Control system for the vertical cryostat

GERSEMI

of the FREIA laboratory

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30th October 2019

**Introduction**

GERSEMI, future vertical cryostat of the FREIA laboratory, needs an operational monitoring system able to allow both an individual command of each actuator and the use of preset sequences.

This non-exhaustive document gives a first description of different operating modes before describing the various sequences required for the monitoring of the vertical cryostat in order to test superconducting cavities and magnets. Each sequence will be presented through some cryogenic schemes to identify the fluids flows, the actuators and the sensors involved in the process. A logic diagram describes with more details the course of the sequence. The cryogenic schemes and their nomenclature are given in appendix.

1. **Different running modes**

*Manual mode*: The user has access to the command of each actuator. He can force the state of each actuator in its operating range. He has access to the variables and the instructions used to control the actuators.

In manual mode, at least two windows are available. The first is the general view of the cryogenic process, the second gives access to the state of the sensor or actuator selected.

*Sequence mode:* The user has access to the whole of the preset sequences which allow the conditioning and the running of the cryo-system. When a sequence is started, this one requires that several parameters are defined by the user before the automatic execution of the sequence.

On this mode, at least two windows are available. The first shows the general view of the cryogenic process and the list of the preset sequences. When a sequence is selected, another window opens. The user defines the parameters, and the progress of the sequence is indicated in the sequence window.

*Switch valves to recovery helium circuit*: For each line (L017, L018, L020), the user can select the recovery circuit to connect these lines to the gas bag or the Kaeser circuits. The Switch Valves sequences start when the control system of GERSEMI starts and operates in continuous mode until the end of the GERSEMI operations.

1. **Preset sequences**

The course of each sequence is explained by a logic diagram, showing each step of the sequence.

Some sequences appear several times because the cryostat can be used in three ways:

- as a vacuum vessel with a liquid helium tank to test superconducting cavities (Vacuum mode),

- as a cryostat which operates with saturated liquid helium to test cavities (Liquid mode),

- as a cryostat which operates with pressurized liquid helium to test magnets (Magnet mode).

*Logic diagram*:

The instructions that the user has to give to start the sequence are indicated.

The logic diagram describes the sequential course of the steps. It shows the sensors to watch and the actuators used in the process. For each step, the logic diagram defines the state of the actuators and the logical conditions required to take the next step.

Every valve is considered as normally closed except for those with the specification "N.O." (Normally Open).

For technical reasons, the large helium level probes are composed of two probes, but in the description of the control system, it will be considered only the value linked to the concatenation of the two probes (LI660, LI670, LI680).

When a sequence is stopped, all ON/OFF valves used during the sequence are closed, but the control valves continues to operate and keep the last setpoint defined during the sequence.

**The valves in red in the text are used for the operations of the HNOSS and GERSEMI cryostats.**

1. **Liquid insert in operation**

When the liquid insert is in operation, the valve box and the cryostat are filled with liquid helium that means the valve box and the cryostat helium circuits must be purged of the air they contain: used the valve box and the cryostat conditioning sequences (sequences 1 and 2). To reduce the conductive thermal losses through the cryostat neck, it is possible to thermalize at 20K the cryostat neck with the supercritical helium circuit. The supercritical helium circuit must be conditioning with helium gas (sequence 3).

The operations of the valve box are very similar whatever the insert chosen, these sequences are: cooling of the thermal shield (sequence 5), when the thermal shield is cooled, the cooling of the helium circuits can start (sequence 9). The measures of the helium level probes start when the cooling is started (sequence 8). At the end of the helium circuits cooling, the helium level of the 4K tank is regulated or controlled (intermittent transfer to maintain the helium level between a minimum and a maximum setpoint level).

Concerning the cryostat, the cooling of its thermal shield (sequence 6) can start at the same time of the valve box thermal shield cooling. When the cryostat thermal shield is cold, the cooling of the helium circuit can start (sequence 10). The cooling is finished when the cryostat helium level setpoint is reached; this helium level is regulated or controlled.

To operate with the cryostat at atmospheric pressure (T ≈ 4.2 K) or at higher pressure (T > 4.2 K), the sequence 10 must be stopped and the sequence “Cavity in operation at 4K” (sequence 12) started.

To operate with the cryostat at low pressure (T < 4.2 K), the sequence “Cavity in operation at 2K” (sequence 13) must be started and the sequences 10 and 12 stopped.

The sequence “Cavity - Standby at 40K” (sequence 14) allows maintaining the cavities at a temperature below 70 K to avoid that the cavities from suffering the 100K effect. The sequences 10, 12 and 13 must be stopped when the standby is started.

The supercritical helium circuit is used to reduce the conductive thermal losses of the cryostat neck. The sequence 11 “Supercritical helium in operation” must be started when the liquid helium level of the cryostat is higher than 75% of the LI670. At this value the liquid helium level is higher than the lambda plate seat and the thermal losses are huge at 2K (40 W).

A the end of an experiment, the volume of liquid helium stored in the cryostat is very large, it is possible to transfer the liquid helium to an external Dewar before the cryostat warm-up starting. The liquid helium retro-transfer is made with the sequence “Emptying of the cryostat” (sequence 20). This sequence stops when the cryostat is empty or when the Dewar is full. The sequences 10, 12, 13 and 14 must be stopped.

The warm-up of the cryostat (sequence 22) checks the liquid helium level, if this level is higher than 5% of liquid helium level LI670, the warm-up power of the cryostat is limited. The goal of the power limitation is to reduce the helium mass flow rate which goes to the helium recovery system during the warm-up. As soon as, the level LI670 is lower than 5% the maximum power can be used to warm-up the cryostat. The sequences from 10 to 14 and 20 must be stopped.

The insert warm-up (sequence 23) can be started in the same time of the cryostat warm-up, but the insert warm-up can be started without the cryostat warm-up, in particularly, if it is necessary to change quickly the cavity insert by another cavity insert. In this case is preferable to avoid the warm-up of the cold vessel and this of the cryostat thermal shield. The sequences from 10 to 14 and 20 must be stopped.

The sequence “Valve Box warm up” (sequence 21) warms up the thermal screen and the helium circuit. When this sequence is started that involves the sequences from 5 to 20 are stopped and the warm-up of the cryostat is started.

When the warm-up of the cryostat and the valve box are finished (sequences 21, 22, 23), it is possible to leave the helium circuits of the cryostat and the valve box connected to the helium recovery system or to isolate the cryostat of the helium recovery system. The sequence 24 isolates the cryostat, the sequence 25 isolates the valve box. All sequences from 5 to 20 must be stopped.

1. **Magnet insert in operation**

When the magnet insert is in operation, the valve box and the cryostat are filled with liquid helium that means the valve box and the cryostat helium circuits must be purged of the air they contain: used the valve box and the cryostat conditioning sequences (sequences 1 and 2). To reduce the conductive thermal losses through the cryostat neck, it is possible to thermalize at 20K the cryostat neck with the supercritical helium circuit. The supercritical helium circuit must be conditioning with helium gas (sequence 3).

The operations of the valve box are very similar whatever the insert chosen, these sequences are: cooling of the thermal shield (sequence 5), when the thermal shield is cooled, the cooling of the helium circuits can start (sequence 9). The measures of the helium level probes start when the cooling is started (sequence 8). At the end of the helium circuits cooling, the helium level of the 4K tank is regulated or controlled (intermittent transfer to maintain the helium level between a minimum and a maximum setpoint level). The valve box operates with the liquid helium provided by the liquefier Dewar, but the valve box can be connected at an ancillary Dewar when the liquid helium level of the liquefier Dewar is too low. This choice is made in the sequence 9.

Concerning the cryostat, the cooling of its thermal shield (sequence 6) can start at the same time of the valve box thermal shield cooling. When the cryostat thermal shield is cold, the cooling of the helium circuit can start (sequence 15). During this sequence, the cool down of the magnet is controlled by the mass flow FT583 and the cryogenic valve CV601. The cooling is finished when the cryostat helium level setpoint reached the lambda seat. To complete the helium level, the filling of the cryostat is carry out by the valve CV602 on the top of the cryostat neck. The valve CV602 regulates the liquid helium level above the lambda plate.

To operate with the cryostat at atmospheric pressure (T ≈ 4.2 K) or at higher pressure (T > 4.2 K), the sequence 15 must be stopped and the sequence “Magnet in operation at 4.2K” (sequence 16) started.

To operate with the cryostat at low pressure (T < 4.2 K), the sequence “Magnet – cooling at 2K” (sequence 17) must be started and the sequences 15 and 16 stopped. The sequence 17 prepares the helium pumping equipments, makes the cooling of the liquid helium and regulates the liquid helium temperature (pressure regulation) inside of the heat exchanger HX683. The sequence 17 starts and stops the sequence 18 “Magnet – control of the level and pressure at 2K” which regulates the liquid helium levels (LT682 above the lambda plate, and LT683 inside of HX683).

The sequence “Magnet – Current leads cooling” (sequence 19) allows the cooling of the current leads when the magnet is in operation. For each current lead, it is possible to choose between a temperature regulation of the current lead or a helium mass flow rate regulation.

The supercritical helium circuit is used to reduce the conductive thermal losses of the cryostat neck. The sequence 11 “Supercritical helium in operation” can be started when the helium mass flow rate measured by FT583 is too high.

A the end of an experiment, the volume of liquid helium stored in the cryostat is very large, it is possible to transfer the liquid helium to an external Dewar before the cryostat warm-up starting. The liquid helium retro-transfer is made with the sequence “Emptying of the cryostat” (sequence 20). This sequence stops when the cryostat is empty or when the Dewar is full. The sequences 15, 16, 17, 18 and 19 must be stopped.

The warm-up of the cryostat (sequence 22) checks the liquid helium level, if this level is higher than 5% of liquid helium level LI680, the warm-up power of the cryostat is limited. The goal of the power limitation is to reduce the helium mass flow rate which goes to the helium recovery system during the warm-up. As soon as, the level LI680 is lower than 5% the maximum power can be used to warm-up the cryostat. The sequences from 15 to 20 must be stopped.

The insert warm-up (sequence 23) can be started in the same time of the cryostat warm-up.

The sequence “Valve Box warm up” (sequence 21) warms up the thermal screen and the helium circuit. When this sequence is started that involves the sequences from 5 to 20 are stopped and the warm-up of the cryostat is started.

When the warm-up of the cryostat and the valve box are finished (sequences 21, 22, 23), it is possible to leave the helium circuits of the cryostat and of the valve box connected to the helium recovery system or to isolate the cryostat of the helium recovery system. The sequence 24 isolates the cryostat, the sequence 25 isolates the valve box. All sequences from 5 to 20 must be stopped.

Main sequences

Sequence 1: Valve Box, conditioning He circuits,

Sequence 2: Cryostat, conditioning He circuits

Sequence 3: Supercritical helium, conditioning He circuits

Sequence 4: High Voltage electrical insulation tests

Sequence 5: Valve Box thermal shield cooling

Sequence 6: Cryostat thermal shield cooling

Sequence 7: Insert thermal shield cooling

Sequence 8: LHe level measurement

Sequence 9: Valve Box cooling and 4K tank control level

Sequence 10: Cavity cooling down

Sequence 11: Supercritical helium in operation

Sequence 12: Cavity in operation at 4K

Sequence 13: Cavity in operation at 2K

Sequence 14: Cavity - Standby at 40K

Sequence 15: Magnet - Cooling down

Sequence 16: Magnet in operation at 4.2K

Sequence 17: Magnet - Cooling at 2K

Sequence 18: Magnet - Control of the level and pressure at 2K

Sequence 19: Magnet - Current leads cooling

Sequence 20: Emptying of the cryostat

Sequence 21: Valve Box warm up

Sequence 22: Cryostat warm up

Sequence 23: Inserts warm up

Sequence 24: Cryostat isolated or connected to the He recovery circuit

Sequence 25: Valve Box isolated or connected to the He recovery circuit

Switch Valves to recovery helium circuits

Sensors, actuators and information used:

- Valve: FV580, FV581, FV583, FV584, FV585, FV586

- Control valve: CV580, CV581, CV583

- Cryostat-2K: Boolean

For each line; Valve Box Circuit, Cryostat 4K Circuit, Magnet 4K Circuit, the user chooses the recovery circuit:

* Switch: Gas bag or Kaeser

Switch valves “Valve Box circuit”

Gas Bag

L018 – Valve Box Circuit

Kaeser

Gas bag closed

Close FV586

Kaeser opened

Open FV580

Kaeser closed

Close FV580

Gas bag opened

Open FV586

Circuit Isolated

CV580 closing with slope

FV580 opened

Circuit connected

CV580 opening with slope

FV586 opened

Circuit Isolated

CV580 closing with slope

FV586 opened

Circuit connected

CV580 opening with slope

FV580 opened

CV580 closed

CV580 closed

FV586 closed

FV580 closed

FV586 opened

FV580 opened

Gas Bag

Kaeser

CV580 100% open

CV580 100% open

Wait change circuit

Waiting

Wait change circuit

Waiting

Switch Valves “Cryostat 4K Circuit”

Gas Bag & Cryostat-2K = false

L017 – Cryostat 4 K Circuit

Kaeser & Cryostat-2K = false

Gas bag closed

Close FV584

Kaeser open

Open FV581

Kaeser closed

Close FV581

Gas bag open

Open FV584

Circuit Isolated

CV581 closing with slope

FV581 opened

Circuit Isolated

CV581 closing with slope

FV584 opened

Circuit connected

CV581 opening with slope

FV581 opened

Circuit connected

CV581 opening with slope

FV584 opened

FV584 opened

FV581 opened

FV584 closed

CV581 closed

FV584 closed

CV581 closed

Kaeser & Cryostat-2K = false

Gas Bag & Cryostat-2K = false

Wait change circuit

Waiting

Wait change circuit

Waiting

CV581 100% open

CV581 100% open

Switch Valves “Magnet 4K circuit”

Gas Bag & Magnet

Kaeser & Magnet

Circuit Isolated

CV583 closing with slope

FV585 opened

Gas bag closed

Close FV585

Kaeser open

Open FV583

Circuit connected

CV583 opening with slope

FV583 opened

Circuit Isolated

CV583 closing with slope

FV583 opened

Kaeser closed

Close FV583

Gas bag open

Open FV585

Circuit connected

CV583 opening with slope

FV585 opened

CV583 closed

FV583 closed

FV585 opened

Kaeser & Magnet

CV583 closed

FV585 closed

FV583 opened

Gas Bag & Magnet

L020 – Magnet 4K Circuit

Liquid OR Vacuum

Magnet

Circuits Isolated

Close FV583

Close FV585

Liquid OR Vacuum

Liquid OR Vacuum

Wait change circuit

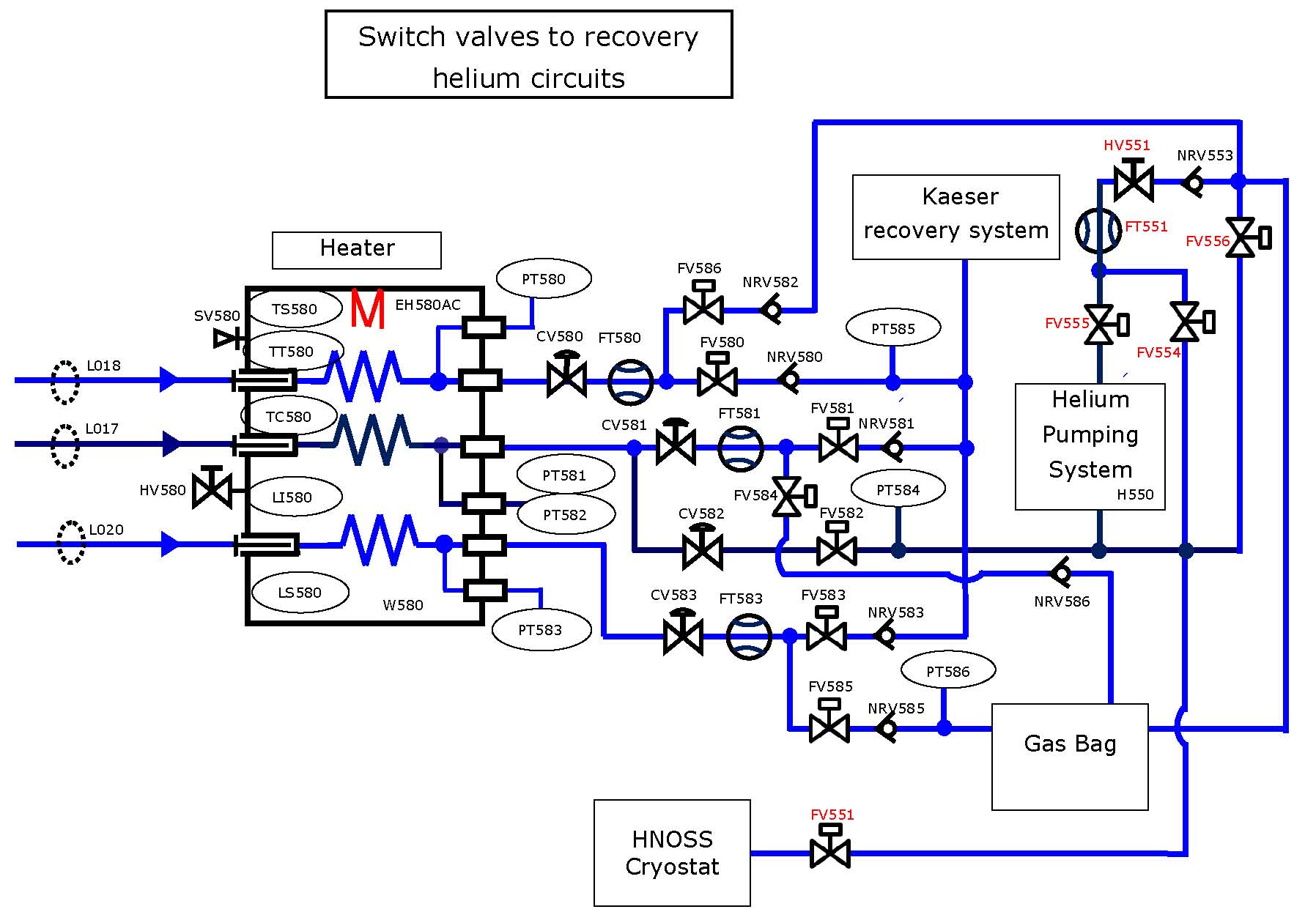
Waiting

Wait change circuit

Waiting

CV583 100% open

CV583 100% open



**The valves in red in the text are used for the operations of the HNOSS and GERSEMI cryostats.**

Switch Valves “Valve Box Circuit” closed means that the valves FV580, FV586 are closed.

Switch Valves “Valve Box Circuit” opened

* Kaeser selected : FV580 opened, FV586 closed
* Gas Bag selected : FV580 closed, FV586 opened

Switch Valves “Cryostat 4K Circuit” closed means that FV581, FV584 are closed.

Switch Valves “Cryostat 4K Circuit” opened

* Kaeser selected : FV581 opened, FV584 closed
* Gas Bag selected : FV581 closed, FV584 opened

Switch Valves “Magnet 4K Circuit” closed means that the valves FV583, FV585 are closed.

Switch Valves “Magnet 4K Circuit” opened

* Kaeser selected : FV583 opened, FV585 closed
* Gas Bag selected : FV583 closed, FV585 opened

Switch Valves closed means that all valves (FV580, FV581, FV583, FV584, FV585, FV586) are closed.

1 – Valve Box, conditioning He circuits

**Sensors and actuators used:**

- Pressure: PT580

- Valve: FV090, FV091NO, FV092, FV600, FV601, FV602, FV640, FV641, FV642, FV643, Switch valves

- Control valve: CV600, CV601, CV602, CV603, CV580, CV590, CV-He-liquefier

- Purging system: vacuum pump P090

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Number of cleaning cycle: Nb cycle | - Sequences from 5 to 20 stopped |
| - Delay: tstarting, tvac1, tvac2, tp1, tp2 |  |
| - Mode: Vacuum, Liquid or Magnet |  |
| - Pressure: Pvac, PvacMax, P He, P He min |  |

Vacuum mode

PT580 < Pvac

Alarm validated

PT580 < PvacMax & t > tvac1

PT580 ≥ PvacMax & t < tvac1

Leak test at high pressure

Close FV092 & FV600

Delay tp1

PT580 > P He

PT580 > P He min

& t > tp1

& N ≥ Nb cycle

PT580 > P He min

& t > tp1

& N < Nb cycle

Alarm validated

t > tvac2 & PT580 > Pvac

t > tp2 & PT580<P He

High level vacuum alarm

P090 running

Alarm validated

No

Yes

“Do you want to stop the conditioning?“

“Do you want to keep lines under vacuum?“

Yes

Flushing with

GHe

Open FV092 & FV600

Delay tp2

t > tstarting & (CV-He-liquefier & CV590) closed

“Do you want to stop the conditioning?“

No

Yes

PT580 P He min & t < tp1

Alarm validated

Low level pressure alarm

FV600 closed

CV580 closed

Helium conditioning stopped

Close FV090, FV092, FV601, FV602 Close CV600, CV601, CV602, CV603, CV580

P090 stopped

Pump stopped

Stop P090

Open FV091NO

Open CV580

Open CV601, CV602, CV603,

Close Switch Valves “Valve Box Circuit”

Close FV640, FV641, FV642, FV643

Open CV600, FV601, FV602

Close CV-He-liquefier, CV590

Start the Pumping

Close FV091NO

Open FV090

Start the Pump P090

Open FV600

Delay tvac2

Pumping

CV580, CV600, CV601, CV602, CV603 opened FV601, FV602 opened

CV580, CV600, CV601, CV602, CV603 opened FV090, FV601, FV602 opened

FV091NO closed, P090 running

CV580, CV600, CV601, CV602, CV603 opened FV601, FV602 opened

FV091NO closed, P090 running

Valve Box circuits isolated

Close FV600

Start conditioning

Stop

Prepare for purging

No

Flushing

with GHe

Open FV092 Open FV600

Delay tp2

PT580 > P He

t > tp2 & PT580<P He

Alarm validated

Leak test at low pressure

Close FV090 & FV600 Delay tvac1

CV580, CV600, CV601, CV602, CV603 opened FV601, FV602 opened

FV091NO closed, P090 running

Vacuum

Alarm

Close FV090

Pressure

Alarm

Close FV092

Close FV092

“Not possible to pressure the line”

FV090 closed

Close FV090

Liquid/Magnet modes

PT580 < Pvac

Alarm validated

PT580 < PvacMax & t > tvac1

PT580 ≥ PvacMax & t < tvac1

Leak test at high pressure

Close FV092 & FV600

Delay tp1

PT580 > P He

PT580 > P He min

& t > tp1

& N ≥ Nb cycle

PT580 > P He min

& t > tp1

& N < Nb cycle

Alarm validated

t > tvac2 & PT580 > Pvac

t > tp2 & PT580<P He

High level vacuum alarm

P090 running

Alarm validated

No

Yes

“Do you want to stop the conditioning?“

“Do you want to keep lines under vacuum?“

Yes

Flushing with

GHe

Open FV092 & FV600

Delay tp2

t > tstarting & (CV-He-liquefier & CV590) closed

“Do you want to stop the conditioning?“

No

Yes

PT580 P He min & t < tp1

Alarm validated

Low level pressure alarm

FV600 closed

CV580 closed

Helium conditioning stopped

Close FV090, FV092, FV601, FV602 Close CV600, CV601, CV602, CV603, CV580, FV641, FV643

P090 stopped

Pump stopped

Stop P090

Open FV091NO

Open CV580, FV641, FV643,

Open CV601, CV602, CV603,

Close Switch Valves “Valve Box Circuit”

Close FV640, FV642

Open CV600, FV601, FV602

Close CV-He-liquefier, CV590

Start the Pumping

Close FV091NO

Open FV090

Start the Pump P090

Open FV600

Delay tvac2

Pumping

CV580, CV600, CV601, CV602, CV603 opened FV601, FV602, FV641, FV643 opened

CV580, CV600, CV601, CV602, CV603 opened FV090, FV601, FV602, FV641, FV643 opened

FV091NO closed, P090 running

Leak test at low pressure

Close FV090 & FV600 Delay tvac1

CV580, CV600, CV601, CV602, CV603 opened FV601, FV602, FV641, FV643 opened

FV091NO closed, P090 running

CV580, CV600, CV601, CV602, CV603 opened FV601, FV602, FV641, FV643 opened

FV091NO closed, P090 running

Valve Box circuits isolated

Close FV600

Start conditioning

Stop

Prepare for purging

No

Vacuum

Alarm

Close FV090

Flushing

with GHe

Open FV092 Open FV600

Delay tp2

PT580 > P He

t > tp2 & PT580<P He

Alarm validated

Close FV092

“Not possible to pressure the line”

Pressure

Alarm

Close FV092

Close FV090

FV090 closed

2 – Cryostat, conditioning He circuits

**Sensors and actuators used:**

- Pressure: PT581

- Valve: FV090, FV091NO, FV092, FV660, FV640, FV641, FV642, FV643, FV582, FV587, Switch Valves

- Control valve: CV581, CV582, CV583, CV680, CV650, CV651, CV652, CV653

- Purging system: vacuum pump P090

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Number of cleaning cycle: Nb cycle | - Sequences from 5 to 20 stopped |
| - Delay: tstarting, tvac1, tvac2, tp1, tp2 |  |
| - Mode: Vacuum, Liquid or Magnet |  |
| - Pressure: Pvac, PvacMax, P He, P He min |  |

PT581 < Pvac

Alarm validated

PT581< PvacMax & t > tvac1

PT581 ≥ PvacMax & t < tvac1

PT581 > P He

PT581 > P He min

& t > tp1

& N ≥ Nb cycle

PT581 > P He min

& t > tp1

& N < Nb cycle

Alarm validated

t > tvac2 & PT581 > Pvac

t > tp2 & PT581<P He

High level vacuum alarm

P090 running

Alarm validated

“Do you want to stop the conditioning?“

Flushing with

GHe

Open FV092 & FV660

Delay tp2

t > tstarting & (CV581 & CV582) opened

“Do you want to stop the conditioning?“

PT581 P He min & t < tp1

Alarm validated

Low level pressure alarm

FV660 closed

CV581&CV582 closed

Helium conditioning stopped

Close FV090, FV092

Close CV581, CV582

P090 stopped

Pump stopped

Stop P090

Open FV091NO

Open CV581, CV582

Close Switch Valves “Cryostat 4K Circuit”

Close FV582

Close FV640, FV641, FV642, FV643

Start the Pumping

Close FV091NO

Open FV090

Start the Pump P090

Open FV660

Delay tvac2

Pumping

CV581, CV582 opened

CV581, CV582 opened

FV091NO closed, P090 running

FV090 opened

Leak test at low pressure

Close FV090 & FV660 Delay tvac1

CV581, CV582 opened

FV091NO closed, P090 running

CV581, CV582 opened

FV091NO closed, P090 running

Cryostat circuits isolated

Close FV660

No

Yes

“Do you want to keep lines under vacuum?“

Yes

No

Yes

Leak test at high pressure

Close FV092 & FV660

Delay tp1

Start conditioning

Prepare for purging

Stop

Vacuum

Alarm

Close FV090

Pressure

Alarm

Close FV092

No

PT581 > P He

t > tp2 & PT581<P He

Alarm validated

Flushing

with *GHe*

Open FV092 Open FV660

Delay tp2

Close FV092

“Not possible to pressure the line”

Close FV090

FV090 closed

Vacuum/Liquid modes

Magnet mode

3 – Supercritical helium, He conditioning circuits

PT581 < Pvac

Alarm validated

PT581< PvacMax & t > tvac1

PT581 ≥ PvacMax & t < tvac1

PT581 > P He

PT581 > P He min

& t > tp1

& N ≥ Nb cycle

PT581 > P He min

& t > tp1

& N < Nb cycle

Alarm validated

t > tvac2 & PT581 > Pvac

t > tp2 & PT581<P He

High level vacuum alarm

P090 running

Alarm validated

“Do you want to stop the conditioning?“

Flushing with

GHe

Open FV092 & FV660

Delay tp2

t > tstarting & (CV581 & CV582 & CV583) opened

PT581 P He min & t < tp1

Alarm validated

Low level pressure alarm

FV660 closed

CV581&CV582&CV583 closed

Helium conditioning stopped

Close FV090, FV092

Close CV581, CV582, CV583

Close CV650, CV651, CV652, CV653

P090 stopped

Pump stopped

Stop P090

Open FV091NO

Open CV581, CV582, CV583

Close Switch Valves “Cryostat 4K circuit”

Close Switch Valves “Magnet 4K Circuit”

Close FV582, FV587

Close FV640, FV641, FV642, FV643

Open FV680, FV681

Open CV680

Open CV650, CV651, CV652, CV653

Start the Pumping

Close FV091NO

Open FV090

Start the Pump P090

Open FV660

Delay tvac2

Pumping

CV581, CV582, CV583, CV680 opened

FV680, FV681 opened

CV650, CV651, CV652, CV653 opened

CV581, CV582, CV583, CV680 opened

FV091NO closed, P090 running

FV090, FV680, FV681 opened

Leak test at low pressure

Close FV090 & FV660 Delay tvac1

CV581, CV582, CV583, CV680 opened

FV091NO closed, P090 running

FV680, FV681 opened

CV650, CV651, CV652, CV653 opened

CV581, CV582, CV583, CV680 opened

FV091NO closed, P090 running

FV680, FV681 opened

CV650, CV651, CV652, CV653 opened

Cryostat circuits isolated

Close FV660

Close CV680, FV680, FV681

Leak test at high pressure

Close FV092 & FV660

Delay tp1

No

Yes

“Do you want to keep lines under vacuum?“

Yes

“Do you want to stop the conditioning?“

No

Yes

Start conditioning

Stop

Prepare for purging

CV650, CV651, CV652, CV653 opened

Vacuum

Alarm

Close FV090

Pressure

Alarm

Close FV092

No

PT581 > P He

t > tp2 & PT581<P He

Alarm validated

Flushing

with *GHe*

Open FV092 Open FV660

Delay tp2

Close FV092

“Not possible to pressure the line”

Close FV090

FV090 closed

**Sensors and actuators used:**

- Pressure: PT381

- Valve: FV090, FV091NO, FV092, FV380, FV381, FV382, FV383

- Control valve: CV380

- Purging system: vacuum pump P090, He gas

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Number of cleaning cycle: Nb cycle | - Sequences from 5 to 20 stopped |
| - Delay: tstarting, tvac1, tvac2, tp1, tp2 |  |
| - Pressure: Pvac, PvacMax, P He, P He min |  |

PT381 < Pvac

Alarm validated

PT381 < PvacMax & t > tvac1

Start conditioning

PT381 ≥ PvacMax & t < tvac1

PT381 > P He

PT381 > P He min

& t > tp1

& N ≥ Nb cycle

PT381 > P He min

& t > tp1

& N < Nb cycle

Alarm validated

t > tvac2 & PT381 > Pvac

t > tp2 & PT381<P He

High level vacuum alarm

P090 running

Alarm validated

Flushing with

GHe

Open FV092 & FV380

Delay tp2

Stop

t > tstarting & FV383 closed

PT381 P He min & t < tp1

Alarm validated

Low level pressure alarm

FV380 closed

(FV090&FV092) closed

P090 stopped

Pump stopped

Stop P090

Open FV091NO

Prepare for purging

Open CV380

Open FV381, FV382

Close FV383

Start the Pumping

Close FV091NO

Open FV090

Start the Pump P090

Open FV380

Delay tvac2

Pumping

CV380 opened

FV381, FV382 opened

CV380 opened

FV090, FV381, FV382 opened

FV091NO closed, P090 running

Leak test at low pressure

Close FV090 & FV380 Delay tvac1

CV380 opened

FV381, FV382 opened

FV091NO closed, P090 running

CV380 opened

FV381, FV382 opened

FV091NO closed, P090 running

SHe circuits isolated

Close FV380, FV381, FV382

Close CV380

No

Yes

“Do you want to keep lines under vacuum?“

Yes

Leak test at high pressure

Close FV092 & FV380

Delay tp1

Helium conditioning stopped

Close FV090, FV092

No

Yes

“Do you want to stop the conditioning?“

Vacuum

Alarm

Close FV090

“Do you want to stop the conditioning?“

Pressure

Alarm

Close FV092

No

PT381 > P He

t > tp2 & PT381<P He

Alarm validated

Flushing

with *GHe*

Open FV092 Open FV380

Delay tp2

Close FV092

“Not possible to pressure the line”

FV090 closed

Close FV090

4 – High Voltage electrical insulation tests

**Sensors and actuators used:**

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
|  |  |

This sequence is not defined

5 – Valve Box thermal shield cooling

**Sensors and actuators used:**

- Temperature: TT700, TT704, TT705, TT706, TT707

- Valve: EV700

- Control valve: CV700

- Heater: EH700

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Temperature: TT700L, TT700H, TT705L, TT705H, TT700C, TT700W | - Sequence 1 stopped  - Sequence 21 stopped |
| - Control valve: CV700%opening |  |

6 – Cryostat thermal shield cooling

Subsequence

Subsequence

Valve Box, start cooling

TT700 <TT700L

Opening CV700, slope 10%/s,

Open EV700

TT704 < 200 K or TT706 < 200 K

(TT705 OR TT707)<TT705L OR

TT700<TT700C OR Stop

CV700 opened

Close EV700

(TT705 OR TT707)>TT705H

& TT700>TT700W

Stop

Stop

Starting LN2 flow

CV700 closed

Stop

Start LN2 Circulation

CV700 opened

Open EV700

Stop LN2 circulation

TT700 >TT700H OR Stop

Start GN2 heating

Start EH700

Stop heating

Stop EH700

Close filling valve

Closing CV700, slope 10%/s

**Sensors and actuators used:**

- Temperature: TT740, TT744, TT745, TT747, TT748, TT749, TT750, TT752, TT753, TT754, TT755

- Valve: EV740, EV744, EV748

- Control valve: CV740

- Heater: EH740, EH744, EH748

|  |  |  |  |
| --- | --- | --- | --- |
| **The user chooses:** | | **Initial conditions:** | |
| - Temperature: TT740H, TT740L, TT740C, TT740W, TT744L, TT744H, TT744C, TT744W, TT745L, TT745H, TT747L, TT747H, TT748L, TT748H, TT748C, TT748W, TT750L, TT750H | | - Liquid or Magnet insert selected  - Sequences 2 & 3 stopped  - Sequence 22 stopped | |
| - Control valve: CV740%opening |  | |

Subsequence

Subsequence

**A**

**B**

Cryostat, start cooling

TT740 <TT740L

Opening CV740, slope 10%/s

Open EV740, EV744, EV748

TT752 < 200 K or TT749 < 200 K

(TT745 OR TT753)<TT745L

OR TT740<TT740C OR Stop

CV740 opened

Close EV740

(TT745 OR TT753) >TT745H

& TT740>TT740W

Stop

Stop

**C**

CV740 closed

Start LN2 Circulation

CV740 opened Open EV740

Stop LN2 circulation

Stop

Closing CV740, slope 10%/s

Close end valve

Starting LN2 flow

TT740 >TT740H OR Stop

Start GN2 heating

Start EH740

Stop heating

Stop EH740

7 – Vacuum insert thermal shield cooling

Subsequences

**B**

(TT750 OR TT755)>TT750H

& TT748>TT748W

Stop

(TT750 OR TT755)<TT750L

OR TT748<TT748C OR Stop

TT748 < TT748L

Stop LN2 circulation

CV740 opened

Close EV748

Start LN2 Circulation

CV740 opened

Open EV748

**A**

(TT747 OR TT754)>TT747H

& TT744>TT744W

Stop

(TT747 OR TT754)<TT747L

OR TT744<TT744C OR Stop

TT744 < TT744L

Stop LN2 circulation

CV740 opened

Close EV744

Start LN2 Circulation

CV740 opened

Open EV744

**C**

TT744 > TT744H OR Stop

Start GN2 heating

Start EH744

Stop

Stop

Stop heating

Stop EH744

TT748 > TT748H OR Stop

Start GN2 heating

Start EH748

Stop heating

Stop EH748

**Sensors and actuators used:**

- Temperature: TT746, TT760, TT762, TT764, TT766, TT767

- Valve: FV740, EV760, EV762

- Heater: EH760, EH762

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Temperature: TT760L, TT760H, TT762L, TT762H, TT766L, TT766H, TT767L, TT767H | - Vacuum insert selected  - Sequences 2 &3 stopped  - Sequence 23 stopped |
| - Mode: vacuum |  |

A

TT767>TT767H & TT762>200K

Stop

TT767<TT767L OR TT762<150K OR Stop

TT762 < TT762L

Stop LN2 circulation

FV740 opened

Close EV762

Start LN2 Circulation

FV740 opened

Open EV762

A

Start cooling & Vacuum

TT760 < TT760L

Starting LN2 flow

Open FV740, EV760, EV762

TT746 < 200 K or TT764 < 200 K

TT766<TT766L OR TT760<150K OR Stop

Stop LN2 circulation

FV740 opened

Close EV760

TT766>TT766H & TT760>200 K

Stop

Start LN2 Circulation

FV740 opened

Open EV760

Close filling valve

Close FV740

Stop

Stop

TT762 > TT762H OR Stop

TT760 > TT760H OR Stop

Start GN2 heating

Start EH760

Stop heating

Stop EH760

Stop heating

Stop EH762

Stop GN2 heating

Start EH762

Stop

FV740 closed

8 – LHe level measurement

Subsequence

Subsequence

Subsequence

**Sensors and actuators used:**

- Temperature: TT603, TT613, TT642, TT644, TT646, TT647, TT662, TT663, TT666, TT684

- Level: LT600, LT660, LT661, LT670, LT671, LT680, LT681, LT682, LT683, LI660, LI670, LI680

This sequence starts the level measurement.

The level measurement is stopped at the end of the warm-up sequence.

(TT603 & TT613)> 200 K

& LT600 < 5%

Start cool down VB

(TT662 OR TT663)< 100 K

(TT662 & TT663)> 200 K

& LI660 < 5%

Warm-up finished

TT644 OR TT647< 100 K

LT670 & LT671 in operation

(TT644 & TT647)> 200 K

& LI670 < 5%

Temperature control

Waiting

(TT644 OR TT647)< 100 K

(TT644 & TT647)> 200 K & LI680 < 5%

Start cool down Vacuum Insert

Start cool down Magnet OR Liquid

Start cool down Liquid Insert

Start cool down Magnet

User wants to stop

Temperature control

Waiting

Stop

LT680, LT681, LT682, LT683 in operation

Stop

Stop

Heating

Stop EH670AC

(TT670A OR TT670B OR TT670C) > 30°C

(TT670A OR TT670B OR TT670C )< 0°C

LT660 & LT661 in operation

LT660 & LT661 OFF

Stop

Cde Vacuum LT OFF

Stop

Cde Magnet LT OFF

LT680, LT681, LT682, LT683 OFF

(TT603 OR TT613)< 100 K

Temperature control

Waiting

LT600 in operation

LT600 OFF

Stop

Cde LT600 OFF OFF

LT670 & LT671 OFF

Stop

Cde Liquid LT OFF

Heating

Thermal Shield

Start EH670AC

Temperature control

Waiting

Subsequence

Subsequence

Subsequence

Subsequence

Subsequence

9 – Valve Box cooling and 4K tank control level

|  |  |
| --- | --- |
| **Sensors and actuators used:** |  |
| - Pressure: PT600 | - Control valve: CV600, CV580, CV590, CV-He-liquefier |
| - Flow rate: FT580 | - Level: LT600 |
| - Valve: FV601, FV602 | - Temperature: TT602, TT614 |

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Level: LT600setpoint, LT600mini, LT600Maxi | - Sequences from 1 to 3 stopped |
| - Pressure: PT600setpoint | - Sequences 5 & 8 in operation |
| - Flow: FT580limit |  |
| - Valve: CV600%opening, CV580%opening, CV-He-liquefier%opening, CV590%opening |  |
| - Mode: Regulation or Intermittent |  |
| - Helium supplier: Liquefier/Stop Liquefier or Dewar/Stop Dewar |  |

Stop

Stop Liquefier

OR Stop

Intermittent

Stop Liquefier OR Stop

Regulation & Liquefier & Validation

Regulation

CV580 fully opened

CV600 closed

LT600 < LT600mini OR Stop

A

C

LT600 > LT600 Maxi OR Stop

CV-He-liquefier closed

Liquefier valve closing

Close CV-He-liquefier

CV580 regulated

PT600=PT600setpoint

CV600 regulated

LT600=LT600setPoint

FV601 opened

CV580 regulated

PT600=PT600setpoint

CV-He-liquefier closed

Avoid closed volume

Tank 4K

outgassing

Preparation to regulate

Close FV601

CV-He-liquefier %opening

Open CV580

Cool down TL L010

Regulation

mode

CV-He-liquefier %opening

CV600 regulated

LT600=LT600setPoint

FT580 < FT580limit

CV580 regulated

PT600=PT600setpoint

4K tank

Filling

CV-He-liquefier %opening

CV580 regulated

PT600=PT600setpoint

Close FV601

CV600 open and controlled

FT580 < FT580limit

End of

Filling

CV-He-liquefier %opening

CV580 regulated

PT600=PT600setpoint

Close CV600

Close CV-He-liquefier

Liquefier valve closing

Close CV600

Open FV601

CV580 regulated

PT600=PT600setpoint

Dewar

B

LT600 < LT600mini

Waiting for Level

CV-He-liquefier %openingCV580 regulated

PT600=PT600setpoint

Open FV601

CV-He-liquefier %opening

Intermittent & Liquefier & Validation

Regulation OR Stop

A

Liquefier

Waiting for level

Close CV600

TT602 < 10K OR TT614 < 10K OR Stop

Regulation

Intermittent & LT600 < LT600mini

LT600 value > LT600min

C

stop

Dewar

Liquefier

A

B

TT602 < 10K OR TT614 < 10K OR Stop

Stop Dewar

OR Stop

Stop Dewar OR Stop

Start

Regulation

CV580 fully opened

CV600 closed

Intermittent & Dewar& Validation

LT600 > LT600 Maxi OR Stop Regulation

FV602 closed

CV590 closed

Avoid closed volume

Preparation to regulate

Close FV601

CV590 %opening

Open CV580, Open FV602

Cool down TL L010

CV580 regulated

PT600=PT600setpoint

Open FV601

CV590 %opening

FV602 opened

4K tank

Filling

CV590 %opening

CV580 regulated

PT600=PT600setpoint

Close FV601

CV600 open and controlled

FT580 < FT58limit

FV602 opened

End of

Filling

CV590 %opening

CV580 regulated

PT600=PT600setpoint

Close CV600

FV602 opened

Close FV602

CV580 regulated

PT600=PT600setpoint

Close CV600

Open FV601

CV580 regulated

PT600=PT600setpoint

Liquefier

A

Stop

“Have you chosen the recovery circuit for the valve Box? “

Regulation & Dewar & Validation

Yes

“Do you want operate with an extra Dewar or with the liquefier Dewar? “

Intermittent & LT600 < LT600mini

FV601 opened

CV580 regulated

PT600=PT600setpoint

Tank 4K

outgassing

Dewar Isolated

“Do you want close the valve of the Dewar?”

FV602 closed

Close CV590

Dewar valve closed

Yes

No

Dewar Isolated

Close FV602

CV580 regulated

PT600=PT600setpoint

CV600 regulated

LT600=LT600setPoint

FV602 opened & LT600 < LT600mini OR Stop

Intermittent

Regulation OR Stop

LT600 < LT600mini

Preparation to fill

Open FV602

“Have you connected the extra Dewar? “

Yes

B

Dewar

Waiting for level

Close CV600

Waiting level

Regulation

mode

CV590 %opening

CV600 regulated

LT600=LT600setPoint

FT580 < FT580limit

CV580 regulated

PT600=PT600setpoint

FV602 opened

10 – Cavity cooling down

**Sensors and actuators used:**

- Pressure: PT660

- Flow rate: FT581

- Valve: FV640, FV641, FV642, FV643

- Control valve: CV601, CV602, CV581

- Level: LI660 (LT660+LT661), LI670 (LT670+LT671)

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Level: LI660setpoint, LI660mini, LI660Maxi, LI670setpoint, LI670mini, LI670Maxi | - Liquid or Vacuum insert selected  - Sequences from 1 to 3 stopped  - Sequences from 12 to 13 stopped  - Sequences 6 & 8 in operation |
| - Pressure: PT660setpoint |
| - Flow: FT581limit |
| - Control valve: CV601%opening, CV602%opening, CV581%opening |
| - Mode: Regulation or Intermittent |

B

LI660>LI660Maxi

Stop

Intermittent

FV641, FV643 opened

CV602 %opening and controlled

FT581<FT581limit

CV581 regulated

PT660=PT660setpoint

Stop

Intermittent& LI660 < LI660mini

Regulation

Intermittent & (LI660<LI660mini OR Stop)

)

Regulation

(LI660>LI660Maxi) OR Stop

End of

Filling

FV641, FV643 opened

Close CV602

CV581 regulated

PT660=PT660setpoint

Regulation

CV601 fully closed

FV641, FV643 opened

CV581 regulated

PT660=PT660setpoint

Preparation to regulate

Cryostat

Filling

End of

Cool down

Close CV601, FV641, FV643 opened

CV581 regulated

PT660=PT660setpoint

Stop

Cooling

Close FV641, FV643

Close CV602

CV581 regulated

PT660=PT660setpoint

CV602 fully closed

Cooling cavity

Open FV641, FV643

CV601 %opening and controlled by

FT581<FT581limit

CV581 regulated

PT660=PT660setpoint

A

Waiting for level

Close CV602

LI660<LI660mini

Regulation OR Stop

Regulation

mode

FV641, FV643 opened

CV602 regulated

LI660=LI660setPoint

CV581 regulated

PT660=PT660setpoint

Vacuum mode

Liquid mode

11 – Supercritical helium in operation

Yes

LI670>LI670Maxi

Stop

LI670<LI670mini

FV640, FV642 opened

CV602 %opening and controlled

FT581<FT581limit

CV581 regulated

PT660=PT660setpoint

Stop

Intermittent& LI670 < LI670mini

Regulation

Intermittent & (LI670<LI670mini OR Stop)

Regulation

(LI670>LI670Maxi) OR Stop

End of

Filling

FV640, FV642 opened

Close CV602

CV581 regulated

PT660=PT660setpoint

Regulation

CV601 fully closed

FV640, FV642 opened

CV581 regulated

PT660=PT660setpoint

Preparation to regulate

Cryostat

Filling

End of

Cool down

Close CV601, FV640, FV642 opened

CV581 regulated

PT660=PT660setpoint

Stop

Cooling

Close FV640, FV642

Close CV602

CV581 regulated

PT660=PT660setpoint

CV602 fully closed

stop

Start

“ Have you chosen the recovery circuit for the cryostat? “

B

Vacuum & Yes

Liquid & Yes

Cooling cavity

Open FV640, FV642

CV601 %opening and controlled by

FT581<FT581limit

CV581 regulated

PT660=PT660setpoint

A

Waiting for level

Close CV602

Regulation OR Stop

Intermittent

Regulation

mode

FV640, FV642 opened

CV602 regulated

LI670=LI670setPoint

CV581 regulated

PT660=PT660setpoint

LI670<LI670mini OR Stop

Waiting level

**Sensors and actuators used:**

- Temperature: TT370, TT371, TT372

- Flow rate: FT380

- Valve: FV381, FV382

- Control valve: CV380

- Heater: EH370

- Compressor

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Temperature: TT370L, TT370H, TT371setpoint, TT372setpoint | - Sequence 3 stopped |
| - Flow: FT380setpoint |  |
| - Control valve: CV380%opening |  |
| - Delay: tc1, tc2 |  |
| - Mode: InletTemp (TT372) or OutletTemp (TT371) or Flow regulation (FT380) |  |

start

TT370 < TT370L

Compressor stopped

Inlet Temp. regulation

FV381, FV382 opened

CV380 regulated

TT372 = TT372setpoint

Compressor running & t > tc2 (10s)

FV381, FV382 opened

Start compressor

Stop

t > tc1 (3s)

Open circuit

Open FV381, FV382

Open CV380

CV380 fully closed

Stop

(TT370 > TT370H) OR Stop

Start compressor

Gas heating

Start EH370

Stop heating

Stop EH370

Compressor running & t > tc2 (10s)

& Inlet Temp

Compressor running & t > tc2 (10s)

& Flow

Outlet Temp

Flow

Flow

Inlet Temp

Stop SHe

Open CV380

FV381, FV382 opened

Stop the Compressor

Close circuit

Close FV381, FV382

Close CV380

Flow regulation

FV381, FV382 opened

CV380 regulated

FT380 = FT380setpoint

Inlet Temp

Outlet Temp. regulation

FV381, FV382 opened

CV380 regulated

TT371 = TT371setpoint

Outlet Temp

Stop

Stop

Stop

Compressor running & t > tc2 (10s)

& Outlet Temp

12 – Cavity in operation at 4K

Subsequence

**Sensors and actuators used:**

- Pressure: PT660

- Flow rate: FT581

- Valve: FV642, FV643

- Control valve: CV602, CV581

- Level: LI660 (LT660+LT661), LI670 (LT670+LT671)

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Level: LI660setpoint, LI660mini, LI660Maxi, LI670setpoint, LI670mini, LI670Maxi | - Liquid or Vacuum insert selected  - Sequences from 1 to 3 stopped  - Sequences 10 and 13 stopped  - Sequence 8 in operation |
| - Pressure: PT660setpoint (Patmospheric<P<1.5 bar) |
| - Flow: FT581limit |
| - Control valve: CV602%opening, CV581%opening |
| - Mode: regulation or intermittent |

Vacuum mode

B

Stop

Intermittent

FV643, FV641 opened

CV602 opened and controlled

FT581<FT581limit

CV581 regulated

PT660=PT660setpoint

Stop

Intermittent& LI660 < LI660mini

Regulation

Regulation

LI660 > LI660Maxi OR Stop

End of

Filling

FV643, FV641 opened

Close CV602

CV581 regulated

PT660=PT660setpoint

A

Regulation

Regulation

mode

FV643, FV641 opened

CV602 regulated

LI660=LI660setPoint

CV581 regulated

PT660=PT660setpoint

Start

Filling

(FV643 & CV602) closed

Filling ready

Open FV643, FV641

Stop

4K

Close FV643, FV641

Close CV602

CV581 regulated

PT660=PT660setpoint

Intermittent & (LI660 < LI660mini OR Stop)

)

Waiting for level

Close CV602

Regulation OR Stop

LI660 < LI660mini

Liquid mode

13 – Cavity in operation at 2K

Start 4K & Vacuum

A

B

Stop

Start 4K & Liquid

Stop

Intermittent

FV642, FV640 opened

CV602 opened and controlled

FT581<FT581limit

CV581 regulated

PT660=PT660setpoint

Stop

Intermittent& LI670 < LI670mini

Regulation

LI670<LI670mini OR Stop

Regulation

LI670>LI670Maxi OR Stop

End of

Filling

FV642, FV640 opened

Close CV602

CV581 regulated

PT660=PT660setpoint

Regulation

Filling Ready

Open FV642, FV640

Stop

Cooling

Close FV642, FV640

Close CV602

CV581 regulated

PT660=PT660setpoint

Start

Filling

Regulation

mode

FV642, FV640 opened

CV602 regulated

LI670=LI670setPoint

CV581 regulated

PT660=PT660setpoint

(FV642 & CV602) closed

Waiting for Level

Intermittent

Waiting for level

Close CV602

Regulation OR Stop

LI670<LI670mini

|  |  |
| --- | --- |
| **Sensors and actuators used:** |  |
| - Pressure: PT584, PT660, PT661 | - Control valve: CV603, CV581, CV582 |
| - Flow rate: FT551 | - Level: LI660, LI670 |
| - Valve: FV642, FV643, FV581, FV582, FV584, FV554, FV555, FV556, Switch valves | - Cryostat-2K: Boolean |

|  |  |
| --- | --- |
| **The user chooses:** | **The initial conditions:** |
| - Level: LI660setpoint, LI660mini, LI660Maxi, LI670setpoint, LI670mini, LI670Maxi | - Liquid or Vacuum insert selected  - Sequences from 1 to 3 stopped  - Sequences 10 and 12 stopped  - Sequence 8 in operation |
| - Pressure: PT660setpoint, PT584setpoint |
| - Flow: FT551limit |
| - Control valve: CV603%opening, CV581%opening, CV582%opening |
| - Mode: regulation or intermittent |

Vacuum mode

LI660 < LI660 mini & Yes & **FV551 closed**

LI660 >= LI660 mini & Yes & **FV551 closed**

PT660 close to PT660setpoint

Stop 2 K

PT584 ≥ PT584setpoint

Pumps stopped

PT660 > 1020 mbar

FV582 closed

newPT660setpoint < oldPT660setpoint

Start 2 K Vacuum & (S10 &S12) stopped

The tank 2K is not filled,

“Do you want continue?”

No

Yes

Stop

No

Pumping 2K tank

CV582 opening step by step

Cryostat-2K = true

FV582 opened, **FV555 opened**

**Start 13V**

2K tank pressure

regulated

CV582 regulated

PT660 OR PT661=PT660setpoint

Cryostat-2K = true

FV582 opened, **FV555 opened**

Isolating 2K tank

CV581 closing with slope

**FV555 opened**

2K circuit closed

FV554 closed & FV555 open

CV581 opened

FV581 & FV584 closed

Close Switch Valves « Cryostat 4K circuit »

Cryostat-2K = true

Open FV582, **FV555 opened**

Pumps ok (user command)

CV581 closed

FV556 closed

Starting pumps

Waiting,

**FV555 opened**, CV581 opened

Stop pumping system and filling

Close FV582, **Stop 13V**

Cryostat-2K = true,

CV582 fully open

**FV555 opened**

Prepare the 2K pump

**Close FV554, Open FV555**

CV581 opened

You are starting the 2K pumping. The HNOSS valve **FV551** must be closed.

“Do you want continue?”

“Do you want continue?”

Cryostat connected to the recovery helium circuit

Switch Valves « Cryostat 4K circuit » opened

Open CV581

Pressure control

CV582 opened

Cryostat-2K = true

Cryostat connected at the recovery He circuit

Open Switch Valves « Cryostat 4K circuit »

Cryostat-2K = false

Open CV581

Close CV582

« 2K pumps stopped ? »

Pump line at atmospheric pressure

**Close FV555**

**Open FV556**

Stop filling line

**Close FV556**

CV581 opened

Stop 13V

LI660 < LI660mini

CV603 opened and controlled

FT551<FT551limit

FV643, FV641 opened

Stop 13V

Intermittent& LI660 < LI660mini

Regulation

Intermittent & (LI660 < LI660mini OR Stop 13V)

Regulation

(LI660 > LI660Maxi) OR Stop 13V

End of

Filling

Close CV603

FV643, FV641 opened

Regulation

Stop Filling

Close CV603

FV643, FV641 opened

Start sequence 13V

CV603 closed

Filling circuit closed

Close FV643, FV641

FV643 closed

Stop

**Sequence 13V**

Filling ready

Open FV643, FV641

Regulation

mode

CV603 regulated

LI660=LI660setPoint

FV643, FV641 opened

Start

Filling

Waiting for level

Close CV603

Intermittent

Regulation OR Stop 13V

Liquid mode

LI670 < LI670mini & Yes & **FV551 closed**

LI670 >= LI670mini & Yes & **FV551 closed**

PT660 close to PT660setpoint

Stop 2 K

newPT660setpoint < oldPT660setpoint

Start 2 K Vacuum & (S10 &S12) stopped

The tank 2K is not filled,

“Do you want continue?”

No

Yes

Stop

No

Pumping 2K tank

CV582 opening step by step

Cryostat-2K = true

FV582 opened, **FV555 opened**

**Start 13L**

2K tank pressure

regulated

CV582 regulated

PT660=PT660setpoint OR

PT661=PT660setpoint

Cryostat-2K = true

FV582 opened, **FV555 opened**

Isolating 2K tank

CV581 closing with slope

**FV555 opened**

2K circuit closed

FV554 closed & FV555 open

CV581 opened

FV581 & FV584 closed

Close Switch Valves « Cryostat 4K circuit »

Cryostat-2K = true

Open FV582, **FV555 opened**

Pumps ok (user command)

CV581 closed

Starting pumps

Waiting,

**FV555 opened**, CV581 opened

Prepare the 2K pump

**Close FV554, Open FV555**

CV581 opened

You are starting the 2K pumping. The HNOSS valve **FV551** must be closed.

“Do you want continue?”

“Do you want continue?”

Cryostat connected to the recovery helium circuit

Switch Valves « Cryostat 4K circuit » opened

Open CV581

PT584 ≥ PT584setpoint

Pumps stopped

PT660 > 1020 mbar

FV582 closed

FV556 closed

Stop pumping system and filling

Close FV582, **Stop 13L**

Cryostat-2K = true,

CV582 fully open

**FV555 opened**

Pressure control

CV582 opened

Cryostat-2K = true

Cryostat connected at the recovery He circuit

Open Switch Valves « Cryostat 4K circuit »

Cryostat-2K = false

Open CV581

Close CV582

« 2K pumps stopped ? »

Pump line at atmospheric pressure

**Close FV555**

**Open FV556**

Stop filling line

**Close FV556**

CV581 opened

Stop 13L

LI670 < LI670mini

CV603 opened and controlled

FT551<FT551limit

FV642, FV640 opened

Stop 13L

Intermittent& LI670 < LI670mini

Regulation

Intermittent & (LI670 < LI670mini OR Stop 13L)

Regulation

(LI670 > LI670Maxi) OR Stop 13L

End of

Filling

Close CV603

FV642, FV640 opened

Regulation

Stop Filling

Close CV603

FV642, FV640 opened

Start sequence 13L

CV603 closed

Filling circuit closed

Close FV642, FV640

FV642 closed

Stop

**Sequence 13L**

Filling ready

Open FV642, FV640

Regulation

mode

CV603 regulated

LI670=LI670setPoint

FV642, FV640 opened

Start

Filling

Waiting for level

Close CV603

Intermittent

Regulation OR Stop 13L

LI670 < LI670mini OR Stop 13L

14 – Cavity - Standby at 40 K

**Sensors and actuators used:**

- Temperature: TT664, TT665

- Pressure: PT660

- Flow rate: FT581

- Valve: FV640, FV641

- Control valve: CV601, CV581

- Level: LI660, LI670

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Level: LI660Maxi, LI660mini, LI670Maxi, LI670mini | - Liquid or Vacuum insert selected  - Sequences from 1 to 3 stopped  - Sequences 10, 12 and 13 stopped  - Sequence 8 in operation |
| - Temperature: TT665Maxi, TT665mini |
| - Pressure: PT660setpoint |
| - Flow: FT581setpoint |
| - Control valve: CV601%opening, CV581%opening |

Standby Liquid

Stop

Close FV640, FV642

CV581 regulated

PT660=PT660setpoint

Stop

Conditioning

Open FV640, FV642

CV581 regulated

PT660=PT660setpoint

CV601 opened & controlled

FT581<FT581setpoint

CV581 regulated

PT660=PT660setpoint

FV640, FV642 opened

FV640 closed

(TT665 & TT664) < T665mini OR LI670>LI670Maxi

(TT665 OR TT664)>TT665Maxi & LI670<LI670mini

Stop cooling

Close CV601

CV581 regulated

PT660=PT660setpoint

FV640, FV642 opened

Cool down LHe

Standby Vacuum

Stop

Close FV641, FV643

CV581 regulated

PT660=PT660setpoint

Conditioning

Open FV641, FV643

CV581 regulated

PT660=PT660setpoint

CV601 opened & controlled

FT581<FT581setpoint

CV581 regulated

PT660=PT660setpoint

FV641, FV643 opened

FV641 closed

(TT665 & TT664) < T665mini OR LI660>LI660Maxi

(TT665 OR TT664)>TT665Maxi & LI660<LI660mini

Close CV601

CV581 regulated

PT660=PT660setpoint

FV641, FV643 opened

Cool down LHe

TT665 OR TT664 > TT665Max

TT665 OR TT664 > TT665Max

Stop

Standby

Stop cooling

Stop

Standby

15 – Magnet - Cooling down

**Sensors and actuators used:**

- Pressure: PT660, PT681

- Flow rate: FT581, FT583

- Valve: FV640, FV642, FV680, FV681

- Control valve: CV601, CV602, CV581, CV583, CV680

- Level: LI680, LT682, LT683

- Temperature: TT662, TT665, TT680, TT685

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Levels: LI680Maxi, LT682setpoint, LT683setpoint | - Magnet insert selected  - Sequences from 1 to 3 stopped  - Sequences from 16 to 18 stopped  - Sequence 8 in operation |
| - Pressure: PT660Max, PT681Max, PT681setpoint, PT660setpoint |
| - Flow: FT581limit, FT583limit |
| - Control valve: CV601%opening, CV602%opening, CV581%opening, CV583%opening, CV680%opening |
| - ΔT/ΔLmagnetMax (TT665-TT662)/ΔLmagnet, dT/dt\_magnetMax (TT662), ΔLmagnet |
| - Temperature: TT680setpoint, TT685Max  TT680 < TT680setpoint OR  LT683 > LT683setpoint  Cooling Magnet  Open FV640, FV642, FV680  CV601 regulated  FT583=FT583setpoint  ΔT/ΔL magnet<ΔT/ΔL magnetMax  dT/dt\_magnet<dT/dt\_magnetMax  CV583 regulated  PT681=PT681setpoint  TT685>TT685Max  Cooling HX680  & HX683  Open FV681, CV680  CV581 regulated  FT581=FT581limit  PT660<PT660Max  Close FV681, CV680  CV581regulated  PT660=PT660setpoint  Stop  Cooling  LI680 > LI680max  Close CV601,  FV640, FV642 opened  FV680 opened  CV581 regulated  PT660=PT660setpoint  Start  CV601 closed  Finished  Cooling  Stop  (FV642 & FV680) closed  CV602 regulated  LT682=LT682setPoint  FT583<FT583limit  PT681<PT681Max  CV583 regulated  PT681=PT681setpoint  CV581 regulated  PT660=PT660setpoint OR  PT661=PT660setpoint  Regulation  CV680 regulated  LT683=LT683setpoint  FT581<FT581limit  PT660<PT660Max  FV642, FV640 opened  FV680 opened  CV583 regulated  PT681=PT681setpoint  “ Have you chosen the recovery circuit for the cryostat? “  Stop  Yes  Close FV642, FV640  Close FV680  Close CV602, CV680  Stop  Cooling  CV583 regulated  PT681=PT681setpoint  CV581 regulated  PT660=PT660setpoint OR  PT661=PT660setpoint |

16 – Magnet in operation at 4.2K

**Sensors and actuators used:**

- Pressure: PT660, PT681

- Valve: FV642, FV680

- Control valve: CV602, CV581, CV583, CV680

- Level: LT682, LT683

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Level: LT682setpoint, LT683setpoint | - Magnet insert selected  - Sequence from 1 to 3 stopped  - Sequence 15,17, 18 stopped  - Sequence 8 in operation |
| - Pressure: PT660setpoint, PT681setpoint |
| - Control valve: CV602%opening, CV581%opening, CV583%opening |

17 – Magnet - Cooling at 2K

Stop

Stop 4K

Regulation

Close FV640, FV642

Close FV680

Close CV602, CV680

(CV602 & CV680) closed

Open FV640, FV642, FV680

CV602 regulated

LT682=LT682setPoint

CV583 regulated

PT681=PT681setpoint

CV680 regulated

LT683=LT683setpoint

CV581 regulated

PT660=PT660setpoint

CV581 regulated

PT660=PT660setpoint

CV583 regulated

PT681=PT681setpoint

Start

Stop

Regulation

**Sensors and actuators used:**

- Pressure: PT660, PT661, PT584

- Valve: FV581, FV582, FV584, FV554, FV555, FV556

- Control valve: CV581, CV582

- Level: LT682, LT683

- Cryostat-2K: Boolean

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Level: LT683mini | - Magnet insert selected  - Sequences from 1 to 3 stopped  - Sequences 15 and 16 stopped  - Sequence 8 in operation |
| - Pressure: PT660setpoint, PT584setpoint |
| - Control valve: CV581%opening |

LT683 < LT683mini & Yes & **FV551 closed**

LT683 >= LT683mini &Yes & **FV551 closed**

PT660 close to PT660setpoint

Stop 2 K

newPT660setpoint < oldPT660setpoint

Start Cooling Magnet & (S15 &S16) stopped

The HX683 is not filled,

“Do you want continue?”

No

Yes

Stop

No

Pumping HX683

CV582 opening step by step Cryostat-2K = true

FV582 opened, **FV555 opened**

HX683 pressure

regulated

CV582 regulated

PT660=PT660setpoint OR

PT661=PT660setpoint

Cryostat-2K = true

FV582 opened, **FV555 opened**

FV582 opened, **FV555 opened**

Isolating 2K circuit

CV581 closing with slope

**FV555 opened**

2K circuit closed

FV554 closed & FV555 open

CV581 opened

FV581 & FV584 closed

Close Switch Valves « Cryostat 4K circuit »

Cryostat-2K = true

Open FV582, **FV555 opened**

Pumps ok (user command)

CV581 closed

Starting pumps

Waiting,

**FV555 opened**, CV581 opened

Prepare the 2K pump

**Close FV554, Open FV555**

CV581 opened

You are starting the 2K pumping. The HNOSS valve **FV551** must be closed.

“Do you want continue?”

“Do you want continue?”

Cryostat connected to the recovery helium circuit

Open CV581

**Start S18**

Pumps stopped

PT660 > 1020 mbar

FV582 closed

FV556 closed

Stop pumping system and filling

Close FV582,

Cryostat-2K = true,

CV582 fully open

**FV555 opened**

Pressure control

CV582 opened

Cryostat-2K = true

Cryostat connected at the recovery He circuit

Open Switch Valves « Cryostat 4K circuit »

Cryostat-2K = false

Open CV581

Close CV582

« 2K pumps stopped ? »

Pump line at atmospheric pressure

**Close FV555**

**Open FV556**

Stop filling line

**Close FV556**

CV581 opened

PT584 ≥ PT584setpoint

18 – Magnet - Control of the level and pressure at 2K

Start

**Sensors and actuators used:**

- Pressure: PT681,

- Valve: FV642, FV680

- Control valve: CV602, CV680, CV583,

- Level: LI680, LT682, LT683

- Cryostat-2K: Boolean

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Level: LI680Maxi, LT682setpoint, LT682mini, LT683setpoint | - Magnet insert selected  - Sequences from 1 to 3 stopped  - Sequences 15 and 16 stopped  - Sequences 8 & 17 in operation |
| - Pressure: PT681setpoint |
| - Control valve: CV583%opening |

19 – Magnet - Current leads cooling

Stop OR S17 stopped

Normal state & LI680<LI680Maxi

Normal state & LI680>LI680Maxi

Start

Cryostat-2K = true (Pumping HX683 started )

Quench detection

Stop

Cooling Magnet

Open CV602

FV640, FV642 opened

CV583 regulated

PT681=PT681setpoint

CV680 regulated

LT683=LT683setpoint

LT682>LT682mini

Stop

Cryostat filling

Close CV602

Open CV583

CV680 regulated

LT683=LT683setpoint

Regulation

Two bath connected

Open FV642, FV640 Close FV680

CV602 regulated

LT682=LT682setPoint

CV583 regulated

PT681=PT681setpoint

CV680 regulated

LT683=LT683setpoint

LT682>LT682mini

Regulation

Two bath connected

OpenFV680

Open CV602

CV583 regulated

PT681=PT681setpoint

CV680 regulated

LT683=LT683setpoint

Close FV640, FV642

Close CV602, CV680

CV583 regulated

PT681=PT681setpoint

Stop

Cooling

CV602 closed

Regulation

Lower bath cooling

Close FV680,

FV640, FV642 opened

CV602 regulated

LT682=LT682setPoint

CV583 regulated

PT681=PT681setpoint

CV680 regulated

LT683=LT683setpoint

**Sensors and actuators used:**

- Temperature: TT690, TT691, TT692, TT693 and list in the table 1

- Flow rate: FT650, FT651, FT652, FT653,

- Valve: FV587,

- Control valve: CV650, CV651, CV652, CV653,

- Heater: list in the table 1

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Temperature: TT690setpoint, TT691setpoint, TT692setpoint, TT693setpoint and list in the table 1 | - Magnet insert selected  - Sequences from 1 to 3 stopped |
| - Flow: FT650setpoint, FT651setpoint, FT652setpoint, FT653setpoint, |  |
| - Valve: CV650%opening, CV651%opening, CV652%opening, CV653%opening, |  |
| - Mode: Temperature or Flow regulation. |  |

start

Current lead IL651

stop

Cooling in operation

CV650 regulated

TT690 = TT690setpoint OR

FT650 = FT650setpoint

FV587 opened

Gas and Current lead

heating

EH650 regulated

TT650 = TT650setpoint

EH654 regulated

TT654 = TT654setpoint

stop

Cooling in operation

CV651 regulated

TT691 = TT691setpoint OR

FT651 = FT651setpoint

FV587 opened

Gas and Current lead

heating

EH651 regulated

TT651 = TT651setpoint

EH655 regulated

TT655 = TT655setpoint

(CV650&CV651&CV652&CV653) closed

Current lead IL650

Stop

Open the cooling circuit

FV587 open

FV587 closed

Stop

cooling

CV650 closing with slope

FV587 opened

Stop

cooling

CV651 closing with slope

FV587 opened

Close the cooling circuit

FV587 closed

A

B

Current lead IL652

Current lead IL653

Stop

Cooling in operation

CV652 regulated

TT692 = TT692setpoint OR

FT652 = FT652setpoint

FV587 opened

Gas and Current lead

heating

EH652 regulated

TT652 = TT652setpoint

EH656 regulated

TT656 = TT656setpoint

Stop

Cooling in operation

CV653 regulated

TT693 = TT693setpoint OR

FT653 = FT653setpoint

FV587 opened

Gas and Current lead

heating

EH653 regulated

TT653 = TT653setpoint

EH657 regulated

TT657 = TT657setpoint

Stop

cooling

CV653 closed with slope

FV587 opened

Stop

cooling

CV652 closing with slope

FV587 opened

A

B

Table 1: List of the heaters with the thermometers used to their control

|  |  |  |
| --- | --- | --- |
| Heater | Thermometer | Temperature setpoint |
| EH650  EH651  EH652  EH653  EH654  EH655  EH656  EH657 | TT650  TT651  TT652  TT653  TT654  TT655  TT656  TT657 | TT650setpoint  TT651setpoint  TT652setpoint  TT653setpoint  TT654setpoint  TT655setpoint  TT656setpoint  TT657setpoint |

20 – Emptying of the cryostat

**Sensors and actuators used:**

- Level: LI670, LI680, LT590

- Pressure: PT590, PT660, PT681

- Valve: FV602, FV640, FV641, FV642, FV643, FV680, FV681, Switch valves

- Control valve: CV601, CV602, CV603, CV680, CV581, CV583, CV590, CV591

- Temperature: TT645, TT591

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Level: LI670setpoint, LI680setpoint, LT590setpoint | - Liquid or Magnet insert selected  - Sequences from 1 to 3 stopped  - Sequences 10,12, 13, 14 stopped  - Sequences from 15 to 19 stopped  - Sequence 8 in operation |
| - Pressure: PT660setpoint, PT681setpoint, PT590setpoint |
| - Valve: CV581%opening, CV583%opening, CV590%opening |
| - Temperature: TT645setpoint |

Liquid mode

Start

Stop

CV601 closed

Close CV601, CV602, CV603

Close FV642, FV643

Stop

FV641 closed

Close FV602

Prepare to L021 connection

FV602 closed

No

Yes

“The cryogenic Line L021 is it connected to the cryostat?”

“Do you want to stop the emptying?“

No

Yes

TT645 OR TT590 < TT645setpoint

Isolate Valve Box tank

Open FV640, FV641

CV590 opens with a slope

Cool down

L021

LT590 > LT590setpoint

Stop

LI670 < LI670setpoint

CRYOSTAT EMPTY

“Do you want to stop the emptying or define a new level setpoint?“

DEWAR FULL

“Do you want to stop the emptying or define a new level setpoint?“

LI670 < LI670setpoint OR LT590 > LT590setpoint

New setpoint

Stop

New setpoint

Filling Stopped

Close FV641

CV581 regulated

PT660=PT660setpoint

Pressurization

Cryostat

CV581 regulated

PT660=PT660setpoint

DEWAR FULL

“Have you defined the new level setpoint?“

Yes

CRYOSTAT EMPTY

“Have you defined the new level setpoint?“

Yes

Stop LHe transfer

Close FV640, CV590

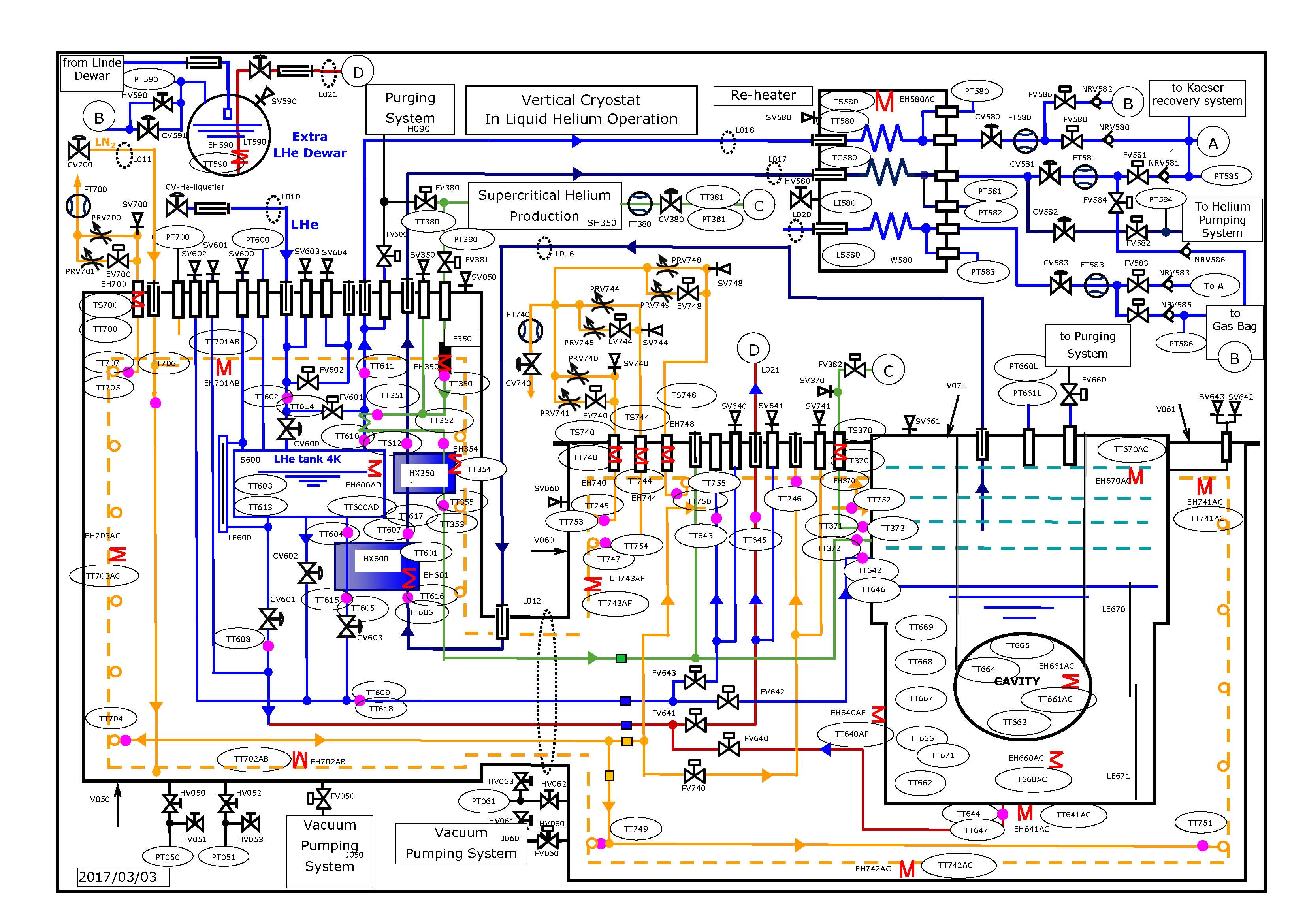
FV641 opened

FV640, FV641 opened

CV590 regulated

PT590=PT590setpoint

Start LHe transfer

Magnet mode

Start

Stop

CV601 closed

Close CV601, CV602, CV603

Close FV642, FV643

Stop

FV641 closed

Close FV602

Prepare to L021 connection

FV602 closed

No

Yes

“The cryogenic Line L021 is it connected to the cryostat?”

“Do you want to stop the emptying?“

No

Yes

TT645 OR TT590 < TT645setpoint

Isolate Valve Box tank

Open FV640, FV641

CV590 opens with a slope

Cool down

L021

LT590 > LT590setpoint

Stop

LI680 < LI680setpoint

CRYOSTAT EMPTY

“Do you want to stop the emptying or define a new level setpoint?“

DEWAR FULL

“Do you want to stop the emptying or define a new level setpoint?“

LI680 < LI680setpoint OR LT590 > LT590setpoint

New setpoint

Stop

New setpoint

Filling Stopped

Close FV641, FV680

CV583 regulated

PT681=PT681setpoint

CV581 opened

Pressurization

Cryostat

CV583 regulated

PT681=PT681setpoint

Close CV680, FV681

Open CV581

Open FV680

DEWAR FULL

“Have you defined the new level setpoint?“

Yes

CRYOSTAT EMPTY

“Have you defined the new level setpoint?“

Yes

Stop LHe transfer

Close FV640, CV590

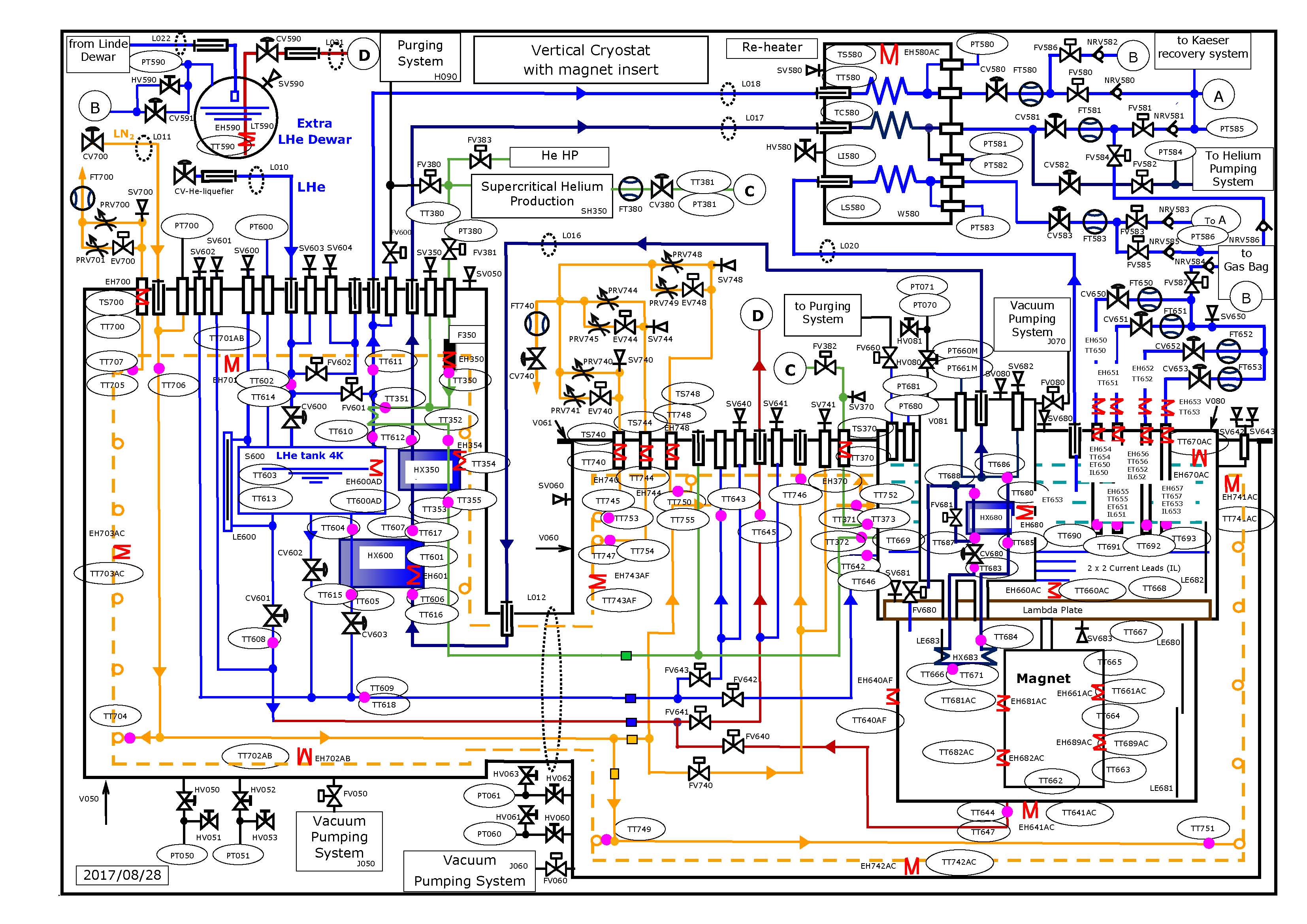
FV641 opened

FV640, FV641 opened

CV590 regulated

PT590=PT590setpoint

Start LHe transfer

21 – Valve Box warm-up

**Sensors and actuators used:**

- Valve: CV580

- Temperature: list in the tables 2, 3 and 4

- Heater: list in the tables 2, 3 and 4

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Temperature setpoint: list in the tables 2, 3 and 4 | - Sequences from 1 to 3 stopped  - Sequences 5 and 9 stopped  - Sequence 8 in operation |

This sequence drives the electrical heaters implicated in the warm-up of the valve box. Each set of heaters has its own cycle. To limit the current draw when starting the heater, the sequences work this way: each set of heaters starts its cycle 10 seconds after the previous. The sequential starting of heaters may take several minutes. The cycles of heater control run in parallel until the user decides to stop the warm-up. The cycles then all stop at the same time.

The sequences used to warm-up the thermal shield and the helium circuits are very similar, but for the helium tank warm-up, the program checks the helium level. As long as the helium tank contains liquid helium, the heating is intermittent and allows evaporating the liquid stored in the tank. The heating operates in continuous mode when the helium tank is empty (LT600<5%).

The sequence 21 can start only when the valve box thermal shield cooling (sequence 5) and the valve box helium cooling sequences are stopped (sequence 9 to 20).

The sequences 21.1, 21.2 and 21.3 are started one after the other as described below:

**21.1:** Warm-up of the valve box thermal shield

All helium tank heaters are started

All thermal shield heaters are started

Warm-up VB

Stop

Stop

Warm-up of the valve box thermal shield

Start 21.1

Start 21.2

21.1 in operation

Warm-up of the helium tank

Start 21.3

21.1 in operation

21.2 in operation

Warm-up of the helium heat exchangers

“Do you want start the warm up of the Cryostat?”

Yes

“You must stop the sequences from 10 to 20”

Sequence 10 to 20 are stopped

Stop LN2

Sequence 5 stopped

Close CV700

The cycle 21-1 used for the control of the electrical heaters glue on the thermal shield heaters (EH701AB) is given below:

TT701 A or B >TT701setpoint

Warm-up VB

Stop

Stop

To other heaters

Stop warm-up

Stop EH701AB

Warm-up

Start EH701AB

TT701 A and B < (TT701setpoint - 5°C)

Delay

Subsequence

The table 2 gives the list of heaters implicated in the warm-up of the thermal shields.

|  |  |  |
| --- | --- | --- |
| Heater | Thermometer | Temperature setpoint |
| EH701AB  EH702AB  EH703AC | TT701AB  TT702AB  TT703AC | TT701setpoint  TT702setpoint  TT703setpoint |

**21.2:** Warm-up of the helium tank

The cycle 21-2 used for the helium heaters glue on a helium tank is given below:

TT600A OR B OR C OR D >TT600setpoint

LT600 ≤ 5

Start 21.2

Stop

Stop

Warm-up

Start EH600AD

CV580 opened

LT600 > 5

Stop

Warm-up

Stop EH600AD

CV580 opened

TT600A and B and C and D < (TT600setpoint – 5°C)

EH600AD running 5s, Delay 20s

Open CV580

Check liquid level

Subsequence

The table 3 gives the list of heaters implicated in the warm-up of the helium tanks.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Heater | Pt thermometer | Level | Temperature setpoint | CX thermometer | Temperature threshold |
| EH600AD | TT600AD | LT600 | TT600setpoint | TT603 | 30K |

**21-3:** Warm-up of the helium heat exchangers

The cycle 21-3 used for the helium heaters glue on the heat exchangers is given below:

Start 21.3

TT601 < (TT601setpoint – 5°C)

Stop

Stop

Warm-up

Start EH601

Stop

Warm-up

Stop EH601

Stop

Warm-up

Start EH354

Open FV381

Stop

Warm-up

Stop EH354

FV381 opened

TT354 >TT354setpoint

TT354 < (TT354setpoint – 5°C)

TT601 >TT601setpoint

Delay

He circuits closed

Close FV381

FV381 closed

Subsequence

The table 4 gives the list of heaters implicated in the warm-up of the heat exchangers.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Heater | Pt thermometer | Level | Temperature setpoint | CX thermometer | Temperature threshold |
| EH601  EH354 | TT601  TT354 |  | TT601setpoint  TT354setpoint | TT606  TT355 | 30K  50K |

22 – Cryostat warm-up

**Sensors and actuators used:**

- Temperature: list in the tables from 5 to 7

- Heater: list in the tables from 5 to 7

- Level: LI670, LI680

- Valve: CV581

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Temperature setpoint: list in the tables from 5 to 7 | - Sequences from 1 to 3 stopped  - Sequences 6 and 7 stopped  - Sequences from 10 to 20 stopped  - Sequence 8 in operation |
| - Level: LI670mini, LI680mini  - Flow: FT581limit, FT583limit |

This sequence drives the electrical heaters implicated in the warm-up of the cryostat. Each set of heaters has its own cycle. To limit the current draw when starting the heater, the sequences work this way: each set of heaters starts its cycle 10 seconds after the previous. The sequential starting of heaters may take several minutes. The cycles of heater control run in parallel until the user decides to stop the warm-up. The cycles then all stop at the same time.

The sequences used to warm-up the thermal shield and the helium circuits are very similar, but for the pressure vessel warm-up, the program checks the helium level. As long as the cryostat contains liquid helium, the heating is intermittent and allows evaporating the liquid stored in the cryostat. The heating operates in continuous mode when the cryostat is empty (Liquid helium level<5%).

The sequence 22 can start only when the cryostat thermal shield cooling (sequence 6) and the cryostat helium cooling sequences are stopped.

The sequences 22.1 and 22.2 are started one after the other as described below:

All thermal shield heaters are started

Warm-up Cryostat

Stop

Stop

Warm-up of the cryostat thermal shield

Start 22.1

Start 22.2

22.1 in operation

Warm-up of the pressure vessel

“Do you want start the warm up of the Cryostat?”

Yes

“You must stop the sequences 6 and from 10 to 20”

Sequence 6 and 10 to 20 are stopped

Stop LN2 – stop the sequence 5

Sequence 5 stopped

**22-1:** Warm up of the cryostat thermal shield

The sequence used for the warm-up of the cryostat thermal shield is similar to the valve box thermal shield sequence 21-1.

Subsequence

(TT741A OR TT741B OR TT741C) >TT741setpoint

Stop

To other heaters

Stop warm-up

Stop EH741AC

Warm-up

Start EH741AC

(TT741A & TT741B & TT741C) < (TT741setpoint - 5°C)

Open CV740

GN2 circuits

opened

Close CV740

GN2 circuits

opened

Stop

CV740 closed

Delay

Sequence 6 stopped

Stop

Vacuum or Liquid or Magnet mode

Table 5: Cryostat warm-up - Thermal shields

|  |  |  |
| --- | --- | --- |
| Heater | Thermometer | Temperature setpoint |
| EH741AC  EH742AC  EH743AF | TT741AC  TT742AC  TT743AF | TT741setpoint  TT742setpoint  TT743setpoint |

**22-2:** Warm-up of the pressure vessel

This sequence 22-2 is similar to the sequence Warm up Valve Box 21-2.

Liquid mode

Subsequence

TT641A OR B OR C >TT641setpoint OR FT581<FT581limit

LI670 ≤ 5

Stop

Warm-up

Start EH641AC

CV581 opened

LI670 > 5

Stop

Warm-up

Stop EH641AC

CV581 opened

Stop

Warm-up

Start EH640AF

Stop

Warm-up

Stop EH640AF

TT640A OR B OR C OR D

OR E OR F > TT640setpoint OR FT581>FT581limit

TT640A OR B OR C OR D OR E

OR F < (TT640setpoint – 5°C)

& FT581<FT581limit

TT641A and B and C < (TT641setpoint – 5°C)

& FT581<FT581limit

EH641AC running 5s, Delay 20s

Open FV640, FV642

Open CV581

Check liquid level

Delay

All thermal shield heaters are started

Closing circuits

Close FV640, FV642

Stop

FV640 & FV642

closed

Table 6: Cryostat warm-up - Helium tank – Liquid mode

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Heater | Pt thermometer | Level | Temperature setpoint | CX thermometer | Temperature threshold |
| EH640AF  EH641AC | TT640AF  TT641AC | LI670  LI670 | TT640setpoint  TT641setpoint | TT644  TT644 | 50K  50K |

Magnet mode

TT641A OR B OR C >TT641setpoint

OR FT583>FT583limit

LI680 ≤ 5

Stop

Warm-up

Start EH641AC

CV581, CV583 opened

FV680 opened

LI680 > 5

Stop

Warm-up

Stop EH641AC

CV581, CV583 opened

FV680 opened

Stop

Warm-up

Start EH640AF

Stop

Warm-up

Stop EH640AF

TT640A OR B OR C OR D

OR E OR F > TT640setpoint

OR FT583>FT583limit

TT640A OR B OR C OR D

OR E OR F < (TT640setpoint – 5°C)

& FT583<FT583limit

TT641A and B and C < (TT641setpoint – 5°C)

& FT583<FT583limit

Stop

EH641AC running 5s, Delay 20s

Open CV581, CV583

Open FV680

Check liquid level

Delay

Close the Lambda plate valve

Close FV680

Close FV640

Close FV642

FV680 closed

Subsequence

All thermal shield heaters are started

Table 7: Cryostat warm-up - Helium tank – Magnet mode

|  |  |  |  |
| --- | --- | --- | --- |
| Heater | Thermometer | Level | Temperature setpoint |
| EH640AF  EH641AC | TT640AF  TT641AC | LI680  LI680 | TT640setpoint  TT641setpoint |

23 – Inserts warm-up

**Sensors and actuators used:**

- Temperature: list in the tables from 8 to 11

- Heater: list in the tables from 8 to 11

- Level: LI660, LI670, LI680, LT682

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Temperature setpoint: list in the tables from 8 to 11 | - Sequences from 1 to 3 stopped  - Sequences 6 and 7 stopped  - Sequences from 10 to 20 stopped  - Sequence 8 in operation |
| - Flow: FT581limit, FT583limit  - Level: LI660mini, LI670mini, LI680mini |

This sequence drives the electrical heaters implicated in the warm-up of the inserts. Each set of heaters has its own cycle. To limit the current draw when starting the heater, the sequences work this way: each set of heaters starts its cycle 10 seconds after the previous. The sequential starting of heaters may take several minutes. The cycles of heater control run in parallel until the user decides to stop the warm-up. The cycles then all stop at the same time.

The sequences used to warm-up the thermal shield and the helium circuits are very similar, but for the helium circuits warm-up, the program checks the helium level. As long as the cryostat or helium tank contains liquid helium, the heating is intermittent and allows evaporating the liquid stored in the cryostat or in the insert helium tank. The heating operates in continuous mode when the cryostat (helium tank) is empty (Liquid helium level<Liquid helium level mini).

The tables from 8 to 11 give the list of heaters implicated in the warm-up of the inserts.

The sequences 23.1 and 23.2 are started one after the other as described below:

**23-1:** Warm-up of the vacuum insert thermal shield

Yes

Sequence 10 to 20 are stopped

All thermal shield heaters are started

Warm-up Vacuum

Stop

Stop

Warm-up of the

insert thermal shield

Start 23.1

Start 23.2

23.1 in operation

Warm-up of the helium circuits

Warm-up Liquid

Stop

Start 23.2

Warm-up of the helium circuits

Start 23.2

Warm-up of the helium circuits

Warm-up Magnet

Stop

“Do you want start the warm up of the Cryostat?”

“You must stop the sequences from 10 to 20”

The sequence used for the warm-up of the vacuum insert thermal shield is similar to the warm-up of the valve box thermal shield sequence 21-1 and the cryostat thermal shield 22-1.

The sequence 23 in vacuum mode can start only when the cryostat thermal shield cooling (sequence 7) and the cryostat helium cooling sequences are stopped.

Vacuum mode

Subsequence

Stop

Stop

To other heaters

Stop warm-up

Stop EH761AC

Warm-up

Start EH761AC

(TT761A OR TT761B OR TT761C) >TT761setpoint

(TT761A & TT761B & TT761C) < (TT761setpoint - 5°C)

Delay

Stop LN2

Sequence 7 stopped

Table 8: Insert warm-up – Thermal shield – Vacuum insert

|  |  |  |
| --- | --- | --- |
| Heater | Thermometer | Temperature setpoint |
| EH761AC  EH763AF  EH765AC | TT761AC  TT763AF  TT765AC | TT761setpoint  TT763setpoint  TT765setpoint |

**23-2:** Warm-up of the helium circuit

This sequence 23-2 is similar to the sequences Warm up Valve Box 21-2 and Warm-up Cryostat 22-2.

Vacuum mode

Subsequence

TT661A or B or C >TT661setpoint

OR FT581>FT581limit

LI660 ≤LI660mini

Stop

Warm-up

Start EH661AC

CV581 opened

LI660 >LI660mini

Stop

Warm-up

Stop EH661AC

CV581 Opened

Stop

Warm-up

Start EH660AC

Stop

Warm-up

Stop EH660AC

TT660A OR B OR C > TT660setpoint

OR FT581>FT581limit

TT660A & B & C < (TT660setpoint – 5°C)

& FT581<FT581limit

TT661A & B & C < (TT661setpoint – 5°C)

& FT581<FT581limit

Stop

EH661AC running 5s, Delay 20s

Open CV581

Check liquid level

Delay

Sequence 10 to 20 are stopped

Table 9: Insert warm-up – Helium circuits – Vacuum insert

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Heater | Pt thermometer | Level | Temperature setpoint | CX thermometer | Temperature threshold |
| EH660AC  EH661AC | TT660AC  TT661AC | LI660  LI660 | TT660setpoint  TT661setpoint | TT663  TT663 | 50K  50K |

Stop

Stop

TT661A & B & C < (TT661setpoint – 5°C)

& FT581<FT581limit

TT660A & B & C < (TT660setpoint – 5°C)

& FT581<FT581limit

Subsequence

TT660A OR B OR C >TT660setpoint

OR FT581>FT581limit

LI670 ≤ LI670mini

Warm-up

Start EH660AC

CV581 opened

LI670 > LI670mini

Warm-up

Start EH661AC

TT661A OR B OR C > TT661setpoint

OR FT581>FT581limit

Stop

EH660AC running 5s, Delay 20s

Open CV581

Check liquid level

Delay

Sequence 10 to 20 are stopped

Stop

Warm-up

Stop EH660AC

CV581 opened

Stop

Warm-up

Stop EH661AC

Liquid mode

Table 10: Insert Warm-up – Helium circuits – Liquid insert

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Heater | Pt thermometer | Level | Temperature setpoint | CX thermometer | Temperature threshold |
| EH660AC  EH661AC  EH670AC | TT660AC  TT661AC  TT670AC | LI670  LI670 | TT660setpoint  TT661setpoint  TT670setpoint | TT663  TT663 | 50K  50K |

Magnet mode

Sequence 10 to 20 are stopped

Subsequence

TT661A or B or C >TT661setpoint

OR FT583>FT583limit

LI680 ≤ LI680limit

Stop

Warm-up

Start EH661AC

CV581, CV583 opened

FV680 opened

LI680 > LI680limit

Stop

Warm-up

Stop EH661AC

CV581, CV583 opened

FV680 opened

Stop

Warm-up

Start EH660AC

Stop

Warm-up

Stop EH660AC

TT660A or B or C > TT660setpoint

OR FT583>FT583limit

TT660A & B & C < (TT660setpoint – 5°C)

& FT583<FT583limit

TT661A and B and C < (TT661setpoint – 5°C)

& FT583<FT583limit

Stop

EH661AC running 5s, Delay 20s

Open CV581, CV583

Open FV680

Check liquid level

Close the Lambda plate valve

Close FV680

FV680 closed

Delay

Table 11: Insert Warm-up - Helium circuits – Magnet insert

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Heater | Pt thermometer | Level | Temperature setpoint | CX thermometer | Temperature threshold |
| EH660AC  EH661AC  EH680  EH681AC  EH682AC  EH689AC  EH670AC | TT660AC  TT661AC  TT680  TT681AC  TT682AC  TT689AC  TT670AC | LT682  LI680  LI680  LI680  LI680  LI680 | TT660setpoint  TT661setpoint  TT680setpoint  TT681setpoint  TT682setpoint  TT689setpoint  TT670setpoint | TT668  TT663  TT685  TT664  TT664  TT664 | 50K  50K  50K  50K  50K  50K |

24 – Cryostat isolated or connected to the He recovery circuit

**Sensors and actuators used:**

- Pressure: PT660, PT681

- Valve: FV581, FV582, FV583, FV584, FV585, FV587, FV640, FV641, FV642, FV643, Switch Valves

- Control valve: CV581, CV583.

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Cryostat isolated or not isolated | - Sequences 6 and 7 stopped  - Sequences from 10 to 20 stopped |
| - Mode : Vacuum/Liquid, Magnet |
| - Pressure setpoint: PT660Maxi |

PT660 > PT660Maxi

OR

PT681> PT660Maxi

Alarm validated

Cryostat isolated

Close Switch Valves “Cryostat 4K circuit”

Close Switch Valves “Magnet 4K circuit”

Close FV640, FV641, FV642, FV643, FV587

Close FV582

Open CV581, CV583

Open Switch Valves “Cryostat 4K circuit”

Open Switch Valves “Magnet 4K circuit”

Magnet

Stop

Not isolated

Alarm validated

Cryostat isolated

Cryostat isolated

Close Switch Valves “Cryostat 4K circuit”

Close FV640, FV641, FV642, FV643

Close FV582

Open CV581

Open Switch Valves “Cryostat 4K circuit”

Pressure control

He Circuits

Pressure Alarm

Liquid OR Vacuum

Not isolated

Stop

Not isolated

Cryostat connected at the He recovery circuit

Cryostat connected at the He recovery circuit

PT660 > PT660Maxi

He Circuits

Pressure Alarm

Cryostat isolated

Stop

Pressure control

Not isolated

25 – Valve Box isolated or connected to the He recovery circuit

**Sensors and actuators used:**

- Pressure: PT600

- Valve: FV580, FV586, FV640, FV641, FV642, FV643, Switch Valves

- Control valve: CV580, CV-He-liquefier, CV590

|  |  |
| --- | --- |
| **The user chooses:** | **Initial conditions:** |
| - Valve Box isolated or Not isolated | - Sequences 5 and 9 stopped |
| - Pressure setpoint: PT600Maxi |  |

PT600 > PT600Maxi

Alarm validated

Valve Box Isolated

Cryostat isolated

Close CV-He-liquefier, CV590

Close Switch Valves “Valve Box circuit”

Close FV640, FV641, FV642, FV643

Cryostat connected at the He recovery circuit

Open CV580

Open Switch Valves “Valve Box circuit”

Pressure control

He Circuits

Pressure Alarm

Start

Stop

Stop

Stop

Not isolated

Not isolated

Not isolated