Liquid nitrogen pre-cooling of large infrared instrument at ESO

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ABSTRACT

Since the last decade, most of the large infrared instruments are kept at operating cryogenic temperature using mechanical cryo-coolers. Generally Gifford MacMahon Closed Cycle Coolers or Pulsed Tubes are doing this duty.
These coolers are well dimensioned to keep the instrument and the detector at a sufficiently low operating temperature. Using the only cooling power provided by the steady state mechanical cryo-coolers would lead to several days for the initial cooling down. Therefore an additional cooling has to be used to allow a reasonable cooling time.
The present paper describes the liquid nitrogen continuous flow cooling system developed at ESO for ISAAC. During the past years, this system has also been used successfully for a number of VLT instruments (CRIRES, HAWK-I..). After a short comparison with the more common technique using an instrument internal tank, we list in detail the various developments which have been required to get the continuous flow working in a reliable and efficient way.
This paper also presents the advantages making this technology as a potential very attractive way to replace definitively mechanical coolers in most of the cases.

Keywords: Cryogenics, cryo-coolers, liquid nitrogen

1. INTRODUCTION

In the early time of the Infra-Red astronomy most of the instruments were directly packed into a standard commercial Dewar with in most of the cases, the optical assembly directly bolted on the bottom plate of the nitrogen tank. This practice changed slowly during the last decades when reliable closed cycle cooler systems became available. Actually, in most of the cases, the mechanical coolers have replaced the liquid nitrogen and the liquid helium to maintain the instruments and the detectors at cryogenic operating temperature. In most of the cases the power needed to cool the instrument in a reasonable time is an order of magnitude higher than the power required to keep then cold. Some additional cooling is then required during the original cool-down phase. This paper describes such a cool-down system based on a continuous open circulation of liquid nitrogen.

This principle is used at ESO since years where a series of instruments and test facilities has been built around this technique. We will analyze it in the specific case of CRIRES the CRyogenic Infrared Echelle Spectrograph for the VLT. With a total cold mass of 570 kg and the goal to reach a cryogenic “test” temperature after 24 hours this was the most challenging instrument to benefit of this system.

2. PRINCIPLE

This technology is using a very simple principle which is very similar to the technique which is generally used in most of the fluid cooling systems. A cold fluid is forced into a circuit including a number of heat exchangers. The heat exchangers are strongly bolted to the object to be cooled-down. In this particular case, most of the difficulties come from the nature of the coolant and to the fact that it is used at the phase (liquid/gas) transition point.

Figure 1 shows a general view of the cryogenic system of CRIRES. In addition to the various temperature control loop systems, this shows a schematic representation of the cooling circuit with the various components. This diagram includes also the safety overpressure valves which are necessary in order to protect the cooling lines in case of evaporation of trapped gas during warm-up.

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This figure shows also practically the process used for pre-cooling. The liquid nitrogen, provided from an external storage tank, circulates in a series of heat-exchanger before to be collected in single tubes by the end collector. The temperature measured at this point is used to control the pre-cooling valve which, when opening, leaves new LN2 flowing into the circuit.

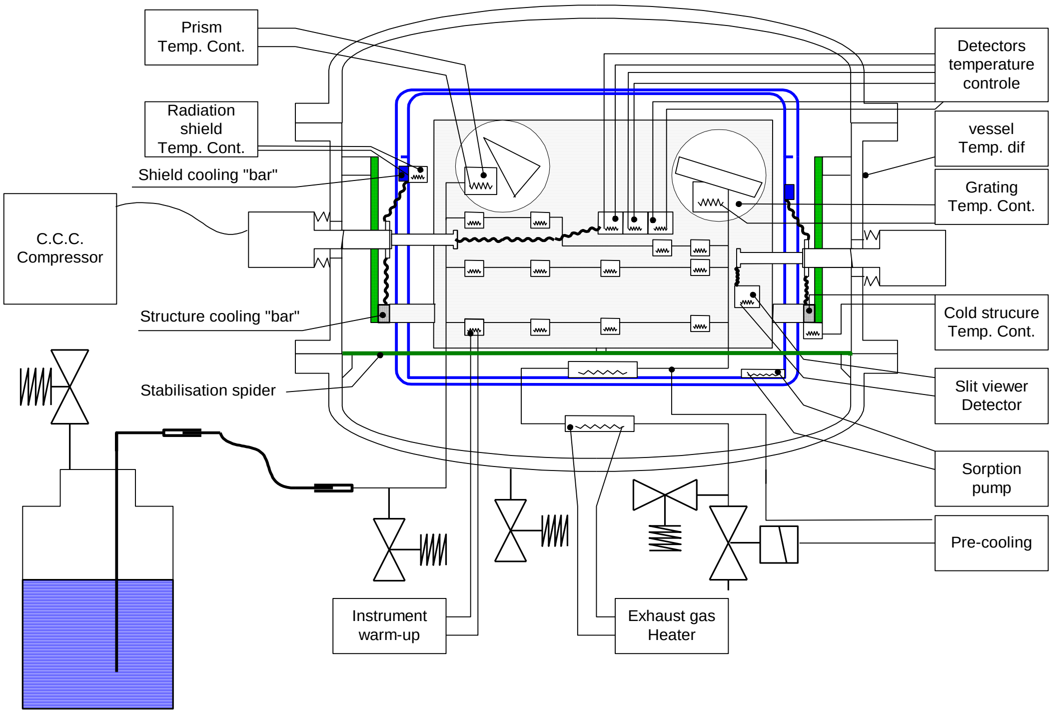

Figure 1: Cryogenic design of CRIRES

The design presented above shows the complete cryogenic infrastructure of CRIRES. It shows the closed cycle coolers system (3 cold heads Coolpower 10MD from Leybold Oerlikon powered by 2 Coolpack 6000 compressors) used to keep the instrument at cryogenic operating temperatures. It shows also the thermal stabilization system used keep the temperature of sensitive dispersive components within 1 mK. Even if all of this is irrelevant for the present discussion, it illustrates the complexity of CRIRES.

3. DESIGN AND REALISATION

Figure 2 below shows 3D views of the cooling circuit used for the pre cooling of CRIRES. The liquid nitrogen is fed to the circuit via the inlet connection (IN). This is a special bayonet connection for vacuum insulated transfer line. Special splitters (S) are used to divide the cooling circuit in 5 sub-circuits. This provides a well distributed cooling power and allows an easy dismounting of the various sub-systems. The various sub-circuits are clearly shown (various colours) on the left view of figure 2. On this general view we can also clearly see the last heat exchanger (EGH) which is used to warm-up the gas to ambient temperature before leaving the vacuum envelope. This component, which is directly attached to the inside wall of the vacuum vessel is actively controlled. The pink circuit with 4 heat-exchangers is used to cool the pre-dispersion unit. This 120kg unit includes the entrance slit, the pre-dispersion collimator mirror, the pre-dispersion prism and some additional re-imaging optic. The green circuit is used to cool the 100kg heavy grating unit. Two of the five heat exchangers are directly mounted on the rotating grating carrier. The blue/green circuit is cooling the main cold structure.

The right part of figure 2 shows a close on the the main collimator with its two dedicated circuits. Two sub-circuits with a total of 12 heat exchangers are used for the cooling of this complex 200kg welded structure housing very accurately the three mirrors and the detector mosaic assembly.

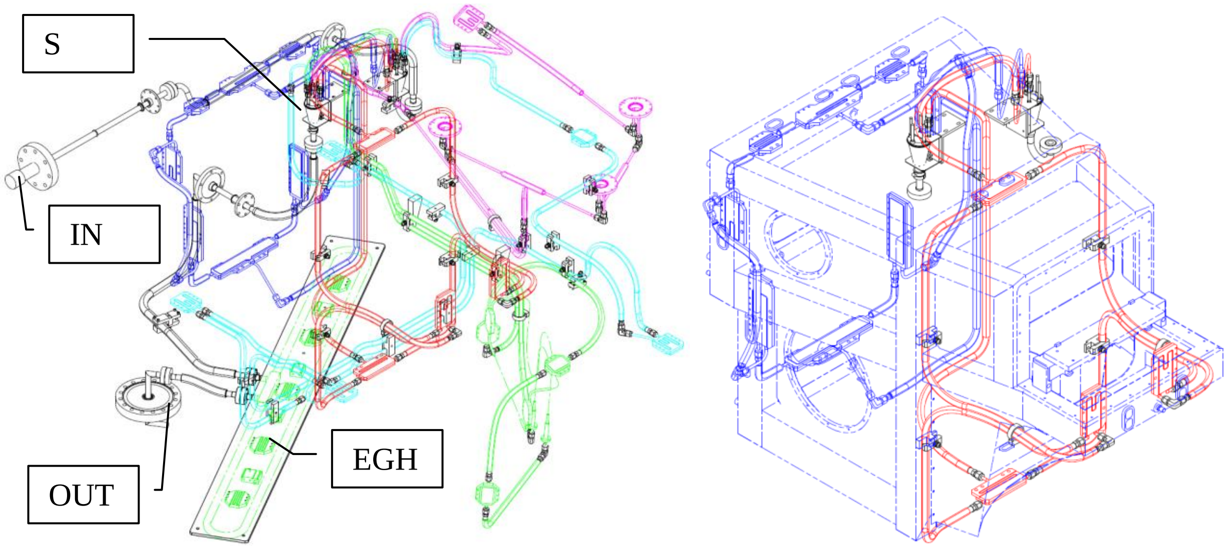

Figure 2: Cooling circuitry of CRIRES

3.1 Distributers, splitters

The design of the splitter and its mounting was one of the first challenges we had to face while implementing this technology for the first time. Early testing has shown the strong limitation of a simple manifold system. During the first hours of operation, the turbulences caused mainly by the phase transfer, are such that very few coolant is effectively transferred. Figure 3 shows the final optimized design of this component. The right view show the mounting of the in and out splitters. Both have a similar design, the exhaust one carries the temperature sensor. The inner one is mounted thermally insulated (HGW plates) in order to reach very rapidly the LN2 temperature.

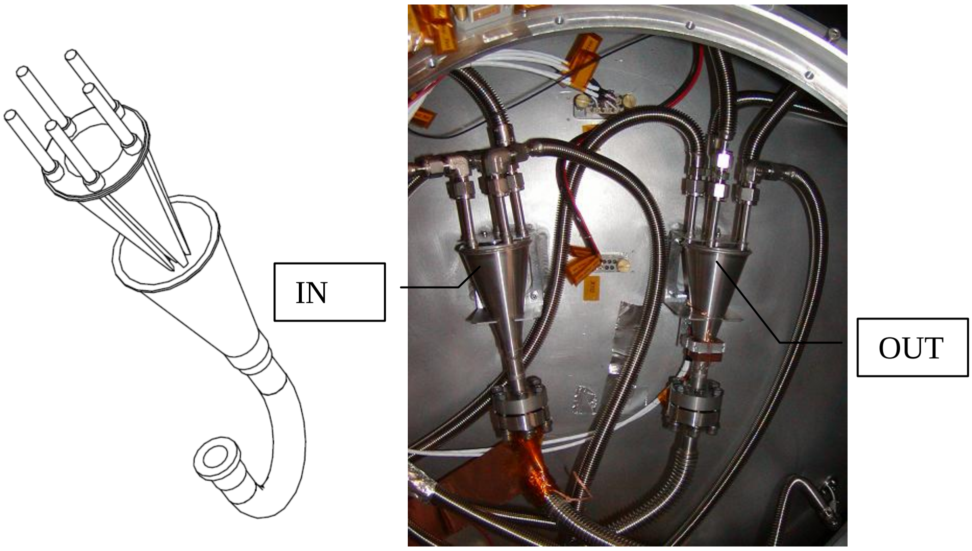

Figure 3: Distribution heads

3.2 Heat exchanger

For obvious thermal reasons copper is the optimal material for the heat exchanger. On the other hand stainless steel tubes are required for providing optimal interfaces for the connections. Technically the problem has been given to the industry. There are some companies with wide range of experience in this type of specific welding. Two different types of junctions have been used welding by fusion and silver brazing.

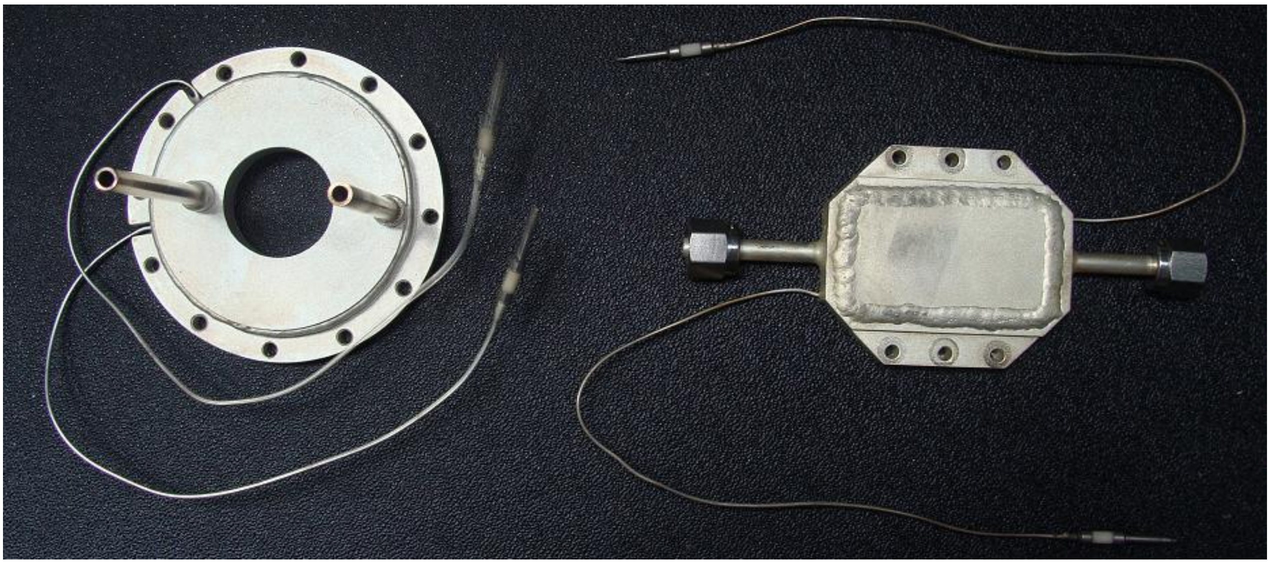

Figure 4: Heat exchangers (the left view shows a specific heat exchanger used to cool directly the ball bearing of rotating mechanisms, the left view shows our standard heat exchanger)

All heat exchangers are built following the same principle. The lower base is a massive copper part in which the special circulation labyrinth is directly machined. This is closed by a lighter top plate bound by fusion welding. The two connection interface tubes are located according to the geometry and the space situation.

The standard heat exchanger has been well characterized. It provides a cooling power which is progressively decreasing with the temperature from 100W at 300K to about 10W at 80K. This performance is also reduced by a 10% factors for any additional exchanger added in series to the circuit. Having heat exchanger manufactured out of copper offers also the possibility of integrating directly the heater by soldering. In our case we selected the vacuum tight encapsulated heaters from thermo-coax and integrate them by silver brazing.

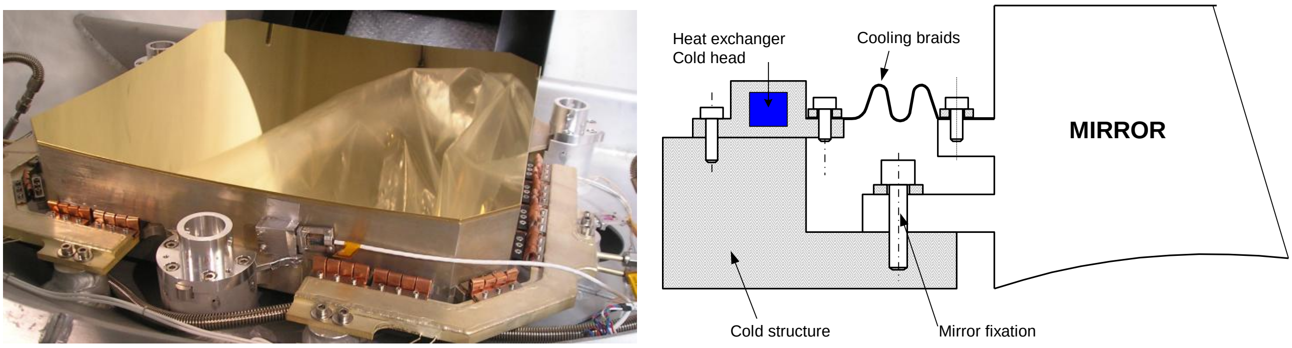

Figure 5: Mirror cooling arrangement

Figure 5 shows the special arrangement which has been selected for a cooling of large mirrors. The heat exchangers cool simultaneously the mirror and the surrounding surface. The interface with the structure has been carefully designed in order to prevent any significant gradient to develop between the mirror and the structure.

3.3 Connections

Connect tubes at cryogenic temperature inside a vacuum vessel containing extremely sensitive and expensive optical devices can be regarded as technically risky and challenging. The industry offers a series of solution to this problem. For smaller diameters (up to 6mm) the standard connection system with double metallic cutting seals (type Swagelock) are fully suitable. For larger diameter it was necessary to improve further commercial solution. Figure 6 shows the large diameter connector based on the Kenol commercial connector. The implementation of the spring loading system guaranty a full tightness even during the original phase of cooling where strong thermal stress are developed.

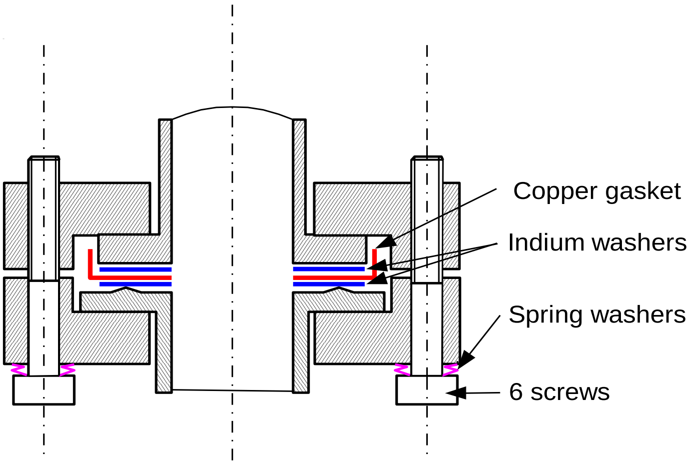

Figure 6: Connection system for large diameter

4. RESULTS OF CRIRES COOLING

Figure 7 shows the evolution of various temperatures inside CRIRES during the cool-down. This record shows that most of the instrument reaches the temperature of liquid nitrogen after one day.

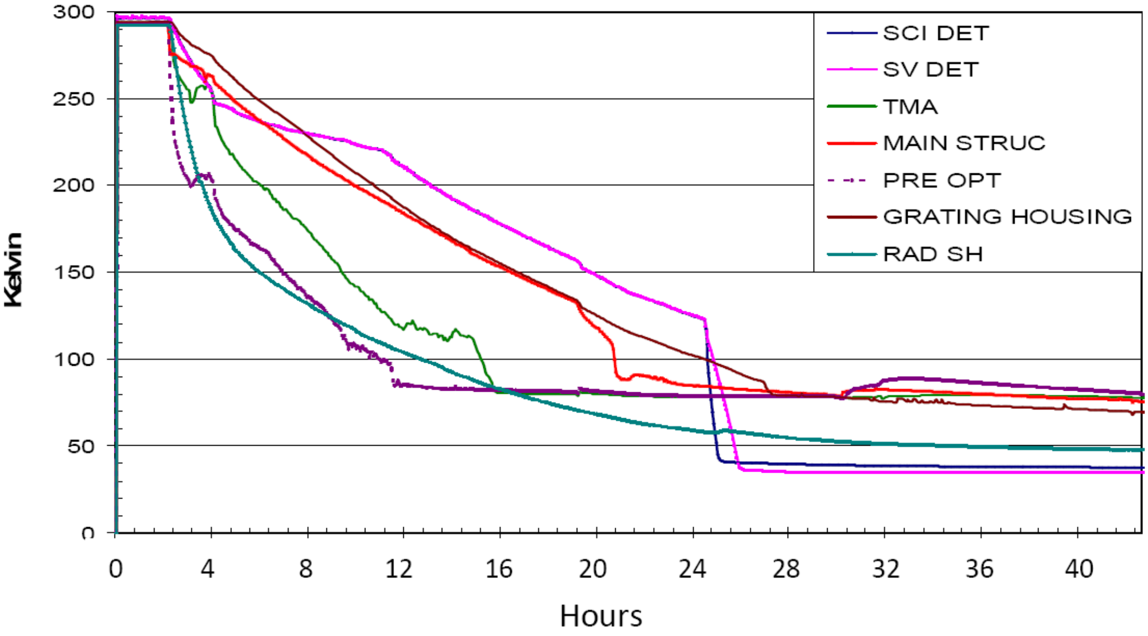

Figure 7: CRIRES cool-down

The ESO standard requirement is to cool instruments within 24 hours. This is a reasonable goal and specially valid during the development and the testing of the instrument in order to shorten the thermal cycling period. CRIRES is operational as high resolution spectrograph only after the optic assembly is perfectly stabilized at 65K.

Such LN2 cooling system can drastically reduce the cooling time from ambient temperature down to 76K (The boiling temperature at 2500m, the altitude of Paranal observatory). A number of additional hours is still required for the last part of the cool-down which is only ensured by the mechanical cry-cooler: 3 Closed Cycle Cooler cold heads. Technical tests have been carried out to investigate the possibility of reducing this last phase using a reduction of the boiling pressure in the cooling line. As a result a significant reduction of the last period could be gained providing some additional work to make it effectively usable without attendance. The use of pumped nitrogen in a continuous flow system implies a few conditions which were not considered in the original design. It was still possible to implement a monitoring of the temperature to prevent the freezing and clogging of the line. The adaptation of the cross section of the internal lines to guaranty an efficient pressure reduction all over the cooling circuit would have been more difficult implement.

5. CONCLUSION, COMPARISON WITH OTHER SYSTEMS

Considering the pre-cooling of large infrared instruments, this technology has to be compared to the use of LN2 internal storage tanks. The continuous flow has the main advantage of a better distribution of the cold and a very effective cooling at the strategic points. It also has a clear advantage in the relation of the mass and volume used in the instrument. Such system can also be consider as easier to handle on the point of view of safety as no nitrogen is stored inside the instrument.

The numerous connections inside the instrument could be considered as a risk factor although our long experience has demonstrate that the use of the proper connectors guaranty an extremely reliable vacuum tightness, even after multiple dismounting.

Even if it looks like a step backward, the use of liquid nitrogen to keep large instruments at cryogenic operating temperature is still discussable at a time where we are looking for very stable and quite telescopes to be operated as an interferometer. This technology brings some very interesting and attractive answers to this problem. This has been verified at ESO in the frame of the reduction of the vibration on the VLT. HAWK-I (the VLT large field Near Infrared imager) is now kept at cryogenic operating temperature with the original pre-cooling system. Compare to the traditional mechanical coolers this system induces nearly no vibration. Small adaptations can also make this system less sensitive to power failure. The last and least is the considerable reduction of power dissipation in the telescope that the use of such system would bring compare to traditional mechanical coolers.

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REFERENCES

1. http://www.eso.org/sci/facilities/develop/integration/
2. Kaeufle, H., Ballester, P., "CRIRES: a high-resolution infrared spectrograph for ESO’s VLT” Proceedings of SPIE Vol.5492, pp 1218-1227 (2004).
3. Casali, M., Pirard, J., "HAWK-I: the new wide-field IR imager for the VLT” Proceedings of SPIEVol.6269, 62690W (2006).
4. Roelfsema, R., Alberts, P. Lizon, J.L, "X-Shooter near infra-red spectrograph cryogenic design” Proceedings of SPIE Vol.7017, 701717 (2008).
5. Omata, K., Tetsuo, N., "Automatic Pre-cooling System for Large Infrared Instruments” Proceedings of SPIE Vol.7018, 80182E1 (2008).