Cooling plant core

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 particle produced by the collisions. Due to the vicinity to the interaction point (i.e. the small region where the particle collision), the radiation harm has a major impact on the lifetime of the silicon sensor. To limit the radiation damage effect, the temperature of the silicon sensors must be kept below -10°C. In order to cope with the increase in the radiation dose 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.

In order to handle the requirements of the CMS Pixel upgrade [PP1], at first stage a full-scale prototype of a 15 kW evaporative CO2 cooling system has been designed, constructed and commissioned in 2013 [2] in a 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.

The prototype represents one-half of the final cooling system which was installed in the underground area of the CMS experiment.

Control system architecture

The control system for the CMS CO2 cooling is separated for BPix and FPix. However, the system is equipped with one common Schneider Premium Programmable Logic Controller (PLC) and two private EtherCAT® networks for the distributed Input/Output (IOs). Each of the cooling systems is equipped with one dedicated EtherCAT® network card at the PLC level, two WAGO EtherCAT® couplers for the distributed IOs and one FESTO EtherCAT® coupler for pneumatic valve piloting. In total, the PLC manages almost 800 IOs via the EtherCAT® 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 OPC® (Unified Industrial Control System for Continuous Process Control) framework of CERN [3] (4). The PLC communications 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 network failure, the CO2 cooling 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 HWI (Human Machine Interface). Such user interface is very similar to the WinCC OA SCADA UIs. The whole cooling system is powered from the DIESEL backed network.

During normal operation, both BPix and FPix cooling are controlled as an integrated system by a common PLC. Due to different evaporation temperature setpoints and temperatures readout comes from the measurement of a thermocouple installed inside the heater cartridge. The measurement is based on the same thermocouple as in the first level protection.

Safety

In the CO2 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 CO2 cooling manifold, T0. They are installed on 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 CO2 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 thermometer, installed inside the heater cartridge.
- The second level is 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 thermometer 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].

Final

The final CO2 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 CO2. It is connected to the return line of the refrigeration loop, keeping the 2-phase CO2 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 CO2 is cooled down and liquefied in a heat exchanger by a standard primary chiller, based on R744 refrigerant. Afterwards, the liquid CO2 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 valve 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.

System operation

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Summary

After the commissioning period, the described CMS CO2 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 EtherCAT® distributed I/Os architecture is an interesting solution especially for control systems where the space and budget are limited.

References

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