DEVELOPMENT OF SUPERCONDUCTING CAVITIES AND RELATED INFRASTRUCTURE FOR HIGH INTENSITY PROTON LINAC FOR SPALLATION NEUTRON SOURCE

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Abstract

Raja Ramanna Centre for Advanced Technology (RRCAT) has taken up a program on R&D activities of a 1 GeV, high intensity superconducting proton linac for a spallation neutron source. The proton linac will require a large number of superconducting Radio Frequency (SCRF) cavities ranging from low beta spoke resonators to medium and high beta multi-cell elliptical cavities at different RF frequencies. A dedicated facility is being set up for development of multi-cell superconducting cavities and their performance characterization. 1.3 GHz single-cell SCRF niobium cavities have been developed to establish the fabrication procedure. These cavities has exhibited high quality factor with an accelerating gradients up to 37 MV/m. A novel technique of laser welding of 1.3 GHz niobium cavity has been developed and demonstrated performance comparable to electron beam welded cavity. A dedicated facility for SCRF cavity forming, machining, electron beam welding, RF characterization, cavity tuning and cavity processing is being set up. To characterize a SCRF cavity at 2K, a vertical test stand has been developed and a horizontal test stand has been designed.

INTRODUCTION

Raja Ramanna Centre for Advanced Technology (RRCAT) has taken up a program on R&D activities of a 1 GeV, high intensity superconducting proton linac for a spallation neutron source for research in the areas of condensed matter physics, materials science, chemistry, biology and engineering. The major sub-systems of the spallation neutron source would comprise of a 1 GeV high power superconducting pulsed H- linac, an accumulator ring, spallation target and beam lines. The first step towards realizing these long term objectives is to develop capabilities to build superconducting linac that can reliably and efficiently deliver a high intensity H-/ proton beam of 1 GeV energy. RRCAT has taken up R&D activities for the development of a 1 GeV superconducting pulsed H- linac for Indian spallation neutron source (ISNS) [1].

A program for setting-up of a infrastructure facility for development of SCRF cavity at RRCAT was approved. The facilities include SCRF cavity forming, machining, electron beam welding, RF characterization, cavity tuning and cavity processing has been set up at RRCAT. The cavity processing includes centrifugal barrel polishing, electro-polishing, thermal processing and high pressure rinsing. A dedicated building has been constructed to house this infrastructure and clean rooms for assembly and testing of cavities. Few 1.3 GHz and 650 MHz cavities have been fabricated and tested, showing excellent performance. A prototype blade tuner mechanism for 1.3 GHz niobium cavity has also been developed. A vertical test stand (VTS) has been commissioned.

INFRASTRUCTURE FACILITY FOR DEVELOPMENT OF SCRF CAVITIES

Cavity Fabrication Facility

A dedicated 120 Ton hydraulic press has been installed for forming of cells of SCRF cavity from high RRR niobium sheets. High strength aluminium alloy 7075-T6 is used for fabricating deep drawing die-n-punch, tooling and fixtures for trim machining of cavity halves. The cavity halves are joined together using an electron beam welding (EBW) in high vacuum. An EBW machine of 15 kW beam power has been procured and installed, as shown in Figure 1. The EBW machine has a large size vacuum chamber which is capable of welding from low to high beta SCRF cavities required for the high intensity proton linac.

Figure 1: 15 kW electron beam welding machine.

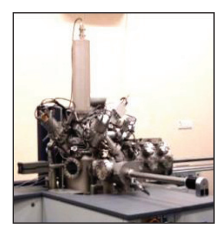

Figure *2*: Secondary ion mass spectrometer.

Material Characterization Facility

A material characterization facility has been set up to support the SCRF cavity development. This includes a 50 kN universal testing machine capable of measuring mechanical properties of samples of cavity materials and stiffness of multi-cell SCRF cavity. A time of flight secondary ion mass spectrometer (TOF-SIMS) has been installed, to analyze the impurity distribution in high purity niobium at different processing steps as shown in Figure 2. A 3-D laser scanning confocal microscope with 1 nm depth resolution, capable of measuring the surface

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roughness and profile of various defects has also been set up. Metallographic facilities comprising of a polishing machine, a mounting press, a precision cutting machine, and a micro-hardness tester are also set up. A test setup for RRR measurement for niobium samples is available and routinely operated for niobium material qualification.

SCRF Cavity Processing Facility

Major sub-systems of cavity processing facilities installed are centrifugal barrel polishing (CBP) machine, electropolishing setup, high pressure rinsing (HPR) setup, horizontal high vacuum annealing furnace for thermal processing etc. 1.3 GHz single-cell SCRF cavities have been polished and processed using the facility.

A larger CBP machine to accommodate up to five-cell 650 MHz cavity is under fabrication. A horizontal continuous electro-polishing setup is developed for electro-polishing of the niobium cavities Figure 4. EP process testing has been carried out on a single-cell 1.3 GHz and 650 MHz cavity using this facility. A HPR set-up has been developed. It comprises of a linear motion system, a rotary mechanism to rotate the water jets at 2 to 20 rpm, coming out from fine nozzle tips fitted at the end of a vertical pipe. A high pressure pump is used to produce water jets of 100 bar pressure.

Figure 3: Barrel polishing machine.

Figure 4: Electro-polishing setup.

One fine-grain and one large grain single-cell 1.3 GHz cavity was processed by utilizing the in-house developed facility [2]. As a first stage of processing, the cavity was mechanically polished using centrifugal barrel polishing (CBP) machine. The cavity was barrel polished for with various media, including final polishing by a 0.04 micron colloidal silica solution. After the barrel polishing, the cavities were chemically polished by electropolishing.

A dedicated high vacuum annealing furnace has been commissioned for thermal processing of SCRF cavities. Thermal processing of cavities at 800°C for 2-3 hours or 600°C for 6-10 hours is necessary to reduce the hydrogen concentration to a few atomic ppm in the bulk and in the surface layer. The furnace has a hot zone of diameter 825 mm and 1525 mm length with a maximum temperature of 1400°C and a temperature stability of ±5°C. For processing, assembly and low power RF testing of the cavities clean rooms from Class-10000 to Class-10 are planned.

Construction of a cavity fabrication and processing building has been completed for housing infrastructure facilities for cavity fabrication, chemical processing and assembly. Construction of new Cryogenics building has also been completed for housing cavity test facilities (VTS and HTS) and related infrastructure.

DEVELOPMENT OF SCRF CAVITY

Stage-wise development of SCRF cavity manufacturing technology has been carried out, starting from single-cell cavity to multi-cell cavities. Design and development of various tooling and fixtures for forming, machining, welding and RF testing were carried out. The electron beam welding was carried out at Inter university accelerator centre (IUAC), New Delhi and industries. The cavity processing and testing at 2 K was carried out at Fermilab and Argonne National Laboratory (ANL), USA under Indian Institutions and Fermilab Collaboration (IIFC). The cavities achieved an accelerating gradient > 37 MV/m with the quality factor > 2.1×10^{10} during testing at 2 K. [3]

Figure 5: 1.3 GHz Nine cell SCRF cavity.

The development of 1.3 GHz five-cell and nine-cell SCRF cavities was taken up as next step. A 1.3 GHz nine-cell SCRF cavity has been fabricated recently shown in Figure 5. This will now be taken up for various qualification processing including RF, mechanical and vacuum leak testing. It is planned to process and test the cavity at 2 K using RRCAT VTS facility.

A single-cell 650 MHz, beta=0.9 SCRF cavity was fabricated at RRCAT and EB welding was carried out at IUAC, New Delhi facility Figure 6. The processing and 2 K testing was done at Fermilab under IIFC for performance evaluation [4]. The cavity achieved the accelerating gradient (Eacc) of 19.3 MV/m with excellent quality factor Q_0 7×10^{10} at 2.1K during VTS testing. The cavity performance exceeds the rated specification of acceleration gradient (Eacc) of 17 MV/m with quality factor $Q_0 > 2.0 \times 10^{10}$ shown in Figure 7. The cavity was free from field emission and multipacting.

Laser Welding of 1.3 GHz SCRF Niobium Cavities

An innovative technique to fabricate SCRF niobium cavities by laser welding has been developed. The idea was conceptualized and developed for the first time at RRCAT. An international patent has been filed with title "Niobium based superconducting radio frequency cavities comprising niobium components joined by laser welding, method and apparatus for manufacturing such cavities".

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The laser welding setup developed for the purpose is shown in Figure 8. A 10 kW fibre coupled Nd:YAG laser developed at RRCAT has been used. The laser welding experiments were carried out on more than 150 samples for parameter optimization and the world's first laser-welded 1.3 GHz SCRF cavity was developed. This cavity was processed and tested at Fermilab, USA. It reached an acceleration gradient of 31.6 MV/m with a quality factor of 1.0 x 10^{10} at 2 K as shown in Figure 9. [5].

Figure 6: 650 MHz single-cell SCRF cavity.

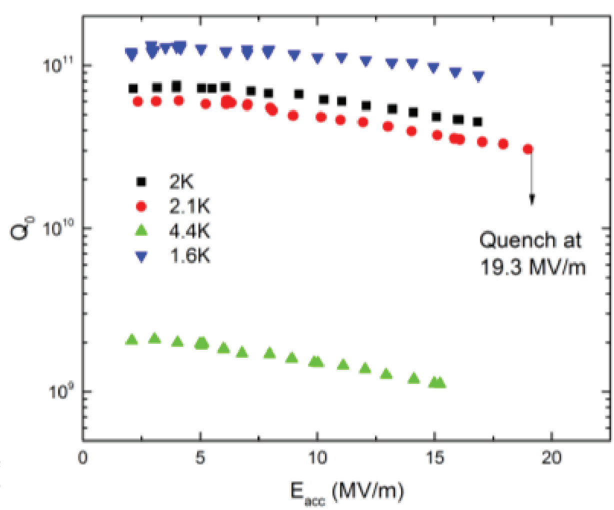

Figure 7: The Q_0 vs E plot of 650 MHz cavity.

SCRF Cavity Tuner Development

Tuner is an essential part of an SCRF cavity, which corrects the resonance frequency after cool down to 2 K. It also controls the resonating frequency instabilities (Lorentz detuning, microphonics etc.) during operation. A prototype blade tuner has been fabricated along with a prototype nine-cell 1.3 GHz cavity (in copper) for qualifying the tuner. The tuner sensitivity, stiffness, hysteresis, resolution and precise control of the tuner was tested at liquid nitrogen temperature. The tuner is also tested with piezo actuators, which are required for fast tuning control of the cavity frequency.

Figure 8: Laser-welding setup.

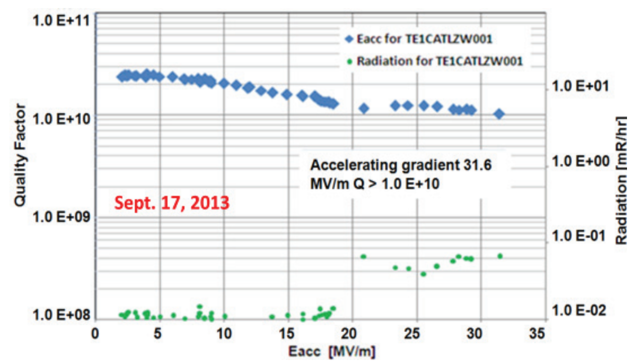

Figure 9: Test results of laser-welded single cell cavity.

CAVITY TESTING FACILITY

SCRF cavities have to be qualified for their performance prior to installation in a cryomodule of a superconducting linac. First, the bare cavities are tested in a saturated bath of liquid helium at a temperature of 2 K in the Vertical Test Stand (VTS). Cavities, qualified in VTS are then dressed with their auxiliary equipments, like helium vessel, HOM couplers, cold tuner and main coupler. These dressed cavities are then tested in a Horizontal Test Stand (HTS).

The vertical test stand consists of a large size liquid helium cryostat, an RF power supply and control system, and a liquid helium (LHe) and liquid nitrogen (LN_2) piping system. The SCRF cavity is tested for the quality factor (Q) and accelerating gradient (E) at 4.2 K and 2 K. The facility has been commissioned and benchmarked by testing a single-cell 1.3 GHz SCRF cavity tested earlier at Fermilab, USA. The details of development and commissioning of VTS facility has been reported else where in this conference [6].

A horizontal test stand (HTS) has been designed. This system will facilitate testing two SCRF cavities at a time. It can be used for testing SCRF cavities in both CW and pulse mode.

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