# RUNNING THE CAVITIES AT HIGHER GRADIENTS

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## *Abstract*

Conditioning methods used in the LEP tunnel are outlined and results presented for the 1998 start-up and for the conditioning MD in October 1998. Work under way during the present shut-down and the strategy for this year's start-up are discussed.

## 1 INTRODUCTION

During the forthcoming conditioning period, the Nb/Cu cavities installed in LEP must be conditioned to a hitherto unattained average gradient.

This note covers the work under way for the preparation of this period and attempts to give an estimation of the possible outcome. This estimation is based on previous conditioning results, notably on the October 1998 conditioning MD. This MD gave valuable information on the limitations and problems that are likely to be encountered.

The spread in fields observed between cavities run by the same klystron can, as well as having other harmful consequences, limit the maximum average field attainable in a unit. An extensive programme of work is presently under way in order to alleviate this problem.

The scope of this note is restricted to cavity conditioning and performance without beam. Field levels given here refer to conditioning levels and not to operational gradients. The latter are necessarily lower. Prospects for this year's operation are discussed elsewhere in these proceedings [1].

In the next section, the conditioning methods used in the LEP tunnel are briefly reviewed.

## 2 CONDITIONING IN THE LEP TUNNEL

### *2.1 Standard procedure*

In the standard conditioning procedure, there is no change to the RF unit hardware configuration from that used during machine operation, with the exception that the main coupler DC bias is switched off. The conditioning procedure is controlled automatically by a locally run programme which checks cavity tune and steps up klystron output power until:

i) power limits because of rise in module radiation level or main coupler vacuum pressure,
OR
ii) pre-defined maximum power or field reached,
OR
iii) unit interlock trip. Automatic restart follows.

Conditioning is always started using this procedure. However, if progress is slow or if a hard limit is reached, other procedures can be tried.

### *2.2 Additional procedures*

If the limitation is due to main coupler vacuum activity, the standard procedure can be very inefficient. This is because the unit can trip frequently on a vacuum interlock due to a fast pressure rise before the conditioning programme has had time to react and step back the klystron power. This problem is overcome by using faster analogue control of the klystron power (Fig. 1). A voltage controlled attenuator, placed before the klystron's driver amplifier, is controlled directly from the sum of the cavity main coupler vacuum signals.

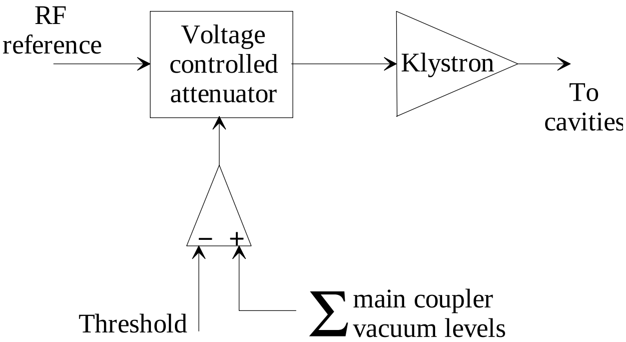

Figure 1: Vacuum conditioning with fast analogue control.

Pulse processing is very useful for completing conditioning and reducing radiation levels when performance is limited by electron emission. It enables higher peak fields to be reached for a given cryogenic load. The klystron is typically pulsed for around 10 ms with a duty factor of 10. Care will have to be taken when using this technique at higher field levels during the 1999 start-up since the large transient concurrent with each pulse switch-off presents a risk for components in the high power distribution network (notably the circulator).

In previous years, only a limited amount of analogue vacuum conditioning and pulse processing equipment was available. For the 1999 start-up, this equipment will be installed in each unit.

If pulse processing is insufficient, Helium processing can be used. It was not necessary last start-up, but was used on seven modules installed in the LEP tunnel during the 1996/1997 shutdown. It was very successful in improving the performance of the Nb/Cu modules that were limited by field emission [2]. However it is not without risks. Injection of Helium gas is a critical procedure. In addition, during conditioning, the vacuum interlock levels have to be relaxed and there is a danger of a sustained spark in the over-coupled cavities.

## 3 CONDITIONING RESULTS IN 1998

### *3.1 1998 start-up*

The average field level obtained during the start-up conditioning period was 6.8 MV/m. The unit with the highest field attained 7.1 MV/m. Analogue vacuum conditioning and pulse processing were used on about half of the units. No Helium processing was required.

### *3.2 October 1998 MD*

The purpose of this MD was twofold. Firstly, to see whether or not there had been any degradation of cavity performance over the year's physics running. Secondly, to attempt to push unit average fields to 7.2 MV/m and to record the cause of any limitation. Only the standard conditioning procedure was used.

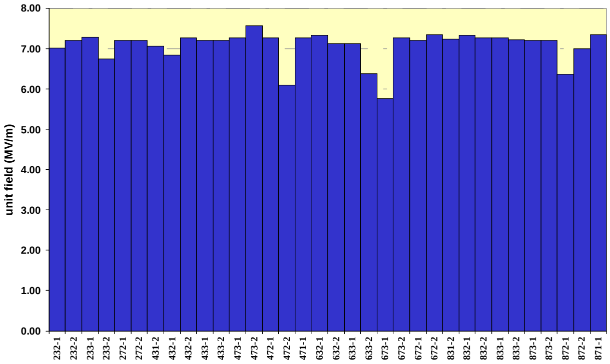

Figure 2: Unit field distribution, October 1998 MD.

252 of the 256 Nb/Cu cavities were available for this MD. The other four had tuning problems (primarily due to broken antenna cables), and in the average field values presented here these cavities are not taken into account. The field levels obtained for each unit are shown in Fig. 2. The overall average field level obtained was 7.07 MV/m. 23 of the 34 units reached 7.2 MV/m.

The main limitation to reaching 7.2 MV/m was due to main coupler vacuum activity (8 units). However it should be noted that there was no time in this MD period to set up analogue vacuum conditioning, so better results can be hoped for next start-up. Of more serious concern were the very high radiation levels from several modules. These are shown in Fig. 3 together with the measurements made at last year's start-up, nominally at 6 MV/m.

The results of this MD tend to indicate that field emission will be the major limitation to increasing the gradient in 1999. Pulse and Helium processing will be required extensively in an attempt to reduce the radiation to a tolerable level.

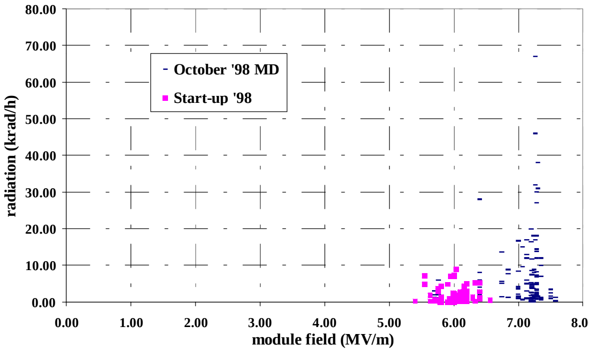

Figure 3: Radiation levels at 1998 start-up and October 1998 MD.

## 4 CAVITY FIELD EQUALISATION

In some units, large differences can be observed between the fields of cavities run by the same klystron.

Those observed only with beam, due principally to electrical length differences within the waveguide system, are particularly problematic during injection, giving rise to cavities with zero field and consequent loss of tuning. They are covered elsewhere [3].

Differences observed without beam are due to differences in the external Q's of the cavities. For a unit average of 6 MV/m, cavities running at 4.5 MV/m and 7.2 MV/m have been observed. Such large spreads can limit the unit's maximum attainable average field. During the last shutdown, the external Q's of 16 cavities at Point 8 were modified by placing $\lambda/4$ transformer plates in the waveguides, in the correct position so as to either increase or decrease the field. Their beneficial effect is evident in Fig 4. The histogram includes all 72 cavities at Point 8 before and after installation of the 16 transformers. This work is presently being extended. The positions of the plates at Point 8 are being optimised and transformers are being added at the other three points. In total, 40 cavities are being adjusted.

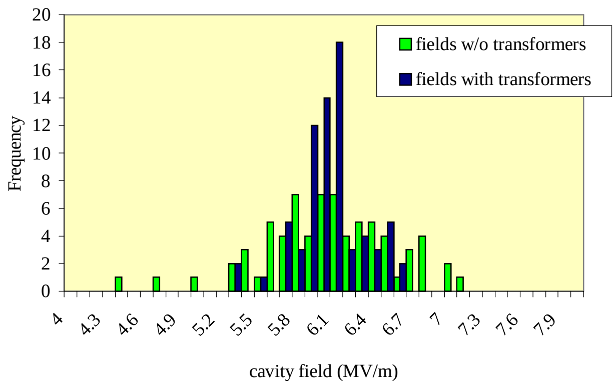

Figure 4: Effect of λ/4 transformer plates on field spread at P8. No beam.

## 5 CONCLUSIONS

The results of the October 1998 MD lead to the conviction that an average gradient of 7.2MV/m for the installed Nb/Cu cavities is attainable and this will be the goal for this year's start-up conditioning period. The achievement of this will be facilitated by the work that is under way this shut-down to equalise the fields of the individual cavities within an unit. However, this gradient will only be achieved with excessive radiation from some modules and it is not certain if this can be conditioned down to an acceptable level throughout.

## REFERENCES

[1] Geschonke, G., "Strategy for increasing the energy in 1999", these proceedings.

[2] Brunner, O., Cavallari, G., Jimenez, M. and Tuckmantel, J., "First experience with helium processing of RF superconducting cavities in LEP", Eighth workshop on RF superconductivity, Abano Terme (PA), Italy, 6-10 October 1997.

[3] Ciapala, E., "The RF system at injection and ramp", these proceedings.