Manufacture at ANSALDO of 350 MHz superconducting cavities for LEP

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Abstract

This paper summarizes the manufacturing method for 52 superconducting cavities developed by ANSALDO and CERN during the transfer of know-how and technology to industry. Of course in this period some improvements have been carried out for adapting the CERN laboratory technology to the requirements of an industrial production. The results of the first cavities produced by Ansaldo are shown.

1. INTRODUCTION

In 1991 a collaboration started between Ansaldo-Genoa (I) and CERN in developing industrial production of niobium coated copper superconducting r.f. cavities for LEP. This development work has been carried out in the aim of LEP energy upgrading up to about 100 GeV: Ansaldo will provide 52 s.c. cavities of 352 MHz frequency, fully equipped with cryostat and rf devices, and assembled in 4-cavity modules. Each cavity is a copper 4-cell structure, with internal surface niobium coated by cylindrical magnetron sputtering procedure, which has been developed for many years at CERN laboratories [1] [2].
Niobium coated copper cavities will provide a Q_0 value of $8.0\ 10^9$ at an accelerating field E_a =0.1 MV/m and Q_0=4.0 10^9 at E_a =6 MV/m.
This product demands high technology methods of manufacture so many efforts have been carried out, as in installing new plants (clean areas, chemical plant, electron beam (EB) welding machine, UHV and sputtering equipments), as for the acquisition of necessary know-how in chemical treatments, EB welding procedure and thin film deposition.

2. MANUFACTURING PLANTS AND INSTALLATIONS

The fabrication of superconducting copper coated cavities requires equipments not usually available in an industrial environment.
Ansaldo prepaired the necessary plants described in the following paragraphs.

2.1 Electron beam welding machine

In cavities manufacturing, electron beam (EB) welding technique is necessary to obtain an inner surface free from inclusions, holes and projections: this is of great importance to guarantee the required tolerances and a very high radiofrequency performance.
The EB welding machine installed in Ansaldo is, at present, one of the largest in Italy and it is equipped with state-of-the-art programming and computer control system.
This equipment is used to weld thin copper, as for the cavities, but also steel up to a thickness of 130 mm in a single pass, carrying out high quality surface.
Main components are:
- vacuum chamber and pumping system;
- automatic piece-holder carriage;
- electron guns with magnetic deflector.

The large stainless-steel vacuum chamber (32 m^3) requires a high speed pumping system, composed by a set of Roots and cryogenic pumps (pumping speed 17000 lt/s), to reach a pressure better than 10^{-4} Torr and to provide hydrocarbon free vacuum.
Two interchangeable guns of 6 KW and 70 KW output power are installed.
The main characteristic, that makes different Ansaldo equipment from conventional EB welding machines, consists in using a fixed horizontal gun (6 KW), in conjunction with a magnetic deflector to deviate the electron beam and weld components from the inside.

2.2 Vacuum electric furnace

Copper tubes and stainless-steel flanges are joined by brazing in a vacuum furnace.
Ansaldo is equipped with a furnace of 280 l of volume, reaching a temperature of 1320 C at 10^{-6} Torr of pressure.

2.3 Chemical plant

Highly polished and cleaned surfaces are required for cavities production.
Ansaldo chemical plant consists of:
- chemical equipment for electropolishing and chemical polishing treatment of niobium and copper surfaces;
- chemical degreasing equipment for stainless steel ultra-high vacuum components;
- water demineralizing 2-level system and ultrapure water plant for final rinsing of niobium coated cavity.

Execution, controls and certification of work cycles are fully computer controlled.
An automatic handling system for component racks, a fumes extraction equipment and an advanced electric control device, give high flexibility and operative security to this chemical plant.
A cromatography system to analyze chemical polishing solutions and to control liquid composition during and at the end of treatments, is also available (Fig. 1).

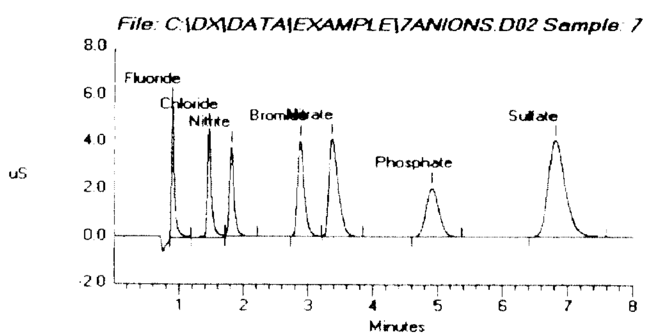

Fig. 1. Example of chemical analysis with cromatography system.

2.4 Clean-areas

In cavity production many operations, as cavity drying, rinsing process, cathode mounting, installation of rf couplers and final cavities assembling in a 4-cavity module, must be carried out in clean-areas to avoid any particles contamination.

Two different sized clean-areas are installed in Ansaldo:
- a clean-area of 55 m^2 working area with class 100 and class 1000 conditioned rooms used for all the operations on the 4-cell cavity (before the assembly in cryostat);
- a clean-area class 1000 (cl. 100 in the operating area), 30 m long, used for the assembly of the module.

Electronic equipments for conditioning system control, provides to maintain thermohygrometric conditions within the following limits:
- temperature = 23 (+/-1) C
- humidity = 55 (+/- 5%)

Dust free air flow is ensured by recirculation units and distributed to the absolute filter pressurization hoods through insulated pipes.

2.5 Coating system

Sputtering procedure allows the coating of internal copper surface of the cavity by deposition of a very thin superconducting niobium film.
A magnetron sputtering system has been developed in Ansaldo on the basis of CERN design.

The main components of sputtering plant are:
- the UHV system used for film deposition by glow argon discharge;
- the UHV diagnostic system composed by a quadrupole spectrometer as residual gas analyser;
- the niobium cathode with magnetron device (set of magnets coaxial to niobium cathode)
- the cathode power supply 800 V/50 A.

Data acquisition is performed by an HP-scanner connected to a personal computer: that allows a continuous monitoring of temperature, pressure, current and voltage values during each different step of the sputtering procedure.

3. MANUFACTURING AND QUALITY PROCEDURE

During the process of adapting CERN laboratory technologies to the requirements of Ansaldo industrial production, some improvements have been carried out.
In the aim of executing quality control tests during each step of the sequence of production and to improve working organization, we decided to mark every components (flanges, half-cells, cavities, cryostat, etc.).
All the components are verified by a numerically controlled equipment.
During each process a check list is compiled: chemical and sputtering procedures are controlled by data acquisition systems.

3.1 Manufacture of half-cells and cut-off tubes

The requirements of high quality surfaces implies many tests and visual inspections to detect any surface defects like scratches, inclusions, holes, etc.
Cut-off tubes are joined to flanges by brazing in a vacuum furnace.
However the main characteristic in cavities production by Ansaldo consists in the development of a new strategy for half-cell manufacturing by deep-drawing instead of conventional spinning procedure.
An hardened stainless-steel drawing die has been successfully used.
Geometrical profiles and tolerances are tested by the use of a numerically controlled equipment.
Computer code has been used to control rf **performances** of half cell during the development of deep-drawing procedure (Fig. 2).
Tests experienced on the first prototypes showed that deep-drawing method guarantees very good reproducibility and repetitiveness of shapes.
For each half-cell, eight different profiles were checked: dimensional variations from nominal values were within 0.5 mm (Fig. 3).

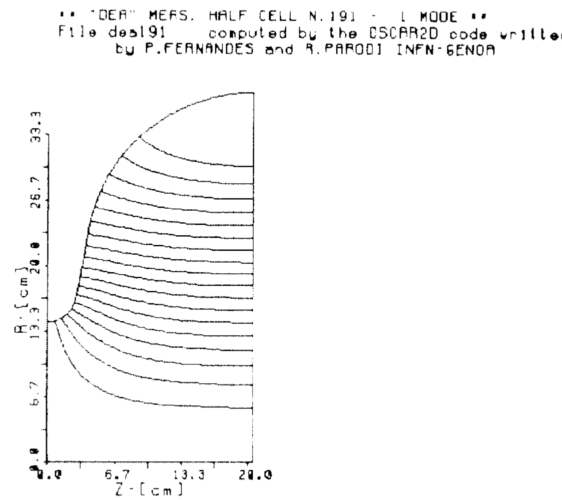

Fig. 2. RF test computed with OSCAR2D code [1]: 352 MHz half-cell measured profile.

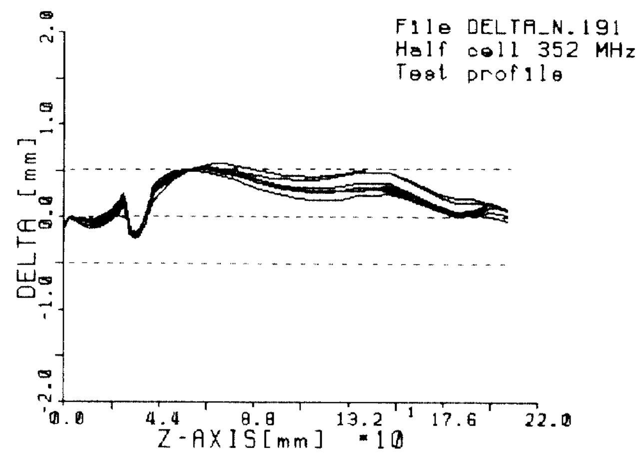

Fig. 3. Example of tolerances control performed on half-cell profile.

3.3 Electropolishing and chemical treatments

Electropolishing treatment is necessary to prepare all the components before welding. A first step of degreasing, with alkaline detergent and ultrasonic agitation, is followed by electropolishing to remove a layer of the inner surface. A mixture of phosforic acid and n-butenol (55%:45%) and a current density of 5 A/dm^2 give good results.

3.4 RF measurements and tuning

Before welding in the 4-cell structure, each single cell must be tested (RF test) to control good reproduction of the theoric shape, which defines the resonant frequency (Fig. 4). This operation provides the necessary correction in welding parameters and in assembling procedure for the purpose of minimizing the following process of tuning of the 4-cell cavity.
A simple jig to deform individual cell and a computer controlled system (HP Spectrum Analyzer) is used to tune the cavity. This process allows to obtain the frequency value within a +/- 50 KHz range: the prescribed field-flatness is also reached and field deviation is less than 5% from the average value.

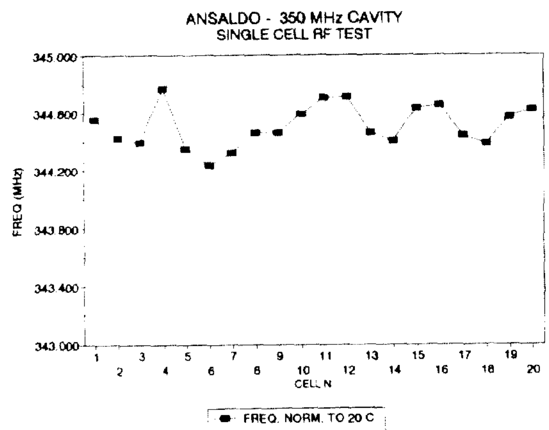

Fig. 4. RF test performed on single cell: frequency values are within about a 0.4 MHz range.

3.5 Coating procedure

The coating procedure developed at CERN laboratories, consists of thin niobium film deposition by magnetron sputtering.
The magnetron system is a set of 10 magnets coaxial with the cavity: the magnetic field provides the necessary plasma condition to obtain a discharge at a pressure of 5.0 10^{-4} Torr of argon in the region of the cells. The main constant voltage power supply works at about 6.4 KW during film deposition.

4. RESULTS AND CONCLUSION

Many experiences in chemical treatments and in sputtering procedure have been carried out.
The deep-drawing procedure showed a large reproducibility and a very high repetitiveness in manufacturing half-cells with the required tolerances.
RF test performed on single cells confirmed the reliability of the procedure: that means a tuning process easier.
Up to now Ansaldo has produced 4 niobium coated cavities, the Q_0-value increasing every time up to about the goal: Q_0 vs E_{acc} for the last cavity tested by CERN at 4.2 K, are presented (Fig. 5) [4].

Now Ansaldo is going to carry out esperiences in the welding of the helium tank and in the assembling of the cryostat. In a following paper Ansaldo will present the results on next cavities and the developments we shall obtain on the assembly of the helium tank, the tuners system and the modules.

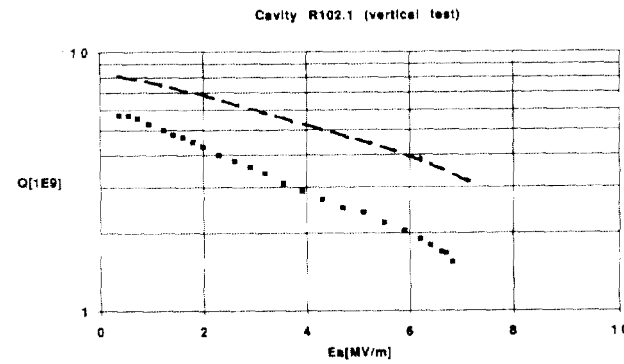

Fig. 5. Q_0 vs E_{acc} at 4.2 K and target value (dot line).

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