COMMISSIONING OF VERTICAL TEST STAND FACILITY FOR 2 K TESTING OF SUPERCONDUCTING CAVITIES AT RRCAT

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Abstract

Raja Ramanna Centre for Advanced Technology (RRCAT) has developed a 2K vertical Test Stand (VTS) facility for characterization of Superconducting RF (SCRF) cavities, under Indian Institution Fermilab Collaboration (IIFC). The VTS is used for qualifying bare SCRF cavities for their required performance by measuring quality factor and cavity accelerating gradient at a cryogenic temperature of 2 K. The VTS facility comprises of a large size liquid helium (LHe) cryostat, cryogenic system, RF power supply, control and data acquisition system and radiation monitoring system. It will facilitate testing of superconducting cavities of different frequencies ranging from 325 MHz low beta to 650 MHz / 1.3 GHz medium and high beta cavities. The helium vessel has an inner diameter of 923 mm and an overall depth of 4860 mm with a capacity to store up to 2900 litres of liquid Helium. The engineering design and fabrication of VTS cryostat was carried out in accordance with ASME B&PV code.

The cryostat is installed inside a vertical pit in the cryogenic test building. It is equipped with facilities for supply of liquid nitrogen and liquid helium and vacuum system for pumping out helium gas to lower the temperature of liquid helium bath down to 1.8 K. A 500 W, 1.3 GHz RF system has been indigenously developed to supply required CW power for testing of the SCRF cavities. The VTS facility has now been commissioned and its performance validation has been successfully carried out by benchmarking it with respect to the facility at the Fermilab, USA.

INTRODUCTION

The VTS facility at RRCAT is designed to test superconducting cavities ranging from 325 MHz low beta to 1.3 GHz/ 650 MHz medium and high beta cavities at their operating frequencies in a 2K LHe bath [1]. The cryostat can accommodate six 1.3 GHz nine-cell cavities or two 650 MHz five-cell cavities in a single cool down. Presently, a 40 litres/hour capacity liquid helium plant is being utilized for testing of cavities. The facility will be upgraded with a new plant with a liquefaction rate of 145 litres/ hour by the end of this year [2]. The VTS cryostat assembly is installed below the ground level in a pit. A 500 W, 1.3 GHz RF system along with its low level RF (LLRF) control & data acquisition system has been developed for testing of the SCRF cavities. A system of radiation shielding comprising of internal radiation shield and movable external radiation shielding lid shall ensure that ionizing radiation exposure levels are maintained below prescribed levels.

MAJOR SYSTEMS OF VTS FACILITY

VTS Cryostat and Insert Assembly

VTS cryostat assembly comprises of an ASME Code stamped stainless steel liquid helium vessel (LHe) suitable for 2K liquid helium and suitable process tubing for flow of liquid helium & liquid nitrogen. The helium vessel and tubing are thermally shielded with a LN2 cooled thermal shield to reduce the cryostat's overall static heat load at 2K. The assembly of LHe vessel and thermal shield is housed in a stainless steel insulating vacuum vessel. The cryostat has an overall dimension of diameter 1370mm and length of 5420mm. A schematic of the cryostat assembly is shown in Figure 1.

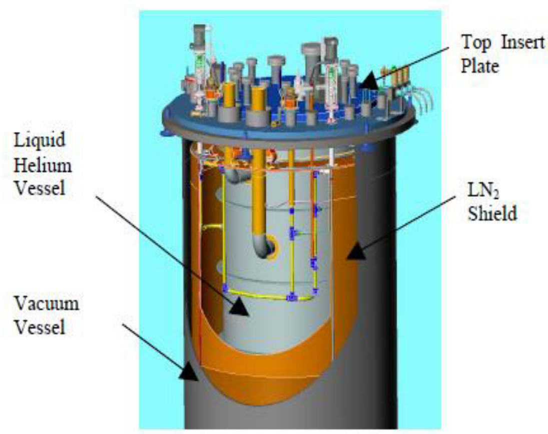

Fig 1. Schematic of VTS Cryostat Assembly

The VTS insert assembly supports the cavity in the liquid helium bath during the RF testing and provides penetrations for RF cables, diagnostics, vacuum line etc. It also provides thermal shielding for the liquid helium bath.

The engineering design of the cryostat was carried by RRCAT in collaboration with Fermilab [3]. Fabrication of the cryostat vessels was carried out by an US based vendor in strict accordance with ASME BP&V code under joint supervision of engineers from RRCAT and Fermilab [4].

Magnetic Shielding

To avoid trapping of magnetic flux which may degrade the SRF cavity quality factor, the cavity must be

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shielded from magnetic fields during the cool down process. Two-layer of cylindrical magnetic shields are incorporated in the cryostat to reduce the residual magnetic field to less than 1μT in the cavity test region. The design incorporates a room temperature outer shield made of 1 mm thick Mu-metal and an inner shield with perforated end cap at the bottom (for LHe flow), in 1 mm thick Ammuneal 4K (A4K) material [5]. The external magnetic shield is mounted on the outside of the vacuum vessel whereas the inner magnetic shield is mounted on the outer surface of an aluminium cylinder for support and protection as shown in Figure 2.

Fig 2 : VTS cryostat and cavity insert

Cryogenic System and Up-Gradation of Infrastructure

Cryogenic transfer lines have been installed for supply of liquid helium, liquid nitrogen and return line for gaseous helium & nitrogen Figure 3. A helium pumping line has been laid along with large capacity vacuum pumping system for pumping of helium to achieve 2 K temperature, Figure 4. Presently, a 40 litres/hour capacity liquid helium plant is being utilized for testing of cavities. The facility will be upgraded with a new plant with a liquefaction rate of 145 litres/ hour by this year end.

Fig 3: Cryogenic Transfer lines for VTS

Fig 4: Helium Pumping setup for 2 K operation

RF and Data Acquisition System

The 1.3 GHz 9-cell SCRF cavities require ~250 W of CW power to produce accelerating gradient in excess of 35 MV/m. Keeping in view the maximum field gradient to be achieved in the cavities and the margins for other losses, a 1.3 GHz, 500 W CW solid state power amplifier system has been designed and developed, Figure 5. The amplifier operates with a bandwidth of 1270-1310 MHz. The amplifier consists of a water-cooled high power stage driven by an air-cooled 50 W amplifier. The high power stage is realized with two dual 250W LDMOS transistors @1.3 GHz where the output power is combined using two-stage quadrature combiners.

The low level RF (LLRF) system tracks the cavity frequency using a phase locked loop (PLL) which maintains the frequency of the RF source equal to the cavity resonance frequency. The amplitude and phase of RF power going to the cavity is controlled with an I&Q modulator. The LabView based data acquisition and control software provides the complete control of phase in 0-360° and amplitude in 0-40 dB range. The incident, reflected and transmitted power from the cavity is measured using power meters in CW mode and diode detectors in pulsed mode. The power meter, generator and counter are connected via a GPIB to the data acquisition software which records the data and facilitates real-time plotting of quality factor (Q_0) v/s accelerating gradient (E) and calculates errors associated with all measured and calculated quantities.

Fig 5: 1.3 GHz 500 W RF source for VTS

Interlocks and Safety Systems

In order to make the various parameters available to the operators sitting in control room and to enable them to set various values in the field, a Control system has been developed and installed. Siemens SCADA WinCC has been used for designing the Graphical User Interfaces. Figure 6 shows the scheme of VTS control system.

Internal and External Radiation Shielding

In order to prevent radiation exposure to personnel a system of radiation shielding has been designed. The radiation shielding is achieved using an internal radiation shielding (mounted on VTS insert assembly) and an external shield placed over the cryostat top plate during

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cavity testing. The internal shielding consists of two lead disks of 100 mm thickness each mounted just above the cavity, a 50 mm thick stainless steel disk mounted above the lead disk, and four borated polyethylene disks of 25 mm thickness each above the steel disk.

The planned external shielding comprises of a movable lid. The lid is fabricated from 100 mm thick steel base and 630 mm high concrete blocks.

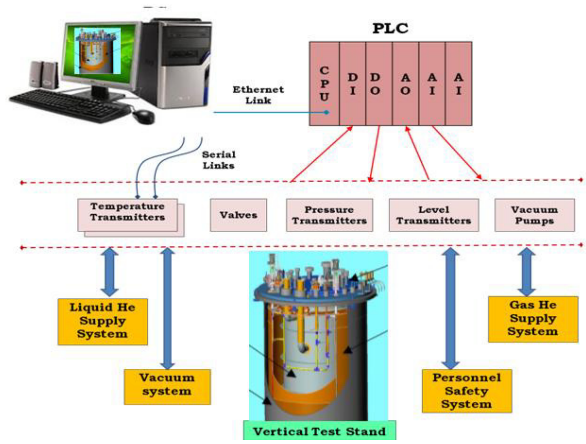

Fig 6: Schematic of VTS control system

COMMISSIONING AND BENCHMARKING OF VTS FACILIY

A single-cell 1.3GHz SCRF cavity fabricated by RRCAT and tested earlier at Fermilab, USA was re-tested to benchmark the VTS facility. This cavity was vacuum sealed after its last testing in October 2012 at Fermilab and sent back to RRCAT. For the present commissioning trials, the cavity was assembled on the cavity insert and placed in the VTS cryostat along with temperature sensors, liquid helium level sensors and low temperature compatible RF cables. A total of 1400 litres of liquid helium was used to fully immerse the cavity in the helium bath. Temperature down to 1.8 K was achieved, Figure 7.

RF power was coupled to the cavity to measure quality factor (Q_0) and accelerating gradient (E_{acc}). Ionization radiation level was continuously measured using a gamma radiation monitor during the commissioning run. The result of 1.3 GHz single-cell SCRF cavity at 2 K is shown in Figure 8.

The cavity frequency, quality factor and accelerating gradient obtained are 1298.71 MHz, $2x10^{10}$ and 36.7 MV/m respectively. This result may be compared with those on the same cavity obtained during testing at Fermilab on October 15, 2011 (Black curve) and October 5, 2012 (Red and green curve : forward / reverse direction). The Q_0 v/s E_{acc} plots in Figure 8 and Figure 9 shows similar pattern. It may be noted that the cavity was tested without any further processing after more than 15 months of its last testing at Fermilab.

ACKNOWLEDGMENT

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Fig 7 : Transfer of liquid helium in the VTS cryostat

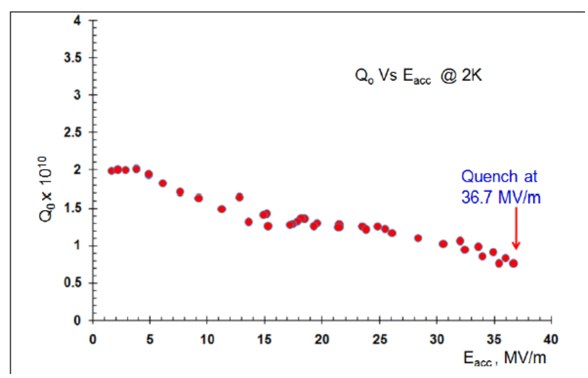

Fig 8 : Result of a single-cell 1.3 GHz niobium cavity at RRCAT VTS facility

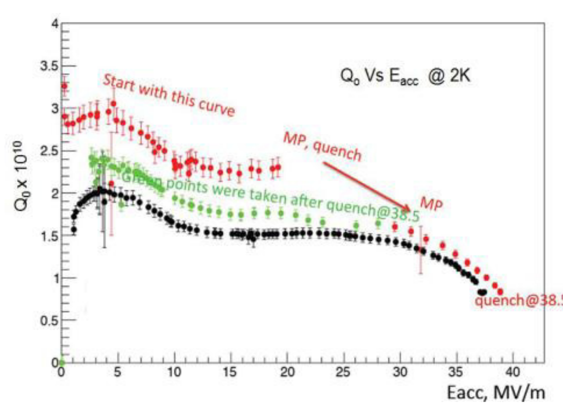

Fig 9: Result of the same cavity tested earlier at Fermilab VTS facility.

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