EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN — SL DIVISION

CERN-SL-98-009 RF

First Experience with *in situ* Helium Processing of the LEP Superconducting Modules

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Abstract

The helium processing technique has been used at CERN to improve the performance of the accelerating RF cavities with respect to field emission. It was extensively used in the vertical bare cavity tests to improve the superconducting cavities for the LEP Project. However this technique was rarely used on fully equipped production modules because of the risk of damaging the power couplers and its ceramic window by a possible glow discharges. First experience with helium processing on finished modules equipped with additional vacuum interlocks to protect the power couplers was acquired in the test area in October 1996. He processing was applied to three modules limited by field emission. Their overall performance was increased up to about 7 MV/m. Confident with these results, one module was processed in the LEP tunnel just before the shutdown 1996. The results obtained confirmed the feasibility of this method on a module already installed in the LEP tunnel and its efficiency in improving the performances. During the winter shutdown 1996-97, helium processing was done separately on seven installed in LEP.

Presented at the Eighth Workshop on RF Superconductivity, Abano Terme (Padova), Italy, 6-10 October 1997

Geneva, Switzerland
March 1998

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Abstract

This helium processing technique has been used at CERN to improve the performance of the accelerating RF cavities with respect to field emission. It was extensively used in the vertical bare cavity tests to improve the superconducting cavities for the LEP Project. However this technique was rarely used on fully equipped production modules because of the risk of damaging the power couplers and the ceramic window by a possible glow discharge. First experience with He processing on finished modules equipped with additional vacuum interlocks to protect the power couplers was acquired in the test area in October 1996. He processing was applied to three modules limited by field emission. Their overall performance was increased to about 7 MV/m. One module was then processed in the LEP tunnel just before the 1996 shutdown. The results obtained confirmed the feasibility of this method on a module already installed in the LEP tunnel and its efficiency in improving the performances. During the 1996-97 winter shutdown, He processing was done separately on seven modules installed in LEP.

1. INTRODUCTION

This He processing technique has been used at CERN for a long time to improve the performance of the LEP Superconducting RF cavities during acceptance tests of the cavities not yet equipped with power and HOM couplers. This technique consists of injecting dry and dust-free He gas into the cold cavity evacuated to 10^{-10} up to a total pressure of 9.10^{-6} mbar and of applying RF power.

He processing was already applied successfully on the first superconducting modules equipped with power and HOM couplers in 1990. But after problems with the power couplers it was suspended as being a possible culprit. First experience with He processing of finished production modules equipped with additional vacuum interlocks to protect the power coupler and the ceramic window was acquired in the test area in 1996. From October to November 1996, three modules were processed in the test area outside LEP. The performance was increased well above the specifications, namely to 7 MV/m in CW mode and 8 MV/m in pulsed mode. The radiation levels were significantly reduced too.

One module was processed in the LEP tunnel just before the 1996 shutdown. The results obtained confirmed the feasibility of this method on a module already installed in the LEP tunnel and its efficiency in improving the performances.

During winter 1996-97, He processing was done separately on seven modules installed in LEP. The results obtained are described below.

2. RF CONDITIONING

Before installation in the LEP tunnel, the finished modules are tested and conditioned up to full field in a surface test stand. In most cavities, conditioning is necessary mainly for the power coupler. *Standard* conditioning, which is normally done in CW as well as in pulsed mode, proved to be very efficient. However, some cavities had degraded in performance during fitting of power and HOM couplers, after transport and installation and were limited in gradient to 4-5 MV/m. Above these gradients, abnormal thermal losses occurred leading to a loss of liquid He or to sharp pressure rises in the LHe bath. In addition a considerably increased level of X-radiation emanating from the cavities was observed.

Many of these cavities and also one which had degraded during LEP operation could be recovered *in situ* by RF processing with high power pulses. The pulses used were 3-10 ms long, with a repetition time of 100 ms, and a peak pulse height was 7.5 MV/m. The peak pulse height is presently limited by the reflection peak at the end of the pulse. After only a few hours of pulsing, the radiation emitted by the modules was significantly reduced. The evolution of radiation for this process is shown in Fig. 1.

In some cases, degraded cavities could not be recovered by pulse processing and He processing was applied to the modules as installed in LEP. Typically 2-6 hours of RF processing were necessary to suppress field emission and to recover the cavities. Radiation versus field curves are presented in Fig. 2. Note that the radiation is measured near the vacuum valves at the extremities of the modules.

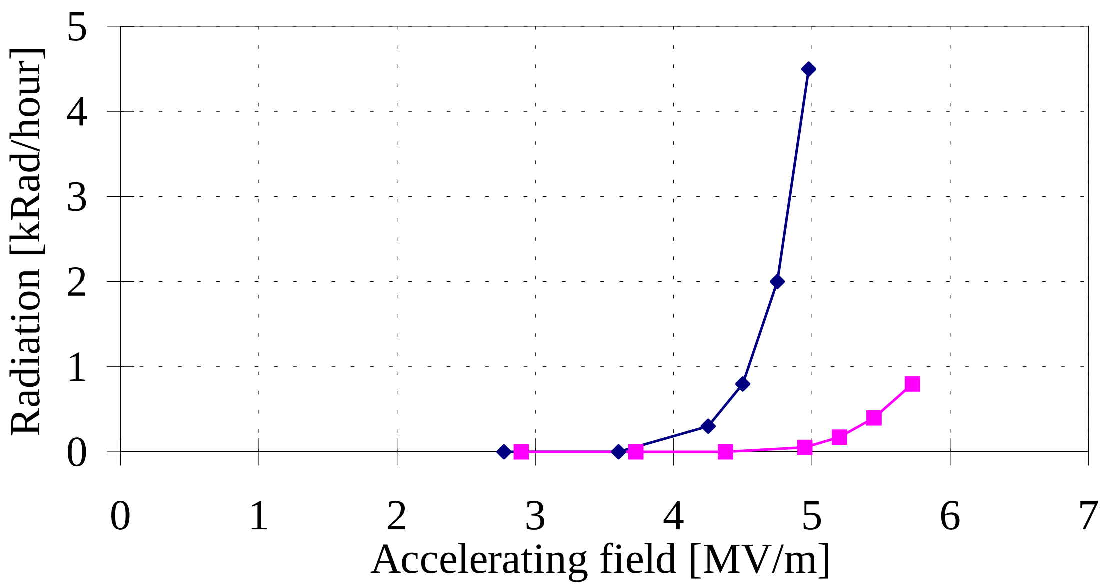

Figure 1. Effect of *in situ* pulse processing of different modules in LEP. The diamonds represent the radiation before processing; the squares show the radiation after processing.

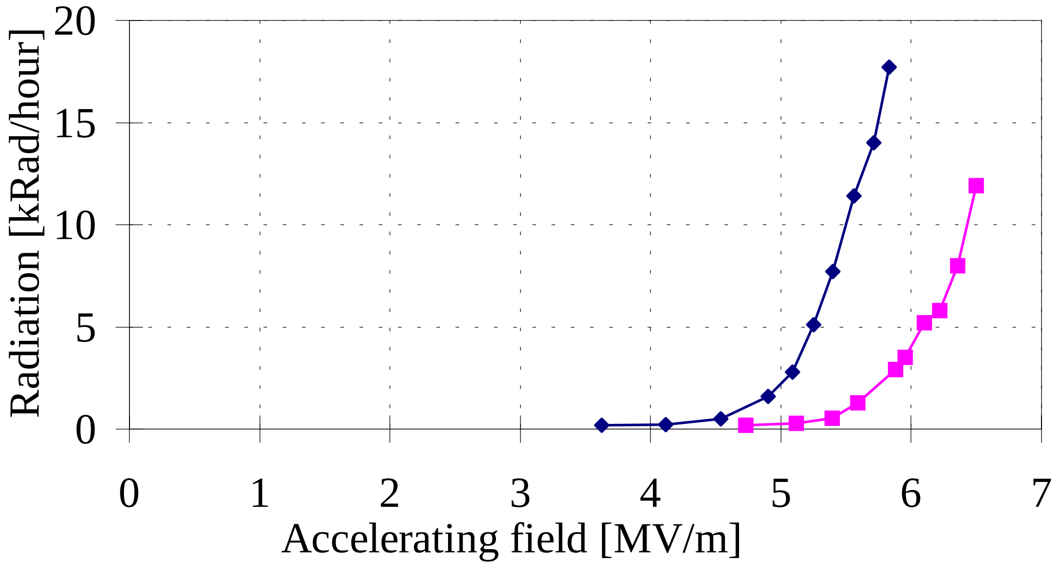

Figure 2. Effect of *in situ* He- processing of a module in LEP. The diamonds represent the radiation from the modules before processing; the squares show the radiation after processing. After only a few hours of processing the radiation emitted by the modules was significantly reduced.

3. VACUUM EXPERIENCE

The injection of a gas inside the vacuum of an RF module filled with liquid He is a critical operation and a detailed procedure has been established. The main steps of this procedure concern the connection of the vacuum pumping unit to the cavity vacuum, the injection of the He gas, the set-up of the vacuum interlocks and the pumping of the He gas after the processing.

3.1. Injecting the helium gas

The time needed to prepare for the He gas injection is about 20 hours. This includes the transportation of the pumping unit (turbo molecular pump), the connection to the module and the bake-out needed to reach the pressure limit of the pumping station (~10^{-9}mbar).

The injection of He gas into the cavity vacuum of a cold module is the most critical operation of the whole procedure: after saturation of the cooled inner surface of the cavities, the pressure increases exponentially with the quantity of gas injected. The injection has to be stopped when the total pressure reaches $9 \cdot 10^{-6}$ mbar at the pressure probes mounted on the main power couplers, which are at room temperature.

3.2. Safety interlocks

Several vacuum parameters, which are used as safety interlocks during normal operation, need to be modified:

- *Sputter ion pump*
  The cavity vacuum is usually interlocked at a level of $4 \cdot 10^{-7}$ mbar measured with sputter ion pumps. These pumps are switched off and the interlock is shorted.
- *Pressure controllers of the main couplers and of the machine vacuum*
  The power couplers are equipped with penning vacuum gauges which are interlocked with the RF generator ($4 \cdot 10^{-7}$ mbar). During He processing the level is increased to $4 \cdot 10^{-5}$ mbar.

3.3. Pumping out of the helium gas

After He processing, the He gas has to be removed from the module. Fig. 3 shows the pumping diagram of three modules processed in the LEP tunnel.

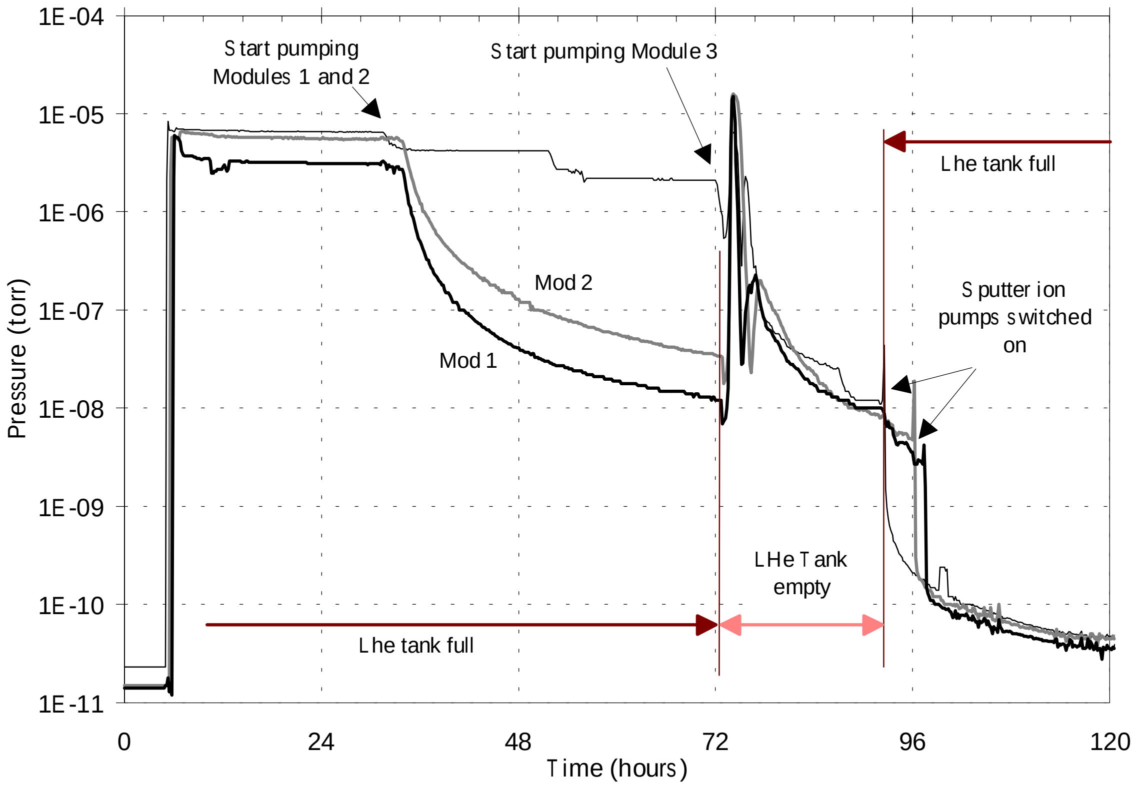

Figure 3: Evolution of the pressure in three different modules after He processing

The pumping process was started on modules 1 and 2 with the cryostat filled with liquid He. The diagram shows that, after three days of pumping, the total pressure inside the modules tends towards a limit of 10-8 mbar. In these conditions, the sputter ion pumps must not be used.

To decrease the total pressure, it was necessary to warm up the cavities to about 20K. After emptying the cryostats, the pressures increase up to 2.10 5 mbar due to the He gas released by the inner surfaces no longer cooled and then decrease to 3.10-9 mbar after only 17 hours of pumping. At this pressure the sputter ion pumps may be switched on and the cryostat filled with liquid He again. The ultimate pressure is better than 10-10 mbar in less than one day.

Although module 3 was not pumped before emptying the cryostats, it still reached the same final pressure. This shows that it is no advantage to pump filled modules and that the cryostat can be emptied just after finishing the He processing.

CONCLUSIONS

He Processing has been applied to modules fully equipped for accelerator operation both in the test stand and in the accelerator. It allowed the accelerating gradients to be recovered in most of the cases where the RF operation was limited by LHe pressure rise and high radiation dose (Field Emission). However, it was not effective for example when processing a bulk

Niobium module where the limit is probably set by a thermal quench (no radiation at the maximum field).

Its main drawback resides in the risk of human errors (installation and handling of vacuum equipment and of gases on cold cavities) and of glow discharges in the power couplers where multipactor levels may develop leading to permanent damage. In fact, the cavity vacuum level during He Processing is two orders of magnitude higher than the interlock levels normally set during RF operation.

ACKNOWLEDGEMENTS

This work is the result of continuous effort from many groups at CERN. The success of this undertaking would not be possible without their ability and commitment.