R&D ACTIVITIES ON HIGH INTENSITY SUPERCONDUCTING PROTON LINAC AT RRCAT

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Abstract

Raja Ramanna Centre for Advanced Technology (RRCAT), Indore has taken up a program on R&D activities of 1 GeV, high intensity superconducting proton linac for Spallation Neutron Source. This will require several multi-cell superconducting cavities operating at different RF frequencies. To start with, a number of single-cell prototype cavities at 1.3 GHz have been developed in high RRR bulk niobium. These single-cell cavities have exhibited high quality factor and accelerating gradients. Superconducting properties of niobium are being studied for varying composition of impurities and different processing conditions. Physics design of linac configuration and various accelerating structures have been initiated. Development activities on cryomodules, cavity test facilities and solid state RF amplifiers to power the SRF cavities at various RF frequencies are being pursued. Infrastructure setup required for SRF cavity fabrication, processing and testing is under progress at RRCAT.

INTRODUCTION

A programme is envisaged to develop a pulsed, MW range Spallation Neutron Source based on 1 GeV, 1 MW superconducting RF H- Ion linac, a full-energy injector for a 1GeV Accumulator Ring. The pulsed Spallation Neutron Source will be used for applications in the field of condensed mater physics, material sciences, chemistry, biology and engineering. In addition to setting up of SNS facility, it will enhance capacity building in the area of high intensity proton accelerators in India.

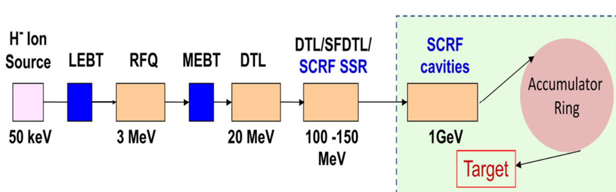

Figure 1. Schematic of Pulsed Proton Linac for Indian Spallation Neutron Source.

R&D ACTIVITIES

R&D activities for a SRF linac and accumulator ring for SNS would include prototype development of various sub-systems and setting up of infrastructure in the following areas:

- Ion source and front end component
- Materials R&D, cavity & cryomodule development
- Niobium cavity fabrication and processing facility
- Test facility for large number of SRF cavities and cryomodules
- Cryogenics setup for large size LHe Plant & supply network
- RF power sources and control electronics
- Sub-systems for 1 GeV accumulator ring including magnets, power supplies, RF cavity, UHV system and controls
- Manpower development and training

Ion Source and Front End

Development of a 3 MeV H- ion linac front end has been initiated for 1 GeV proton accelerators for a pulsed Spallation Neutron Source [1]. The front-end system will comprise of a filament driven multi-cusp H- ion source, Low Energy Beam Transport (LEBT) system, Radio Frequency Quadrupole (RFQ), RF power sources, Controls, Beam dump and Beam diagnostics.

H- Ion Source: In order to meet the requirement of H- ion front end linac system, a multicusp filament based 50 keV, 30 mA, low emittance H- ion-source operating in pulsed mode with a repetition rate of 25 Hz has been initiated. Physics design of the multicusp source was carried out analytically and also using computer simulations based on finite element method. This system has recently been tested for extraction of hydrogen ion current of 1.0 mA at 15 kV accelerating field. Figure 2, shows the multi-cusp H- ion source system.

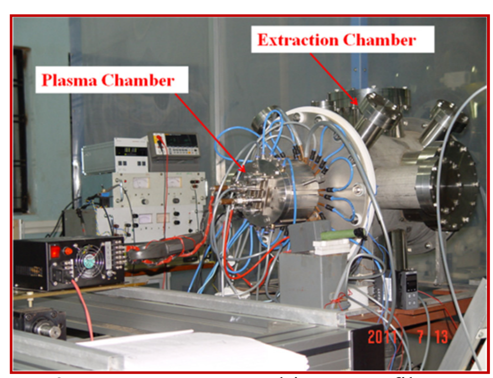

Figure 2. Prototype multi-cusp filament based source pulsed H^- ion source.

LEBT and RFQ: For prototype studies, design has been carried out for a suitable LEBT for beam transport from Ion Source to RFQ and a 3 MeV, 352 MHz RFQ. A Low Energy Beam Transport (LEBT) line, consisting of solenoid magnets of maximum strength 3.5 kG and steering coils having a maximum field of 100 G has been

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designed for transporting the beam from Ion Source to RFQ with the matched beam parameters at RFQ entrance, and with minimum emittance growth.

For prototype RFQ, physics and engineering design has been carried out for a 352.2 MHz, 3.47 m long, four vane type RFQ to accelerate 50 keV, 30 mA pulsed H- ion beam with 1.25% duty factor to 3 MeV. The inter-vane voltage has been chosen to be 80 kV, the optimized value of the minimum aperture radius is 2.31 mm and modulation parameter has been varied in the range 1 – 1.95. The synchronous phase is initially kept at -90 degree to maximize the capture efficiency, which is ramped to -30 degree.

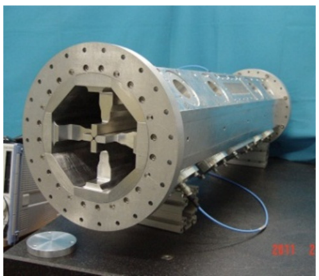

Figure 3. Prototype fabrication of 1st segment of RFQ structure.

Materials R&D for SRF Cavities

Since the major part of proton linac will be build using SRF cavities, intensive materials R&D activities have been taken up at RRCAT. The SRF cavity materials studies include superconducting properties of fine grain (50 micron average grain size), large grain (1 mm average grain size) and single crystal samples of Niobium materials. It was observed that a buffered chemical polishing of these Niobium materials caused a distinct reduction in the superconducting parameters like transition temperature (T_C), lower critical field (H_{C1}) and upper critical field (H_{C2}) [2.3]. These results indicate that BCP treatment possibly introduces Oxygen and Hydrogen in quantities large enough to degrade the superconducting properties of the Niobium materials, which, in turn, adversely affects the performance of the Niobium-SRF cavities.

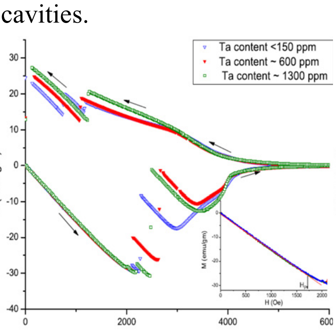

Figure 4. Magnetization v/s magnetic field plot of pristine fine grain Niobium with different Tantalum-contents at T=2 K [3].

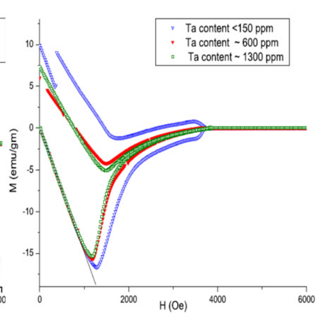

Figure 5. Magnetization v/s magnetic field plot of fine grain Niobium with different Tantalum-contents, subjected to BCP & annealing at 600^{O}C[3].

It was also seen that tantalum impurity content even up to several hundred to ~1300 ppm does not significantly affect the superconducting properties of Niobium materials [3]. These observations suggest that a less refined Niobium material may be deployable for cavity applications, provided the inclusions of the impurity elements do not influence the surface conductivity of Niobium materials significantly.

SRF Cavity Development

As an initial effort, four prototype 1.3 GHz single cell bulk niobium cavities have been developed under Indian Institutes Fermi Lab Collaboration (IIFC).

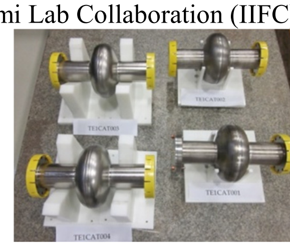

Figure 6. Prototype 1.3 GHz Single Cell cavities fabricated, processed and tested under IIFC Program.

Development of forming tools, forming of half-cells, machining of components, development of welding fixtures along with RF & vacuum qualification were carried out at RRCAT. The electron beam welding was carried out at IUAC. The fabricated prototype cavities were tested for RF and vacuum leak tightness up to 77 K at RRCAT before shipment to Fermi Lab. Processing, consisting of Centrifugal Barrel Polishing (CBP), Electro Polishing (EP), heat treatment and high pressure rinsing (HPR) was carried out jointly by Fermi Lab and Argonne National Laboratory in USA [4].

The cavity TE1CAT004 was successfully tested in the first test itself to achieve Eacc of 37.5 MV/m with a Q > 8.4 x E09 as shown in Figure 7.

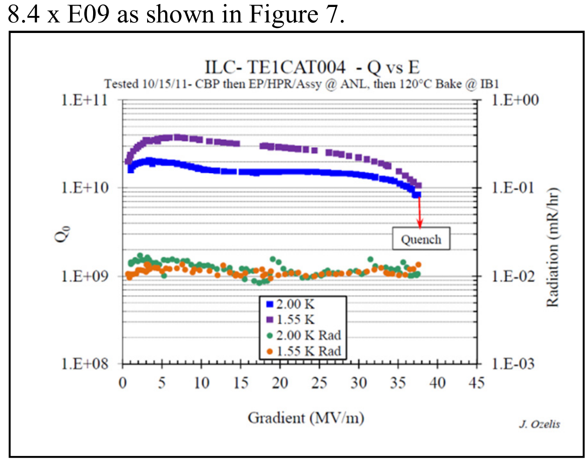

Figure 7. 2 K Performance test curve of 1.3 GHz single cell SRF cavity TE1CAT004 at VTS Facility, Fermi lab.

Prototype development of SRF cavities for medium energy is also under progress. Forming tools for 650 MHz cavities are undergoing forming trials for the first prototype single cell cavity.

Design and Development of Cryomodule

Design studies for a medium beta cryomodule for eight SRF cavities (Frequency 600-700MHz) are under progress. This work is in parallel to the cryomodule studies for Project-X under IIFC. The cavity support system will be a modified support system. The cavities will be supported from a helium gas return pipe with the help of a laser welded C-T shaped joint. This improvisation will reduce the machining time and cost for cavity support. Prototype Laser welded joints have been made and tested. The system has been designed and a scaled down prototype has been fabricated (Fig8).

The system will be tested under cryogenic conditions in the cryomodule component test rig.

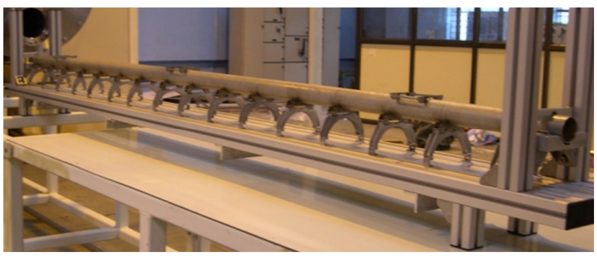

Figure 8. Laser welded prototype cavity support system

SRF Cavity Test Facility

A Vertical Test Stand Facility is under commissioning at RRCAT for testing SRF cavities at 2K. The 2K cryostat was designed by RRCAT along with Fermi Lab. To test the cavities, 1.3 GHz, 500W CW/600 W peak power solid state RF amplifier system has been designed and tested.

The building for VTS is also ready for commissioning.

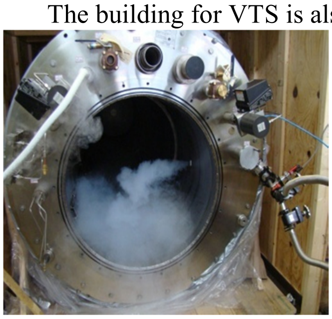

Figure 9. VTS Cryostat under cold shock testing

Figure 10. 500 W Solid State RF system for VTS

A Horizontal Test Stand for testing SRF cavities at high power RF, is being designed under collaboration with Fermi lab. The horizontal test stand cryostat is a continuous flow type cryostat and capable of testing two dressed SRF cavities/SC magnets in a single test cycle.

Development of RF Power Sources

Design and development of 30 kW, 650 MHz high powers solid state RF source for CW as well as pulse power, has been initiated at RRCAT[5]. The indigenous development efforts will be useful for the proposed high power proton accelerators for SNS applications. In this 650 MHz amplifier scheme, 30 kW CW RF power will be generated using modular combination of 8 kW amplifier units. Each 8 kW amplifier unit will be housed in a standard cabinet employing 32 numbers of 300W RF amplifier modules , 2 power dividers, 2 power combiners and high power directional coupler. The RF power unit will have provision for safety interlocks, data acquisition system and water cooling circuit. developed indigenously.

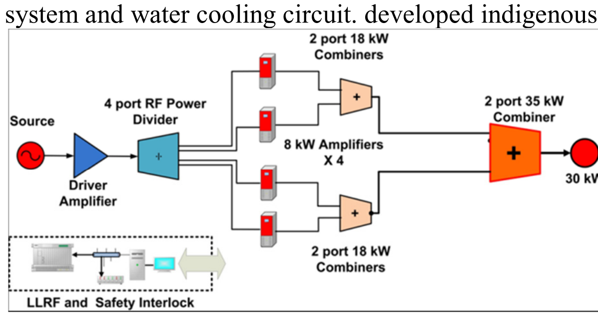

Figure 11. Solid State High Power RFM Amplifier Scheme.

Infrastructure Facility Development

A dedicated building for SRF infrastructure facilities has been completed. Cavity forming facility which includes a 120 Ton Hydraulic Press, suitable tooling have been established for SRF cavity parts. A 15 kW electron beam welding machine and a high vacuum annealing furnace are being procured. Cavity processing facilities including Barrel Polishing Machine for 1.3 GHz single cell cavity, prototype Electro polishing setup, high pressure rinsing facility, clean room facility, for low power RF characterization facility etc. have been set up. A Secondary Ion Mass Spectrometer (SIMS) has been set up for surface characterization of Niobium samples. A Confocal Microscope for defects identification and surface roughness measurement and a high accuracy 3D Co-ordinate measuring machine for mechanical measurement of a cavity profile have been installed [6].

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