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PARTICULARITIES OF THE ARIEL E-LINAC CRYOGENIC SYSTEM

I. Bylinskii, G. Hodgson, D. Kishi, S. Koscielniak, A. Koveshnikov, R. Laxdal, R. Nagimov, D. Yosifov, TRIUMF, Vancouver, Canada

Abstract

The Advanced Rare IsotopE Laboratory (ARIEL) is a major expansion of the Isotope Separation and Acceleration (ISAC) facility at TRIUMF [1]. A key part of the ARIEL project is a 10 mA 50 MeV continuous-wave superconducting radiofrequency (SRF) electron linear accelerator (e-linac). The 1.3 GHz SRF cavities are cooled by liquid helium (LHe) at 2 K [2]. The 4 K-2 K LHe transition is achieved onboard of each cryomodule by the cryoinsert containing counterflow heat exchanger augmented with JT-valve [3]. Air Liquide LHe cryoplant provides 4 K LHe to cryomodules. After successful commissioning of the cryoplant, 2 K sub-atmospheric (SA) system and cryomodules, the ultimate integration test confirmed stable operation of two cryomodules comprising two 9-cell SRF cavities. Particularities of this cryogenic system include conservative design of the oil removal system, original design heat exchanger in the SA pumping system, hermetic SA pumps, inline full SA flow purifier, multipurpose recovery/purification compressor, modular LHe distribution system, top-loaded design cryomodules, and overall radiation resistant design. The paper presents details of these features as well as integration tests results.

INTRODUCTION

The TRIUMF ten year plan (2010-2020) seeks to triple the laboratory nuclear physics scientific output by the additional of two new rare isotope beam (RIB) sources. These sources will supply the three existing experimental areas at the ISAC research facility which presently shares a single "driver" proton beam line (BL2A) for RIB production - resulting in under-utilization of experimental potential. The plan foresees a 50 MeV and 10 mA e-linac. Its major components are a 300 keV electron gun, 10 MeV injector cryomodule (ICM) with one 9-cell Nb elliptical cavity, and two 20 MeV accelerator cryomodules (ACM) each containing two 9-cell Nb elliptical cavities. The cavity frequency (1.3 GHz), type (9-cell elliptical), and operating temperature (2 K) have been chosen to benefit from the two decades of development, at the TESLA Test Facility.

For both budgetary and resource allocation reasons the e-linac project is planned in two phases. The first stage, ARIEL phase-I, includes two cryomodules (ICM and ACM #1). A third cryomodule will be added in ARIEL phase-II. The architecture of the ARIEL cryogenic system is shown in Figure 1.

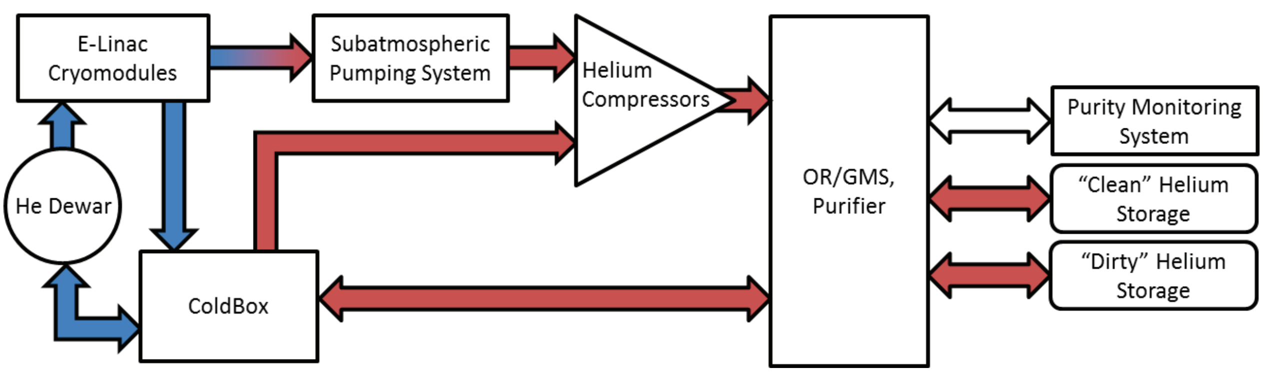

Figure 1: Architecture of the e-linac cryogenic system.

COMPRESSION AND GAS HANDLING

Compression Station

The compression station contains two Kaeser oil-flooded screw-type compressors (Figure 2). The main compression unit (Kaeser FSD571SFC) has 112 g/s capacity at the nominal discharge pressure of 14.5 bar(a). In addition, a smaller air-cooled recovery/purification compressor is installed. This unit (Kaeser CSD85) provides 15 g/s flow rate and is used for a dual purpose. In the event of a power failure the compressor uses power from an emergency power generator to recover all helium boil-off. During regular operation, this same compressor handles the entire throughput of the sub-atmospheric pumps when cryomodules are at full RF load. This helium flow can then be cleaned of impurities by passing through the purifier. This compressor is equipped with dedicated oil-removal and gas management system (OR/GMS). Additionally, this compressor will be used as a purification compressor, moving helium inventory through the purifier from the 'dirty' storage tank (to be installed as a part of ARIEL phase-II upgrade) to the 'clean' storage tank.

Oil Removal and Purification Systems

Oil removal system shall remove any oil vapors or oil aerosol particles from the process gas. The size of the

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coalescers and charcoal adsorber was increased to optimize the operation of helium cryoplant. Both main and recovery compressors oil removal systems are equipped with a 3rd additional coalescer to decrease the risk of oil migration. Custom design of the charcoal adsorber includes high-temperature resistant materials (~150°C) to increase the temperature of charcoal bake-out and improve water regeneration. A larger volume carbon bed allows to increase period of maintenance free operation without charcoal replacements from one to three years.

Figure 2: Main and recovery/purification compressors.

Helium purity is monitored downstream of the charcoal adsorber by Linde multicomponent detector. The warm helium piping connects the new stand-alone compressor building to the electron-hall (accelerator facility). The total length of warm helium lines between the compressor and coldbox exceeds 90 m.

Potentially contaminated helium from the SA system is checked for impurities after passing through a purification compressor and its OR/GMS. If the purity is satisfactory, helium flow can go to the 'clean' storage tank. If not, helium passes through the freeze-out purifier and after another purity check merges either 'clean' or 'dirty' streams depending on gas cleanliness.

The freeze-out stand-alone helium purifier is built with a technical assistance from Fermi National Accelerator Laboratory. The oversized carbon bed allows to increase interval between regeneration up to one month with impurities level not exceeding 10 ppm(v).

COLD HELIUM SYSTEMS

Liquid Helium Cryoplant

The supplied "HELIAL LL" coldbox is an automatic helium liquefier-refrigerator provided by Air Liquide Advanced Technologies (Figure 3).

Table 1: Cryoplant Commissioning Results [4]

Performance parameter	**Specified / measured values**
Pure liquefaction capacity with LN2 precooling	288 L/hr / 367 L/hr
Pure refrigeration capacity with LN2 precooling	600 W / 837 W

The standard 4 K helium liquefier-refrigerator is chosen both for budgetary and technical reasons. 4 K-2 K transition required for operation of e-linac cryomodules is achieved on-board of each cryomodule. The cryoplant was specified with 30% capacity contingency with respect to the e-linac cryogenic loads. During the acceptance tests the performance of the cryoplant in main regimes was confirmed (Table 1).

Figure 3: Helium cryoplant during commissioning phase.

Liquid Helium Distribution Systems

Helium coldbox and 1000 L liquid helium storage dewar are positioned in the immediate vicinity of the e-linac cryomodules in order to minimize losses associated with LHe transfer. To minimize engineering efforts the concept and design of the major subsystems is based on previous experience with ISAC-II SRF linac operational at TRIUMF [2]. The LN2 precooled vacuum-jacketed 4 K helium distribution system is designed as a modular structure. It uses a standard compression flange technology and allows a non-welded execution of the field joints. Due to positive gauge pressure of both LHe supply and GHe return lines risk of helium contamination from cryomodule interfaces is eliminated.

Cryomodules

The cryomodules have top-loading box-like structure with cold mass suspended from the lid and surrounded by LN2 cooled thermal isolation box. The 2 K liquid is produced in each cryomodule by passing the 4 K liquid through a counterflow plate-fin heat exchanger, cooled by returning exhaust gas from the 2 K dual phase reservoir, and expanding the forward-flowing gas to 31 mbar through a JT-valve [3]. To reduce the risk of contamination due to the negative gauge pressure of the 2 K return gas, the vacuum jacketed piping was designed with hermetic welded field joints.

SUB-ATMOSPHERIC SYSTEMS

To decrease the overall length of the subatmospheric vacuum-jacketed return line, a counter-flow tube-in-tube heat exchanger is installed in the accelerator hall upstream of the sub-atmospheric warm pipe. The heat exchanger brings the temperature of subatmospheric stream close to ambient. This heat exchanger is designed in a way of utilizing high-pressure helium flow to prevent

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overcooling of its outer walls without vacuum jacketed insulation (Figure 4). Pre-cooling of the high pressure helium flow reduces coldbox LN2 consumption.

The downstream end of the SA heat exchanger is connected by non-insulated piping to SA pumping system. It removes helium vapour from the cryomodules 2 K dual phase reservoirs and keeps the pressure at 31 ± 0.5 mbar independent of the variable RF load [5]. The pressure in the 2 K reservoir of each cryomodule is controlled by proportional control valves. These valves are used to tune conductance of each branch independently according to individual cavity performance, CM static and dynamic loads, etc.

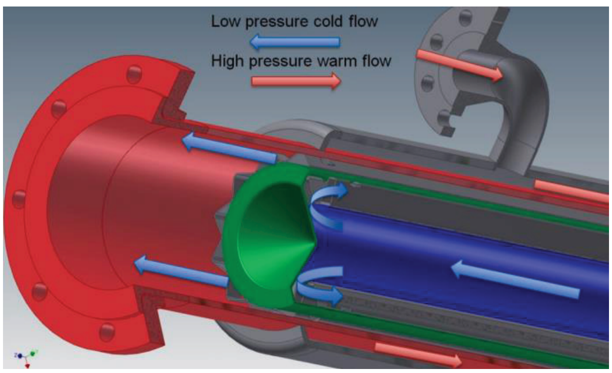

Figure 4: Sub-atmospheric heat exchanger [6].

The common pressure in the SA line is controlled by a warm throttling gate valve. This valve provides coarse pressure control while the fine regulation for each cryomodule is achieved by the cold proportional valve. The two stage pressure control system increases reliability and flexibility of the operation.

Busch Cobra DS3010-He pump consisting of a Roots blower and a dry screw backing pump was chosen as the sub-atmospheric pumping unit. The configuration of the pumping system is based on a modular approach of parallel connection of several pumps. This solution is chosen due to the following advantages.

- As a dry pump it does not require an extra oil-separation system. This eliminates oil-compatibility issues with main and recovery helium compressors.
- Water cooled canned motor design eliminates the dynamic seal on a motor shaft prone with a static seal reducing the risk of air leaks.
- Using several pumps in parallel permits adjusting pumping capacity based on the number of installed cryomodules and their heat load. An individual pump can also be removed for refurbishing without compromise to operations.

RADIATION ENVIRONMENT

The electron hall is a radiation environment. The prompt radiation field in the transverse plane of the beam line is estimated to be in the range of 1-5 mSv/h. All the valves are equipped with radiation-resistant seats and diaphragms. The warm piping flanged joints are sealed with radiation resistant gaskets. Based on expert assessment the mean life-time for many electronic devices at this level would be as short as 0.2 to 2 years [7]. In order to protect sensitive electronics, the controllers of the helium and nitrogen distribution proportional valves are located remotely behind the shielding wall which will reduce the radiation fields to less than 0.1 mSv/h. All the cables routed to the e-hall are rated to the radiation resistance index 5.

SYSTEM INTEGRATION AND COMMISSIONING

In 2013-2014 the e-linac project team has accomplished the complex task of system integration, which includes e-linac cryogenic system limited to ARIEL Phase-I components. The installation, integration, device and sub-system testing proceeded according to plan. The acceptance test of the cryoplant confirmed that the manufacturer fully satisfied the design requirements for the liquefier-refrigerator. Both injector and accelerator cryomodule #1 were successfully integrated into the e-linac cryosystem.

All custom-designed elements were successfully integrated to e-linac cryogenic system during the commissioning phase. Custom-designed SA heat exchanger provides adequate heat transfer to SA helium gas flow to prevent overcooling of its outer shell. SA trunk pressure regulation control loops meet the requirements of pressure stability in the cryomodules. SA pumping system with just two pumps successfully passed the performance test.

ACKNOWLEDGEMENTS

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REFERENCES

[1] L. Merminga et al., "ARIEL: TRIUMF's Rare IsotopE Laboratory," IPAC'2011, San Sebastian, September 2011, p. 1917 (2011).
[2] I. Bylinsky et al., "ARIEL e-linac cryogenic system development at TRIUMF," ICEC'24-ICMC'2012, Spokane, May 2012, p. 653 (2012).
[3] R. E. Laxdal, et al., "The Injector Cryomodule for the ARIEL E-Linac at TRIUMF," LINAC'2012, Tel-Aviv, September 2012, p. 389 (2012).
[4] G. Hodgson et al., "Acceptance Tests and Commissioning of the ARIEL e-Linac Helium Cryoplant," IIR'13, Prague, April 2014, p. 41 (2014).
[5] A. Koveshnikov, et al., "Progress Update on Cryogenic System for ARIEL E-linac at TRIUMF," CEC'2013, Anchorage, June 2013, p. 201 (2013).
[6] V. Strickland, Design Note TRI-DN-13-34 "Helium Heat Exchanger Final Design," TRIUMF, Vancouver (2014).
[7] A. L. Perrot and T. Wijnands, Internal Note TS-Note-2006-001 "Radiation Tolerance of the Cryogenic Equipment Installed in the LHCB Experimental Cavern," CERN, Geneva (2006).