RF HARDWARE CHANGES IN LEP FOR 1999

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Abstract

The planned RF hardware modifications for LEP in 1999 are presented. In particular the behaviour of the cavity antennae cables during 1998 operation and the current status of their replacement is presented. Additionally the initial results of an active damping system for the ponderomotive instability together with a review of some different methods of tuning the cavities is given. Finally some implications of the new hardware on operations are discussed.

1 MODULES

1.1 New Modules

The installation of the last four modules planned for LEP will be completed for the 1999 start up. Their layout however is quite different from the other sixty-eight modules because they are located some 100m further away from their klystron and control racks.

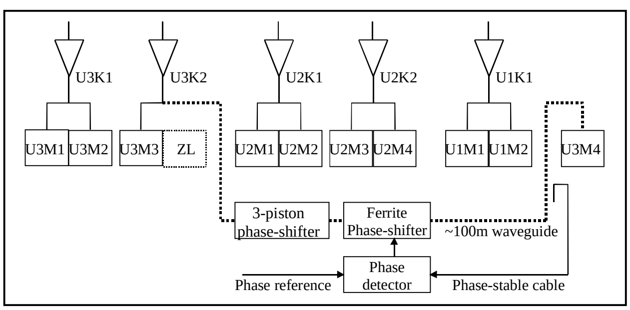

Figure 1. New module Layout

The 100m length of waveguide (WG) along the machine tunnel is expected have RF phase changes of up to 20º due to RF losses causing heating and thermal expansion of the WG. This phase variation will be automatically compensated using feedback loop driving a high-power ferrite phase shifter as shown in figure 1.

The phase shifter has a phase range of 40º however part of this range is used correcting its own phase variations caused by heating. Although it has been thoroughly tested at 350 Mhz with continuous RF power up to 500 kW, it is never the less a new device in the LEP RF system and it's behaviour under operational conditions is still to be confirmed. Of particular concern are the transients caused by pulse processing, rapid beam loss or RF trips and effects of HOM power from the beam.

1.2 HOM cables

A limit to the maximum beam current and therefore the performance of LEP has been the power rating of the RF cables connecting the HOM couplers to the cryostat output. For the 1999 start up all 272 Nb-Cu cavities will be fitted with rigid coax lines and the 16 solid Nb cavities with "Kaman" cables. This will increase the HOM power limit allowing beam currents above 12 mA which is well above the cryo limit.

2 HIGH POWER

2.1 Longitudinal Feedback Cavities (LFB)

For a substantial period of 1998 one of the four cavities in the LFB system had a faulty power coupler. Because a rapid change of coupler is not possible the cavity concerned was disabled by removing the input drive. In this situation the beam generated signals extracted by the power coupler must be absorbed by a matched load. From the 1998 experience we learnt that for any similar interventions in the future, an improved waveguide to coax transition together with a new load which can easily be connected to the water cooling system are required. These items will be ready in place for the 1999 start up.

Also the LFB coupler spares situation needs reviewing because at the start up 1999 we will be reduced to one spare working coupler.

2.2 High Power Components

During 1998 six klystrons and one circulator were replaced in LEP. The reasons for the klystron failures and their operational life times are shown in table 1.

Table 1. Replaced klystrons

Fault	HT hours
Arcing in gun region	32209
Arcing in gun region	5730
Vacuum	28095
Heater short circuit	2145
Heater open circuit	3093
Arcing in output region	6990

The current inventory of LEP spares is:

10 Klystrons

3 Circulators

This should be enough to cover the remaining two years of LEP operation, however, it should be noted that although the majority of the forty-four klystrons installed in LEP are relatively new, eight already have more than 30 Khrs of operation as shown in figure 2.

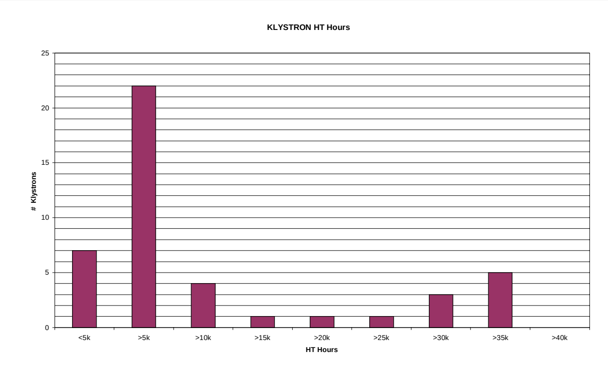

Figure 2. LEP Klystron Operating Hours

2.3 New Klystron Parameters

The LEP klystrons have been operated at an HT of 77 kV corresponding to a maximum RF power of 650 kW. For the start up 1999 the HT will be 82 KV increasing the maximum RF power to 850 kW which is sufficient for about 8mA of beam current at 7 MV/m.

However optimising this new working point requires terminating the klystrons with a matched load. A 1 MW mobile water cooled load has been specially constructed for this purpose.

The absolute maximum HT is 88 kV giving max RF powers of > 1 MW. However for reasons of efficiency and reliability it is always preferable to operate the klystrons at the lowest HT consistent with RF power requirements.

3 LOW POWER

3.1 Longitudinal Feedback

The longitudinal feedback system has been modified to damp the quadrupole mode at 2Qs [1]. Because of the cavity bandwidth only one type of particle can be damped but this is sufficient to enable the Q-loop to lock properly.

3.2 LEP Frequency Reference

The LEP frequency is now derived via the GPS system, the existing Rubidium standard had been rather unreliable with long repair delays.

3.3 Cavity Measurements

Several improvements have been made to the cavity monitoring. The most significant improvement is the new cavity temperature measurement system. A partial installation of this system was already done in 1998 and it proved to be much more reliable, virtually eliminating RF trips caused by faulty temperature measurements. For the 1999 start up the new system will be installed on all cavities and a similar system for the HOM temperature measurements will be progressively installed during 1999.

Another consequence of increasing the cavity gradients above 6 MV/m is saturation of the cavity field measurement electronics. To avoid this coax cable attenuator-filters have been installed on all cavities and the system re-calibrated.

4 TUNING AND ACTIVE DAMPING AGAINST PONDEROMOTIVE INSTABILITIES

4.1 Ponderomotive Oscillations

Ponderomotive (electroacoustic) instabilities have been observed in the LEP cavities even at moderate field gradients [2]. The growth rate of the instability depends on the detuning angle ϕ_z and Vc^2 both of which will be worse in 1999 when LEP runs with more beam current and higher cavity gradients. In practice individual cavities behave very differently with strong coupling between cavities in the same module.

4.2 Tuning

During LEP operation the only remedy presently available against this instability is to reduce the detuning angle $\rightarrow$zero by introducing an offset to the tuning system. Unfortunately due to a large spread in phase and Qext setting the same offset to all cavities was not effective. Instead each oscillating cavity was treated individually. This was initially done manually and later automatically. The result is a large spread in offsets which at each step increase in beam current require a new optimisation. Additionally for large beam current some cavities required a second offset as the current decayed.

To overcome these problems more automatic methods of keeping the cavity on resonance have been proposed [3]. They are based on observing the cavity response to small narrow band FM modulation of the cavity tune. This is done by “wobbling the magnetostrictive tuner of the cavities.

A first method is based on synchronous detection of the resulting AM of the cavity field caused by the FM of the cavity tune. This method was tried in a LEP half unit. Where it successfully damped the instability but was incompatible with vector-sum voltage control.

A second method based on separation and phase detection of the two side bands has been built but not tested in LEP. This system is completely different and apart from technical problems it is doubtful if such a complicated system could be built within an acceptable time scale and budget to be a practical solution for LEP.

4.4 Active Damping

Another remedy against this instability is active damping and a study by Supelec, Paris was completed during 1998. However, in view of the large number of LEP cavities the proposed corrector appears too complicated. However, hardware studies based on this system are still continuing.

In search of a easier solution it was decided to return to a much simpler narrow band system. Initial tests with this system had been disappointing. It was sensitive to parameter changes and difficult to stabilise both resonance's simultaneously. Tests with new electronics as shown in figure 3 which allows better phase control immediately looked more promising.

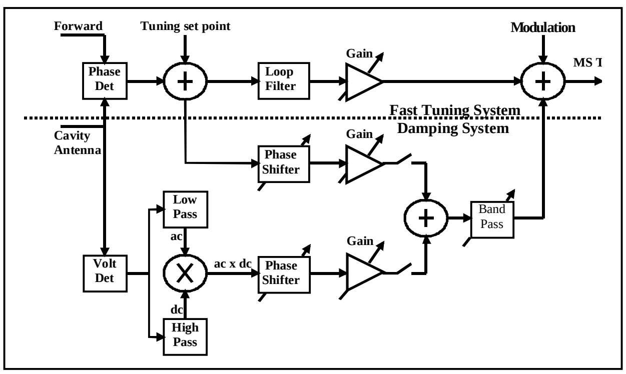

Figure 3. Block Diagram of Damping System

Further tests in LEP confirmed that the system was effective on most cavities and Figure 4 is an example from half unit 873-1. During the last week of LEP physics operation a complete damping system successfully ran on half unit 831-1. It should be noted however, that on some other cavities the system was not so effective.

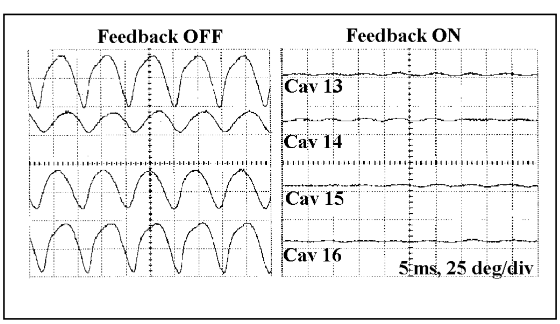

Figure 4. Effects of Feedback on Phase Detector Output

5 ANTENNA CABLES

As early as 1997 a few antenna cables had shown intermittent faults and two were definitely broken. However the extent of the damage was not realised until an inspection of five modules removed from LEP showed that all ten antenna cables had been damaged by overheating. TDR measurements on other modules confirmed cable damage extended to most LEP modules. Some examples of these TDR measurements is shown in figure 5.

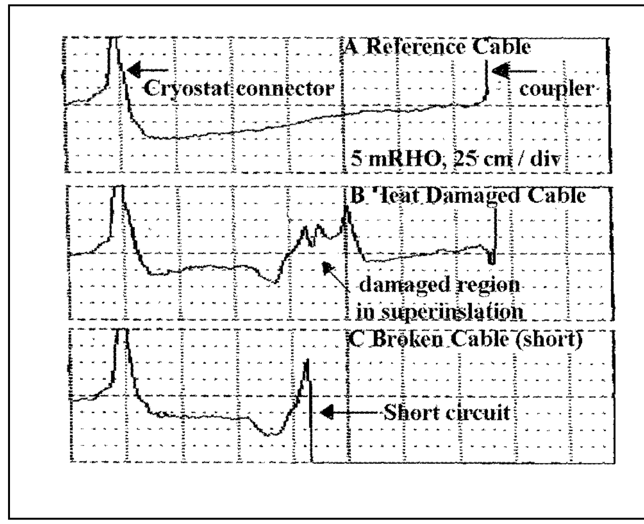

Figure 5. TDR Measurements on Antenna Cables

The field antennae are located in cavity like structures which are exited by the beam. A typical spectrum of modes coupled out by an antenna from this cavity is shown in figure 6 and is significantly different from the HOM spectrum of the accelerating cavities, having no modes at 640 MHz and other modes to extending to much higher frequencies.

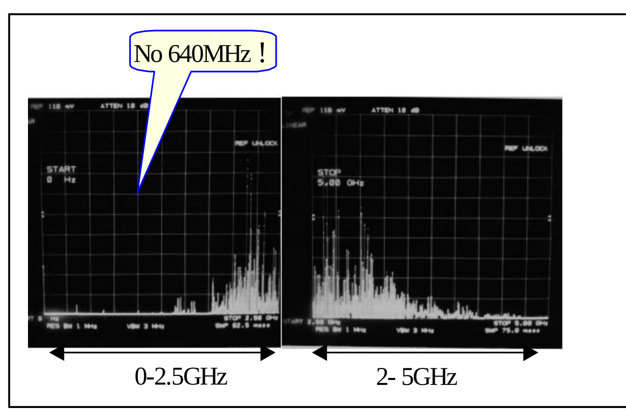

Figure 6. HOM Spectrum from Antenna Cables

Attenuation losses cause part this HOM power to be dissipated in the cable. The region where the antenna cables are routed through the super insulation blankets becomes hot enough for the cable dielectric to soften and allow the centre conductor to short to the outer screen.

Eventually some of this power is dissipated in the cryostat and explains the unexpectedly high beam related cryo losses.

There was some suggestion that the main part of the cable damage was done during an experiment with high intensity short bunches specifically to investigate these beam related cryo losses.

Before 1998 operation tests and measurements were made to establish a safe level of HOM power for the antenna cables [4] and a hard limit was set at 8 Watts measured at the output of the cryostat. To keep the HOM power below this limit the maximum beam current was restricted to about 6 mA and to maintain the bunch length during the ramp required complicated operational gymnastics. In this mode of operation 14 antenna cables were broken during 1998.

Towards the end of 1998 running it was decided to increase the beam current and the HOM limit was raised to 9 W. Immediately the rate of cable breakage increased even after returning back to the 8 W limit. By the end of running 31 cables had broken and on 8 cavities both antennae were lost which necessitated cavity tuning and voltage control using waveguide signals. One can only conjecture the ramifications on 1998 LEP performance if the HOM limit had been set to a higher level from the start up.

The obvious solution was to change the these antenna cables with a low loss type installed with the shortest possible length trapped inside the super insulation.

In situ replacement was initially considered difficult if not impossible due to accessibility. There was also a risk to the insulation vacuum seal. However a solution was proposed [5] and verified during the technical stop in October. 1998.

A second solution was to improve the cooling of the existing cables. In this case the access was via a vacuum flange but there was some doubt over the effectiveness of this solution particularly in view of the damage already sustained by the cables.

All things considered it was decided to replace both antenna cables of all the Nb-Cu cavities during the shutdown. This modification is a huge task involving 62 modules (248 cavities).

For the 6 modules removed from LEP (HOM coupler upgrade described in section 1.1) the antenna cables can be changed on the surface. For the remaining 56 modules (224 cavities) the work is done entirely in the LEP tunnel. To access the antennae requires removing all WG, air cooling and cabling from the modules before opening the insulation vacuum skin. This allows the barrel staves to be removed giving access to the superinsulation blankets and eventually the antennae. The output connector of the cable is accessed via a vacuum flange. This huge modification is progressing extremely well, only 5 cavities out of more than 200 completed have needed "intensive care". The whole operation will be completed by mid February 1999.

There is still some concern about the integrity of the cabling and especially the interlock system after such a major intervention. This implies treating units as new installations requiring lengthy check out procedures before switching on. The consequence is a very short conditioning period especially so in view of the aim of conditioning towards 7 MV/m.

REFERENCES

[1] J. Sladen, "Longitudinal Quadrupole Mode Feedback Tests", These proceedings.

[2] D. Boussard, P. Brown, J. Tuckmantel, "Electroacoustic Instabilities in the LEP2 SC Cavities", 7th Workshop on RF Superconductivity, Gif-sur-Yvette, Oct 1995

[3] D. Boussard], "LEP Towards 100 GeV", 8th LEP Performance workshop, Chamonix, Jan 1998

[4] G. Cavallari, Private communication

[5] E. Chiaveri, Private communication