EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Large Hadron Collider Project

LHC Project Report 393

THE CRYOGENIC SYSTEM FOR THE ATLAS LIQUID ARGON DETECTOR

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on behalf of the ATLAS Liquid Argon Collaboration

Abstract

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LHC Division

Presented at the Eighteenth International Cryogenic Engineering Conference (ICEC 18)
21-25 February 2000, Bombay Mumbai, India

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Geneva, 26 July 2000

The Cryogenic System for the ATLAS Liquid Argon Detector

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1. INTRODUCTION

To exploit the capabilities of the future CERN Large Hadron Collider (LHC) with colliding protons and heavy ions, four particle detectors are being designed and will be installed in underground caverns. ATLAS [1] will be the largest of these detectors, comprising a complex cryogenic system for superconductive magnets and liquid argon ionization sampling calorimetry [2]. The calorimeters will be housed in three cryostats with a total volume of 83 m^3 of sub-cooled liquid argon at a temperature of approximately 87 K.

The design of the associated cryogenic system is based on the requirements for the temperature uniformity in the cryostat, on the all year round functioning of the system and on the safe handling of the large volumes of cryogenic liquids in underground areas.

2. DESCRIPTION OF THE CRYOGENIC SYSTEM

2.1 The argon cryostats

The liquid argon cryostats, consisting of two "end-caps" (argon volume 19 m^3 each) and one "barrel" (argon volume 45 m^3), are placed in the center of the ATLAS detector which will be installed at 100 meter below surface level. The vacuum space of the barrel cryostat is shared with the superconducting central solenoid which is thermally shielded, on the external side, by the liquid argon vessel.

Each cryostat is connected via a cryogenic transfer line to its respective expansion vessel (see fig. 1) which is placed at about 3 meter above the top of the cryostat. Correct filling of the liquid will be monitored, during normal operation, by the liquid level indication in the expansion vessel.

Several heat exchangers (two for each end-cap cryostat and six for the barrel cryostat) are placed inside the liquid argon volumes, while one more heat exchanger is placed in the gaseous volume of every expansion vessel to control the argon pressure at 1.25 bar (89.3 K saturation). Each expansion vessel is designed such that it can take, before the relief pressure (1.7 bar) is reached, the total volume of argon resulting from the expansion of the liquid in case of very large heat input like failure of the corresponding insulation vacuum.

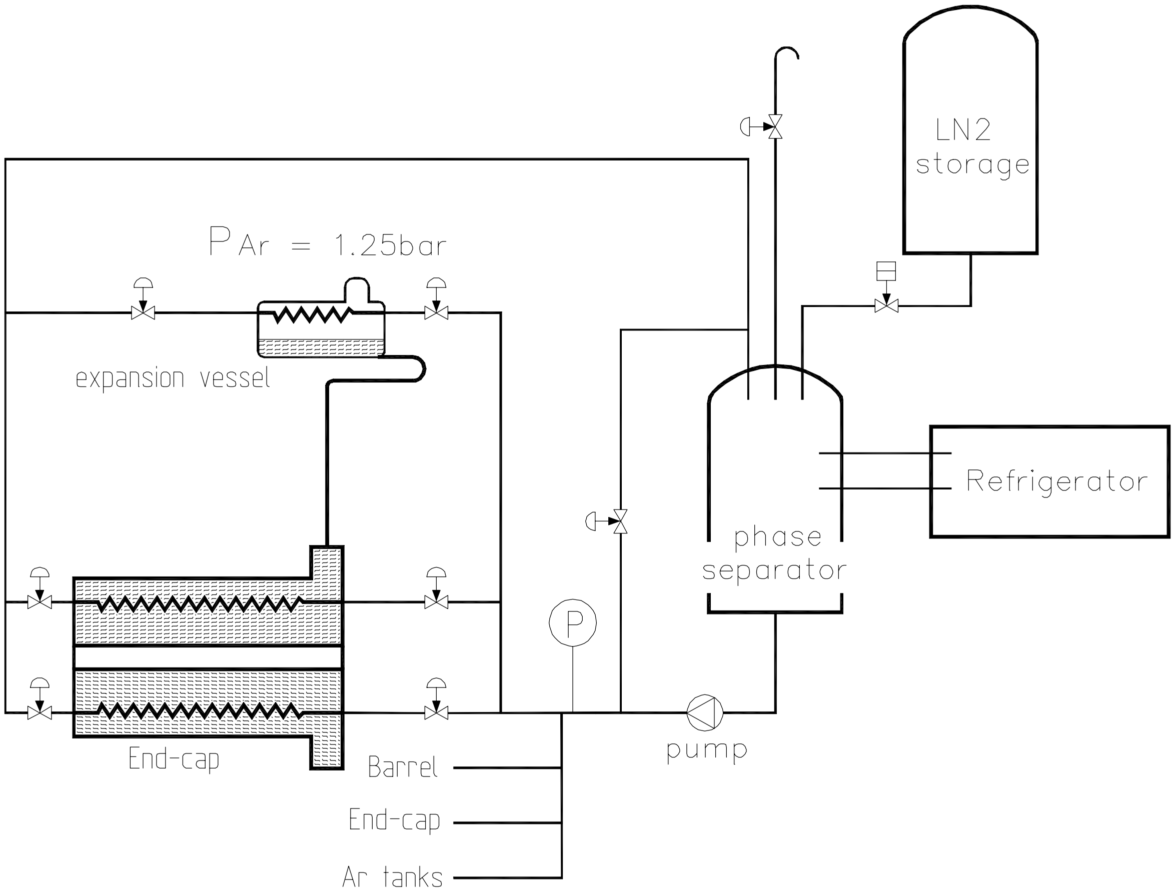

Figure 1. The principle of the nitrogen cooling circuit.

The internal heat exchangers will regulate the argon volume of each cryostat at about 87.3 K, creating a liquid which is sub-cooled by 5 K to 7 K, depending on the height in the cryostat. Gas bubbling formation being detrimental for the functioning of the detector, will be thus prevented. Furthermore, the heat exchangers will keep the temperature differences over the overall detector volume within 0.6 K in order to guarantee optimal performance of the calorimeter. The same heat exchangers will allow cool-down from ambient temperature of the calorimeter total mass in less than 70 days.
The total heat input for an end-cap cryostat is estimated at 3 kW in normal working conditions, for the barrel cryostat at 2 kW. The total heat input for the rest of the system (expansion vessels, valve boxes, several hundreds of meters of transfer lines, two argon storage tanks) is estimated at 4 kW.

2.2 The nitrogen cooling circuit

The cooling principle is based on the vaporisation of saturated liquid nitrogen flowing through the heat exchangers placed in the argon volumes.
In normal operating conditions the nitrogen coolant is kept in a closed circuit. Re-liquefaction into a 15000 liter nitrogen phase separator kept at 2.1 bar, is done with a refrigerator of 18 kW isothermal capacity at 84 K. Two liquid nitrogen storage tanks of a total liquid nitrogen volume of 100 m^3, shared with the ATLAS magnet cryogenic system, are on standby to take over the nitrogen supply during refrigerator periodical maintenance or failure. The vaporised nitrogen will, in this case, be evacuated to atmosphere.
The liquid nitrogen is pressurized by a centrifugal pump placed below the phase separator. The pressure after the pump is regulated to 4 bar, independently from the mass flow needed for the rest of the nitrogen circuit, by means of a control loop returning directly to the phase separator. An intermediate valve box distributes the nitrogen to heat exchangers of the three cryostats and of the two argon storage vessels.
Each of the heat exchangers is equipped with two control valves. The inlet valve regulates the mass flow and the outlet valve controls the pressure of the saturated nitrogen flowing through the heat exchanger.

The nitrogen mass flow regulation is based on information from a void fraction meter placed at the outlet of the exchanger. In order to avoid dry-out of part of the heat exchanger length, the mass flow is regulated such that at least 10% of the total nitrogen mass flow is leaving the heat exchanger in liquid phase.
The pressure in the heat exchangers is regulated as function of the requested cooling power and liquid argon temperature in the range 3.6 bar corresponding to a temperature of 90 K, to 2.1 bar corresponding to a temperature of 84.1 K, just above the argon triple point. The highest pressure will be only used during calorimeter cool-down from ambient temperature to prevent argon condensation which might produce excessive thermal stresses in the calorimeter detector modules.

2.3 The argon circuit

Under normal circumstances the liquid argon will stay in the cryostats. In case of emergency the liquid will be emptied into two 50 m^3 liquid argon storage tanks situated in the underground area. These tanks, entirely made of stainless steel (i.e. including vacuum vessel and feet), and the calorimeter cryostats are positioned in such a way, that the total argon volume of the three cryostats can be transferred by gravity. A centrifugal cryogenic pump can be used to speed up this process. The tanks are equipped with a liquid nitrogen cooling loop for the re-condensing of the argon vapor.
In case the argon in the tanks has to be evacuated or replaced because of contamination, the transfer to the surface will be done with the help of a cryogenic centrifugal pump.

3. SPECIAL FEATURES

3.1 Operating conditions

It is foreseen that the cryostats stay filled with argon over several years and all maintenance, of the cryogenic as well as of the detector equipment, has to be carried out fulfilling this condition. The cryogenic system includes several features to satisfy the above requirement, namely:

- The cryogenic lines between the expansion vessel and the cryostat as well as the transfer lines supplying liquid nitrogen to the heat exchangers are designed to follow a 12 meter longitudinal movement of the end-cap cryostats (see figure 2). This will allow access to the electronics placed close to the cryostats without interruption of the cryogenic operation;
- The inserts of valves placed in the nitrogen cooling circuit can be replaced without risk of contaminating the circuits, making use of a glove box pressurized with nitrogen gas;
- Three nitrogen pumps will be installed in parallel. One is running, the second is redundant and the third one can be dismounted for the maintenance without affecting the operation of the others;
- The two external nitrogen storage dewars will take over the supply of liquid nitrogen during the annual maintenance work on the refrigerator;
- All the devices essential for the functioning of the cooling system, including the nitrogen circulators, will be powered via an uninterruptable power supply (UPS) guaranteeing their functioning during power failures and test periods.

3.2 Safety aspects

All items containing large volumes (the entire ATLAS detector, the argon storage vessels and the nitrogen phase separator) are placed respectively on retention volumes or in pits able to collect large spillage of liquid. The gas on top of these areas is constantly extracted with the help of ventilators placed at the surface, this to prevent the diffusion of argon gas in the underground area with consequent risk of asphyxiation. Oxygen detectors are installed at relevant places.

4. CONCLUDING REMARKS

The ATLAS liquid argon detector cryogenics system has been finalized after a final review. The different equipment are now in the design phase or ready for tendering. Before the installation in the underground area, each of the cryostats will be tested individually, using a cryogenic system based on the principles

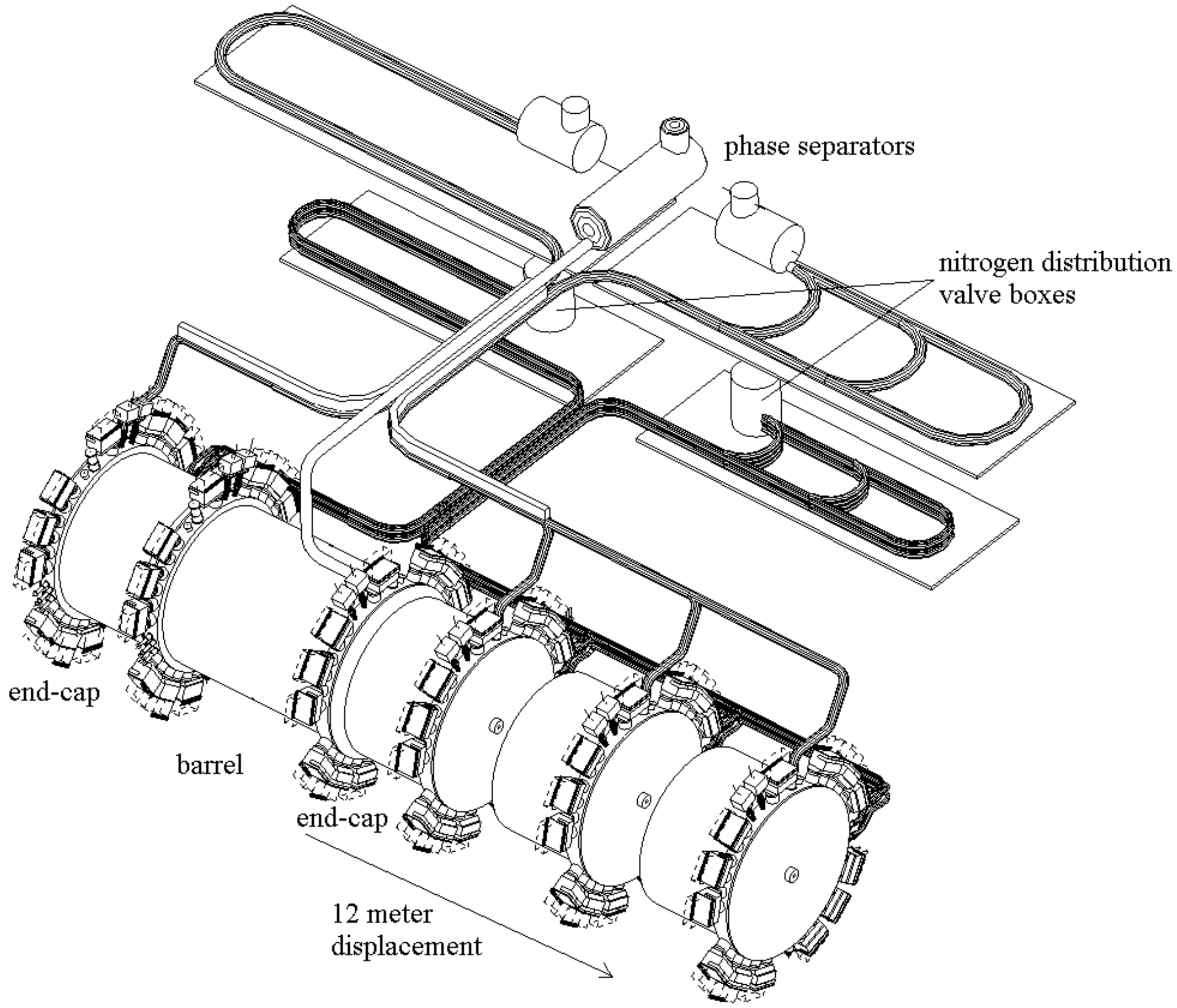

Figure 2. Overall view of the three cryostats and their respective argon and nitrogen lines, showing the displacement of one of the end-caps.

presented here. During these tests each of the cryostat will be equipped with its final expansion vessel and heat exchanger regulation valve box. Cryogenic tests will be also carried out for all the other components, like the liquid argon storage tanks, before underground installation.

REFERENCES

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