CRYOGENICS OPERATION AND ON-LINE MEASUREMENT OF RF LOSSES IN THE SC CAVITIES OF LEP2

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Abstract

Conclusions from the cryogenic operation of superconducting cavity modules in LEP during the 1994 run are presented, together with results of tools and procedures permitting the on-line measurement and analysis of radiofrequency induced losses, as seen from the side of cryogenics.

I. INTRODUCTION

CERN is in the process of receiving from industry, equipping and installing 236 superconducting (SC) cavities for the energy upgrade of the LEP collider. The current status and programme of this LEP2 project is presented elsewhere at PAC95 [1]. The situation of cavity production is summarized by E.Chiaveri et al. [2] and the good progress with the RF power couplers by J.Tückmantel et al. [3]; the latter had become a critical item and delayed installation during recent years.

The present paper is reporting on the cryogenic aspects of operating a number of LEP2 cavity modules with LEP in 1994, is then analyzing the particular question of how well the radio-frequency (RF) losses in the cavities can be monitored from cryogenic measurements using electric heater compensation, and is finally giving an outlook to further progress expected in 1995.

II. CRYOGENICS OF CAVITY MODULES

The LEP2 SC cavities are 4-cell cavities with a sputtered niobium layer on copper, designed for 352 MHz fundamental mode operation; four such cavities are assembled together and installed as one module of 10 m length, with common vacuum tank and interconnected stainless steel containers for liquid helium (LHe) bath cooling of all outer cavity surfaces. About 0.7 m^3 of LHe is necessary to fill the bath, leaving only some 0.1 m^3 of vapour volume in a manifold on top of the cavity string; there the liquid level is kept constant (± 10 mm in height or ± 2 dm^3 in volume) by control action on the supply valve.

As up to 9 cavity modules will have to be operated, in the final LEP2 configuration, in parallel between vacuum insulated supply and return manifolds in each straight tunnel section on both sides of the LEP interaction points 2, 4, 6 and 8, the right level must be maintained in each bath container to separate well the evaporated gas (GHe) from the liquid and send only gas back to the return manifold. Only then can all modules be sufficiently filled, even if the RF load is pushed to the limit of the re-liquefying cryoplant.

A second control valve is installed on each gas return line; it is part of another control loop which keeps the bath pressure as constant as possible (± 2 mbar around 1.25 bar abs.); this is not only important for a smooth boiling and a stable load for the cryoplant, but also to avoid de-tuning of the cavity resonance (typically 7 Hz/mbar) and interaction with RF phase control.

A fraction (typically 0.8 g/s per module) of the evaporated GHe is used for cooling heat intercepts, tuner and RF coupler components inside the modules and is returned to the cryoplant at room temperature. Details on component cooling and the static (without RF load) heat load of LEP2 modules are given in [4]; an internal helium flow scheme can be found in [5]. A typical static heat load of LEP2 modules is 80 W of refrigeration @4.5 K, and the warm gas return is seen as "liquefaction' load with equivalence to about 100 W of 4.5 K refrigeration.

The RF load of four LEP2 type cavities for 352 MHz is near 400 W at the target acceleration field of 7 MV/m and the reference quality factor $Q= 3.10^9$; it is varying with the square of the field and inversely proportional to Q. Most of the Nb/Cu cavities received at CERN and built into LEP2 modules could be conditioned to reach more than 7 MV/m and achieve $Q= \geq 3.2.10^9$ @6 MV/m; they are expected to be operated reliably in LEP with fields of typically 6 MV/m.

III. CRYOPLANTS

Cooling for the LEP2 cavity modules at 4.5 K is provided by separate large cryoplants of 12 kW equivalent cooling power @ 4.5 K at each of the four acceleration points of LEP2. They were described in [6], together with their transfer line system for the cold helium distribution to the cavity modules. Commissioning results for the first 3 of them were given in [7] and the control system was presented in [8]. The specified capacity of these cryoplants was 10 kW refrigeration @4.5 K, plus 13 g/s liquefaction rate and 6.7 kW of 50-75 K radiation screen cooling, resulting in a total of 12 kW refrigeration equivalent at 4.5 K.

All four 12 kW plants are commissioned and operational. The cooling performances were generally as specified [4] with excellent overall efficiency, reliable automatic operation and good power saving capability for part-load operation. However, under the pressure of competitive tendering, the two suppliers did not provide much spare capacity and the total cooling power values achieved are generally rather at the low end of the tolerance band with typically 11.5 kW @ 4.5 K.

Counting 0.5 kW for control inside the plant, 0.8 kW for about 800 m of supply and return transfer lines, 0.4 kW for cooling the sc low-ß quadrupoles of the adjacent experiment and the static load of the modules mentioned above, on average there will be for RF related dynamic losses a 4.5 K cooling power of at least 500 W per module, if not more than 14 modules are operated at each LEP2 point, and only some 350 W if the module number per point is increased to 18.

With series installation hopefully starting now and better statistics on average field limits and quality factors of modules in LEP, the ultimate beam energy limit of LEP2 can be anticipated and a rational decision made whether a possible upgrade should only increase the module number or also boost cryoplant performance, e.g. by adding compressors for more mass flow.

IV. OPERATION EXPERIENCE

Table 1:
Number of modules and cryogenic operation hours in LEP in years 1990-1994, with projection for 1995

Year	Number of installed modules	Cryoplant & Point ;	cryo operation period
1990	1 @2	1.2 kW @2;	5000 h
1991	3 @2	1.2 kW @2;	5000 h
1992	2 @2	6 kW@2;	6200 h
1993	2 @2	6 kW@2;	3800 h
	1 @6	12 kw @6	1400 h
1994	2 @2	6 kW@2	4600 h
	3 @6	12 kw @6	1500 h
1995	8 -> 16	12 kW @2,6	5000 h
		12 kw @8	1500 h

Experience with cavity cooling in the LEP tunnel started during machine runs in 1990/91 with prototype modules and a refurbished 1.2 kW refrigerator. This plant has been phased out and operation of the new generation of large refrigerators started in 1992 with modules from industry and a 6 kW plant [5]. In Sept. 1993 the first 12 kW plant started cooling of cavity modules and since beginning of 1995 the second 12 kW refrigerator replaces the 6 kW one. A varying number of modules has been cooled so far at two LEP points. At present 2 and 6 modules respectively are operated at the two first LEP points, a third point will come into service with module installation summer 1995 and the forth from spring 1996. Table 1 is summarizing this history.

The process control system of the LEP2 cryoplants is programmed for fully automatic operation of the whole system, in particular for automatic cool-down, restart after utility failures or adaption of the plant capacity (by varying compressor pressure and switching off one or two of 5) to reduced 4.5 K loads. As a consequence operator interventions and down-time of cavities could be considerably reduced [5]. Reliability turned out to be quite high, but careful preventive maintenance on all components and follow-up of compressor-motor alignment and vibrations is necessary.

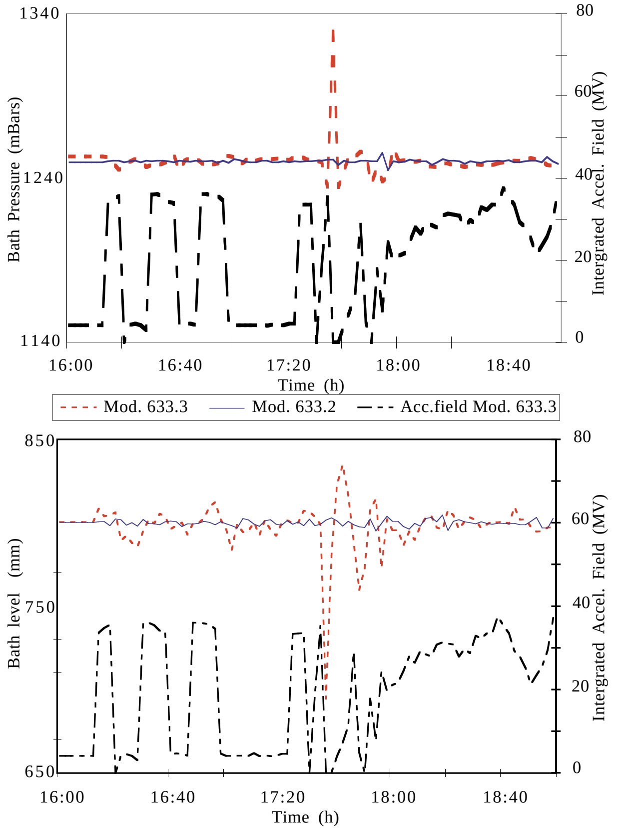

Figure 1: Recording over 2 h of bath pressures and levels in two adjacent modules during conditioning of one module. In the centre is visible, in one module but not in the other, a heat spike with RF cut by pressure and level interlocks.

V. STABILITY OF CRYOGENICS WITH VARYING HEAT LOAD FROM RF

To achieve the required stability (s. chapter II) of bath pressure and level in all modules with many interacting control loops also in the cryoplant, rapid changes of dynamic heat load must be compensated as well as possible directly inside the modules. This is achieved by using electric heaters in each cavity bath to which at zero RF a pre-determined heat load is applied (in 50-150 W range). From an analog signal proportional to the varying RF level the control system is calculating the expected RF load and is changing instantaneously the heater power correspondingly. If the right value is chosen for the effective Q of each module, even drastic and rapid changes of the RF field have almost no influence on bath pressure and bath level. (Figure 1).

The position of the cold gas return valve of each module bath is varying with gas flow and thus, if stable conditions are maintained on the supply side, is directly related to the total heat load going into the bath. We are studying and will implement algorithms in the control system which, during conditioning, will vary the Q value used for heater control such that the return valve is kept in constant position. In this way the effective Q value of the module can be monitored and displayed on-line.

VI. EFFECTIVE MODULE QUALITY FACTOR Q.

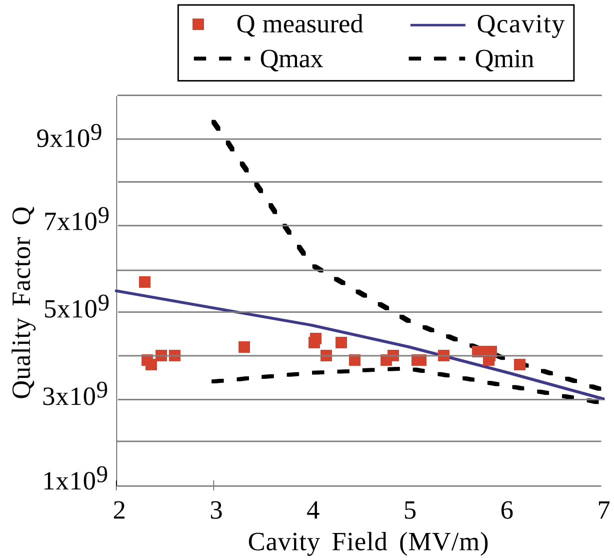

Figure 2: Comparison of average Q of module 633.2 measured on RF test bench (—) to those measured from cryogenics with heater compensation; dotted lines give error range corresponding to ± 20 W on heater power.

Figure 2 shows an example of the monitoring of the average quality factor for one of the modules operated in LEP in 1994. Each time measurements were averaged over typically 15 min, and quite a range of field strengths covered between 2 and 6 MV/m. An approximate Q factor was used for heater compensation of the RF load, and the residual movement of the gas return valve corrected off-line on the recorded monitoring data. As these measurements were done over an extended period, no identical supply conditions could be maintained, with varying 'flash' gas content as consequence of temperature changes in the supply manifold. Nevertheless good agreement of cryogenic and RF measurements was observed. Due to the quadratic nature of losses as function of field strength, cryogenic measurements cannot provide a satisfactory precision at lower fields.

VII. OUTLOOK

During the current operation period of LEP, we shall have for the first time at one of the LEP points two strings of 4 modules on each side of a 12 kW cryoplant and have a chance to operate the system under realistic charge conditions with around 50% of the final load. We expect then not only to be able to demonstrate the efficiency of our automatic procedures, but also be able to monitor continuously cavity module performances on-line.

VIII. ACKNOWLEDGEMENTS

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