RF TESTS OF A FULLY ELECTROFORMED 500 MHz FOUR CELL COPPER CAVITY

D.Romanini
G.Dalmut, A.Laurenti, G.Maragliano, F.Terzi
Ansaldo-ABB Componenti.
Via Nicola Lorenzi 8
16100 Genova
A.Cattoni, C.Pagani, S.Tazzari
INFN-LNF
Via Fermi 40 Frascati
and
R.Parodi,
INFN-GENOVA
Via Dodecaneso 33
16143 Genova Italy

Abstract

The results of rf tests on a four cell copper cavity operating at 500 Mhz, prototype for a superconducting Niobium-Copper accelerator structure, are presented.

The cavity was obtained by electroforming, ie growing by electrodeposition a thick layer of copper on a suitable mould. The mould is subsequently removed leaving the surface of the cavity with a very smooth and regular finish.

This method of production allows for a very careful control of the mechanical tolerances of the accelerating structures. The final shape of the cavity matches perfectly the shape of the mould, as shown by the agreement between the computed and measured E-field distribution on the cavity axis.Data are presented on the mechanical, thermal and electrical properties of the electodeposited copper.

Introduction

In the RD studies of the Superconducting cavities for the ARES project, we tried to state the possibility of using mass production techniques for copper RF accelerating structures alternative to the usual method of metal sheet forming and Electron-Beam Welding (EBW).

For a niobium cavity no better solution of sheet forming and EB-Welding is found, nevertheless for composite Cu-Nb cavities techniques can be foreseen to avoid the reproducibility problems often met in EB-welding and polishing sheet formed cavities.

In fact the EBW procedure can in principle leave some small "Worm Hole" in the welding region, holes that can,after polishing, eventually give some troubles to the sputtered niobium coating.[1]

A further problem coming from the welding is the dimensional change of the welded parts.[2]

In applications like standing wave accelerating structure, operating in the Pi-like mode, those effects will produce , if not properly mastered by a careful design, severe departures from the field flatness of the accelerating field.

Sure this problems can be and finally have been solved [2],but great deal of care and operator skillness are needed and, in case of failure, a lot of costly and labor intensive cures must be used to rescue an out of tolerance cavity.

Aiming to a series production to build an accelerator we looked at some different way of production for a complete copper 500-Mhz four cell structure.

Furthermore, in order to save money, we wanted a method suitable for building, eventually, cavity operating at different frequencies without the need of starting whit an oversized and huge apparatus (as in the case of Hydroforming).

We decided for that reasons of investigating the production of cavities by electrolytic deposition of Copper,because that technique can result inherently in a very good mechanical reproducibility, and keep at a minimum the man power needed for a mass production.

Furthermore this Technique, we known under way, was recently successfully used for production of S/C accelerating cavities.[3]

The electroforming of the cavity by deposition of a thick copper layer on a suitable mould was proven efficient from a mechanical point of view.

In producing the first prototype of cavity we learnt that a lot of attention must be paid to the deposition process of the copper in order to get an homogeneous copper layer having same mechanical and electrical properties of a good OFHC copper.

Manufacturing

It is already well known,in principle, the possibility off producing (by Galvanic Deposition)objects of any reasonable shape (also complex one) starting from a mould reproducing the inner shape of the object.

Nevertheless, to investigate the problems related to thickness variation, copper quality and so on, after some successful test of deposition, we decided to start the production of a full scale prototype of an ARES 500 MHz cavity.

The prototype's shape is shown in Figure 1, with superimposed the E-field lines of the accelerating mode. We used the input data of our EM-field solver OSCAR2D[4] to produce an aluminum mould with the shape of the cavity.

This mould was built by careful machining to he final shape with very tight tolerances on a CNC-lathe aluminum sheets dye formed and welded together.

The mould was electroplated by a thick layer of copper by company specialized in electroplating and electroplating equippements.

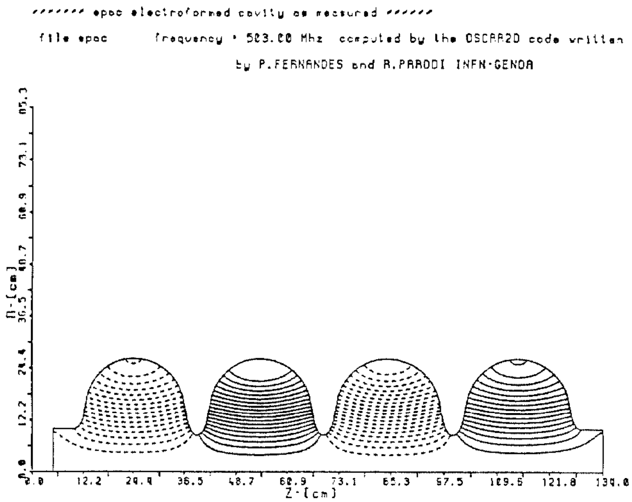

Fig.1-Four cell ARES cavity.

After the deposition the mould was removed by etching the mould in a chemical bath (based on a sodium Hydroxide solution) that leaved the copper completely unaffected.

The inner surface of the copper cavity reproduced in the finer details the mould's outer surface.

Mechanical test on the structure

To ascertain the uniformity of the deposition a series of mechanical measurements was performed to check the thickness of the copper.

Because the inner surface exactly reproduced the mould shape,the difference between the mould dimension and the measured values gives us the thickness of the copper.

The mean value for the thickness at the equator was 5.01mm and 2.15mm at the irises where the deposition of the copper is more difficult.

This distribution of the copper gives a very good stability to the structure giving more thickness to the region more sensitive to the buckling effect and less the stiff region of the irises.

Mechanical properties of the copper

The first check performed on the copper was a complete test of the mechanical characteristics.

To do that we cut at both ends of the cavity 50mm of beam tube to be used for destructive tests.

We measured first the tensile properties; the results for two specimen are reported in TABLE I

TABLE I

Sample number		1	2
yield	(N/mm^2)	305	302
strenght	(N/mm^2)	394	412

The copper shows very good yield and tensile strength.

after we measured the hardness in 7 different points of a longitudinal cross cut of the tube. The mean value of the hardness in HRB units is 150 with a large random fluctuations (50 HRB units peak) claiming for a not so good material homogeneity.

These results are confirmed by an optical inspection of the cross cut that showed a multilayer structure due to a non continuous deposition process and some holes in the bulk dues to a bad removal of the gas during the deposition.

finally high magnification shows a very different orientation of the copper crystallites in the different layers and clear random orientation at the interface layers.

Electrical Characteristics

The electrical properties of the copper gives information about the quality of the material and trough the Lorentz Ratio also about the thermal properties of the copper. for that reason the copper resistivity was measured in the range 300 K-4.2K. At room temperature the resistivity was equal to the one of a good commercial ETP copper.

But improved only of a factor 5.6 at 77 K and 6.6 at 4.2 this value of RRR was found to be in good agreement with the value found for coppers with an high value of gaseous contaminants and a large inhomogeneity in the crystal lattice, as shown by the metallographic analysis

The contaminants were mainly Oxygen, Nitrogen, and Hydrogen, coming from the electrolitic process.

The last electrical check was a complete test of the mechanical tolerances and of the RF behavior of the structure via the measurement of Qo, frequencies and axial field distribution of the modes.

The computed and measured frequencies at room temperature are reported in TABLE II.

TABLE II

MODES	1	2	3	4
	FREQUENCY MHz			
Meas	494.9	496.4	499.6	501.9
Comp	494.5	497.7	501.0	503.0

The measured Qo was 45.000 an the computed one 48.000.

Finally we measured the field distribution of the axial field of the modes by the Slater's Perturbation method [5] by pulling a Dielectric bead along the cavity axis and recording the phase shift of the RF transmitted power as a function of the bead position.

The plot of the measured field for the accelerating mode is shown in Figure-2 superimposed to the computed one.

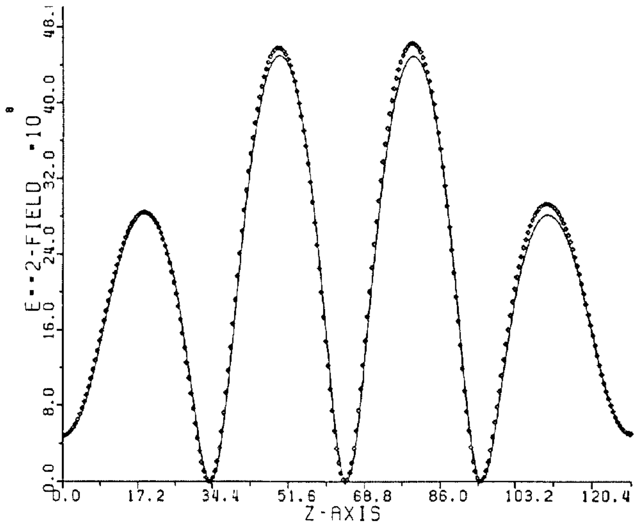

Fig.2-Measured (dot) and computed (line) axial field of the Pi-like accelerating mode.

Discussion

The method of producing a full shape 4-cell cavity operating at 500 MHz seems to be very promising from the point of view of the fulfillment of the mechanic characteristics.

Nevertheless the first attempt was not so successful from the point of view uf the copper quality, due to the gas contamination affecting the thermal an electrical properties of the copper at low temperature.

Also the multilayer structure of the deposition end the gas impurities can be a serious problem in welding and sputtering operations.

Nevertheless from our first trial we learnt a lot about the copper deposition and in a second attempt of depositing a copper tube 250mm in diameter we succeeded (by a thorough specification of the process) to obtain a copper as good for our application as an OFHC certified copper.

The thermal conductivity at low temperature , as measured at the CERN , was a good 670 W/mK and also a test of deposition of niobium (also performed at CERN) by sputtering succeeded to coat the sample by a 1.6 micron layer with a very high sticking coefficient of 45 N/mm^2 .

Conclusions.

The technique of building a 4-Cell cavity by electroforming was successfully tested,

The Mechanical characteristics of the structure was proven satisfactory on the point of view of robustness and reproducibility.

Initial problems with the copper quality (mainly due to a lack of knowledge about how to specifie an electrodeposited copper for our applications) are solved and a well specified sample of copper meeting the quality needed for S/C copper niobium cavities was produced.

The following step will be the production of an electroformed 500 Mhz cavity to be Niobium coated at the ANSALDO-ABB works in Genoa.

Acknowledgments

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