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Four 12 kW/4.5 K Cryoplants at CERN

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Abstract

The LEP 2 project at CERN, designed to increase the collision energy in the LEP electron-positron collider from 50 to 90 GeV/beam, involves the installation of 192 superconducting (sc) accelerating cavities in the straight sections of the LEP ring close to the four interaction points. To provide the refrigeration power for the cavities, four 12(18)kW/4.5 K cryoplants were ordered in 1991, two from L'Air Liquide (France), two from Sulzer (now Linde, Switzerland/Germany). These plants have been installed in the past years, and two of them have already accumulated a considerable number of operating hours. Processes, construction, commissioning and acceptance tests of the four plants will be described, and their main features will be compared. Performances of the liquid helium distribution systems delivered by L'Air Liquide (France) and Cryogenmash (Russia) will also be given.

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INTRODUCTION

Cryogenics for the LEP2 project originally started in 1990 with the order of two 6kW plants, continuously operated since two years, one for cooling sc cavities in LEP and one as a test plant for sc cavities and prototype magnets for LHC. In 1991, it was decided to purchase four cryoplants of 12kW equivalent cooling power at 4.5K [1-2-3], upgradable for future LHC use.

During the last three years, CERN and the firms involved studied, built, installed and commissioned the plants without major problems. Now, in June 1994, three cryoplants have reached the nominal performances and the fourth one is under final testing. The entire planning was extended by six months mainly due to late availability of buildings and a less tight project programme.

GENERAL LAYOUT

The cryogenic system at each of the four even interaction points of LEP consists of a 12kW cryoplant and its associated LHe distribution system to supply up to 32 sc cavities on each side. Due to the existing infrastructure, the cold equipment is devided into 2 parts with a cut at a temperature level of 20K, an Upper Cold Box (UCB) at ground level and a Lower Cold Box (LCB) limited in size in the underground tunnel. The boxes are interconnected by a transfer line system mainly vertical in the machine access shaft of 50 to 140 m depth.

The He compression group is located in a sound isolated building and the He gas is stored outdoors in 10 vertical vessels ($76m^3$/2MPa or 20 bar) of 15000 Nm^3 capacity. The plant is connected to a 5g/s purifier collecting the gas from low pressure balloons of 1000 Nm^3.

An industrial process control system delivered by ABB is used for fully automatic operation and remote control from a central control room [4].

DESIGN COMPARISON

Process

The splitting of the boxes at about 20K did not influence the process layout. The main process difference is that Linde has a two pressure cycle as shown in Fig. 1a (three pressure cycle for an upgrade to 18kW) and Air Liquide (AL) designed a three pressure cycle shown in Fig. 1b using for the first time a high number of turbines to increase the plant efficiency. Provisions are made by each supplier to add easily another turbine for upgrading to 18kW.

AL mounted the upper two first turbines in series and the next two in parallel with the third one dedicated for the shield cooling. The cooling could continue if any turbine is damaged. Linde installed the upper 4 turbines in series. This requires an accurate design of the pressure drop and would oblige to stop the UCB cooling if one of them fails.

The process part of the LCB implies the parallel arrangement of turbines and heat exchangers for Linde and the serial distribution for AL. Both use a wet turbine.

Compression unit

Both suppliers installed five STAL (S) oil lubricated screw compressors of types S73, S75, S93 but in different combinations for the two stages. The Linde layout offers better redundancy with more than one machine for each stage. AL uses a separate machine to supply the turbine gas bearings enabling part loads with reduced process high pressure.

Cold Boxes

The imposed constraint of split box system and the limited LCB space led to extremely compact design and special shape. The turbine efficiencies are similar (75-80%). Linde turbines have dynamic gas bearings whereas AL uses static gas bearings needing continuous injection of pressurised He.

The AL turbine control is quite sophisticated using for each turbine an independent programmable controller to adapt the safety limits to the various operating conditions, thus allowing for optimum efficiency. Linde combines hardware interlocks with software conditions in the general control system.

COMMISSIONING AND ACCEPTANCE TESTS

The specified values were: 6.7kW shield cooling below 75K, 13g/s of liquefaction and 10kW of isothermal refrigeration at 4.5K.

Capacity measurements results

Cool-down of the first plant took place in January 1993. A temporary equipment was installed to measure the cryoplant capacities before connecting them to the distribution system.

The shield load was simulated by external electrical heaters and the 13 g/s of LHe withdrawn and heated up to ambient to be rejected to the compressors. The remaining power measured in the phase separator was compared to the specified 10kW. After stabilisation at full cooling capacity, the plants passed through a 100 h steady run before partial load tests.

The 3 plants already accepted up to now reached the nominal capacity within the specified tolerances as shown on Fig. 2 with power factors of 218 and 232 W/W.

The lack of a few 100 W could be explained by some slightly lower compressor flows and design parameters such as minimised pressure drop (AL).

Part load tests, covering the range from 12kW to 2kW were carried out by varying the high pressure. A pressure change of 0.1 MPa was equivalent to 1 kW of cooling capacity for both suppliers.

Experience of commissioning phase

After thorough testing of all components, especially the electrical and instrumentation parts, the first cooldown of all plants was particularily straightforward. The split box solution turned out to be of no effect on the operation. The cool down time is about 30 hours. These large cryoplants are very flexible at part load, automatically reducing the pressure and the number of running compressors.

The compressors give a few percent less flow than expected, mainly coming from the S93 STAL compressors recently proposed for He operation. Relatively high vibration level within the compressor sets have been damped by quite empirical methods, with problems not always well mastered so far. Components on some units showed problems due to high vibration levels, below tolerable limits for the machines themselves but not for the equipment mounted nearby.

Some problems appeared with turbine controls. With Linde due to the inlet valve control, with AL due to bearings temperature control.

A significant effort was necessary to develop automatic procedures for the compression unit.

For rapid refill of He after an accidental loss, injection of LHe directly from a transportable dewar into the low pressure gas at a transfer rate of 700 Nm^3/h was obtained during normal operation.

LHe distribution system

Three of the four LHe distribution systems previously presented [1] were commissioned during the same period, the last one is scheduled for end of 1994. For the performance measurements, all supply and recovery hoses to the cavity modules were connected to short circuits, with two of them equipped with 250 W heaters to measure the heat losses of the lines at approximately 15K by help of the ratio of temperature difference with and without additional heating.

The thermal measurements showed that the performances of the cryogenic lines are within the specified values. The heat leaks were, on a total length of 550m of "soft-screened" manifold, incl. 64m of unscreened flexible lines, 18 cold valves...420W (Point 6/AL) and for 800m manifold, 128m of flexible line, 34 cold valves... 740 W (Point 8/Cryogenmash).

FIRST OPERATION EXPERIENCE AND AVAILABILITY

First operation experience with LEP

Due to delays in the production of sc cavity modules, so far only one 12kW Linde plant was running in autumn 1993 cooling a module of 4 cavities. During this period of about 3 months, the system turned out to be very reliable, working smoothly at reduced capacity without cryogenic failures, restarting automatically after utility failures.

Operation and availability

Long term goals are the increase of availability and reduction of the down-time of the cavities being part of the accelerator. To this end, the automatic restart programs have to be optimised in time. Another task is to ensure safe operation of one of the compressors switching to an emergency power and water supply in case of a general electric power supply failure, in order to recover evaporating He, and to maintain the necessary flowrate through the coldbox to reliquify as much as possible the cold gas from the cavities. This recovery operation will also roughly maintain the normal operation temperature profile in the heat exchangers thus reducing the danger of critical mechanical stresses at a fast restart of the plant with cold upper heat exchangers.

More work will be needed on homogenisation of procedures, programmes and instrumentation to increase the efficiency of operation done by a minimal team.

CONCLUSION

The cooling power increase from 24kW to 72kW in the past three years with expenditures of about 55 MCHF for cryoplants and infrastructure, 12 MCHF for the LHe distribution system and 6.5 MCHF for the control system. These considerable cryogenic activities were based on a close collaboration between the suppliers and CERN with teams well experienced from similar work for the previously installed 6kW plants.

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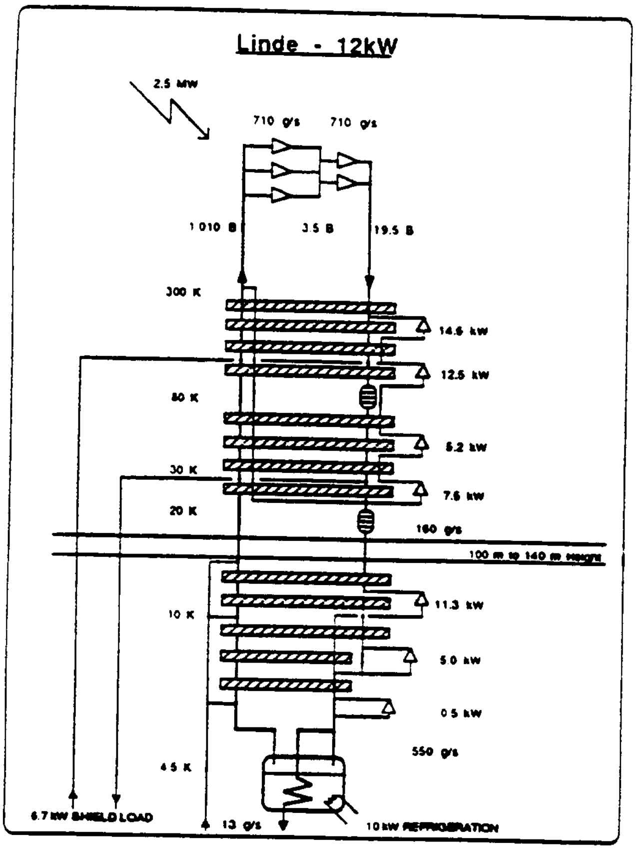

Fig. 1a: Linde 12kW flow scheme

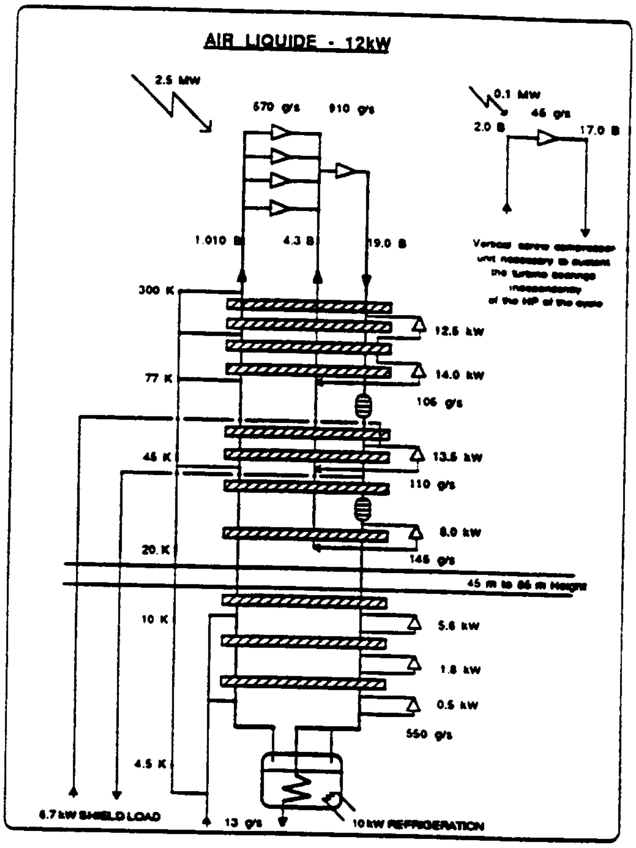

Fig. 1b: Air Liquide 12kW flow scheme

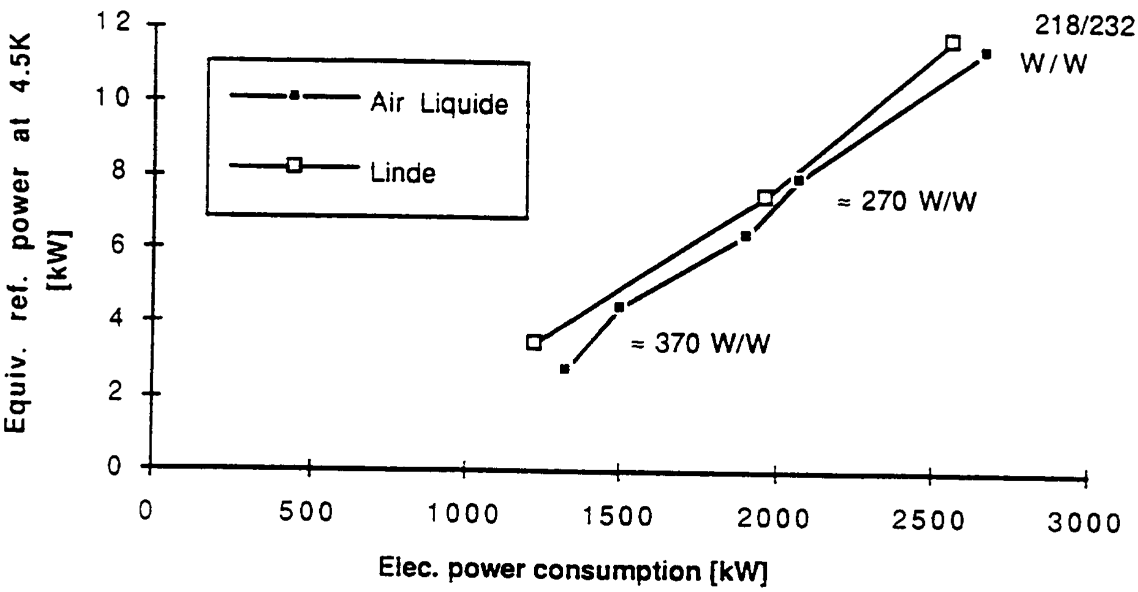

Fig. 2: Performances measured during the acceptance tests