# REPORT ON SUPERCONDUCTING RF ACTIVITIES AT CERN

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*Abstract*

After the dismantling of LEP, shut down for the last time in November 2000, there are no more superconducting cavities installed in CERN's accelerators. Efforts are now mostly devoted to the construction of the cavities for the LHC, whose production, described in the following, is advancing regularly. We are investing some of our existing resources in R&D for the development of reduced beta cavities for the acceleration of protons. The prototypes of the β=0.7 and β=0.8 cavities reached the baseline specification values for the SPL project. Future programmes will be illustrated.

A number of collaborations for the design, production and test of superconducting cavities were established with other laboratories. A summary of this work will be given.

## 1 SUPERCONDUCTING CAVITIES FOR THE LHC

The groups involved in superconducting RF at CERN are now fully concentrated on the production of the cavities for the LHC. In the LHC the two beams will run in separate vacuum chambers, receiving 8 MV of acceleration at injection and 16 MV in collision. In spite of the low accelerating voltage needed, it was decided that superconducting cavities would be used for their low R/Q, that minimizes transient beam loading effects due to the high RF beam current. Each beam will pass through eight 400 MHz superconducting cavities, grouped in two separate cryostats, while the other beam will run in a vacuum chamber included inside the same cryostat at a distance of 420 mm from the other beam axis.

Twenty-one cavities were produced (16 to be installed plus five spares) with Nb/Cu technology and have all been successfully tested at the operational temperature of 4.5 K. All the cavities have reached the specification value ($Q = 2\cdot10^9$ @ 5 MV/m) and can attain more than 9 MV/m with a Q factor in excess of $10^9$. The cavities are mounted four by four in eight-metre long cryostats, made of stainless steel and having large apertures to insure full accessibility to the inner components (Fig. 1).

On each cavity four Higher Order Mode (HOM) couplers are mounted, two for the damping of longitudinal modes, and two for transverse modes. Low power measurements at 4.5 K have proved that a good rejection of the fundamental mode ($Q_{ext}>10^{11}$) can be achieved by fine tuning of the couplers [1], and that HOMs are damped according to the specifications [2].

The power coupler of the LHC cavity is a complex mechanical assembly since the coupling to the cavity must be changed during operation by a factor 10 to minimize the RF power during the different modes of operation. Two different DC biases are applied between the inner and the outer conductor to suppress all multipacting levels as much as possible. On the first module four prototype couplers have been tested successfully up to 200 kW CW and up to 300 kW in pulsed mode. The conditioning took only four days and the RF phase was varied to nearly all the possible values without encountering special problems or instabilities.

The tuner deforms the LHC cavity elastically to tune it to the right frequency with a resolution of 20 Hz/step. It consists of a mechanical structure driven by a stepping motor that gives a total range of tuning of at least 180 kHz with a high speed (up to 4000 steps/sec).

Figure 1: The first LHC module ready for measurements.

All the cavities have already been equipped with their stainless steel helium vessel, three modules have been assembled, the fourth will be ready by the end of the year and the last one will be prepared early next year.

Low-power measurements are foreseen on all the modules to check the quality of the assembly work. This campaign of measurement will be finished by April 2002, and will be followed by high-power conditioning with the power couplers till the end of 2002, when hopefully the production phase will be closed.

In the beginning of 2003 one or two series LHC klystrons will be installed in the test facility of building SM18 in order to start the test of low-level controls with the baseline components in the feedback loop.

In 2004 the four modules will be installed in the tunnel.

## 2 REDUCED-β CAVITIES FOR THE SPL

In November 2000 the RF system installed at LEP was shut down for the last time. All the 72 modules (288 superconducting cavities) have already been dismounted and stored properly in the ISR tunnel, together with the high power RF system. The whole system represents more than 3 GV of acceleration and several proposals for its re-utilization have been published. The SPL project (Superconducting Proton Linac [3]) plans to replace the injectors of the CERN PS (Proton-Synchrotron) accelerator with a Linac, based on superconducting technology and capable to deliver a 2.2 GeV $H^-$ beam.

Figure 2: The 72 LEP modules stored in the ISR ring.

At the stage of the first layout, the Project team chose to work at the same frequency as LEP (352 MHz) using four different types of superconducting cavities (β = 0.52, 0.7, 0.8, 1), to accelerate protons above 120 MeV. This option permitted the maximum number of LEP cavities to be re-used with no modifications, leading to considerable savings on the whole cost of the accelerator.

The new baseline layout, detailed for the high-energy part in Table 1 and described in [4], makes use of only the reduced-β cavities. This is not in contradiction to the previous statements on cost savings, since β=0.8 cavities have a transit time factor vs. β characteristic more favourable to the acceleration of high energy protons than LEP cavities. The new layout is therefore shorter than the first one by 85 m, and β=0.8 cavities can be built using a big part of LEP hardware [5] with a cost that is about 30% of a brand new cavity.

Table 1: SPL baseline layout

| $\beta_0$ | Energy range [Mev] | Eacc [MV/m] | Cavities/ Cryostat | Number of cryostats |
|---|---|---|---|---|
| 0.52 | 120-236 | 3.5 | 3 | 14 |
| 0.7 | 236-383 | 5 | 4 | 8 |
| 0.8 | 383-2235 | 9 | 4 | 32 |

A solution for the β = 0.7 and β = 0.8 sections is already available: a four-cell β = 0.7 cavity and a five-cell β = 0.8 cavity made with the Nb/Cu technology have reached the specified accelerating field at 4.5K (respectively 5 MV/m and 9 MV/m [4, 6]).

For the β = 0.52 section on the contrary we are now convinced that the standard sputtering technique used for LEP cavities and for the other reduced-β, cannot lead to satisfactory performances [6]. For the years to come we will therefore put some effort into developing a new procedure to be able to reach the baseline values of Table 1. A back-up normal conductive solution will be prepared as well.

A study of the complete accelerating system (including klystrons and feedbacks) has been initiated [7], demonstrating that full characterisation of the cavities from the mechanical point of view is necessary for stable operation in pulsed mode (50 Hz for the SPL).

This is true in particular for β = 0.8 cavities that will be driven in groups of four by each klystron. The feedback loop in this case can stabilise only the vector sum of the cavities' field, so each cavity can start to oscillate without changing the sum, leading rapidly to a catastrophic effect [7].

An R&D programme has therefore been established to investigate:

- the behaviour of the cavities with respect to Lorentz forces under pulsed regime;
- the frequencies of the main mechanical resonances;
- the requirements on the stability of the cryogenic system;
- the possibility of using active compensating devices such as piezo actuators.

## 3 COLLABORATIONS

Several agreements have been signed with other laboratories for the production of both massive niobium and Nb/Cu cavities using existing CERN facilities. A brief summary of these collaborations follows:

### *3.1 SOLEIL*

Figure 3: CEA and CERN staff working together in a CERN clean room on the SOLEIL cryostat.

CERN is working in close collaboration with CEA-Saclay, and ESRF, Grenoble, to test with a real beam in the ESRF the two cavities built at CERN under CEA design for the SOLEIL project [8]. Made of Nb/Cu, the cavities work at 352 MHz and at 4.5 K and have been assembled and tested at both low and high power in CERN facilities, reaching the specified performances ($Q = 3\cdot10^9$ at 5 MV/m). After final conditioning at CERN the cavities will be shipped to Grenoble for their installation in October 2001.

### *3.2 TESLA.*

In collaboration with DESY and CEA-Saclay, CERN set up a chemical facility for the treatment of single-cell 1300 MHz massive Nb cavities. More than 100 treatments (and RF tests at 2 K) have been performed in the last two years. We started from classic BCP (Buffered Chemical Polishing), shifting then to Electropolishing. Introducing an improved procedure for high pressure rinsing and baking out the cavities for 24 hours at 120°C we were able to produce several cavities that could be tested up to more than 40 MV/m with Q values over $5 \cdot 10^9$. More details can be found in [9]

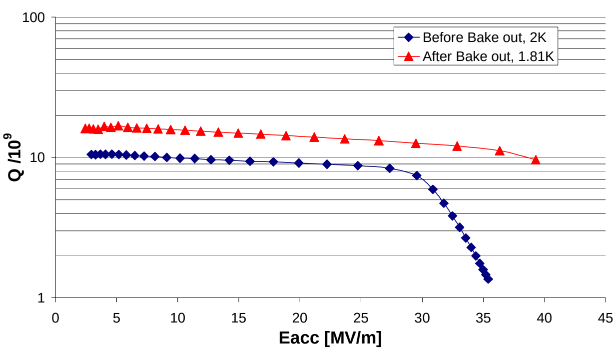


Fig. 4: Performance of a cavity after 100 μm of EP etching (blue: before 120°C bake out, 2 K; red: after bake out, 1.8 K).

### *3.3 Super 3HC*

Fig. 5: Prototype of the S3HC cavity built at CERN.

S3HC are 3rd harmonic passive superconducting cavities to be installed in the two synchrotron light sources of PSI in Villigen (Switzerland) and ELETTRA in Trieste (Italy) [10]. CERN is committed to building the cavities and their helium vessels according to the CEA-Saclay, design. Each cavity is made of two cells separated by a tube on which HOM couplers will be installed. They will work at 1500 MHz and at 4.5 K, using Nb/Cu technology. A prototype has already been realised and successfully tested (see Fig. 5).

### *3.4 CERN and CORNELL University.*

CERN is responsible for the design and production of a 200 MHz single-cell superconducting cavity using Nb/Cu technology that will be tested in CORNELL's facilities. The goal of this project is to investigate the performance of superconducting cavities at these frequencies, which have been proposed for the acceleration of muons for Neutrino factories. The design of the cavity is the result of a trade-off among RF optimisation (High R/Q, low peak E-field etc), and practical considerations, such as the difficulty of making a vacuum-tight flange for a diameter larger than 400 mm. The diameter at the equator of the cell is 1370 mm, and in Fig. 6 a half-cell is shown next to a 1500 MHz single cell, giving an idea of the difficulty in handling such a cavity. The cavity will be welded by an outside firm, and then treated at CERN using a "standard" SUBU chemical etch. The sputtering of the niobium film will also be done at CERN, followed by a high pressure rinsing treatment. Then the cavity will be shipped to Cornell, where low-power RF tests will be performed in an especially built cryostat.

The first results should be available by the end of this year.

Fig. 6: A 1500 MHz cavity and a 200 MHz half cell.

### *3.5 CERN and INFN*

Several collaborations were set up with different units of INFN.

- Two single-cell and one five-cell β=0.8 Nb/Cu cavities were built at CERN for the TRASCO project. The measured performance at low power exceeded 9 MV/m for the single cell and 7 MV/m for the five-cell with a Q factor of more than $2 \cdot 10^9$. High power tests are foreseen before the end of the year.
- A cavity for the detection of gravitational waves was treated in the CERN chemistry workshop for INFN Genova. An agreement for the production of a prototype of another type of superconducting cavity (PACO, [11]) has already been signed.
- Several λ/4 cavities have been chemically treated for INFN Legnaro, as well as the first superconducting 80 MHz RFQ [12] and a prototype cavity designed and built by Legnaro for ISAC (Triumf).

## 4 ACKNOWLEDGEMENTS

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We are indebted as well to colleagues from other laboratories who worked with us, enriching our know-how and carrying out interesting development together with us.

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