SRF ACTIVITIES AT IUAC

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Abstract

The SRF infrastructure at Inter-University Accelerator Centre was commissioned for fabricating superconducting niobium resonant cavities. Since then several quarter wave resonators have been successfully built for the linac. Designing of a low beta resonator for the high current injector system was recently completed, and two prototype niobium resonators are presently under construction. Fabrication of two single spoke resonators for Fermi Lab's Project-X, is nearing completion. In addition, two 1.3 GHz Tesla-type single cell cavities were successfully built in collaboration with RRCAT, Indore. This paper briefly reports the status of the present activities and future plans at IUAC.

INTRODUCTION

The infrastructure for fabricating superconducting niobium resonators was commissioned at Inter-University Accelerator Centre (IUAC) about nine years ago. Since then several quarter wave resonators (QWR) have been successfully built for the IUAC superconducting linac. In cold tests at 4.5 K the resonators have performed well over their nominal design goal.

Presently a high current injector (HCI) system is under development at IUAC, which will become an alternate injector for the superconducting linac. The HCI system will have different types of accelerating structures including a superconducting module containing low beta resonators. The low beta resonator has been designed and a room temperature model has been built. Prototype niobium resonators are presently under fabrication.

In addition to the in-house projects, the facilities have also been used for making cavities for other laboratories. For Fermi Lab's Project-X, IUAC is building two single spoke resonators, which are nearing completion. Raja Ramanna Centre for Advanced Technology (RRCAT), Indore and IUAC, have jointly built two 1.3 GHz niobium single cell cavities. They were successfully tested at Fermi Lab. In order to further improve their performance incorporating all the features from the lessons learnt out of the initial experience, two more single cell cavities are presently under fabrication.

The SRF infrastructure consists of an electron beam welding facility, surface preparation laboratory for electropolishing the resonators and high vacuum furnace for annealing and heat treatment of the resonators and its components. In addition, a test cryostat facility is available for testing the resonators at 4.5K.

In the following sections we briefly present details of the various projects, test results and their present status.

QWRs FOR SC LINAC

The superconducting linac consists of three modules. The first cryomodule is already commissioned and beams have been accelerated through it and delivered for user experiments [1]. QWRs for the second and third modules have been built using the infrastructure at IUAC [2]. Several resonators have been tested, and their performance has substantially exceeded the nominal design goal of 4 MV/m accelerating gradient with 4-6 W rf input power. As can be seen from figure 1, QWR-I15 has achieved the design gradient at less than 1 W power, whereas QWRs I6 and I4 have achieved it with about 2 W of rf power. The accelerating gradient at 6 W of rf power for QWR-I15 is 6.4 MV/m and for QWR-I6 & I4 around 5 MV/m. In pulsed operation the resonators could achieve almost 25% higher gradients. So QWR-I15 could be pulsed upto 8.8 MV/m, corresponding to a peak magnetic field of around 116 mT. In figure 2, the performance of this resonator is shown. The QWRs are now being readied for installation in the second and third cryomodules.

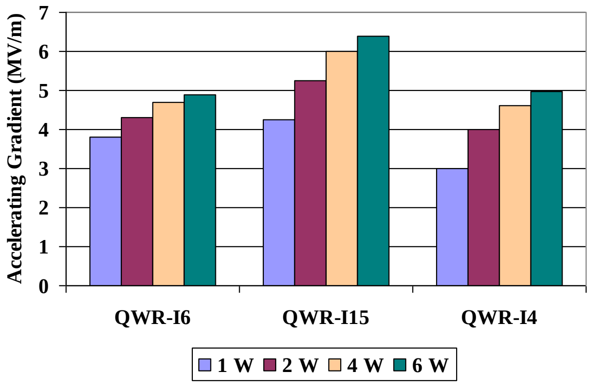


Figure 1: Accelerating gradient achieved in three different QWRs at different input power levels.

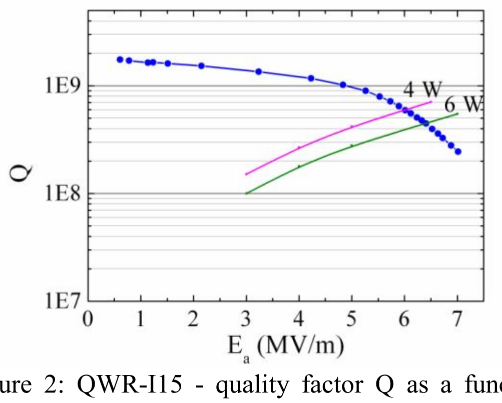


Figure 2: QWR-I15 - quality factor Q as a function of accelerating gradient E_a at 4.5 K.

LOW β RESONATOR

A high current injector (HCI), as an alternate injector for the superconducting linac, is currently under development at IUAC. The HCI system will consist of several different types of accelerating structures including a superconducting module containing low beta resonators. Designing of the low beta quarter wave resonator has been completed; the details are presented elsewhere [3]. In figure 3, a cut away 3D view of the low beta resonator is shown, which is optimized for β=0.05 operating at 97 MHz. This is the same frequency as the QWRs in the main linac. The electromagnetic design of the resonator has been carefully optimized to minimize the peak electric and magnetic fields while maintaining high values for the shunt impedance and geometry factor. In order to validate the electromagnetic parameters, a room temperature copper model was built. Bead pull measurements were made on the copper model to measure the on-axis electric field, stored energy, energy gain and transit time factor. Construction of two niobium prototype resonators is currently underway.

The niobium resonator will be jacketed in an outer stainless steel vessel, like the QWRs in the main linac. The transition from niobium to stainless steel will be provided using flanges made out of explosively bonded niobium-SS plates. Over the past several years many modifications and improvements have been made in this clamp-shell type outer vessel design and its fabrication, which has made it quite reliable.

The slow tuner, presently used on the QWRs in the main linac, will also be used on the low beta resonator. It is expected to provide a tuning range of about 100 kHz for a pressure change of 20 psi, corresponding to about 3 mm motion of the bellow. The tunability of the low beta resonator, using a mock slow tuner, has been verified on the room temperature copper mode.

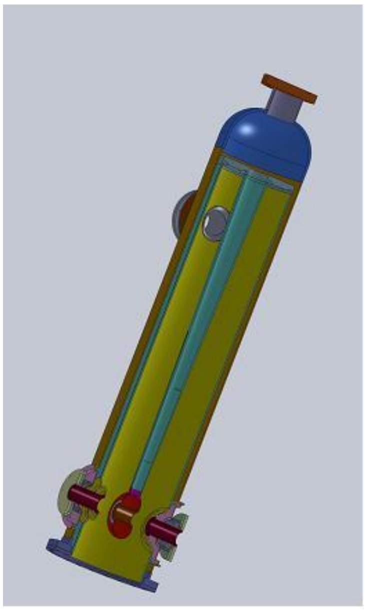


Figure 3: 3D cut away view of the low beta resonator.

SINGLE SPOKE RESONATORS

IUAC is constructing two niobium single spoke resonators – SSR1, for Project-X at Fermi National Accelerator Laboratory (FNAL), USA. The resonator is optimized for β=0.22 and operates at 325 MHz. In figure 4, an exploded view of SSR1 is shown. The resonator has three major sub-assemblies; namely the outer cylindrical shell, spoke and end walls. The stainless steel jacketing will be done at Fermi Lab.

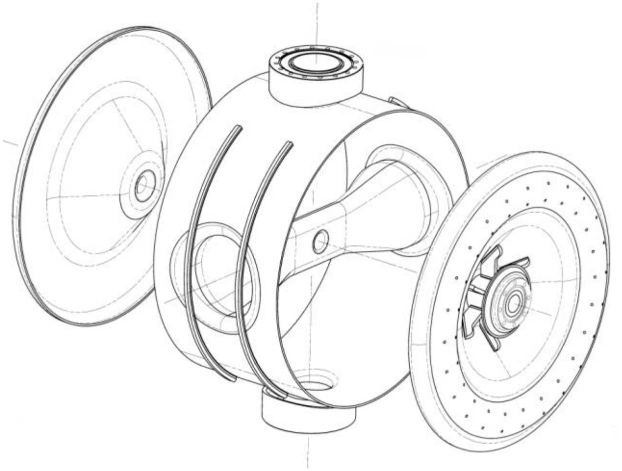


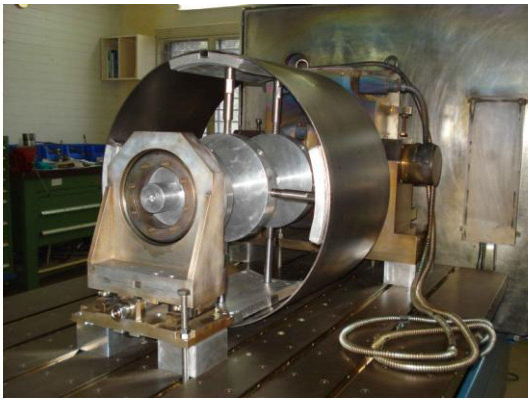
Figure 4: 325 MHz, β=0.22 Single Spoke Resonator - SSR1. The outer shell diameter is about 500 mm.

The spoke is formed in two hales and welded together. The end wall is formed from a single sheet of niobium, whereas the shell is rolled and seam welded. The spoke joins the shell through the two collars attached on either side of the spoke. The coupler ports on the shell and the beam ports on the end wall are made of niobium tubes brazed to stainless steel flanges. While the tubes for the coupler port were made at IUAC, the brazing itself was done at Argonne National Lab, USA.

Due to the large size of SSR1 and the tight tolerance required on the components for electron beam welding, fabrication of the resonator is non-trivial. For process validation, several trials were taken on copper material after the dies had been made. Even then, there was a lot of difficulty faced during the forming of the niobium components, primarily due to the difference in the physical properties and annealing condition of the copper and niobium sheets. The problem was worsened due to lack of contingency niobium material available. In figure 5, the niobium end wall and half spoke are shown.

Figure 5: (a) Left – End Wall formed in niobium. (b) Right – Half Spoke formed in niobium and after machining the edges and ends.

In figure 6 (a) and (b) the shell seam welding and half spoke welding setups respectively, are shown. At present the end wall assembly is being completed. Simultaneously the outer shell is being readied for attaching the coupler ports. After completion, the three major sub-assemblies will be electropolished before joining them together. We plan to ship the two spoke resonators to FNAL by May of this year.



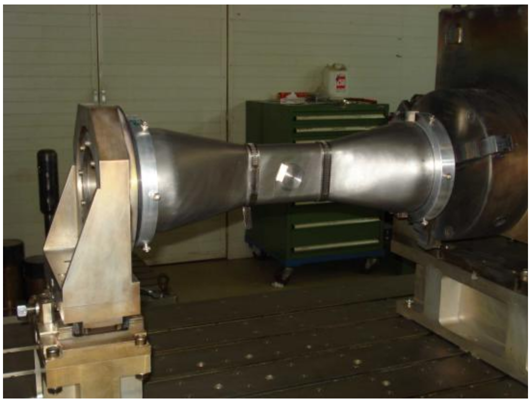


Figure 6: Electron beam welding setups showing, (a) above – outer shell, (b) below – spoke halves.

1.3 GHz SINGLE CELL CAVITY

Under the Indian Institutions and Fermi Lab collaboration (IIFC), RRCAT and IUAC have jointly fabricated two 1.3 GHz Tesla-type niobium single cell cavities. In figure 7, one of the cavities is shown. The cavity components were formed and machined at RRCAT, while the pre-weld cleaning and electron beam welding were performed at IUAC. In addition to extending its facilities, IUAC has also shared its expertise and experience in process development as well as in designing fixtures, especially those required for welding.

The single cell cavity development posed several challenges for the IUAC team, most notably in developing good welding parameters for the niobium-titanium flange to the niobium tube, and the equator joint which joins the two half cells. The physical properties of Nb-Ti and niobium are significantly different, which is further worsened by the thick flange, which acts like a large heat sink, compared to the niobium tube.

The equator joint lies in the crucial high magnetic field region. The joint is accessible only from outside for welding. Parameter for this joint was tricky to develop within the limited amount of niobium material available. The equator welding on the first cavity produced a reasonably good weld bead, with plenty of scope for improvement. On the second cavity the parameter was slightly adjusted and it produced a better bead, although it was felt that there was still scope for improvement.

The cavities were shipped to Fermi Lab, where they were processed and tested. Details of this will be presented elsewhere [4]. In cold test at 2 K the first cavity produced an accelerating gradient of 19 MV/m, before quenching. The second cavity was tested twice. In the first test the cavity achieved an accelerating gradient of 21 MV/m, before quenching. After further processing, the cavity was again tested and it could achieve a gradient of 23 MV/m. In figure 8, the 2 K test results of the second cavity are shown. The slightly better equator weld bead produced in the second cavity is perhaps responsible for the marginally higher accelerating gradient achieved in it.

Figure 7: 1.3 GHz Tesla-type niobium single cell cavity.

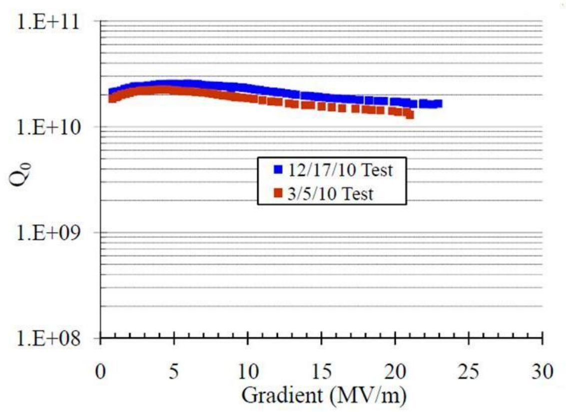


Figure 8: Quality factor Q_0 as a function of accelerating gradient at 2 K, on the second 1.3 GHz single cell cavity.

Encouraged by the results achieved on the first two cavities, two more single cell cavities are now being built. They will incorporate several features out of the lessons learnt from the initial construction. They include, buffer chemical polishing of the half-cups (to remove 20 μm material) before completing the cavity, better control on the forming and handling of the cavity components and development of a better welding parameter for the equator joint. Trial weldings are being done on niobium half-cups to simulate the actual cavity. The development is aimed at producing a smooth and uniform under bead on the equator joint.

At present two half cells, for completing the first cavity, have been fabricated. The parameter development for the equator joint is expected to be over in the next few weeks. The first cavity will be completed soon after that.

FUTURE PLANS

After the improved 1.3 GHz single cell cavities are completed, there are plans to fabricate a 1.3 GHz 5-cell niobium cavity with simple end tubes. The decision to make a 5-cell cavity was dictated by the available chamber size in the electron beam welding machine at IUAC. It is believed that several issues, such as frequency tuning, field flatness, tooling design etc. will get addressed during this exercise. The lessons learned would be useful when the 9-cell cavities will be made at RRCAT. In figure 9, the five cell cavity is shown. Development of the end group for the 9-cell cavity will be taken up separately. In the second stage the simple end tubes may be replaced with the proper end groups. In addition, there are plans to develop a single cell β=0.9, 650 MHz cavity (see figure 10), eventually leading to a 650 MHz 5-cell cavity.

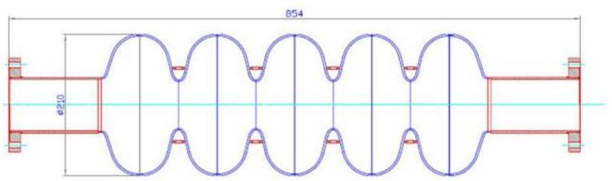


Figure 9: 1.3 GHz 5-cell cavity with simple end tubes.

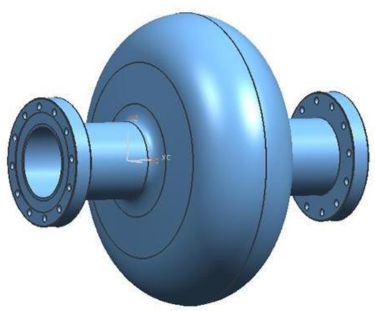


Figure 10: 650 MHz, β=0.9 single cell cavity.

CONCLUSIONS

The SRF infrastructure at IUAC has been operational since 2002. Presently this is the only facility in India for constructing superconducting niobium resonant cavities. The QWRs fabricated using the in-house facilities have performed exceedingly well. Construction of two prototype low beta niobium resonators has started. The single spoke resonators for Project-X are in advanced state of completion. The first two 1.3 GHz single cell cavities have achieved high gradients. Two more improved single cell cavities are being built, with the first cavity expected in the next few weeks. There are plans to build 1.3 GHz 5-cell cavity and 650 MHz single cavity in the next one year.

ACKNOWLEDGEMENTS

The authors would like to thank all the members of the linac group for their help in testing the QWRs. Help received from the cryogenics group and electronics group is acknowledged. Some portion of the work reported here is done in collaboration with Fermi Lab, USA and Raja Ramanna Centre for Advanced Technology, Indore. The authors acknowledge the help received from all the technical collaborators from these two institutions.

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