A.3: Testing of dressed superconducting RF cavity at 2 K in horizontal test facility

Development and setting-up of infrastructure facilities for fabrication, processing and testing of 650 MHz superconducting radio frequency (SCRF) cavities have been taken up at RRCAT. The horizontal test stand (HTS) facility is commissioned at RRCAT for high power testing of "dressed" SCRF cavities at 2 K. The facility is developed with indigenous efforts in collaboration with Fermilab, USA under Indian Institutions Fermilab Collaboration (IIFC). After qualifying bare SCRF cavities in the vertical test stand (VTS) at 2 K, the cavities are dressed with titanium helium vessel, high power coupler and tuner. As the dressing involves complex welding process and handling of cavity, it becomes necessary to re-test the cavity at 2 K temperature as final qualification for assembly in cryomodule. The testing of a jacketed cavity is performed in HTS facility, which provides a cryomodule type environment.

The HTS facility comprises of a cryostat, cryogenic distribution system, high power RF system, low level RF control, RF protection & interface, control & safety system, etc. The cavity to be tested is placed in a cryostat housed in a shielded vault of size 15 m x 9.5 m. The facility is capable for simultaneous cooling down of two SCRF cavities. The cryostat was fabricated in an Indian industry. The cavities are cooled down with liquid helium using a 145 l/h (600 W at 4.5 K) capacity helium refrigerator and associated cryogenic infrastructure. Thermal shield is cooled with liquid nitrogen. Liquid nitrogen and helium are supplied through in-house fabricated cryogenic transfer lines and distributed in the cryostat using the feedcan of the cryostat. The helium bath is pumped down to a pressure of 30 mbar to achieve testing temperature of 2 K. Figure A.3.1 shows cryostat with cavity in the vault.

Fig. A.3.1: HTS cryostat with cavity in the vault.

The high power RF is fed to the cavity using in-house developed 32 kW, 650 MHz solid state power amplifier (SSPA), circulator, low level RF (LLRF) and RF protection interlock (RFPI) system. The data from all the diagnostic sensors/devices are handled by a control system developed at RRCAT. The residual magnetic field around cavity is maintained using magnetic shielding around cavity and de-gaussing/bucking coil on the cryostat.

To benchmark the facility, a five-cell 650 MHz dressed superconducting RF cavity with high power coupler, received from Fermilab in sealed condition, was tested at high power. The cavity along with multi-layer insulation, mu-metal magnetic shield, warm coupler end, and temperature and magnetic flux gate sensors was loaded in the cryostat. The cool down of the cavity to cryo-temperature was obtained with saturated liquid helium produced by Joule-Thompson expansion of super-critical helium gas coming from helium refrigerator. 2 K temperature was achieved by simultaneous liquid fill and pump-down and was maintained with required pressure stability and liquid level for more than 50 hours during RF testing of SCRF cavity at high power.

During the test in February 2022, LLRF system of the VTS facility was utilized for phase - amplitude control and measurement of the transmitted power along with HTS RFPI system due to a malfunction in LLRF system of HTS. Subsequently in June 2022, LLRF system of HTS system was upgraded and successfully tested. The incident power was recorded manually at the directional coupler mounted at the input of circulator. The dynamic heat load (power loss in cavity due to RF powering) was estimated by averaging the mass flow rate of the helium boil-off. The cavity was first conditioned for more than 20 hours, at pulse repetition rate of 20 Hz with duty cycle upto 40% and power up to 22 kW to mitigate multipacting. After conditioning, cavity was operated at gradients of up to 14.8 MV/m in CW (incident power 8.8 kW) and 19.9 MV/m in pulsed mode (20 Hz, 40% duty cycle and with 22 kW incident power). During the operation, the supervisory control system was used extensively and it performed well for various operations like cryostat and cavity cool down, cryostat demagnetization, calorimetric measurement, monitoring of parameters, man & machine safety, maintaining coupler window temperature at room temperature and data logging. The magnetic flux around the cavity was maintained below 5 mG in all directions using bucking coils over the HTS. The slow and fast tuner were also tested during commissioning trials.

This is an important milestone in the development of superconducting cavities as it completes a full development cycle of fabrication, processing, tuning, dressing and testing of superconducting cavities at RRCAT.

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