EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Divisional Report

CERN LHC/97-07 (ACR)

Beam Effects on the Cryogenic System of LEP2

Ph. Gayet, D. Kaiser, G. Winkler

Abstract

The LEP collider was operated during 1996 for the first time with superconducting cavities at the four interaction points. During operation for physics it was observed that the dissipated heat in the cavities is not only a function of the acceleration gradient, but depends also on beam characteristics such as intensity, bunch length and beam current. These beam effects had not been foreseen in the original heat budget of the LEP cryogenic system.

The observations indicating the beam effect and its origin are presented. The available capacity of the refrigerators demonstrates that cryogenics might become a limiting factor for the performance of the LEP collider.

Presented at CEC-ICMC'97 - Portland - OR -USA
July 28th- August 1st, 1997

Administrative Secretariat
LHC Division
CERN
CH - 1211 Geneva 23
Switzerland

Geneva, 27 October 1997

BEAM EFFECTS ON THE CRYOGENIC SYSTEM OF LEP 2

Philippe Gayet, Dieter Kaiser, Gunter Winkler

LHC Division , CERN
CH-1211 Geneva, Switzerland

ABSTRACT

The LEP collider was operated during 1996 for the first time with superconducting cavities at the four interaction points. During operation for physics it was observed that the dissipated heat in the cavities is not only a function of the acceleration gradient, but depends also on beam characteristics such as intensity, bunch length and beam current. These beam effects had not been foreseen in the original heat budget of the LEP cryogenic system.

The observations indicating the beam effect and its origin are presented. The available capacity of the refrigerators demonstrates that cryogenics might become a limiting factor for the performance of the LEP collider.

INTRODUCTION

The CERN Large Electron Proton (LEP) collider is a 26.6 km circumference e+ e- storage ring. Originally equipped with a room temperature RF-system, it underwent an energy upgrade (LEP2) during the last years by installing superconducting (sc) cavities. At the end of the 1996 run, 176 installed sc cavities permitted operation for physics at 86 GeV per beam. During the shutdown 1996/1997 64 new cavities were installed.

The cryogenic system at each of the four acceleration points of LEP consists of up to 18 modules of 4 cavities each, and a cryoplant with an equivalent cooling capacity of 12 kW at 4.5 K. This power is required for cooling the sc cavities proper as well as various sub-systems. A summary of the refrigeration capacity available at the different points and the various sources of thermal load is given in Table 1, which shows that at 1996 operating conditions, about 6 kW were available for compensation of dynamic heat loads during operation of LEP.

The main contribution to the dynamic heat load in a module is due to surface resistance of the sc material. The dissipated heat is proportional to the square of the acceleration gradient (figure 6). At the nominal gradient of 6 MV/m acceleration field the specification predicts losses of less than 280 W per module, which leaves a reserve of 55 W per module at the more heavily loaded cryoplants.

During last year, additional, unexpected dynamic losses were seen on the cryogenic system in the presence of beam. These losses, related to the beam intensity, particle bunch length and energy, show clearly both in the remaining cooling capacity available in the cold box and in the power dissipated in the modules.

This paper will review the different contribution and the foreseen solutions to achieve the maximum possible energy of LEP machine.

HEAT LOAD MEASUREMENT PRINCIPLES

The cavities are cooled in a liquid helium bath at 4.45 K. Four cavities assembled in one cryostat form a module. Once filled, the modules have to be kept under stable conditions with minimum variation of helium level and pressure. For this task two feedback control loops and one feed forward calculation are performed.

The level is maintained with a PID control loop acting on the inlet valve. The pressure is kept constant at 1.25 bar with a PID control loop acting on the outlet valve. In order to achieve satisfactory stability, the changing dynamic RF loads must be compensated within the module. This is done using an electrical heater in each cavity, to which a pre-determined power (50-100W) is applied at zero RF. During operation, a feed-forward calculation reduces heater power as a function of the acceleration gradient in order to keep the total thermal load of the module constant.[1]

Table 1. Refrigeration capacity and heat load budget of 12kW cryoplant

Specified duty	Power @4.5K
Cooling power @4.5K	10000W
Liquefaction 13g/s (1g/s ≡ 125W @4.5K)	1625W
Shield cooling 6700W @70K	400W

	P2	P6	P4	P8
Measured cooling power @4.5K before 1997 tuning	9000W	9200W	9200W	9000W
Load composition				
Nb-sheet modules	4			
Nb-film modules	12	16	18	18
SC-quadrupoles	2	2		
Static heat load				
Module connections (27W/module)	432W	432W	486W	486W
SC-quadrupoles (4g/s)	500W	500W		
Transfer lines	340W	340W	500W	500W
Remaining power in pot for control	400W	400W	400W	400W
Static load of modules (80W/mod)	1280W	1280W	1440W	1440W
TOTAL	2952W	2952W	2826W	2826W
Available power for dynamic RF-load	6048W	6048W	6174W	6074W

Each of the cryoplants runs in steady state. The high and low pressure sides of each plant are maintained constant by compensating load variations with an electrical heater. The helium is supplied to the modules at constant vapour quality, since the overall heat load of the plant is almost constant.

The inlet and outlet valve positions of the modules are therefore proportional to the heat loads and their variations provide a measurement of the power dissipation.

DYNAMIC RF-LOAD MEASUREMENTS WITHOUT BEAM

The measurements done before the 1997 run show that the measured losses are generally lower than the predicted ones. However, the variations among modules are large. Figure 1 shows the distribution of RF-load and acceleration gradient over 46 modules. The average load is 210 W with an overall acceleration gradient of 5.7 MV/m instead of 240 W given by the specification for that gradient.

Beam current

In Figure 2 it is shown that after a stabilisation period of the thermodynamic parameters following injection and increase of beam energy there is a strong correlation between heat load in the module and beam current. This was confirmed by similar data from a large number of modules.

The magnitude of the heat load variation induced by the beam current is about 15 W per module at a beam energy of 86 GeV and for a total beam current decreasing from 3.5 mA to 2.5 mA. It is proportional to the square of the beam intensity.

Bunch Length

In November 1996, tests with variable bunch length and constant beam current were performed showing an increase from 30 W to 50 W of the power dissipated in the modules with a bunch length decreasing from 7.2 mm to 4.5 mm (Figure 3).

Beam Energy

A preliminary cross-check done on different modules shows that at high beam energy, the variation in heat load with beam intensity is higher than at low beam energy. This result is consistent with temperature measurements on the bellows of the accelerator vacuum chamber outside the modules, which show a linear dependence on the energy.[2]

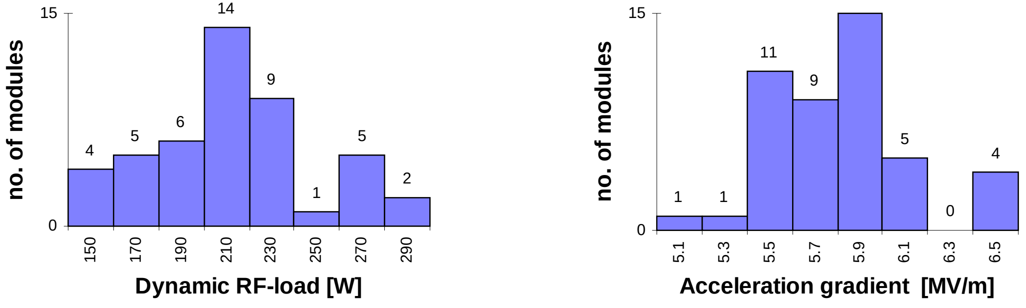

Figure 1 Variations of dynamic RF-load and acceleration gradient measured before the 1997 run

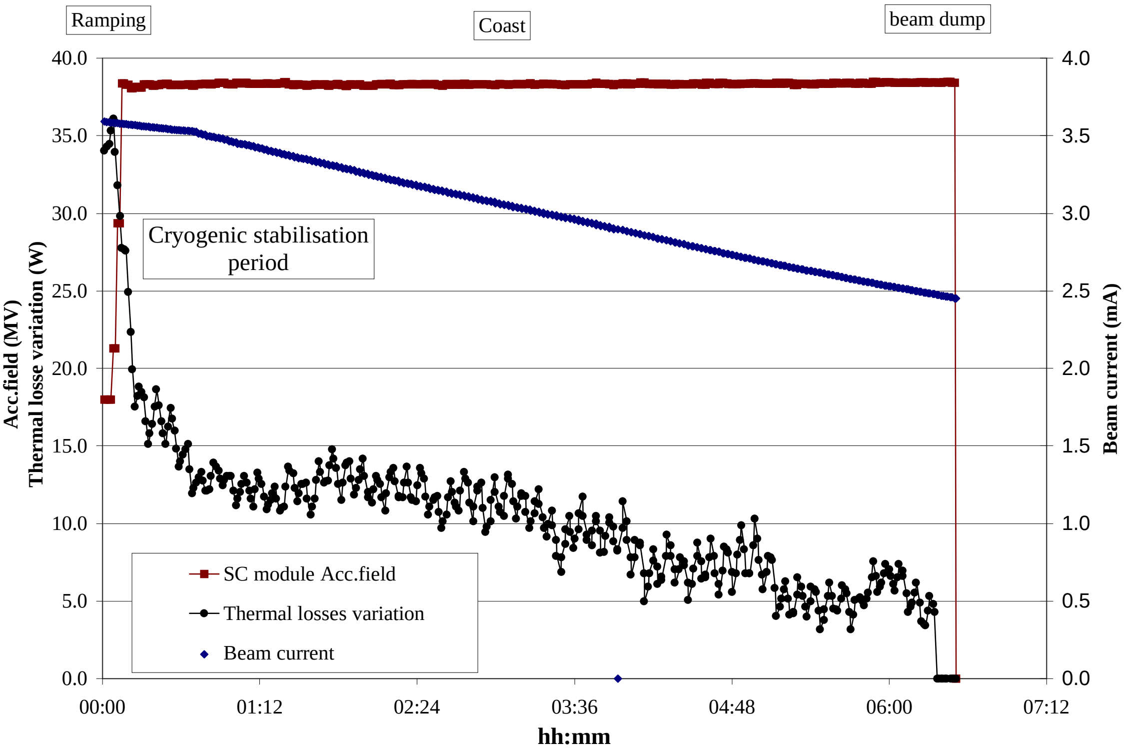

Figure 2 Effect of beam current on heat load of module 6332

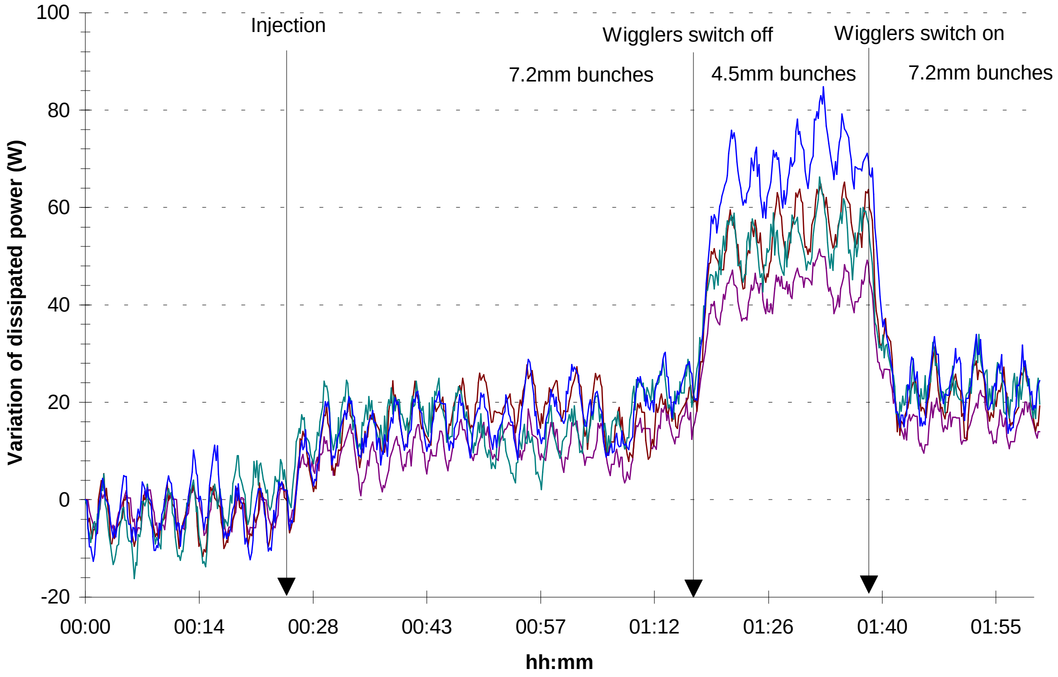

Figure 3 Beam heat load on four modules with varying bunch length at 22 GeV without accelerating field

ORIGINS OF BEAM EFFECT

Thermometric measurements done inside the modules show that a beam load is detectable on the normal conducting bellows, which link together adjoining cavities in a module (Figure 4).

The power dissipation calculated from the temperature rise of the bellows shows the same general dependency on beam current as the module heat load seen by the cryogenic system (Figure 5).

The origins of this power dissipation are not yet completely understood. They may be caused by beam excited field, synchrotron radiation or radiation issued from other modules. A series of measurements will be made in the 1997 run to understand the causes and to scale the effect with the beam energy and total current.

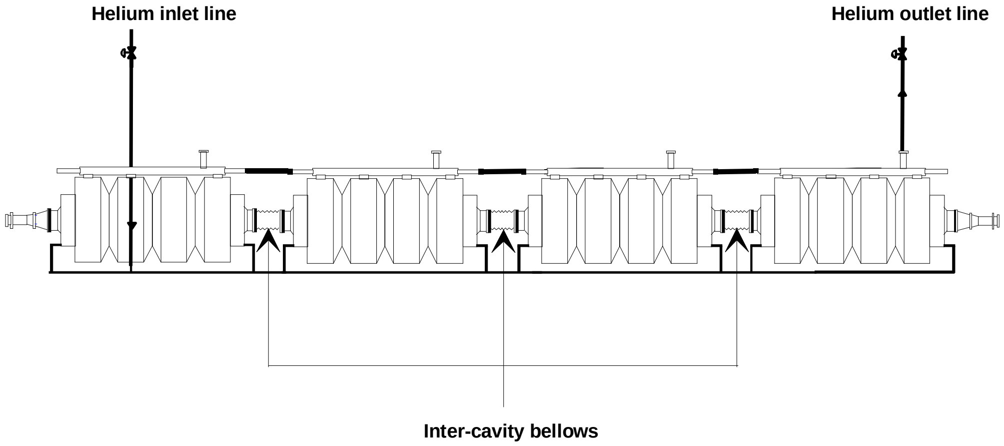

Figure 4 Main components of the helium tank in a module

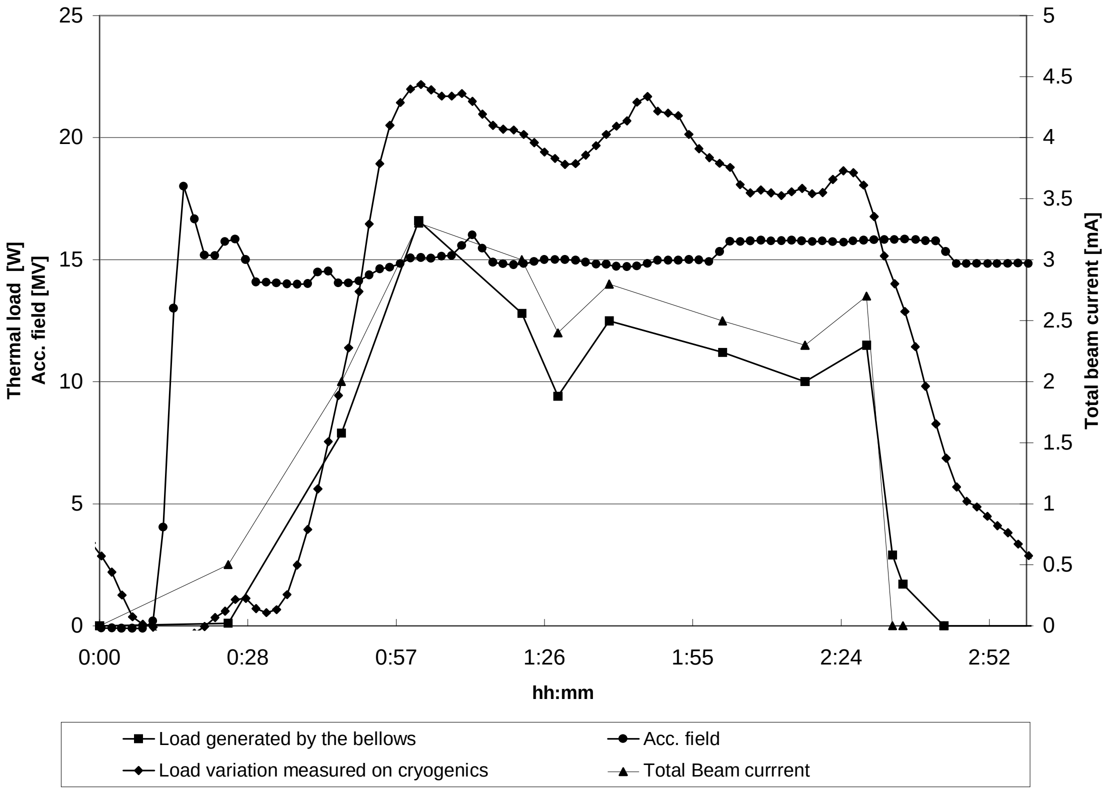

Figure 5 Correlation between cryogenic load measurements and power dissipation on bellows

CONSEQUENCES

The unexpected heat loads on the superconducting cavities of the LEP2 collider produced by particle beams were observed at the end of the 1996 run, but could not be precisely measured. There are several possible mechanisms explaining the heat deposition in the modules, but a reliable prediction for losses at higher energies, higher beam currents or shorter bunches has not yet been made.[2]

In order to increase the limited reserve in cooling capacity, a tuning of the operating condition of the cryoplants was done before the 1997 run. By reduction of the outlet pressure of the last turbine from 2.5 to 2 bar and with a 2% increase of mass flow achieved by rising the low pressure of the cycle from 1.01 bar to 1.03 bar, which also allowed an increase of the high pressure of the cycle, a gain of 600W per cryoplant was achieved. Another 200 W were gained by improving the control parameters of the phase separator heater used to stabilise the remaining power, and by a reduction of cooling flow through ancillary RF-equipment.

However, the LEP2 program foresees a push to higher beam energy to the limit of the existing RF installation. This implies the use of accelerating gradients above 6 MV/m and the installation of four additional modules. Therefore a study of possible upgrades of the cryoplants was launched. Two alternatives are possible:

- a partial upgrade using the additional flow given by the recently commissioned redundant compressors, addition of an oil removal unit and replacement of some turbines,
- a complete upgrade using the additional flow given by the redundancy compressors and the addition of one extra compressor per cryoplant, and of an oil removal unit and the exchange of the turbines

The refrigeration power available to absorb dynamic heat loads is increased from 6.8k W to 10 kW in the first case and to 13kW in the second case. The upgrades would have to be implemented before the 1999 run.

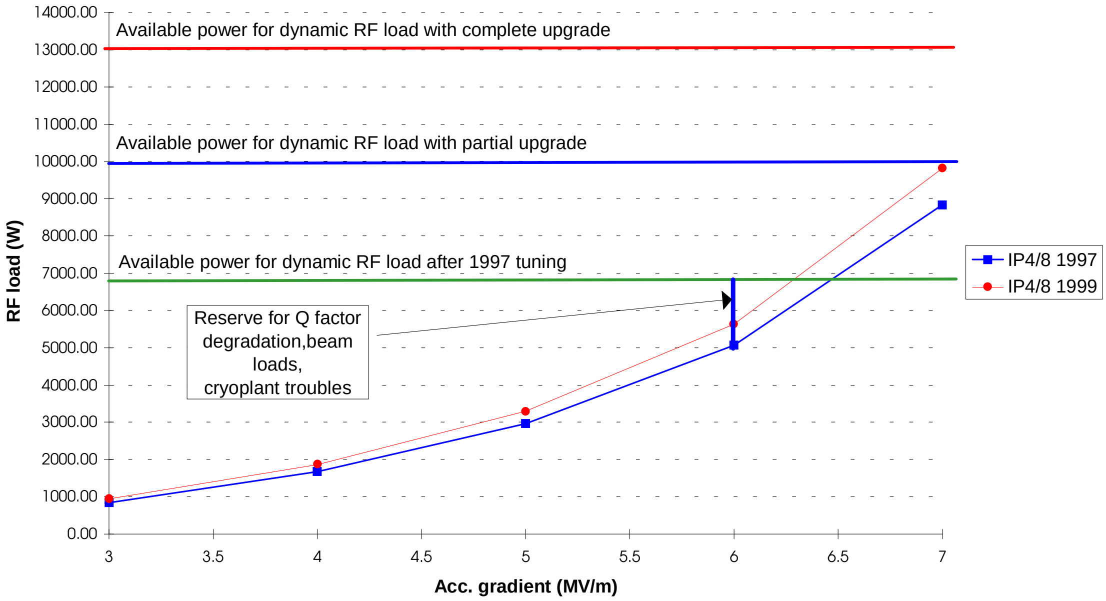

Figure 6 Dynamic heat loads due to RF system and cooling capacity limits for P4 and P8 cryoplants

Figure 6 shows the limitation of the existing plants by the higher loads at points 4 and 8 as well as possible upgrades. The curve show the variation of dynamic heat load as a function of acceleration gradient for the currently installed number of modules as well as for the 1999 configuration. The observed beam effects have not been added to the curves.

REFERENCES

1. C. Wyss et al, LEP design report vol. III LEP2, CERN-AC/96-01(LEP2) (1996)
2. G. Cavallari, P. Gayet, G. Geschonke, M. Jimenez, S. Myers, Beam related thermal losses in the LEP SC RF system, CERN LEP2 note 97-40 (1997)