THE RF SYSTEM TO 102 GeV: HOW DID WE GET THERE AND CAN WE GO FURTHER?

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Abstract

After a review of the results of the 1999 start-up cavity conditioning, the evolution of the available RF accelerating gradient through the year and the problems encountered with running at high fields are presented. Based on this experience, the aims of the forthcoming conditioning period and the strategy for increasing the energy in 2000 are discussed.

1 INTRODUCTION

Hardware modifications and changes of operational procedures, all of which contributed to the success of last year, are discussed elsewhere in these proceedings [1]. This paper will concentrate on cavity conditioning and the aspects of last year's performance which are likely to limit any increase in gradient in 2000, notably the problem of field emission.

In the 1998/1999 shut-down, the last four Nb/Cu modules were installed in LEP, two at P4 and two at P8. With the same performance as obtained with the Nb/Cu system in 1998 (6 MV/m average), these extra cavities would have permitted a maximum energy of around 96 GeV. To go higher, an increase in average gradient was required.

The foundations for last year's success were therefore laid in April when the Nb/Cu cavities were conditioned to a remarkably high average gradient. No less remarkable was the steady increase of gradient through the year, culminating in the majority of units running at or close to the conditioning level (in previous years there had always been a sizeable margin between conditioning and operational levels, typically 0.5 MV/m). However, the increase in energy was only achieved at the expense of integrated luminosity and maintaining the gradient for 101 GeV running was a continuous struggle.

2 1999 START-UP PERIOD

2.1 Conditioning

In the conditioning MD of October 1998, an average gradient of 7.07 MV/m was obtained for the Nb/Cu cavities and 23 of the 34 units reached 7.2 MV/m. This encouraging result led us to set a goal of 7.2 MV/m for the average gradient of these cavities for the 1999 start-up conditioning period.

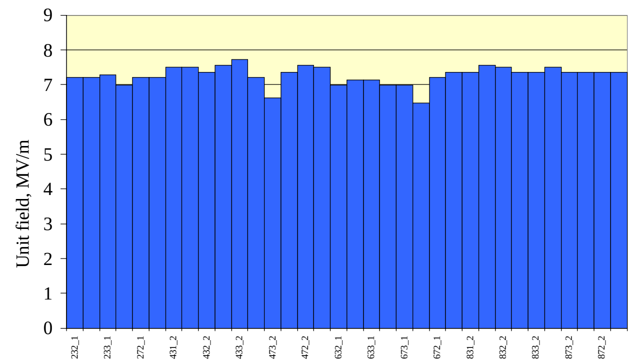

Fig. 1: Unit field distribution after 1999 start-up conditioning.

7.27 MV/m was achieved, the results for each of the Nb/Cu units being shown in Fig. 1. Newly installed fast analogue vacuum conditioning equipment was used extensively with the result that no units were limited by main coupler vacuum activity. The limits were helium level or pressure rises or excessive radiation. Pulsing was successfully used on a few units when absolutely necessary. However, it could not be used systematically as it would provoke arcing in the waveguide system due to the large switch-off transient. A summary of the results obtained by intersection point and including the copper and solid niobium cavities is given in Table 1.

	Cu	Nb	Nb/Cu	Totals
P2	55 (1.08)	136 (5.00)	586 (7.18)	777
P4			1005 (7.39)	1005
P6	54 (1.06)		765 (7.03)	819
P8			1007 (7.40)	1007
Totals	109 (1.07)	136 (5.00)	3363 (7.27)	3608

Table 1: Field levels obtained after conditioning, MV and (MV/m).

2.2 Problem cavities

One cavity (unit 233 C13) was found to have an excessive leakage of fundamental power through an

HOM coupler and had to be de-tuned throughout 1999. This was one of the cavities that had rigid HOM lines installed in the previous shut-down and it was believed that the HOM coupler's fundamental frequency notch filter had been damaged during this operation. In the present shut-down (1999/2000), the fundamental frequency filter was found to be only 3 dB off. This, unfortunately, does not explain the problem and we will have to wait until the start-up to see if this cavity will be usable in 2000.

One of the newly installed modules (unit 473, module 4) which had reached 7.0 MV/m in the test string only conditioned to 5.5 MV/m in LEP. The limitation was helium level loss in C15. Pulsing, carried out several times throughout the year, proved ineffective. Helium processing was carried out on this module both in CW and pulse mode in the October 1999 Technical Stop. This too proved ineffective and actually degraded the module performance. After helium processing, C15 had not improved and the module was limited a further 5 MV lower due to helium pressure rises in C16. This module was consequently removed from LEP in the current shut-down for water rinsing of C15 and C16. During this process, some of the niobium coating of C15 detached. The cavity has been re-coated and will be re-installed in LEP for the start-up.

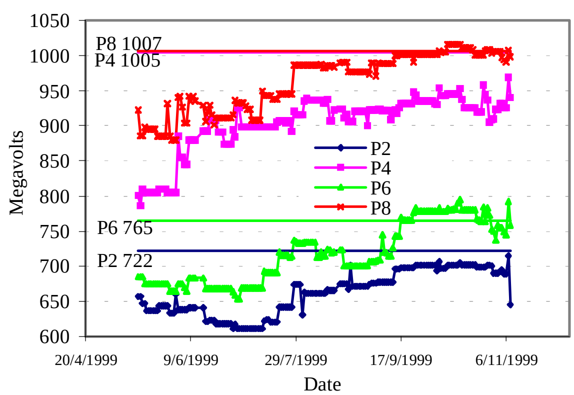

Fig 2: Evolution of available field in superconducting cavities. Numbers of cavities: P2 48 Nb/Cu and 16 Nb; P6 64 Nb/Cu; P4 and P8 80 Nb/Cu.

3 1999 OPERATION

3.1 Strategy and overall performance

The strategy chosen for increasing the RF gradient in 1999 made a major contribution to the year's success. This strategy consisted of establishing physics at a reasonable current and at an energy where the RF was stable with a satisfactory trip margin. The RF units were then pushed up in field gradually to the level required for the next energy step. Only when the RF was stable at this gradient was the energy increased. The steps were facilitated by, at least temporarily, lowering the beam current. This was a very efficient way to increase the energy, firstly because RF adjustments could be made during physics and, secondly because it was possible to verify that the RF units were stable under physics conditions before risking an energy increase. In this way the energy progression was 96 GeV, 98 GeV, 100 GeV, and 101 GeV. On the 7th November 1999 102 GeV was obtained, albeit for a few minutes, with a total RF voltage of 3530 MV.

The evolution of the available fields from the superconducting cavities is shown in Fig. 2 for each intersection point. The horizontal lines are the levels obtained after start-up conditioning. The poorer performance of P4 compared to P8 is due to a number of factors. Firstly, the newly installed 473 module 4 never performed satisfactorily; secondly, P4 had more than its fair share of cavities that degraded during the running period (see Section 3.2) and thirdly, this intersection point was the one most limited by the cryogenic system. However, it should be noted that, when normalised to the number of cavities, the performance of P4 throughout the year was comparable to that of P6.

The available field from the copper system stayed fairly constant at around 110 MV throughout the year.

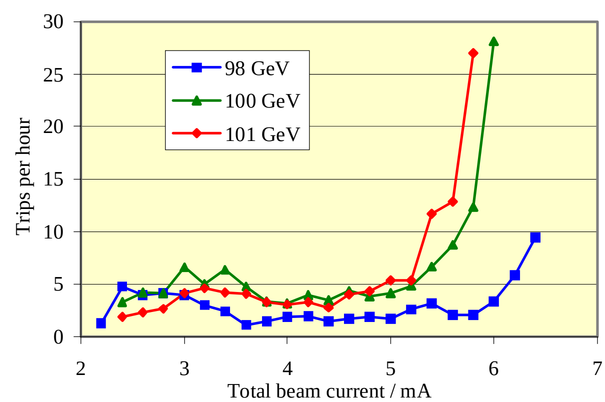

Fig 3: RF unit trips as a function of beam current.

Fig. 3 shows the number of RF trips as a function of bunch current for three different energies. It leads to the rather obvious conclusion that higher energies were only reached at the expense of integrated luminosity. It was also apparent from last year's running that efficiency dropped to a great extent whenever a trip margin of two klystrons was not available.

3.2 Problem cavities

Unit 673 C13 had to be de-tuned for much of 1999 due to intermittent trips of HOM temperature and fundamental power. The cavity was stable with low beam current. Most trips occurred during the ramp but the exact reason for them is not understood.

Eight cavities degraded significantly in performance during the running period and required either running at reduced field or complete de-tuning to avoid helium level or pressure trips or excessive radiation. One of these degradations occurred just after the conditioning period and the other seven, significantly, in the period of the year after the gradient was raised for 100 GeV running. Three recovered fully by conditioning and pulse processing. Four could only be recovered partially and were responsible for a loss of about 25 MV at the end of the year. However, even after recovery of field, some of these cavities exhibited much higher radiation values than previously (see below). The eighth cavity was unit 473 C16, which degraded when helium processing this module in an attempt to recover C15 and was referred to in Section 2.2.

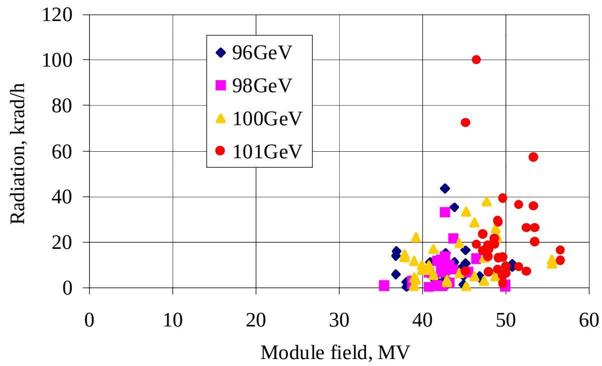

Fig. 4: Module radiation in P6.

3.3 *Radiation plots*

Fig. 4 shows radiation levels during LEP operation at four different energies for the modules in P6. The modules at the other intersection points have a similar behaviour. The sharp increase at the 101 GeV level is apparent. What this plot does not show us is whether or not, for a given field level, the radiation has changed during the course of the year. It would be hoped that, after running at high fields for a long time, the radiation would drop. Unfortunately this is not generally the case. Fig. 5 shows radiation plots for one module taken in May, September and October. Although this is a particularly high radiation module, it is common to find no improvement as the year progressed. Radiation plots for two modules that degraded during the year are shown in Figs. 6 and 7. Unit 472 module 1 degraded in May 1999 shortly after conditioning. It was recovered partially by further conditioning and by the end of the year the radiation had fallen, although its performance was still inferior to that obtained in April. Unit 433 module 2 conditioned easily with low radiation to over 50 MV and ran satisfactorily at the beginning of the year. However, in August, C7 had to be de-tuned because of helium pressure rises. It was partially recovered, but still exhibited high radiation.

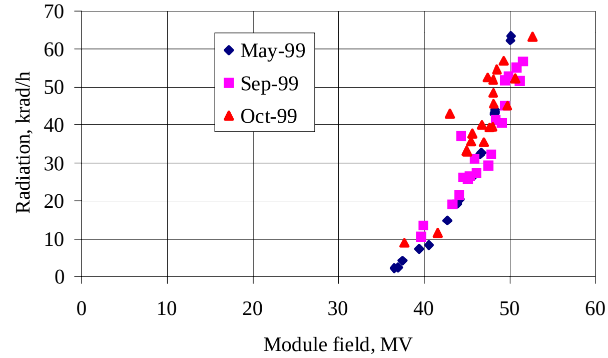

Fig. 5: Radiation, unit 673 module 4.

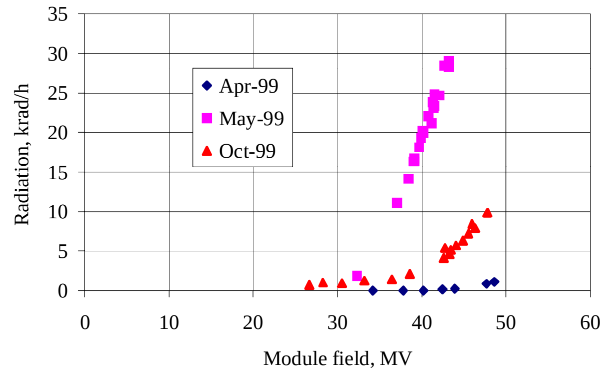

Fig. 6: Radiation, unit 472 module 1.

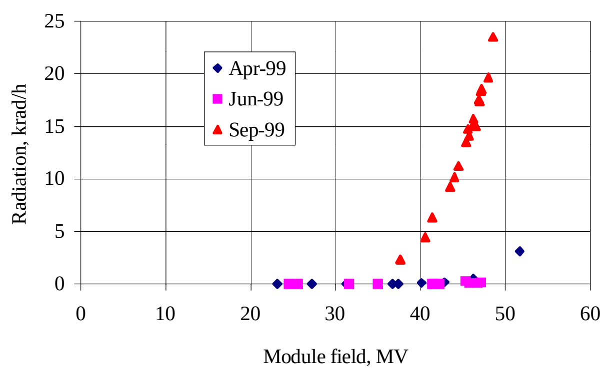

Fig. 7: Radiation, unit 433 module 2.

4 WHAT NEXT?

Despite the significant increase in gradient in 1999 and the performance of the RF system that surpassed all expectations, the degradation of some cavities last year would indicate that the scope for further increases is very limited. In addition, conditioning at higher fields has other risks and limitations. CW conditioning in some units is close to being limited by the circulator's 400 kW load. Pulsing at high fields often provokes waveguide arcs. Helium processing risks a vacuum accident or cavity damage due to a sustained spark. Even so, we will set a goal of 7.5 MV/m for Nb/Cu conditioning.

Concerning the copper system, eight cavities have been re-installed this shut-down and should supply an extra 16 MV. In addition, seven power couplers that were exhibiting the largest temperature increases with RF power have been replaced.

Last year's strategy of raising the gradient gradually once stable physics conditions had been achieved was very successful and it is proposed to repeat it this year. It is hoped to miss out the first stage and start at 98 GeV. Unfortunately, it is not possible at present to estimate the gradient that will be available and, consequently, the subsequent energy steps for this year. However, an estimation should be possible at the end of the forthcoming conditioning period.

The RF maintenance periods will again be essential this year.

5 CONCLUSIONS

Apart from a small contribution from the extra copper cavities, any increase in gradient in 2000 will again have to come from running the Nb/Cu cavities at higher field. It would seem that the margin for any increase is now slight due principally to the problem of field emission. Nevertheless, we will try to build on last year's success by attempting to condition higher and by sticking with the same running strategy.

REFERENCES

[1] E. Ciapala, "RF system hardware improvements and new procedures", these proceedings.