SRF ACTIVITES AT IUAC, NEW DELHI AND OTHER LABORATORIES IN INDIA

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Abstract

SRF activities in India started with the programmes of superconducting linac boosters for the Pelletrons at IUAC, New Delhi and TIFR, Mumbai. Recently work on characterisation of Nb material has been initiated at RRCAT, Indore. A status of these activities is reported.

INTRODUCTION

Currently the programmes for addition of superconducting linac boosters for increasing the energy of heavy ions from the Pelletron accelerators at Inter-University Accelerator Centre (IUAC), New Delhi and Tata Institute of Fundamental Research (TIFR), Mumbai are nearing completion. The accelerating structures for both linacs are quarter wave cavity resonators (QWR). The QWR for IUAC is made of bulk Niobium while that for TIFR is made of Lead plated Copper. The accelerating structure for IUAC linac is a Nb QWR cavity operating at 97 MHz and optimised for β= 0.08 [1], whereas that for TIFR it is a Pb plated Cu QWR operating at 150 MHz, optimised for β = 0.1 [2]. At IUAC, 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.

At TIFR, all the QWR cavities required for the linac have been fabricated using the facilities at TIFR and Bhabha Atomic Research Centre (BARC) and tested for their performance. Recently there was a successful run of the linac with 23 out of 28 cavities tuned to the required frequency for acceleration of ion beams from the Pelletron.

At Raja Ramanna Centre for Advanced Technology (RRCAT), a programme for R & D on superconducting materials for accelerators has been recently started.

DEVELOPMENT AT IUAC, NEW DELHI

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 figure 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) at 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.

Three cavities have been fabricated and tested. Fabrication of 15 more cavities are nearing completion. The measured Q curve for the first cavity fabricated at IUAC is presented in figure 2.

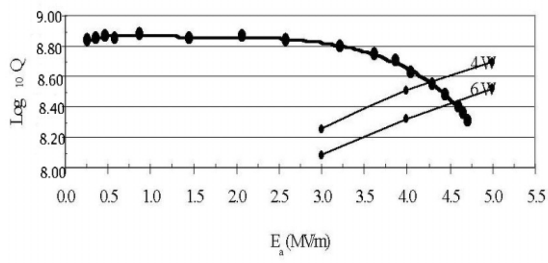

Figure 2: QWR-I1 cold test performance.

Repair Work on Existing QWRs

In addition to resonator fabrication for the linac modules several critical repair jobs have also been undertaken. 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 (figure 3) of the QWR has been adopted.

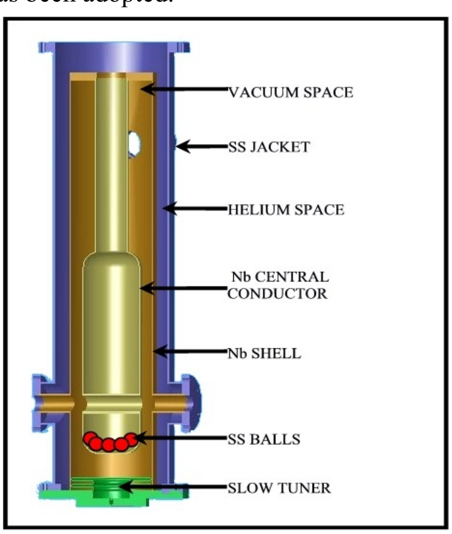

Figure 3. Schematic for the damping of vibrations of central conductor through stainless steel balls.

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 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[3].

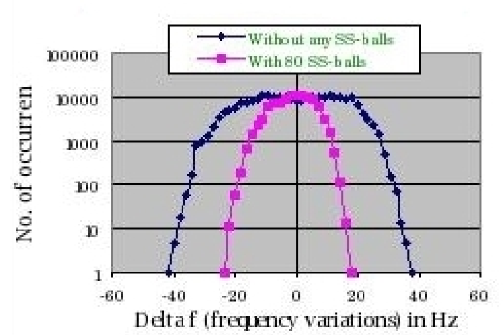

Figure 4. Damping in frequency jitter with ss balls in central conductor of resonator.

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. Two new designs of drive coupler were made. In one design, the rack and pinion was replaced by an worm and worm wheel and liquid nitrogen is used to cool the central and outer conductor. In the second design, the rack and pinion is kept outside of the cavity so that there is no chance of contamination.

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 with the rack and pinion outside.

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 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.

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) 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.

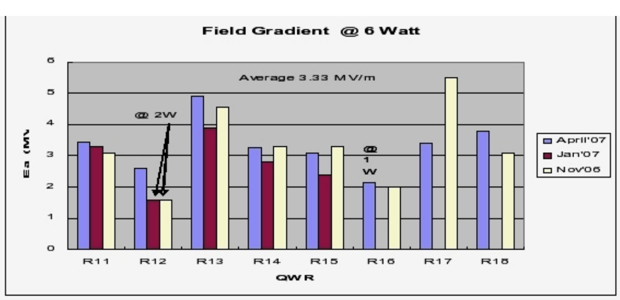

Figure 5. Field gradient achieved by 8 resonators on 3 on-line tests.

DEVELOPMENTS AT TIFR, MUMBAI

Each accelerating module in LINAC is a liquid He cryostat housing four lead coated (2µm) copper quarter wave resonators. The design and fabrication of the OFHC copper quarter wave resonators (QWR) was a major R&D effort. The resonators (figure 4) were fabricated and e-beam welded by Central Workshop, BARC. The frequency tuners and the RF couplers were made at Central Workshop, TIFR. Aarti Engineering, Mumbai was also involved in the machining during the production phase. The resonant frequencies of the cavities were matched prior to the brazing of the beam ports in a hydrogen furnace at SAMEER, Mumbai. The resonant frequencies were later fine-tuned by differential electro-polishing to within a few kHz. The cavities were Lead plated using a commercially available MSA (Methyl Sulfamic Acid) plating bath and were qualified by measuring the Q-value as a function of accelerating electric field. The QWR cavity is shown in figure 6.

Figure 6. End view of the lead plated Cu QWR for BARC-TIFR Linac booster.

The frequency tuner and the RF coupler mounted on the resonators in the cryostats are controlled by an external stepper motor drive. The tuner has a range of ±10 kHz and is used to match the resonant frequencies in the superconducting state to within 1 Hz. The RF Coupler has a wide range capable of coupling the cavity to a 50 Ω source over several decades of Q~10^4 (normal state) to Q~10^8 (superconducting state).

Each linac module houses 4 QWR and 7 such modules have been constructed and installed in the beam line. In the first phase 3 linac modules were used for beam acceleration followed by user cycle of experiments. In a recent test all seven modules were used for acceleration of ion beam and 23 out of the 28 resonators could be used. The energy gain for a Si 13+ beam achieved through each cavity during operation is shown in figure 7 and the total energy gain in figure 8..

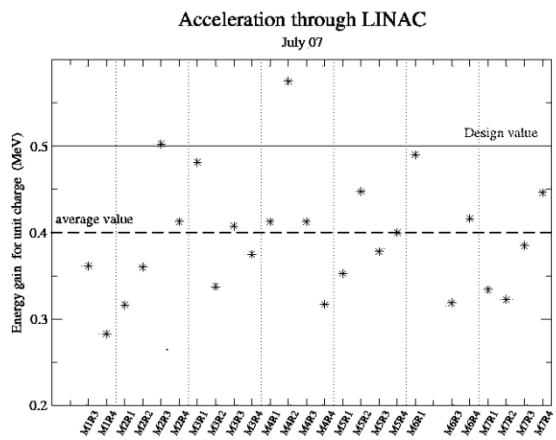

Figure 7. Energy gain through each QWR resonator for a Si13+ beam injected from the Pelletron.

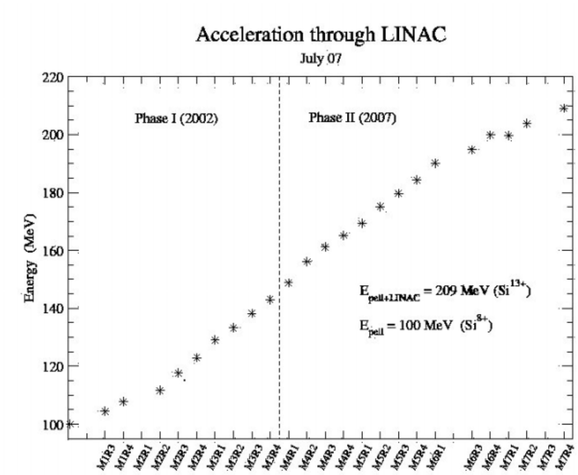

Figure 8. Energy gain by the Si beam from the Pelletron accelerator.

WORK AT RRCAT, INDORE

R &D on superconducting materials

The team at RRCAT, has started a programme for study of the effect on the surface properties of Nb material undergoing different treatments during the cavity fabrication process. They have measured the magnetisation versus temperature and magnetic field for Nb samples with different grain sizes and find that the value of Hc_1 for large grain sample(1mm grain size from Jefferson Lab) is higher (1200 Oe at 6K) than that for polycrystalline samples from Fermilab (for 30-35 ❍m grain size, the value is 1100 Oe at 5 K).

There are plans to set up a full fledged Nb cavity fabrication and testing facility for working on multi-cell cavities for high energy protons and electrons.

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