RF RELIABILITY AND OPERATION

A. Butterworth, CERN SL Division

Abstract

A brief review of RF system operation in 1998 is presented. The key problems of the past year were those of power dissipation in the antenna cables and HOM couplers. However, an ongoing program of improvements to RF and controls hardware and software has resulted in higher overall reliability than in previous years. These changes are outlined, along with perspectives for operation in 1999.

1 REVIEW OF 1998 OPERATION

1.1 Available RF voltage

The RF system configuration in 1998 is summarized in Table 1.

Cavity type	Gradient (MV/m)	Number	Voltage (MV)
SC (NbCu)	6	256	2611
SC (Nb)	5	16	136
Copper	1.3	48	136
Total			2883

Usual operating voltage	2700
τ_q = 24h at 94.5 GeV, J_x = 1.5	2633
Voltage margin	220

Table 1. RF system configuration in 1998.

The voltage margin is the difference between the total installed RF voltage and the voltage required for a quantum lifetime of 24 hours under standard conditions at 94.5 GeV. Fig. 1 shows this voltage margin as a percentage of the total installed voltage for the case of one or two klystrons off, compared with that of previous years and at 96 GeV with the 1999 RF configuration.

Fig. 2 shows the total available RF voltage on a daily basis throughout the year.

1.2 Reliability

Although the relative voltage margin was smaller than in any previous year, the overall reliability of the RF system was greatly improved, with a mean time between

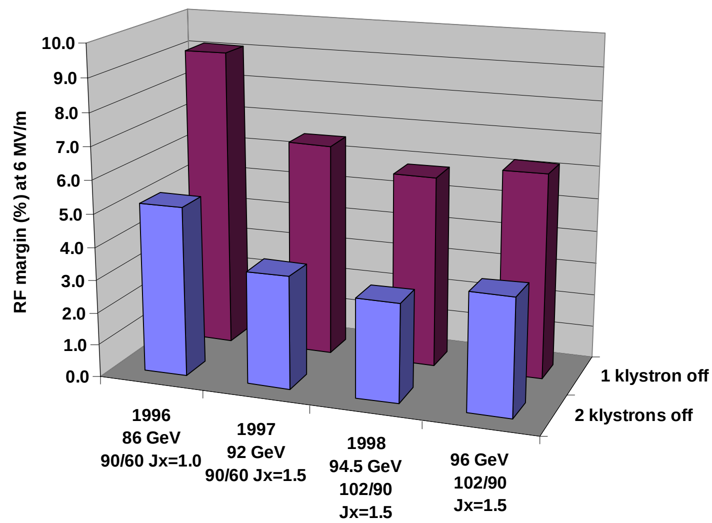

Fig. 1. Relative RF margin in the years 1996 to 1998.

unit trips (MTBT) of 129 minutes, compared with 54 minutes in 1997 (Fig. 3). In previous years the MTBT has tended to increase during the year, as problems were solved and operational procedures refined. However in 1998 the MTBT decreased progressively throughout the year, which was mainly due to progressive failures of the cavity antenna cables (Section 1.6).

The number of trips due to various causes can be seen in Fig. 4. The proportion of trips involving both klystrons connected to one power converter (HV and beam dump interlocks) amounted to only 10% of the total. The biggest cause of trips was cavity maximum field interlocks which can be attributed to cavity field oscillations, occasional problems with the klystron modulator and voltage loop control, and intermittent faults in the antenna cables (Section 1.6).

The RF contribution to lost physics fills, filling without coast, down-time and access are shown in Fig. 5 [1].

1.3 Reasons for improved reliability

A number of improvements were responsible for the improved reliability of the RF system:

Software: The Global Voltage Control system was modified so as to automatically adjust the maximum voltage for each RF unit according to the state of the cavities [2]. For example, if a cavity loses tuning at injection due to high beam loading, the old GVC software would try to make the maximum voltage from the unit at the end of the ramp with one cavity missing, causing the unit to trip. The modified GVC, however, reduces the unit voltage by an amount corresponding to one cavity,

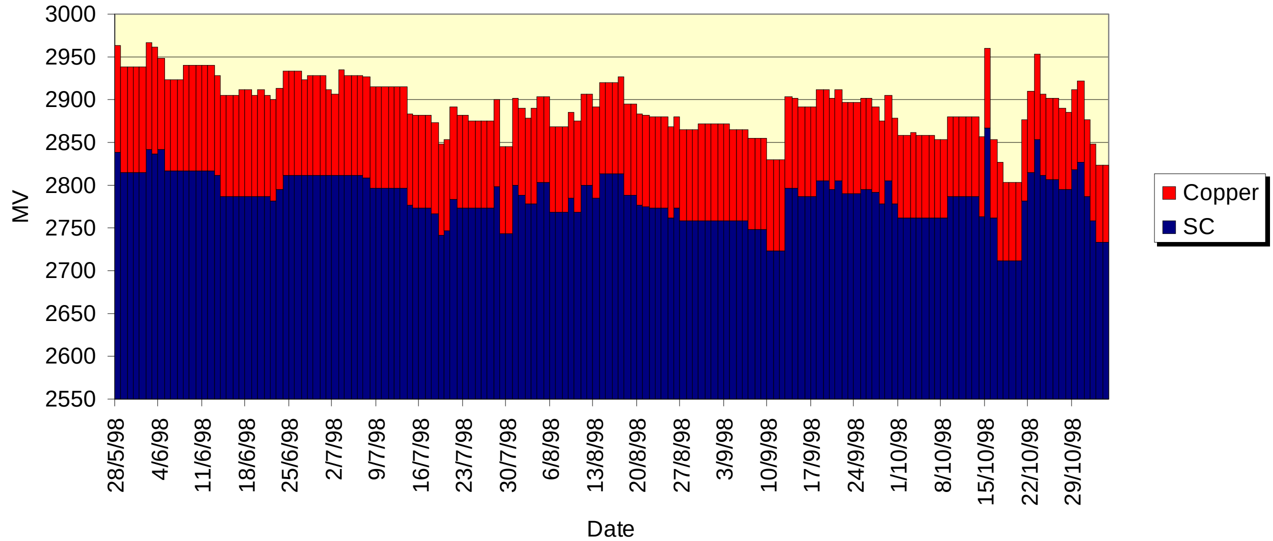

Fig. 2. Available RF voltage during 1998.

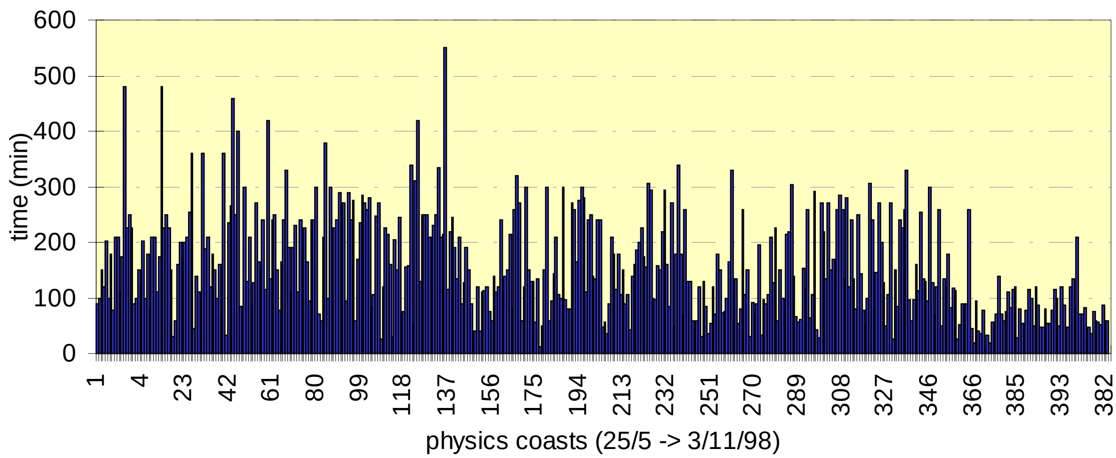

Fig. 3. Mean time between trips in 1998.

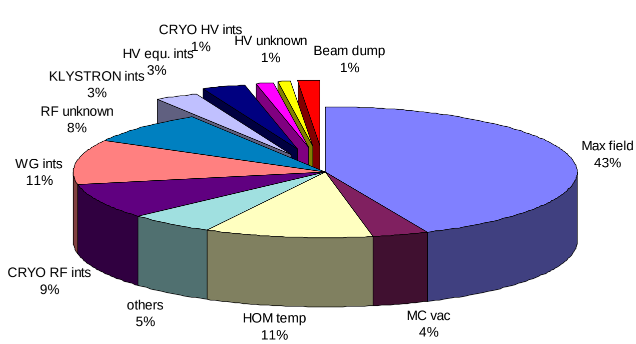

Fig. 4. Statistics of trips at high energy in 1998.

avoiding the risk of a trip. When the cavity comes back into tune, the GVC increases the unit voltage back to its nominal level.

Hardware: Many modifications have been made to the RF and controls hardware:

- All electronic modules for the temperature measurement system have been upgraded to a new microcontroller-based version.
- Filters have been incorporated into the reflected power interlock system (Wattchers) to reduce the sensitivity to transients.

- The klystron voltage control loop and modulator control have been improved to eliminate spurious high power transients.
- The cavity tuning system has been modified to provide fast detuning after a trip, reducing the risk of damage due to arcs in the waveguide system.
- The vulnerable coaxial elbows in the 300kW circulator loads have all been replaced by a modified waveguide section.
- Interlock levels have been adjusted for HOM coupler temperatures and cavity maximum field.

1.4 Operational procedure

The operational procedures for the control of the RF system are summarised as follows:

Injection:

- Between one and four units were usually left OFF so as to avoid problems with voltage control and instabilities in some units. A Q_s of 0.133 was used at injection.
- Longitudinal feedback was switched ON; transverse feedback was not necessary as the bunch current was limited by power dissipation in the cavity antenna cables.
- A RF frequency shift of +100Hz was used to maximise the bunch length to minimise power dissipation in the antenna cables.

Ramp:

- The programmed RF voltage function arrived at its maximum value just before 92 GeV.
- The "RF stop" at 92 GeV was used to switch on all units and wait for any tuning cavities.
- The GVC was switched to CONSTANT mode at a voltage of 2700 MV before ramping LEP to 94.5 GeV.

Physics:

- The GVC was left ON in CONSTANT mode at 2700 MV. In the event of an RF unit tripping, the GVC would increase the voltage on the remaining units to compensate.
- A total RF frequency shift of +120Hz (Jx=1.69) was used to reduce the emittance and therefore enhance luminosity.
- A negative RF frequency shift of -50Hz was applied in case of a multiple RF trip to increase the quantum lifetime and minimise losses.
- The automatic unit switch-on facility was enabled to restart tripped units without the need for operator intervention

1.5 Control of cavity field oscillations

A continuing problem with the cavities is that of ponderomotive oscillations. These occur with high cavity gradient under high beam loading conditions, and can be suppressed by adjusting the tuner phase to bring the cavity close to the maximum of its resonance curve [3]. As in previous years, a tuner setpoint which suppressed the oscillations under physics conditions was found empirically for each cavity.

It was discovered already in 1997 that in some cavities the setpoints used in physics led to instabilities at 22GeV. Thus it was decided to use different setpoints at injection and at high energy. The setpoints are stored in non-volatile memory in the equipment controllers and the switch is initiated from the LEP Exec during the ramp at around 60 GeV.

It was found early in 1998 that the setpoints used in physics at high beam current also caused some cavities to become unstable as the beam current diminished towards the end of the fill. A third setpoint was thus switched in automatically by the surveillance software in the RF unit if oscillations were detected under these conditions.

A new active damping system for cavity oscillations was also tested during 1998 [4].

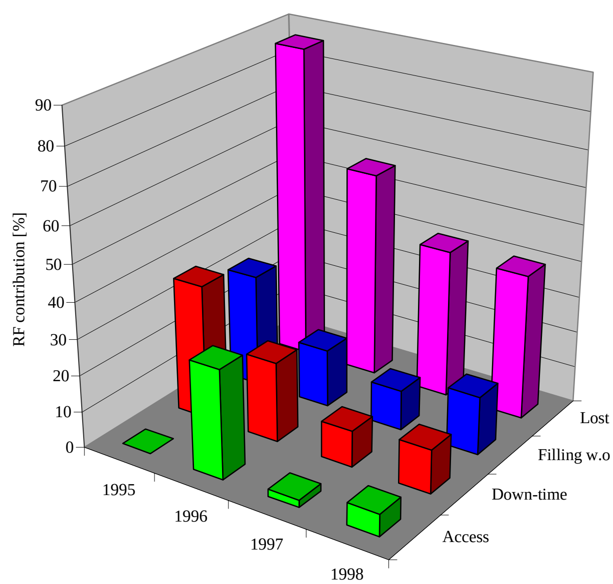

Fig. 5. RF contribution to downtime in 1998.

1.6 Problems

The major problem of 1998 was the damage caused by higher order mode power to the cavity antenna cables, which is discussed elsewhere in these proceedings [4]. This led to a total of 8 cavities without field measurements or tuning at the end of the year. A partial solution was to tune the cavities using the waveguide directional coupler signals, but this was found to suffer from medium-term stability problems.

Intermittent failures of the cables, resulting in momentary loss of the antenna signal, led to many trips as the voltage control loop increased the klystron power to compensate the apparent loss of field, causing interlocks on maximum field, He pressure and main coupler vacuum.

A number of faults in the tuner bars of the SC cavities (1 heater and 2 sets of temperature probes) left one cavity non-operational.

Quenches of the higher order mode couplers were observed in several cavities. These seem to have two causes: synchrotron radiation, which can be cured by adjusting the collimator settings, and RF heating, which is related to the beam intensity. This was seen systematically in one cavity, and sporadically in a two others. There seems to be no cure, other than to increase the interlock threshold so that the unit does not trip. The design of the couplers is such that the risk of hardware damage is low. However, 100W additional heat load has been measured in the cryogenic system [5], and this may be a serious problem in the future.

In the RF high power system, six klystrons and one circulator were replaced for various reasons, and one copper cavity main power coupler was replaced due to a broken window.

2 OPERATOR COMMENTS

2.1 Requests from Chamonix 1998

The requests from Chamonix 1998 [6] which have been successfully implemented during 1998:

- Automatic switch-on of tripped units. This was implemented in the front-end software. It was disabled during filling and ramp, and enabled at 94.5 GeV.
- A cavity field and oscillation fixed display was provided in the main control room as a quick check for oscillating cavities.
- An automatic tuner adjustment program was provided for oscillation control, which worked in almost all cases (tuner offsets can only suppress ponderomotive oscillations).

However, some work still needs to be done in streamlining the control room user interface, in which several different applications are used to drive the RF system.

2.2 Operator comments 1999

What the operators appreciated:

- Fixed displays: these worked well but still some communication problems
- The Global Voltage Control worked efficiently except for very occasional failures
- The automatic switch-on facility was appreciated, but questions were raised about its reliability
- On a more general note, an effective RF link-man and piquet service is still seen as essential to efficient operation of LEP.

What the operators didn’t like:

- In the operator interface, some RF commands do not work, and certain tasks require the use of piquet programs. Some of these problems are linked to long-standing bugs in the Sloppysoft RF black box, which will be fixed before startup 1999.
- Some RF applications still need confirmation buttons, e.g. the demanded voltage for the GVC.

3 CONCLUSIONS

In 1998 the RF system achieved its highest reliability to date, with a mean time between trips of 129 minutes at high energy, over twice the 1997 value.

Improvements and new features in the RF control system software led to easier operation, but further improvements are needed in the control room interface.

4 REFERENCES

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