PERFORMANCE AND EARLY OPERATING EXPERIENCE WITH THE ISAC-II CRYOGENIC SYSTEM

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Abstract

A 500 W class refrigerator has been installed and commissioned at TRIUMF to cool the new 20 MV superconducting linac. The refrigerator liquefies helium into a common supply dewar. The dewar feeds a common manifold and the five cryomodules are fed via parallel cold distribution circuits. The system operates at 4.3 K. Measurements have been done to estimate the static loads of the cryomodules and the distribution system and to characterize plant performance. The paper will include a system description, performance results and early operating experience.

INTRODUCTION

The ISAC facility, operational since 1998, is a world-leading facility in the production, acceleration and study of radioactive ion beams. The ISAC-I post-accelerator includes an RFQ and a IH-DTL to bring ions with $A/q \leq 30$ to 1.5 MeV/u. TRIUMF is now commissioning the medium-beta section of the new heavy ion superconducting linac as an extension, ISAC-II, to the ISAC facility [1]. The medium-beta section is composed of five cryomodules with each cryomodule containing four bulk niobium, two-gap, quarter wave RF cavities for acceleration, and one superconducting solenoid for periodic transverse focussing. The total of twenty cavities gives a combined increase of 20 MV to the ISAC radioactive ion beam post-accelerator. Starting with a cool-down of the cryomodules in late March, first acceleration was achieved on April 8, 2006. SC-Linac commissioning continues throughout 2006 with first beam to experiment in Nov. 2006. An overview of the ISAC project is shown in Fig. 1 with the ISAC-II linac vault and associated cryogenic equipment noted.

An engineering description of the cryomodule is reported in [2]. Each module has two main assemblies, the top assembly and the tank assembly. The top assembly shown in Fig. 2 includes the vacuum tank lid, the lid mu-metal and LN2 forced flow thermal shield, the cold mass and the cold mass support. The cold mass consists of a 120ℓ helium reservoir, four rf cavities and the solenoid. The efficiency of cooldown is improved by a manifold and distribution system 'spider', connected to the LHe transfer line, that delivers cold gas and liquid to the bottom of each element through 5 mm Cu tubing. The tank consists of the vacuum tank, the mu-metal liner and the LN2 thermal shield insert.

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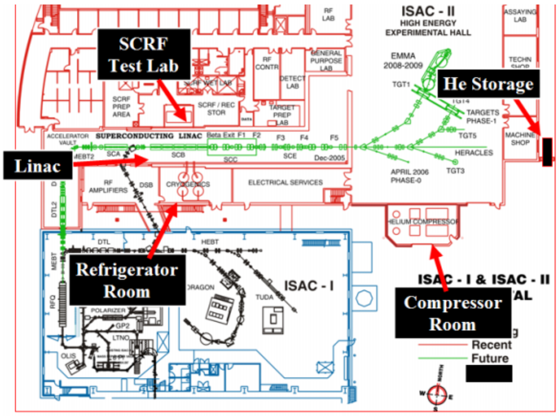

Figure 1: Overview of the ISAC project.

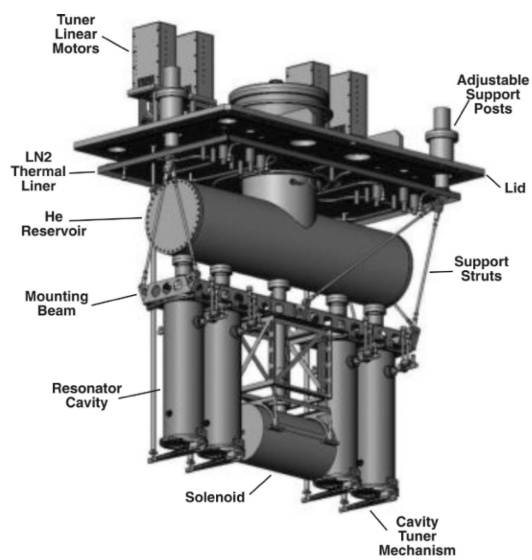

Figure 2: Cryomodule top plate assembly.

ESTIMATED HEAT LOADS

Cold tests of single cryomodules in the test facility have demonstrated a static heat load to 4K of $\sim$13 W and a LN2 flow of 5ℓ/hr for each cryomodule as per design estimates. The budget for the active load component is 8 W per cavity giving 160W for the medium-beta section of twenty cavities. The conservatively estimated load to the cold distribution is 72 W based on the heat load budget for various line sizes presented in Table 1. The total (static and dynamic) estimated heat load is 297W.

Table 1: Estimated heat loads for components of the helium distribution system (FJ=field joint, VB=vacuum break).

Element	0.375NPS	0.5NPS	1NPS	1.5NPS
FJ (W)	0.3	0.3	0.4	0.5
FJ/VB (W)	1.5	1.5	2.0	2.0
Valve (W)	0.7	1.1	2.0	2.9
Pipe (W/m)	0.2	0.2	0.3	0.3

CRYOGENIC SYSTEM OVERVIEW

TRIUMF took a large role in the refrigeration project in order to reduce capital costs. The scope of the contract with LINDE cryogenic, Switzerland, was restricted to the major refrigerator components: TCF50 refrigerator (liquefaction rate of 5.2 g/s and a continuous refrigeration rate of at least 530 W at 4.5K), main compressor (Kaeser ESD441SFC direct drive screw compressor of 268 kW, 79 g/s, 14 bara equipped with variable frequency drive) and recovery compressor (Kaeser BSD62 screw compressor of 37.5 kW, 12 g/s, 14 bara), and oil removal and gas management system. TRIUMF assumed the responsibility for installation of the LINDE refrigerator components as well as the management of the contract for the installation of the warm piping by a local installer. In addition TRIUMF acquired and installed a 114 m^3 horizontal buffer tank and a 1000 liter helium dewar. The cold distribution specified by TRIUMF was built and installed by DeMaCo, Holland. A helium gas analyzer was purchased from Analytic Instruments.

HELIUM DISTRIBUTION SYSTEM

The refrigerator supplies liquid helium to the dewar. The main linac manifold supply line is fed LHe from the dewar via an overpressure of 200 mBar. The cryomodules are fed in parallel from this helium supply 'trunk' line through variable supply valves and field joints. The cold return from the cryomodules comes back to the trunk cold return line through open/close valves and field joints. The field joints have outside sliding bellows with VCR fittings for supply, and ConFlat fittings for return. During cooldown, when warmer than 30°K, the returning gas is sent back to the suction side of the compressor through the warm return piping and in-line vaporizers. Keep cold sections with proportional valves join the trunk supply and the trunk cold return at each end. A schematic of the cold distribution system is shown in Fig. 3

Future expansion will involve demounting the keep cold sections, extending the trunk and cryomodule feed lines and remounting the keep cold sections. A second refrigerator will be added in two years. Pipe sizes and estimated mass flows for the cold distribution are given in Table 2. Valves specified for the middle of the two trunk lines are for future installations to divide flows between two refrigerators. In addition to the branch lines supplying the five cryomodules a secondary line off the main trunk supply is

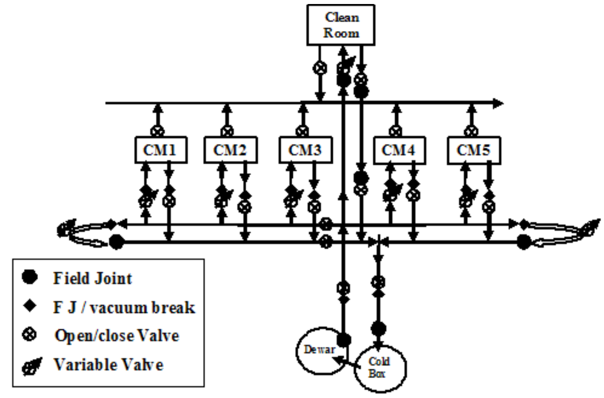

Figure 3: Schematic of the ISAC-II LHe distribution system.

Table 2: Cold distribution specifications.

Pipe	Supply ID (mm)	Return ID (mm)	Mass Flow (gm/sec)
Dewar to Trunk	18	45	25
Trunk	18	45	25
Cryomodule	13.8	32	5
Clean Room	13.8	32	5
Keep Cold	-	13.8	2

required to deliver LHe to the ISAC-II test/assembly area. All supply and cold return piping is vacuum jacketed and except for the short feed line from supply valve to cryomodule is cooled with LN2.

A cross-section of vault and refrigerator room is shown in Fig. 4.

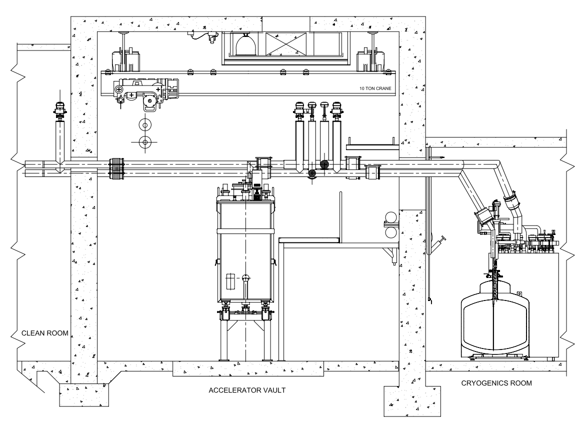

Figure 4: Vault and refrigerator room cross-section showing cryomodule, cold piping, service platform, helium dewar and cold box.

NITROGEN DISTRIBUTION SYSTEM

The liquid nitrogen distribution plumbing runs along the helium system, supplying liquid nitrogen to the internal thermal shields of the helium trunk lines, and the thermal shields of the cryomodule, as well as carrying back the nitrogen vapor to be exhausted outside (Fig. 5). A phase

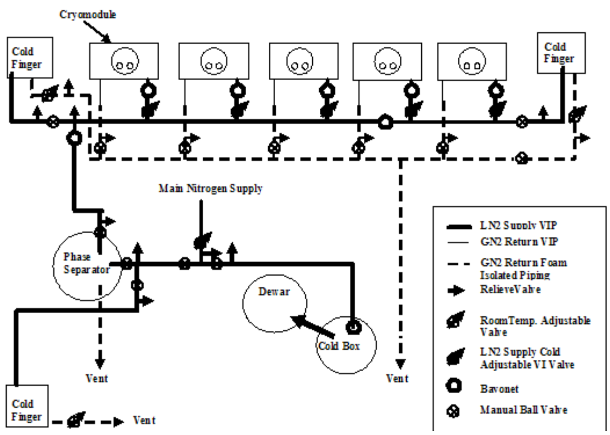

Figure 5: Schematic of the ISAC-II Nitrogen distribution system.

separator in the refrigerator room accepts the two-phase nitrogen supplied from the main nitrogen supply tank of 34 m^3 through a 60 m long transfer line. The phase separator is based on a 240 liter nitrogen dewar, supplied by Cryofab. It is equipped with a pressure-differential level-monitor (controlling the solenoid supply valve), pressure switch at 10 psig, controlling a vent solenoid valve, and a manual supply valve. The vent valve and vent lines are oversized (25mm diameter) to reduce pressure fluctuations during dewar refills.

INITIAL COMMISSIONING AND COOLDOWN

The refrigerator was commissioned in March 2005. The measured refrigeration power with LN2 precooling is 610 W at 0.7gm/sec liquefaction. In addition three turn down modes are possible by utilizing the variable frequency drive on the main compressor corresponding to peak refrigeration power of 375 W, 280 W and 190W and fractional wall power of 0.7, 0.59 and 0.53 respectively compared to the full output. The demonstrated liquefaction rate based on a rising dewar level is 225 ltr/hr. There is a periodic slow oscillation (T=12 min.) of the suction pressure of ~ 10 Torr peak to peak.

The initial cooldown of the cold distribution and linac began in March 2006. The refrigerator and helium dewar are cooled down and a helium volume of ∼700 liters is collected. The dewar level, once attained, is regulated automatically using an immersion heater in a PID control loop. The helium distribution is cooled down by running a return-flow through the keep cold sections back through the cold box.

The cavities are first baked at ∼90°C for 48 hours. LN2 is then fed through the side-shields and the cold mass is cooled by radiation for at least 48 hours to bring the average temperature to about 200K before helium transfer. Linac cooldown is done sequentially, one cryomodule at a time, to achieve a cavity cooling rate of ∼100K/hour to mitigate the effects of Q-disease[3]. This requires a LHe flow of ∼100-150 ltr/hr. It takes about five hours to establish a 120 ltr inventory in the cryomodule and roughly 24 hours to complete the bulk of the thermalization. A full cooldown takes a minimum of seven days with two days for the cold box, dewar and trunk line and one day each for the cryomodules. After each module is filled it remains at level even as the warm modules are cooled.

INITIAL OPERATING EXPERIENCE

The LHe production and delivery system has worked very well with only two unplanned cold box trips in four months of operation. A level probe in the cryomodule helium reservoir is used to regulate the variable supply valve during operation. Together with the main dewar regulation the helium levels are maintained independent of the rf active load. Before linac tuning commences a refrigerator mode is selected to allow enough headroom in the dewar heater to accept the planned active load. As the cavities are turned on the dewar heater value decreases to maintain the dewar level. One concern is the high heat load from the cold distribution. During standard operation in the first turn down mode (ECO1) the dewar heater reaches an equilibrium setting of $\sim 150\ W$ to maintain constant levels in the supply dewar plus in each of the cryomodules. If the dewar is isolated from the distribution system the heater must be at ~ 350 W to maintain the level. This change of 200 W is due to the added load of the cryomodules and the distribution system. From previous measurements during cryomodule characterization it is known that the static heat loads are ~ 13 W/cryomodule. These static loads can be verified *in situ* by closing the supply valve and monitoring the rate of the falling LHe level. The five cryomodules then add ∼65 W extra heat load. This would suggest that the helium distribution is responsible for a static load of 135 W or about double the initial estimates. We are in the process of investigating the possible causes.

The LN2 system has given the most problem. The variable distribution valves were not correctly sized to provide adequate control and provided too much flow. In addition the valves are not sufficiently robust mechanically and have stuck open or closed on occasion. The valve seats have been replaced to allow better control but we are in contact with the manufacturer to arrange a rebuild.

REFERENCES

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[3] R.E. Laxdal, et al, "ISAC-II QWR Cavity Characterizations and Investigations", Physica C 441 (2006) 193-196.