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CO_2 evaporative cooling: the future for tracking detector thermal management

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Abstract

In the last few years, CO_2 evaporative cooling has been one of the favourite technologies chosen for the thermal management of tracking detectors at LHC. ATLAS Insertable B-Layer and CMS Pixel phase 1 upgrade have adopted it and their systems are now operational or under commissioning. The CERN PH-DT team is now merging the lessons learnt on these two systems in order to prepare the design and construction of the cooling systems for the new Upstream Tracker and the Velo upgrade in LHCb, due by 2018. Meanwhile, the preliminary design of the ATLAS and CMS full tracker upgrades is started, and both concepts heavily rely on CO_2 evaporative cooling. This paper highlights the performances of the systems now in operation and the challenges to overcome in order to scale them up to the requirements of the future generations of trackers. In particular, it focuses on the conceptual design of a new cooling system suited for the large phase 2 upgrade programmes, which will be validated with the construction of a common prototype in the next years.

Keywords: Tracking detectors, CO_2 cooling, LHC phase 2 upgrades
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1. Introduction

Carbon dioxide two-phase cooling is being selected with increased frequency as solution for the thermal management of high energy physics tracking detectors. Evaporative cooling presents several advantages with respect to liquid cooling: the higher heat transfer coefficient allows for smaller pipes, thus reducing the total material budget, and the isothermal evaporation helps maintaining a very uniform and constant temperature inside the detector. Moreover, CO_2 presents additional features with respect to the perfluorocarbons now in use on tracking detectors: its high latent heat of evaporation and the low viscosity further contribute to the reduction of the pipe sizes, the enviromental impact of CO_2 is much lower and the fluid refilling is substantially cheaper.

Considering the very positive experience on LHCb Velo detector [1], both ATLAS and CMS experiments have chosen the same technology for their first upgrades. The ATLAS IBL detector [2] is now being cooled by two redundant CO_2 cooling plants, designed to cope with 3 kW of cooling power each at -35°C. The CMS phase 1 Pixel upgrade [3] will be cooled in 2017 by two CO_2 cooling systems, presently under commissioning, each one delivering 15 kW of cooling power at -25°C. For the future, three LHC experiments have already chosen evaporative CO_2 as thermal management technology for the upgrade programs of their silicon detectors: LHCb for the upgrade of the Velo and the new silicon Upstream Tracker detectors, requiring 7 kW cooling at -30°C; ATLAS and CMS for the phase 2 upgrade of their strip and silicon trackers. The former will require approximately 140 kW of cooling power at -35°C, the latter will need about 100 kW of cooling power at -30°C. Whilst the LHCb upgrade is planned for 2018, the phase 2 upgrades of ATLAS and CMS are foreseen for 2023. A common strategy is chosen for developing the conceptual design of the future CO_2 plants, which shall cope with power requirements up to 10 times higher than those required by any other existing tracking detector and approach the operational limits of CO_2 with evaporating temperatures down to -35°C.

2. Technological challenges

The CO_2 cooling systems used so far for detectors in high energy physics are all based on the ”2 Phase Accumulator Controlled Loop” (the so called ”2PACL”) thermal cycle [4]. This design features a liquid pumped system with the evaporating pressure (hence the temperature) being controlled through pressure control inside a 2-phase storage tank, called accumulator. The 2PACL cycle perfectly fits the needs of limited scale systems, but the vessel size and the regulation system may not be optimal for undergound systems of large scale. As well, due to the severe temperature (-40°C) and pressure (up to 100 bar design pressure) requirements, well suited components are limited on the market and have been tested so far only up to powers of 15 kW.

The strategy chosen to cope with higher cooling power requirements is to build modular systems, with several units running CO_2 in parallel through the detector. In order to optimize the modular design, several open points need to be investigated: the maximum size of the single cooling system module, the

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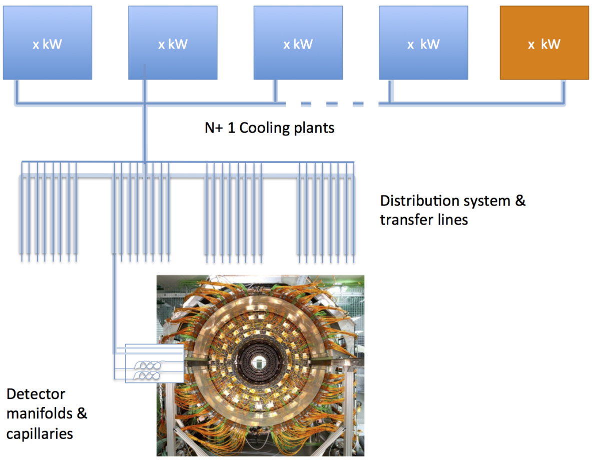

Figure 1: Simplified schematic of modular design for large scale detector cooling systems.

control system to run all of them in parallel, the method to store the total CO_2 fluid volume and the optimization of the transfer line system. All these aspects will be addresseded by the design, construction and commissioning in the coming years of a baseline cooling plant module, whose design will then be tuned for the detailed need of each experiment.

2.1. Modularity and redundancy

Both the ATLAS IBL and the CMS Pixel phase 1 CO_2 cooling system mount a membrane LEWA pump, the only model having demonstrated so far a very high reliability with carbon dioxide in the demanded temperature ranges. These pumps can mount a triple head and the option exists for a remote head: both options have already been separately tested on the CO_2 plants and a combination of the two features is the baseline for the new cooling system module, in order to achieve up to 50 kW of cooling power. One option of control system to operate multiple plants in parallel is now being validated with the commissioning of the CMS Pixel phase 1 upgrade plant, featuring two systems that can feed half or all the detector depending on the request of the experiment. This concept will then be extended to the parallel operation of N+1 cooling systems, where N is the total number of modules needed to achieve the full required performance, increased by at least one idle system that guarantees the operation of the detector in case one of the previous is out of order or under maintenance. Figure 1 shows the schematic of such system, with the modular plants and the full set of transfer lines distributing the coolant to the different parts of the detector.

2.2. Temperature regulation and CO_2 storage

The CO_2 freezing point of -55.6°C puts an operational limit to the final evaporating temperature at the detector. Furthermore, in order to safely run the pumps, pure liquid at a temperature about 10°C lower than the target saturation temperature is needed at the pump suction. The freezing point sets the technical limit on the evaporation temperature of the primary system (external chiller) at about -50°C and requires a challenging regulation system on this temperature to be stable independently of the heat load applied to the system. On top of this, in order to obtain a CO_2 evaporating temperature of about -40°C, one needs to limit as much as possible any pressure drop on the return lines. In terms of technology for the primary system (however limited to evaporating temperatures of about -35°C) a promising solution comes from the CO_2 industrial chillers nowadays taking a large part of the market, featuring compact design and an easy regulation.

The regulation of the detector evaporating temperature has been achieved so far by direct control of the pressure in the two-phase accumulator at the cooling plant. The same vessel has been used to collect and store all the CO_2 of the system when idle. Due to the large volumes of the future systems, including both the detector and the distribution transfer lines, such method could prove unpractical in underground experimental areas. Two alternative solutions are presently under study. The first relies on the decoupling of the storage and control functions, still maintaining a "2PACL" baseline concept. The second one is based on a totally different concept, featuring a warm vessel located on surface, from which CO_2 is injected or extracted by means of pressure regulation valves. Both these options will be further developed and compared to the "2PACL" system, in order to propose the most functional for the future large scale systems.

3. Conclusions

Based on the positive experience of LHCb Velo, ATLAS IBL and CMS phase 1 Pixel cooling plants, the upgrade detectors of LHCb Velo and UT, the upgrade ATLAS and CMS trackers have chosen CO_2 evaporative cooling. The CERN PH-DT team is applying the lessons learnt on the previously designed systems in order to optimize the design of the LHCb cooling plant, due by 2018. For the longer term developments of ATLAS and CMS, the team is going to develop a new concept which will allow higher cooling power, a bigger size and an optimized regulation system.

Acknowledgments

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