DEVELOPMENT OF INFRASTRUCTURE FACILITIES FOR SCRF CAVITIES AT RRCAT

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Abstract

RRCAT has taken up a project on development and setting up of a necessary infrastructure for development of superconducting cavities for Department of Atomic Energy's future programs (domestic and International collaboration) related to development of medium beta – high beta range SCRF cavities for H- ion/proton linac for spallation neutron source and also for high energy electron linac for IRFEL /ILC applications. Under this program a separate building is presently being constructed to house the SCRF cavity forming and fabrication facility, electron beam welding machine, cavity processing facility, high pressure rinsing facility, assembly, low power RF characterization etc.. A bench for electro-polishing of SCRF cavity has also been developed. A facility is also being setup to study the centrifugal barrel polishing of SCRF cavity. A high pressure rinsing facility for cavity cleaning has setup. A pilot clean room is ready to measure the cavity RF parameters like frequency for half cells, dumbbells and bead-pull perturbation setup for measuring the field distribution in the cavity. For characterization of a SCRF cavity a 2 K Vertical Test Stand is required. Engineering design of a large size 2 K cryostat has been completed and fabrication is under process. Separate buildings are also under construction to house the necessary lab space for materials and cavity polishing process characterization.

INTRODUCTION

RRCAT has taken up a Project on "Development of Superconducting Cavities and Associated Technologies for High Energy Accelerators & their Applications" to establish basic infrastructure and to develop the technologies needed for production of superconducting cavities required for various accelerator programs in DAE. Fabrication of SCRF cavities is an important accelerator technology to provide efficient, high current and high gradient accelerating structure for nearly all major accelerator projects. This project will develop manpower and technology in the required direction.

The infrastructure will be developed in the areas of SCRF cavity fabrication, chemical processing, cleaning, assembly and testing for accelerator applications like XFEL, SNS, ERLs etc.

The infrastructure facilities will be capable to develop SCRF cavities required for electron and proton acceleration. High purity Niobium (~300 RRR) will be the material for cavity fabrication. Cavity shapes designed for producing the suitable electromagnetic fields for the required acceleration will be formed by deep drawing process using special die-n-punch. The joining of Niobium cavities (halves and cell to cell) and their parts will be performed using Electron Beam Welding, since this process ensures a smooth weld joint for Niobium sheet material and also controls the impurities level in the cavity welding region. The cavities will be tuned for the resonating RF frequency and field distribution. A frequency tuning setup will be developed. The high quality factor and low surface resistance are important for achieving high accelerating gradient in the SCRF cavities. The chemical processing of cavities helps in improving Q value. Around ~ 100 microns layer of Niobium surface is removed in chemical processing by employing Electro Polishing, Buffered Chemical Polishing and / or mechanical polishing (Barrel Polishing). The cavities will be cleaned by high pressure rinsing using Ultra Pure water and dried in clean room before assembly. The cavity surface would be analyzed for elemental contaminations using Secondary Ion Mass Spectrometry (SIMS) techniques. The cleaned cavities will be tested in test cryostat for the Q and the accelerating gradients. The cavities will be assembled with RF power coupler and tuners in clean room area of Class 10 before finally dressed in the cryomodule for testing and beam acceleration.

SCRF CAVITY FABRICATION FACILITY

The SCRF cavities will be made using high purity bulk Niobium material. Niobium blanks cut from high purity fine grain rolled Nb sheets. A detailed quality control is needed for checking the quality of Nb sheets received from the manufacturer for pits, scratches or inclusions of foreign material prior to use in forming cavities. The cavity shapes (halves) are will be formed by deep drawing of Niobium sheet using special die-n-punch on special hydraulic press (Fig. 1).

Figure 1 : Deep drawing 120 ton capacity hydraulic press and few deep drawn half cells of 1.3 GHz SCRF cavity

High strength grade of Aluminum alloy 7075-T6 is used for deep drawing die-n-punch, tooling & fixtures for trim machining of cavity halves for proper sizing before welding. A metallurgical laboratory containing different material testing equipments like universal testing machine, micro hardness tester, metallurgical microscope has been setup.

A CNC 3-D co-ordinate measuring machine will be procured for assessing the form accuracy of the cavity and sizes.

The cavity halves will be joined together using Electron Beam Welding Machine in high vacuum to minimize contamination during welding. Initially single cell elliptical cavities will be produced using EBW. After establishing the fabrication, processing and performance testing of single cell cavity, multi-cell cavities will be produced. An EBW machine of 15 kW beam power is being procured and will be installed for welding SCRF cavity parts. The EBW machine procured will also be capable to handle larger SCRF cavity fabrication for low beta superconducting cavities required for proton linac.

It is proposed to set up a chemistry lab to optimized the process parameters for chemical processing of SCRF cavities.

SCRF CAVITY PROCESSING FACILITY

It is a challenging task to produce SCRF cavities with required high accelerating gradient (~ 25 MV/m and higher). To achieve reliable production of high performance cavities one needs to couple processing and performance tests in a tight-loop program to determine which parameters or processes lead to the observed variability in cavity performance.

During SCRF cavity processing bare cavities (single cell / multi-cell) are chemically processed and vertically tested in a test cryostat at 4.2 / 2 K. The goal is to develop a specification and reproducible procedures for the chemical processing. It must be demonstrated that the design gradient can be repeatedly produced. Since more than one recipe may have to be explored in the next few years, extensive infrastructure is needed.

After vertical test, successfully tested cavities are dressed with helium vessels and prepared for horizontal test. Cavities which fail vertical test are reprocessed at and returned again to vertical test until design gradient is met.

The Cavity Processing Facility will include centrifugal barrel polishing (CBP), buffered chemical processing (BCP) and Electro-polishing (EP) to produce smooth RF surfaces, High Pressure Rinse (HPR) stations to remove particulates from cavity surfaces, vacuum furnaces to remove hydrogen and for low temperature baking, cavity tuning equipment to remove cell to cell variation and achieve field flatness, cavity initial QC, and other infrastructure and equipment to support the cavity processing.

Major infrastructure & systems of the Cavity Processing Facility are listed below:

Mechanical and Chemical Polishing Setups

Centrifugal Barrel Polishing Machine

Superconducting RF cavities are designed to operate for accelerating gradients of ~ 35-40 MV/m. The fabrication processes introduce defects in the surface layer. Therefore surface layer of up to 120-150 microns is to be removed by mass finishing operations. Surface finish of the cavities needs to be of a high quality for operation at high RF voltages. A surface finish of around 100 nm is obtained using barrel polishing. Fig. 2 shows a centrifugal barrel polishing designed and developed at RRCAT, Indore with the help of a local fabricator. The machine has been designed to accommodate two numbers of single cell 1.3 GHz SCRF cavities. The rotational speed can be varied from 0 to 200 rpm.

Figure 2 : Barrel polishing machine for Single cell 1.3 GHz SCRF cavity

The mass finishing media is filled inside the cavity. The cavity is mounted on fixtures Fig 3 & Fig 4. and placed in barrels that are fixed on a rotating turret. The barrels rotate on their own axis as well as revolve about the turret axis.

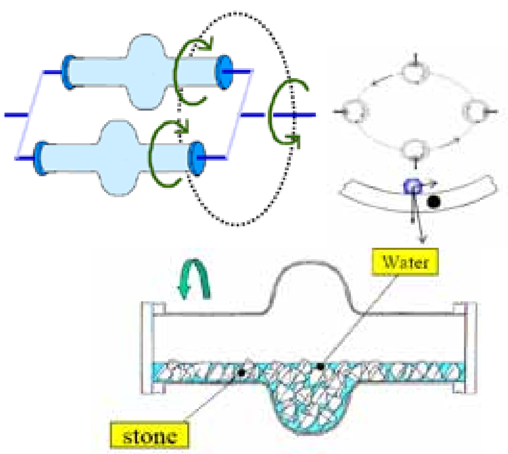

Figure 3 : Working of barrel polishing machine cavity filled with water and abrasive media.

Figure 4 : Single cell cavity with mounting fixture for centrifugal barrel polishing machine.

Centrifugal Barrel Polishing Process

Mass finishing media (ceramic and plastic) shown in Fig 5, are used along with water for barrel polishing of SCRF cavities. Finishing media is filled up to half the volume of the cavity and water is filled to just cover the media. At the start coarse ceramic media is used. It is followed by plastic media. Final finishing is done using corn cob. Barrel polishing is followed by cleaning with ultra pure water agitated by ultrasound.

(a) (b) (c)

Figure 5 : Different types of mass finishing media
(a) Ceramic media, (b) Plastic media, (c) Corn cob

Barrel polishing machine trials on few single cell 1.3 GHz cavities fabricated in OFE Copper and Aluminium were carried out. With the use of ceramic and plastic media the surface finish of ~ 0.20mm was achieved.

Electro-polishing set-up

EP is an electro-chemical method of removing thin layers of metal from cavity surface by anodic dissolution.

In the basic electro-polishing set-up, SCRF niobium cavity is the anode and the hollow coaxial Al pipe is cathode, placed along the cavity beam axis. The cathode is made from pure aluminum (1100 series). The electrolyte is a mixture of hydrofluoric (HF) and sulphuric acid (H_2SO_4). As current flows through the electrolytic cell, the niobium surface absorbs electrons and oxygen to convert to niobium pentoxide, which subsequently dissolves in the electrolyte.

A horizontal continuous electro polishing setup (Fig. 6) is being developed for electro polishing of SCRF cavities. In this system, the cavity is held in a horizontal position during electro- polishing. About 60% of the cavity volume is filled with the electrolyte. The cavity is rotated at a low speed.. The hydrogen evolved during the process is flushed away using a flow of Nitrogen gas. The system can move the cavity from horizontal to vertical position for mounting of cathode and for draining of electrolyte and rinsing of cavity after the process.

Typical operational parameters (Table 1) for Electro polishing system are:

Table 1: Parameters of EP system

Parameter	Value
Voltage	0-20 V
Current density	30-150 mA/cm^2
Temperature	25-35^{o}C
Temperature stability	+/- 1 ^{o}C
Acid flow	2 - 15 lpm
Cavity rotation	2-5 rpm
Removal rate	0.3 to 0.4 μm/min

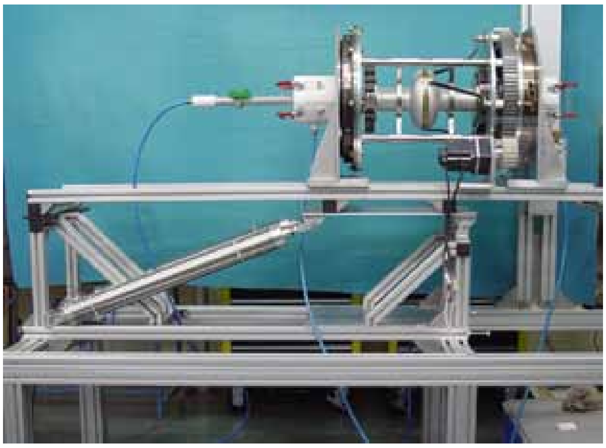

Figure 6 : Electro polishing setup.

Clean Room Facility

As any particulate impurity on the SCRF cavity surface can influence the maximum achievable gradient, contamination by particulates has to be avoided. For the optimum performance of the SCRF Cavities it is recommended to work under clean and controlled conditions. For processing, assembly & low power RF testing of super conducting cavities clean rooms from Class 10000 to Class10 are planned in the SCRF processing building at RRCAT. The layout of the clean rooms planned is shown in Fig. 7

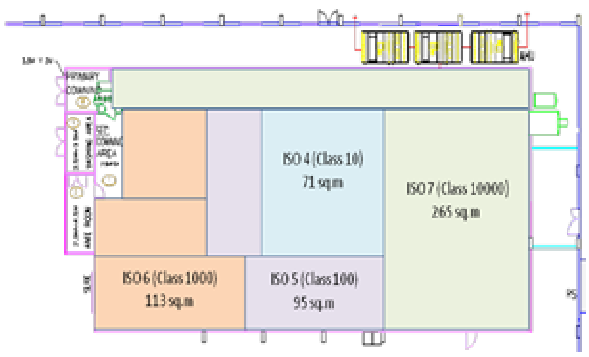

Figure 7 : Clean room layout in SCRF Building

High pressure rinsing set-up

High pressure rinsing (HPR) is a super-cleanliness process for the surface preparation of high field superconducting cavities. In this process high pressure jets of ultra-pure water dislodge surface contaminants from the cavity surfaces that normally resist removal with conventional rinsing procedures, leading to substantial reduction in field emission and better cavity performance. A HPR set-up has been developed at RRCAT. The set-up comprises of a linear motion system capable of moving 1.2 meter long 9-cell cavity, vertically up and down at a speed of 50 to 500 mm per minute and 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. In order to remove any particulate contaminants in the water generated at the rotary joint, a water filter of 0.05 micron rating has been provided before the nozzles. A piston pump is used to produce water jets of 100 bar pressure. The set-up shown in Fig. 8 is installed in a class 100 clean enclosure.

Figure 8 : Photograph of HPR set-up and working scheme

Ultrapure water (UPW) treatment system for producing ultrapure water required for HPR process has been procured and installed. It has a capacity to deliver Ultra pure water with resistivity of 18 M-ohm-cm at a flow rate of 10-12 litres per minute, having a TOC count of less than 5 ppb.

Facility for Thermal processing of SCRF cavities

EP generates copious quantities of hydrogen at the cathode, which can penetrate into the niobium. The danger increases during EP process when hydrogen bubbles come in direct contact with the Nb surface. With more than 100 atomic ppm; Hydrogen dissolved in Nb surface/bulk; there is a danger of Niobium hydride precipitation during cool-down (at around 100 K), especially for high RRR cavities. This results in reducing the quality factor of the cavity at high accelerating gradient. This is known as Q-decease. A furnace treatment at 800°C for 2 hours or 600°C for 10 hours reduces the hydrogen concentration to a few atomic ppm in the bulk and in the surface layer. For thermal processing of Niobium superconducting RF cavities, a dedicated high vacuum annealing furnace is being procured. The furnace is required for –

- heat treatment of super conducting RF cavities after electro polishing to remove absorbed hydrogen and to
- Remove stresses generated during mechanical fabrication processes.

Building for SCRF Cavity Development

A building (Fig. 9) is under construction for infrastructure facilities for cavity fabrication, chemical processing, assembly and testing. For setting up various laboratories for material evaluation, surface sciences studies and materials study, laboratory space is also being constructed.

Figure 9 : Building under construction for SCRF infrastructure facilities

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