ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPOGE10

A FINAL ACCEPTANCE TEST KIT FOR SUPERCONDUCTING RF CRYOMODULES

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Abstract

UKRI-STFC Daresbury Laboratory is currently undertaking several projects involving assembly of superconducting RF cryomodules, including HL-LHC crab cavities and PIP-II HB650 cavities. As part of the final acceptance tests before shipping of the modules, extensive leak testing, pressure testing, and thermal cycling with gaseous and liquid cryogens must be performed. A Final Acceptance Test kit (FAT-kit) has been developed to support these tests. The FAT-kit, designed as a single portable unit, sits as an interface module between the cryomodule under test and the required utilities (liquid cryogen supply and return, gaseous cryogen supply and return, warm gas supply and return, vacuum pumps, leak detectors, etc.). The kit features a valve manifold to make or break connections to, from, and between circuits in the cryomodule, safety groupings to provide protection for the circuits as required, and various instrumentation. We report here on the design and commissioning of the kit.

INTRODUCTION

Several projects to assemble and test superconducting radio frequency (SRF) cryomodules for forthcoming accelerators are underway at UKRI-STFC Daresbury.

In 2018, operation of the prototype DQW crab cavity cryomodule was successfully demonstrated in CERN's Super Proton Synchrotron (SPS) as part of the HL-LHC project [1]. Following on from this, STFC Daresbury are working closely with CERN to assemble first the preseries RFD cryomodule and subsequently four series DQW cryomodules [2].

STFC-Daresbury are also responsible as part of the PIP-II project for the assembly of HB650 cryomodules [3].

FINAL ACCEPTANCE TESTING

After completion of assembly of the aforementioned cryomodules, final acceptance testing is required before shipping from STFC-Daresbury to their onward destinations. These tests vary by project [4, 5], but generally include the following cryogenic and vacuum tests:

- Leak testing of the insulating vacuum and various cryogenic circuits
- Pressure testing of the various cryogenic circuits
- Thermal cycling of the cryogenic circuits

Leak and pressure tests are generally to be repeated after thermal cycling back to room temperature to confirm mechanical integrity after thermal stresses have been experienced. As nearly all thermal contraction occurs above 80 K, this thermal cycling may be done using liquid nitrogen (LN_2).

FAT-KIT DESIGN

In order to support final acceptance testing of cryomodules at Daresbury, an interface module (FAT-kit) has been developed to sit between the assembled cryomodule and the required utilities for the tests. Originally, this design was developed for the HL-LHC crab cavity cryomodule, but can be modified as required for HB650 tests. The main goal of the kit is to improve consistency between, as well as safety and quality of FAT tests compared with connecting the various utilities in an ad hoc manner. The module is required to be portable between different experimental areas. The utilities required to interface to are as follows:

- High-pressure/low-pressure room-temperature He gas
- High-pressure/low-pressure room-temperature N_2 gas
- 80 K N_2 gas
- LN_2
- Vacuum pumping station
- Leak detector
- Vent lines

Figure 1 shows the top-level piping and instrumentation diagram (P&ID) with the FAT-kit between the utilities as described and the cryomodule.

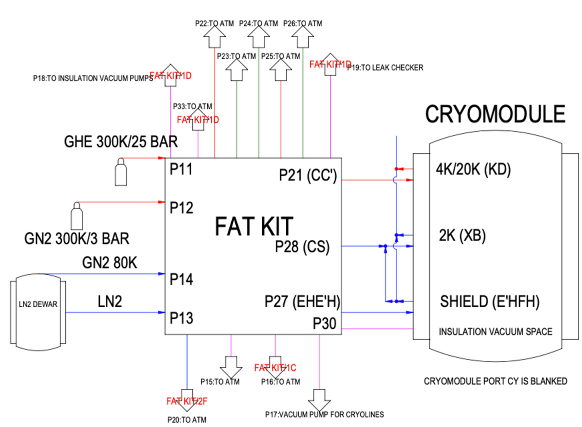

Figure 1: Top-level P&ID showing the FAT-kit sitting between utilities and cryomodule

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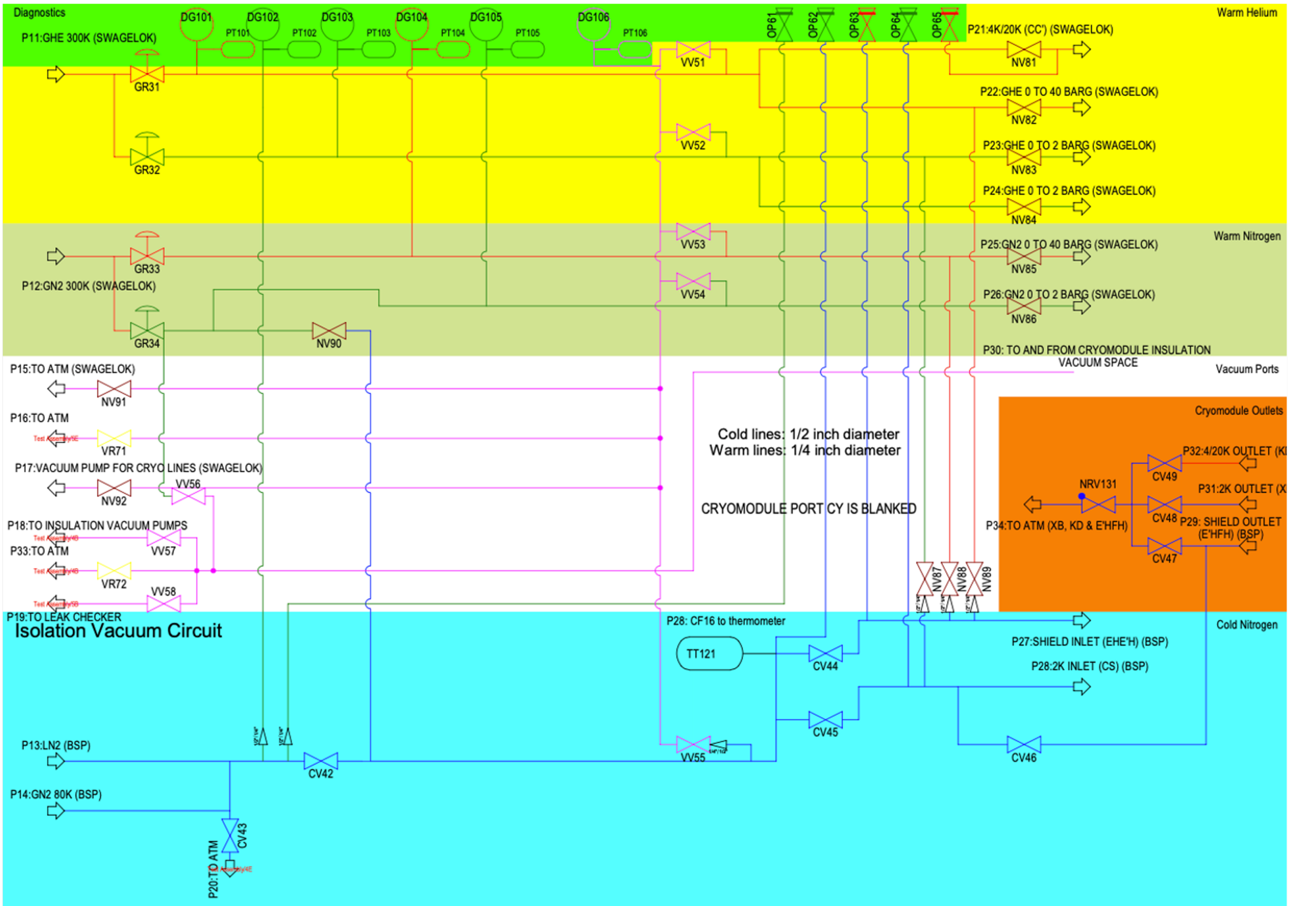

Figure 2: P&ID for FAT-kit module showing all internal circuits and components

Fig. 2 shows the detailed P&ID for the FAT-kit module (i.e., the internal P&ID for the central block in Fig. 1). All utilities are shown down the left-hand side. Connections to the cryomodule and auxiliary outlets are shown down the right-hand side.

The green-shaded section of Fig. 2 shows the diagnostics and safety devices; these are dial gauges (denoted DG), corresponding pressure transducers (PT), and pressure relief valves (OP).

In the yellow-shaded section, room-temperature helium is connected to the FAT-kit and supplies low-pressure and high-pressure regulators (GR). These supplies are used for pressurising the cryogenic circuits of the cryomodule for leak and pressure testing respectively.

The white-shaded section shows the vacuum circuits; these are for pumping the insulating vacuum, cryogenic lines as part of pump and purge procedures, and connecting a leak detector operating in vacuum mode. Vacuum relief valves protecting these circuits are denoted VR.

The blue-shaded section shows the cold circuits, which are supplied by LN_2 and GN_2 from the dewar shown in Fig. 1. A solenoid control valve on the dewar (not shown) allows control of pressure/flow rate of cryogens to the FAT-kit and hence the cryomodule cryogenic circuits. Cryogenic valves are denoted CV. The construction of these valves is such that they must be mounted with the handles vertically above the valve bodies; as such, a "piano" type arrangement has been devised as described in the following section and shown in Fig. 3. The outlets of the cryogenic circuits are routed back into the FAT-kit and directed to a vent line for personnel protection. Furthermore, it may be seen that the outlet of the shield cooling circuit may be redirected back into the inlet of the cavity cooling circuit; the motivation for this is to give the option of supplying LN_2 to the shield cooling circuit and using the boil-off gas to cool the cavities. This allows cooling of the cavities without the level of thermal shock that would be experienced if LN_2 was introduced directly to the cavity cooling circuit (as well as being a more efficient use of the LN_2 as it makes use of the enthalpy of the cold gas).

A separate instrumentation rack (not shown) houses the monitors for pressure gauges, thermometry, vacuum gauges, fluxgates, and liquid level probes from both the FAT-kit and cryomodule. The data acquisition system that is being developed will allow real time monitoring and logging of data from these monitors. Data will be visualised via EPICS (including plotting tools) and archived.

As part of cold cycling, it will also be possible to carry out functional tests of the various valves, tuners, rf components, heaters, and cavity position monitors in the cryomodule. If

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desired, experimental measurements of heat loads to the circuits at 80 K may be made with minimal adjustments to the FAT-kit (i.e., installation of additional pressure and temperature sensors at the outlet of these lines).

FAT-KIT MANUFACTURE

The FAT-kit fabrication is being undertaken by an industrial partner. Fig. 3 shows a photograph of the kit during assembly. Pressure gauges are visible at the top of the image. Needle valves are visible in the centre and on the right hand side of the image. The "piano" structure described in the previous section is visible at the bottom of the image where the LN_2valve handles can be seen to be mounted vertically.

Figure 3: Photograph of FAT-kit during assembly

The instrumentation rack has been assembled and is currently being populated with monitors as described in the previous section.

CURRENT STATUS AND FUTURE PLANS

The FAT-kit fabrication is nearing completion with the contractor as described above. Commissioning of the system is planned for September 2022. Final Acceptance Testing of the HL-LHC preseries RFD cryomodule is planned for November 2022. Beyond that, the FAT-kit will be utilised for the HL-LHC series DQW cryomodules and PIP-II HB650 cryomodules.

ACKNOWLEDGEMENTS

The authors would like to thank collaborators from CERN and Fermilab, as well as industrial partners.

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