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ATLAS "Baby-DEMO"

L. Zwalinski [a,*], K. Bojdol [d], C. Bortolin [a], D. Chmielewski [k], P. Dziurdzia [a], D. Giakoumi [a], J. Godlewski [h], I. Ilyashenko [g], M. Kalinowski [a], R. Kantor [c], L. Klimczyk [e], T. Kuczek [c], M. Marziani [i], B. Niezgoda-Zelasko [c], R. Puppo [b], C. Rossi [b], B. Verlaat [a], S. Vogt [f], A. Volpe [b], J. Witek [j]

[a] *CERN, CH-1211 Geneva 23, Switzerland*
[b] *INFN Universita Genova, Via Dodecaneso 33, 16146 Genova, Italy*
[c] *Cracow University of Technology, Warszawska 24, 31-155 Krakow, Poland*
[d] *PONAR ul. Wojska Polskiego 29, 34-100 Wadowice, Poland*
[e] *HYDROAUTOMATYKA Sp. z o.o., ul. Kosciuszki 25, 32-620 Brzeszcze, Poland*
[f] *Max-Planck-Institut fuer Physik, Fohringer Ring 6, D-80805 Munich, Germany*
[g] *Petersburg Nuclear Physics Institut PNPI, 1, Orlova roscha mcr., Gatchina, Leningrad region, 188300, Russia*
[h] *Institute of Nuclear Physics PAN, ul. Radzikowskiego 152, 31-342 Krakow, Poland*
[i] *University of Cape Town, Private Bag X3, Rondebosch 7701, South Africa*
[j] *Z. P. D. CEBEA Sp. z o. o., ul. Krasinskiego 29, 32-700 Bochnia, Poland*
[k] *"Darclim", os. 2 Pulku Lotniczego 3 m. 52, 31-867 Krakow, Poland*

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ABSTRACT

Evaporative CO_2 has been selected as the main detector cooling technology for the Phase II upgrade of the LHC silicon detectors at CERN. In order to provide input to the ATLAS Pixel TDR about the minimum attainable cooling temperature by the end of 2017, ATLAS, with a contribution of CMS, has launched a dedicated detector cooling R&D study nick-named Baby-DEMO. The Baby-DEMO is the demonstration of a typical 2PACL CO_2 cooling plant operating at the lowest temperature ever achieved. A real size ATLAS mock-up is used to hold realistic manifolding as its critical path might have strong impact on the cooling performance. Additionally, the "Baby-DEMO" program addresses the study of high power flexible vacuum insulated coaxial transfer lines and warm nose boiling enhancement as possible solutions for the Phase II upgrade. This paper describes the system design including CO_2 plant, primary chiller and typical distribution. Challenges and solutions used to achieve the lowest possible evaporation temperatures are reported. The result of this study, even if at the preliminary stage, are of great interest for the design of the cooling systems that ATLAS and CMS will use in the Phase II era.

Contents

1. Introduction

Baby-DEMO is an R&D system for the ATLAS Inner Tracker (ITk), built to provide data for the Pixel TDR about the minimum cooling temperature achievable with evaporative CO_2 2PACL [1] technology by the end of 2017. The target was to reach temperatures down to −40 °C or lower on the evaporator. Confirmation of reaching −40 °C could have an impact on the choice of the sensing elements 3D vs Planar for the most inner layers. A cooling plant with low temperature chiller has been built by collaboration of CUT-PONAR-CEBEA in Poland under supervision of CERN EP-DT group, to start investigating the experimental challenges in the operation of such system.

* Corresponding author.
E-mail address: lukasz.zwalinski@cern.ch (L. Zwalinski).

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The Baby-DEMO has been installed at CERN next to the ATLAS 1:1 Mock-up in building 180 in order to connect real size distribution lines which are key element to evaluate total cooling system performance. Real scale ATLAS ITk geometry and components was proposed.

The challenge of the low temperature chiller is to provide a stable temperature close to the freezing point of CO_2 (−56.6 °C). This stability is needed to not freeze the CO_2 when going too low and not too high to lose the pump sub cooling. The system is equipped with a LEWA membrane pump, similar to what is expected to be used in the future core plants. The goal of the test is to measure the minimum sub cool temperature adoptable to obtain the lowest possible plant temperature.

2. The challenges of CO_2 cooling at low temperatures

The ITk Pixel needs cooling temperatures around −40 °C at the level of the cooling pipes inside the Pixel staves. The cooling flows from and to the cooling plants far away in USA15 is via the transfer lines and local distribution. The fluid transfer is subject to losses, which in a 2-phase system appears as a saturation temperature drop on the return line due to the frictional pressure drop of the flowing media and static height differences. The cooling lines inside the detector (PP0[1] to PP2[2]) are typically designed to small diameters to minimize mass and to ease integration. The performance of these small lines are subject to higher losses and are critical in the design as they increase the detector temperature. A distribution with high losses needs a colder cooling system to achieve still the temperature requirements on the detector. Stave temperatures of −40 °C need therefore a cooling plant temperature of −45 °C if a 5 °C temperature loss in the distribution and transfer is assumed. When taking a −45 °C cooling plant temperature in mind the pumped fluid need to be in the order of −53 °C.

2.1. Real scale cooling distribution

For the PP2 to PP1[3] distribution a flexible concentric transfer has been developed as scaled up technology from ATLAS-IBL. The design cooling power per flex line is 5 kW. The triple concentric line consist of a 5 mm ID inner hose for the liquid inside a 16 mm ID outer hose for the vapor return. The outer CO_2 pipe is insulated with Multi Layer Insulation and placed inside a flexible vacuum hose with an outer diameter of 50 mm. The flex lines are 10 m long. The vacuum level inside the hose needs to be smaller than 10^{-4} mbar to exclude convection.

2.2. Baby-DEMO test results

In December 2017 the Baby-DEMO plant was run successfully for the first time and evaporative cooling temperatures of −47 °C were achieved at the plant level. Fig. 1 shows the test cycle which was made to evaluate the performance of the full system. Accumulator saturation temperature set-point cycles (ST4080) from −47 °C to 10°C were made with different heat loads from 1 to 6 kW. The cycle speed for the measurement was as low as 6 °C/h.

After the first cycle with 5 and 3 kW a cold record attempt was performed manually by the expert around 42 h. During this attempt, the sub cooling of the pump was lost twice (green upward spikes). A loss of sub cooling has often resulted in a full and unrecoverable stop of the flow in many previous cooling systems. In Baby-DEMO the pump showed not to be sensitive to this and recovered without any problem when sub cooling was returned. This is a very important result as it allows the system to operate with lower sub cool margins and hence colder evaporation temperatures can be achieved. During the record attempt, a temperature of −50 °C has been reached in the plant, however it would not respect the safety margins foreseen during normal operation. The −47 °C run over long time has been done after, starting at 68 h.

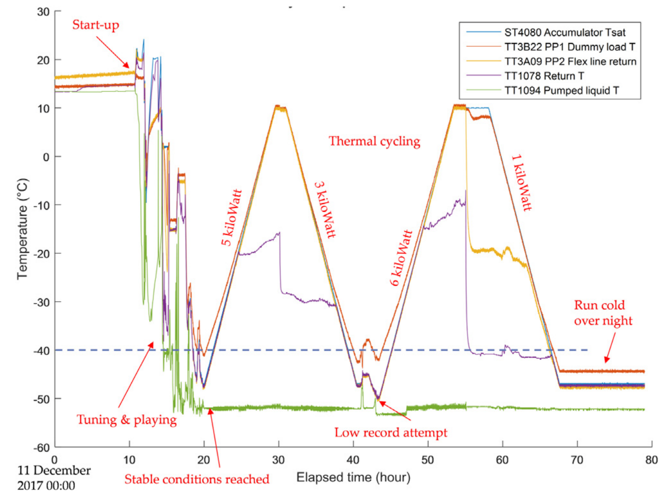

Fig. 1. Thermal cycling tests of Baby-DEMO under different heat loads. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

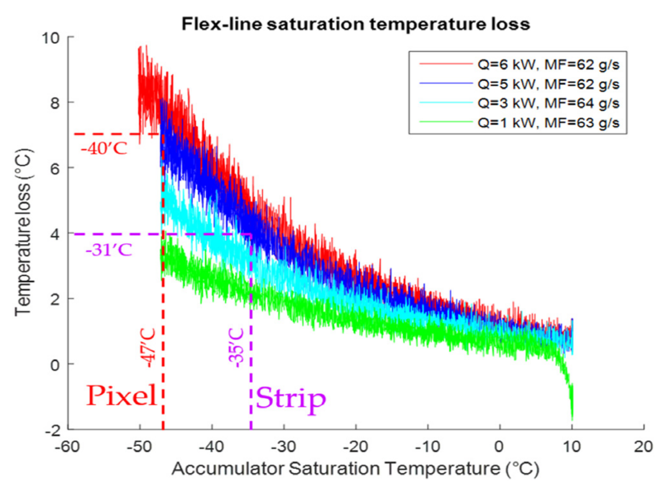

Fig. 2. Measured flex line gradients.

The 50 mm flex line gradients of 7 °C obtained during cycle tests shown as steady states results on Fig. 2 subject to improvements.

3. Conclusion

With a plant operational temperature of −47 °C a temperature in the dummy load below −40 °C was achieved so the goal of the Baby-DEMO to prove an operational temperature on the detector at −40 °C was fulfilled. A larger diameter flex line of 60 mm instead of 50 mm is under prototyping and will be tested in Baby-DEMO in 2018 together with prototype manifolds and so-called warm nose circuits.

References

[1] B. Verlaat, et al., CO_2 cooling for the LHCb-VELO experiment at CERN, in: 8th IIF/IIR Gustav Lorentzen Conference on Natural Working Fluids, Copenhagen, Denmark, CDP 16-T3-08.

[1] Patch Panel 0, serv. interconnection point at the ID detector.
[2] Patch Panel 2, serv. interconnection point at the outside calorimeters region.
[3] Patch Panel 1, serv. interconnection point at the ID endplate region.