Cryogenic behavior of the cryogenic system

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The cryogenic behavior includes

- Cooling down of the magnet
- Operation at 4.5 K temperatures
- Warming up
- Quench recovery

Cooling down of the magnet

Three stages of the cooling down:

- from 295 K to ~ 200 K (50% of energy)
- from ~200 K to ~80 K ()
- from 80 K to 4.5 K

From 295 K to 200 K

At the beginning some time will be spent for vacuum pumping. After several days it will be $10^{-2} \div 10^{-3}$ Pa.

Total stored energy in one coil is ~ 160 MJ, about 50% in this stage.

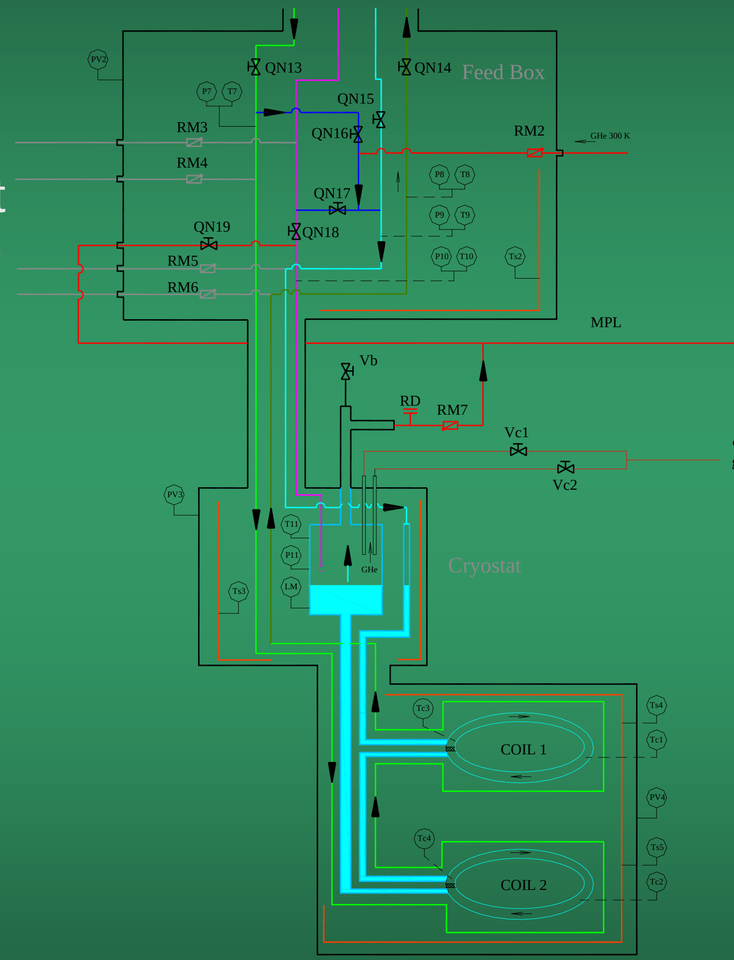
For cooling rate 1 K/h the power needed is ~450 W for two coils.

The radiation shields should be cooled first. The flow rate should be low for condensing water in the FB vicinity.

 They will give from 150 W to ~50 W cooling power.

The magnet is cooled by 50 K helium of slow rate, about 0.4 g/s. Gas enthalpy is working.

Proposal to control temperature difference on the magnet during the cooling down.



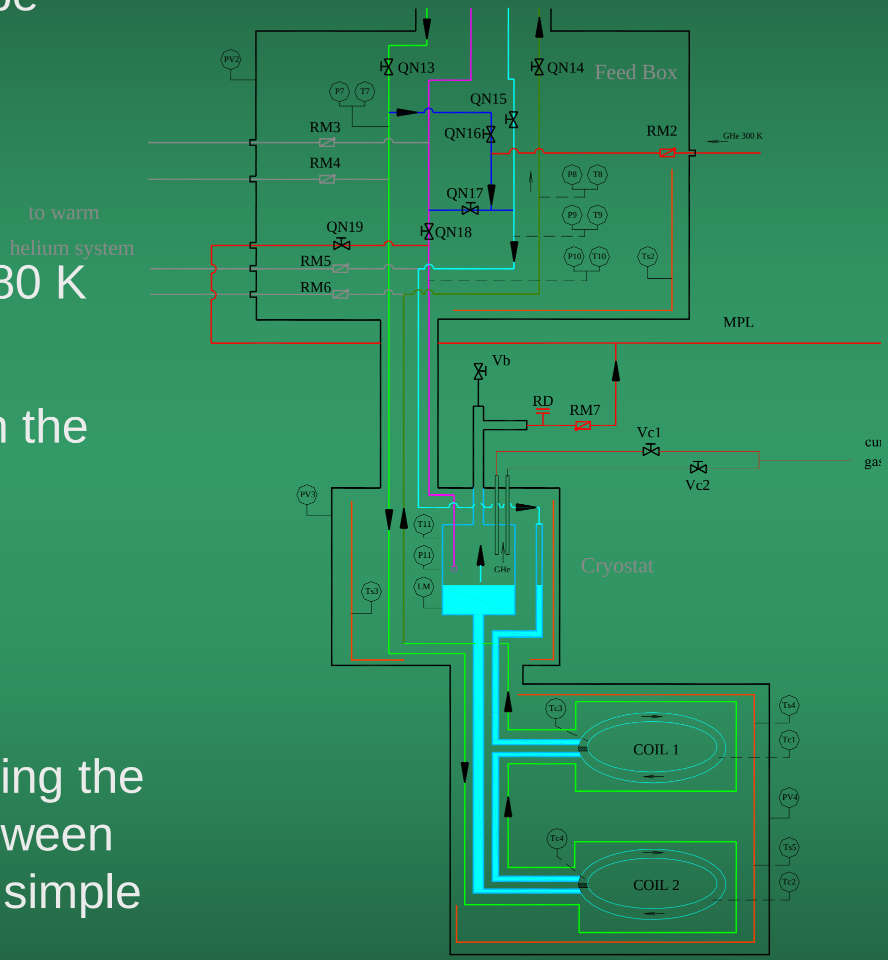
From 200 K to 80 K

About 45% of the initial stored energy will be extracted in this stage.

The cryogenic diagram is the same

The magnet is cooled by 50 K helium of increasing flow rate, about 1 g/s. Close to 80 K the flow rate will increased higher.

The temperature difference is controlled on the magnet.



For discussion

As alternative to use warm helium for cooling the magnet, installation of heat exchanger between the QN16 and QN17 valves may be more simple solution.

Cooling down from ~80 K to 4.5 K

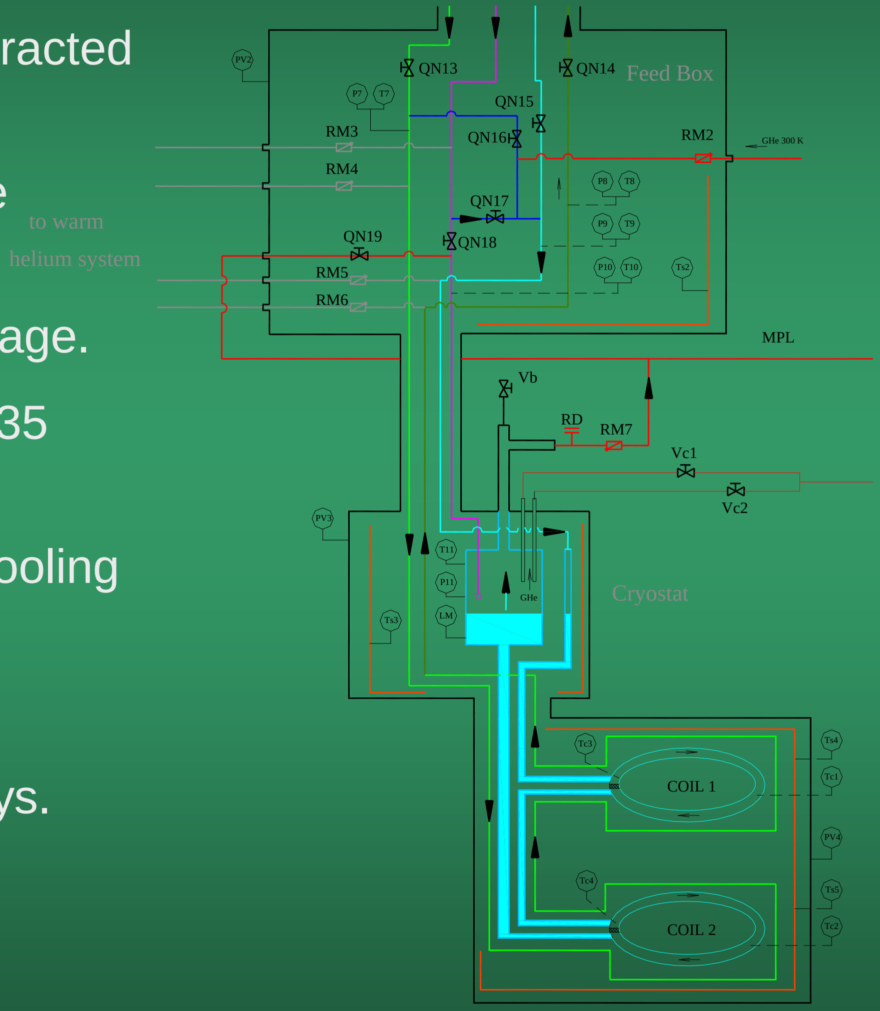
About 10% of the stored energy will be extracted in this stage, about 16 MJ for one coil.

The cooling scheme is changed like on the diagram.

The 4.6 K will be used for cooling in this stage.

At 1.5 g/s mass flow rate it will take about 35 hours in this stage.

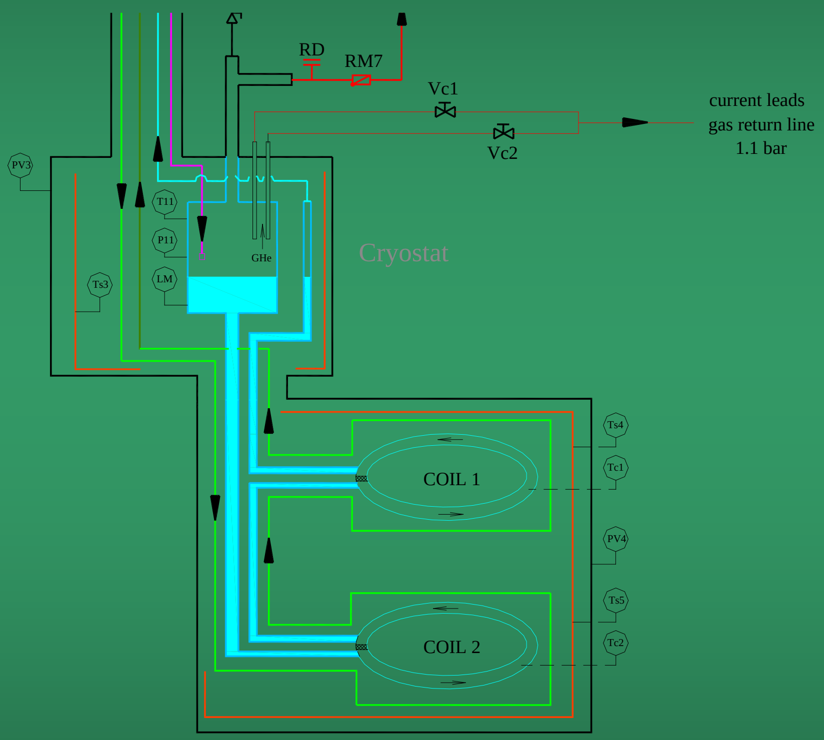
After reaching the 5 K temperatures, the cooling diagram becomes as for ordinal operation.



Total time for cooling the magnet is ~ 8 days.

Operation at 4.5 K temperatures

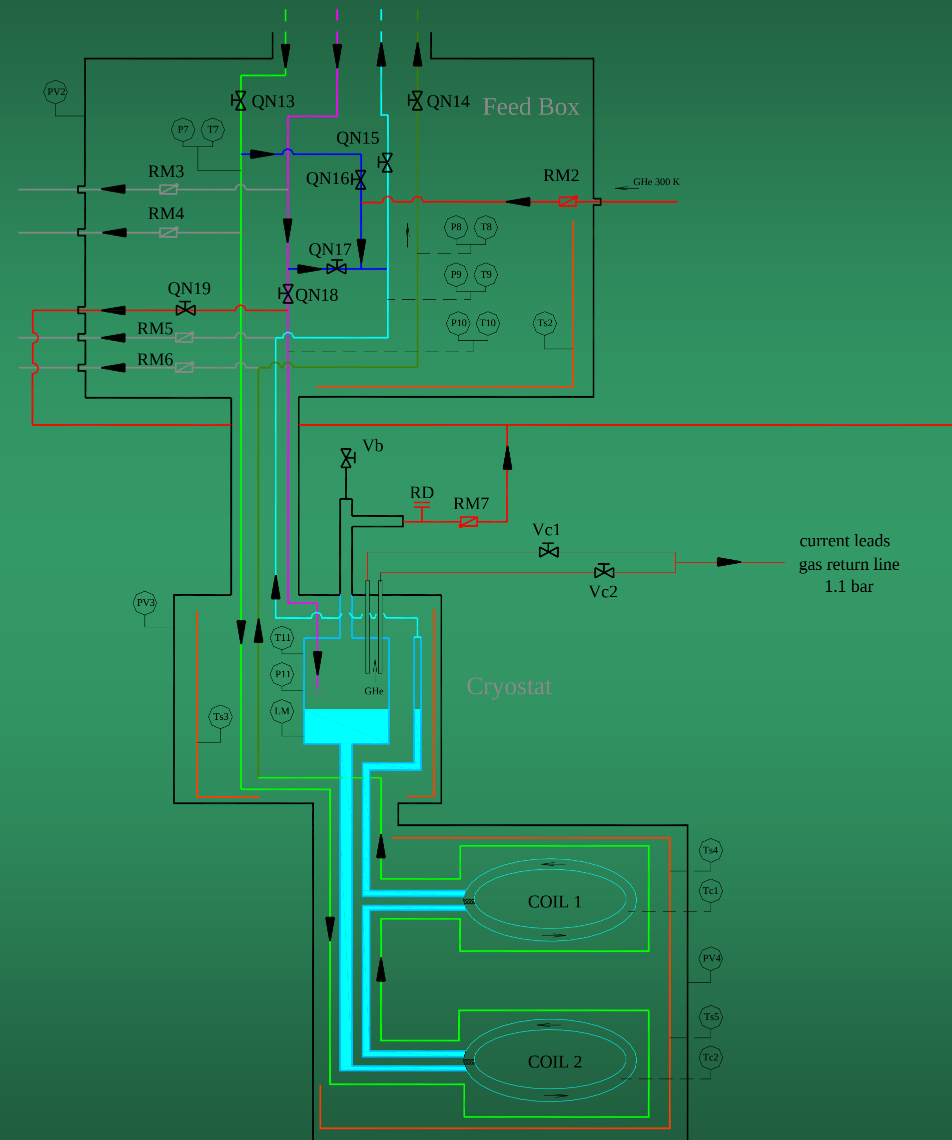
Some part of gaseous helium will go through the current leads, its flow will be controlled by a heater installed in the cryostat.
The liquid helium level will be measured by installed LHe level meter.
One of the possible scenarios of LHe level controlling is to operate at insufficient flow of helium by controlling of QN8 valve, i.e. 1.5 g/s instead of demanded 1.7 g/s of flow rate. When the LHe level becomes too low then the QN18 will be opened to supply 1.8 g/s rate until demanded level of helium in the cryostat



Warming up

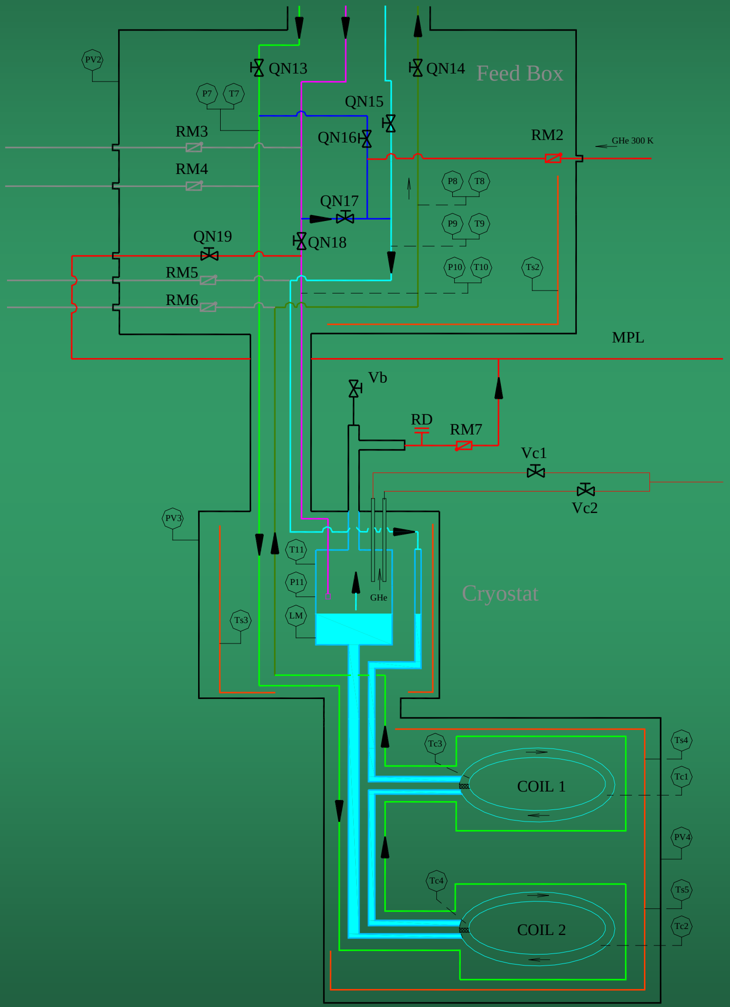
This process will be conducted on the same principle as in the cooling down in the first and the second stages. The supply of 50 K helium should be shut. After increasing the lowest temperature in the cryogenic system beyond 27-28 K the vacuum pressure will be increased rapidly.

As a proposal, a number of heaters may be installed on the cold mass of the magnet to give power 200-400 W. Additional power will come from heat transfer between the radiation shields and the magnet due to radiation and gases of vacuum volume. This power will be greater than from the proposed heaters.



Quench recovery

If quench had occurred then the QN8 and QN9 valves in BB should be closed. The rising pressure in the cryostat will open RM7 valve to the multipurpose line. Liquid helium in the cryostat will not go down to the coils. The highest pressure in the system will be not more than 3 bar due to little amount of stored liquid helium in the system. In the worse case of quench, when the stored energy is fully dissipated in one coil – this coil after a quench will be slowly cooled from ~ 90 K to ~ 50 K due to heat transfer between the winding and the heavy LHe case. After this the cooling down procedure will go as in the third stage of cooling down the magnet.



Safety analysis

Very high pressure may be in the cryostat in case of a quench or any break of insulating vacuum when air or even helium may leak inside the vacuum volume. It will lead to very high heat flux to the liquid helium inside the LHe case.

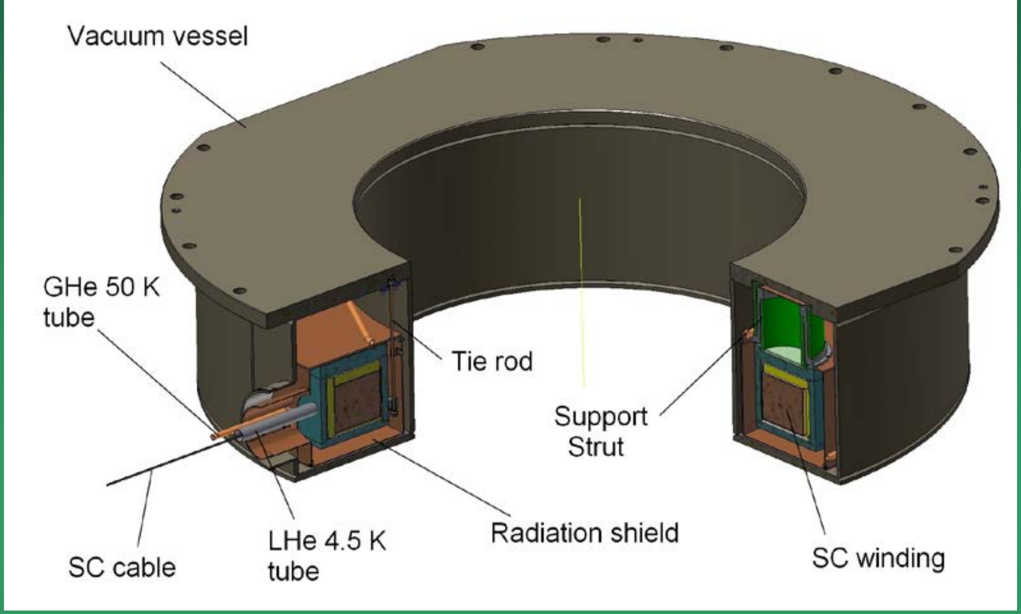
Typical value of the heat flux is 10 kW/m^2. This factors determines the mass flow rate of helium – G to be evacuated from the system.

The tube diameter was taken as

d= 0.03 m. The result is

Δp = 1.7 bar

Helium will be evacuated after 5 s at given parameters.



$$\Delta p = \xi \frac{8G^2}{\pi^2 \rho \cdot Y^2} \cdot \frac{L}{d^5},$$