EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Large Hadron Collider Project

LHC Project Report 327

OPERATION OF THE FOUR 12 KW AT 4.5 K REFRIGERATORS FOR LEP

N.Bangert,[1] and Ph. Gayet[2]

Abstract

In 1998 the first energy upgrade of the LEP Electron/Positron collider, LEP2, was completed at CERN. Sixty-eight superconducting modules supplied by four 12 kW @ 4.5 K equivalent power refrigerators have been operated allowing a colliding beam energy of 94.5 GeV. Meanwhile, the operation and maintenance responsibilities were transferred to an industrial firm on the basis of a result-oriented contract. After a short description of the operational organization, we report on the operation of the LEP2 cryogenic system over the past three years. Particular attention is given to power availability, failure statistics and recovery time after interruptions. The most relevant problems and their solutions are exposed. Finally, we review the interactions between the cryogenic system and the particle beams, which are limiting the ultimate performance of the LEP collider.

1 Air-Product-Thomson, St Genis Pouilly, 01630, rance
2 LHC Division, CERN, 1211 Geneva 23, Switzerland

Presented at the 1999 Cryogenic Engineering and International Cryogenic Materials Conference
(CEC-ICMC'99), 12-16 July 1999, Montreal, Canada

Administrative Secretariat
LHC Division
CERN
CH - 1211 Geneva 23
Switzerland

Geneva, 1 December 1999

OPERATION OF THE FOUR 12 KW AT 4.5K REFRIGERATORS FOR LEP

N.Bangert,[1] Ph. Gayet[2]

[1] Air-Product-Thomson
St Genis Pouilly, 01630, France

[2] LHC Division, CERN
1211 Geneva 23, Switzerland

ABSTRACT

In 1998 the first energy upgrade of the LEP Electron/Positron collider, LEP2, was completed at CERN. Sixty-eight superconducting modules supplied by four 12 kW @ 4.5 K equivalent power refrigerators have been operated allowing a colliding beam energy of 94.5 GeV. Meanwhile, the operation and maintenance responsibilities were transferred to an industrial firm on the basis of a result-oriented contract. After a short description of the operational organization, we report on the operation of the LEP2 cryogenic system over the past three years. Particular attention is given to power availability, failure statistics and recovery time after interruptions. The most relevant problems and their solutions are exposed. Finally, we review the interactions between the cryogenic system and the particle beams, which are limiting the ultimate performance of the LEP collider.

INTRODUCTION

Operated since 1995 by a joint team of CERN/Air-Products-Thomson, the four cryoplants have accumulated a total of 71,000 hours of operation. During this period the upgrade of the LEP e^+/e^- collider from 45 GeV to 96 GeV per beam was achieved by gradually installing 68 modules on both sides of each of the four interaction points (IP) in the ring. In 1998 the 68 accelerating modules installed allowed a colliding energy of 94.5 GeV per beam in physics with a record luminosity of 200 pb^{-1}.

Within the same period the responsibility of the operation and maintenance was transferred to an industrial contractor allowing an important redeployment of CERN resources to the LHC activities without noticeable effect on the cryoplant performance.

During the LEP winter shutdown 1998/99, all four 12 kW@4.5 K refrigerators were upgraded to achieve the equivalent power of 18kW@4.5K necessary to reach the 100 GeV per beam ultimate potential of LEP.

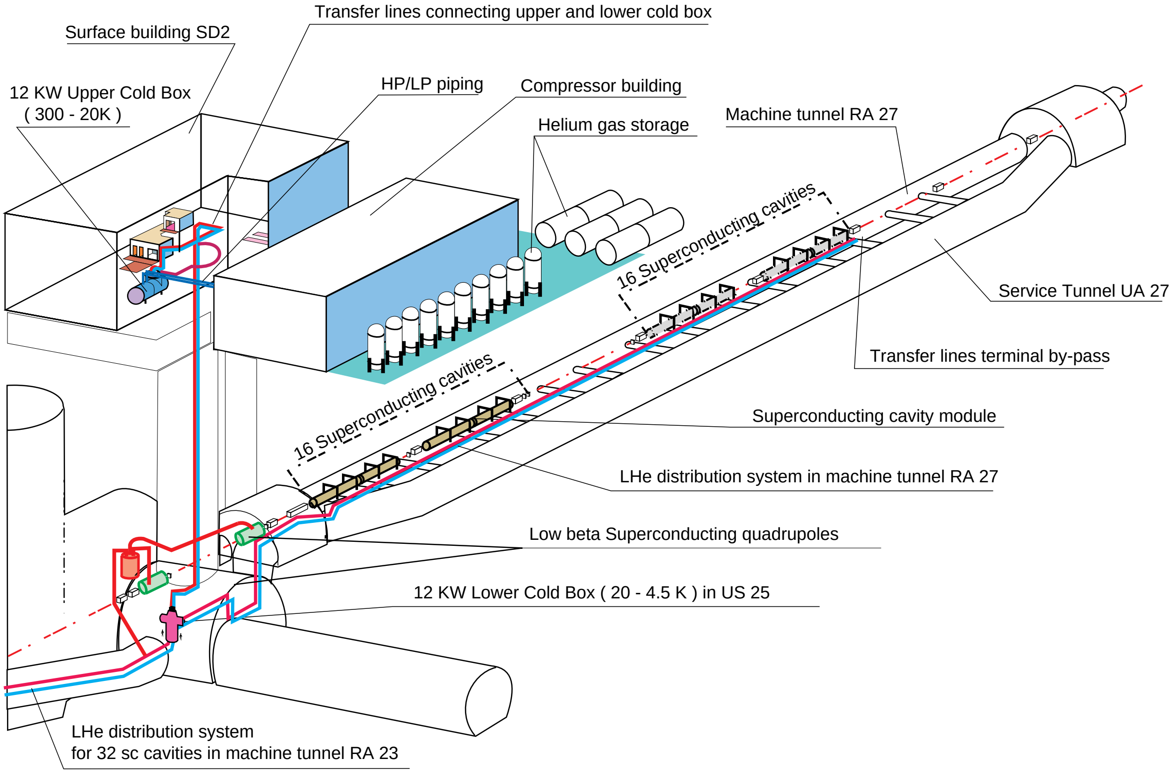

Figure 1. Typical layout of a LEP2 cryogenic system.

THE LEP2 CRYOGENIC SYSTEM

The LEP2 cryogenic system described in earlier publications [1,2,3,4] located at each of the four interaction points of LEP, of a cryoplant and its associated liquid helium distribution system, i.e., 200 m-long supply-and-return transfer lines to feed 8 to 10 superconducting modules on both sides of the point. A description of the liquid and gaseous helium circuits inside the 11 m modules can be found in the references [5]. In addition to the modules, the 12 kW plants are also cooling the low-beta quadrupoles at two LEP points. A typical layout of the cryogenic system of LEP2 is shown in Figure 1.

OPERATION

Operational Organization

In 1995 an operation and maintenance contract was established between CERN and the Air Products – Thomson Consortium with the initial objectives to enlarge the industrial support already present at CERN on the LEP2 operation.

This contract was structured in two phases. In a first contractual phase from 1995 to 1997, the consortium had to provide resources and infrastructure to operate and maintain the cryogenic installations under CERN's supervision and responsibility. In parallel, the contracting consortium had the duty to prepare, write and update operational documentation (operation procedures, control logic description, electrical and P&I Diagrams) and to establish a maintenance plan based on their industrial knowledge.

After three years the responsibility has been transferred to Air Products –Thomson with a new, result oriented, phase of the contract.

The tasks of the consortium for this new phase are:

- to provide and supervise qualified personnel ensuring efficient and uninterrupted operation of the installations with a minimum number of operators fixed within the contract.
- to organize and execute preventive maintenance as defined in the maintenance plan and to perform corrective interventions in case of failure.

In the new phase contract, an important fraction of the payment is based on the evaluation of the cryoplants' availability. This is evaluated by the recovery delay after utility failures and a tolerance related to cryogenic failures depending on accumulated running hours. Figure 2 presents the contract tolerance for the LEP2 cryoplants in case of utility failure.

The staff involved in the consortium consists of 37 persons, of which 30% are related to LEP2 operation and maintenance. For the LEP cryogenic system, the operation team consists of 5 operators and 1 engineer.

A small group of CERN-trained staff is still active and remain in close touch with the installations. The staff, involved in consolidation and upgrade work, operation and maintenance monitoring, as well as interface with the LEP machine, was reduced from 22 man-years in 1995 to 5 man-years in 1998.

Table 1. Overall statistics over three years

	NB of Utility failures	LEP hours lost	NB of Cryo failures	LEP hours lost Cryo origin
1996	2	32	2	6
1997	5	53	1	7
1998	5	113	4	20,5

Table 2. LEP2 cryogenics operation statistics in 1998

	Running Hours	Main Power cut 15/5/1998		Main Power cut 6/8/1998		Other Utilities failures				Cryo failures	total of hours lost for RF(h)	% total	% cryo origin
		Utility failure (h)	Recov. time (h)	Utility failure (h)	Recov. time (h)	Utility failure (h)	Recov. time (h)	Utility failure(h)	Recov. time (h)	Recov. time (h)			
IP2	5196:00	4:32	32:00	1:23	24:00					12:30	68:30	1.32	0.24
IP4	5043:00	1:47	28:00	1:23	12:00	0:08	5:00			3:00	48:00	0.95	0.06
IP6	5139:00	2:00	49:30	1:23	7:00					1:30	58:00	1.13	0.03
IP8	4995:00	3:13	33:00	1:23	27:00					3:30	63:30	1.27	0.07
SPS1	6010:00	3:16	16:20	2:12	7:53	0:02	2:58	1:17	8:15		35:26	0.59	0.00
SPS3	6010:00	3:16	12:50	2:12	4:53	0:02	1:22	1:17	6:15		25:20	0.42	0.00
total	32393:00		171:40		82:46		9:20		14:30	20:30	298:46	0.92	0.06
LEP	4224:00		49:30		27:00		7:58		8:15	20:30	113:13	2.68	0.49

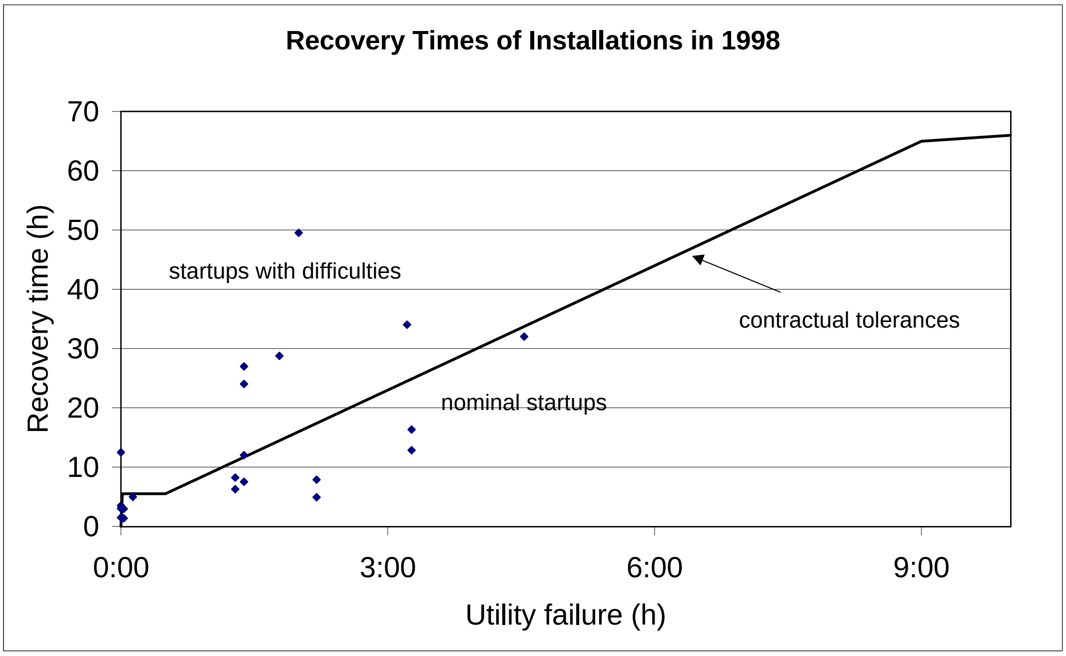

Figure 2. Time for recovery as function of the utility downtime in 1998

Downtime Statistics and Duration of Recovery

It turns out that interruption of operation and LEP downtime are mostly related to utility failures (water, electricity), especially in 1998 with 2 major power cuts resulting in 76 hours of LEP downtime. The time lost due to cryogenic failures, such as defective equipment, is low with a non-relevant increase in 1998 (Table 1). This result is due to the recent careful preventative maintenance on the cryogenic system.

As the installation of the superconducting modules was completed in 1998, the detailed statistics of the cryogenic and utility failures are given for that year in Table 2.

The recovery time for LEP is to be considered as the maximum cryogenic recovery time for each utility failure.

Most of the start-ups after a utility failure in 1998 were nominal as shown in Figure 2. If any difficulties, such as instrument or valve failures, appeared during start-up the recovery time went over the fixed tolerance limits.

For one of the cryoplants (IP8), longer recovery times, caused concerns about its efficiency. The lack of power was due to a leak in a valve between 20K and 4.5K, which was repaired during the last shutdown.

Helium Consumption

Each installation needs a minimum of 17,000 Nm3 of helium. To ensure a refill of the modules after accidental loss additional large storage tanks have been installed. Thus, a total of 24,000 Nm3 of helium can be stored. Over the past three years the annual consumption for the four installations was about 40,000 Nm3. Half of the losses are due to accidental stops of the installation, as the recovery of the 100 g/s of helium outgased by the SC modules at low pressure to the medium pressure storage cannot always be done (lack of utility,..). The other half is lost gradually over the year, mostly during the start-up phase, including purging and regeneration, of the cryoplants after the annual maintenance.

OBSERVED PROBLEMS

Turbine Filter Clogging

In 1996 it was observed in two cryoplants that the helium filter of a 90K turbine was clogging thereby reducing the power capacity of the cryoplant. Based on investigations done in 1998, it appears that the observed clogging was due to traces of water (<10 ppm) coming from the medium pressure storage or from the first heat exchanger.

The clogging induces a power reduction and may cause collapse of the filter. Periodic cleanings are required during the year. Each intervention takes 12-15 hours and was combined with other maintenance or access activities in order to reduce the impact on the running schedule of LEP.

Helium Leak in Inter Cold Box Transfer Lines

In 1996 a helium leak was detected on one of the Interconnecting Transfer Lines (ITL) linking the Upper and Lower Cold Box of one cryoplant. The leak appeared to be on a compensation bellows and induced by a design error existing on all ITL of two cryoplants. In view of the large amount of repair work, the run took place with the leaky part partially repaired, the insulating vacuum under active pumping and monitoring, plus a fallback solution based on spare flexible transfer lines. The repair of the ITL with a corrected design took place during the following shutdown. The work, which required the removal of all the lines from the access shaft to replace all the faulty parts and re-install the lines, was executed within a very tight schedule.

Thermomechanical Oscillations

At the end of the 1994 run a 100Hz oscillation of the accelerating field of two modules was observed [6]. Studies during the 1995 run showed a correlation between this oscillation and a mechanical vibration on the helium outlet of the modules. After elimination of other possible origins such as valve vibration and LHe level influence, a thermo-acoustical origin was identified. This oscillation was inducing the mechanical vibration of the outlet connector to the transfer lines, and as the frequency of this vibration corresponded to a mechanical resonance of the cavities, the accelerating field was affected. During the technical stop in October 1996, Kapton™ foils were placed between the male and female part of the outlet connector in order to limit the thermo-acoustical oscillation building up in the helium space along the connector. Lack of space on the female coupling prevented this installation for several modules. The results obtained are satisfying as most of the 100 Hz oscillations are now damped to an acceptable level for the RF operation. The installation was completed successfully during the 96/97 Shut-Down.

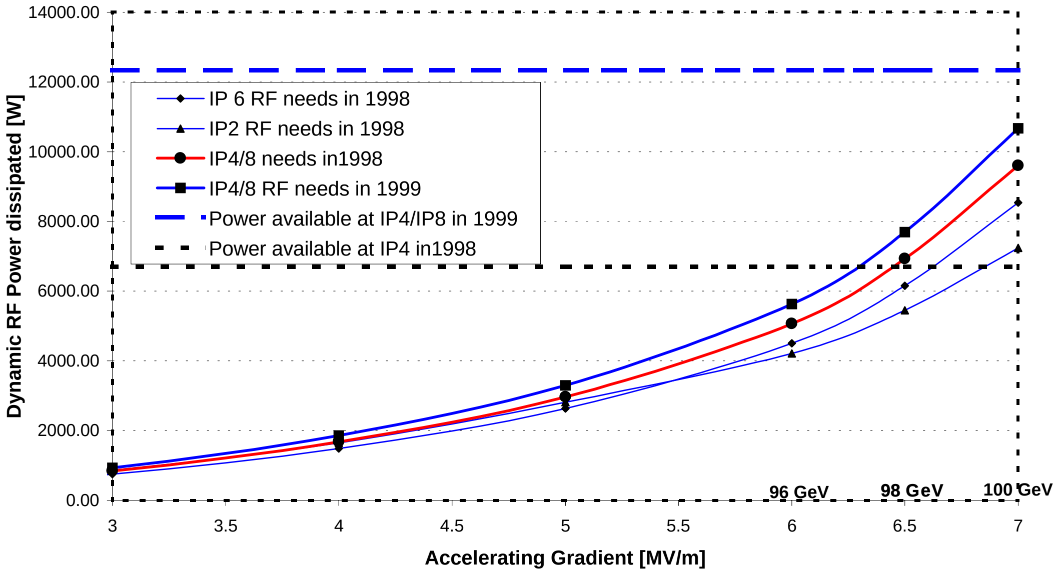

Figure 3. Dynamic power dissipated by RF into the cryogenic system

CRYOGENIC LIMITATION AND BEAM INDUCED THERMAL LOSSES

Maximum Energy

The 12 kW equivalent power at 4.5K in the cryoplant design is split into different parts : 1.6 kW is used for the cooling gas flow through the RF accessories in the modules, 0.4 kW for the shield cooling, and the remaining 10 kW of cooling power at 4.5K is available to compensate the static losses and the dynamic RF load. With all the static loads deducted from the real measured capacity of the cryoplant about 6.7kW are available for dynamic RF use [7].

The RF dynamic load is a quadratic function of the acceleration field divided by a quality factor Q. Figure 3 presents the predictions of the expected RF dynamic power based on measurements of the Quality factor performed during operation.

Influence of Circulating Beam

Since 1996 an influence of the beam on the cryogenic system has been noticed. This influence is correlated to the beam intensity and the bunch length. In order to compare different bunch configurations, an impedance Z has been defined. From the evolution of the power recovery in the phase separator as a function of the beam intensity in stable physics one can compute an average bunch impedance Z_b= 16 MΩ for a bunch length longer than 10mm.

An important sensitivity of losses on the bunch length exists. Bunches of 7 mm length induce twice the losses of 10 mm bunches. To limit this effect it was decided in 1998 to operate the LEP Machine with a bunch length longer than 10 mm.

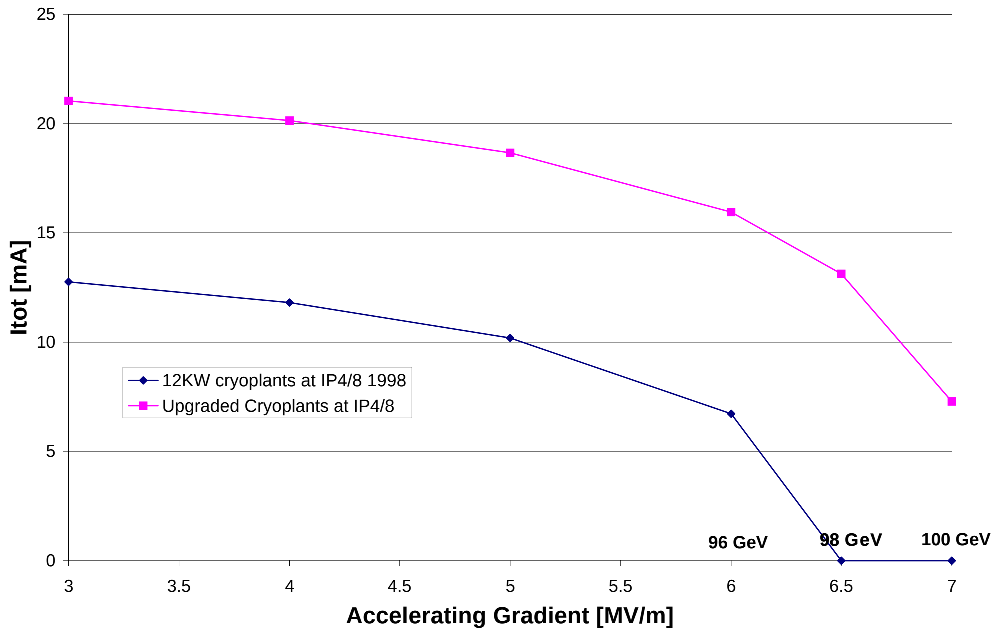

Figure 4. Beam intensity limits as function of the increasing LEP colliding energy

This beam effect reduces the operating margin and prevents physics runs with high bunch intensity affecting the luminosity of the LEP machine. Figure 4 presents the expected limitation in beam intensity as a function of the accelerating gradient [8].

Origin and Cure of the Beam Effect

The origin of the anomalous beam induced heat load on the LEP cryogenic system has been located in the cables of the RF antennas measuring the accelerating field in the cavities. In November 1998, eight cables of a module were successfully replaced by cables of larger cross sections. During the winter shutdown 1998/99 all the faulty cables were replaced. The observation completed during the first part of the 1999 run confirms this result.

HIGHER CURRENT, HIGHER GRADIENT, HIGH LUMINOSITY?

The cooling power available from the cryoplant was sufficient to cover the RF needs over the past years with an increased demand in power related to the rising objectives of the LEP2 energy up to 94.5 GeV. The limits observed in current intensity were coherent with constraints in other LEP systems and did not lower the performance of the LEP collider.

However, to reach the new colliding energy of 100 GeV, required for physics with enough luminosity, it was necessary to upgrade the cryoplant as presented in Figures 3 and 4.

The upgrade of the existing cryoplants provides four times 18kW @ 4.5 K and was installed during the last winter shutdown. Now the cryoplants are in operation and the generated cooling power is sufficient for the present LEP energy of 98 GeV and its future increase to 100 GeV.

The challenge is now to maintain the same level of availability of the cryoplant to keep the highest possible luminosity, required for the last two years of LEP operation.

REFERENCES

1. D. Güsewell, M. Barranco-Luque, S. Claudet, W.K. Erdt, P.K. Frandsen, Ph. Gayet, J. Schmid, N.O. Solheim, C. Titcomb and G. Winkler, Cryogenics for the LEP200 Superconducting Cavities at CERN, Proc. of *the Particle Accel. Conf*. 1993, 2956-2958
2. B. Chromec, W.K. Erdt, D. Güsewell, K. Löhlein, A. Meier, .A.E. Senn, T. Saugy, N.O. Solheim, U. Wagner, G. Winkler, B. Ziegler et. al, A High Efficient 12 kW Refrigerator for the LEP200 Project at CERN, Proc. of the IISSC 1993, Supercollider 5, Plenum Press (1994) 95-100
3. G. Gistau and J. Veaux, A 12/18 kW at 4.5 K Helium refrigerator for CERN's LEP superconducting accelerating cavities, *Cryogenics* (1994) 34 ICEC Supplement 103-106
4. S. Claudet, W.K. Erdt, P.K. Frandsen, Ph. Gayet, N.O. Solheim, C. Titcomb and G. Winkler, Four 12 kW/4.5 K Cryoplants at CERN, *Cryogenics* (1994) 34 ICEC Supplement 99-102
5. G. Winkler, Ph. Gayet, D. Güsewell and C. Titcomb, Cryogenics Operation and On Line Measurements of RF Losses in the SC Cavities of LEP2*, Particle Accel. Conf. 1995* Dallas
6. Ph. Gayet, S. Claudet, D. Kaiser, G. Winkler, *Cryogenic issues*, VII LEP Chamonix workshop, 1997
7. Ph. Gayet, S.Claudet, D. Kaiser, G. Riddone, LEP2 in 1998 and beyond, *Cryogenic issues*, VIII LEP Chamonix workshop, 1998
8. Ph. Gayet, S. Claudet, D. Kaiser, M. Sanmarti, *Cryogenic issues* for LEP2 in 1999, IX LEP Chamonix workshop, 1999