Lectures in Honour of Emilio Picasso
Pisa – Italy, 13th May 1999

Superconducting RF Cavities

(Philippe Bernard, CERN)

1. INTRODUCTION

It was 20 years ago when the research and development programme for LEP superconducting cavities was initiated. It lasted about 10 years. Today, my aim is not to tell you in great detail about the many innovations made thanks to our research, but I would like to point out some milestones in the development of superconducting cavities where Emilio’s influence was particularly important.

2. THE FIRST STEPS TOWARDS S.C. CAVITIES

In November 1978, CERN Executive Director-General John Adams decided to promote research and development of superconducting cavities thereby hoping to increase the ultimate energy of the future LEP machine.

He therefore asked Herbert Lengeler and myself to prepare a programme. We did just that, planning to make use of the overall knowledge of the various European laboratories involved in this type of research. In a memorandum addressed to JBA on December 11th, 1978 we made a proposal for a programme in which we specifically suggested that a CERN physicist be chosen as the leader (Fig.1). In view of this, I put forward Emilio Picasso’s name. Indeed, I had already known Emilio for some time (since 1976), whilst working together on a gravitational waves detector with superconducting cavities [Ref.1]. Furthermore, Emilio enjoyed excellent relations with a large number of people from European universities.
At the Scientific Policy Committee in February 1979, JBA presented our proposal [Ref.2], Emilio Picasso having been chosen as the Team Leader. Hence the programme was well under way and at the SPC in June of the same year Emilio gave a detailed presentation of the know-how then available and of the expected future programme [Ref.3].

3. TEMPERATURE MAPPING

In those days diagnostic systems for superconducting cavities were fairly rudimentary. This lead us to develop a temperature measuring system consisting of carbon resistances, held by beryllium-copper springs, which could be moved around on the surface of the cavity (Fig.2).

The data acquisition system was automated and in order to increase the system's sensitivity, measurements were made in a sub-cooled helium bath [Ref.4]. This system proved to be extraordinarily powerful and made it possible for us to detect various defects, as well as their location (Fig.3). Its sensitivity was such that it enabled us later to prove the presence of dielectric losses at the level of the iris. These losses occurred from drying residues of the rinsing water used in the cavities. Since then our system has been used by nearly all the laboratories who study superconducting accelerating cavities.

4. NIQUEMEN ON COPPER

Very quickly we saw that the maximum field reached by the cavities was limited by hot spots which were induced by the presence of a non-superconducting material on the niobium surface. These hot spots have enough power to heat the surrounding niobium and trigger the quench phenomenon, because the underlying niobium did not possess sufficient thermal conductivity.

Somebody had written that the idea of the niobium deposit on the copper had been born in the CERN canteen...! There is some truth in this. Indeed, Emilio who had only just been nominated LEP Project Leader, nevertheless continued to be very interested in superconducting cavities. In my new role as the team leader, we often met at the end of the day for coffee in the canteen where I made my report of progress and research work to Emilio. It is correct to say that during these discussions we gradually developed the idea that since superconductivity only used
a few hundred Å thickness of superconducting niobium, we could apply a thin coating of niobium on a heat conductor, much more efficient than niobium, that is to say on copper. Moreover, by sputtering niobium onto the copper surface it was possible to dilute the impurities (mainly tantalum) and so the volume of the heating mass would decrease.

In parallel, niobium producers made an effort to improve the purity. This resulted in a sharp price increase; thus it became more economic to use only a very small quantity of niobium. Happily, Cris Benvenuti was a member of our team and he tackled the delicate problem of the niobium deposit on copper. His efforts were rewarded and in 1983 we were able to measure the first 500 MHz copper cavity with a coating thickness of about 1 µ-niobium [Ref.5].

We were pleasantly surprised when we found out that these cavities had a quality factor Q about twice as high as the ones made of bulk niobium, and an insensitivity to the earth's magnetic field or small residual magnetic fields (Fig.4). This meant a further economy because this way we avoided placing a µ-metal screen around the cavities. – Finally, just as we had predicted, the cavities no longer showed any signs of the quench phenomenon. New problems awaited us, especially the field limitations due to field emitted electrons.

5. **THE CAVITIES IN THE ACCELERATORS**

5.1 **Superconducting Cavity at DESY**

Right from the beginning Emilio insisted that we should perform an experiment with a cavity in the PETRA accelerator at DESY [Ref.6]. The first test was carried out in 1983 with a 500 MHz niobium cavity of five cells. This test showed that the superconducting cavities behaved normally in the beam. However, the difficulties encountered had been rather important and so we had to make fundamental modifications to the design of the system. It was nonetheless the first time that an electron beam was stored at an energy of 7 GeV with the help of a superconducting niobium cavity.
5.2 Superconducting Cavities in the SPS

Even though we already had a test in DESY, Emilio wanted a superconducting cavity in working condition in an accelerator, and he convinced the people in charge at the SPS to install a LEP-type cavity in the accelerator [Ref.7]. Daniel Boussard tackled the difficult problem of the proton beam interaction with the cavity and indeed the first cavity was operational in 1987. Since then, there has always been one or several superconducting LEP-type cavities in the SPS, which subsequently became the first circular accelerator where the electron acceleration system was entirely superconducting.

At the present moment the SPS is equipped with two modules of two cavities each. This acceleration system has never given any trouble (Fig.5).

1) Superconducting Cavities in LEP

A Short Description of LEP Cavities.

The basic choices for the LEP s.c. cavities are:

352 MHz for compatibility with the previous accelerating system; four-cell structure with couplers on the cut-off tubes (Fig.6).

The four-cell cavity is fabricated from oxygen-free copper, using spinning and electron beam welding techniques. Proper preparation of the copper surfaces (electropolishing, chemical treatment, high purity water rincing) before thin film deposition is a critical process.

Sputtering the niobium layer is achieved with a magnetic discharge between a high purity niobium cathode and the cavity walls.

The cavity is surrounded by its helium tank and its three tuner bars. This tuning is based on the combined magnetostrictive and thermal effects on nickel tubes 2m long. All is suspended inside a vacuum tank. The latter with its three wide barrel straves provides easy access to the cavity in order to guarantee assembly of various couplers in the cleanest possible way.

It was René Stierlin who developed the entirely new concept of this vacuum tank made of welded aluminium [8]. This caused quite a stir from one of our visiting colleagues from a big American laboratory: "Philippe" – he exclaimed – "to see a vacuum tank at CERN which is not made of stainless steel!! Shocking!!" – Don’t worry! Very quickly stainless steel was back at CERN and the LHC vacuum tanks for
the niobium-copper accelerating cavities are machined from massive stainless steel. Luckily for the CERN budget, there are only 21 cavities to be built!

Intervention inside the cryostats is very easy, as neither a magnetic shield nor an intermediate thermal shield is necessary. Thermal insulation is achieved with super-insulation mattresses alone. Four units are assembled together in a common cryostat to form a cryomodule 12.5 m long, including the end covers (Fig.7).

During the last LEP stop one was in a position, thanks to our cryostat, to change the set of cables which had mistakenly been placed inside the super-insulation mattress. Subsequently the increased LEP intensity and shortened bunches developed heat excess during the ramping. This lead to melting of the cables inside the super-insulation. Repair would not have been possible with a conventional cryostat.

**Industrial Production of Cavities**

At the end of 1990, CERN awarded the contract for manufacturing the cavities and modules to three European companies (Fig.8). Technology transfer and know-how took longer than we thought. The first production went smoothly under the supervision of Enrico Chiaveri and came to an end in 1995. Since then, three more production stages followed.

Today, 72 modules are installed in the LEP tunnel (Fig.9). Not only do they reach their designed value of 6 MV/m at a Q of 310^9, but with processing they are able to work at more than 7 MV/m allowing to pass the 100 GeV.

6. **CONCLUSION**

It is largely thanks to Emilio's enthusiasm, which he so readily communicates to others, and to the push which he gave to the LEP Programme, that LEP will reach 200 GeV in the centre of mass. We have not given up hope that this accelerator may yet find the Higgs particle. It is however most regretful to think that this marvellous machine will be irretrievably stopped next year (Fig.10).

Allow me to conclude with a few words, specially addressed to Emilio. I have been immensely fortunate to have met him in the seventies and thus participate with him, Luigi Radicati and Francesco Pegoraro in the proposal of an electromagnetic detector for gravitational waves. – Ever since then, my professional life has become
even more intense and successful. I am naturally proud to share this important day with Emilio and his friends and it is with great pleasure that I look forward to continue our collaboration around the topic which is at the origin of our friendship: the gravitational waves.

HAPPY BIRTHDAY EMILIO!

7. REFERENCES


[3] Developments in Superconductivity by Dr. E. Picasso, CERN/SPC/444 (31 August 1979)


[7] Test of a 352 MHz Superconducting Cavity in the CERN SPS, Ph. Bernard et al. EPAC: 1st European Particle Accelerator Conference Rome, Italy; 7-11 June 1988
MEMORANDUM

To: Dr. J.B. Adams, Executive Director-General
From: Ph. Bernard, H. Lengeler (EF)
Subject: Tentative programme for studies of superconductivity in view of LEP-applications

1. AIM

Recent studies of large $e^+e^-$ storage rings have shown the interest of a superconducting (SC) acceleration system as regards to both power consumption and achievable maximum particle energy. Unfortunately the present status of R.F.-SC and the technical know-how accumulated hitherto in SC accelerator and R.F. separator projects appears to be an insufficient basis for a large scale application involving many hundred metres of SC accelerator structures. Therefore we consider that the first stage of a programme aiming at a large SC electron storage ring should be a feasibility study.

We propose that such a study should be under-taken at CERN and, in close association with European research centres and universities already working in the field of R.F.-SC.

As a first period for the programme we consider three years, taking into account that a running-in period at CERN of 6-12 months will be necessary. It may not be possible to give in three years time a clear answer on the possibility of a large scale programme and a decision on the continuation of the study should be taken at this moment.

2. ORGANIZATION

We propose as an organization scheme for the activities inside CERN an inter-divisional structure similar to the one of ICE which has made its proof in a very successful way.

We furthermore think that the collaboration with outside laboratories should be coordinated by a CERN physicist. As a coordinator we propose Emilio Picasso. We feel that E. Picasso has already shown a vivid interest in R.F. superconductivity, mainly in connection with the detection of gravitational waves and that he has excellent contacts with some of the outside physicists working in R.F.-superconductivity.

The structure should leave sufficient flexibility to associate as consultants any outside experts willing to contribute full or part-time to this programme.
Figure 2
Comb of resistors
on the cavity surface
Temperature Maps

Fig. 3 Temperature map of cavity. The surface of the cavity body is projected on a plane, temperatures are plotted along the AT axis (a) after $E_{acc} = 1.0$ MV/m, (b) after $E_{acc} = 3.2$ MV/m.

Fig. 4 Temperature map of cavity. The surface of the cavity body is projected on a plane, temperatures are plotted along the AT axis (a) at quench field (b) with a surface damage produced by electron impact but below quench field.
Figure 4

Q values vs accelerating field $E_a$

$10^9$ $10^8$ $10^7$ $10^6$ $10^5$ $10^4$ $10^3$ $10^2$

$Q_0$

$10^8$ $10^9$ $10^10$

$E_a [MV/m]$
Figure 10
Prize-winning photograph, taken at CERN by a German photographer - Peter Ginter. Was he moved by the beauty of the cavity or did he have a premonition about its impending fate?