SUPERCONDUCTING RF DEVELOPMENT AT NUCLEAR SCIENCE CENTRE

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Abstract

A Superconducting Linac is being installed as a booster for the 15 UD Pelletron accelerator at Nuclear Science Centre (NSC). The accelerating structure for this linac is a Nb QWR cavity, designed and fabricated as a joint collaboration between NSC 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 NSC. Three quarter wave resonator (QWR) cavities have been fabricated using the in-house facility. This facility has been used for repairs on the resonators which sprung leaks. Fabrication of fifteen resonators for the second and third linac modules is under progress. Eight resonators along with a superconducting solenoid has been installed in the first linac cryostat and tested for energy gain with a pulsed beam of 90 MeV Si from the Pelletron. Acceleration of the ions to 96 MeV was measured downstream and beam transmission through the linac was measured to be ~ 100%.

INTRODUCTION

The Pelletron accelerator at NSC 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]. This project is in the final stages at NSC and is based on Niobium Quarter Wave Resonators (QWR) optimized for NSC Pelletron. This QWR was designed and fabricated as a joint collaboration between NSC and Argonne National Laboratory (ANL), USA[2]. The Linac will consist of one superbuncher (SB) cryostat consisting of a single QWR, three Linac cryostats, each consisting of eight QWRs and a solenoid as focussing device 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. 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. 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.

RESONATOR FABRICATION

After successful completion of the prototype Niobium superconducting resonator in collaboration with ANL, the production to fabricate another ten resonators had been started at ANL in May 1997. The entire machining, forming, rolling and electron beam welding was carried out in USA and India. Electro-polishing and heat treatment of different parts of the resonator were carried out by NSC personnel using ANL facilities. Though the project had called for building ten resonators, twelve resonators had been built in about two years of time [3]. Out of twelve resonators fabricated, three were cold tested in ANL and seven of the resonators had been tested in NSC. 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 order to fabricate the resonators in house, a Superconducting Resonator Fabrication Facility (SuRFF) at Nuclear Science Centre (NSC) 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.

The electron beam welding facility is a 15 kW beam power machine (60 kV, 250 mA) with a vacuum chamber of size 2.5 m (L) x 1.0 m (W) x 1.0 m (H). The machine offers full CNC programming capability, movable gun with provision for mounting the gun in either vertical or horizontal position, rotary table with tilting facility.

The Surface Preparation laboratory houses the following facilities,

1) A fume hood with blower.
2) An Ultrasonic Cleaner.
3) Chiller plant.
4) Acid circulating pumping system for electro-polishing 1000 Ampere / 20 Volt power supply.

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5) A class 100 clean room.
6) High pressure rinsing facility.
7) 18 MΩ-cm DI water plant.
8) Safety overhead shower and Eye wash.
9) Acid storage refrigerator.

The high vacuum furnace was supplied by M/s Hind High Vacuum, Bangalore. Its salient features are,

1)	Maximum Temperature	: 1300°C
2)	Ultimate Vacuum @ RT	: 5 X 10^{-8} Torr
3)	Vacuum @1300°C	: < 1 X 10^{-6} Torr
4)	Effective Heat Zone	:Dia 600mm X 1000mm Height
5)	Maximum Charge	: 100 Kgs
6)	Operation Mode	: Manual / Auto

Initially, a single QWR was successfully constructed and tested using this facility and then installed in the first module of the NSC linac. In the past year, two more QWRs have been fabricated. One of these cavities is shown in figure 1 along with the slow tuner Nb bellows. The measured Q curve for the first cavity is presented in figure 2. In addition, this facility has been used very successfully for repairs on the resonators which sprung leaks. The process for fabrication of fifteen resonators for the second and third linac modules have already begun.

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

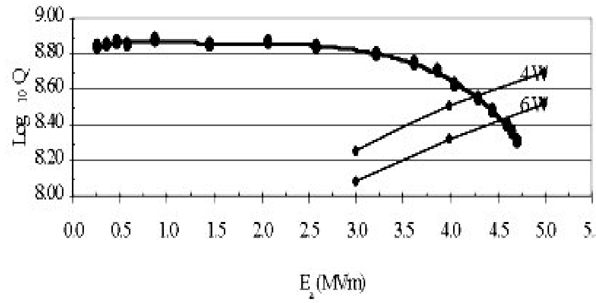

Figure 2: QWR-I1 cold test performance.

RESONATOR TESTS

Performance of the resonators are checked using the test facility before they can be mounted in the linac module. In this test set up, the resonators are phase locked using the resonator controller and Q value at different field levels are measured. The power required for achieving a filed level can thus be determined. The tuning range of the slow tuner is also measured using this set up.

Figure 3: View of top portion of Test Cryostat.

The test setup consists of the test cryostat, and the associated equipment that include the RF electronics for powering the cavity, the thermometry for temperature monitoring and the vacuum system controller. The Resonator is cooled to superconducting temperatures in the test cryostat shown in figure 3. The top flange of the cryostat is de-mountable and supports the liquid helium vessel and the resonator. A copper shield cooled through conduction provides thermal isolation to the helium vessel from the room temperature at the top. The outer body of the cryostat contains an annular liquid nitrogen vessel which completely surrounds both the helium vessel and the resonator and provides thermal isolation. The static heat load of the cryostat is ~ 4 W. The cryostat has been placed in a 5ft deep pit to allow easy lifting of the top flange and accessibility to the top flange connections.

The cryostat is wrapped on the outside with a 2mm thick lead sheet followed by a thin sheet of mu metal. The purpose of the lead sheet is to shield the X Rays emitted during the high power pulse processing of the cavity. The mu metal sheet has been installed to provide magnetic shielding to the Resonator from the earth's magnetic field with ambient magnetic field values of <15 mG at the center of the cryostat.

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 NSC 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. The assemblies had been procured from and welded by a vendor in USA. 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. One such repaired cavity is shown in figure 4.

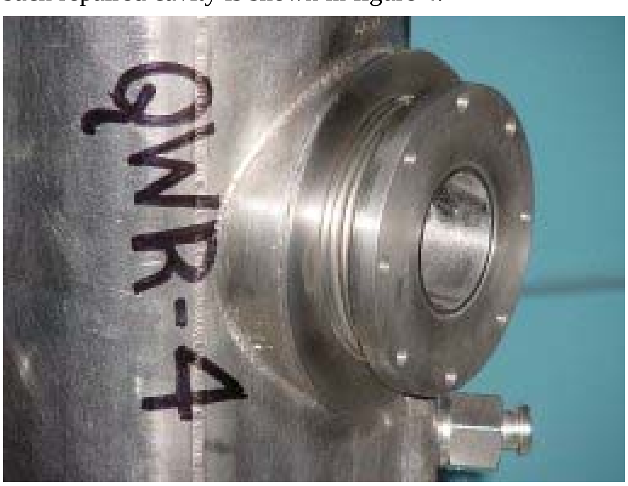

Figure 4: Coupling port bellow on a cavity after repair.

RF POWER & CONTROL

The aim of the resonator control unit is to adjust and maintain the amplitude and phase of the resonator constant with respect to the master reference. The approach for control is based on the principle of dynamic phase control. The circuit is designed in collaboration with Electronics division, BARC, Mumbai and is similar to the one being used for TIFR lead plated super-conducting cavities. 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. In order to incorporate the slow-tuner with the fast control a interface circuit has been designed and implemented with the resonator control circuit. Depending on the frequency error slow tuner control electronics works to bring the frequency close to reference by adjusting the pressure in the Nb bellows and during phase lock condition the phase error signal is used to take care of the slow scale perturbations to the resonator. During the testing of the resonator with the resonator control it was realized that 200Watt RF amplifier used for the control may not be sufficient to stabilize the amplitude and phase of the resonator at higher field gradients. Since some of our resonators are capable of giving high fields, a 400Watt, 97 MHz RF amplifier has been designed 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 numbers of amplifiers and parallel production job is taken up at NSC for more units.

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. It is necessary to know the phase of each resonator for proper tuning of the beam through LINAC. The commercially available phase meters work in the region of AF range. In order to use them for RF phase monitoring a phase meter input module has been developed. The module 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.

ON-LINE TEST OF LINAC

After carrying out about twenty cold tests of niobium resonators in test cryostat, eight resonators and a superconducting solenoid has been installed and aligned

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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.

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. Recently eight resonators along with a superconducting solenoid had 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. The beam bunching system of NSC [4] 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 is 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. A pulsed beam of $^{28}Si^{+7}$, 90 MeV, 1.5 ns FWHM was injected into the superbuncher which produced a beam of 300 ps FWHM at the entrance of Linac. A scattering chamber with two surface barrier detectors was installed at the entrance of linac to measure the energy and time width of the ion beam. Another scattering chamber with two surface barrier detectors was also installed after the first linac module to measure the energy of the ion beam after gaining acceleration from Linac. During this test, with five resonators live a total energy gain of ~ 6 MeV was measured at the exit of linac. No major problem was faced while accelerating the beam through the resonators of Linac and all five resonators could be maintained in phase locked condition for several hours. The transmission of the beam through Linac was close to 100%. The field levels in this test were quite low (1-2 MV/m) although field levels > 4 MV/m have been reached in previous tests. After opening the cryostat, coating of the brass was observed on the coupling ports of the resonators, through which rf power was fed to the resonators. The source of the coating was identified as the brass rack and pinion arrangement for movement of the rf coupler drive. The coupler design is being changed to avoid exposure of the brass portion to inside of the resonator and to provide better cooling through liquid nitrogen.

ACKNOWLEDGEMENT

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