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Engineering Specification

Piping and Instrumentation Diagram description for the LHCb Velo and UT Upgrade CO2 cooling system (MAUVE)

This document describes the P&I (Piping and Instrumentation diagram) for the LHCb UT and Velo Upgrade CO_2 cooling systems (MAUVE)
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Distribution List:

History of Changes

Rev.	Date	Nb of Pages	Description of Changes
0	14/06/17	8	First draft
1	4/12/17	9	Update after PRR

Outline

1. INTRODUCTION

This document describes the architecture of the CO_2 cooling system for the LHCb UT and Velo Upgrade detectors, called MAUVE. It presents the piping and instrumentation diagram and gives some input to the back-up strategy chosen including the power architecture and the operational scenarios.

2. Piping and instrumentation diagrams

Figure 1 shows the overall concept of the LHCb Velo & UT cooling system, which is composed of 2 identical CO_2 plants (Velo & UT); in normal operation, one of them serves the UT detector and the other serves the Velo detector. Each system includes a plant core, an accumulator system, a junction box and a local manifold at the detector entrance. Detailed P&I of the plant and the junction box and manifolds are given in the next paragraph. Both plants are connected to a primary chiller and eventually to a brine circuit, which is not represented in the schematics.
Plant cores and accumulator systems sit in the accessible part of the UX85 cavern, whilst the junction box is to be installed some 50 m away, on the experimental side of the same cavern. Concentric transfer lines connect each plant to the junction box. From the junction box, 2 pairs of transfer lines distribute the coolant to the two sides of the UT and Velo detector.
Both plants are identical, and each one of the two can, in case of need, feed the necessary coolant to both detectors. The connection between the two systems is done in the junction box, thus minimizing the volume of fluid swapped between systems. A unique control system pilots and supervises both plants and sits in the same alcove as the cooling plants, in the accessible area.

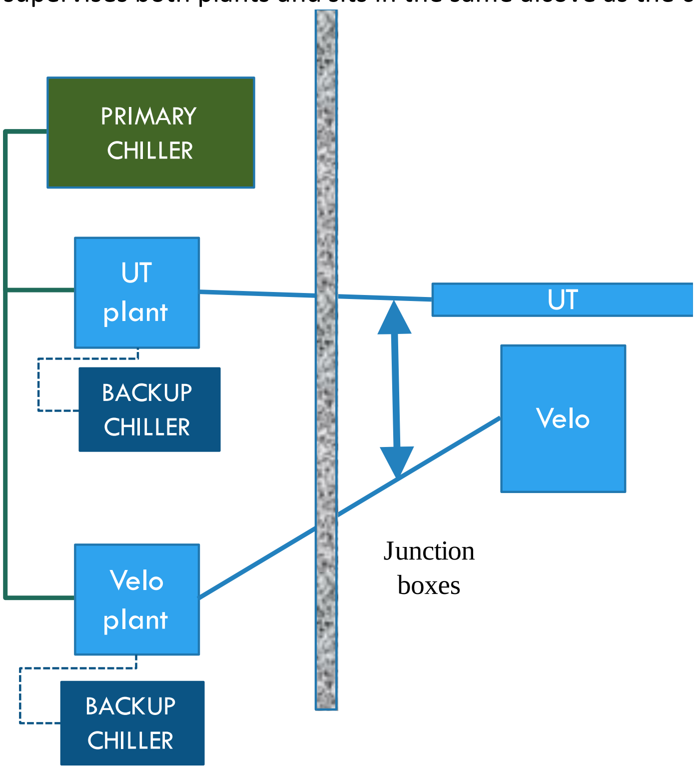

Figure 1: simplified schematic of the LHCb Velo and UT upgrade CO2 cooling system

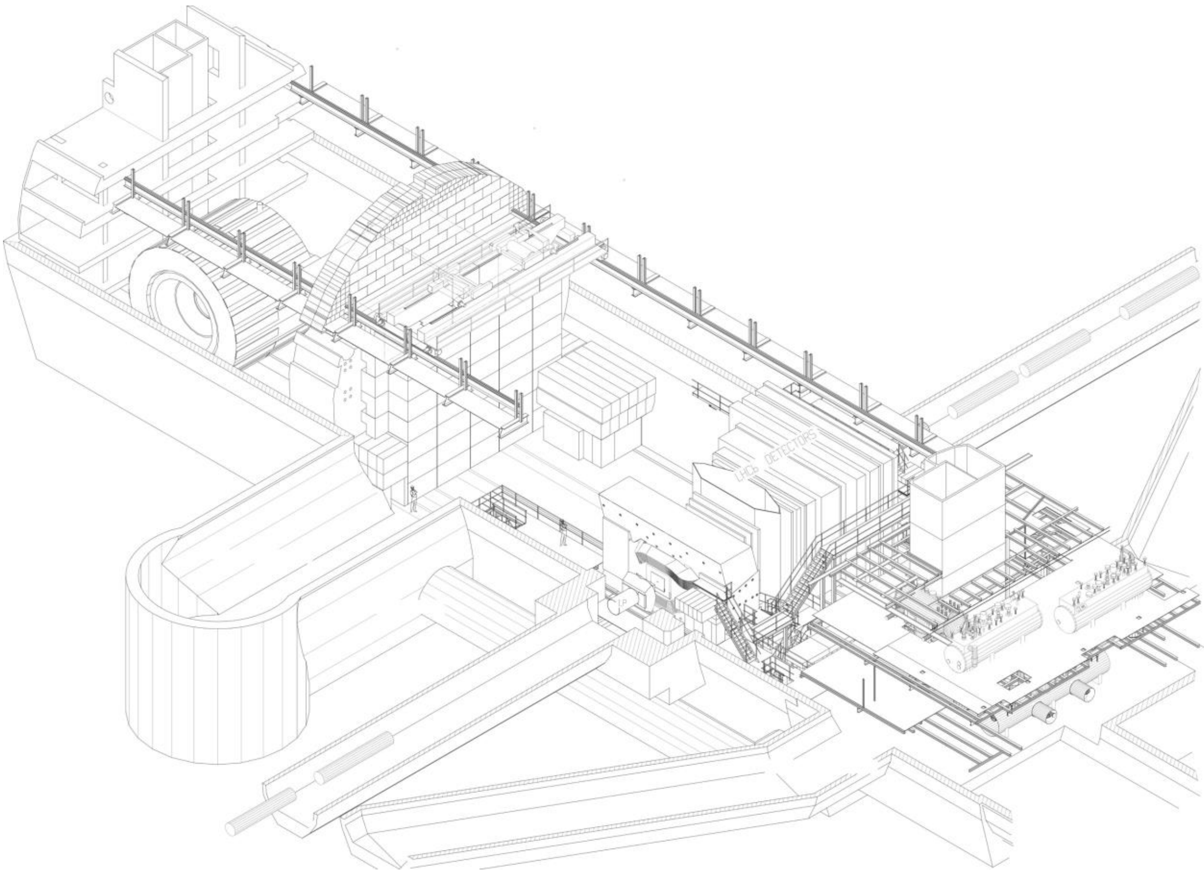

Figure 2: The LHCb caverns

2.1. Naming conventions

The systems are labeled following the so-called state-point numbering. An upward numbering is distributed along the flow path labeling with 2 digits the several locations where the fluid state can be changed with respect to the previous (pressure or enthalpy). Components labels include a maximum of 17 digits, following the scheme of Table 1

4 digits: System identifier (omitted for single system documentation)

3 digits: location (omitted for single system documentation)

2 digits - letters - components name (see **Error! Reference source not found.**)

1 digit – number, starting from 0 – subsystem (Common, CO2 plant, transfer line, junction box, accumulator, main chiller, backup chiller)

1 digit – letter – parallel loop

2 digits – state point

For detector specific parallel loops, two more digits are added

The full nomenclature is used to uniquely identify components in the control system.

Table 1: Equipment naming for CO2 cooling systems (LHC logging standard)

VERSION 3, 27 September 2017				
				LHC logic: AAAA_LOCATION_LLXXXX
First 4 digits System identifier (type, U or S, experiment, system)				
Equipment name (system level)				
Cooling system naming			DIGIT	
C	Cooling	Functionality (letter)	1	
S	Surface	Installation (letter)	1	
U	Underground			
1	ATLAS, Point 1	Experiment (number_	1	
5	CMS, Point 5			
8	LHCb, Point 8			
2	Alice, Point 2			
a	System 1 (LUCASZ A)	System (letter)	1	
b	System 2 (LUCASZ B)			
c	System 3 (LUCASZ C or common)			
d				
e				
u	UT			
v	Velo			
x	Vacuum			
y	Main chiller			
z	Backup chiller			
underscore			1	
Second 3 digit for location in CERN nomenclature				
UXC		Location	3	ALWAYS
USC				
SX-				
underscore			1	
Component digits are 5				
2 letters component				
1 digit (number) subsystem				
2 digit state point				
1 letter for detector side/type/granularity				
Ex for LHCb				
	(examples)	Component/variable letters	2	
BD	Burst disc			
BR	Back pressure regulator			
CU	Chiller unit			
CV	Control valve (any actuator)			
EH	Electrical heater			
EV	Electrical operated valve (shut-off)			
PD	Pressure drop (capillary or orifice)			
ST	Saturation temperature			
SP	Saturation pressure			
SH	Super heating			
0	Common to more subsystems	Subsystem (letter)	1	
1	CO2 plant			
2	Transfer line			
3	Junction box/Manifold			
4	Accumulator			
5	Main chiller			
6	Backup chiller			
7				
8				
9				
a to	system level parallel (sides/loops)	Distribution	1	
	A side/B side ..PUT 0 FOR NON PARALLEL			
10		State point (number)	2	
20				
99				
10		Detector specific	2	UT plane + UT stave (1 digit each)
20		(number)		Velo loop 01-29 on each side

Table 2: Labeling convention for the CO2 cooling system of the LHcb UT & Velo CO2 cooling system

Component identifier			Fluid property identifier	
AC	Accumulator		ST	Saturation temperature
AV	Adjustable restriction valve (manual)		SP	Saturation pressure
BD	Burst disc		SH	Super heating
BR	Back pressure regulator		SC	Sub cooling
CU	Chiller unit		DP	Delta pressure
CV	Control valve (any actuator)		VQ	Vapour quality
EH	Electrical heater		DT	delta temperature
EV	Electrical operated valve (shut-off)			
EX	Electrically operated expansion valve			
FL	Filter			
FR	Forward pressure regulator			
FT	Flow transmitter			
GP	Gas pump (Compressor)			
HX	Heat exchanger			
LP	Liquid pump			
LT	Level transmitter			
MV	Manual operated valve (shut-off)			
NV	No return valve			
PD	Pressure drop (capillary or orifice)			
PS	Pressure switch			
PT	Pressure transmitter			
PV	Pneumatic operated valve (shut-off)			
SV	Safety relieve valve			
TS	Thermal switch			
TT	Temperature transmitter			
TX	Thermostatic expansion valve			
VP	Vacuum pump			
WT	Weight transmitter			
YZ	Chiller command			
ZH	Position high			
ZL	Position low			
ZT	Position transmitter			
ZZ	Actuator			

2.2. Cooling plants P&I diagram

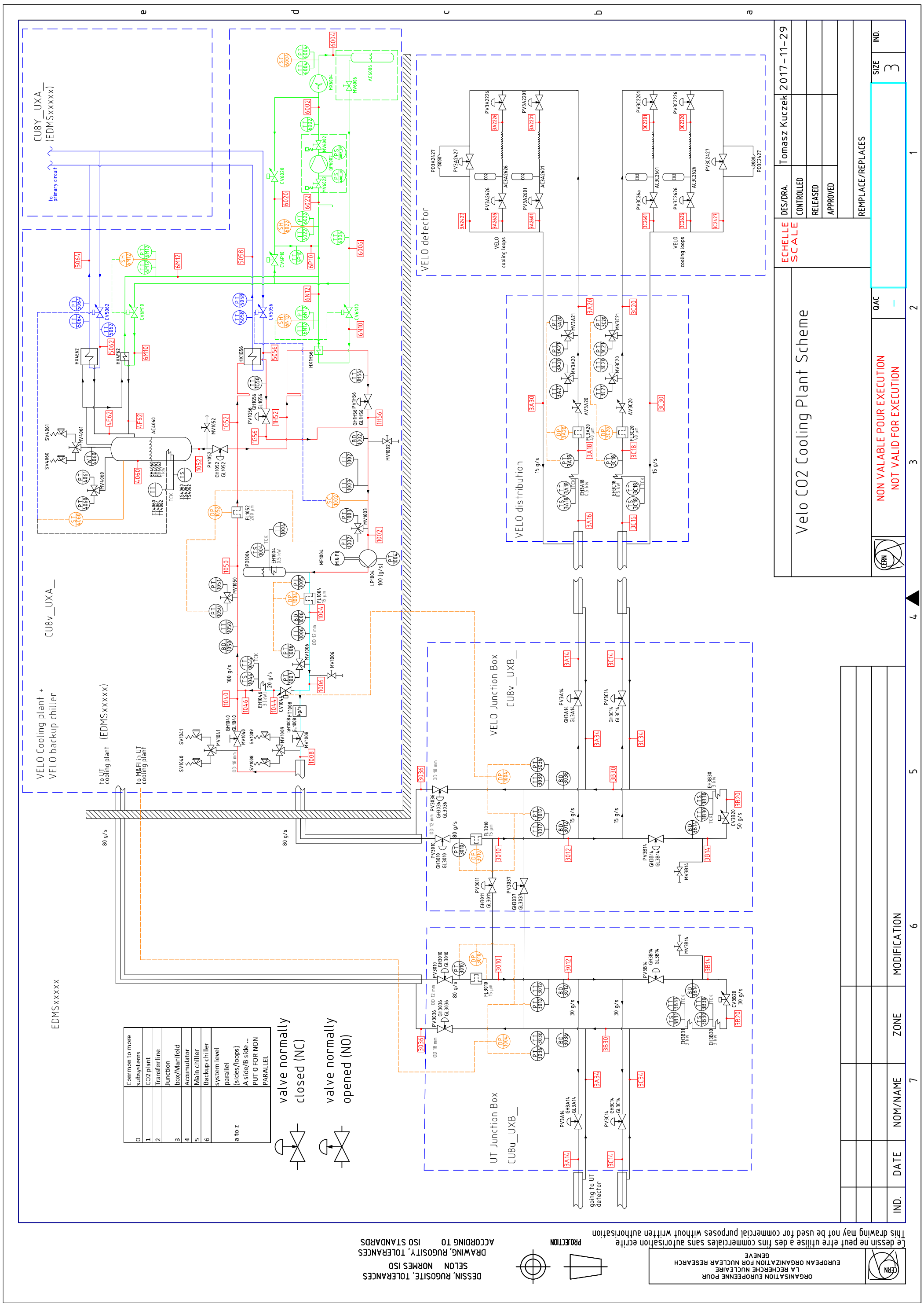

Figure 3: MAUVE P&ID

In Figure 3, the process and instrumentation diagram for one of the two systems (the Velo one) and for the full junction box is represented.

The systems each include three modules, one plant with the core components for the CO_2 cooling process, one accumulators and one backup chiller. On the experiment side of the shielding wall, a unique junction box is installed to distribute the coolant to the two detectors and eventually allow a swap to the use of one plant only for both detectors in case of failure of a plant core.

The plant cores feature the heat exchanger (HX1G56) connected to the primary chiller, where the CO_2 is condensed, the Lewa membrane pump (LP1004) to circulate the liquid CO_2, together with its damper (PD1004) and all the needed instrumentation, including a flowmeter (FT1008) on the distribution line, in order to measure the flow rate of CO_2 sent to the junction box. The damper is used to mitigate the flow pulsations created by the membrane pump and is equipped with a rod heater controlled on the heater surface temperature in order to maintain a gas volume on the top part of the vessel. A by-pass is installed between the feed and return line, with a control valve (CV1044), in order to allow local circulation of the cold fluid at the startup of the plant and to maintain a constant differential pressure across the inlet and outlet main lines at the junction box (DP1004). In this way, the flow to the detector is maintained at the desired values no matter which number of loops are powered or not. The pump speed control is used only at startup and in order to set the overall needed flow to the system in normal operation or in backup mode.

Each plant is connected to its own accumulator (AC4060), used for regulation of the evaporation temperature inside the detector and for storage of the CO_2 fluid in case of maintenance. A backup chiller on each one of the systems allows for reduced load operation and allow the detectors to be maintained cold even in case of issues and maintenance of the main chiller.

Each of the plants is connected to the other one at the level of the junction boxes, the interconnect pipes being sectioned by a pneumatic shut-off valve (PV3010 and PV3036). This allows for one plant to feed both detectors in case of failure of the other.

All valves on the system process are pneumatically driven. Manual valves are used only for maintenance purposes. All pneumatic valves on the plant cores and junction boxes are normally closed. In all parts of the system, each section where cold liquid may be trapped between two closed valves is equipped with a set of safety valves or burst disks.

2.3. Junction box Process an Instrumentation Diagram

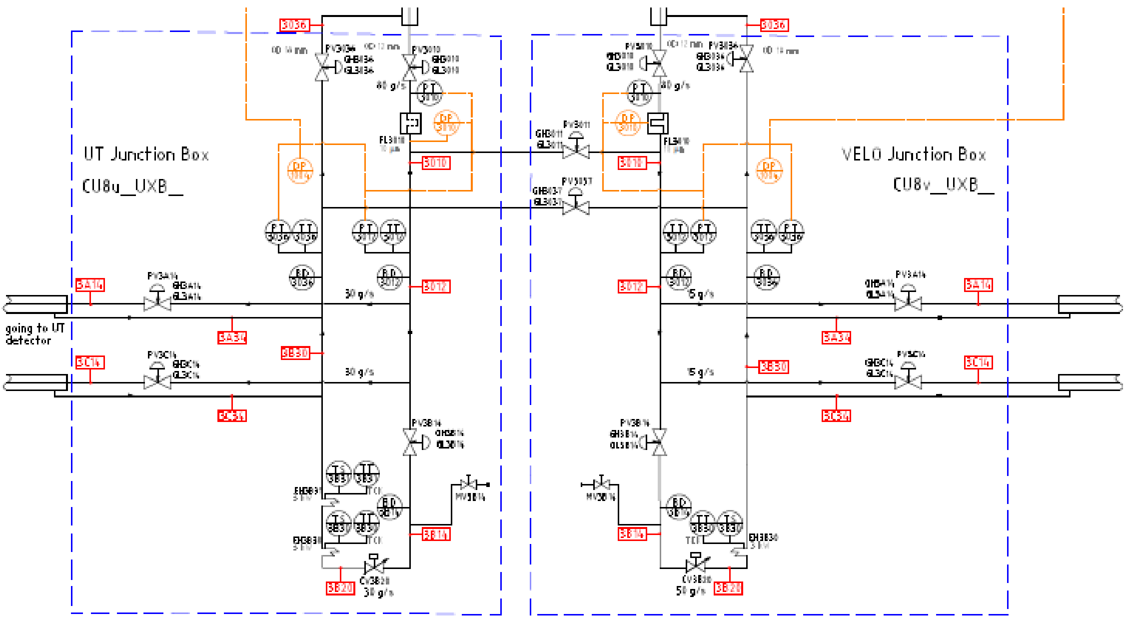

Figure 4: The Junction box P&ID

The junction box serves three functions:

- Allow commissioning, with a by-pass circulation of the coolant through the Carel valves CV3B20, which can, during this phase, be piloted to simulate the detector impedance
- Distribute the flow to the detectors when each one is cooled down by its own plant: PV3011 and PV3037 are closed, each plant feeds the detector trough the PV3A14 and PV3C14 of the relative subsystem
- Allow both detectors to be served by the same plant, with the opening of PV3011 and PV3037 while PV3010 and PV3036 of the idle plant are closed

2.4. Local distribution box

The local distribution boxes are assemblies to be installed as close as possible to the detector manifolds at each detector half (Figure 5.

At each detector entrance, a manual flow distribution valve (AV3C20 or AV3A20) allows for flow balancing (creates an additional pressure drop on the detector which has less pressure drops than the other). An enthalpy heater (EH3A18 and EH3C18) is used at this stage to ensure that the liquid CO_2 arrives in saturated conditions at the entrance of the detector.

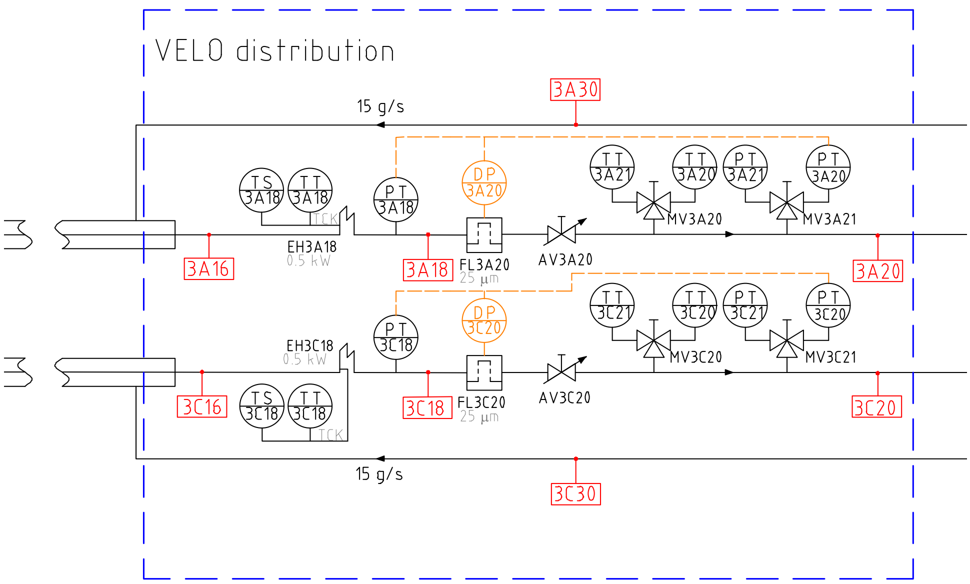

Figure 5:Tthe P&ID of the Local Distribution for the Velo (same schematic for the UT)

3. Operation modes

This chapter briefly describes the operation and control philosophy of the system. All details are described in the functional analysis.

3.1. Stop

Stop is not a mode, but an emergency safe state where all active components are not powered. The pneumatic operated valves on the junction box, transfer lines and plant are all CLOSED. All system separate volumes are protected for overpressure by safety valves or burst disks and buffer volumes (not visible on the P&ID). The reason for such a drastic measure is to ensure that, in case of a detector interlock due to vacuum issues the system protects the vacuum volume from any possible CO_2 feed.

3.2. Stand-by mode

Stand-by mode is a state in which circulation of fluid is achieved through the junction box local by-pass (PV3B14 is OPEN). The interconnection valves and the distribution valves to the detector (PV3011, PV3037, PV3A14 and PV3C14) are CLOSED. If the detector is NOT connected, plugs must be put at the Junction box exit.

3.3. Operation mode

In normal operation mode, each plant serves its own detector: interconnection valves (PV3011, PV3037) are CLOSED, detector distribution valves (PV3A14 and PV3C14) are OPEN. The evaporating temperature at the accumulator is regulated by feedback on the PT4060 and PT4061 sensors at the accumulator, acting on the heaters EH4060, EH4061 and EH4062 or the expansion valve on the refrigeration system (Primary, CV5062 or backup, CV6M10).
The non-availability of the primary chiller would automatically trigger the running of the backup chiller of that plant.

3.4. Backup mode

Backup mode is selected at the top level of the system. By selecting backup mode, it is necessary to select the plant that will be active and automatically the other one will be the passive one. This state can only be selected when both cooling plants are in Stop mode. A dedicated backup set point shall be input by the user as well and is taken as common temperature set point for both subdetectors.

Backup active

When in backup active mode, the active plant feeds both the Velo and UT detectors. In this state, the interconnection valves at the junction box PV3011 and PV3037 are OPEN and the regulation of temperature is done only on the active plant accumulator, using the controllers and the measured values of the active system.

Backup passive

In backup passive mode, the system doesn't feed its detector and no controls are active at the plant level. In this state, interconnection valves at the junction box PV3011 and PV3037 are OPEN. The transfer line shut off valves for the idle system (PV3036 and PV3010) are CLOSED.

3.5. Maintenance and commissioning

For maintenance, the system is completely stopped. Only experts can switch on components manually. The shut-off valves are all normally closed and thus safe for opening the plant also in a no power situation. In this event, also valve MV1052 shall be manually closed. A position switch on this valve will check that the valve has been reopened before moving to operation. The system can be emptied and serviced with or without power through the MV1002, MV1006 on the plants, MV3B14 on the junction box. When filling, the weight of the bottle is read by WT4060 and recorded. The service line containing the manual valves MV1002, MV1006 on the plants, MV3B14 on the junction box can be used for vacuuming, venting or flushing the system.
Commissioning will be done in all available modes to test the modes themselves and to use the implemented control and safety algorithms. In the WinCC OA UNICOS SCADA control interface all objects can be taken over manually if user is granted sufficient level of privileges. The manual takeover of objects in WinCC OA can be used to manipulate the system to create special scenarios, which are in a normal operation not possible. Common practice during commissioning is to put

components in manual mode, such that they come back automatically to their safe state when switching off the system. In case of need, the experts can also pilot objects in forced mode, i.e. they will maintain the position even after a stop of the system.

4. Regulation concepts and transition sequences

Different set points for the system are defined at the level of the accumulator AC4060 on each of the two plants.

- AC4060_Usp = User temperature set point, input by Users on PVSS
- AC4060_Bsp = Backup temperature set point (common for both accumulators), input by Users on PVSS
- AC4060_Asp = Automatic temperature set point = MAX (AC4060_Usp, TT1003+6, Detector T), limited to 27 maximum
- AC4060_Tsp = Temperature set point, which can be, depending on the regulation state, a fixed value, the Automatic set point or the User or Backup set point.
- AC4060_Psp = Pressure set point calculated from AC4060_Tsp, in order to reach saturation pressure in the accumulator: this is the value used for AC4060 regulation at any stage of the process.

4.1. Startup sequence

Once the system is in Stop and Operation or Stand-by option mode are selected, the command start/on would trigger an automatic startup procedure, bringing the evaporators in the detector to the desired temperature set-point. Once the set-point is reached the detector power can be switched on. An accumulator temperature between -35°C and +15°C can be selected from the SCADA system or local touch screen.
The startup of the system will be described in details in the functional analysis. In the following, a brief description is given.
1) “Startup”
The accumulator pressure (PT4060) is regulated by means of EH4060/62 to increase the pressure in the system for full liquid filling, achieved by liquid delivery from the accumulator.
The accumulator set point AC4060_Tsp is equal to the automatic set point AC4060_Asp, but not higher than 27°C. During this process, all valves on both plant and manifold are open but PV3036 and PV3010; the pressure is the same everywhere in the circuit. The local temperature at the detector depends on the last set point and the time spent with idle system.
When SC1002 >6 (SC1002_sp) for about 1 minute the startup step is completed.

2) “Cool down plant loop”
On the main chiller, the back pressure regulator BR5068 is set to -50 evaporating T and the CV5056 valve let Freon pass in order to condense CO2.
30 seconds afterwards, the system starts circulating liquid CO_2 with the pump (LP1004) via the internal by-pass (CV1044) cooled by the condenser HX1G56. The speed of the pump is set accordingly to the nominal detector value + a small flow to always have a by-pass circulation in the plant. The liquid feed valve PV3010 is closed, all other valves open. The accumulator set point is still AC4060_Tsp = AC4060_Asp, but not higher than 27°C. Accumulator is still kept in high pressure and only heating action is active.
When pump is ON and ST4060=ST4060_sp +/- 1°C, the cool down plant step is completed.

3) “Cool down manifold loop”

The detector inlet valves get closed (PV3A14 and PV3C14). When confirmation of closed position is received, flow is obtained to the manifold by-pass by opening PV3010 and PV3B14. When confirmation of opening of both valves, CV1044 starts regulating in pressure over DP1004, given by the difference of return and inlet pressure at the junction box and stand-by mode is achieved.
If Operation Option mode selected instead of Stand-by, the system continues with following steps.

4) "Cool down detector loop"
The detector distribution valves PV3A14 and PV3C14 are open and PV3B14 (junction box by-pass) is closed. Accumulator is still on automatic set point.
When the total flow measured at the plant is equal to the nominal +/- 5 g/s the step is completed.

5) "Cool down accumulator"
The accumulator starts to regulate with both cooling and heating actions to achieve USPT.
When PT4060 reaches the value PT4060sp +/-0.02 bar for at least 2 minutes, the enthalpy heaters at the detector inlet start regulating and a signal is sent to the detector for "ready to operate".

Once step 5 of the startup procedure is achieved and the set point reached, the system is in operation mode.

4.2. Backup sequence

The backup sequence is, for the active plant, identical to the operation sequence, with the difference that also the other detector inlet valves are piloted, the transfer lines valves of the idle plant are closed and the interconnection valves PV3011 and PV3037 are opened at the beginning of the sequence.

4.3. Flow regulation

The flow regulation is achieved by means of a control valve, placed at the plant (CV1044), which maintains a constant pressure difference between junction box inlet and outlet lines, independently of the number of detector circuits that are open. In case of too high pressure (all detector loops closed or clogged on the detector side), the opening of PV3B14 is triggered before sending the plant in safe state.
The pump frequency driver is used to set the total pump flow to one of the two given set points: Normal Operation (detector nominal flow+ by-pass, different for each subdetector) or Backup Operation (Velo+ UT flow + by-pass).

4.4. Inputs to the system

The only variable adjustable by the user in the system through the SCADA interface is the temperature set point. The total flow can be adjusted during the commissioning phase in collaboration with the cooling team.
Each detector shall send to the cooling system its own temperature reading, in order to set the startup temperature on the CO2 cooling system.

5. Safety approach

Several safety critical items are present in the system. In the following paragraph the safety approach to the several hazards is explained.

5.1. Pressure safety

The pressure in the system can be increased by several factors. When a fluid of a certain quantity is contained in a closed off volume, the pressure of the fluid increases as a function of the fluid temperature caused by environmental or active heating. The 2nd method to increase the pressure in the system is achieved by the pump. The discharge pressure of the pump is a function of the provided mass flow and the hydraulic resistance of the circuit.

Closed volumes

Each section that can be isolated from the rest of the circuit creates the hazard of trapping fluid, which can cause undesired high pressures. To avoid local pressurization each closed off section is protected with a 130 bar safety valve or burst disk. Safety valves are in redundant configuration, such that even in case of maintenance of one valve the system remains protected. Safety valves need to be recalibrated periodically.

The accumulator being a large volume it is designed to store the entire fluid content. A 110 bar pressure will be obtained at 35°C warm temperatures when all fluid is inside. The accumulator is therefore rated to 110 bar and protected by a dual safety valve. All other components in the system will are rated to 130 bar. The pressure test factor is defined by the European Pressure Directive (PED) and is 1.43 times. All components used in system must be tested before operation: at least 157 bar for the accumulator and 186 bar for the rest of the system (detector included).

In order to avoid possible trapped liquid to trigger the safety valves during normal operation, the different parts of the circuit are equipped with buffer volumes: the accumulator acts as buffer for the plant and transfer lines, separate volumes need to be installed for the path junction box/detector.

Pump discharge

The discharge pressure of the pump will be limited to 90 bar. No pressures higher than 90 bar will occur in the system due to the pump discharge. The 90 bar is limited by the pump design (internal overflow) and by the control system (pump full stop interlock when PT1005 >70 bar).

5.2. Heater safety

Heaters in a cooling system pose a severe safety risk. The heaters used are often high-density power heaters whose temperature depends strongly on the provided coolant flow. When the cooling flow is not present or not sufficient, very high temperatures could be achieved due to dry-out of the heater surface. To eliminate the risk of heater overheating a 3 level redundancy approach is used in the cooling safety system.

Level 1: Software - HT threshold on thermocouple, would cut that heater power only via PLC

Level 2: Software - HHT threshold on thermocouple, would cut all system heaters (both Velo and UT) via PLC

Level 3: Hardware - Thermal switch, would cut all system heaters (both Velo and UT). The Third level is a hardware protection using normally closed thermal switches. The chain of thermal switches of all heaters is connected in series. An opening of the chain by one heater over temperature will cut the main power to all the heaters similar to level 2.