High Capacity 30 K Remote Helium Cooling Loop

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Abstract. Absolut System has built several 50 K remote helium cooling loops used as high capacity and very low vibration cooling source into large wavelength IR detectors electro-optical characterization test benches. MgB_2 based superconducting electro-technical equipment's under development require also distributed high cooling power in the 20-30 K temperature range. Absolut System has designed, manufactured and tested a high capacity 30 K remote helium cooling loop. The equipment consists of a CRYOMECH AL325 type cooler, a CP830 type compressor package used as room temperature circulator and an intermediate LN_2 bath cooling used between two recuperator heat exchangers (300 K-77 K and 77 K-20 K). A cooling capacity of 30 W @ 20 K or 80 W @ 30 K has been demonstrated on the application heat exchanger, with a 4-meter remote distance ensured by a specifically designed gas circulation flexible line. The design and the performance will be reported in this paper.

Keywords: Helium, circulation loop, cryocoolers, Gifford-MacMahon.
PACS: 07.20.Mc (Cryogenics; refrigerators, low-temperature detectors, and other low-temperature equipment).

30 K REMOTE HELIUM COOLING LOOP DESCRIPTION

A schematic representation of the present cooling loop is attached in Fig. 1 hereafter. It is composed of Gifford-MacMahon (GM) AL325 type cold head supplied by a CP1110 helium compressor package (CP) from Cryomech, Inc. A dedicated CP830 helium compressor package is used as room temperature circulator to flow the required helium mass in closed loop to the recuperator heat exchangers, the cold heat exchanger, the transfer line and the application heat exchanger to absorb the heat load. Two copper tube-in-tube recuperator heat exchangers have been specifically designed and optimized to match the required mass flow rate and pressure drops imposed by the room temperature circulator functional parameters. An intermediate LN_2 bath cooling is used between the 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 77 K down to 30 K or less.

A dedicated copper cold heat exchanger integrated with the cold tip of the AL325 cold head 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 very low thermal gradient.

In order to reduce the parasitic heat losses, a 4-meter long super insulated 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 wound pipe for the return flow. The so called "return-gas" flexible line provides a low- loss unique line with reduced mass and dimensions (DN32 mm bellows) compared to the use of two standard one-way flexible lines.

A high vacuum pump is used to evacuate commonly the cryostat and the flexible line. Another vacuum pump is required to evacuate separately the application heat exchanger.

A 3D CAD cut view of the 30 K cold helium cooling loop cryostat is presented in Fig. 2 hereafter showing the two stages wound recuperator heat exchanger around the liquid nitrogen bath and the AL325 GM cold finger equipped with the cold heat exchanger.

The 4-meter long high performance return-gas flexible line principle is shown in the Fig. 3.

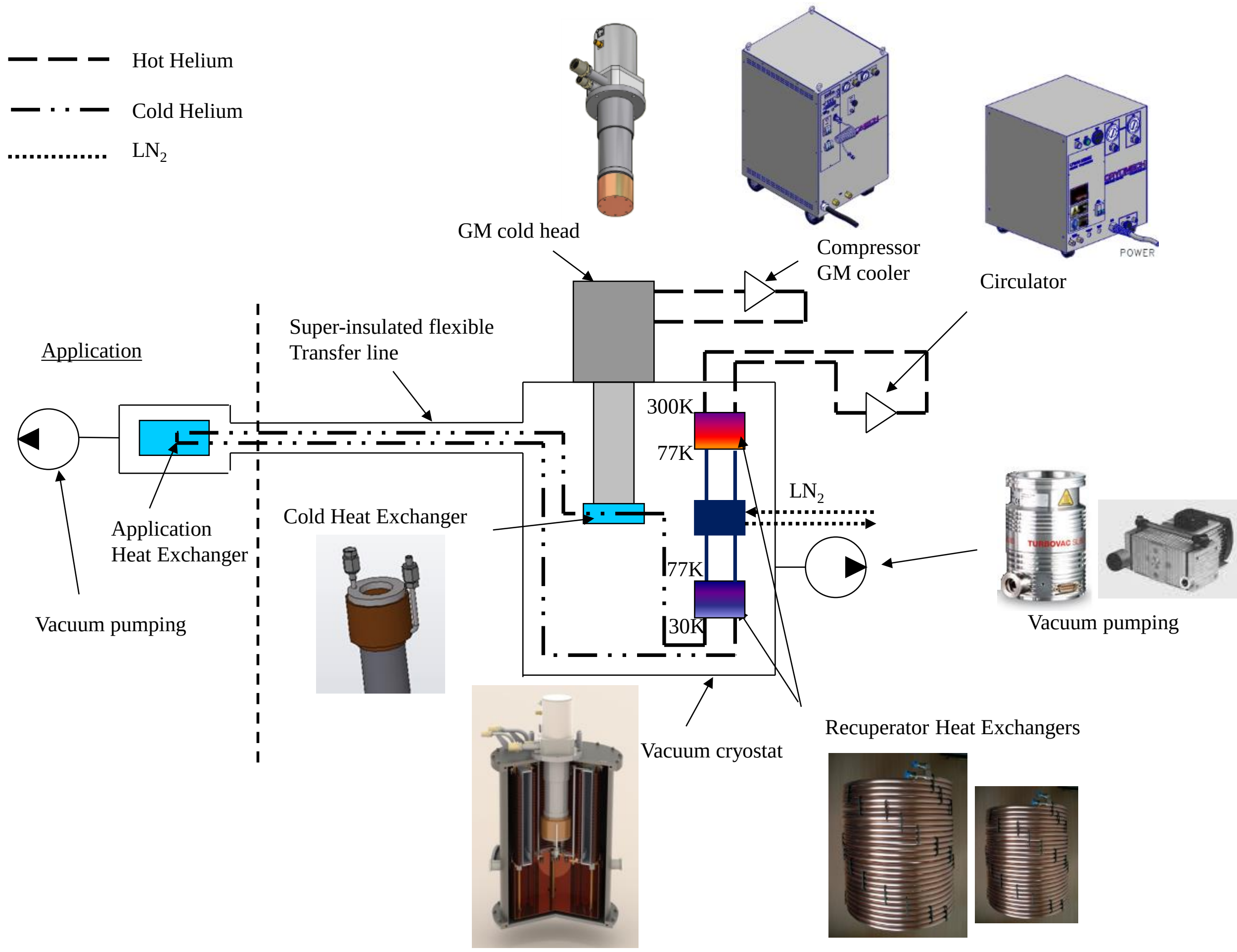

FIGURE 1. Schematic representation of the 30 K remote helium cooling loop.

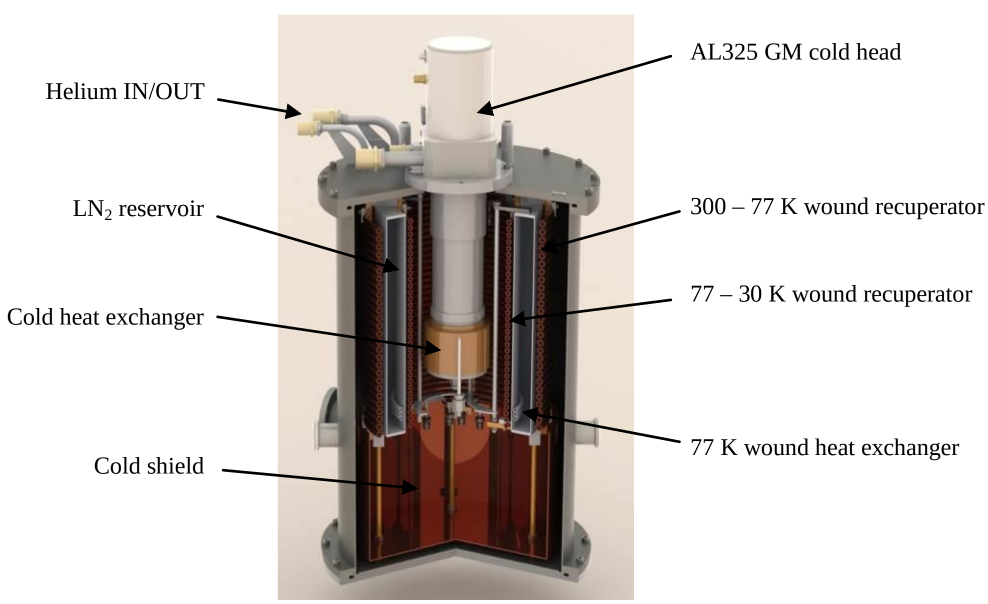

FIGURE 2. CAD section view of the 30 K cold helium cooling loop cryostat.

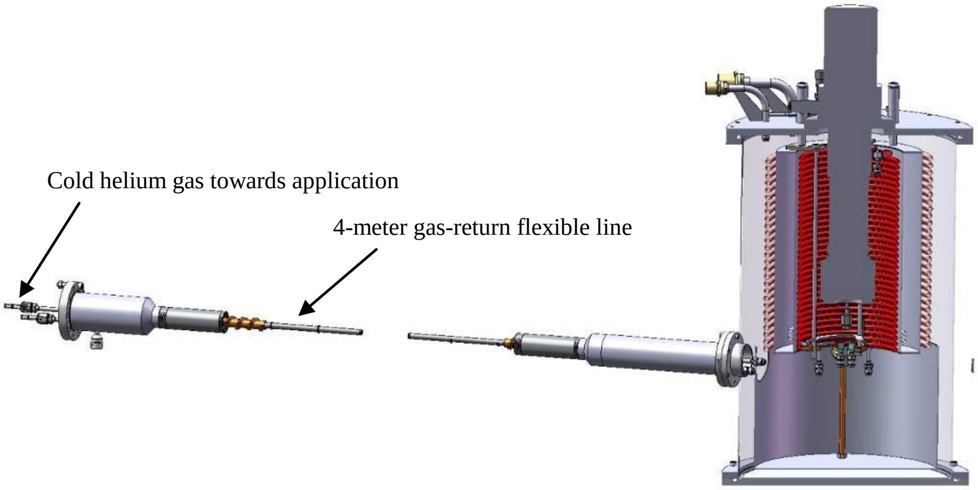

FIGURE 3. 30 K remote helium cooling system design shown with the 4-meter long flexible line.

30 K REMOTE HELIUM COOLING LOOP MANUFACTURE

The first stage tube-in-tube recuperator heat exchanger (300 K – 77 K) is composed of an inner copper tube Ø8.0/Ø6.0mm inside an outer copper tube Ø12.7/Ø10.7mm. This 27-meter long heat exchanger is wound on the outside wall of the LN_2 annular vessel as shown on the Fig. 4. The second stage tube-in-tube recuperator heat exchanger (77 K – 20 K) is composed of an inner copper tube Ø6.35/Ø4.75mm inside an outer copper tube Ø8.0/Ø6.0mm. This 21-meter long heat exchanger is wound on the inside wall of the LN_2 annular vessel (12.3 liters capacity). Both stages are connected to a third heat exchanger composed of a 2-meter long wound stainless steel Ø8.0/Ø6.0mm pipe plunged inside the LN_2 vessel. In both tube-in-tube heat exchangers, the low pressure gas flows in the inner coil and the high pressure gas flows in the outer coil. Multi-Layer Insulation (MLI, Jehier IR405 type) is wrapped between the recuperators and the LN_2 vessel.

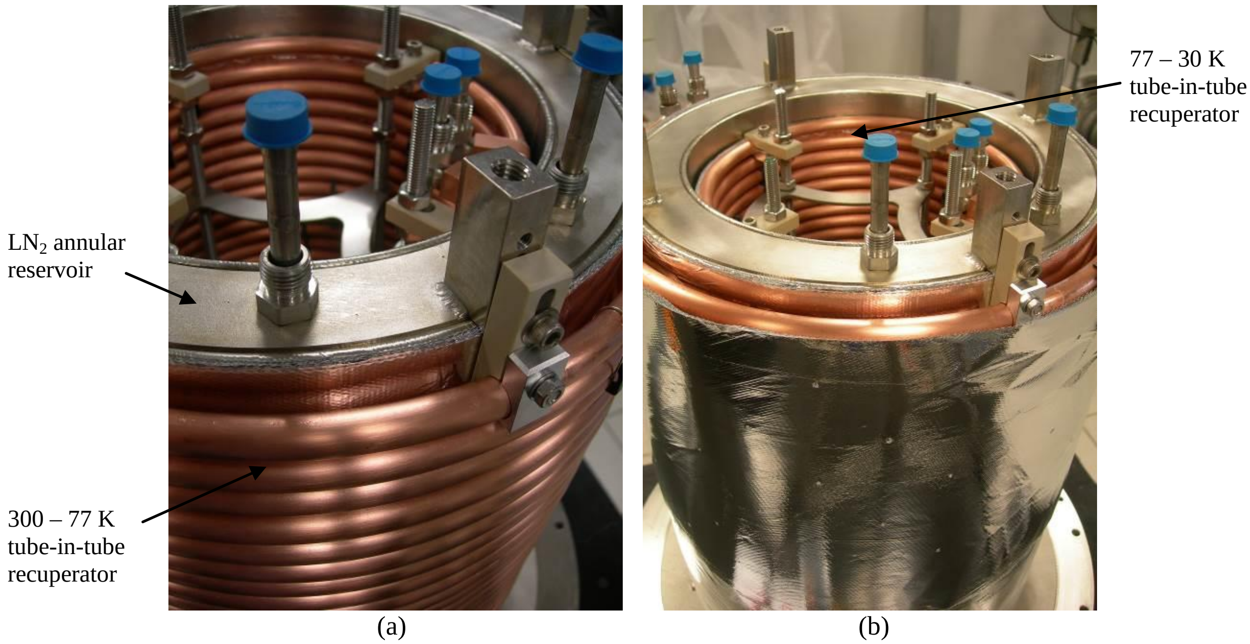

FIGURE 4. Two-stage tube-in-tube recuperator heat exchanger wound on the inner and outer wall of the LN_2 annular vessel. (a) Without MLI wrapping, (b) with MLI wrapping on the first stage

Figure 5 shows the cold head equipped with the cold heat exchanger integrated with both recuperators and LN_2 vessel inside the stainless steel vacuum jacket. All the piping junction between the recuperators, LN_2 vessel, cold heat exchanger and way-in / way-back of the transfer line are made of stainless steel DN8 flexible pipe reinforced with a metal braid. All the piping is also wrapped into MLI as shown on the Fig. 5. After this stage of integration, a copper cold shield, thermally anchored at the bottom side of the LN_2 vessel and super-insulated, is covering all the piping to reduce radiative heat losses.

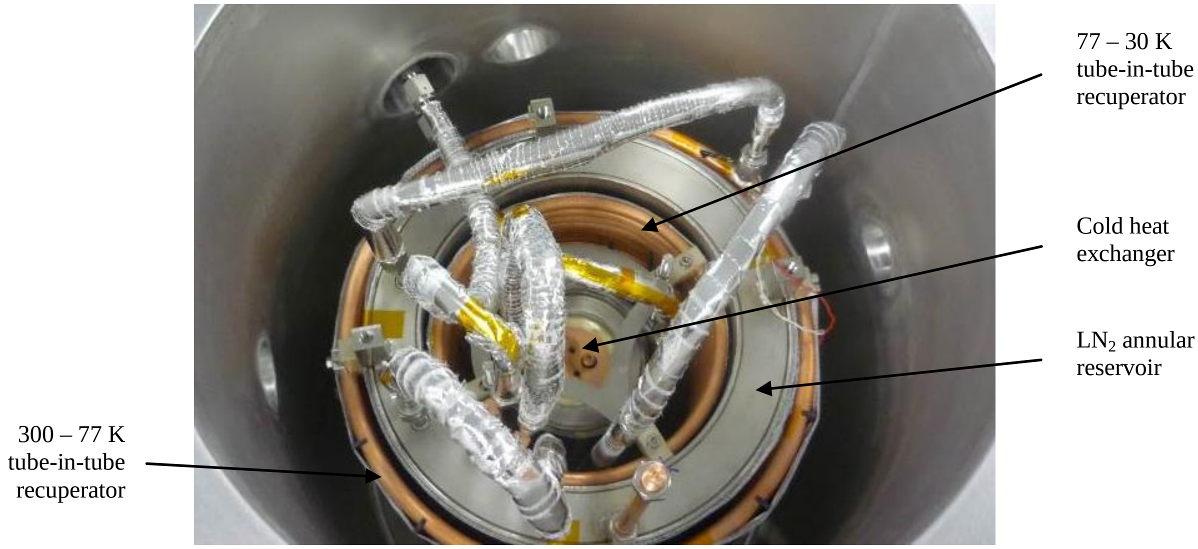

FIGURE 5. Cold head heat exchanger, 2 stages recuperators, LN_2 vessel and relevant piping integrated inside the vacuum jacket. (Copper cold shield removed).

Finally, the cryostat is closed and the connections of the 4-meter flexible line, the CP1110 helium compressor and the CP830 helium circulator are made. The cryostat and the flexible line are evacuated with turbo-molecular pump and the vessel is filled with LN_2. The system ready for testing is shown on the Fig. 6.

FIGURE 6. Remote helium cooling loop ready for testing.

30 K REMOTE HELIUM COOLING LOOP TESTS

First of all, the AL325 Gifford-MacMahon cryorefrigerator has been tested on 50 Hz electrical network as a stand-alone unit by CRYOMECH, Inc. prior to shipment to ABSOLUT SYSTEM. The cold head produces a cooling capacity of 70 W @ 20 K or 143 W @ 30 K as shown on the load curve reported in the Fig. 7 which is in accordance with our considerations for the modeling (70 W @ 20 K or 140 W @ 30 K).

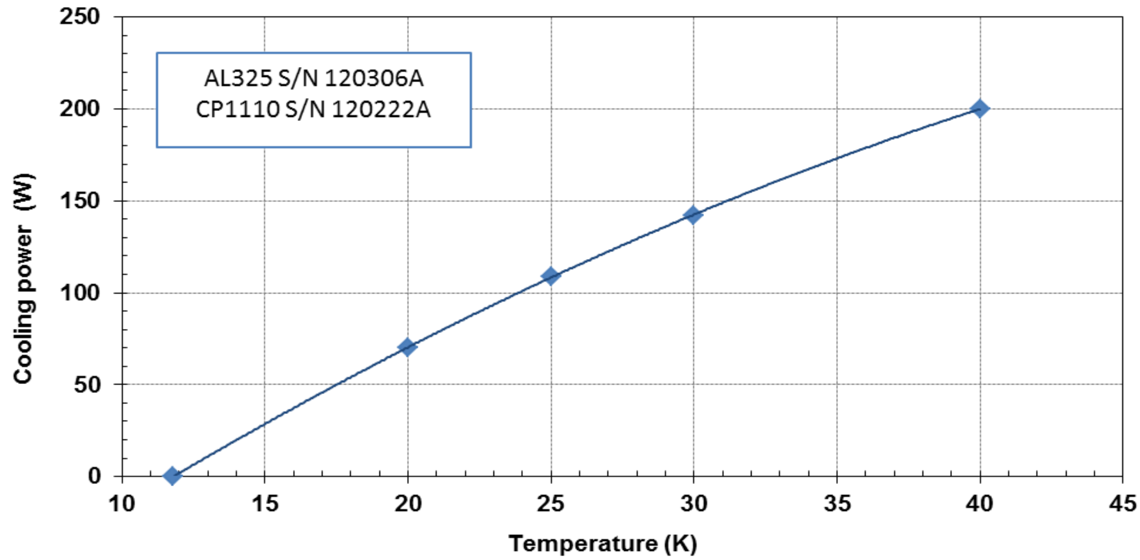

FIGURE 7. AL325 load curve on 380 – 420 V / 50 Hz / 3 Phases electrical network.

In order to measure the load curve of the remote cooling loop, a copper block heat exchanger has been implemented at the exit of the 4-meter flexible line to simulate the application load. Once the LN_2 reservoir is completely filled, the system is turned on and a temperature of 20 K is reached within one hour on the application heat exchanger. During the tests, the LN_2 reservoir is completed to its 3/4 level regularly.

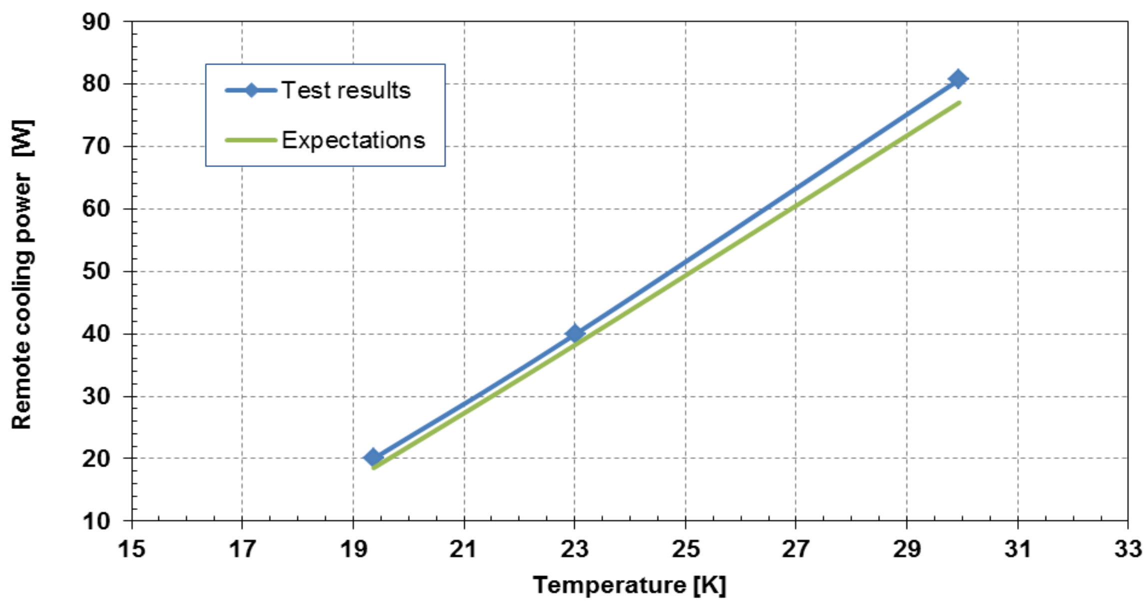

FIGURE 8. Remote cooling power as function of the application heat exchanger exit temperature.

It is preferable to load the system once 20 K is reached on the application in order to keep the suction and exhaust circulator's pressure levels in the minimum operating range. 20 W, 40 W and 80 W have been respectively applied on a heater and the temperature at the exit of the heat exchanger has been recorded. The remote load curve is reported in the Fig. 8. As shown, a cooling capacity of about 24 W @ 20 K or 80 W @ 30 K is available which is a bit above our expectations. A thermal balance has been made based on temperature gradient measurements on the application heat exchanger in order to determine the helium mass flow (2 g/s @ 20 W, 2.2 g/s @ 40 W and 2.6 g/s @ 80 W). The difference between the results and the predictions could come from the cooling capacity of the cold head which might increase thanks to better insulation inside the cryostat. After the final commissioning, the cryostat has been integrated in a dedicated cabinet as shown in the Fig. 9. The cabinet gathers also the control-command for both compressors, solenoid vacuum gate valve and vacuum level display. The system has been delivered and will be used to cool down BSCCO coils at 30 K for an HTS motor demonstrator.

4-meter flexible line

FIGURE 9. Helium cooling loop cryostat integrated inside a cabinet.

CONCLUSIONS

A remote helium cooling loop has been designed, manufactured and successfully tested with room temperature circulator. It provides 50 W @ 25 K or 80 W @ 30 K with a 4 meters remote distance. For larger cooling power, a cold circulator will be more efficient. We are presently developing a 100 W @ 20 K loop with cold circulator for HTS electro-technical application.

ACKNOWLEDGMENTS

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REFERENCES

1. T. Trollier, J. Tanchon, Y. Icart and A. Ravex, "Remote Helium Cooling Loops for Laboratory Applications", in *Cryoccolers 17*, 2012, pp. 503-510.