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# INNOVATIVE CRYOGENIC TEST FACILITY FOR TESTING SRF CAVITY SERIES PRODUCTION

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*Abstract*

Testing SRF cavities in a vertical cryostat is the first step in qualifying the performance of SRF cavities before being integrated into a cryo-module. The European Spallation Source (ESS) requires 84 + 4 high-beta 5 cells, 704 MHz cavities (HβC) which will be manufactured and qualified for their RF performance in a vertical cryostat at Science and Technology Facility Council (STFC) Daresbury Laboratory (DL) in the United-Kingdom. Taking a conventional approach each vertical test would require a large cryostat demanding more than 8500 litres of liquid helium for testing 3 cavities simultaneously. In order to reduce the overall operating time / cost, an alternative method has been developed to divide the liquid helium consumption by 5 by filling liquid helium only in each individual helium vessels enclosing each cavity placed horizontally in the cryostat (see Table 1).

Therefore the test is performed in more realistic conditions such as in a cryo-module and reduces the operating time / cost. This also reduces the mass flow-rate to be handled by a factor of 10, leading to 2 g/s, thus reducing the size of the associated components such as the 2 K pumps, safety devices, valves and transfer lines.

## INTRODUCTION

This paper presents all cryogenic aspects of the new test facility at STFC DL for testing the high-beta SRF cavity production for the ESS [1] accelerator. The test facility shows some peculiarities regarding the conventional way to perform SRF tests. First, the cryostat tests cavities with their jacket (their helium tank). This allows a significant reduction of the helium consumption in comparison to a big bath of LHe where cavities are soaked. The second main difference compared to other large-scale facilities is the orientation in which the cryostat holds cavities: horizontally. This enables the configuration to be close as possible to the final assembly in the cryo-module. Therefore, the main topic presented in this contribution is the cryogenic process, and the different modes of the facility operation. At the end, test rate estimation for the production is given. Figure 1 presents a schematic of the overall facility with a focus on the cryogenics systems.

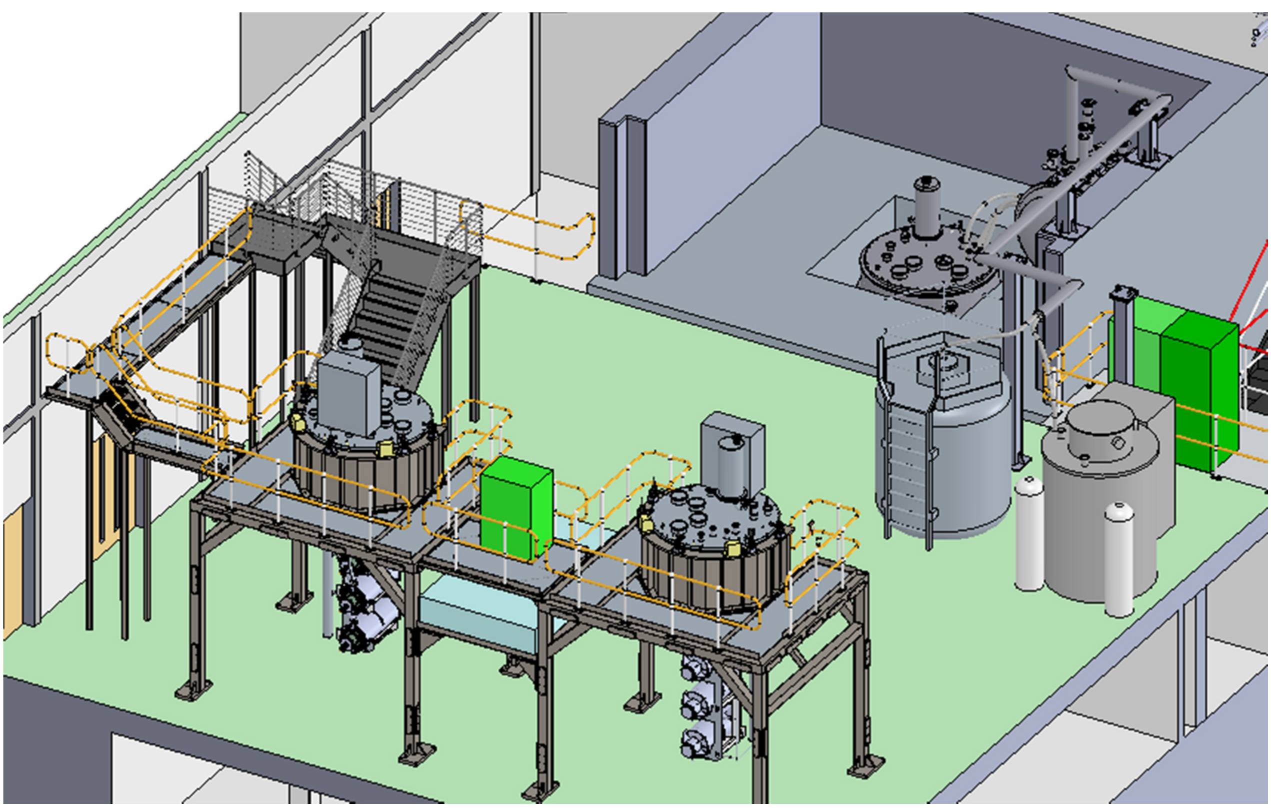

Figure 1: Overall Daresbury test facility CAD view.

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## CRYOGENIC PROCESS

The system has been designed for testing cavities with their jacket at 2 K with superfluid helium. Three cavities are located in a large vacuum chamber under a liquid helium buffer and surrounded by a thermal radiation shield.

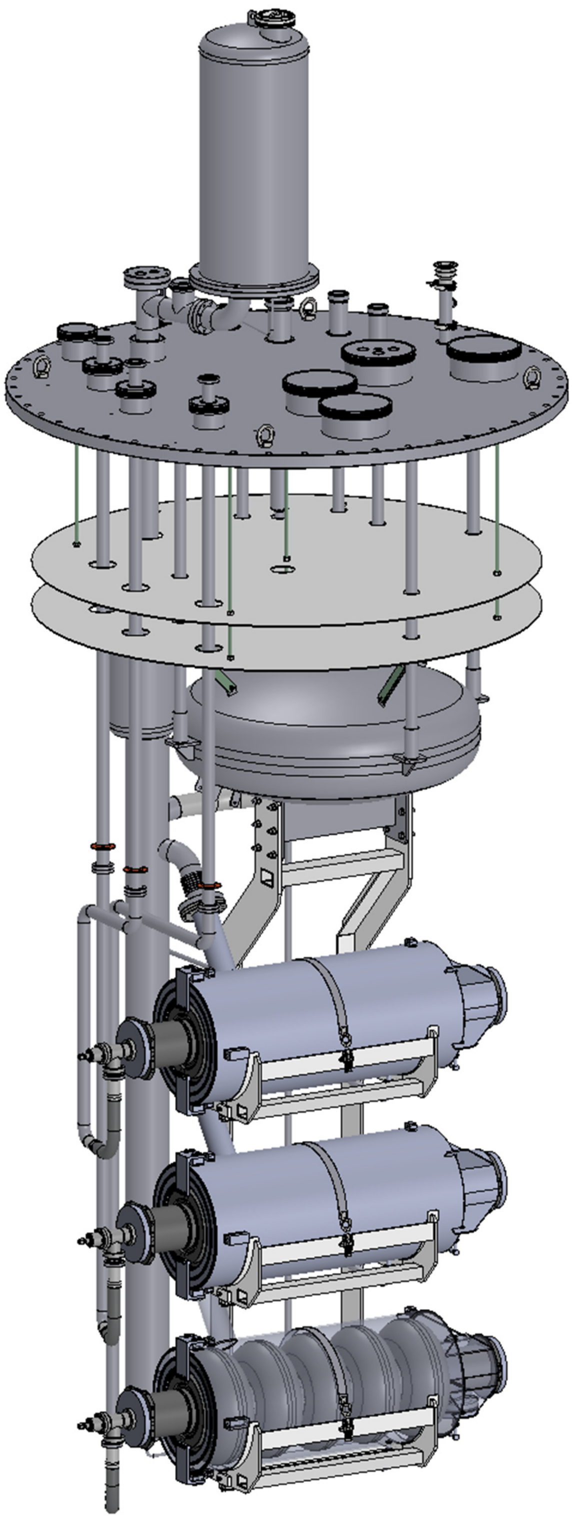

Figure 2: Cavity supports insert (CSI).

The radiation shield is cooled down by a flow of cold gaseous helium produced by the first heat exchanger of the helium liquefier. Afterwards, the whole cavity support system, so-called CSI (Cavity Support Insert), is cooled down through exchange He gas in the vacuum chamber allowing convection with the thermal shield (see Figure 3).

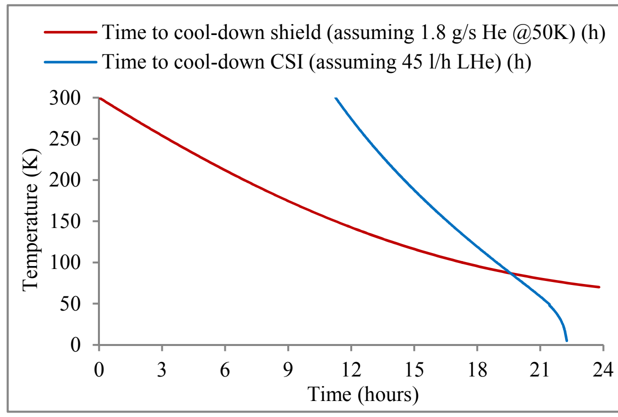


Figure 3: Thermal shield and CSI cool-down duration.

Once the whole CSI reaches an average temperature of 100 K (average temperature of the cavities and the liquid helium bath) the cool down of the whole circuit, heat exchanger, valves and CSI including helium bath and cavities commences with liquid helium.

All of the cavities' helium tanks plus the CSI helium buffer can then be filled up with liquid helium. Once this volume is full of helium the first SRF measurement can be done (read *mode 05* of the next part).

Finally the last step of the cool down can be achieved by sub-cooling the entire liquid helium inventory to 2 K using a pumping system and a combination of 2 K heat exchanger / Joule-Thompson valve.

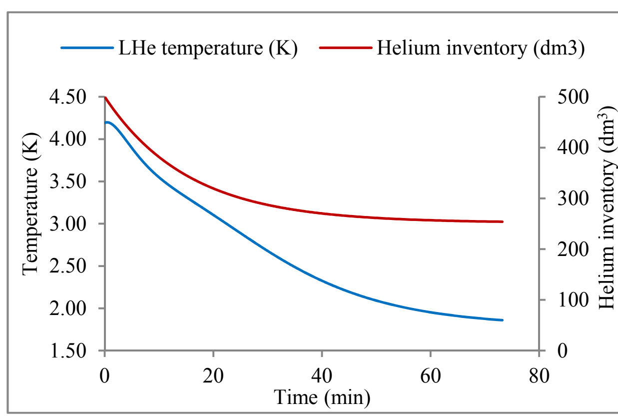


Figure 4: Sub-cooling LHe to 2 K.

The cavities are to be tested at 2 K and, once the entire liquid helium inventory and the CSI including HβC are at 2 K, the SRF acceptance test can be performed on each cavity. At this temperature, the cryostat design has an overall heat-leak of about 5 W.

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Table 1: Cryostat Technical Data Testing Jacketed Cavities

| | |
|---|---|
| Liquid helium required | 1500 litres |
| Cool-down to 4.2 K duration | 22 hours |
| Cool-down to 2 K duration | 1.5 hours |
| Cavities orientation | Horizontal |

## MODES OF OPERATION

The above thermal studies and cool down described are part of different modes of operation which are the following ones:

### *Mode 01: Mounting Cavities on the CSI*

This mode consists of assembling cavities and all required equipment on the CSI. The main critical operation here is to connect the beam-pipe to the UHV system. Typically this step is one of the most times consuming as it necessary to perform this step in low particle environment (glove-box type) to avoid any dust contamination in the beam-pipe. All the sensors are installed and the subsequent required tests are performed at room temperature. For example quick checks of the signals on each temperature sensors were performed, along with leak checks of each beam-pipe etc.

### *Mode 02: Loading CSI in the Main Cryostat*

Simply load the CSI on the cryostat vessel, plug RF, cryogenics and control and ensure that all these connection have been made properly.

### *Mode 03: Pump and Purge Operation*

Once the CSI is fully set up in the cryostat a "pump and purge" is performed with gaseous helium. This allows the safe cool down for the instruments, cavities and auxiliary systems (no ice blocking, no contamination).

### *Mode 04: Cool down to 4.2 K*

This mode consists of the following steps: thermal shield cool down (gaseous 50 K He), pre-cooling of cavities and other CSI components to 100 K (helium convection with thermal shield) and cool down of cavities to 4.2 K with LHe.

### *Mode 05: Operation at 4.2 K*

At 4.2 K, measurements will be made of incident, transmitted and reflected RF power levels. The loaded Q and coupling coefficient will also be evaluated. The cavity will be filled with RF power of approximately 200 W, for about 4 s. Then the input power will be turned off, and the transmitted power will be monitored, as the energy in the cavity decays with time. From these measurements, it is possible to calculate the unloaded Q of the cavity, as well as the size of the electric field inside the cavity. Then the graph of Q unloaded versus E acc field can be produced [2].

### *Mode 06: Cool down at 2 K*

The whole LHe inventory is sub-cooled to 2 K using sub-atmospheric pumps. During this operation the LHe bath is pumped down to a vapour pressure of 30 mbar. This process takes about half of the helium inventory which evaporates while the pressure drops (see Figure 4).

### *Mode 07: Operation at 2 K*

At 2 K the final RF test will be performed. It will be the same as the test performed at 4.2 K in *mode 05*. At this temperature the unloaded $Q_0$ will be much higher, of the order of $5 \times 10^9$

### *Mode 08: Warm up*

This final mode aims to boil off all remaining LHe and warm up the overall CSI and cryostat to allow the CSI to be dismounted and cavities to be swapped for the next batch of dressed cavities to be tested.

### *Future Mode of Operation*

This facility has not been only designed to test jacketed cavities; it is also possible to test bare cavities into it. In this case, the main chamber previously shown as a vacuum chamber can be fully filled with a large amount of LHe (conditions are shown in Table 2). The thermal radiation shield (LHe reservoir in this case) can be disconnected and another radiation shield in between the main vessel and the LHe reservoir can be operated (see Figure 5).

Table 2: Cryostat Technical Data Testing Bare Cavities

| | |
|---|---|
| Liquid helium required | 8500 litres |
| Cool-down to 4.2 K duration | 30 hours |
| Cool-down to 2 K duration | 16 hours |
| Cavities orientation | Vertical or horizontal |

## PRODUCTION

Since 84 + 4 ESS HβCs have to be produced and tested within 2 years, the facility has been designed to enable 3 cavities to be tested every 2 weeks. This means that the full production of HβC can be tested within 1.5 years. According to the above defined timescales the period of time to test from *mode 03* to *mode 08;* 300 K → 4.2 K → 2 K → 300 K, takes one full week. This doesn't take into account *mode 01* and *mode 02*. The required time for all these technical operations at room temperature is also estimated at one full week. This means that no margin would be allowed in terms of the schedule. To address this problem it has been decided to build two CSIs. In this case it enables *mode 01* and *mode 02* on CSI A to be undertaken in parallel with *mode 03* to *mode 08* on CSI B.

This allows a margin of 50% on the schedule for testing the entire HβC production to be achieved. This margin will allows us to cover the expected amount of cavities requiring more than one test according to the X-FEL experience [3].

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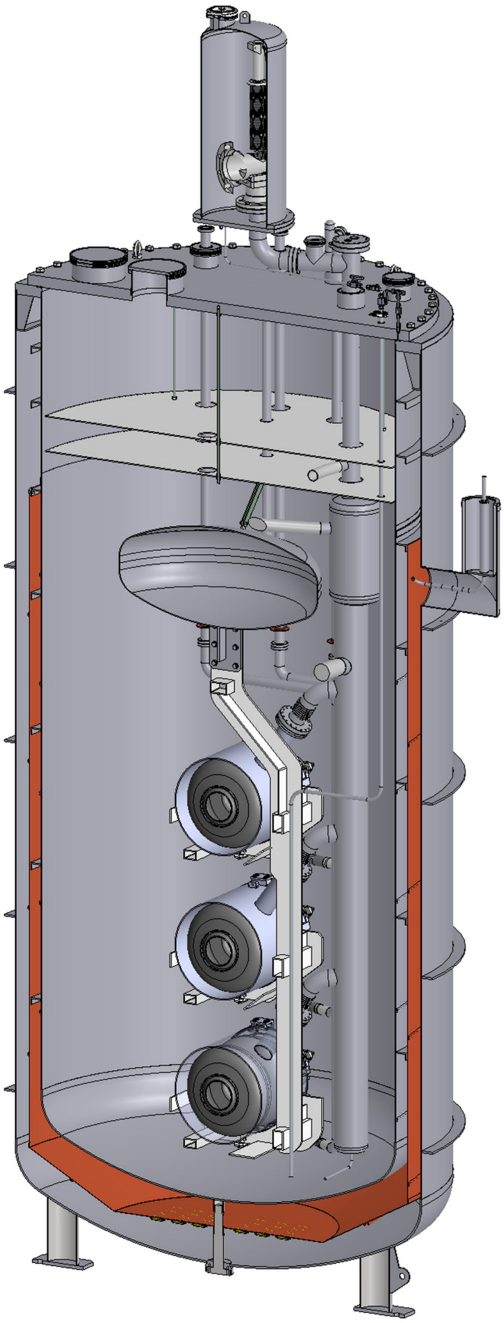

Figure 5: Cryostat section view.

## CONCLUSION

This new facility for the test of SRF cavities, first designed for ESS high beta series production, will give DL the possibility to test high scale production. It is expected to test 3 cavities per week at the highest rate and the facility will be fully commissioned by 2018.

## ACKNOWLEDGEMENT

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