21. CRYOGENIC PLANT

21.1 REFRIGERATION PLANT (COMPRESSORS, REFRIGERATOR, TRANSFER LINES, LHE 5000 L DEWAR)

21.1.1 Compressors, helium gas and liquid nitrogen storage

The compression system will consist of two screw compressors installed at the surface of P5, in the purpose-built Building SH, (see Fig. 21.1, p. XX). They will be set in their final position from phase one and will be used first for the magnet test at the surface and then for the commissioning and operation in the experimental cavern. The nominal mass-flow of the compression system is ~ 180 g/s. The maximum pressure level is expected to be ~ 18 b. In the same building a third screw compressor with a capacity limited to 40 g/s, will be used for the recovery of helium gas from the magnet in the event of the main cryogenic plant being shut down. This gas will be compressed and stored without contamination and thus can be re-usable after the shut-down. Building SH will also house the complete oil removal and purifier system needed for the operation of the screw compressors.

The helium will be stored at the surface outdoors (see Fig. 21.1, p. XX) in two 250-m^3 cylinders at 20 b. This storage capacity provides a supply of two full loads for the refrigeration plant and the magnet system. An addition helium supply can be provided by connection the CMS gas holders with those of the LHC accelerator, located at the same surface area.

A 50 000 l liquid nitrogen dewar for pre-cooling the magnet in the temperature range 300 to 100 K is also located at the surface. During this cooling phase, the expected liquid nitrogen mass-flow is 500 l/h. During the magnet testing period at the surface in Building SX, the liquid nitrogen dewar is located between Buildings SH, SX and the "Cryogenic Alcove" (SHL) which will temporarily house the cold box for the test. In the final phase, when the liquid nitrogen is supplied to the cold box in the experimental cavern, the dewar will be moved next to Building SDX so as to minimise the length of the required liquid nitrogen transfer line.

21.1.2 Cold Box, transfer lines and 5000 l liquid helium cryostat

On the base of the thermal loads of the superconducting magnet system and of the operating conditions (thermal sequencing during the technical shutdowns of the LHC, cooling-down time and quench recovery), it was agreed to use a refrigerator with a power rating of 1.5 kW @ 4.5 K (entropic equivalent).

The upper part of the cold box contains a set of liquid nitrogen/helium heat exchangers for magnet cooling down to 100 K. In addition the liquid nitrogen pre-cooling should allow to increase the helium liquefaction of the plant when necessary.

The cold box will be connected to the magnet via an intermediate cryostat (see Fig. 21.2, p. XX), which will house all the cryogenic valves needed to pre-cool the magnet and its heat shield. The intermediate cryostat includes a 5000 l reserve of liquid helium to allow the magnet slow discharge in the event of failure of the cryogenic system or other facilities.

The cold box will be connected to the intermediate cryostat by a single thermally shielded transfer line 600 mm in diameter and 30 meters long containing 4 separate lines.

Two for the magnet circuit helium, diameter of 80 mm at the outlet, 50 mm at the inlet and two for the heat shield circuit, 60 mm in diameter. The cryostat will be connected to the valve box and helium phase separator (on top of the detector) by means of 4 separate transfer lines performing the same functions as described above.

The magnet's heat shield will be cooled by tapping off the required mass-flow at the level of the outlet of the first expansion turbine of the cold box and reinjecting the shield return at the inlet to the second expansion turbine (in case of a cycle with only two turbines in series).

21.2 CRYOGENIC FLOW-SHEET AND PROCESS DEFINITION (COOL-DOWN, NORMAL AND RECOVERY CONDITIONS, WARMING-UP)

21.2.1 Cooling-down phase from 300 K to 100 K

The magnet will be pre-cooled using the liquid nitrogen/helium heat exchanger in the cold box designed for this purpose (see Fig. 21.2, p. XX). The 50 mm lines will be used (identical to those used for the liquid phase) to convey all the nominal mass-flow of the screw compressors (approximately 180 g/s with a total pressure drop across the system of 10 b at ambient temperature). Both the valve box and the intermediate cryostat have a bypass for this purpose. Valves V271, V272, V273 will be closed and valves V260, V290 open. By-pass V3 in the valve box will be used to allow the necessary mass-flow. The gas return from the magnet will be channelled inside the cold box to the appropriate temperature level. Assuming a maximum temperature gradient of 50 K, the cooling-down time to 100 K will be ~ 20 days. During this phase the expansion turbines are switched off and cooling of the heat shield has not yet started.

21.2.2 Final cooling-down phase from 100 K to 4.5 K

From this point onwards the cold box expansion turbines are in operation. Circulation in the magnet heat shield starts and in parallel a minimal mass-flow of 80 g/s is maintained in the circuits of the coil. At the same time, part of the main mass-flow is tapped off to cool the intermediate cryostat and the 5000 l liquid helium dewar. This final cooling phase will last approximately 10 days.

21.2.3 Normal operation at 4.5 K

The cold box with its own phase separator, upstream of V260, will supply the supercritical liquid helium at 3b to the 5000 l cryostat. V271 will allow the level of liquid helium in the dewar to be regulated. The pressure of the cryostat will be set at 1.5 by V273, located at the cold return to the cold box. Transfer to the magnet valve box and phase separator will be done by the supply valve V272. The shield will be cooled via valves V280 and V281 with a helium mass-flow of 35 g/s, at an input temperature of 60 K and an output temperature of 80 K. The input pressure will be 5 b and the pressure drop lower than or equal to 150 mb.

21.2.4 Operation at 4.5 K without cold box and with or without compression system

In case of failure of the refrigerating system, the dewar continues to supply liquid helium to the phase separator of the valve box. The 5000 l capacity will ensure the supply of liquid helium to the magnet throughout the current slow discharge phase which takes approximately 4 hours. With the expansion turbines out of operation the heat shield is no longer cooled. After depressurisation of the shield circuits from the nominal operating pressure, the V7 by-pass valve conveys the flow evaporated by the magnet into the circuits of the heat shield. The evaporation rate of the magnet will be 20 g/s and the total expected pressure drop in the shield circuits is less than 120 mb (excluding atmospheric heat exchanger).

If the compressors for the cryogenic cycle are in operation, the helium from solenoid return and current leads may be recovered and stored in the gas holders. These flows will be injected at the low pressure level of the main compression system. In the event of total shutdown, including that of the cycle compressors, these flows will be recovered and stored by the recovery compressor, which must be connected to the auxiliary external safety services allowing its operation in the event of the main facilities failure.

Valve V283 controls the pressure in the phase separator of the magnet when the cold box is not in operation and the heat shield during depressurisation.

21.2.5 Fast energy dump

During rapid discharges

Valves V1 and V3 are closed and the expansion turbines are shut down. The cold box is isolated by valves V260 and V290, as is the 5000 l dewar by its valves. The cryostat has its own exhaust through V275 via a heat exchanger to the low pressure of the compression system.

Post-quench depressurisation

The "thermosiphon" circuit is depressurised by the V7 by-pass valve through the shield.

Post-quench cooling

Two options are being considered for thermal recovery of the magnet from the average temperature of 50 K reached after a fast energy dump. As there are no valves on the thermosiphon return, cooling may be done either by controlling the opening of the by-pass of the Joule-Thomson in the cold box so as to limit the pressure rise in the low-pressure circuit, or by supplying the magnet directly with liquid helium from the cryostat's 5000 l reserve. The time required to cool the magnet from 50 K to 4.5 K after a quench will be about 3 days. Assuming that only 20% of this stored energy is discharged in the cold mass.

21.2.6 Warming-up of the magnet

During the LHC technical shutdowns, it is agreed that the magnet will be electrically re-heated and decoupled from the cryogenic circuits to allow maintenance of the compressors, the refrigerator and auxiliary equipment.

21.3 VACUUM INSULATION OF THE MAGNET

The magnet's vacuum insulation will be done by:

- a primary pumping station consisting of two vane pumps and two 900 m^3/h Roots pumps. These will be installed in the service cavern and connected by a 300 mm diameter pipe to the distribution pumps described below.

- a diffusion pumping station connected to the vacuum chamber of the magnet. One 8000 l/s diffusion pump will be directly connected by a 600 mm spool piece to the vacuum chimney (400 x 800 mm^2). A second 2000 l/s pump will be directly connected to the vacuum chamber of the magnet's valve box.

21.4 CRYOGENIC PLANT FOR THE SURFACE TEST OF THE MAGNET

A test of the overall cryogenic plant and its auxiliary equipment is planned at the surface of LHC P5. The plant will be connected to the magnet system which, at that time, will be located in Building SX. Extensive magnet tests are planned before installation in the experimental cavern. For this purpose, the following cryogenic equipments are provided (see Fig. 21.3, p. XX):

- the complete compression system and its auxiliary equipment in Building SH,
- the helium gas holders opposite to building SH connected to the compressors,
- the cold box and its control equipment will be temporarily installed in the building known as the "Cryogenic Alcove" (SHL) adjacent to the Compressor Building SH (see Fig. 21.1, p. XX). The first floor of the Cryogenic Alcove will house the cold box and its auxiliary equipment, and the ground floor will house the main supply for the magnet and the pumping stations for the insulation vacuum.

As can be seen on the surface layout for the magnet test, the intermediate cryostat is located next to the magnet and forms an integral part of its structure. It is coupled to the valve box of the magnet by the required transfer lines. This unit is designed to move as one component when being lowered and installed in the experimental cavern.

From the layout studies it appears that the main transfer line (four in one) linking the cold box to the intermediate cryostat containing the 5000 l liquid helium dewar must be purpose-built for the magnet surface tests and cannot be reused for the final transfer system in the underground cavern. Nevertheless, it is intended to standardise the connection equipment of this transfer line to the cryostat.

21.5 INSTALLATION OF THE COLD BOX, TRANSFER LINES AND LIQUID HELIUM CRYOSTAT IN THE UNDERGROUND AREA

The final layout of the cryogenic equipment is shown in Fig. 21.4, p. XX. It should be noted that the cold box and its auxiliary equipment are now located in the service cavern, to which access is permitted at all times when the accelerator is in operation. Conversely, the magnet intermediate cryostat and valve box are located in the experimental cavern where access is not allowed when the beam is on (controlled access).

The transfer lines between the intermediate cryostat and the valve box remain unchanged after the surface test of the magnet. However, the multiple transfer line connecting the cold box to the intermediate cryostat will now be straight and at the same height. The main transfer line and the other gas lines or auxiliary pumping lines will pass from the service cavern into the experimental cavern via a hole in the concrete blocks of 1.2 m in diameter in accordance to the rules required by the radiation safety.

The pumping stations and power supply for the magnet will also be installed in the service cavern (see Fig. 21.4, p. XX). The magnet’s power supply cables and the quench detection signals pass through the concrete wall in a specially-designed conduit.

21.6 TIMETABLE FOR THE CRYOGENIC EQUIPMENT INSTALLATION AND MAGNET TESTS

Below is the proposed timetable for the design studies, preparation of the specifications, procurement, installation and testing of the cryogenic equipment, coupling of the installation to the magnet, followed by tests at the surface and in the experimental cavern.

Design studies and definition of the process engineering	...- 08/1997
Preparation of the equipment specifications	09/1997 - 06/1998
Market survey and call for tenders	03/1998 - 12/1998
Equipment orders placed	01/1999
Delivery of the equipment	06/2000 - 12/2000
Installation and testing of the cryogenic equipment (compressors + final infrastructure, cold box at the surface)	01/2001 - 12/2002
Test of the CMS magnet at the surface of P5	01/2003 - 10/2003
Transfer of the cryogenic system to its final position in the cavern - final installation of the equipment and transfer lines	11/2003 - 12/2004