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LONG-TERM OPERATIONAL EXPERIENCE AND UPGRADE OF THE
CRYOGENIC SYSTEM FOR THE SUPERCONDUCTING CAVITIES IN THE
CERN SPS ACCELERATOR

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Abstract

Cryogenics at liquid helium temperature has been requested in the SPS for testing and operating superconducting accelerating RF cavities: in 1988 and 1989 a single LEP prototype cavity made of bulk niobium, in 1990 two cavities made of niobium sputtered copper and finally, in 1991, a single niobium sputtered cavity.

To cope with the various cooling needs, we used the same refrigerator (120 watt at 4.5 K) and the associated cryosystem has been optimized to reduce the thermal load. The original transfer line has been replaced by a flexible and thermally shielded one made of six coaxial bellows. The achieved thermal performance for the various combination of superconducting cavities, the long-term behaviour and operational experience of the cryosystem are given.

While the first cryosystem is maintained in operation, a new one (using a refrigerator of 400 watt at 4.5 K) is now being tested to increase, in 1992, the SPS accelerating field by means of two additional superconducting cavities. A description and the preliminary results of the new cryogenic facility are presented.

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INTRODUCTION

The first superconducting radio frequency (RF) accelerating cavity (LEP2) was installed in the CERN SPS accelerator in 1988. The intention was to test, in a real accelerator environment, a prototype cavity for the LEP energy upgrade [1] well before the completion of the LEP machine. The superconducting (SC) cavities in the LEP collider will increase the electrons and positrons energy from the actual 50 GeV to an energy close to 100 GeV per beam. In the following three years (fig. 1), the SC cavities in the SPS were used not only for tests during machine development periods, but they became an essential component of the accelerating system and long-term operated for injecting electrons and positrons in LEP at about 20 GeV. In 1989 the LEP2 cavity, in 1990 a twin module (cavities 46 and 48 mounted in the same vacuum vessel and cooled by the refrigerator previously used for one cavity) and, finally, in 1991 the cavity 48 alone. The cavities 46 and 48 are made by sputtering niobium on copper while LEP2 is made of bulk niobium [2].

The further step (1993 and 1994) is a progressive partial replacement of the normal conducting (NC) cavities with the SC ones by means of two twin modules capable of providing the total requested acceleration field of about 2X16 Mvolt. To achieve this goal, a new cryosystem has been installed and operated from the beginning of 1992 to cool the first twin module made with the previously used LEP2 and 46 cavities.

CRYOSYSTEMS

Two cryosystems have been used: the first one from 1988 to 1992 and the second one (with a 3 times larger capacity refrigerator) from the beginning of 1992. The main components of the cryosystems (i.e. the refrigerators) are made by SULZER (UK) subcontracting the compressors to KAESER (D), while all the transfer lines have been designed and fabricated at CERN. The three SC cavities and their cryostats were entirely constructed at CERN.

Refrigerators

Cooling capacity, reliability and simplicity were the main criteria for the choice of the two refrigerators (providing respectively 120 watt and almost 400 watt at 4.5 K). Both are based on a Claude thermodynamic cycle with two dynamic gas bearing turbo-expanders. The 120 watt plant is equipped with only one J.T. valve, while the other plant has two J.T. valves to improve its thermodynamic efficiency. Gas compression (ratio of 10) is achieved by single stage oil lubricated screw compressors (respectively 110 and 250 kwatt input electrical power) of very simple design (no slide valves and oil pumps).

Transfer lines

We have used three different transfer lines: two flexible of coaxial design and one (about 20 meters long) rigid with flexible end connections. The 20 meters line is thermally shielded at 60 K. The first two lines and the 20 meters line were used respectively with the smaller capacity refrigerator and for the recently installed cryosystem.

Operation of two SC cavities (46 and 48) with a given refrigerator capacity (120 watt at 4.5 K just sufficient for one) could only be achieved by imposing severe limitation to all the other heat loads. The major improvement was obtained by replacing the existing 7 meters long transfer line (not shielded flexible and coaxial, 4 watt/m in the return 4.5 K channel [3]) with a new one of unique design and meeting the following technical specification:

- 1) Minimum heat load in both the liquid supply and gas return lines at 4.5 K.
- 2) The line must be of flexible type to allow its installation. This was imposed by the complicated geometrical arrangement of the existing equipment in the SPS tunnel.

The above requirements led to a design based on a line (about 8 meters long) made of six coaxial bellows.

Bellow 1: liquid helium supply (diameter 7+11 mm).

Bellow 2 and 3: gas return annulus at 4.5 K (diameters respectively 14+18 and 26+33 mm).

Bellow 4 and 5: annulus for 80 K helium gas thermal shield (diameters respectively 39+48 and 51+61 mm).

Bellow 6: vacuum vessel.

The line is constructed of stainless steel including the spacers. Only the bellow 5 facing the room temperature vacuum bellow is superinsulated. The main technical difficulty to overcome was to match the different deformation produced by the differential pressure (atmosphere/vacuum) on the bellows with their thermal contraction. This was achieved by means of several preliminary tests to establish the mechanical behaviour of the bellows under the various combined forces.

The line was installed in the SPS tunnel at the beginning of 1990 and successfully used in 1990 and 1991. The thermal performance was measured before the installation. The total heat load in the liquid supply and gas return lines (both kept at 4.5 K) was less than 3 watt with the shield annulus cooled by liquid nitrogen.

LOGIC AND CONTROLS

Superconducting cavities are cooled by a saturated helium bath (4.5 K, 180 litres bath volume) with a minimum ullage volume (6 % of liquid volume). They are very sensitive to rapid (>20 Hz) bath pressure variations and to mechanical oscillations (change of cavity shape and, therefore, of frequency which cannot be compensated by the tuners). Good stability in liquid level ($\pm$ a few litres) and pressure is, therefore, mandatory.

We tried different solutions to stay within the above limits, only the control logic shown in fig. 2 gave satisfactory results. The refrigerator is kept at constant load by a heater in the cavity bath controlling the helium level. It turned out that a DC heater was more suitable to avoid mechanical oscillations. Heat dissipated in the helium bath by the applied RF field (dynamic load) is automatically compensated by a reduction in the heating power. The adopted solution minimizes the number of control loops (no liquid control in the refrigerator sump) and avoids the use of valves for level regulation of the cavity bath. We applied the same method for the two refrigerators and for both single cavity and twin module.

The twin module level control deserves a special comment. In this case, the liquid is supplied (by a bottom collector) to the separated baths in parallel. Only one level is controlled, the second one is self regulated by the hydrostatic pressure change with reference to the first one. The control loop output drives symmetrically the two heaters in the baths. When using the 120 watt plant with a twin module, heating was applied in only one bath. In this case heating asymmetry was negligible because of the very small refrigerator over capacity.

For both cryosystems the controls are based on microprocessors. The first refrigerator is still using the control (SATTCONTROL S) provided by the supplier, while for the second refrigerator the control from the supplier (used for commissioning and fast preliminary tests) is now being replaced with the CERN adopted standard for cryogenics (ABB S). This will allow future long-term operation by the same team in charge of running all the other CERN refrigerators.

THERMAL PERFORMANCE

The refrigerator load is shared between isothermal at 4.5 K and liquefaction for the various shields and thermal tuners operation. The dynamic load is small (a few percent of the static one) because of the pulsed mode operation in the SPS (i.e. the maximum RF field is applied only for short time corresponding to a duty cycle of less than 10 %).

The heating power in the cavities bath (when running the refrigerator at given settings) is a measurement of the spare cooling capacity at 4.5 K. Its long-term logging gives a very good indication of the system thermal behaviour including refrigerator capacity, static loads of transfer lines and cavities cryostats and of the dynamic load .

Fig. 3 shows a comparative graph of the spare cooling capacity for the various combination of cavities used with the 120 watt refrigerator. All the data (taken over one month) refer to steady state dynamic load conditions and with liquefaction load set at nominal value (i.e. 0.15 to 0.2 gr/s per cavity). The upper curve refers to the cavity 48. The intermediate curve refers to the LEP2 and the lower curve to the twin module made of 46 and 48 cavities. The large difference between the 48 and LEP2 (about 40 watt) is due to the change of the transfer line (about 25 watt), to improvements in the static load of the cryostats and to a reduced dynamic heat load (better quality factor of niobium sputtered cavities). The twin module spare capacity (about 5 watt) indicates that we were running the system on extreme conditions. Nevertheless, the twin module was operated for about 4000 hours. Even minor change of the cryosystem settings could interrupt the operation and liquid helium refilling, after utilities failure, became too long. We considered this situation not acceptable and the twin module was replaced by a single cavity to reduce the refrigerator load. The difference between the 48 and the twin module (about 55 watt at 4.5 K) is a measurement of the 4.5 K equivalent cooling capacity needed for running one cavity in the SPS pulsed mode. In fact, all the other condition were identical (same kind of cavities and operating RF conditions, same refrigerator and same improved transfer line).

Fig. 4 shows the very long-term behaviour (250 days) of the cavity 48. The drop of cooling power of about 10 watt was due to an increase of the liquefaction load for better operating conditions of the thermal tuners. Apart from this

wanted reduction, no degradation of the thermal performance of the cryosystem was noticed.

Similar preliminary measurements have been carried out with the larger capacity refrigerator and the new twin module. About 200 watt of spare capacity has been measured.

CONCLUSION AND FUTURE ASPECTS

Superconducting cavities and associated cryosystems have been routinely operated in the SPS and are progressively becoming key components of this CERN acceleration complex. In addition to the existing twin module, a new one is under study with the intention of cooling it with another refrigerator. This new facility will provide additional 16 Mvolt. Furthermore, enough NC cavities (for a 16 Mvolt total acceleration field) will be maintained operational in the SPS (fig. 5). Since the three systems are independent and the acceleration of electrons and positrons for injection in LEP requires about 32 Mvolt, the extra 16 Mvolt provided by either the NC cavities or by one twin module of SC cavities will guarantee the requested 50% redundancy.

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Fig. 1 Operating time of SC cavities in the SPS

Fig. 2 Cryosystem control logic

Fig. 3 Refrigerator spare cooling capacity

Fig. 4 Long term behaviour of refrigerator spare cooling capacity

Fig. 5 Past and future acceleration schemes and associated cryogenics