# The Panda Solenoid Proximity Cryogenics.

Andrea Bersani Renzo Parodi
INFN-Genova

**Abstract.**

We describe two possible solutions for the PANDA Solenoid.

Two equally possible solutions are outlined: one using as custom designed closed Loop Helium refrigerator providing adequate refrigeration power both at 50K for the intermediate temperature shields and at 4.5K for the forced flow refrigeration of the coil cold mass.

This first solution, following the Atlas Central solenoid refrigeration scheme, integrate a quite large control Dewar, used also for the refrigeration o the Cryogenic current leads, allowing a limited thermo-siphon operation of the coil in case of sudden failure of the refrigerator.

The second solution follows the refrigeration scheme adopted in the BaBAR magnet. In that scheme only a Helium Liquefier is used, filling a big helium Dewar (2000-4000Litres capacity) used as storage-buffer. The Liquid helium is fed to a small control Dewar in the Cryogenic turret to compensate for the Current leads and coil thermal losses. The right amount of the control Dewar is used to cool to 50K the intermediate shields trough low hydraulic impedance cooling loops.

Both systems can be tailored to guarantee the magnet operation with the needed safety factors

**Introduction.**

For the PANDA Experiment Target Spectrometer a superconducting coil is foreseen.

The operation of the coil requires a quite large refrigeration power to compensate he Cryogenic losses.

The largest Cryogenic losses are coming from the radiation load, and from the current leads boil-off. The heat conduction along the mechanical supports of the cold mass can be reduced at will by a suitable choice of the support material and dimensions. We proved that the total heat input due to the mechanical supports can be reduced to few watts also in the case of axial forces as large as ~1 MN by using Titanium grade 6 and ~ two meters long axial supports.

A big fraction o the radiation load is absorbed at 50K by a thermal shield inserted between the coil and the cryostat outer can. This shield as to be built in insulated section to avoid large forces, eddy current induced, in case of a fast dump of the magnet energy in case of coil quenches.

Last the Cryogenic system need provide the amount of refrigeration, in excess of the steady state operation, to compensate the eddy current heating of the coil during the rap up of the magnet to the operation field.

The total losses foreseen for the magnet are reported in the following, together with the safety margin assumed on the design figures.

The solenoid needs (at the actual stage of the design) Cryogenic supplies from the central Cryo for the operation amounting to (including the quoted safety factors)

60 Watts Refrigeration @4.5K (safety factor 2 included)

150 Watts refrigeration @ 50 K (safety factor 2 included)

1 g/sec liquid helium (liquefaction) for the operation of the Copper counter flow Current leads (safety factor 1.5 included).

**Forced flow Cooling**

In the firsts stage of the design we planned to use forced flow cooling both for the 4.5 K coil and the 50K thermal shields.

A fraction of the 4.5K flow is used, after a Joules-Thompson (JT) expansion, to produce saturated liquid helium at 4.3K stored in a control Dewar housing the counter flow Current leads rated for the 5000A operation of the solenoid. The 1g/sec helium boil-off from the current leads is recovered at Room temperature and 1 bar pressure.

The flow diagram of the forced flow cooling system is shown on figure1

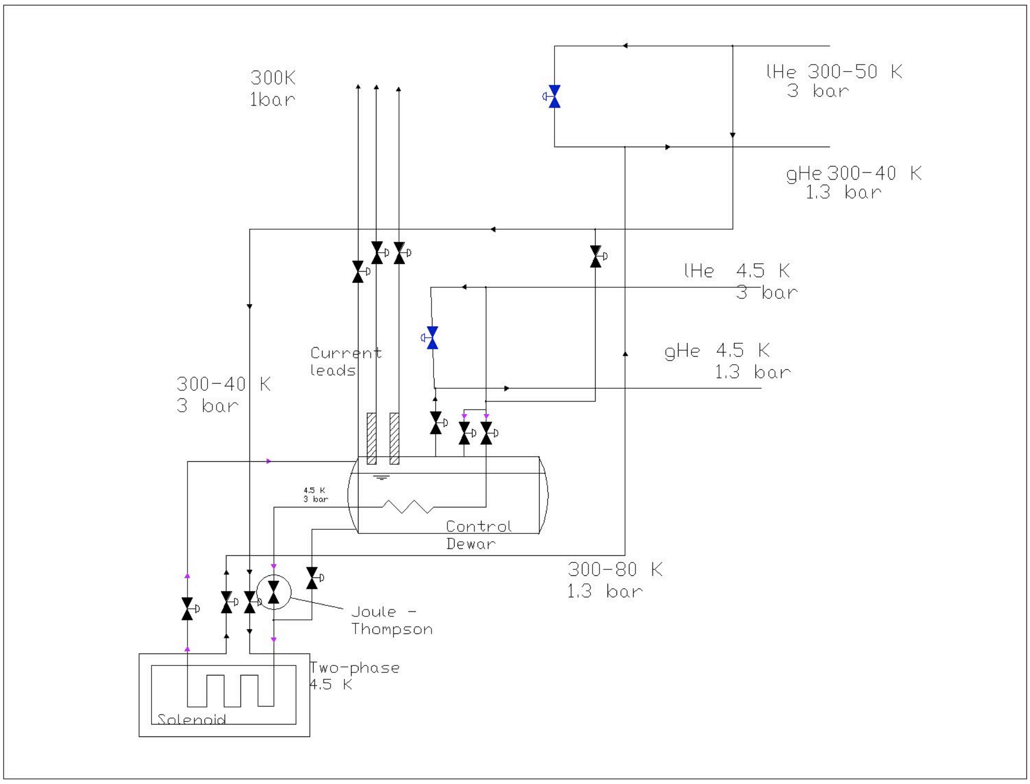


**Figure1, Flow diagram of the Forced Flow refrigeration system**

Following the suggestion of the Panda Magnet independent referees, we decided to implement in or system a safety feature already used by Akira Yamamoto in the Proximity Cryogenics of the Atlas Central Solenoid[1]

The volume of the Reservoir used to cool the Current leads, is increased to a capacity allowing the operation of the Coil refrigeration system (in case of failure of the main refrigerator) for the time needed to slowly discharge the solenoid, without using any fast discharge, to dump the coil energy to an external protection resistor avoiding any Coil quench.

In this way, for minor refrigerator failures, we avoid the dead time of the coil re-cooling due to a partial dump of the stored energy in the winding.

In Normal operation the 4.5K 3bar helium, coming from the refrigerator, pass trough an heat exchanger placed in the control Dewar, to be thermally stabilized; a small amount of this flow ~1/sec), trough a JT expansion, produce the liquid helium used to cool the current leads.

The 4.5K 3 bar helium is fed to the cooling loops of the coil trough a JT expansion producing saturated helium at 4.5K, 1.3bar with a vapor to liquid fraction of about 0.1. The refrigeration of the coil is obtained by the evaporation of the saturated liquid helium, changing the liquid/vapor fraction along the cooling loops to about 0.3-0.4.

The output of the cooling loops is returned to the control Dewar, acting as a phase separator; the 4.5K, 1.3 bar helium gas is then returned to the refrigerator.

In case of refrigerator failure, the flow from the refrigerator stops, the JT valve is closed, and the saturated Liquid helium from the Control Dewar is admitted to the cooling loops of the coil.

With a careful design of the cooling loop hydraulic impedance, the saturated helium start to circulate by natural convection (thermo-siphon effect) giving adequate emergency cooling to the Magnet.

The dimension of this emergency Liquid Helium storage should be decided on the basis of the magnet and experiment needs.

The minimum operation time for a slow magnet discharge is ~ 1 Hour, this meant that the helium storage need not to be seriously depleted on this time.

The planned helium consumption per hour of the PANDA coil correspond to:

1 g/s or ~30 liters per hour evaporated by the current leads, and 60 Watts thermal load. (Safety factors quoted as design criteria included).

To Guarantee an hour of operation (in case of refrigerator failure) the total volume of the “Control Dewar – safety buffer” for forced flow operation “a’ la ATLAS”, should beat least tree to four times larger than this value or~ 350-500litres.

This redundancy will account also for the effect of reduced shielding of the 50K shields left to float freely due to the lack of 50K helium flow.

In the original proposal for the PANDA Cryogenic System, the cooling Power for the magnet was provided by the refrigeration system of the HESR antiproton storage ring (foreseen to use superconducting magnets)

The refrigeration and the return of the low temperature gases are assured by connecting the magnet to the refrigeration lines of the HESR.

The very same scheme can be now transposed to the actual scheme using a dedicated refrigerator to cool down both the PANDA Solenoid and the Compensating

Coil used to reduce to Zero the integral of the magnetic field along the HESR built using resistive magnets.

A dedicated refrigerator with an adequate cooling power (a Linde TCF50 or equivalent), custom tailored to provide, with the needed redundancy, the nominal refrigeration power (both at 50 and 4.5 K) and the needed amount of liquid helium, is situated close to the IP in the HESR hall. The panda Solenoid is connected to the refrigerator very same way foreseen for the connection to the HESR Cryogenic System.

A second line is used to feed the cryostat of the Compensating solenoid sitting upstream the IP of the HESR.

**Natural Convection Cooling**

The opportunity of using a dedicated refrigerator suggested us to investigate a different refrigeration scheme based on the system adopted in the BaBAR magnet[2]

The diagram of the natural convection cooling system is shown in figure2

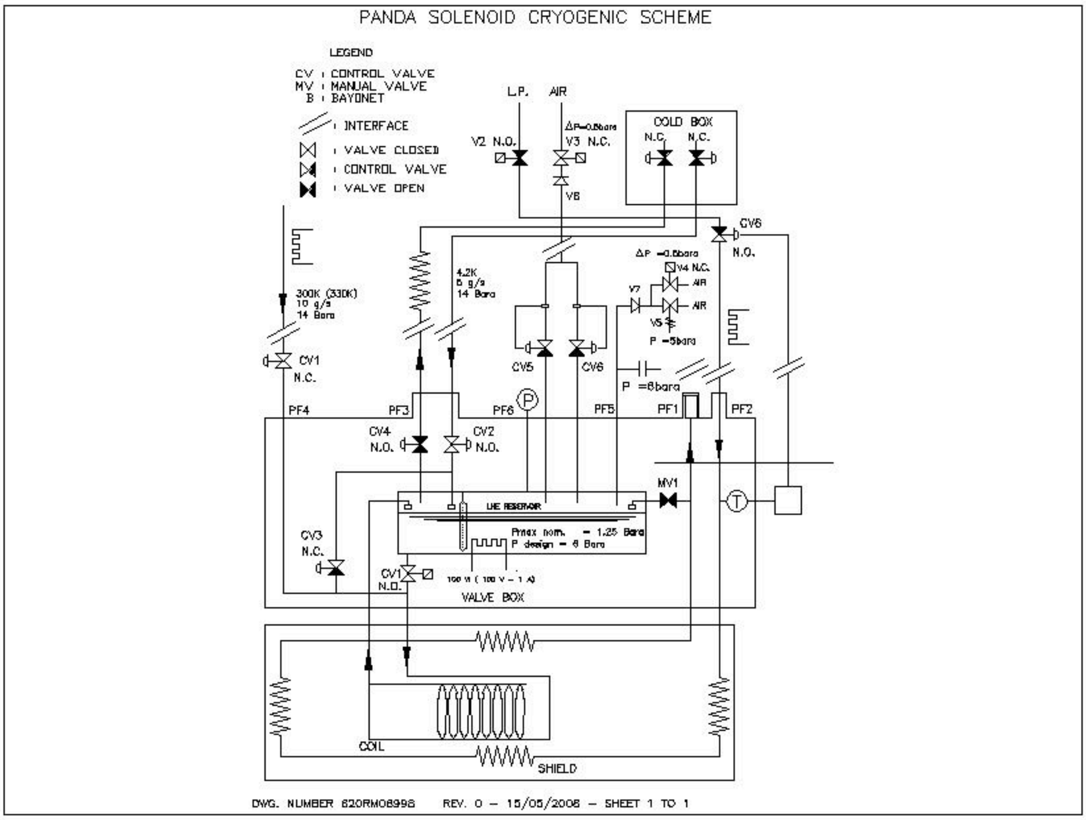


**Figure2, Flow diagram of Natural Convection refrigeration system**

In that scheme we use a Helium liquefier of adequate capacity (a Linde TCF50 is still adequate) used to produce liquid helium in storage Dewar 2000 to 4000 liters in capacity.

The stored liquid helium is transferred to the HESR IP trough a coaxial transfer line (screened by the 4.5K, 1.3Bar return gas from the PANDA Control Dewar).

The two manifolds are connected together by the net of cooling pipes welded to the outer cylinder of the coil.

The liquid helium enters the lower manifold, and leaves the upper, after flowing trough the cooling net, returning to the control Dewar.

The saturated 1.3bar 4.5K liquid helium flows from the control Dewar in the two manifold placed on the top and the bottom of the coil winding, welded to the AL5083 outer cylinder of the coil winding.

In this process the cooling power is given by the vaporization of the amount of liquid helium needed to compensate the thermal load produced by the radiation from the 50K thermal shields and the conduction load from the mechanical supports. (Max. 60 watt)

The coolant circulation is guaranteed (as in Babar, Finuda, Aleph and ATLAS) by the Thermo-siphon effect produced by the change of density in the coolant due to the helium vaporization.

The control Dewar houses the two current leads cooled by the counter flow of the boiled off helium vapor.

The helium gas coming out from the current leads is recovered at Room temperature and 1 bar pressure.

The helium vapor, at 4.5K 1.3 bar, returning to the control Dewar from the Coil Thermo-siphon, is partly used to cool the thermal shield of the main transfer line from the liquefaction Dewar, partly to cool down the intermediate temperature shields at ~50 K of the solenoid.

The 4.5 K gas flows trough a low hydraulic impedance cooling loop welded (riveted) to the thermal shields.

The flow of the gas is controlled trough the valve CV6 actuated trough a PID regulator sensing the Temperature the 50K shields and of the Output gas from the intermediate shields cooling loop.

The foreseen thermal load on the intermediate shields is ~150 Watt (safety factor 2 included). The enthalpy difference for the helium vapor/gas between 4.5K and 50K is ~240 J/g giving a comfortable margin (not ideal heath exchange) for the shield operation with a coolant flow of 1g/sec

The gas flow in the shields account for ~ 60% of the total production of helium vapor at 4.5K, 1.3 Bar coming from the coil (on the basis of the design losses without not including the safety factors), this effect gives us a further operational margin for the operation of the Coil.

This helium gas coming out from the thermal shields is recovered at room Temperature and pressure in the low-pressure recovery system.

The volume of the Control Dewar reservoir can be choose quite small, reducing eventually to a minimum the LHe inventory in the PANDA experimental hall.

In the natural convection refrigeration scheme proposed, the storage-liquefaction Dewar close to the liquefier acts as Buffer for the system. With the projected LHe (safety factor on cryogenic losses included) a 2000 liters storage allows ~ 20 hours of operation in case of the liquefier failure, giving ample time margin for the magnet discharge.

Using a 4000 liters storage (the foot prints for 2000 and 4000 liters Dewar is fairly similar) ~40 Hours of operation is guaranteed.

Even the cooling system can be kept running refilling the storage Dewar with liquid helium transported from some alternative liquefaction plants.

**Safety Issues**

The mains safety concern in Both the Proximity cryogenic system considered is related to the maximum pressure attainable in the system in case of catastrophic failure.

The worst-case scenario is (in the forced flow system) a failure of the Refrigerator-liquefier, applying the pressure of the liquefaction compressor (~20 bars,) to the cooling loops welded to the coil winding and to the 50 K shield.

For this reason all the piping need to be rated to 20 bars, all the other parts of the Cryogenic system can be protected using burst disks and check valves.

**Conclusions.**

Two alternatives for the proximity cryogenic system for the panda solenoid are presented due to the unavailability of helium refrigerator in the PANDA Hall.

Both are based on a local Helium refrigerator-liquefier used also for the cooling of the compensating solenoid installed in the IP of the HESR to reduce to ZERO the Bz integral along the accelerator path.

Both solutions are based on already proven and still running cryogenic system of similar magnet. (BABAR ad Atlas)

At the present status no one seems to give outstanding performances ruling out the other scheme.

The final choice has to be very well weighted, considering in the fine details pros and cons both in the investment costs, easiness of operation and maintenance, reliability and safety regulation during the detector runs.

Also the operation of the Cryogenic system during the coil cool down should be a significant issue for the final decision.

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**References**

[1] Akira Yamamoto et al. *"The ATLAS central solenoid"*, Nuclear Instruments and Methods in Physics Research Section A: Volume 584, Issue 1, 1 January 2008, Pages 53-74

[2] Pasquale Fabricator et al. *"Design and Testing of the 1.5 T Superconducting Solenoid for the BaBar Detector at PEP-I1 in SLAC"* IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 9, NO. 2, JUNE 1999