Manufacturing experience at Ansaldo in large scale production of superconducting cavities for LEP-2 project

P. Gagliardi, V. Sciutto, F. Terzi, G. Zoni

ANSALDO ENERGIA
Magnet & Special Product Division
via N. Lorenzi, 8 - 16152 Genoa - ITALY

Abstract

In 1990 Ansaldo started a very close collaboration with CERN for a technology transfer from laboratory to industry, in the aim of a collaborative development project.

The goal was the transfer of high-tech processes, developed at CERN, for large scale production of superconducting niobium copper sputtered cavities for LEP-2 project.

The necessary transfer of technology has been successfully completed in 1991 and up to now Ansaldo has delivered 80 superconducting cavities assembled in 20 cryomodules.

In this paper we present Ansaldo capabilities in the manufacturing of superconducting cavities, a summary of the development work and the results of LEP cavities production.

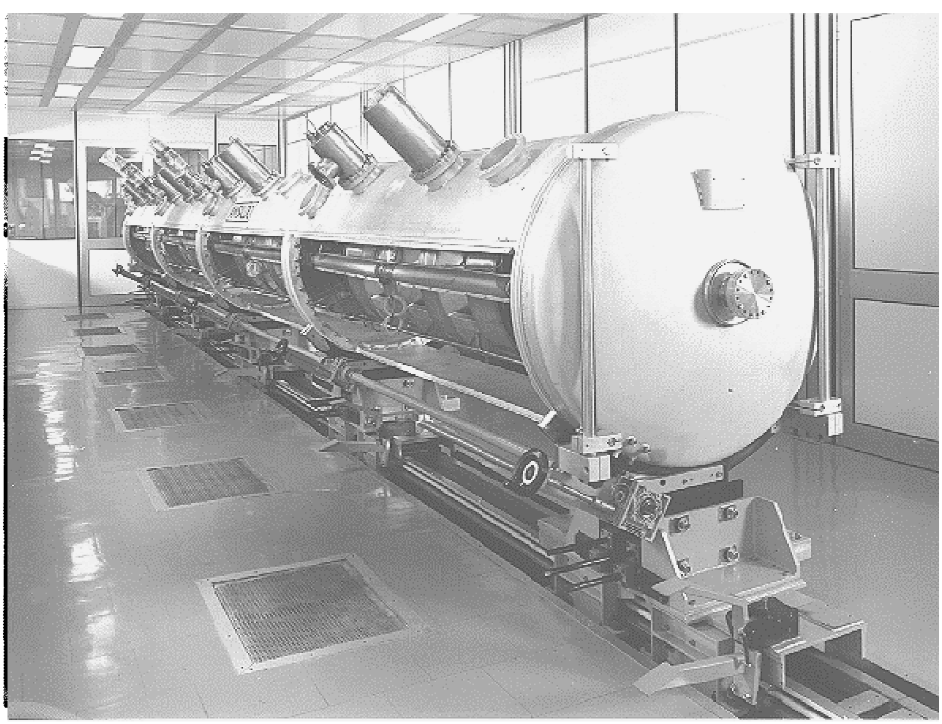

Fig.1 - Assembling of a LEP-2 module in clean-room

1. INTRODUCTION

The LEP-2 programme is the CERN project for energy upgrading of LEP up to about 200 GeV.

At the end of 1990, Ansaldo was involved in the LEP-2 project for the supplying of 52 superconducting cavities + 28 optional cavities fully equipped and assembled in 20 cryomodules of 4 cavities each. [1] [2]

Superconducting LEP cavities are 4-cells Nb/Cu type, 352 MHz of frequency: inner surface of the copper resonator is coated by a Nb film (~1μm of thickness) by using the "magnetron" sputtering technique, developed at CERN. [3] [4]

Before the assembly in a 4-cavities module, each cavity is RF tested (4.5K) at CERN: the acceptance Q_0-value is $3.4{\cdot}10^9$ at the accelerating field E_{acc} = 6 MV/m.

2. SERIES PRODUCTION

2.1. Introduction

For this particular product, Ansaldo installed dedicated equipments and developed special technologies.

The main installations are:

<u>Clean areas</u>

a) cl.100 clean room for the assembly of Nb cathode inside the cavity, water rinsing and drying of the cavity
b) cl.100/1000 clean room 30 m. long for module assembly

<u>Brazing and welding installations</u>

a) electron beam welding machine: two guns 6 KW and 70 KW output power with 90° magnetic deflector for cavity welding from inside
b) vacuum electric furnace for copper / stainless-steel brazing (P=10^{-4} Torr at 1320°C)

<u>Chemical Plants</u>

a) electropolishing plant for components treatment

b) chemical polishing plant for 4-cell treatment
c) water demineralizing 2-level system and ultrapure water plant (ρ=18 MOhm·cm)
d) chromatography system for analysis of chemical bath

Sputtering plant
a) magnetron sputtering plant for Nb film deposition
b) diagnostic device (quadrupole mass spectrometer) and data acquisition system for monitoring of sputtering parameters

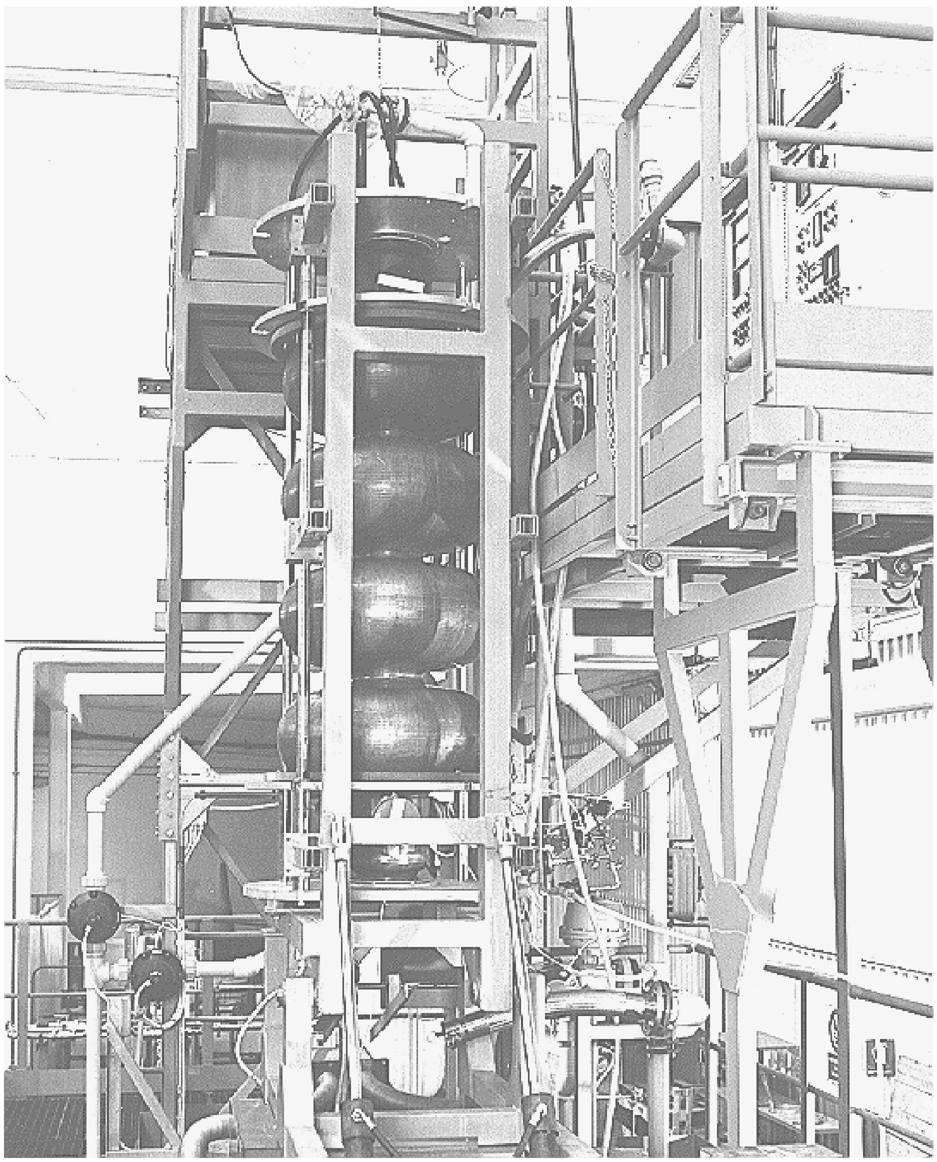

Fig. 2 - Chemical plant for cavity treatment

After a first period of training of Ansaldo staff, through technical meetings at CERN, and a necessary set up of all the installations, Ansaldo started the series production of superconducting LEP cavities.

From the beginning, the surface preparation, before Nb film deposition, seemed to be the critical step of the whole manufacturing process.

During the series production, some problems occurred in the manufacturing processes: they affected the RF performances of the cavities and caused a quite large number of cavities to be recovered, because of low RF performance (a Nb/Cu cavity may be easily recovered by a chemical stripping of the Nb film and a new coating).

Starting from CERN technical specification for electro-polishing (EP) and chemical polishing (CP) of copper, we developed, in collaboration with CERN, special improvements to installations and procedures.

Here below we describe the sequence of the main improvements we adopted during series production.

2.2. First improvements on surface treatment and Nb sputtering procedures

The chemical treatment of copper, according to CERN specification, is a 2 step process:

<u>1st step</u>: EP treatment of single components (half cells and cut-off tubes)

Phosphoric Acid + N-Butanol
3 steps - Tot. removal = 100 μm

<u>2nd step</u>: CP treatment of the whole cavity

Sulfamic Acid + Hydrogen Peroxide + N-Butanol + Ammonium Citrate
2 steps - Tot. removal = 40 μm

During the production we realized that one of the main cause of low RF performance, was a set of defects (inclusions, scratches and holes) on copper surface caused by lamination of Cu sheets and by forming of half cells.

Then it was necessary to increase the total removal of the damaged Cu layer, from 80 μm to 140 μm.

In particular, we set up new parameters for EP treatment in order to obtain the required removal and a slightly satinated shiny surface: this allowed an easier visual inspection to detect any other possible defects to be removed by grinding.

Besides, a second problem that occurred during the series production, was a high rate of cavities to be recovered (about 30%) after the first coating treatment.

The peculiarity was that after a second complete process (chemical treatment + Nb sputtering) or more, we reached good RF performance and an acceptance rate of 90%. That means a complete recovery of a Nb/Cu cavity is possible.

About Nb sputtering, we made a careful control of temperature and a systematic search of any possible cause of contamination by using a residual gas analyzer installed on the pumping system. Besides a UV-ray system was installed on the ultrapure water plant to eliminate any kind of bacterial pollution.

Taking into account the rejection rate for all the series production, CERN technicians realized that the high temperature could change the characteristic of the copper during the thermal treatment: then a reduced temperature for bake-out (from 200°C to 150°C) and for sputtering (from 220°C to 180°C), was applied.

The result was an increasing in the rate of accepted cavities after the first coating.

2.3. Final improvements on the chemical procedure

After the mentioned improvements, we obtained a good quality production over one year: however, after that time, a remarkable number of cavities with low RF performances occurred again.

Then Ansaldo, in close collaboration with CERN, started a careful investigation of any possible cause of contamination of copper surface or niobium film during each step of the production.

A new oil free pumping group and a filtering system for Ar gas were installed on the sputtering plant: a chromatography system was installed for a systematic analysis of the chemical solution and a continuous check of the removal during EP and CP treatments.

At the end of this investigation, we realized that the main causes of low performance cavities could be summarized as follows:

1) the first cause was a possible pollution inside piping and tanks of chemical plant and ultrapure water plant: so we made a very careful cleaning of all the components. In

particular, for the chemical plant, we decided to use a solution containing high concentration of Sulfamic Acid (12.5 g/l).

This mixture was also used, after standard CP, as final treatment of the next cavities: soon good results were obtained.

2) considering these results, we realized that a second cause could be some residual components due to chemical reaction between Hydrogen Peroxide and N-Butanol.

We decided not to use N-Butanol any more: moreover an additional final etching with Sulfamic Acid was systematically performed on all the next cavities.

In fact this treatment may increase the intercrystalline corrosion and then assures a better adhesion of the Nb film to the cavity wall. This can be rightly considered an important characteristic of the substratum, if we consider the different thermal expansion between niobium film and copper surface.

According to this new procedure, we immediately reached good results:

- the acceptance rate increased up to 90%

- RF performances systematically grew up more than 25% with respect to the contractual requirements. The average Q_0-value of the last series of cavities is $4.3{\cdot}10^9$ at 6 MV/m of accelerating field [CERN acceptance value: $Q_0=3.4{\cdot}10^9$ at 6 MV/m]

- the He-processing time (24 hours contractual time) decreased to 7 hours maximum and a large number of cavities did not need to be recovered in Q_0 value.

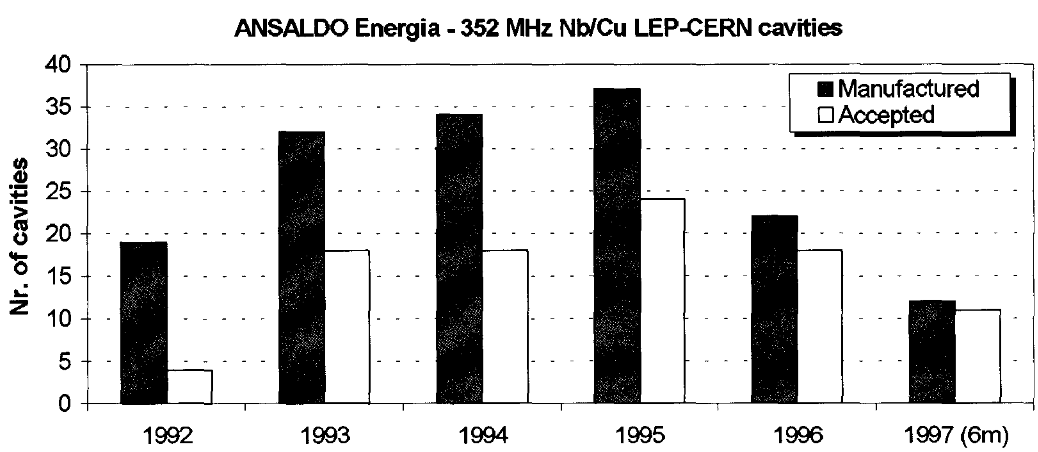

Fig. 3 - Manufactured and accepted cavities during series production

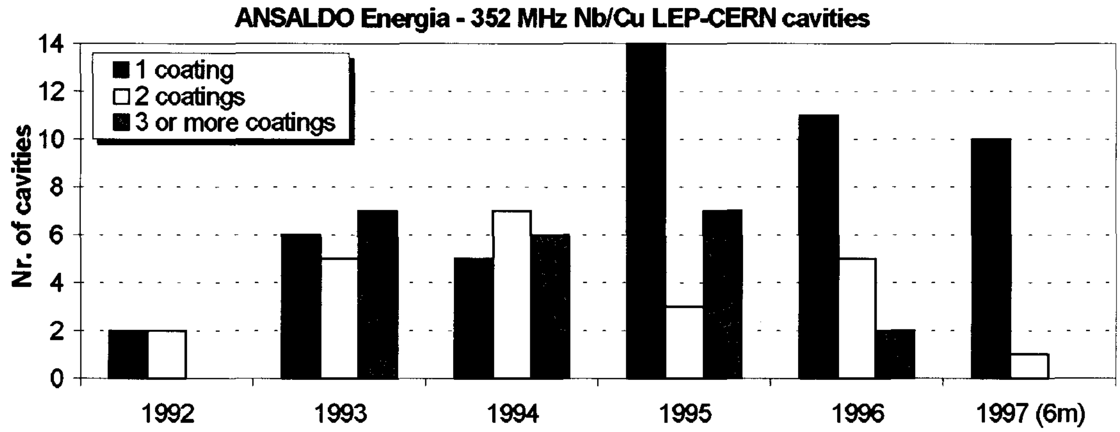

Fig.4 - Acceptance rate for different number of coatings

2.4. Assembly of cryomodules

After CERN acceptance test, LEP cavities are assembled in 4-cavities modules (13 m. long each). All the critical operations - vacuum seal assembly, MC and HOM couplers installing - are performed in a cl. 100/1000 clean room.

However, in particular during the training period, some problems of dust contamination occurred: two cavities had to be recovered by a new coating or by ultra-pure water rinsing. About RF performances, very low degradation was shown between the vertical and the horizontal test. During the last series production (new procedure about chemical treatment) a module recovery needed only few hours of He-processing time.

Ansaldo has delivered to CERN a total number of 20 modules at a production rate of more than 5 modules per year (from June '93 to July '97).

3. CONCLUSIONS

During the large scale production at Ansaldo of superconducting Nb/Cu cavities, some problems occurred.

The main causes can be summarized as follows:

a) defects on copper surface

b) possible pollution of chemical and ultrapure water plants

c) critical composition of chemical solution for Cu treatment

After a complete check of each step of the manufacturing, the following precautions have been taken and all the problems solved:

1) very careful visual inspection of Cu surface, before and after EP treatment

2) optimizing of EP parameters to obtain both the required removal and a satinated surface for a good visual inspection of possible residual defects

3) total removal of 140 μm from Cu surface to remove damaged layers: our experience showed that at least a 40 μm Cu layer must be removed by the 2-step chemical polishing, in order to obtain good performance cavity

4) grinding of surface to remove residual defects, if any

5) systematic inspection of each component of the installations (filters, piping, tanks etc.) to prevent any risk of pollution

6) no N-Butalol should be used in a mixture containing Hydrogen Peroxide

7) after a standard chemical polishing, a final treatment using Sulfamic Acid must be performed to increase the intercrystalline corrosion: this procedure assures a better adhesion of the Nb film to Cu surface.

As we carried out the new procedure, a continuous upgrading of the RF performance and an increasing in the acceptance rate were reached.

During the last period of production, a complete assembly of a module was done in three weeks only.

The technical "know-how" has been successfully transferred from CERN laboratories to Ansaldo.

Now Ansaldo can control each manufacturing process relevant to the production of superconducting Nb/Cu coated cavities.

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