Remote Helium Cooling Loops for Laboratory Applications

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ABSTRACT

In order to provide high cooling capacity to vibration sensitive experiments, remote helium cooling loops have been developed, manufactured and tested by Absolut System SAS. The application is thermally anchored to a heat exchanger through a secondary, cryogenically cooled, closed helium loop which circulates to absorb the heat load. The secondary helium loop makes use of a dedicated circulator, typically a compressor package from Cryomech Inc. It is cryogenically cooled by a Gifford-McMahon (GM) closed cycle cryocooler from Cryomech Inc, and a counter-flow heat exchanger. The GM cooling station is separated by several meters distance (typically 5 meters) from the cold application by a dedicated high performance helium transfer line which eliminates the vibrations and offers the possibility to operate the sensitive system and the GM station in a separated environment (clean room, mechanical or optical benches for example).

Two remote helium cooling loops will be presented and discussed. One is aimed to provide 17 W @ 50 K remote cooling for IR detector electro-optical characterization. The second is aimed to provide 30 W @ 30 K remote cooling for HTS equipment, making use of an intermediate LN2 cooling stage in a counter-flow heat exchanger.

INTRODUCTION

Intensive development and improvement of very large wavelength IR (VLWIR) detectors utilizing Mercury-Cadmium-Telluride (MCT) technology are undertaken to reach a cut-off wavelength of about 15 µm. The temperature dependence on the dark current density imposes low operating temperature to get acceptable dark current: typical operating temperature range is 50-60 K for such low band gap 3rd generation detectors. For electro-optical characterization of such detectors, liquid bath nitrogen is no more suitable. Thus, high capacity 50K cryocoolers are required for cooling down of these huge focal plan arrays in a short duration (typically one hour). Direct coupling of a Gifford-McMahon cooler or even low frequency pulse tube cold fingers does not meet the required induced vibration level. High frequency pulse tube cooler technolgy[1] developed by Absolut System with vibration cancellation is the technology chosen for the flight operation. However, this technology produces limited cooling power at 50 K (about 2.6 W) which is not compatible with the rapid cool down constraints.

Furthermore, recent developments of electro-technical equipment such as motors using superconducting MgB_2 technology require distributed high cooling power at 30 K cryogenic

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temperature. In such case, liquid neon can meet the requirements but it is not envisaged for obvious cost reasons.

Thus, for these two applications, gaseous helium cryogenically, cooling closed loops is the technology of choice, providing versatile remote distributed high capacity cooling with extremely low vibration in a user-friendly turn-key operation.

50K REMOTE HELIUM COOLING LOOP FOR IR ELECTRO-OPTICAL TEST BENCH

A schematic representation of the present cooling loop is in Figure 1. It is composed of a GM AL125 type cold head supplied by a CP830 helium compressor package from Cryomech Inc. A CP820 helium compressor package is used as a room temperature circulator to flow the required helium mass in a closed loop to the recuperator heat exchanger, the cold heat exchanger, the transfer line and the application heat exchanger to absorb the heat load. A stainless steel tube-in-tube recuperator heat exchanger has been specifically designed and optimized to match the required mass flow rate and pressure drops imposed by the circulator functional parameters. A dedicated copper cold heat exchanger integrated with the AL125 cold head heat exchanger has been designed and produced by Cryomech Inc. This provides high heat transfer between the cold head and the helium cold loop mass flow with a very low thermal gradient. In order to reduce the parasitic heat losses, a 5 m long flexible line has been designed by Absolut System with a central bellows for the cold helium flow from the cold heat exchanger to the application, thermally screened by a wounded pipe for the return flow. The “return-gas” flexible line provides low losses with reduced mass and dimensions (DN32 mm bellows) compared to the use of two standard one-way flexible lines.

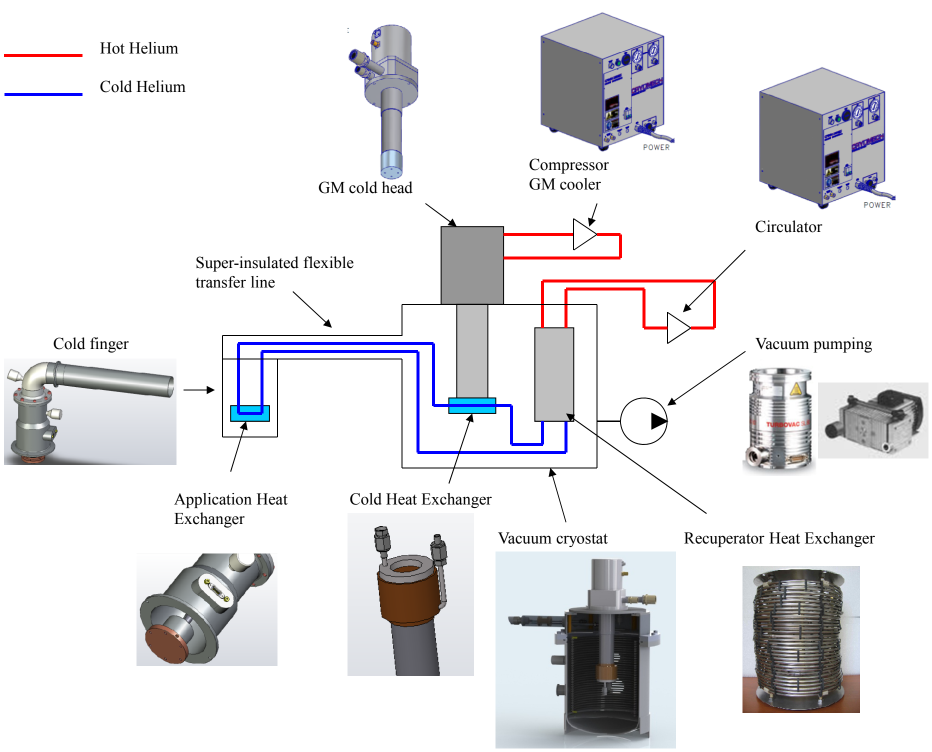

Figure 1. Schematic representation of the 50 K remote Helium cooling loop.

Table 1. Heat losses estimates for the 50K Helium loop.

ΔT Recuperator HX [K]	4
ΔT Cold HX [K]	1
ΔT Application HX [K]	1
Central transfer line way in [W]	0.5
Transfer line way back [W]	8
Cryostat losses[W]	1

For dimensioning the cold helium loop, we started by an evaluation of the heat losses. The inefficiency of the heat exchangers is taken into account by considering a temperature difference (ΔT) between the fluid temperature and the heat exchanger temperature. For the recuperator heat exchanger, a temperature difference at the cold end is considered. Our estimates are reported in Table 1 above. The helium mass flow rate is determined by numerical method to get the maximal cooling power considering these estimates. We found 0.75 g/s as optimal mass flow rate. The recuperator heat exchanger is then designed to obtain the specified efficiency with the optimal calculated mass flow rate and to cope with the pressure drop constraints imposed by the circulator. This results in a stainless steel tube-in-tube (Ø6.5/Ø7.5 mm outer tube, Ø3/Ø5 mm inner tube), 24 m long, providing 3.3 bars pressure drops for a cooling power of 20 W @ 50 K available at the application heat exchanger.

Some pictures of the 24 m long recuperator heat exchanger wounded around the GM AL125 base tube assembly are shown in Figure 2. The assembly is shown at two different steps, with and without MLI wrapping, prior to the integration in the vacuum cryostat. As shown in Figure 2, flexible pipes are used to ease the connections of the circuit between the recuperator heat exchanger, the cold heat exchanger and the way in and way back of the flexible return-gas transfer line.

Figure 3 shows a cross section view of the cryostat and the cryostat integrated inside the cabinet.

Some pictures of the 50K remote helium cooling loop packaged into a mobile rack are shown in Figure 4. The rack includes two bottom cabinets (one for each compressor), and two top cabinets (left side for the cryostat, right side for the vacuum pumping equipment, electrical casing and control panel). As shown, the flexible (5 m) line terminated by the cold finger to connect to the application is located at the back side of the rack, together with the electrical and water services.

Figure 2. Tube-in-tube recuperator heat exchanger wounded around the AL125 cold head and connected to the cold heat exchanger (with and without MLI insulation).

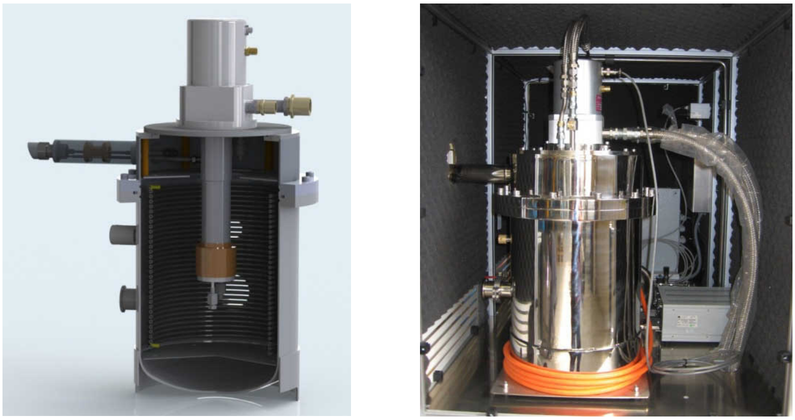

Figure 3. CAD cut view of the vacuum cryostat with the GM AL125 cold head and recuperator heat exchanger (left) and vacuum cryostat integrated in the cabinet (right).

Figure 4. Final delivered 50K remote helium cooling loop installed into a mobile rack.

The test results of the 50 K remote cold Helium cooling loop are presented in Figure 5 for the cool down time and in Figure 6 for the load curve. As shown, a 50 K cold temperature is reached in only 1 hour and 15 minutes. A no load temperature of 33 K is reached and 28 W cooling capacity is available at 50 K for the application. Applied heat load above 30W was not possible due to temperature controller limitation only. The thermal performance of the 5 m remote cooling loop compared to the original stand-alone GM AL125 used is also reported; basically the added thermal load results in degradation by a factor 2 at 50 K.

With the test set up, we measured a temperature difference of 3.5 K at the cold end of the recuperator heat exchanger which is better than our estimates. We also measured pressure drops higher than our estimates. This could lead to higher heat transfer efficiency. Based on these experimental results, we modified our calculation sheet. The penalty of the recuperator performance on the cooling power at 50 K is shown in Figure 7.

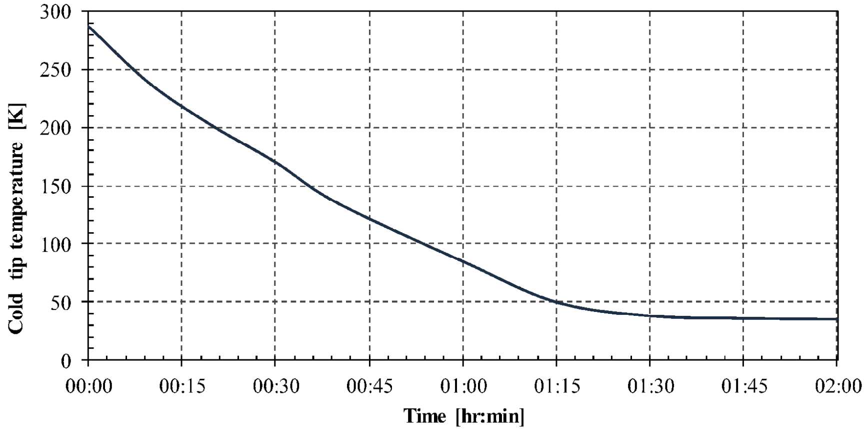

Figure 5. 50 K remote cold helium cooling loop test - cool down curve.

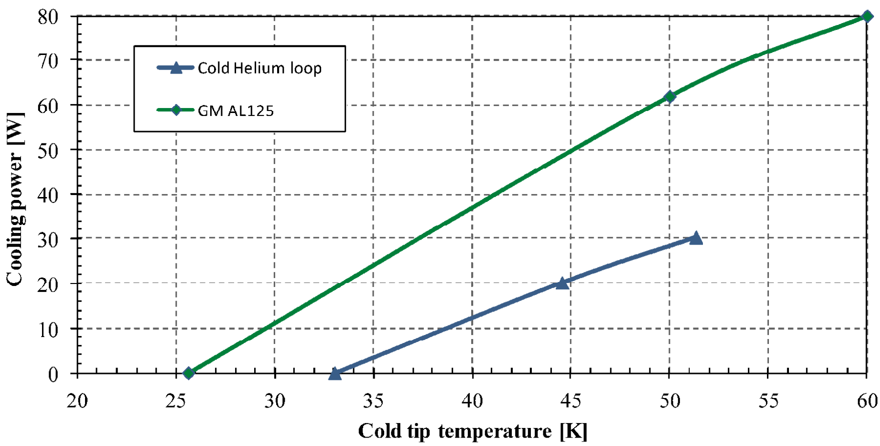

Figure 6. 50 K remote cold helium cooling loop performance test results and confrontation to the stand alone GM AL125 cold head.

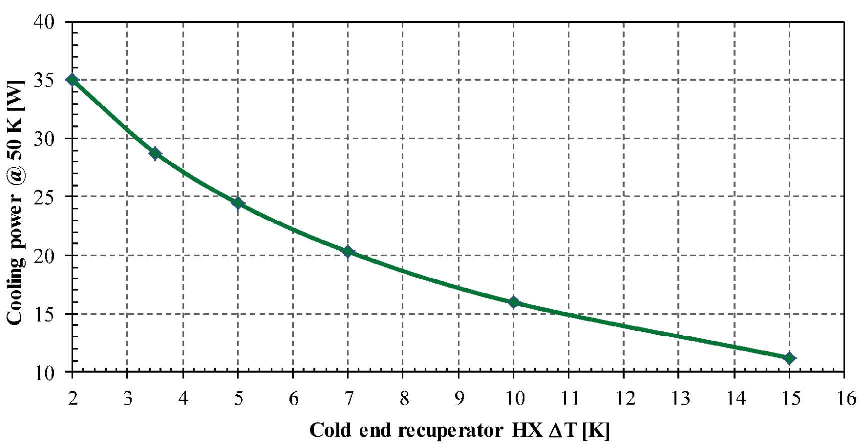

Figure 7. Cooling power at 50 K versus recuperator heat exchanger performance.

30K REMOTE HELIUM COOLING LOOP FOR SUPERCONDING ELECTRICAL MOTOR TEST BENCH

Besides the 50K remote Helium cooling loop, presented above, a 30K Helium cooling loop has been designed and is currently under manufacture.

The schematic representation of this cooling loop is shown in Figure 8. It is composed of a GM AL325 type cold head supplied by a CP1110 Helium compressor package from Cryomech Inc. The circulator used is a CP830 type compressor package. The main architecture difference with the previous 50K cooling loop is that an intermediate LN_2 bath cooling is used between two recuperator heat exchangers. The thermal load due to the inefficiency of the first stage 300 K-77 K recuperator is rejected in the LN_2 bath. The second stage of the recuperator heat exchanger is designed to work between 77K down to 30K or less. The results of our calculations for a 30 W@30 K operation are reported in Table 2.

A 3D CAD cross-section view of the 30 K cold helium cooling loop cryostat is presented in Figure 9 showing the two wounded stages recuperator heat exchanger (respectively 27 m and 21 m) around the liquid nitrogen bath and the AL325 GM cold finger

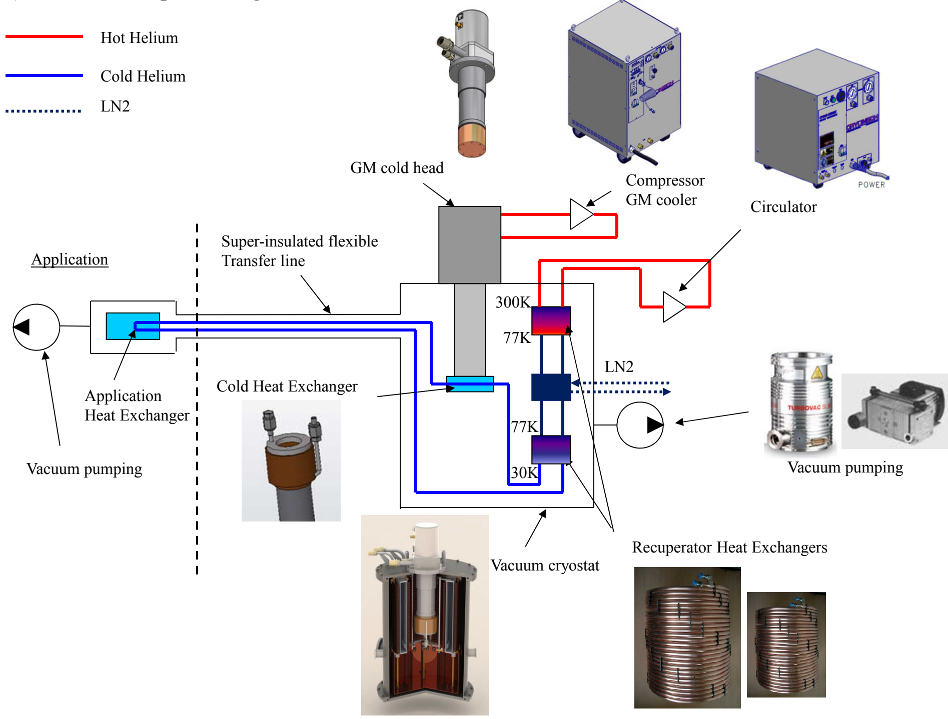

Figure 8. Schematic representation of the 30 K remote **h**elium cooling loop.

Table 2. Optimization results for the 30 K helium loop.

ΔT Recuperator 1st stage HX [K]	7.0
1st stage tube-in-tube recuperator HX dimensions	Ø12.7/Ø10.7 – Ø8.0/Ø6.0 - 27 m
ΔP Recuperator 1st stage HX [Bar]	2.85
ΔT Recuperator 2nd stage HX [K]	2.0
2nd stage tube-in-tube recuperator HX dimensions	Ø10.0/Ø8.0 – Ø6.35/Ø4.75 - 21 m
ΔP Recuperator 2nd stage HX [Bar]	2.81
Helium mass flow rate [g/s]	2.1
Heat intercepted in LN_2 bath [W]	72.2
LN_2 consumption [l/hr]	1.62

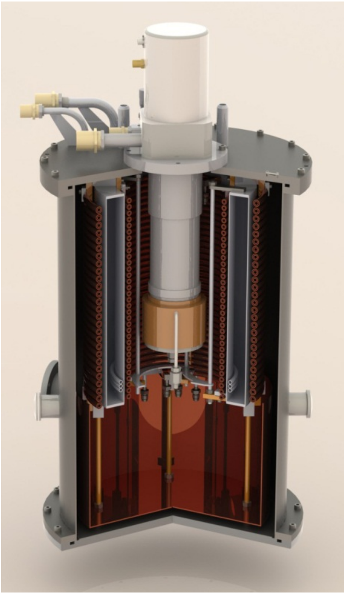

Figure 9. CAD cut view of the 30 K cold helium cooling loop cryostat.

As shown in Figure 10, the remote cooling system is also equipped with a high performance return-gas flexible line, with the same principle than the one used in the 50 K loop previously described. However, the remote length is reduced to 4 meters for this particular application.

A 4 meters remote cooling capacity of 30 W @ 30 K is calculated using a GM AL325 cold head (10.4 kW @ 50 Hz), a CP830 circulator (3.0 kW @ 50 Hz) and 1.6 l/hr LN2. This performance will be validated in the coming weeks.

CONCLUSIONS

Two remote helium cooling loops have been designed: one with a cooling capacity of 28 W @ 50 K at 5 m remote distance, the other with a targeted performance of 30 W@30 K and 4 m remote distance.

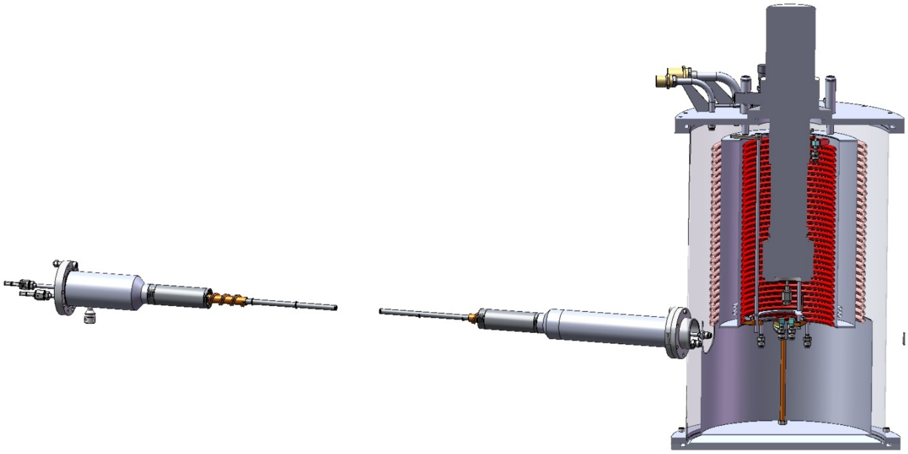

Figure 10. 4 m 30 K remote helium cooling system.

Both cooling loop designs make use of separated room temperature circulator for the secondary helium loop. The use of a dedicated circulator, commercially available GM compressor type, gives the following advantages compared to the use of a unique oversized compressor for the GM cold head and a by-passed secondary Helium loop[2]:

- Acceptance tests of the standard GM cooler product for the cold source, independently to the complete Helium remote cooling loop system,
- Simplified flow tuning of an independent secondary Helium loop which can then accommodate some variations or modifications of the application heat exchanger,
- Possibility to perform thermal cycling operations of the application heat exchanger by switching ON/OFF only the circulator. This allows for reduced duty cycle by keeping the GM cold head permanently cooled.

For the 50 K remote Helium cooling loop, it has been shown that the remote cooling degrades the stand-alone cooling power of the original GM cold head available at 50 K by a factor 2 (28 W compared to 62 W as presented in Figure 6). The recuperator inefficiency contributes significantly to the loss budget. An improvement of the overall performance of the remote helium cooling loop can be made by using a cryogenic circulator suppressing the recuperator heat exchanger. However, the use of a cold circulator, such as centrifugal gas pumps[3], is seen today as having a lack of robustness (mean time between maintenance or failure

is known to be limited) which leads to higher costs (cold circulator hardware, driver and maintenance) compared to the use of a counter flow heat exchanger and a room temperature circulator.

The current 50 K remote helium cooling loop has been demonstrated to be compliant by the end-user, with vibrations requirements as stringent as those required for IR electro-optical test bench. It will be modified for thermal vacuum cycling of IR components, by remote ON/OFF control of the circulator.

The remote helium cooling loops as presented herein are very interesting solutions for high cooling power and very low induced vibrations required by applications at temperature lower than LN_2 temperature.

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