THE CRYOGENIC INFRASTRUCTURE FOR SRF TESTING AT TRIUMF

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Abstract

At the moment TRIUMF operates one superconductive radio-frequency (SRF) accelerator and is building the second one. The superconducting heavy ion linear accelerator of the Isotope Separation and Acceleration (ISAC) facility utilizes medium beta quarter wave cavities cooled down to 4 K. The Advanced Rare IsotopE Laboratory (ARIEL) is a major expansion of the ISAC facility. ARIEL SRF electron linear accelerator (e-linac) operates nine-cell TESLA type cavities at 2 K. Both accelerators have dedicated cryogenic systems including liquid helium plants and distribution systems. In addition to accelerator cryogenic support, ISAC cryoplant provides liquid helium for the SRF testing facility at both 4 K and 2 K temperatures. TRIUMF's SRF development involves both SRF testing facility and accelerators cryogenic support systems. This paper presents the details of the SRF testing cryogenic systems as well as recent commissioning results of the new e-linac cryogenic system.

ISAC FACILITY CRYOSYSTEM ARCHITECTURE

The cryogenic system of ISAC superconducting accelerator facility was installed in two phases. In 2006, the first Linde TCF50 cryoplant was installed and commissioned [1]. Phase-I cryogenic system installation supported five cryomodules with liquefaction rate of ~5 g/s. From the first days of operation the ISAC distribution system allowed for supplying cryogens to SRF test facility for cavities and cryomodule testing. During the Phase-II ISAC facility upgrade the second Linde TCF50 cryoplant was installed and integrated into the existing infrastructure [2]. Liquid helium and liquid nitrogen distribution systems were integrated to the existing lines. At full load both Phase-I (~620 W) and Phase-II (~590 W) cryoplants have enough capacity to handle the entire linac static heat load (in the range of 16 to 23 W per each cryomodule, with additional 95 W for helium distribution lines), allowing minor cryoplants maintenance without warm-up of the cryomodules.

ISAC SRF test facility had been developed in parallel with ISAC linac to support TRIUMF's SRF development. The current state of the SRF test facility includes cavity preparation facility (ultrasound cleaning tanks, high pressure water rinse area, chemical etching facility), cryomodule assembly area and SRF cavities test facility.

Individual cavities and assembled cryomodules undergo set of warm and cold tests at both 4 K and 2 K before the final installation. Individual SRF cavity tests are performed in the test cryostat, designed for the ISAC linac quarter-wave cavity and later upgraded to support 9-cell cavities (Figure 1). Cryomodules went through the cold tests before initial installation, as well as after periodical maintenance operations.

The current ISAC cryogenic system configuration includes the capability to support the following operations:

- ISAC Phase-I and Phase-II cryomodules nominal operation with the support of SRF test facility cryogenic tests using both cryoplants;
- ISAC Phase-I and Phase-II cryomodules maintenance mode (handling static heat load) with the support of SRF test facility cryogenic tests using one cryoplant.

Figure 1: SRF test facility cavity cold test (left), cryostat section view (right).

The SRF testing facility is actively used to perform cryogenic tests of individual cavities for TRIUMF and other laboratories. The tests were performed on a quarter-wave cavities (Legnaro cavities for ISAC Phase-I, TRIUMF-PAVAC cavities for ISAC Phase-II), elliptical cavities (TRIUMF-PAVAC cavities for ARIEL Phase-I and VECC cryomodule). The prototype cavity for ISOLDE facility at CERN was tested at TRIUMF SRF test facility. Currently SRF group is closely involved in R&D efforts testing quarter-wave and half-wave cavities for RISP project in South Korea.

SRF Test Facility

Due to the set of requirements to the cryogenic support of SRF test facility, highly configurable liquid helium supply source is essential. To minimize cavity replacement and cryostat maintenance periods, liquid helium is supplied through the single flexible vacuum-jacketed line with no extra liquid nitrogen or cold return helium gas precooling (Figure 2).

ISBN 978-3-95450-178-6

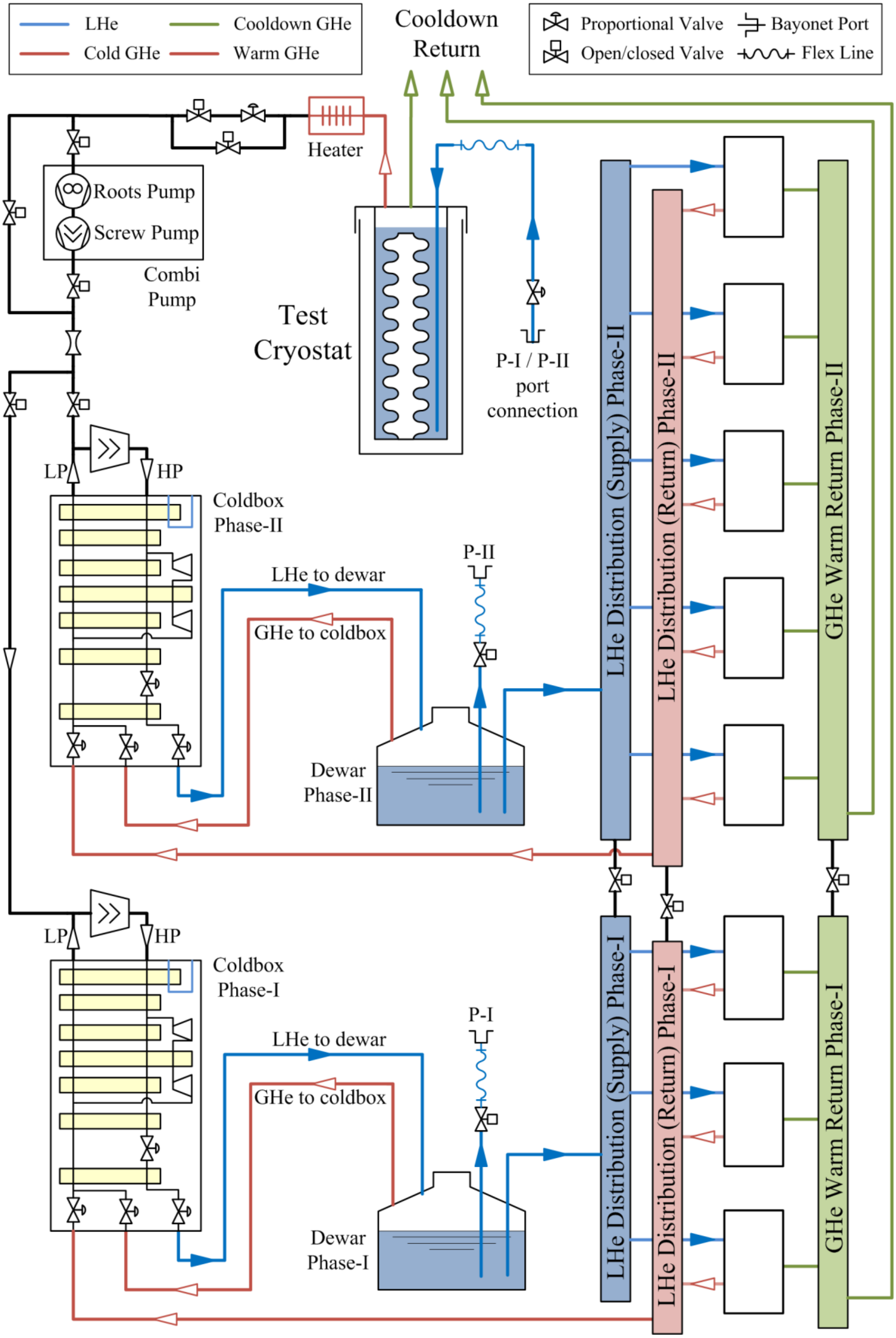

Figure 2: ISAC-II cryogenic system architecture.

Both cryoplant dewars are equipped with an extra withdrawal port to change dewar supply during cryoplants maintenance. Phase-I cryoplant is normally used to support SRF tests as a higher capacity system.

Both 4 K and 2 K temperature tests are supported in the SRF test facility. Initial 300 K to 80 K cool-down is performed using liquid nitrogen to precool thermal shields. To prevent cavities from cooling down below 150 K, thermalization of cryostat or cryomodule on this stage is limited in time. Due to the possibility of Q-disease in the 50 K..150 K temperature range, liquid helium is used to keep a higher cool-down rate within these temperatures (Figure 3).

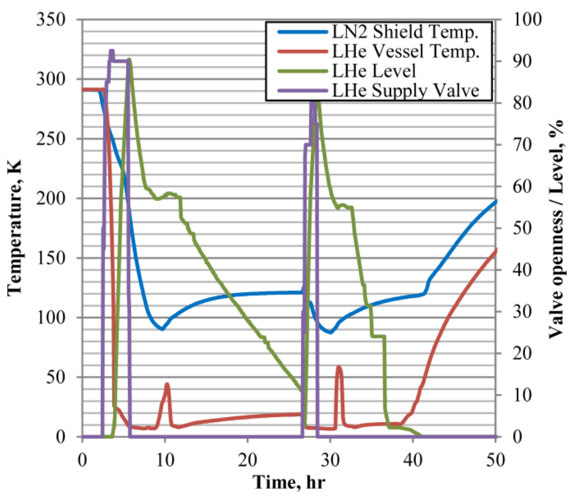

Figure 3: ARIEL 9-cell cavity cold test.

Due to direct heating of cold return helium flow without recuperation in the coldbox, its entire heat load is defined as liquefaction. Because of the high liquefaction load, supply of liquid helium to the test cryostat can only be established using excessive liquid helium inventory for a limited period of time. Therefore, cryogenic tests are limited by time period between cryostat liquid helium refills.

Superfluid helium at 2 K temperature is produced by pumping out helium gas from a closed liquid helium volume. Due to the absence of the heat exchanger and additional JT-stage, low pressure cold return helium flow is not recuperated, and low conversion efficiency does not allow constant 2 K production mode. Approximately a third of the liquid helium inventory in the cryostat is evaporated during 4 K to 2 K cool-down stage. To maintain liquid helium level required to keep 9-cell cavity fully immersed, special geometry of the cryostat with a large buffer above the cavity is utilized (Figure 4).

After achieving 2 K temperature, the control on the pump-out process has to be established to allow fine control on the liquid helium temperature. To support the wide range of the static and dynamic heat loads, high adjustability of operating parameter is necessary. This is achieved through the use of throttling butterfly valve, controlled by a PID algorithm [3].

The original sub-atmospheric pumping system including Pfeiffer Roots blower and Adixen hermetically sealed mechanical vane backing pumps was upgraded to Busch Combi pumping station consisting of a Roots blower and a dry screw backing pump.

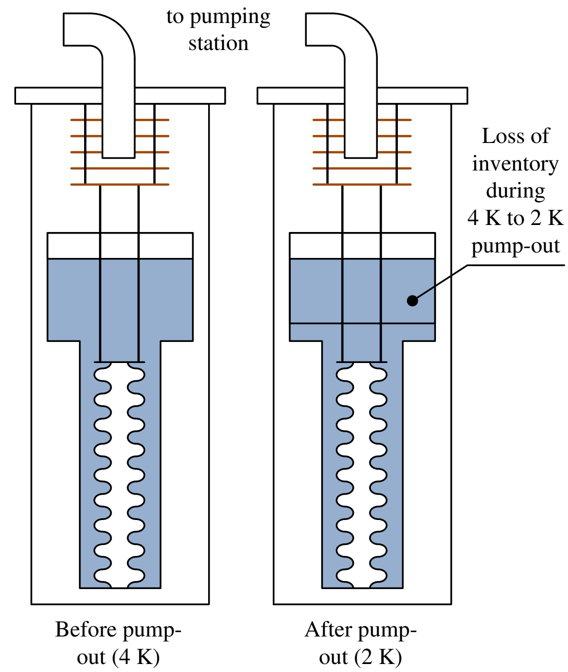

Figure 4: Test cryostat liquid helium bath geometry.

ARIEL FACILITY CRYOSYSTEM ARCHITECTURE

The new TRIUMF's ARIEL facility includes SRF e-linac operating nine-cell TESLA type cavities at 2 K. An Air Liquide HELIAL LL cryoplant was commissioned in 2013 [4] and the integration of the cryogenic system was performed in 2014 [5]. The cryomodule design has been reported elsewhere [6].

The 4 K to 2 K temperature conversion is achieved by a counter flow heat exchanger and a JT-valve installed onboard each cryomodule, increasing the conversion efficiency.

The cryomodule 2 K space temperature control is achieved by regulation of helium saturation pressure. The sub-atmospheric return pumping line is common for all the cryomodules. Therefore, the 2 K space pressure regulation is performed in two stages. Each cryomodule has dedicated sub-atmospheric cryogenic valve which controls the pressure in the 2 K space (SRF cavities bath and 2 K liquid helium phase separator) using PID control algorithm. The sub-atmospheric pumping line is equipped with throttling gate valve at the warm side of the trunk upstream to the pumping units. Adaptive pressure controller performs the pressure control in the sub-atmospheric pumping trunk using the throttling gate valve. Thus, the sub-atmospheric pressure regulation system allows to control the helium saturated pressure and temperature independently at each cryomodule and keep the stable pressure in the return line.

ISBN 978-3-95450-178-6

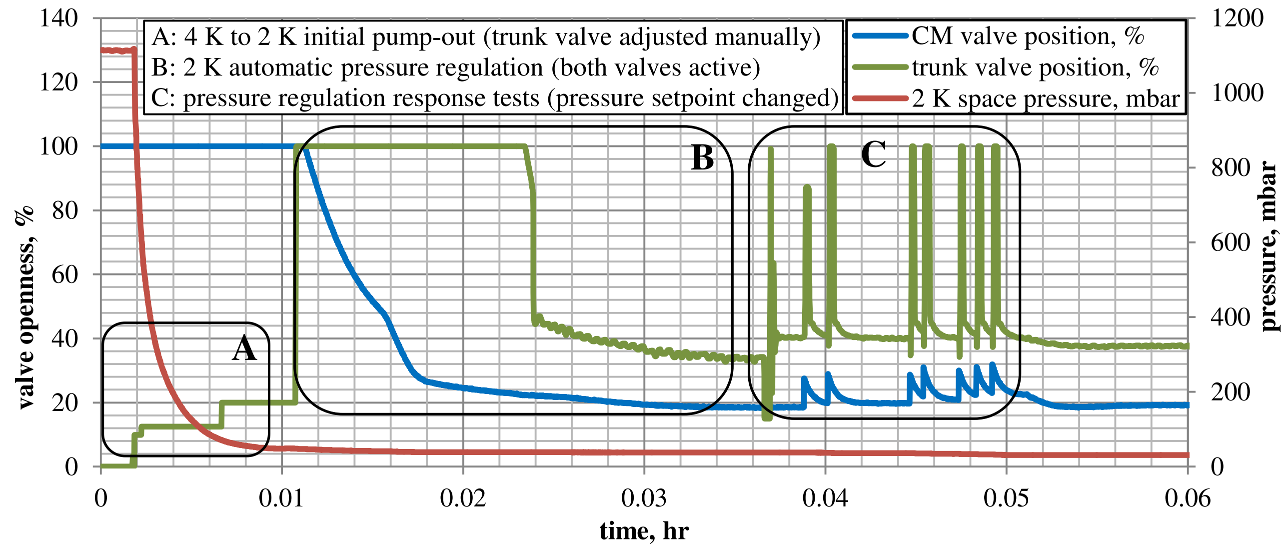

Figure 5: Two-stage pressure control in the 2 K space of ARIEL injector cryomodule.

Two types of pressure control in the 2 K space were tested during the ARIEL cryogenic system commissioning. Two-stage regulation with both active pressure controllers (cryomodule 2 K return valve and sub-atmospheric trunk throttling valve) was tested during both nominal operation and transient response tests (Figure 5). Single-stage pressure regulation was confirmed to be adequate to maintain pressure within 31.2..31.4 mbar (Figure 6).

Both pulse and CW RF mode tests were performed in 2014 confirming specified performance requirements [7].

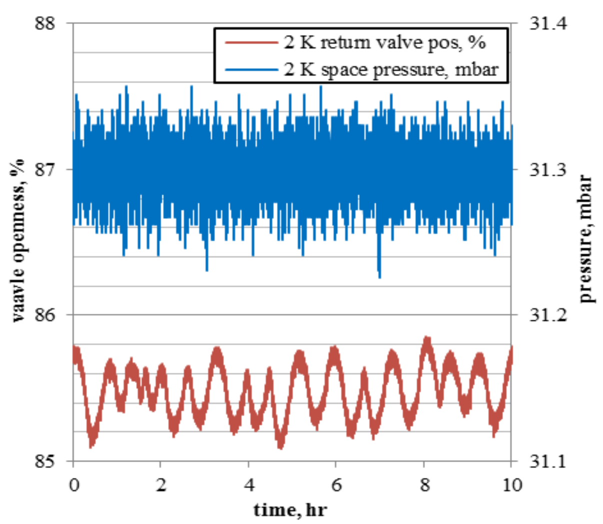

Figure 6: One-stage pressure control in the 2 K space of ARIEL accelerator cryomodule.

CONCLUSION

TRIUMF's experience with stable operation of ISAC-II cryogenic system for 9 years confirms high reliability of chosen architecture to utilize cryoplant for cryogenic support of both superconducting linac and R&D SRF test facility.

The early stage of the ARIEL e-linac commissioning demonstrates that all the e-linac equipment meets performance goals. The cryogenic system performs reliably and supports the stable operation of the cryomodules. The installed cavities met performance specifications.

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