EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Large Hadron Collider Project

LHC Project Report 991

UPGRADE OF FOUR CRYOGENIC HELIUM REFRIGERATORS USED IN THE LEP COLLIDER FOR LHC REFRIGERATION

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Abstract

After the final run of the Large Electron Positron Collider, the four refrigerators used for LEP were free to be used for the Large Hadron Collider project. In order to serve the LHC requirements, these four Ex-LEP refrigerators needed to be modified and upgraded. In this paper we present the requirements for these refrigerators operating for the LHC machine compared to those for LEP, the necessary modifications of the existing machinery and the additional equipment needed. We will also compare the cost of the upgrades with the cost of the new LHC refrigerators.

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Presented at the Cryoprague 2006 Conference
17-21 July 2006 - Praha, Czech Republic

CERN
CH - 1211 Geneva 23
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Geneva, 13 February 2007

Upgrade of four Cryogenic Helium Refrigerators used in the LEP Collider for LHC Refrigeration

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INTRODUCTION

In 1991 CERN had purchased four refrigerators for the Large Electron Positron Collider (LEP). Two refrigerators were delivered by Air Liquide (France) two by Linde Kryotechnik (Switzerland). These refrigerators had an original equivalent capacity of 12 kW at 4.5 K and were designed to allow a capacity upgrade to 18 kW at 4.5 K. The upgrade to 18 kW was done in 1999 to satisfy the cooling requirements for the last years of LEP operation.

After the end of the LEP project these refrigerators were free to be integrated into the cryogenic infrastructure of the Large Hadron Collider (LHC). The LHC has thus eight refrigerators working at 4.5 K, four recently delivered and accepted [1] and four recovered from LEP. All eight 4.5 K refrigerators are complemented by eight cold compressor units [2] that cover the cooling at 1.9 K necessary for LHC. All refrigerators are further connected to gas buffer tanks for storage and control and helium dryers for removal of moisture in helium.

In 2005 CERN placed contracts with industry in order to upgrade the refrigerators originally used for LEP in accordance with the LHC requirements. The upgrade work is scheduled to be finished beginning of 2007.

REQUIREMENTS FOR LHC COMPARED TO THOSE OF LEP

In the following, the four refrigerators originally used for LEP are referred to as “Ex-LEP” refrigerators.

Capacity requirements

Table 1 lists the cryogenic capacity requirements for the Ex-LEP refrigerators as necessary for LEP and LHC.

Table 1 Comparison of capacity requirements for the Ex-LEP refrigerators

Machine	LEP	LHC
Refrigeration load at 4.5 K [kW]	15.5	0 (no load)
Non-isothermal load [g/s]	13.0 (4.5-300 K)	27.0 (4.5-300 K) 183 (4.5-20 K)
Thermal shield load (50-75 K) [kW]	6.7	31.0
Equivalent capacity at 4.5 K [kW]	18	16

Even though the equivalent exergetic capacity required for LHC is smaller than for LEP, the Ex-LEP refrigerators cannot cope with the LHC demands. The change of load from mainly isothermal refrigeration to non-isothermal cooling between 4.5 K and 300 K and the high load on the thermal shield require a considerable upgrade of the installed capacity of the expansion turbines.

Gas-cleaning requirements

The Ex-LEP refrigerators are not equipped to handle gaseous impurities continuously. For the operation of the LHC machine the expected impurities are such that double-bed adsorbers working at 80 K, which can be regenerated during operation, are deemed necessary.

The upgrade of the Ex-LEP refrigerators has therefore to include for two switchable adsorber beds at 80 K allowing each refrigerator to operate with a continuous impurity level of 50 ppm by volume of nitrogen or air.

Pre-cooling requirements

As the mass of the LHC machine is much larger than that of LEP, additional capacity for cooling-down at temperatures above 80 K is required [3]. This cool-down capacity is supplied via pre-cooling with liquid nitrogen (LN_2). Suitable heat exchangers need to be added to the process of the Ex-LEP refrigerators to allow LN_2 cooling with a capacity of up to 600 kW.

MODIFICATIONS

Modifications of the Ex-LEP helium compressor station

In 1999 the compressor stations of the Ex-LEP refrigerators were upgraded to increase the flow capacity for the last years of LEP operation [4]. Preliminary process studies by CERN had shown that the mass flow installed then for LEP would be sufficient for LHC operation. The compressor capacity was consequently specified as a boundary condition for the capacity upgrade of the Ex-LEP refrigerators.

Modifications of the Ex-LEP cold boxes

Once the process defined and the resulting mass flow inside the Ex-LEP refrigerators known, all piping and equipment was verified for hydraulic impedance.

For all four refrigerators an additional transfer-line connection for the external pre-cooler and adsorber unit is required. In order to facilitate such an eventual upgrade these connections had been foreseen in the Ex-LEP refrigerators as blinded-off pipes collected at a pre-prepared transfer line connection. The existing single bed adsorbers located at 80 K and 20 K level in each refrigerator are conserved and each equipped with a by-pass not existing during the LEP project.

In order to reach the specified capacity of the Ex-LEP refrigerators that were originally delivered by Air Liquide, only the modification of expansion turbines is necessary. The cooling capacity of the six modified turbines reaches a total of 154 kW, compared to the original 84 kW for LEP. For these refrigerators the adsorber located at 20 K level is exchanged, as it cannot cope with the increased flow for LHC operation. These refrigerators were during LEP operation also equipped with LN2 pre-cooling equipment. This equipment is removed as it cannot fulfil the LHC requirements and would only add hydraulic impedance.

For the refrigerators that were originally delivered by Linde Kryotechnik, the modification of the expansion turbines and the modification of the process layout is necessary. The piping modifications are required to split the turbine flow, arranged in series for LEP into several parallel streams in order to cope with the higher total flow rate. The cooling capacity of the seven modified and re-arranged turbines reaches a total of 131 kW, compared to the original 76 kW for LEP.

Addition of an external pre-cooler and adsorber unit

The necessary additional equipment for pre-cooling and gas cleaning is added as an external unit to the Ex-LEP refrigerators. The four external pre-cooler and adsorber units comprise:

- Two adsorber beds of 1.4 m^3 active charcoal filling each.
- A stainless-steel coiled tube heat exchanger for liquid nitrogen to helium exchange.
- An aluminium plate-fin heat exchanger for the gaseous nitrogen to helium exchange.
- Cryogenic valves and filters.
- A vacuum-insulated transfer line to connect to the refrigerators
- The regeneration equipment including a helium blower, heaters and vacuum pump
- Valves

Adaptation of the control system

After the end of the LEP project CERN decided to change the process control system for all LHC cryogenic equipment in order to modernise the control hardware and to comply with the requirements of a large distributed control system.

In order to communicate to the new control system, the existing refrigerators need to be equipped with additional electrical cabinets and the existing I/O signals need to be cabled to the new I/O connectors. This work was entirely done by CERN.

COST OF THE UPGRADE

Table 2 lists all cost engaged or planned as of June 2006 concerning the upgrade of the Ex-LEP refrigerators for LHC. All cost are expressed in Swiss Francs and indexed to 2005 values [5]. Not counted into the cost are CERN staff, revisions and maintenance of the existing plants like e.g. the general overhaul of the compressor stations after a more than 40000 hours of operation and the programming of the new control system.

To compare the cost of the upgraded refrigerators to that of new refrigerators we need to take into account the cost of the new refrigerators plus the cost of the vertical transfer lines [6] as these are included in the Ex-LEP refrigerators. In 1998 CERN had placed the contracts for the four new LHC refrigerators working at 4.5 K for an amount of 58 MCHF indexed to 2005 prices [7]. The vertical transfer lines were ordered in 2001 for a total of 6.2 MCHF indexed to 2005 prices.

Table 2 Cost for the upgrade of the four Ex-LEP refrigerators for LHC requirements

Ex-LEP refrigerators originally supplied by	Air Liquide [MCHF]	Linde Kryotechnik [MCHF]	Total cost [MCHF]
Upgrade of the compressor station	5.8	6.4	12.2
Upgrade of the refrigerator cold box	2.4	2.0	4.4
Additional pre-cooler adsorber units	3.8	3.8	7.7
Adaptation to new control system	0.15	0.15	0.3
Total	12.2	12.4	24.6

Following the cost listed in table 2, we may conclude that the cost for the upgrade of the existing refrigerators amounts to about 38 % of the cost for new refrigerators.

PRESENT SITUATION OF THE EX-LEP REFRIGERATOR UPGRADE

At present the modifications of two refrigerators cold boxes are completed and are currently being tested, showing encouraging preliminary results. The tests include performance tests of the expansion turbines, performance and functional tests of the additional instrumentation and valves as well as of the additional pre-cooler and adsorber units.

The third refrigerator shall be completed for testing in October 2006, the fourth in March 2007.

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