FIRST OPERATION OF SUPERCONDUCTING Nb SPUTTERED COATED Cu CAVITIES IN THE CERN SPS


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Abstract

Two four-cell 352 MHz superconducting niobium sputter-coated copper cavities assembled in one cryostat are installed in the CERN SPS. This twin module replaces the existing niobium four-cell cavity in operation since two years. The objectives of the project are to provide more accelerating voltage for the SPS as LEP injector and gain experience with the novel sputter coated superconducting surface in a real accelerator environment. In laboratory tests accelerating fields of 6.7 and 6.8 MV/m and Q-values at 4.2 K and 5 MV/m of 4.1 and 5.5 \times 10^9, respectively have been obtained. The higher order mode couplers of a novel design guarantee, in particular, stronger damping for the TM011 mode. The already existing RF systems for acceleration and fundamental mode damping by RF feedback grouped around a 50 kW tetrode amplifier have been doubled. An additional cooling capacity of the existing refrigerator is desirable to operate the twin module. Tests have shown that the refrigeration power is increased from 120 W to 160 W at 4.5 K by cooling of the first heat exchanger with liquid nitrogen. Initial operating experience with this twin module is reported.

Introduction

At present the CERN Large Electron Positron Collider (LEP) can be exploited up to beam energies of about 55 GeV/c sufficient for the production of Z^0 particles in large quantities. In a second phase which will be realized during the coming years the beams will be taken up to energies approaching 100 GeV, by the installation of superconducting RF accelerating cavities [1]. For this purpose a development program was started at CERN in 1979 [2] using Nb sheet material. Their feasibility has been shown and prototypes have been produced at CERN and from industry [3]. This type of cavity, even using high purity Nb sheets, suffers from the relatively poor thermal conductivity of Nb at liquid helium temperature. For this reason a development program was started at CERN in 1980, aiming at developing a deposition method of thin Nb film on the inner surface of a cavity made of high purity copper (OFHC, with thermal conductivity at 4.2 K of about 460 Wm⁻¹K⁻¹ [4]). For the coating of Cu cavities, sputtering was preferred to other coating methods; at present the coating is made using a cylindrical magnetron [5]. The results obtained at the moment indicate that the performances of Nb coated cavities are satisfactory for LEP use [6]. It has therefore been decided to produce several of these cavities at CERN and to test them as soon as possible. The encouraging results that we had using a superconducting cavity in the SPS as a LEP injector since two years [7] pushed us to replace the existing niobium four-cell cavity by two four-cell Nb coated copper cavities assembled in one cryostat. The objectives were to provide more accelerating voltage and gain experience using this new technique in a real accelerator. Two Nb coated prototypes which were already produced and tested have been used for this purpose.

Fig. 1 shows the accelerating field and Q-values obtained in a vertical test for the two bare cavities.

The cryostat, the tuner and the RF input coupler, have the same design as for the Nb cavity [8]. However, for Nb coated cavities, the Higher Order Mode coupler (HOM) must be fully demountable; a new HOM has therefore been developed [9]. Fig. 2 shows the twin cavity module installed in the SPS tunnel.

Tests of the twin cavity module

The two cavities assembled in the same vacuum tank have been tested horizontally in the same test area previously used for the LEP copper cavities, where RF power is supplied by a 1 MW klystron.
The maximum accelerating fields obtained in the individual cavities (one cavity being operated, the other detuned) fully equipped with RF input couplers and High Order Mode (HOM) couplers were 5.2 and 4.5 MV/m, respectively. However, at the start of the cold test under continuous wave operation of the klystron, both cavities showed instabilities and breakdowns caused by e+ loading detected in the HOM couplers, which heated up such that the rejection of the fundamental mode became insufficient. The external Q-value of one of them decreased to \( 7 \times 10^8 \). Under these conditions, the RF test had to be stopped to avoid a possible damage of the RF output cable of the HOM. After some hours the couplers had cooled down and the external Q-value and the temperature were tolerable again. In a pulsed mode of operation it was possible to perform the conditioning up to the accelerating field of 5.2 and 4.5 MV/m respectively with a gradual increase of the duty cycle up to 20%. In this way heating and excessive fundamental mode power leakage have been avoided. It must be pointed out that, for the SPS operation the RF field is indeed pulsed in the cavities, with a small duty cycle. The \( \gamma \)-radiation emitted from individual cavities at 3 MV/m was 1 to 2 rad/h, but when operated simultaneously, it reached 9 rad/h. No attempt to improve these performances further had been made because of the tight installation schedule.

The radiofrequency system

The two four-cell accelerating modules are driven by two completely independent, identical, power amplifier chains. As in the previous SPS tests [7,8,10], the final elements of these are 50 kW Thomson tetrodes (TH 571B) directly connected to the cavity input couplers, without circulators.

The fully transistorized driver amplifier has been replaced by two more powerful tetrode drivers (5 kW) based on a Thomson design (air cooled tube TH 393). Both final and driver tetrodes operate in class AB to ensure a reasonably linear operation of the RF feedback chain. Each predriver is made of two combined transistorized 100 W modules, giving some redundancy. These modules have an automatic gain reduction in case of overdrive; this feature proved extremely useful for limiting the drive power during fast transients in the RF feedback circuitry. With the new driver stage inserted in the overall amplification chain, care had to be taken to keep the overall delay of the RF feedback path below the allowed 500 ns [10].

In case of failure of an amplifier, the fundamental resonance of the cavity, without circulator, shows such a high impedance (\( R = 5 \, \Omega \)) that the beam must be dumped immediately. To keep the high intensity proton beam running even with an RF chain out of service, a passive damping device can be connected directly to the cavity main coupler through a motorized wave guide switch. Such a device which is nothing but a properly adjusted wave guide short circuit reduces the cavity impedance to a few M\( \Omega \), a value which is acceptable by the high intensity proton beam.

The two cavities being installed in the same cryostat are thus unavoidable coupled through the vacuum pipe section. Thanks to the very careful design, filtering and shielding of the low level RF circuitry, no parasitic oscillations or parasitic coupling between the RF feedback chains have been observed. The reference signal delivered by the LEP synchronization system and transmitted over several kilometers by an optical fibre link is now filtered at the receiving end by a phase locked loop crystal oscillator. This reduces the noise components outside the very narrow cavity resonance (20 Hz) which tend to saturate the amplifier chain.

The cryogenic system

Cooling at 4.5 K of the twin module is achieved by means of a small refrigerator (a TCF 20 cryocooler made by Sulzer, UK) already used for long-term test of a single superconducting cavity in the SPS accelerator. This cryocooler has already accumulated more than 12000 h of operation.

Fig. 3 shows the available cooling capacity for a single cavity operated with RF field. It is only 17 W [11], i.e. 14% of the total (120 W at 4.5 K) provided by the TCF 20. This cryopower was sufficient, as the cavity was operated with 7% duty cycle at 5 MV/m, corresponding to 5 W at \( Q = 2 \times 10^9 \). Cooling two cavities with a refrigerator just sufficient for one could be obtained by:

(a) minimizing the various contributions to the total static (i.e. without RF field) heat load;

(b) boosting the refrigerator by using liquid nitrogen supplied from a dewar at the surface level and transferred to the cold box (installed 60 m underground).

It was realized that the safety margin for operation under these conditions was extremely small.

![Figure 3](image-url)

The flexible and coaxial transfer line (~7 m long, 4 W/m heat inleak in the return channel) used for the interconnection between the cold box and the single cavity has been replaced. The new line designed and constructed at CERN is made of six coaxial bellows which provide the thermal shield (with 90 K helium gas provided by the refrigerator). Fortunately, the static load of the twin module is less than twice that of a single unit because these are only...
two liquid helium to room temperature end transitions instead of four. The sharing between the various heat loads is shown in fig. 3 where the previous (single cavity) thermal balance is also indicated for comparison. There are measured values, except the 10 W for cold valves and couplings which are estimated. Preliminary measurements (~ 30 W) of the available cooling power without RF field confirmed the expectation. After 2000 h of operation and with full RF field, the measured remaining cooling power is less than 10 W.

In preliminary tests with liquid nitrogen supplied by a small underground dewar close to the cold box an increase of the refrigerator cooling capacity from 120 to 160 W has been achieved. For the cavity operation, nitrogen is supplied from a surface dewar via a geometrically complicated system of flexible transfer lines of a total length of ~ 140 m. The pipe layout is made of two horizontal (~ 25 m each), one vertical (~ 60 m) sections and three interconnecting loops. The measured average linear heat leak in the transfer line operated with liquid nitrogen is 2.8 W/m. Two-phase nitrogen flow instabilities occurred when the flow quality factor at the piping outlet is less than 0.8 and this facility is therefore not used at present.

For operating the twin module we adopted the same control logic as previously used for the single unit [10]. The two liquid helium vessels surrounding the cavities are fed by the refrigerator in parallel via a bottom pipe. The liquid level is regulated in only one vessel by an electric heater. To avoid perturbations on the tuning system by the heater electric pulses, these are switched off when RF field pulses are applied to the cavity. Pressure and level stability of the twin module system are fully satisfactory and comparable with that of the single unit (i.e. ± 5 mbar, ± 0.5 litres).

Uninterrupted cryogenic operation of the twin module started at the beginning of the year and presently the running time at 4.5 K exceeds 2000 hours.

Conclusion
The first operation of niobium coated superconducting cavities in a real accelerator has been demonstrated. The field level routinely used for e+e- acceleration exceeds 5.5 MV/m and is not limited by the cavities themselves. Despite the extremely small safety margin for the cryogenic power and thanks to the stability of the system, the cavities are in operational use for LEP filling and will permit in the near future an increase of its injection energy. For the long term an increase of the cryogenic power is considered.

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References