VERTICAL TEST FACILITY FOR SUPERCONDUCTING RF CAVITIES AT DARESBURY LABORATORY

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Abstract

The Vertical Test Facility at Daresbury Laboratory has been recently relocated to enable it to fulfil its potential of performing high power characterisation tests of Superconducting RF Cavities in the 1.3 to 3 GHz range. The 250 litre, 3 metre dewar is capable of operation from 1.6 K to 4 K and has recently been used to test the first Superconducting cavity produced in the UK. This paper outlines the setup, processes and results of these tests.

INTRODUCTION

As part of the accelerator research and development infrastructure at STFC (Science and Technologies Facility Council), Daresbury Laboratory (UK), a vertical test facility (VTF) for superconducting RF (SRF) cavities was manufactured, commissioned and installed in 2008. However, due to location and shielding issues it was not possible to achieve higher accelerating gradients. Thus as part of a further development programme during 2010/ 2011 the facility was relocated in order to enable high power tests to be performed on newly constructed single cell 1.3 GHz niobium superconducting RF (SRF) cavities. These cavities are the first to be fabricated in the UK and have been manufactured by Shakespeare Engineering [1] as part of collaborative programme of work [2] with ASTeC (Accelerator Science and Technology Centre) at Daresbury Laboratory and Jefferson Laboratory in the US.

SYSTEM DESCRIPTION

The cryostat is 3m tall with an internal diameter of 320 mm and can accommodate liquid helium inventories of up to 300 litres [3]. The cryostat consists of a helium vessel, vacuum containment vessel, internal cavity support structure, instrumentation, radiation baffles and of a number of concentric radiation shields; the radiation shields, baffles, vacuum and super insulation insulate the helium vessel from ambient temperatures, the radiation baffles & shields are cooled using a controlled flow of helium gas through the Dewar neck. Typically, liquid nitrogen is used to perform radiation shield cooling; but using helium gas as the cooling medium is advantageous, as it reduces the risk of experiencing microphonics which result from system generated vibration, that is often caused by being in contact with vigorously boiling liquids. A secondary benefit is a reduction in the logistical burden of managing both liquid helium and liquid nitrogen supplies. The gas cooled shields have proved to be very effective, with the total heat load shown to be approximately 1 W.

The majority of the cryostat system is located below ground level, encased in a minimum thickness of 600 mm of high density concrete and the top section, above ground, is surrounded by a 1 m thick removable radiation shielding block configuration. The cryostat is also enclosed in a specially designed µ-metal shield, the purpose of which is to reduce the effect of the earth's magnetic field to an acceptable level of 15 mG.

The thermometry instrumentation consists of silicon diode temperature sensors, which are required for measuring temperatures down to 1.6 K and PT100s. The silicon diode sensors are attached to the test cavity and support structure, whilst the PT100s are used to monitor the temperatures of the shields. The level of the liquid helium column is measured across the full operating range, by a combination of two 50" overlapping American Magnetic Instruments level probes. Pressure conditions are also monitored and all parameters are recorded by means of data logging system which incorporates a national instrument RIO (reconfigurable I/O) and graphics displayed via Labview.

Cooling from 4.2 K to 2 K is achieved by means of a Leybold Sogevac SV500 rotary vane vacuum pump. A schematic of the setup is shown in Figure 1.

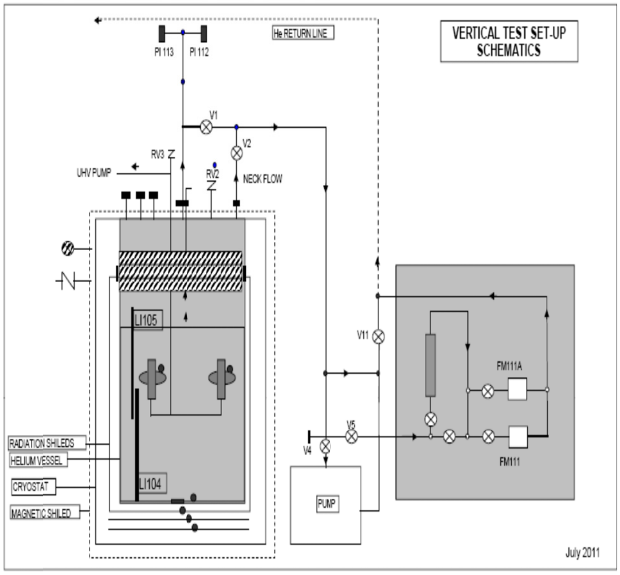

Figure 1: Process schematic.

RF power is applied to the cavity being performance tested using a signal generator via a solid state amplifier (SSA) and is controlled with a Labview based phase locked loop (PLL) system. The PLL system is a National Instruments compact RIO containing a fast; field programmable gate array (FPGA).

SYSTEM OPERATION

Cryogenic System

The cleaned and processed cavity is connected to the VTF insert; the insert is suspended from the top flange of the cryostat assembly with the cavity supported by one of several baffle plates, which are used as a means of reducing heat loss by temperature graduation. The cavity vacuum was maintained at 4×10^{-8} Torr by a turbo pump, which is connected to the cavity via a stainless steel tube to maintain the ultra high vacuum (UHV) conditions required. A new, longer cavity test insert was procured solely for the purpose of the performance testing the 1.3 GHz Shakespeare cavities, this facilitated testing over a longer duration, as being lower in the cryostat the cavity would remain submerged for longer. A drawing of the insert configuration is shown in Figure 2.

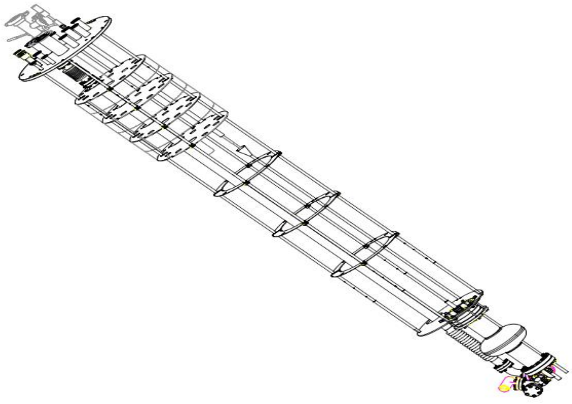

Figure 2: Insert assembly.

The cavity is cooled down via direct injection of liquid helium and the low thermal mass of the components along with the potential risk of 'Q disease' makes rapid cooldown not only possible but essential. The liquid helium is transferred manually via a siphon tube from a standard 500 l transport dewar and is injected into the helium vessel close to the cavity at the bottom of the cryostat. Additionally the liquid helium is used to cool the radiation screens and cryostat neck at the same time. The rapid cooldown is assisted by pressurising the transport dewar with helium gas to around 8 psi (~0.55 bar).

Cooldown to 4.2 K takes approximately 5 hours and consumes in the region of 150 l of liquid helium during this process. Once the system is cold the cryostat fills with liquid helium to a level of around 250 l.

To achieve the required 2 K operating temperature it is necessary to reduce the pressure inside the helium bath to 30 mbar, thus reducing the vapour pressure of the liquid helium to a level where boiling now occurs at 2 K. To achieve these parameters the system is evacuated using an external vacuum pumping system, which has to be of a sufficient capacity to handle the boil off resulting from depressurisation as well as the static (fixed) and dynamic (during testing) heat loads. The vacuum pumping system is currently completely manually controlled, so pump downs are operator maintained to ensure that the vacuum pump is not over cooled. Mass flow is maintained at approximately 7 kg/h by balancing the flow of gas around the bypass. Reduction from 4.2 K to 2 K takes approximately 2 hours and reduces the helium level by approximately 50% (Figure 3). The 30 mbar pressure 'set point' is not currently maintainable as the by-pass valve installed to control the pressure was too large.

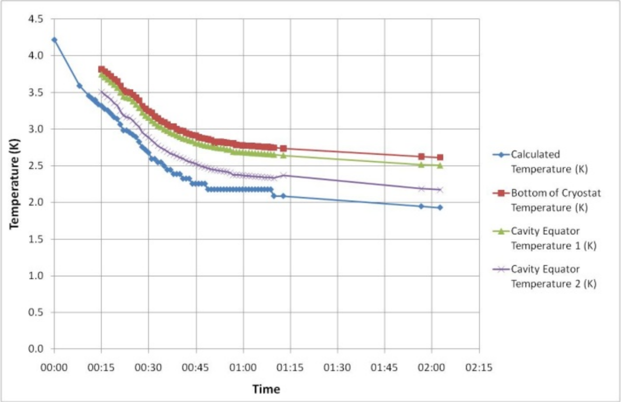

Figure 3: 2 K cooldown.

During these tests the pressure eventually reduced to a base level of 13 mbar. For future tests it is planned to replace the by-pass valve with a needle valve and to add a 2 K heat exchanger to the system, this along with control valves and frequency control on the 2 K vacuum pump will improve the stability of the system and should allow the pressure to be controlled to approximately ± 1 mbar. (Figure 4)

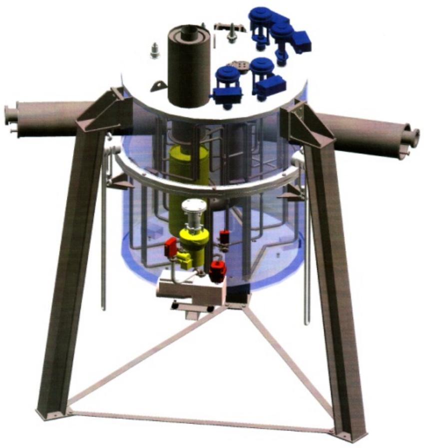

Figure 4: 2 K heat exchanger.

Phase Lock Loop System

In SRF cavities a small mismatch in frequency can lead to a large portion of the input power being reflected due to the high unloaded quality factor (Q_o). In an operational accelerator the cavities are tuned to maintain the frequency of the cavity to that of the RF source, but this is not deemed to be a cost effective method for VTF operation thus the frequency of the RF source is modulated to the varying frequency of the cavity.

The low level RF (LLRF) system used to monitor and control the RF within the cavity incorporates a Labview based PLL system which modulates the RF drive to the cavity. A heavily attenuated cavity probe signal is fed back into the LLRF system, where a RF detector converts the RF signal in to a modulated DC signal. This signal is then fed back into the compact RIO system along with the forward and reflected power signals. A phase detector compares the cavity RF to the RF source; any changes in the cavity tune causes a change in the phase detectors DC outputs. The FPGA is used to run the PLL system, and changes in the phase detector outputs produces an error signal, which is then used to drive the dc-coupled frequency modulator (DCFM) input into the signal generator. This signal generator then provides the input drive to the amplifier and ensures the RF source stays locked to the frequency of the cavity. The set-up is shown in Figure 5. The system is capable of being operated under both continuous wave (CW) and pulsed conditions to allow conditioning and evaluation of the cavity to be performed. Additionally incorporated in the set-up is an interlock system which ensures that the cavity is fully protected.

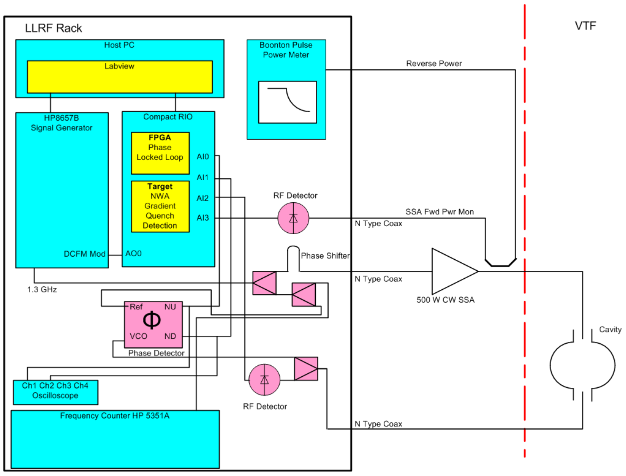

Figure 5: RF schematic.

CAVITY TESTING

Extensive tests were performed on the system at 4 K to ensure that the system was functioning correctly, which ensured that the level of helium boil off was kept to a minimum and allowed the interlock system to be verified.

The cavity was cooled down to 2 K and the RF system was fully calibrated. The cavity was then characterised at approximately 2 K. The pulsed input was increased in 1 dB steps from -12 dB to +7 dB; the accelerating gradient was measured at <4 MV/m. The cavity showed poor results (Figure 6), which is believed to be possibly due to 'Q-disease' caused by hydrogen in the bulk niobium. This may have been caused by errors in the processing of the cavity and may be due to poor temperature control during the Buffered Chemical Polishing (BCP) process or due to the fact that insufficient thickness of material was removed during the BCP etches performed.

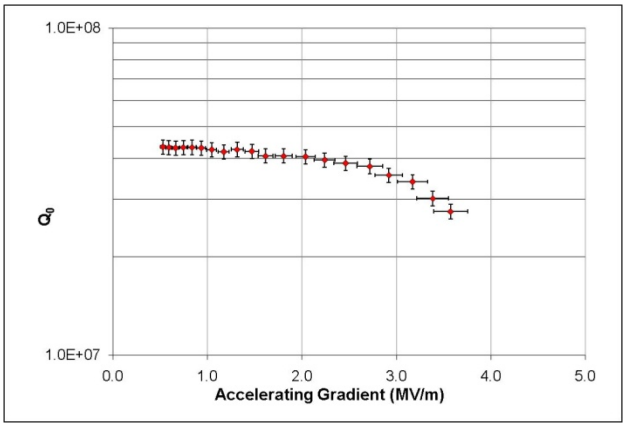

Figure 6: Cavity test performance at 2K.

Thus it is planned to reprocess the cavity, performing further BCP etches, along with a high pressure rinses and a vacuum bake for 10 hours at 600 ºC so that further characterisation tests can be performed.

SUMMARY

The re-location of the VTF system has been successfully achieved, thus allowing the characterisation tests of the UK's first single cell 1.3 GHz SRF cavity to be performed. However, the system was not able to control the pressure at 2 K due to an over-size by-pass valve.

It is intended to process the cavity again and perform further characterisation tests, and for these tests the by-pass valve will be replaced with a needle valve to gain better control of the pressure stability. In the future it is planned to add a 2 K heat exchanger to the system, which along with control valves and frequency control on the 2 K vacuum pump will allow the system to automatically control the pressure.

REFERENCES

[1] Shakespeare Engineering Group, Unit 91, Haltwhistle Road, Western Industrial Area, South Woodham Ferrers, Essex, CM35ZA, UK.

[2] A. E. Wheelhouse et al., "Superconducting RF Cavity Development with UK Industry", SRF 2011, Chicago, TUPO038.

[3] P. A. Corlett et al., "A Superconducting RF Vertical Test Facility at Daresbury Laboratory", EPAC08, pp 850 - 852.