed. Results of performance tests with hat type structure showed marked improvement. At present all eight resonators in linac cryostat are connected to liquid helium dewar using this hat structure.

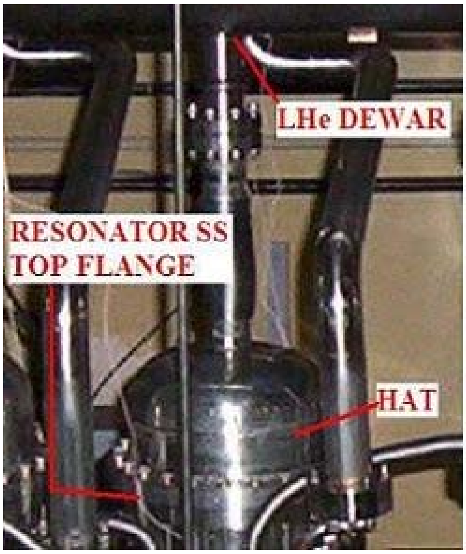


Figure 9. The stainless steel top flange of the resonator jacket in the form of a hat.

ACKNOWLEDGEMENTS

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