Thermal engineering of optical mirrors for use at cryogenic temperature inside a LHC magnet cryostat

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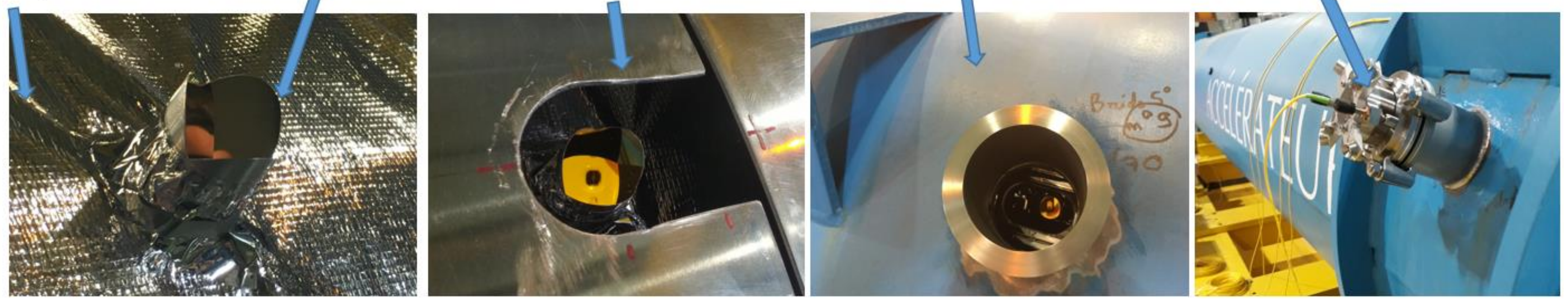
Abstract

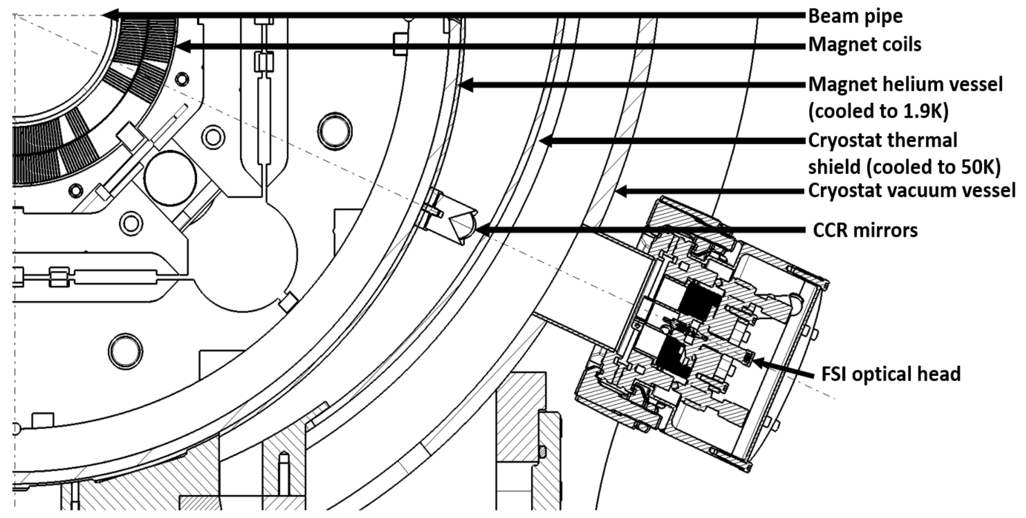
In the frame of the HL-LHC project, innovative technical solutions are sought to measure accurately the position of the magnet helium vessel inside the cryostat. To this end, a system based on laser-interferometry is being designed to monitor the displacement of the vessel through dedicated openings in the new HL-LHC magnet cryostats. In order to test such a system on a full-scale setup in representative operating conditions, a LHC dipole cryostat was modified to integrate the system optical lines of sight and the reflective mirrors were mounted onto the magnet helium vessel. Upon the first cool down of the magnet to 80K, severe ice-like condensation started forming on the reflective surface of the mirrors hence making the system unusable at cold. This was attributed to the condensation of the residual gas remaining in the cryostat insulation vacuum on the mirror surface. In this configuration the mirrors acted as local “cold spots” since they were purposefully sticking out of the multi-layer insulation (MLI) that is otherwise covering the magnet helium vessel. In order to cope with this condensation issue, a dedicated study was carried out to design and manufacture a passive temperature regulation system based on a thermal insulating support and a thermal radiation intercept in order to keep the mirrors just above the expected freezing temperature in operational conditions. This paper details the thermal engineering study leading to the design of the insulated mirrors and presents the technical solution retained as well as the latest test results.

System implantation layout

The system aims at providing an in-situ position measurement between the cryostat and the magnet helium vessel thanks to an interferometer.

A CCR mirror attached to the magnet helium vessel will follow its movements while the interferometer in attached to the vacuum vessel flange.



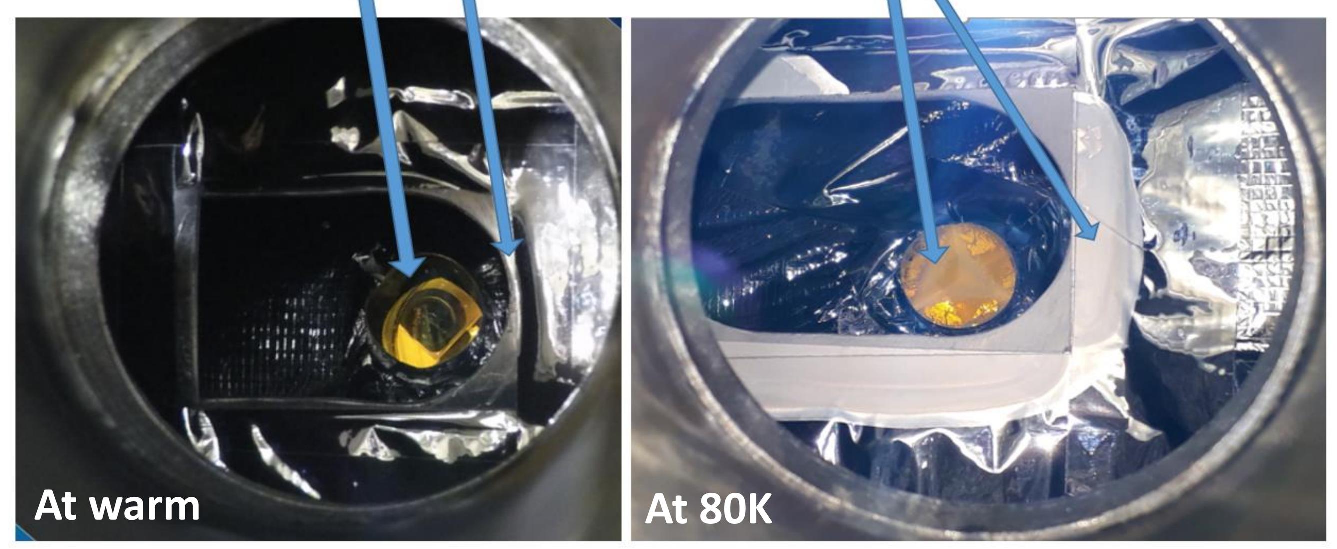


The CCR mirror is attached to the cold mass helium vessel and sticks out from the multi-layer insulation.

The thermal shield is then placed on top and inserted inside the vacuum vessel.

The interferometer is positioned on a flange opening on the vacuum vessel.

First magnet cool down to 80K



The mirror is covered by a frost-like deposit that prevent any usable light reflection.

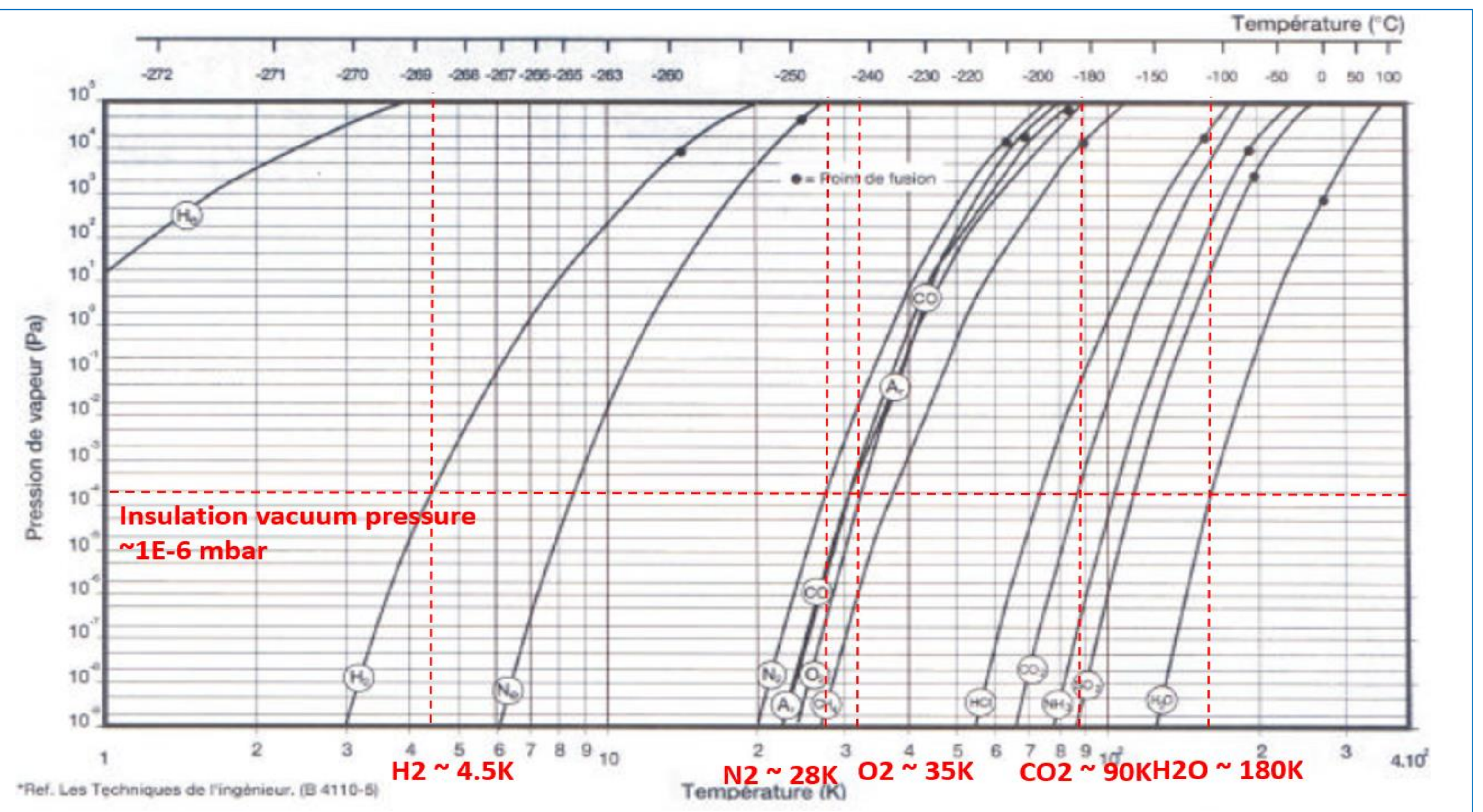
First investigations

The insulation vacuum residual pressure of the LHC magnet cryostat is known to be water dominated[1]

Further analysis of the magnet cool down showed that the deposit appeared at around 200K of helium vessel temperature.

At the insulation vacuum residual pressure, the condensation of water vapor should occur at around 180K (see graph[2]) which is consistent with our analysis.

→ We suspect a water vapor condensation issue on the mirror surfaces



[1]Cruikshank, Paul et al. Insulation vacuum system of the LHC, Vacuum, Volume 48, Issues 7–9, September 1997, Pages 759-762

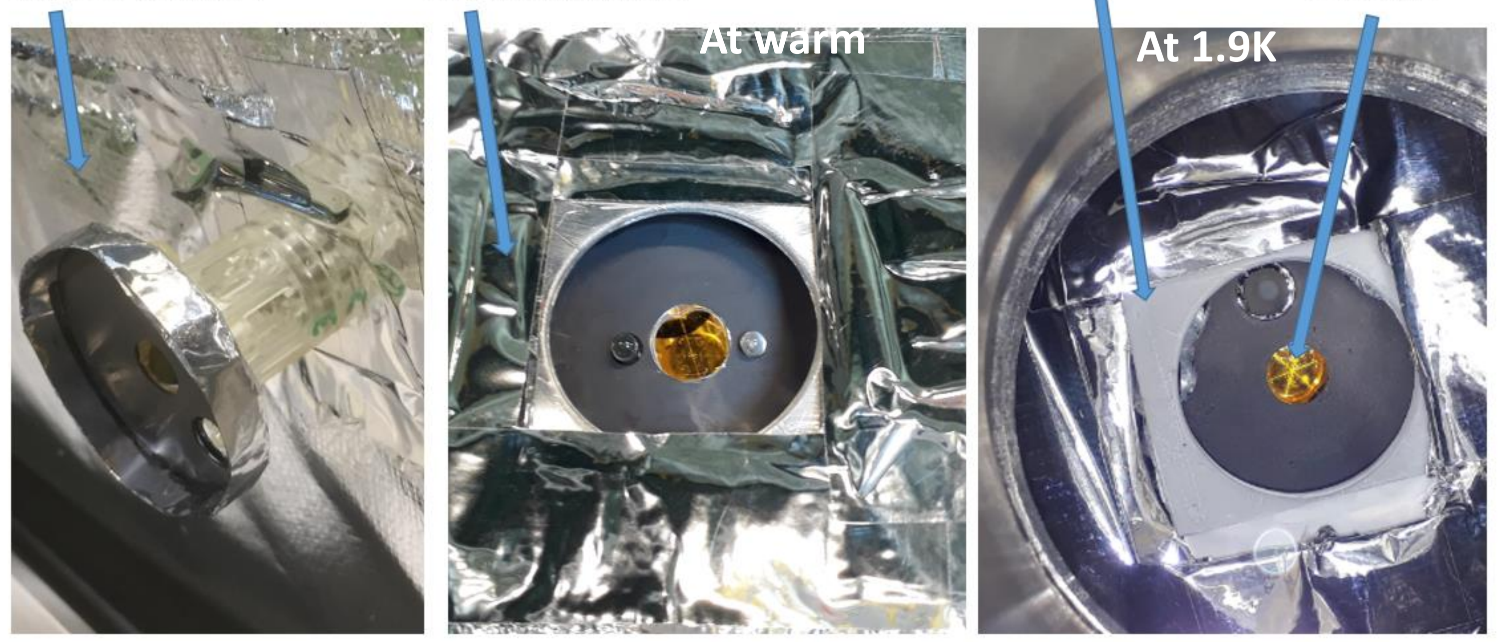
[2] Rommel, Guy Gaz à très basse pression Formules et tables, Techniques de l'ingénieur Technologies du vide (1985)

Final cool down testing

The insulated mirror was mounted on the testing magnet in order to test its functionality.

After cool down all reference mirrors (non-insulated) showed some level of frost deposition while all insulated mirrors were frost-free and reflective.

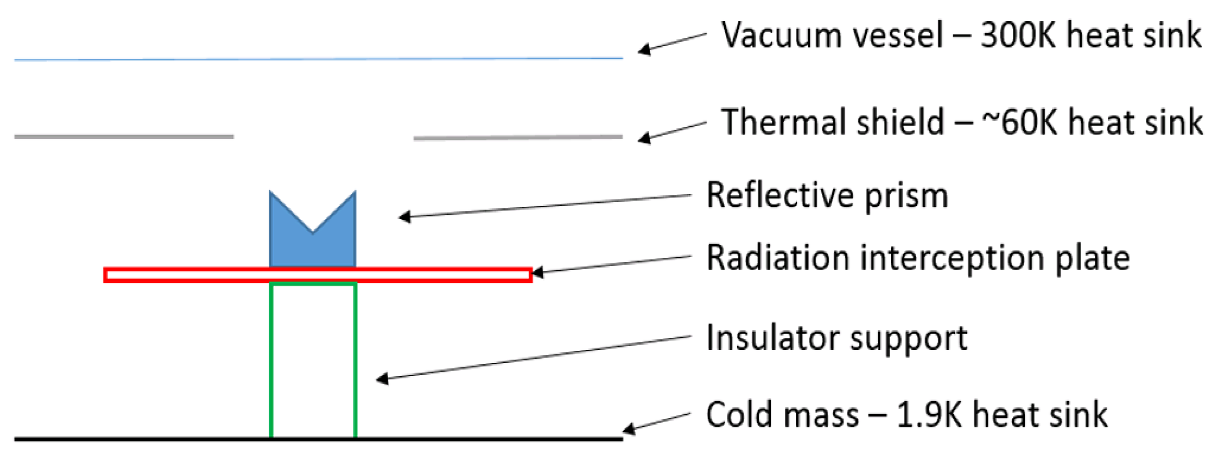
→ The solution principle laid out will then be implemented for the upcoming triplet of the HL-LHC project.

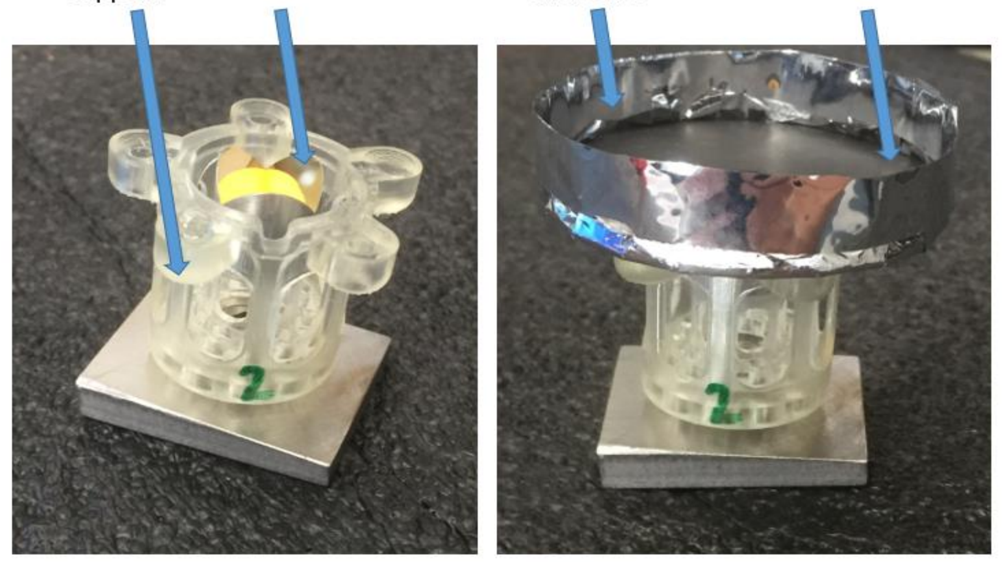


Strategy to cope

By keeping the CCR mirror above 180K while rigidly attached to the helium vessel, we could theoretically prevent any water deposition.

This can be done by insulating the mirror and making use of the 300K “hot” radiation from the vacuum vessel.





The insulator support is made of 3D printed epoxy resin.

A radiation plate is positioned on top and painted with high-emissivity black paint, its underneath is covered in aluminized Mylar to avoid radiation heat losses.

Dedicated analysis show that an incident power on around 100mW is sufficient to maintain an average 200K on the mirror. Most of the heat is then lost by secondary thermal radiation emission from the epoxy resin itself.

Conclusion

In the frame of the development of an innovative position monitoring system for the superconducting magnets, an issue of mirror surface contamination at cryogenic temperature was encountered. After dedicated investigation, this was attributed to the condensation of residual gas directly on the mirrors reflective surface. In order to cope with the issue, a system aiming at keeping the mirror temperature above freezing temperature was designed and implemented with a successful outcome.