DEVELOPMENT, COMMISSIONING AND OPERATION OF THE LARGE SCALE CO_2 DETECTOR COOLING SYSTEMS FOR CMS PIXEL PHASE I UPGRADE

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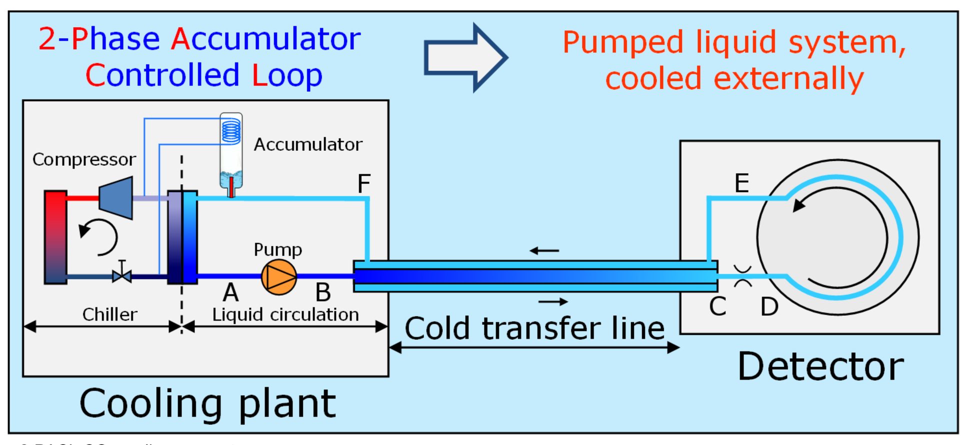
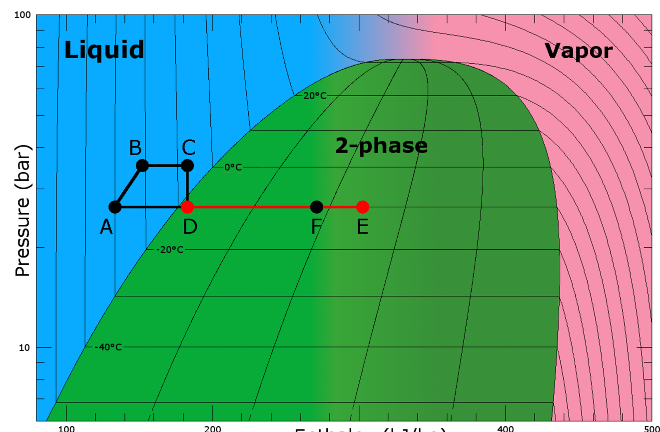
CMS Pixel Phase I Upgrade

Compact Muon Solenoid (CMS) is one of the two large multi-purpose detectors installed on the Large Hadron Collider (LHC), operating at the European Organization for Nuclear Research (CERN). The Pixel detector is the innermost CMS sub-detector and it is used for precise tracking of the particles produced by the collisions. Due to the vicinity to the interaction point (i.e. the small region where the particle collide), the radiation harm have a major impact on the lifetime of the silicon sensor. To limit the radiation ageing effect, the temperature of the silicon sensors must be kept below -10°C. In order to cope with the increase in the collision rate provided by the LHC, the CMS experiment replaced all of its Pixel detector during an extended winter technical stop in 2016/2017 year. The new detector features several important improvements including: new front-end chips, a nearly twofold increase of the active surface, reduced amount of inactive material in the tracking volume. Following the upgrade, the Barrel Pixel (BPIX) grew from 48M to 80M channels and the Forward Pixel (FPIX) from 18M to 45M channels. The new design of the detector, despite the larger area and increase of channels, substantially reduced the amount of material. This was achieved mainly by the introduction of a new two phase CO_2 cooling system that replaced the C6F14 liquid cooling [1].



2-PACL CO_2 cooling concept

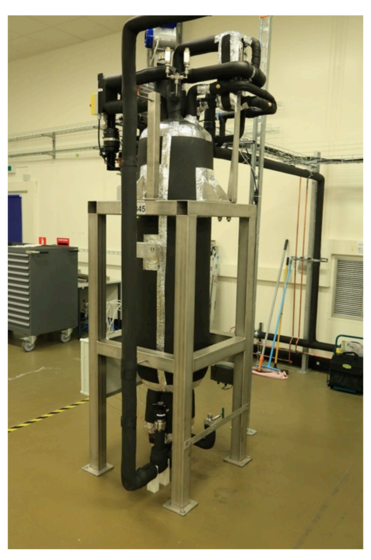


CO_2 Pressure-enthalpy diagram

Prototype

In order to handle the requirements of the CMS Pixel upgrade [PP1], at first stage a full-scale prototype of a 15 kW evaporative CO_2 cooling system has been de-signed, constructed and commissioned in 2013 [2] in a dedicated surface installation called Tracker Integration Facility (TIF). The TIF cooling system prototype consist of three main units: one cooling plant core, one manifold and one accumulator. The prototype represents one-half of the final cooling system which was installed in the underground area of the CMS experiment.

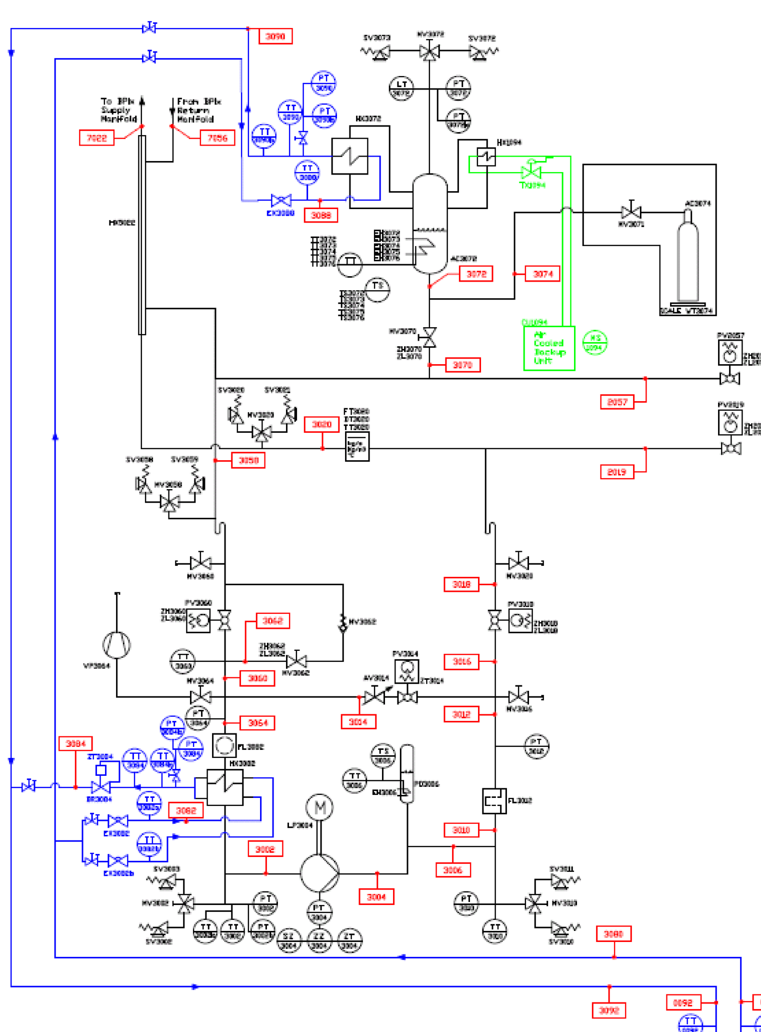
Accumulator

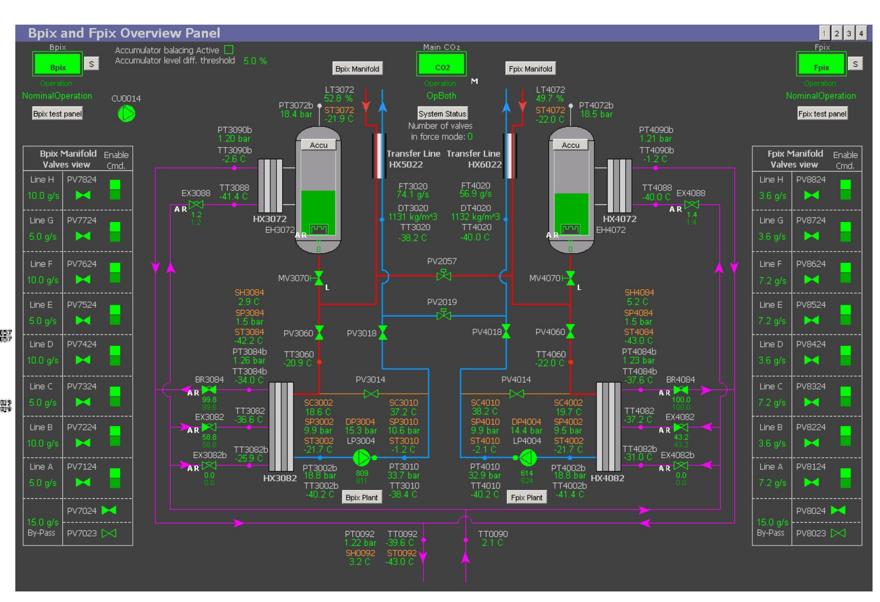


Cooling plant core

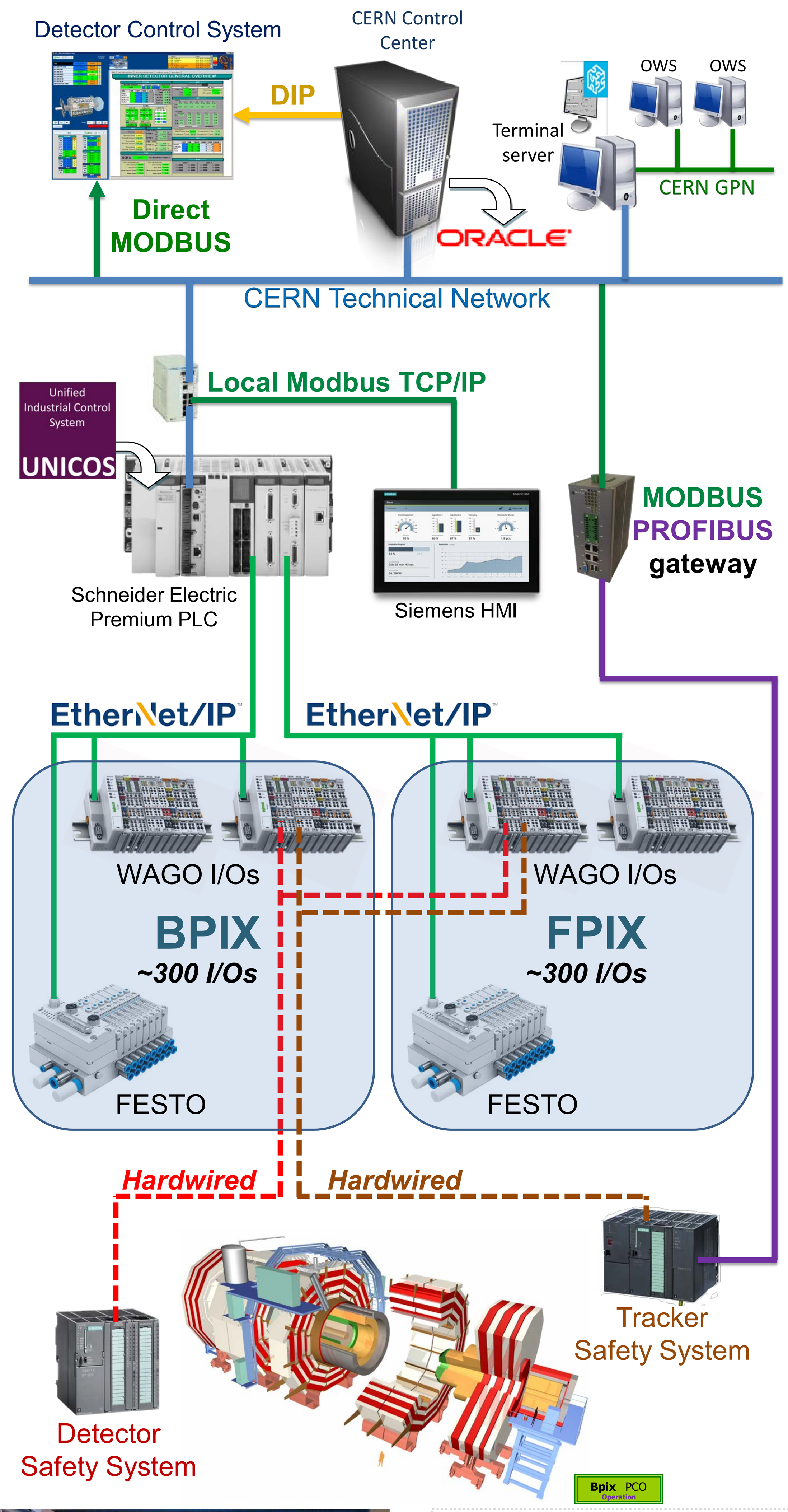
Manifold

Control system



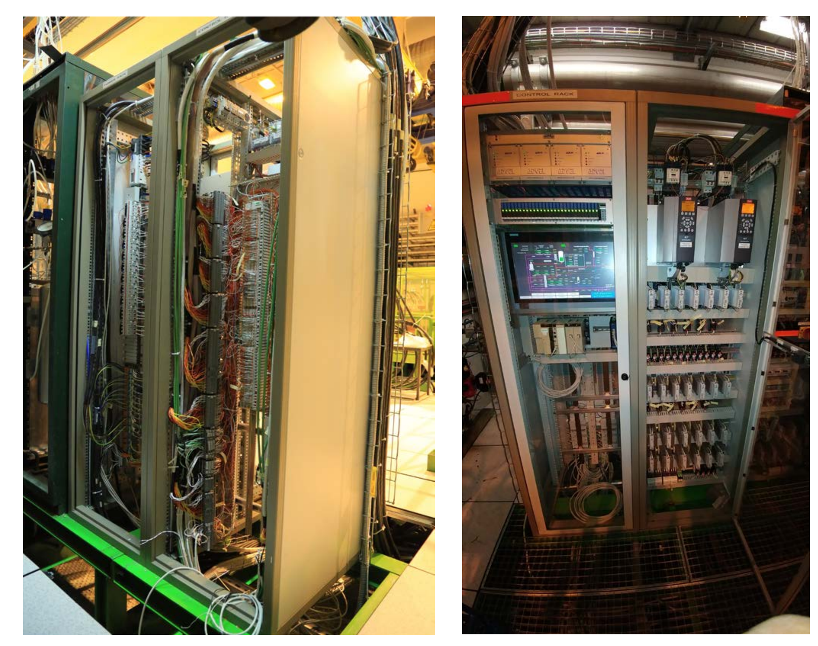


BPIX & FPIX main UI SCADA panel (top)
P&ID of BPIX accumulator and plant core (left)

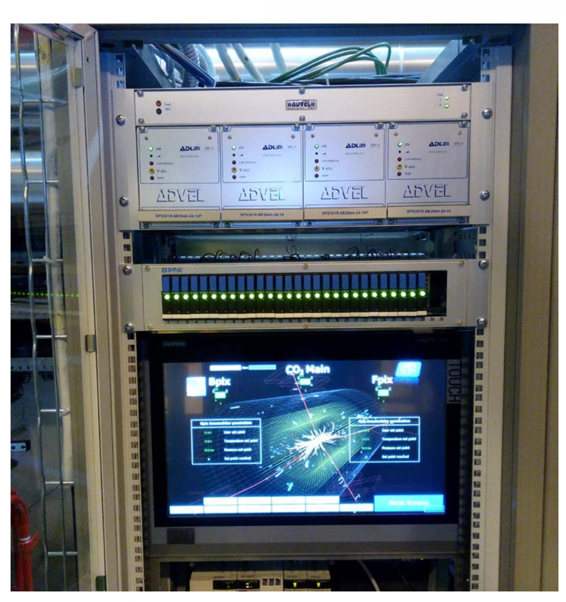


Control system architecture

The control system for the CMS CO_2 cooling is separated for BPIX and FPIX. However, the system is equipped with one common Schneider Premium Programmable Logic Controller (PLC) and two privet EtherNet/IP networks for the distributed Input/Outputs (I/Os). Each of the cooling systems is equipped with one dedicated EtherNet/IP network card at the PLC level, two WAGO EtherNet/IP couplers for the distributed IOs and one FESTO EtherNet/IP coupler for pneumatic valve piloting. In total, the PLC manages almost 600 IOs via the EtherNet/IP protocol. The Siemens WinCC OA based Supervisory Control And Data Acquisition (SCADA) was chosen as a User Interface (UI). The control system follows the UNICOS CPC6 (Unified Industrial Control Sys-tem for Continuous Process Control) framework of CERN [3] [4]. The PLC communicates to the SCADA server, placed in the CERN Control Center (CCC), through the CERN Technical Network, which is isolated from the global network, using the Modbus TCP/IP protocol. In case of a large network failure, the CO_2 cooling control system is equipped with a local touch panel, placed in the control rack, directly connected to the PLC and allowing for safe operation of the system. The touch panel software was programmed according to the UNICOS standard for the Siemens HMI (Human Machine Interface). Such user interface is very much similar to the WinCC OA SCADA UIs. The whole cooling system is powered from the DIESEL backed network. The 24V DC hot-swappable redundant power supply, the PLC and the Siemens Touch Panel are powered from a dedicated UPS (Uninterruptible power supply).

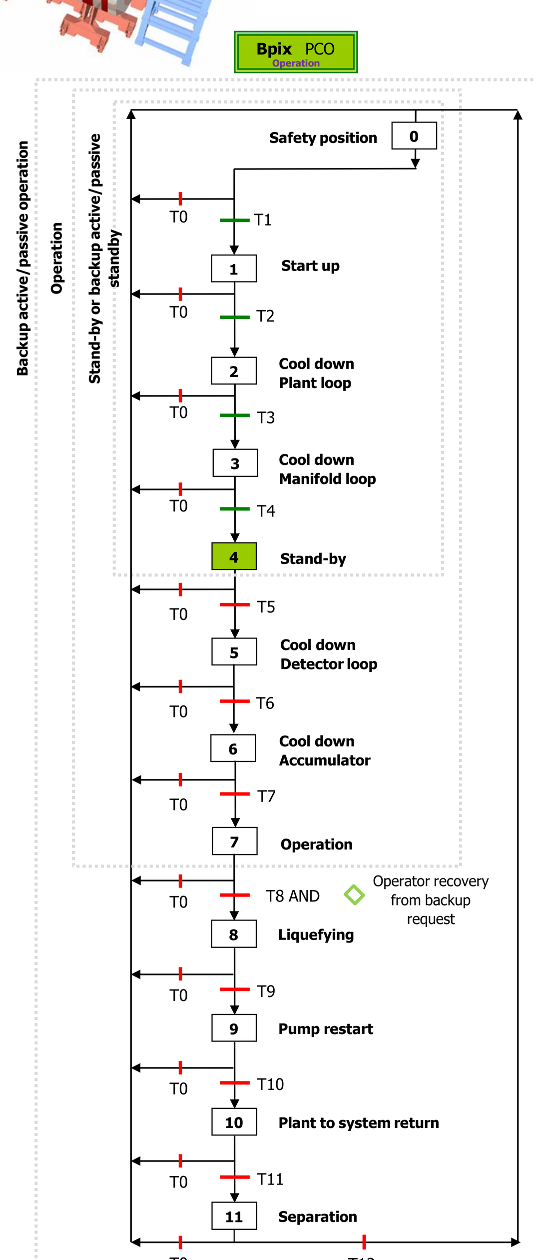


Final system control racks located in the underground service cavern



The 24V DC hot-swappable redundant power supply, DC circuit breakers and HMI

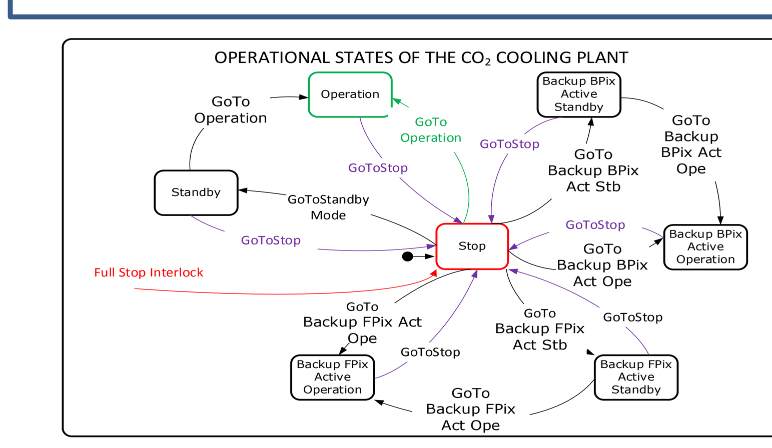
Schneider Electric Premium PLC with 2 EtherNet/IP network cards



BPIX PCO transition logic stepper

System operation

During normal operation, both BPIX and FPIX cooling systems runs as separate systems. They can run with different evaporation temperature set-points and different CO_2 flow requests. Both systems are piloted by the master Process Control Object (PCO), which is the top control object in the hierarchy. In case of failure of one plant core, the PCO stops it, and when the interconnection valves in between the two plants are open, the system can continue the operation. In this scenario, the excluded plant core is removed from circulation by the pneumatic valves, the accumulator control follows the commands sent by the remaining running plant, and the running pump increases the pumping speed to deliver the requested flow to both BPIX and FPIX manifolds. This is the so-called backup option mode, where one plant operates as master and the second runs in the backup. In backup mode, there is only one common evaporation set point available for the two detectors due to the common return pressure.

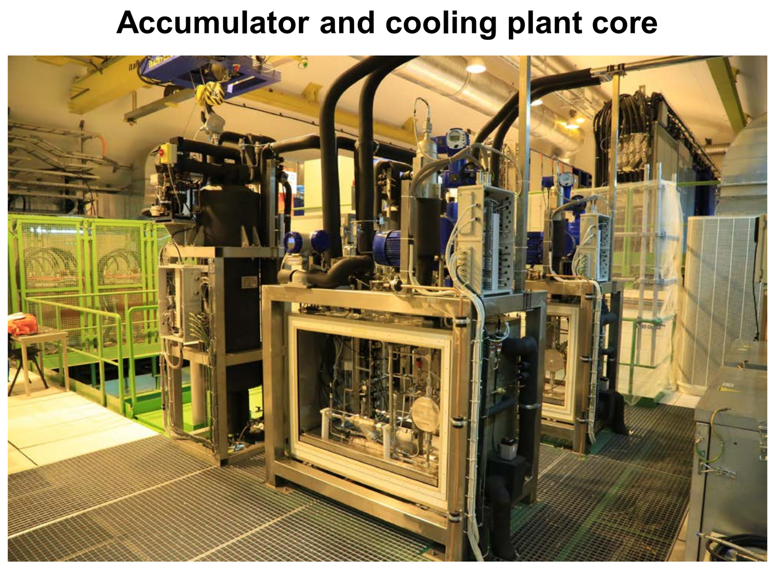


Final

The final CO_2 cooling system comprises two individual cooling units. In normal operation, one is dedicated to the BPIX detector and the other to the FPIX detector. Each unit consists of three main sections: the Accumulator, the Plant Core and the Manifold.

- The accumulator is a vessel always filled with a mixture of liquid and vapour CO_2. It is connected to the return line of the refrigeration loop, keeping the 2-phase CO_2 returning from the detector at the same pressure as in the vessel. The accumulator pressure is regulating by the heating and cooling action.
- In the plant core, the returning two-phase CO_2 is cooled down and liquefied in a heat exchanger by a standard primary chiller, based on R507a refrigerant. Afterwards, the liquid CO_2 is pumped by a membrane pump through vacuum insulated transfer lines to a distribution manifold. The plant core is also equipped with a local bypass, a dumper and shut off valves used during maintenance.
- Each of the detectors (BPIX & FPIX) is served by a manifold, which is responsible for the flow distribution to the detector. In the manifold, there are manual regulation valves, instrumentation for flow measurement and pneumatic shut off vales to separate individual loops. In total, there are 16 loops, 8 per detector, and additionally one bypass loop per manifold, on which is installed the dummy thermal load used during the commissioning period.

Accumulator and cooling plant core



Manifold

Control system

Safety

In the CO_2 cooling system, during the operation but also while the system is switched off, high pressure is present. There are 16 electrical heaters, serving different purposes, with power up to 7.5 kW. All the heaters are in the direct contact with the CO_2, installed in a small pipe volume and covered by thermal insulation. In order to avoid dangerous situations like overheating, rapid pressure increase or even fire, a three levels safety interlock philosophy has been applied for all heaters of the CO_2 cooling systems:

- The first level is a software interlock, which stops the heater when a predefined first temperature threshold is exceeded. The temperature readout comes from the measurement of a thermocouple installed inside the heater cartridge.
- The second level are additional software interlocks, which stop all system heaters when any of the heater temperatures exceeds a predefined second temperature threshold. The measurement is based on the same thermocouple as in the first level protection.
- The third level is a hardware interlock, which cuts the power to all system heaters, when any temperature exceeds the further threshold fixed by one thermal switch. The thermal switches are installed directly on the piping [5].

Summary

After the commissioning period, the described CMS CO_2 cooling system operates with the new pixel detector since 2017. Both plants are running steadily, without any major failure. The system has been prepared for operation 24/7 and due to the redundancy approach, it is possible to keep the cooling active on the detector even during plant maintenance. The presented EtherNet/IP distributed I/Os architecture is an interesting solution especially for control systems where the space and budget are limited.

References

[1] P. Tropea et al., Design, construction and commissioning of a 15kW CO_2 evaporative cooling system for particle physics detectors: lessons learnt and perspectives for further devel-opment, TIPP, Amsterdam, The Netherlands, 2014
[2] J. Daguin, J. Noite, P. Petagna, H. Postema, P. Tropea, B. Verlaat, Evaporative CO_2 cooling system for the upgrade of the CMS Pixel detector at CERN, 10th IIR-Gustav Lorentzen Conference on Natural Working Fluids, Delft, The Nether-lands, 2012
[3] Ph. Gayet et al., UNICOS a Framework to Build Industry-like Control Systems Principles Methodology, ICALEPCS05, Geneva, Switzerland, 2005
[4] B. Fernandez Adiego et al, UNICOS CPC6: automated code generation for process control applications, ICALEPCS 2011, Grenoble, France
[5] L. Zwalinski et al, The control system for the CO_2 cooling plants for physics experiments, ICALEPCS 2013, San Fran-cisco, California