



Experience in Design and Implementation of CO₂ Cooling Control Systems

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PH/DT/PO - Cooling



- Introduction
- CO₂ cooling systems control principle
- Control system standardization approach
- CO₂ cooling test stands at CERN
 - ✓ 2kW CORA – ATLAS and CMS (PH-DT-PO)
 - ✓ 100W TRACI – ATLAS & LHCb (PH-DT-PO)
 - ✓ 2kW CO₂ SR1 – ATLAS (EN-CV-DC & PH-DT-PO)
- What's next?



Why CO₂?

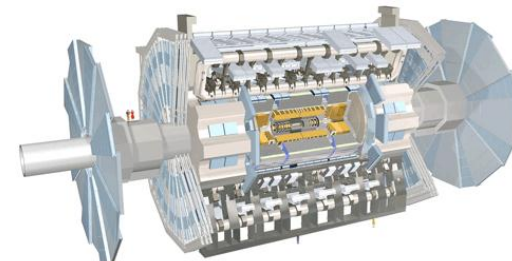
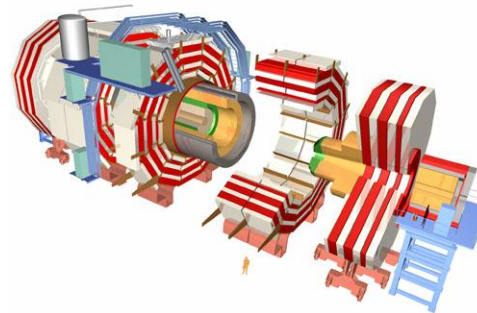
- Allows very small tubing (material budget)
- High heat transfer coefficient
- High thermal stability due to the high pressure

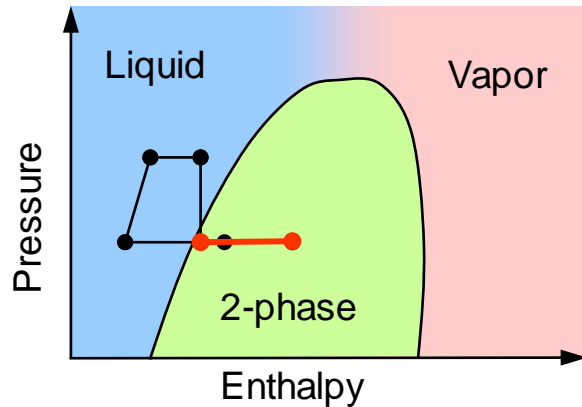
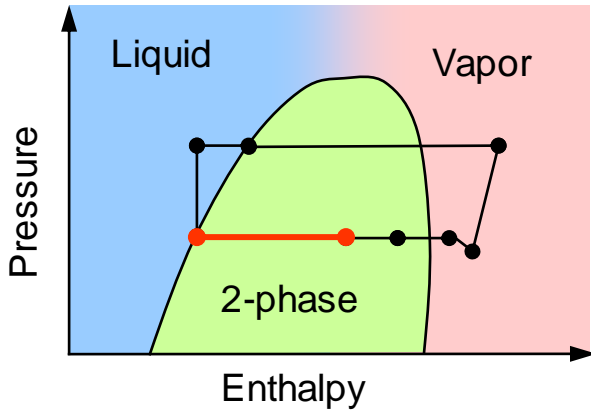
Where currently successfully used?

- AMS-TTCS (Tracker Thermal Control System)
 $Q = 150 \text{ W}$
 $T = +15 \text{ }^\circ\text{C to } -20 \text{ }^\circ\text{C}$
- LHCb-VTCS (Velo Thermal Control System)
 $Q = 1500 \text{ W}$ (2 parallel systems of 750 W)
 $T = +8 \text{ }^\circ\text{C to } -30 \text{ }^\circ\text{C}$

CO₂ cooling systems under development

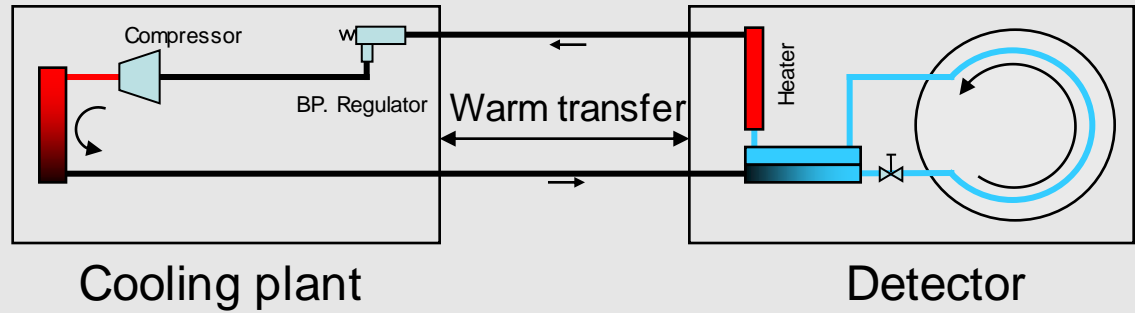
- ATLAS IBL
- CMS - tracker upgrade
- KEKb-Bell 2





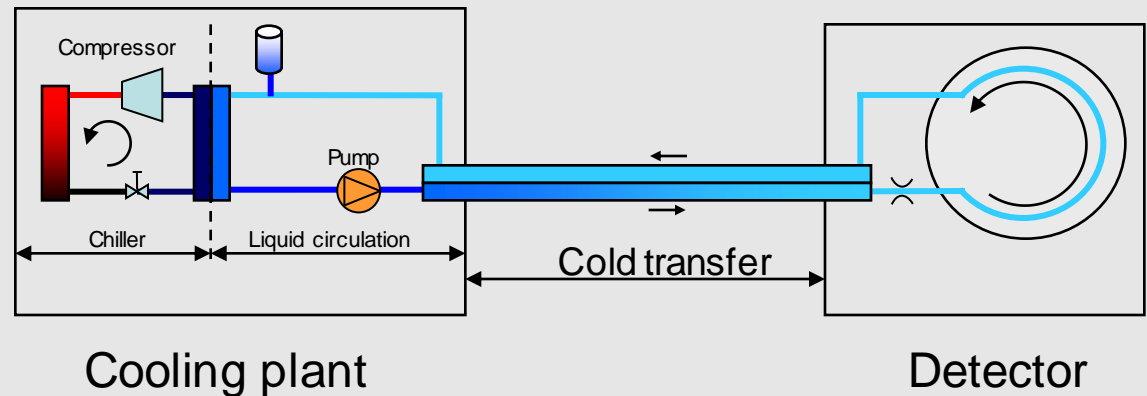
Refrigeration method: (Atlas)

Vapor compression system



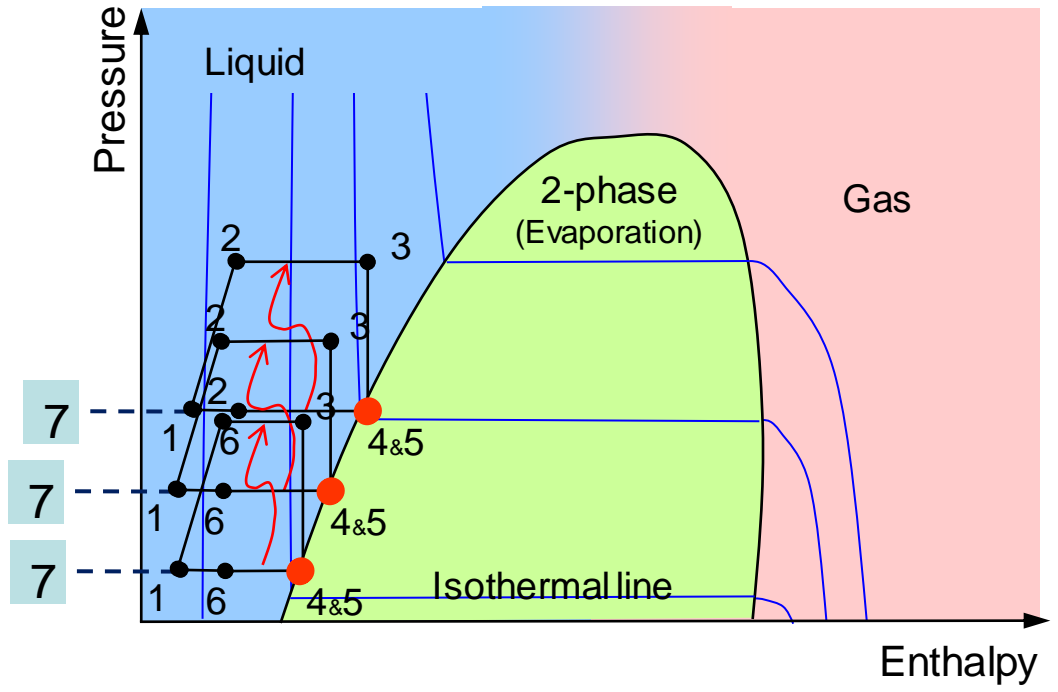
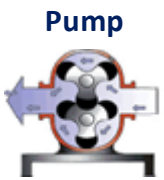
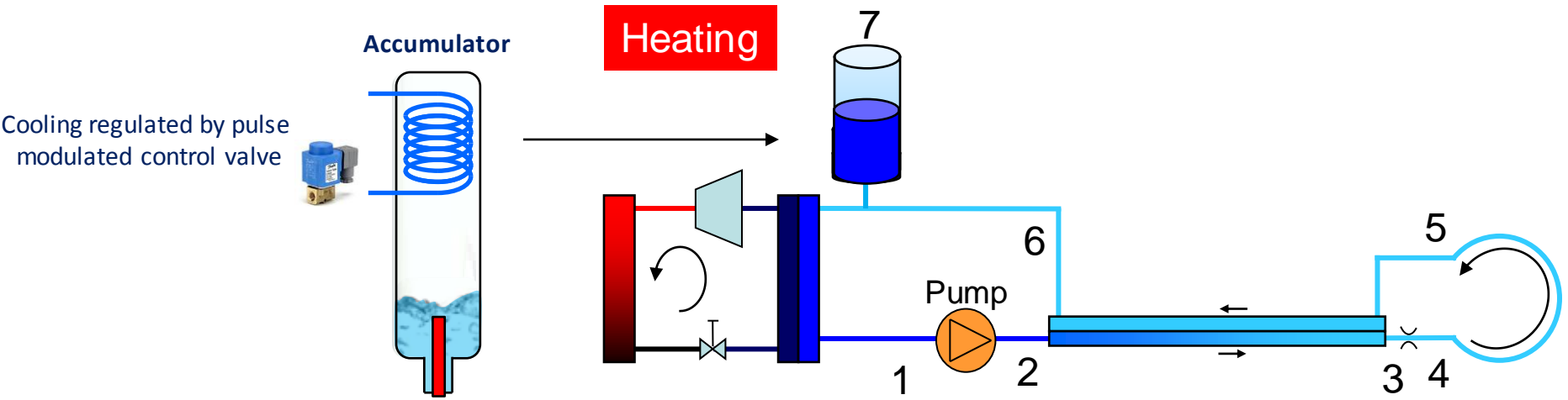
2-Phase Accumulator Controlled Loop method: (LHCb)

Pumped liquid system, cooled externally





Introduction to control CO₂ cooling system





Control system standardization approach

- Why do we need standardization?
 - To design and fully test complete base model of future detector cooling systems (mechanical/electrical/control)
 - Provide a control system in accordance with CERN standards
 - Provide a system easy to integrate with **Detector Control System**

- How do we apply it?
 - Common and easy to manipulate human machine interface for PLC based systems with long term data archiving, trending tools, alarms history and diagnostic tools. PVSS as supervision and data acquisition system well known and widely used at CERN in LHC and in Detector Control Systems (ATLAS)
 - Industrial control/electrical components: Siemens/Schneider/Phoenix/PR electronics
 - **UNified Industrial COntrol System** framework – object orientated framework for PLC and PVSS programming



Schneider PLC standard

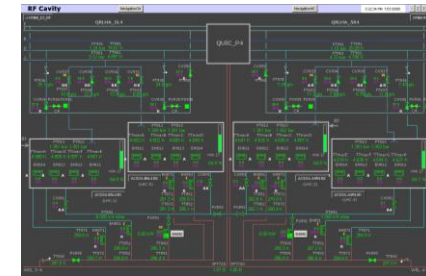
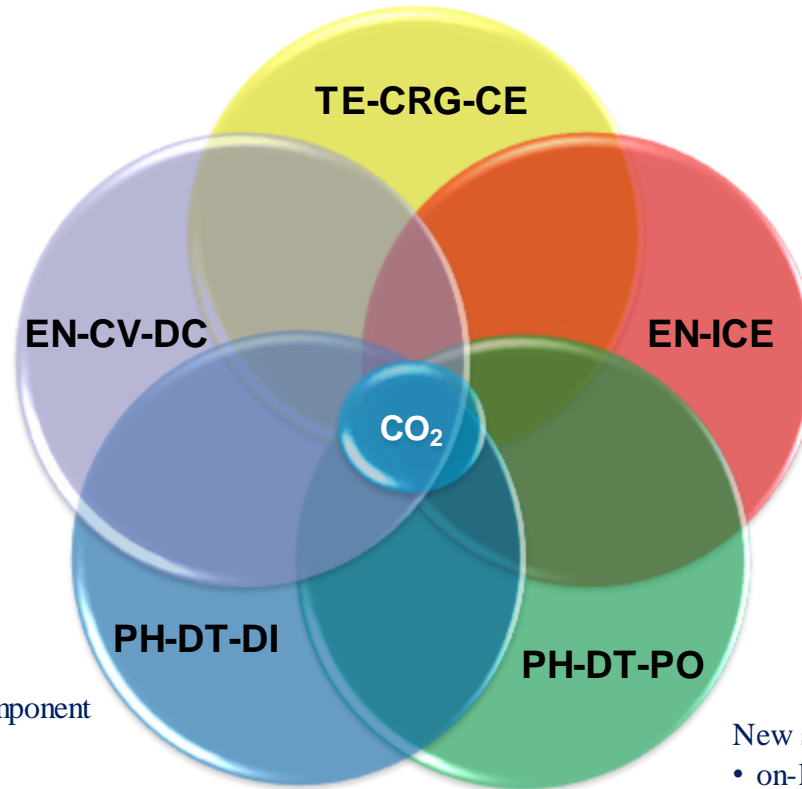
Industrial electrical components
Control hardware equipment
Electrical diagnostic tools
Siemens PLC standard



UNICOS framework
IEC61512-1 standard
PVSS

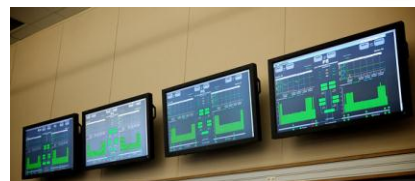


Recipes component



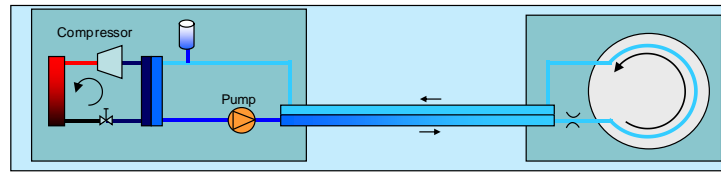
New software components:

- on-line pressure enthalpy diagram
- one button PVSS system start/stop
- Alarm diagnostic

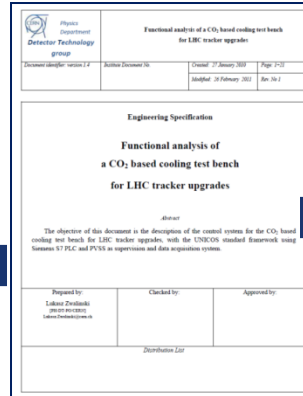


Work flow for control system design and implementation

Process concept



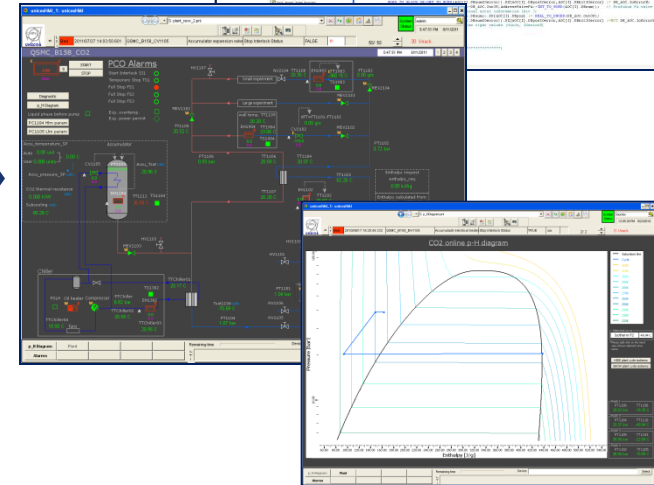
Functional analysis



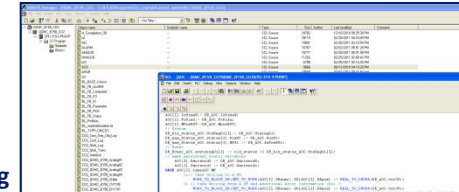
UNICOS



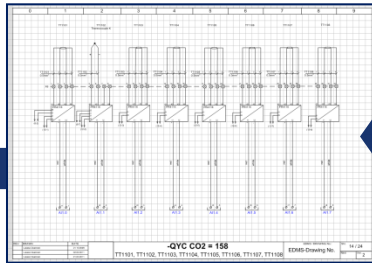
SCADA programming



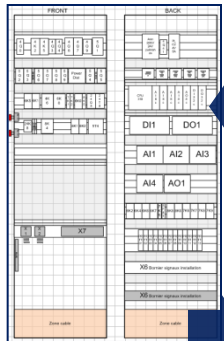
PLC programming



Electrical design



Electrical assembly

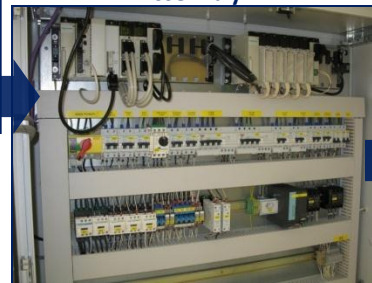


CO2 test stand electrical and control equipment

Order No.	Material	Qty	Unit Price	Total Price	Order No.	Material	Qty	Unit Price	Total Price
1	Control cabinet 400x600x1200 mm	1	15000	15000	1	Control cabinet 400x600x1200 mm	1	15000	15000
2	Control cabinet 400x600x1200 mm	1	15000	15000	2	Control cabinet 400x600x1200 mm	1	15000	15000
3	Control cabinet 400x600x1200 mm	1	15000	15000	3	Control cabinet 400x600x1200 mm	1	15000	15000
4	Control cabinet 400x600x1200 mm	1	15000	15000	4	Control cabinet 400x600x1200 mm	1	15000	15000
5	Control cabinet 400x600x1200 mm	1	15000	15000	5	Control cabinet 400x600x1200 mm	1	15000	15000
6	Control cabinet 400x600x1200 mm	1	15000	15000	6	Control cabinet 400x600x1200 mm	1	15000	15000
7	Control cabinet 400x600x1200 mm	1	15000	15000	7	Control cabinet 400x600x1200 mm	1	15000	15000
8	Control cabinet 400x600x1200 mm	1	15000	15000	8	Control cabinet 400x600x1200 mm	1	15000	15000
9	Control cabinet 400x600x1200 mm	1	15000	15000	9	Control cabinet 400x600x1200 mm	1	15000	15000
10	Control cabinet 400x600x1200 mm	1	15000	15000	10	Control cabinet 400x600x1200 mm	1	15000	15000

Component selection and ordering

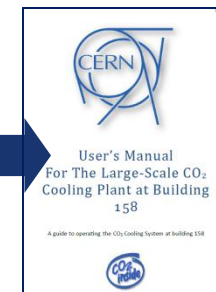
Assembly



Commissioning



User manual

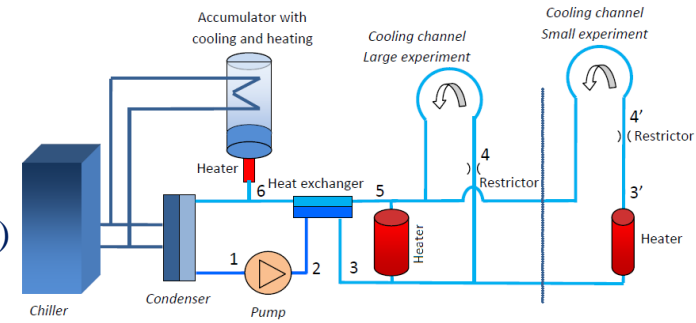


Project organization



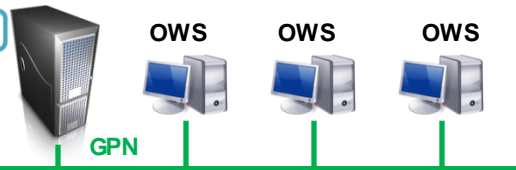
CO₂ Research Apparatus - CORA

- Siemens S7 319 PLC (building 158)
- PVSS 3.8 data server on Windows PC (building 21)
- UNICOS framework (32AI, 4AO, 32DI, 32DO, 7 closed control loops)
- Experiment power redistribution box with temperature protection



PVSS

B21



SIEMENS PLC

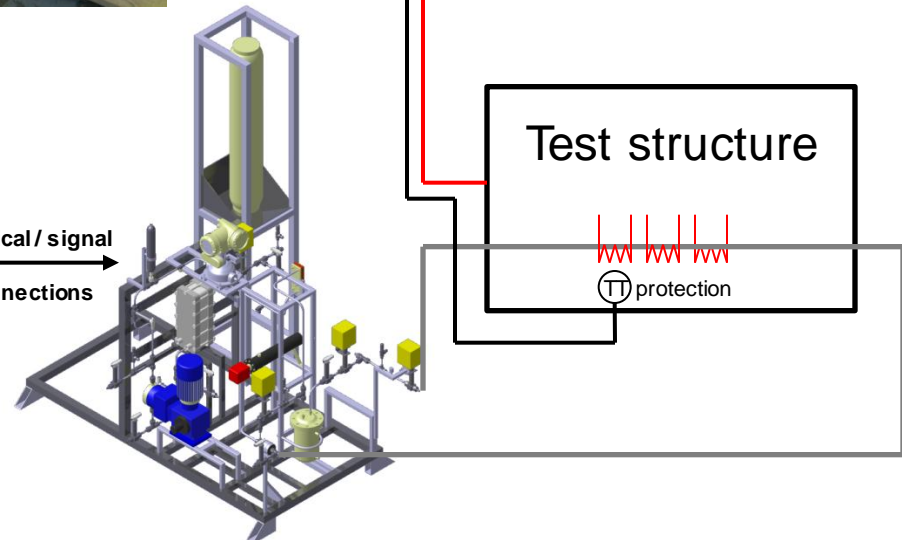


B158



Power permit

Electrical / signal connections





CORA 2kW – control system

unicosHMI_1: unicosHMI

S: plant_new_2.prl

System Status | 9:27:13 AM 10/4/2011

Bad 2011/09/21 14:08:02.867 | QSMC_B158_CB_EH1302_OK | Circuit Bracker Chiller Elect | Position Status | FALSE | 59/ 59 | 27 Unack.

QSMC_B158_CO2

9:27:13 AM 10/4/2011

PCO Alarms

START STOP

Start Interlock SI1

Temporary Stop TS1

Full Stop FS1

Full Stop FS2

Full Stop FS3

Exp. overtemp.

Exp. power permit

Diagnostic

Liquid phase before pump

PC1104 Hlm param

PC1105 Llm param

Accumulator

Chiller

Small experiment

Large experiment

Enthalpy request enthalpy_req: 0.00 kJ/kg

Enthalpy calculated from TT1104 and PT1102 enthalpy calc.: 0.00 kJ/kg

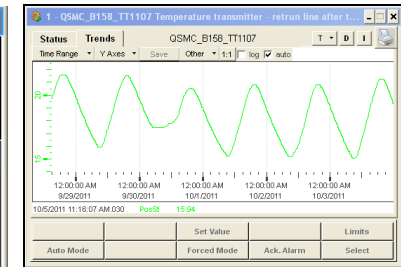
Enthalpy calculation ON if TT1104-2C < Tsat1102 enthalpy calc. ON

p_H Diagram	Plant	Device
Alarms		

Remaining time

2011.10.04 09:26:45.784 INFO QSMC_B158_CB_Pump_OK acknowledgement successful.

2011.10.04 09:26:52.097 INFO QSMC_B158_FT1101_Dens acknowledgement successful.



1 - QSMC_B158_CV2102 By-pass control valve

Status: 100.0%

Operation Modes: Auto, Manual, Forced, Local

Requests: Auto, Manual, Active

Warnings: Alarm Blocked, I/O Error, I/O Simulated, Manual to Auto, Position Warning

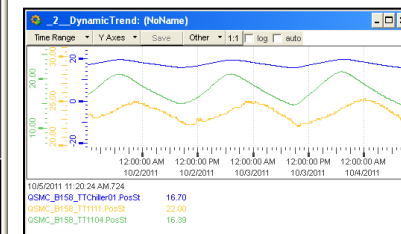
1 - QSMC_B158_FT1101_Dens Flow meter - density

Status: 100.0%

Operation Modes: Auto, Manual, Forced

Requests: Process, Active

Warnings: I/O Error, I/O Simulated, Forced to Process





Alarm diagnostic

unicosHMI_1: unicosHMI

S Alarms_popup_new.plt

monitor 11:31:10 AM 10/4/2011

Bad 2011/09/21 14:08:02.667 QSMC_B158_CB_EH1302_OK Circuit Bracker Chiller Elect Position Status FALSE 59/59 27 Unack

External Experiment

Start Interlock S11 No Option Mode selected
 Temporary Stop TS1 NOT 24VDC_OK
 Full Stop FS1 NOT Process STOP Button OK AND NOT Process STOP OK
 Full Stop FS2 any PT > 95.0 bar OR any PT in IOError
 Full Stop FS3 NOT Pump Thermal Switch

* EH_GL_ST - any T/PT100 on EH is > then threshold set on FR
 Interlock becomes active if above condition is fulfilled or if at least one of the condition's element IOError becomes active.

Interlock	Cause	Reset	Interlock	Cause	Reset
Pump_ST1	Pump of bath temperature TT1101 16.36 C < 10.00 C		Pump oil EH EH1101_ST1	NOT (CB_EH_OK AND CB_EH1104_OK)	
Pump_ST2	Pressure between membranes FT1101 1.01 bar > 0.00 bar		EH1101_ST2	Pump oil EH temperature TT1101 16.36 C > 40.00 C	
Pump_ST3	NOT Liquid phase before pump (TRUE if TT1110 < Tset1104 + 2.0)		EH1101_ST3	NOT TS1101 OR NOT EH_GL_ST	
Pump_ST4	NOT CB_Pump_OK		Dumper EH EH1102_ST1	NOT (CB_EH_OK AND CB_EH1104_OK)	
Pump_ST5	Pressure after pump FT1105 0.97 bar > 95.0 bar		EH1102_ST2	Dumper temperature TT1102 22.36 C > 120.00 C	
Pump_ST6	If pump On for t = 1min and FT1101 0.97 g/s < 0.25 g/s		EH1102_ST3	NOT TS1102 OR NOT EH_GL_ST	
Chiller_ST1	TT1110 15.89 C < -40.00 C		EH1102_ST4	FT1101 0.97 g/s < 0.25 g/s	
	TT1110 15.89 C > -40.00 C + 1.0		Accumu. EH EH1104_ST1	NOT (CB_EH_OK AND CB_EH1104_OK)	
Chiller_ST2	PSLH		EH1104_ST2	Accumulator heater TT1111 22.91 C > 120.00 C	
Chiller_ST3	NOT (CB_Chiller_OK AND CB_Chiller_fans_OK)		EH1104_ST3	NOT TS1104 OR NOT EH_GL_ST	
CV1105_ST1	Accumulator pressure PT1103 83.30 bar < 6.0 bar		EH1104_ST4	Accumulator pressure PT1103 83.30 bar > 68.0 bar	
Samill. Ex. EH			Ch.Comp./Oil EH1301_ST1	NOT CB_EH1301_OK	
EH1903_ST1	NOT (CB_EH_OK AND CB_EH1104_OK)		EH1301_ST2	NOT Chiller_DO ON	
EH1903_ST2	Small Ex. heater temperature TT1903 23.96 C > 80.00 C		Ch.Dum. EH EH1302_ST1	NOT CB_EH1302_OK	
EH1903_ST3	NOT TS1903 OR NOT EH_GL_ST		EH1302_ST2	Chiller dum. load EH temperature TTChiller03 16.44 C > 100.00 C	
EH1903_ST4	FT1101 0.97 g/s < 0.25 g/s		EH1302_ST3	NOT TS1302 OR NOT EH_GL_ST	
Large Ex. EH					
EH1904_ST1	NOT (CB_EH_OK AND CB_EH1104_OK)				
EH1904_ST2	Large Ex. heater temperature TT1904 19.37 C > 80.00 C				
EH1904_ST3	NOT TS1904 OR NOT EH_GL_ST				
EH1904_ST4	FT1101 0.97 g/s < 0.25 g/s				

p_H Diagram Plant Remaining time Device Select

Alarms

Alarm list

1 - PROCESS Alarm List

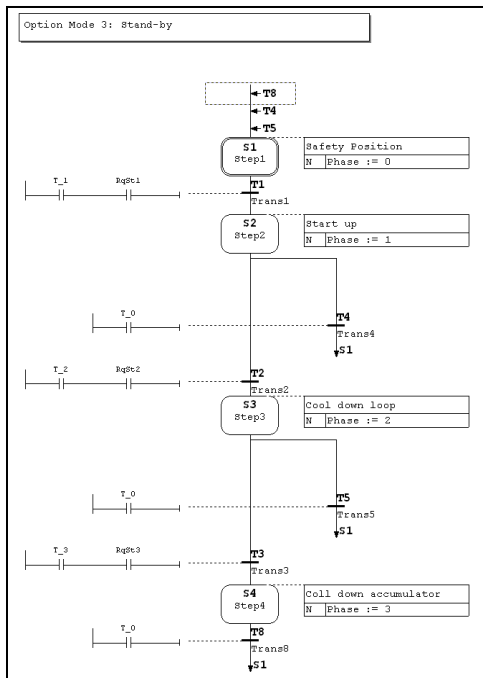
[OVC_CO2_158] Lines displayed 100 59 ALARMS 27 UNACK, ALARMS Ack. Visible

Filter Application Device type Alias Description Alert text Time zone LOCAL TIME Disable Time Query optimization

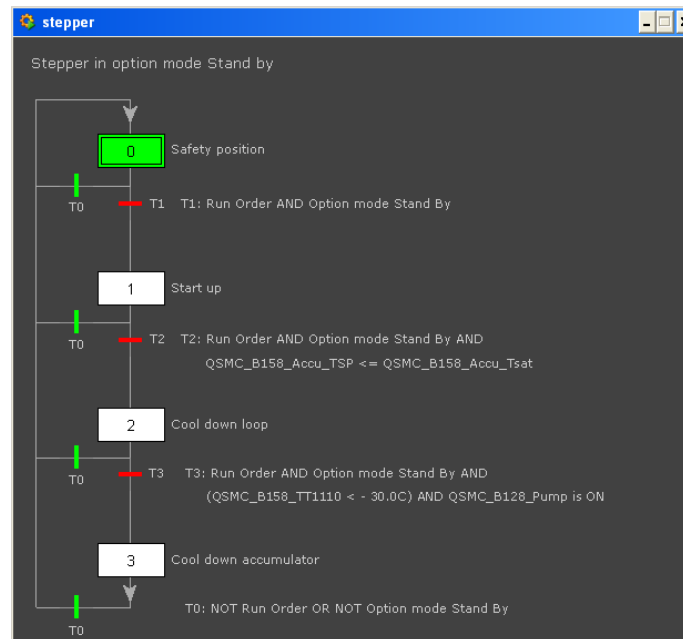
Short	Local Time	Alias	Description	Dom	N	Name	Value	Ack.	S
Bad	2011.08.23 11:40:11.740	QSMC_B158_Chiller_ST1	QSMC_B158 TT1110 < -40.0 [Td=0]			Position Status	TRUE	III	S
Bad	2011.08.23 11:40:11.900	QSMC_B158_Chiller_ST1	QSMC_B158 TT1110 < -40.0 [Td=0]			Position Status	FALSE	III	S
Bad	2011.08.23 11:46:02.951	QSMC_B158_CO2_FS2	Any PT>95.0 or any PT in IOError [Td=0]			Position Status	TRUE	III	S
Bad	2011.08.23 11:46:02.962	QSMC_B158_CO2	Main PCO for CO2			Full Stop Alarm Sta	TRUE	xxx	S
Bad	2011.08.31 15:17:15.232	QSMC_B158_EH1903_ST3	QSMC_B158 TT1903 > QSMC_B158 EH1			Position Status	TRUE	III	S
Bad	2011.08.31 15:17:15.232	QSMC_B158_CO2_FS1	NOT (QSMC_B158 PSButtonOK AND QSM			Position Status	TRUE	III	S
Bad	2011.08.31 15:17:15.233	QSMC_B158_PS_OK	Process Stop OK - DI 1.1.3			Position Status	FALSE	xxx	S
Bad	2011.09.08 19:18:05.582	QSMC_B158_EH1903_ST2	NOT QSMC_B158 TS1903 [Td=0]			Position Status	TRUE	III	S
Bad	2011.09.08 19:18:05.582	QSMC_B158_Pump_ST6	PT1105 > 95.0 [Td=0]			Position Status	TRUE	III	S
Bad	2011.09.08 19:18:05.582	QSMC_B158_EH1904_ST2	Spare alarm object for the CO2 [Td=10]			Position Status	TRUE	III	S
Bad	2011.09.08 19:18:05.582	QSMC_B158_EH1302_ST2	[Td=0]			Position Status	TRUE	III	S
Bad	2011.09.08 19:18:05.582	QSMC_B158_EH1104_ST2	QSMC_B158 TT1111 > QSMC_B158 EH11			Position Status	TRUE	III	S
Bad	2011.09.08 19:18:05.582	QSMC_B158_EH1102_ST2	QSMC_B158 TT1102 > QSMC_B158 EH11			Position Status	TRUE	III	S
Bad	2011.09.08 19:19:06.086	QSMC_B158_EH1903_ST4	QSMC_B158_EH1903_ST4 [Td=0]			Position Status	TRUE	III	S
Bad	2011.09.08 19:19:06.086	QSMC_B158_EH1102_ST2	QSMC_B158 TT1102 > QSMC_B158 EH11			Position Status	FALSE	III	S
Bad	2011.09.08 19:19:06.086	QSMC_B158_EH1904_ST2	Spare alarm object for the CO2 [Td=10]			Position Status	FALSE	III	S
Bad	2011.09.08 19:19:06.086	QSMC_B158_EH1104_ST2	QSMC_B158 TT1111 > QSMC_B158 EH11			Position Status	FALSE	III	S
Bad	2011.09.08 19:19:06.086	QSMC_B158_EH1904_ST4	QSMC_B158_EH1904_ST4 [Td=0]			Position Status	TRUE	III	S
Bad	2011.09.08 19:19:06.086	QSMC_B158_EH1903_ST2	NOT QSMC_B158 TS1903 [Td=0]			Position Status	FALSE	III	S
Bad	2011.09.08 19:19:06.086	QSMC_B158_EH1102_ST4	QSMC_B158_EH1102_ST4 [Td=0]			Position Status	TRUE	III	S
Bad	2011.09.08 19:19:06.086	QSMC_B158_Pump_ST6	PT1105 > 95.0 [Td=0]			Position Status	FALSE	III	S
L	2011.09.08 19:19:06.086	QSMC_B158_FT1101_Dens	Flow meter - density			Position Status	541.9	xxx	S
Bad	2011.09.21 14:02:48.430	QSMC_B158_EH1301_ST2	NOT QSMC_B158_Chiller_DO [Td=0]			Position Status	TRUE	III	S
Bad	2011.09.21 14:02:48.441	QSMC_B158_EH1301	Chiller Electrical Heater			Stop Interlock Stat	TRUE	III	S
Bad	2011.09.21 14:07:54.681	QSMC_B158_EH1104_ST1	NOT (QSMC_B158 CB_EH_OK AND QSM			Position Status	TRUE	III	S
Bad	2011.09.21 14:07:54.681	QSMC_B158_CB_EH_OK	Circuit Bracker EH1903 EH1101 EH1102 C			Position Status	FALSE	xxx	S
Bad	2011.09.21 14:07:54.681	QSMC_B158_EH1904_ST1	Spare alarm object for the CO2 [Td=10]			Position Status	TRUE	III	S
Bad	2011.09.21 14:07:54.681	QSMC_B158_EH1102_ST1	NOT (QSMC_B158 CB_EH_OK AND QSM			Position Status	TRUE	III	S
Bad	2011.09.21 14:07:54.681	QSMC_B158_EH1101_ST1	NOT (QSMC_B158 CB_EH_OK AND QSM			Position Status	TRUE	III	S
Bad	2011.09.21 14:07:54.681	QSMC_B158_EH1903_ST1	NOT (QSMC_B158 CB_EH_OK AND QSM			Position Status	TRUE	III	S
Bad	2011.09.21 14:07:56.542	QSMC_B158_CB_EH1104_C	Circuit Bracker EH1104 OK - DI 1.1.6			Position Status	FALSE	xxx	S
Bad	2011.09.21 14:07:57.631	QSMC_B158_Pump_ST6	QSMC_B158 TT1101 < 25.0 g/s [Td=0]			Position Status	TRUE	III	S
L	2011.09.21 14:07:57.927	QSMC_B158_FT1101_Dens	Flow meter - density			Position Status	-220.4	xxx	S
Bad	2011.09.21 14:07:59.360	QSMC_B158_Chiller_ST3	NOT (QSMC_B158 CB_EH_OK AND QSMC			Position Status	TDIE	III	S

+ email & SMS alarm notification

PLC graph



System stepper



Electrical diagnostic

CO2_utilities.pnl

Process Stop

Process Stop Button OK

Pump Thermal Switch OK

Process Stop Reset

24V Power supply

24V DC Power OK

Heaters

EH1101 & EH1102 & EH1903 Cuircuit Breaker OK

EH1104 Cuircuit Breaker OK

Chiller

Chiller Cuircuit Breaker OK

Chiller Fans Cuircuit Breaker OK

Chiller Heater Cuircuit Breaker OK

PUMP

Process Stop Button OK

Pump ON DO

Pump Cuircuit Bracker OK

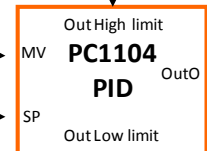
External Experiment

Experimet overtemp.

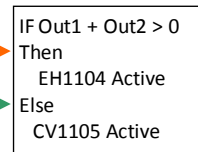
Experimet power permit

To avoid of overheating
(dry out prevention)

Dynamically calculated $f(R_{th})$
0 ÷ 100 %



0%

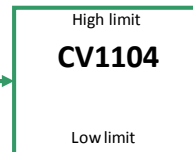


Analog Digital Object



PWM
0÷100%

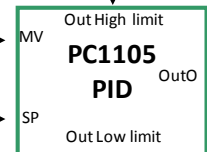
Analog Digital Object



PWM
0÷100%

Dynamically calculated $f(\text{sub-cool})$
0 ÷ -100 %

To keep sub cooling
condition



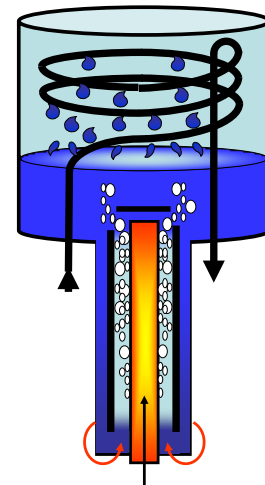
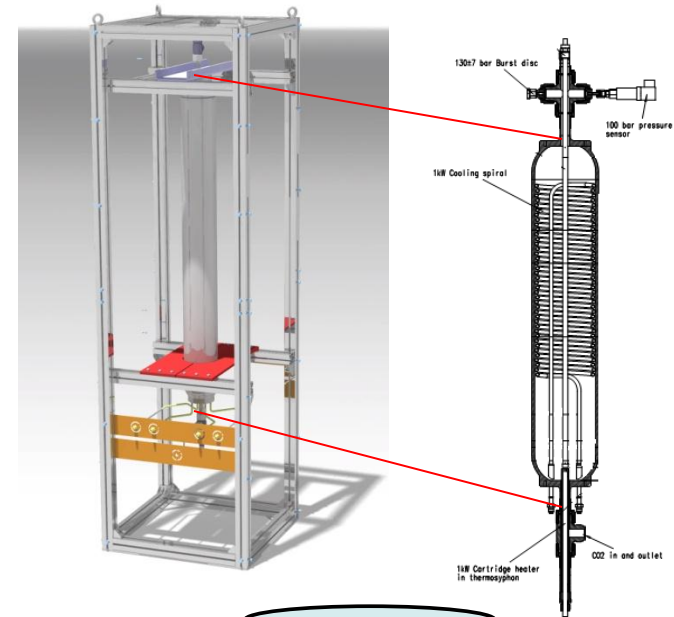
0%

```

PC1104_Hlm_param.pnl
PC1104 Hlm dynamic calculation parameters
Out_Hlm_new= OutHmin+ ((maxRth - Rth)*(outHmax-outHmin)
                    (maxRth - minRth))
minRth 50.0 mK/W    maxRth 75.0 mK/W
outHmin 25.0 %     outHmax 100.0 %
Rth= ((TT1111 - Accu_Tsat)
      Heater Power)
Rth 0.000 kW moving average of 10 last calculations
    
```

```

PC1105_Llm_param.pnl
PC1105 Llm dynamic calculation parameters
Out_Llm_new= OutLmin+ ((subcool - scL)*(outLmax-outLmin)
                    (scH - scL))
scH 5.0 K    scL 3.0 K
outLmin -10.0 %    outLmax -100.0 %
subcooling = Tset1104 - TT1110
88.75 C    -70.80 C    17.98 C
    
```



PVSS control extension:

- Real time calculation
- Connection to external data base REFPROP8
- 11 constantly plotted isotherms
- Possibility of displaying isotherms in measured points
- Proposed as future JCOP component

Point 1 - Outlet of experiment lines

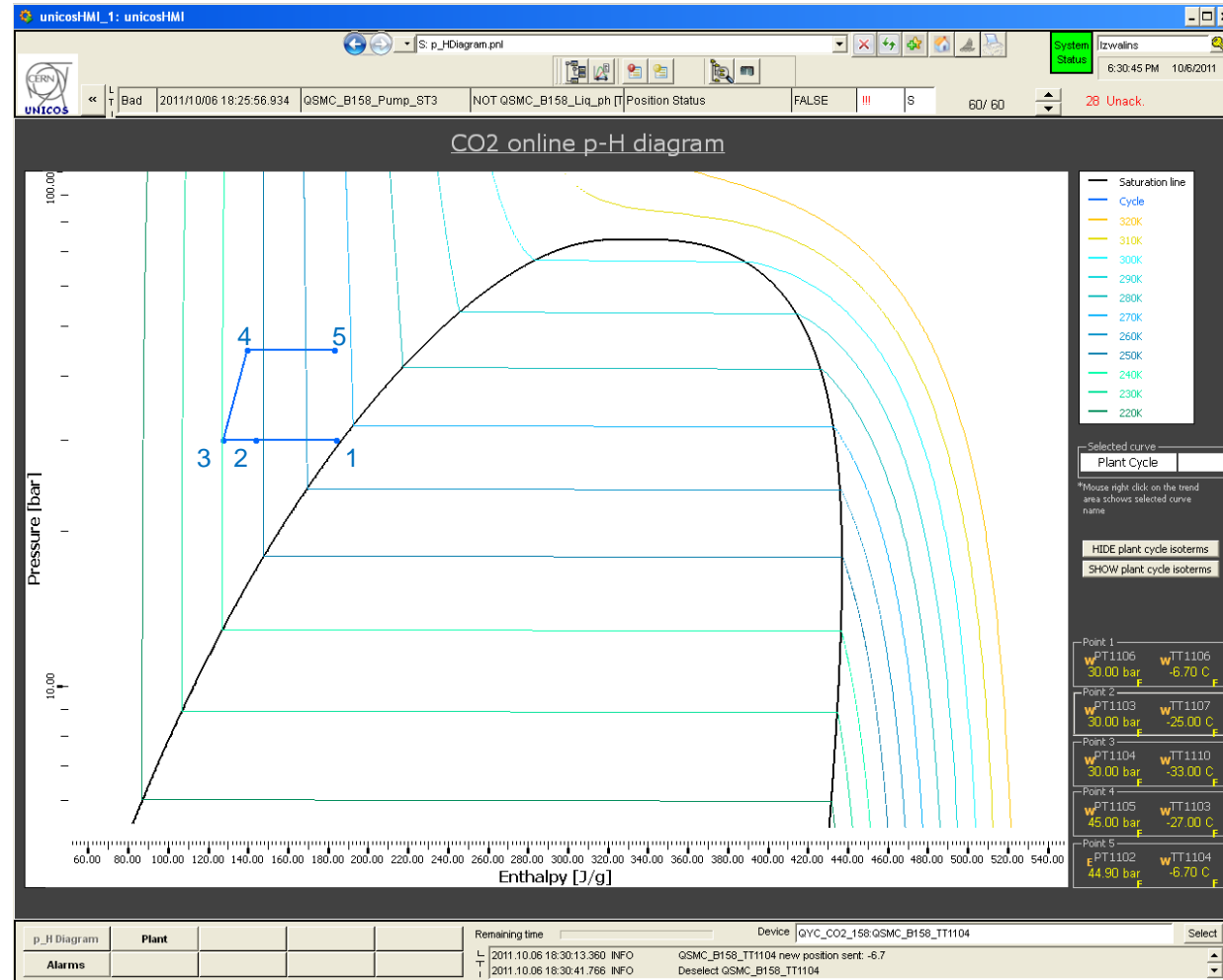
Point 2 - Outlet of return line of internal heat exchanger

Point 3 - Pump inlet

Point 4 - Pump outlet

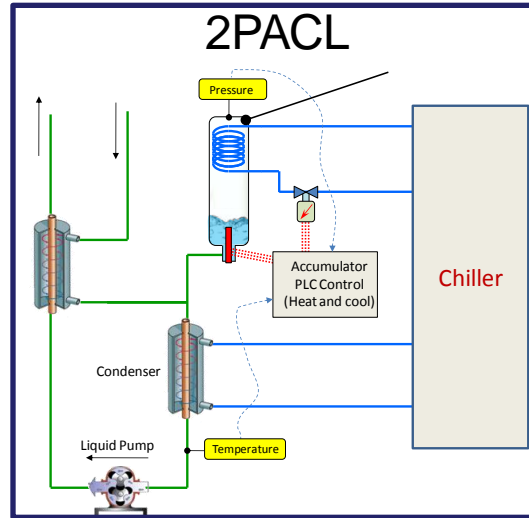
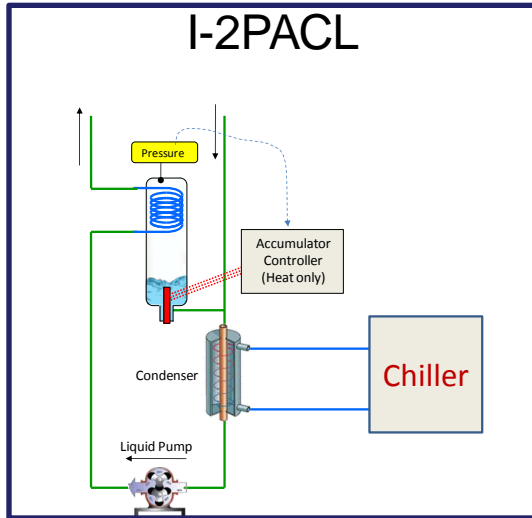
Point 5 - Outlet of supply line of internal heat exchanger

This control extension currently is available on Windows machine only!



Transportable Refrigeration Apparatus for CO₂ Investigation

Simplified concept of 2 Phase Accumulator Controlled Loop



I/O	Number
TT (PT100)	4
TT (TC type K)	3
ΔT	1
PT	3
ΔP	1
EH	3
Compressor	1
VL	1
Pump	1

To simplify the concept the internal heat exchanger function and the accumulator cooling function are integrated by cooling the accumulator with the pump outlet flow. The concept is called **Integrated 2PACL (I-2PACL)**.

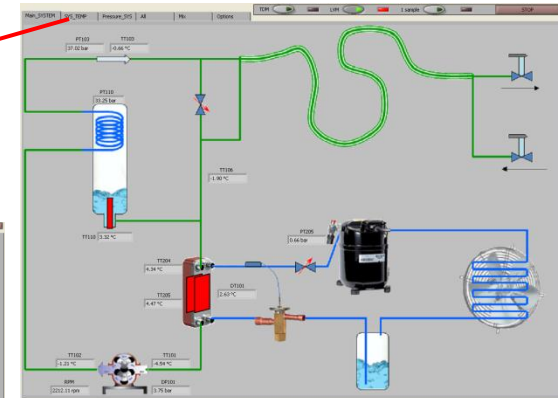
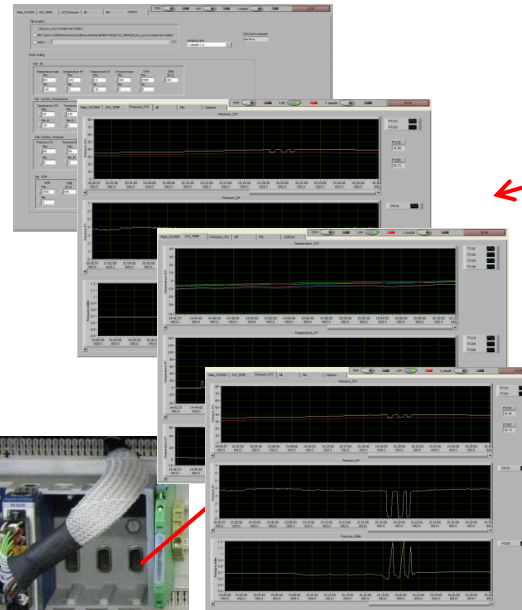
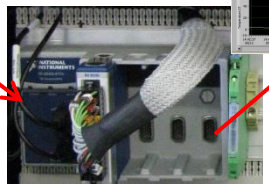
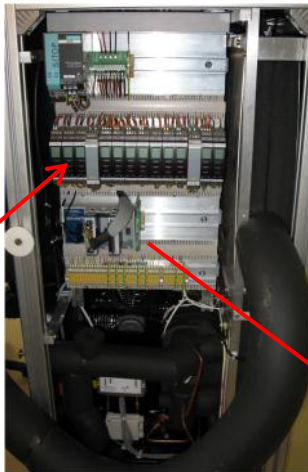
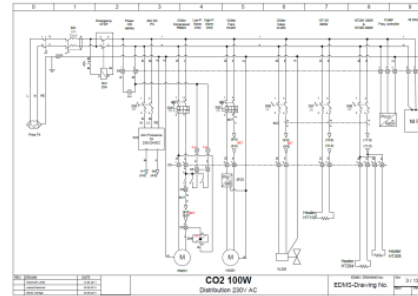
The simplified concept was patented on Friday September 9th, 2011.

Requirements:

- Simplified control concept = **NO PLC!**

Solution:

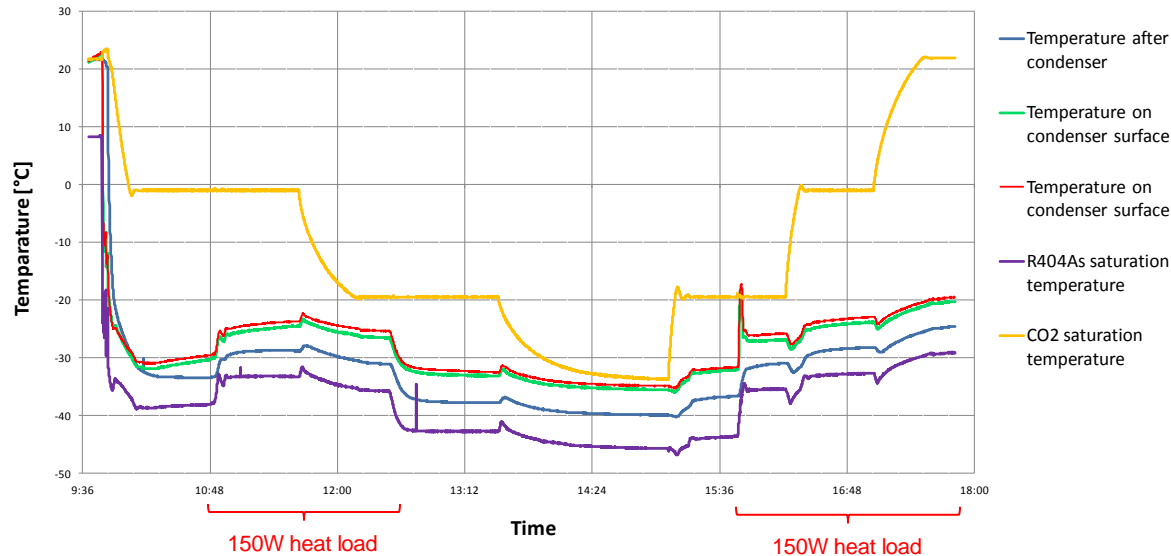
- On-shelf industrial control/electrical components
- All logic realized by relays, universal transmitters and 1 PID controller
- Integrated National Instruments DAQ
- LabVIEW user interface, open to add experimental part
- No need to have PC/PVSS to run the plant



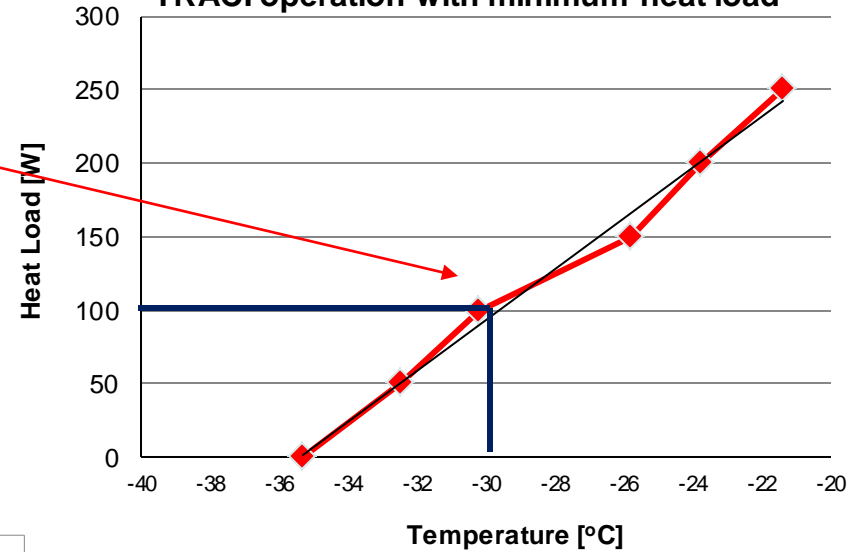
Goal: 100W @ -40°C to +20°C

- -40°C not met
 - More heatleak than expected
- 1.5x larger chiller possible in same mechanical envelope

TRACI operation test



TRACI operation with minimum heat load

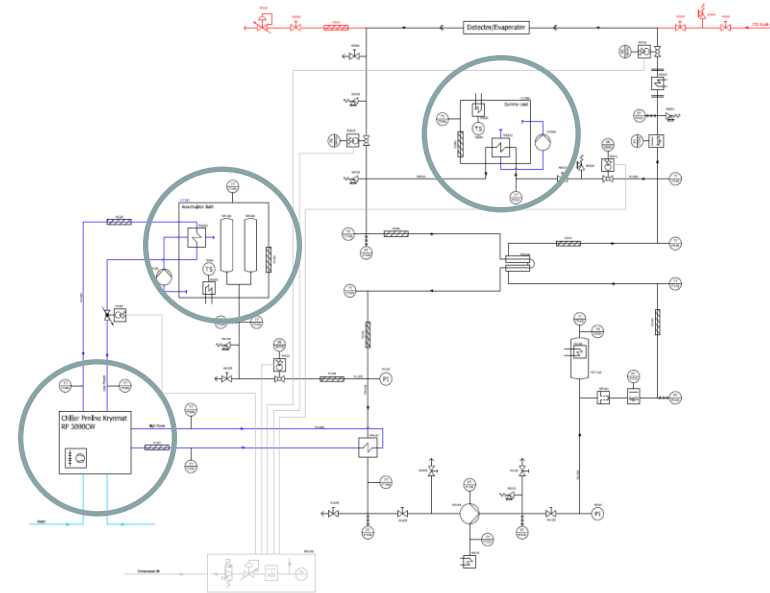


Future control improvements:

- Reduce electronics to micro-controller
- Skip some functionalities in control
- Replace pump to be fixed speed (no frequency control)
- More powerful chiller

Differences to CORA

accumulator design
dummy load design
primary chiller
PLC brand



Modifications

Schneider PLC (EN-CV-DC hw. standard)

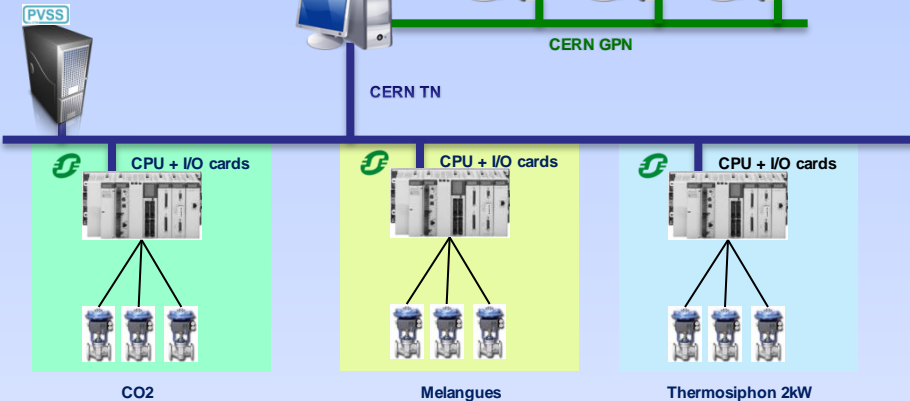


PROFIBUS flow meters



Architecture

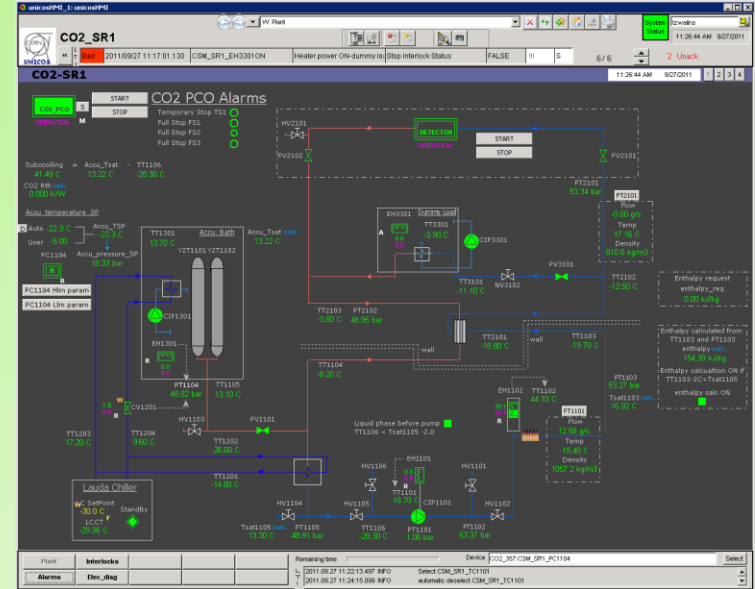
1. CO₂
2. Mélanges
3. Thermosiphon 2kW



- One central PVSS data server in BE-CO for all “test” applications
- Access to all applications form one terminal server
- PVSS accesses control with personal NICE login and password
- All applications in Technical Network

based on CORA experience

Main user SCADA panel



UNICOS based PLC software
UNICOS based PVSS implementation

Modifications

Recipes

Operation with recipes

system: CSM

module: SR1

Name: CSM_SR1_AccuRecipeInitial
 Type: CSM_SR1_AccuRecipe
 Status: [active]
 Description: empty

recipes:

CSM_SR1_Alarm_STRecipeInitial	Creator: monitor	Creation time: 19.08.2008 12:34
CSM_SR1_AccuRecipeInitial	Last modifier: monitor	Last modification time: 20.07.11 14:09
CSM_SR1_SetRecipeOperation	Last activator: lzwalns	Last activation time: 24.08.11 15:20
CSM_SR1_Alarm_ALRecipeInitial		

1	Parameter for PC1104 output high limit dynamic calculation	50	mKwV	[0,1000]
2	Parameter for PC1104 output high limit dynamic calculation	75	mKwV	[0,1000]
3	Parameter for PC1104 output high limit dynamic calculation	62.5	%	[0,100]
4	Parameter for PC1104 output high limit dynamic calculation	100	%	[0,100]
5	Parameter for PC1104 output low limit dynamic calculation	5	K	[0,500]
6	Parameter for PC1104 output low limit dynamic calculation	3	K	[0,500]
7	Parameter for PC1104 output low limit dynamic calculation	45	%	[-100,100]
8	Parameter for PC1104 output low limit dynamic calculation	0	%	[-100,100]

Buttons: Activate, Edit, Duplicate, Delete

Electrical diagnostic

CO₂ SR1

Header power CO₂ Summary | Stop Interlock Status | FALSE

Electrical diagnostic

Power supply	CB Status	Process STOP	S-set, R reset condition
24VDC power supply OK	OK	Emergency Stop Button OK	OK
230VAC	OK	Manual Operator Reset	OK
24VDC PLC power supply	OK		

Pumps	CB Status	Object
CIP1101 - Membrane pump	OK	
CIP001 - Pump in dummy load	OK	
CIP1301 - Pump in accumulator bath	OK	

Electrical heaters	CB Status	Power ON	Interlocks	Object
H10301 Dummy load electric heater	OK	W	EH0301 OP_ S11 EH0301 OP_ S12	NOT (CB_ EH0301_OK) & EH0301_Set for 5 min
H11301 Accumulator bath electric heater	OK	W	EH1101 OP_ S11 EH1101 OP_ S12	NOT (CB_ EH1101_OK) & EH1101_Set for 5 min
H11101 04 bath electric heater	OK	W	EH1101 OP_ S11 EH1101 OP_ S12	NOT (CB_ EH1101_OK) & EH1101_Set for 5 min
H11102 Damper electric heater	OK	W	EH1102 OP_ S11 EH1102 OP_ S12	NOT (CB_ EH1102_OK) & EH1102_Set for 5 min

Flow meters	CB Status	Power ON	Interlocks	Object
FT1101 - main circ. flowmeter	OK		FT1101 OP_ S11	NOT (CB_ FT1101_OK) & 11.70 m ³ /h
FT2101 - small exp. flowmeter	OK		FT2101 OP_ S11	NOT (CB_ FT2101_OK) & 0.00 m ³ /h

Plant: Interlocks | Alarm: Alarm_clear

Running time: 2011.08.27 11:22:13.487 RFD | Select CSM_SR1_1C1101 | automatic disconnect CSM_SR1_1C1101

based on CORA experience

Interlocks diagnostic

CO₂ SR1

Header power CO₂ Summary | Stop Interlock Status | FALSE

Interlocks diagnostic

Process Interlocks	CB Status	Object
Process STOP	OK	

STOP Interlocks	CB Status	Object
Process STOP	OK	

Pumps	CB Status	Object
CIP1101	OK	
CIP001	OK	
CIP1301	OK	

Valves	CB Status	Object
V1101	OK	
V1102	OK	
V1103	OK	
V1104	OK	
V1105	OK	
V1106	OK	
V1107	OK	
V1108	OK	
V1109	OK	
V1110	OK	
V1111	OK	
V1112	OK	
V1113	OK	
V1114	OK	
V1115	OK	
V1116	OK	
V1117	OK	
V1118	OK	
V1119	OK	
V1120	OK	
V1121	OK	
V1122	OK	
V1123	OK	
V1124	OK	
V1125	OK	
V1126	OK	
V1127	OK	
V1128	OK	
V1129	OK	
V1130	OK	
V1131	OK	
V1132	OK	
V1133	OK	
V1134	OK	
V1135	OK	
V1136	OK	
V1137	OK	
V1138	OK	
V1139	OK	
V1140	OK	
V1141	OK	
V1142	OK	
V1143	OK	
V1144	OK	
V1145	OK	
V1146	OK	
V1147	OK	
V1148	OK	
V1149	OK	
V1150	OK	
V1151	OK	
V1152	OK	
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V1157	OK	
V1158	OK	
V1159	OK	
V1160	OK	
V1161	OK	
V1162	OK	
V1163	OK	
V1164	OK	
V1165	OK	
V1166	OK	
V1167	OK	
V1168	OK	
V1169	OK	
V1170	OK	
V1171	OK	
V1172	OK	
V1173	OK	
V1174	OK	
V1175	OK	
V1176	OK	
V1177	OK	
V1178	OK	
V1179	OK	
V1180	OK	
V1181	OK	
V1182	OK	
V1183	OK	
V1184	OK	
V1185	OK	
V1186	OK	
V1187	OK	
V1188	OK	
V1189	OK	
V1190	OK	
V1191	OK	
V1192	OK	
V1193	OK	
V1194	OK	
V1195	OK	
V1196	OK	
V1197	OK	
V1198	OK	
V1199	OK	
V1200	OK	

Buttons: Refresh, Stop, Start, Reset, Acknowledge

Accumulator limiters

PC1104 HMI dynamic collection parameters

Out. HMI: Accumulator dynamic collection parameters

Parameter: Accumulator dynamic collection parameters

Value: 0.00 m³/h

Unit: m³/h

Scale: 1.00

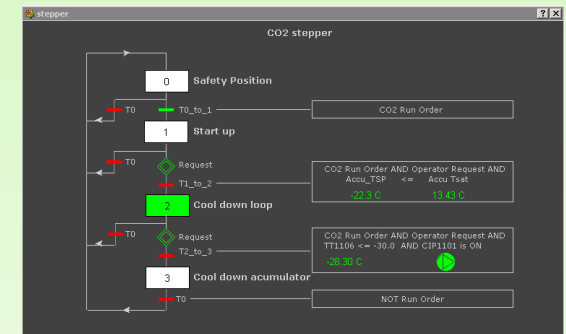
Offset: 0.00

Min: 0.00

Max: 10.00

Buttons: Refresh, Stop, Start, Reset, Acknowledge

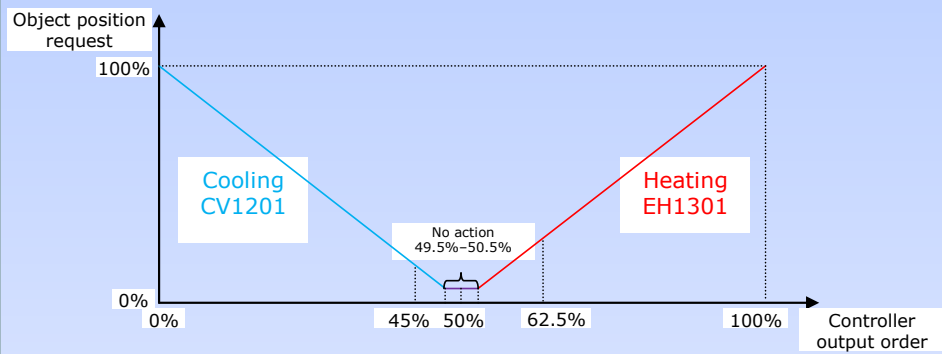
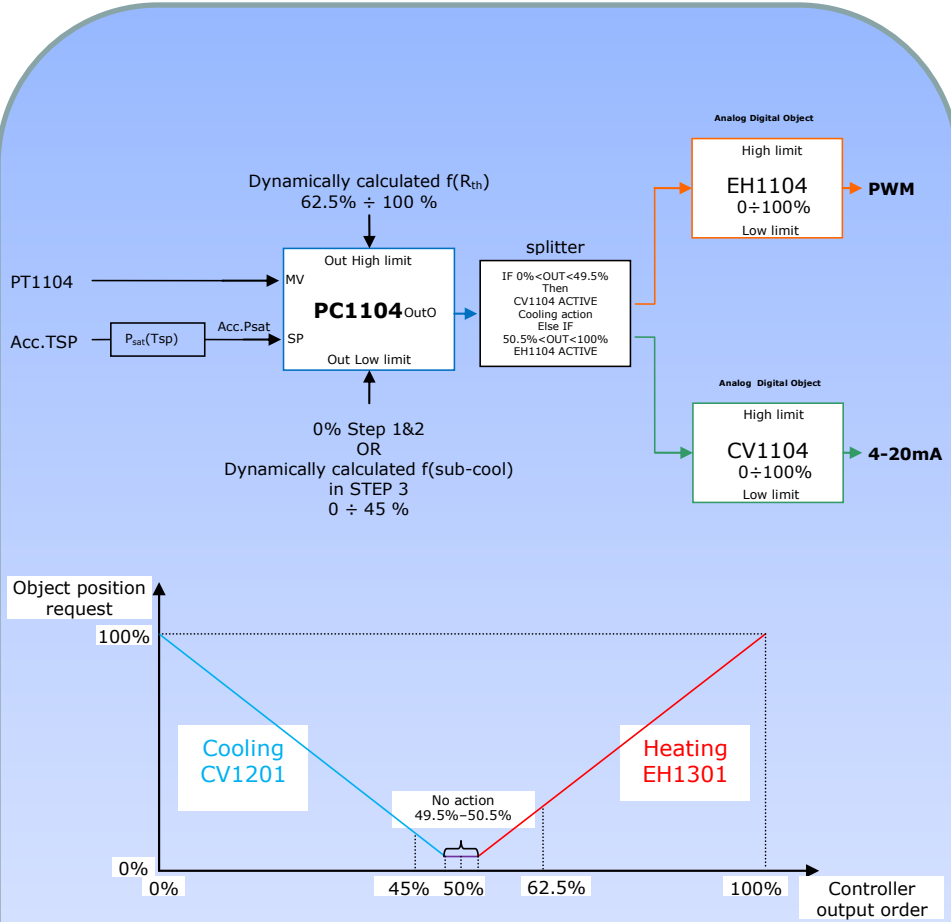
Stepper





Functional analysis and control

Modifications

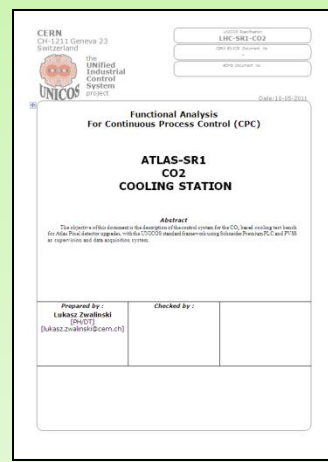


based on CORA experience

Functional analysis:

- process
- actuator operation logic
- system states and transitions
- alarms
- computed parameters
- recipes parameters

https://espace.cern.ch/CO2-SR1/Shared%20Documents/Control/CO2_SR1_Functional_Analysis.doc



Equipment	Operation			
	STOP	RUN		
	Safety position(0)	Start-up(1)	Cool down loop(2)	Cool down accumulator(3)
PV1101 Accu out	CLOSE	IF Accu_Test = Accu_TSP Then OPEN Else CLOSE	OPEN	OPEN
PV3101 By-pass	CLOSE	OFF	IF CIP1101.ONst Then OPEN Else CLOSE	IF FT1101.ONst Then OPEN Else CLOSE
CV1201 Accu	CLOSE	OFF	OFF	Reg on FT1104 AuPaR = PC1104 [Accu_Psat = f(User Accu temp SP)] PC1104 OUT HighLim-calculation OUT LowLim-calculation
EH3301 By-pass	OFF	OFF	Manual operation	Manual operation
EH1301 Accu	OFF	Reg on FT1104 AuPaR = PC1104 SP = Accu_Psat TSP = Accu_TSP IF TSP > 27 Then TSP = -20C END_IF.]	Reg on FT1104 AuPaR = PC1104 SP = Accu_Psat TSP = Accu_TSP IF TSP > 27 Then TSP = -20C END_IF.]	Reg on FT1104 AuPaR = PC1104 SP = Accu_Psat [Accu_Psat = f(User Accu temp SP)]
EH1101 Pump oil bath	OFF	Reg on TT1101 Def SP = 50C	Reg on TT1101 Def SP = 50C	Reg on TT1101 Def SP = 50C
EH1102 Damper	OFF	Reg on TT1102 Def SP = 50C	Reg on TT1102 Def SP = 50C	Reg on TT1102 Def SP = 50C
CIP1101 Lewa pump	OFF	OFF	IF TT1106 < Accu_Test (TTest calculated from PT1104) - 2°C for 30s THEN ON	IF TT1106 < Accu_Test (TTest calculated from PT1104) - 2°C for 30s THEN ON
CIP3301 By-pass	OFF	IF EH3301.PosSt <= 0 THEN ON	IF EH3301.PosSt <= 0 THEN ON	IF EH3301.PosSt <= 0 THEN ON
CIP1301 Accu pump	OFF	ON	ON	ON
EH3301ON EH power ON	OFF	ON	ON	ON
EH1301ON EH power ON	OFF	ON	ON	ON
EH1101ON EH power ON	OFF	ON	ON	ON
EH1102ON EH power ON	OFF	ON	ON	ON
FT1101ON EH power ON	ON	ON	ON	ON
FT2101ON EH power ON	ON	ON	ON	ON
LCStandBy	OFF	OFF	Chiller = ON SP = -40.0C	Chiller = ON SP = -40.0C

MARCO: Multipurpose Apparatus for Research on CO₂

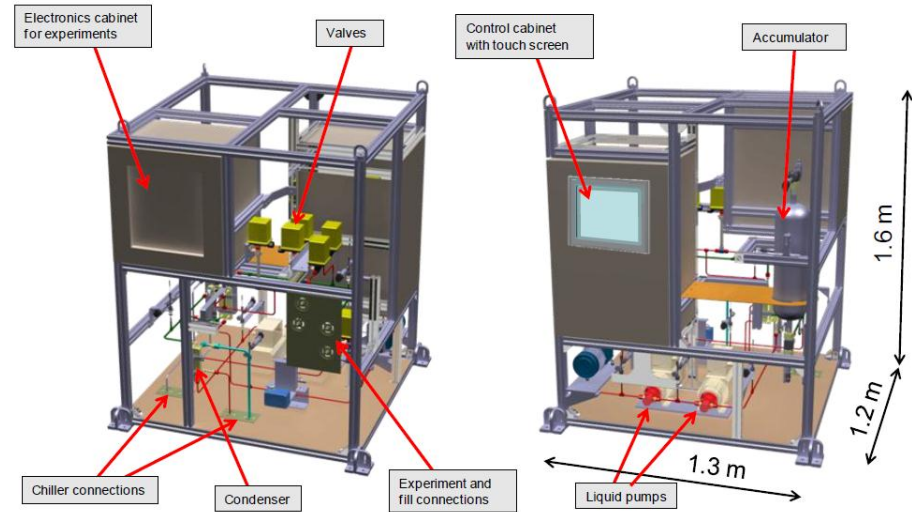
- 2PACL concept
- Temperature range from -40C to room temperature
- Capacity 1kW
- Base for future **ATLAS IBL** and **KEKb-Bell 2** detectors

Control system approach:

- Control system to be easily integrated in DCS
- Siemens PLC
- UNICOS framework
- Integrated control panel (to be introduced, currently not supported solution)
- Use recipe component
- Select tested in previous CO₂ cooling units electrical and control components

Status:

- PLC components delivered
- Electrical study in progress (electrical schematics)





Existing test CO₂ cooling stations at CERN:

- ✓ CORA **operational**
- ✓ TRACI 1a(LHCb) and TRACI 1b(ATLAS) **operational**
- ✓ CO₂ SR1 under **commissioning**
- ✓ MARCO under **construction**

CO₂ cooling systems in HEP experiments:

- ✓ AMS
- ✓ LHCb

CO₂ allows small tubing

Why?

Large latent heat & Low viscosity & High pressure

Allow low flow

Low pressure drop

Allow high pressure drop

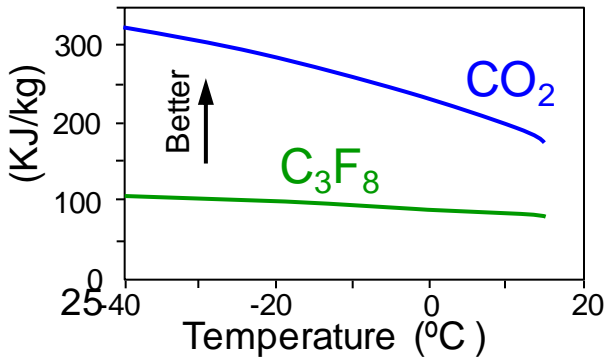
Low pressure drop

Lower pressure drop

Allow very small tubing

But with very high heat transfer capability!

Latent Heat of Evaporation



Liquid Viscosity

