PROGRESS REPORT ON SC CAVITIES FOR ARES

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Abstract

The ARES Superconducting Linac[1], designed for very low emittance electron beams, asks for the development of 500 MHz multicell cavities able to hold an accelerating field of 10 MV/m @ $Q_0 = 3 \cdot 10^9$. A R&D program has been started, collaborating with a few Italian industries, to get these results. Different production technologies have been investigated for bulk Nb and Cu cavities, while a parallel research program on sputtered films of Nb, its alloys and compounds is under way.

Introduction

In the framework of the ARES program[1] a R&D activity on superconducting cavities has been started. This program includes technology developments and investigations on superconducting properties of bulk and thin film materials, related to their application to RF cavities.

At present our program concerns the fabrication of prototypes of single and multicell 500 MHz SC cavities, using either bulk niobium or Nb coated copper.

Bulk niobium cavities.

Fabrication of four-cell bulk niobium superconducting cavities is in progress, in the context of a collaboration with the Italian industry. The process under development is based on:

- deep drawing of the half cells,
- EB welding from inside with a 90° deflected beam,
- electropolishing of the cavity,
- final firing in a vacuum furnace at 700 °C.

The aim of this program, whose completion is expected by the end of this year, is to realize one prototype of a 500 MHz 4-cell cavity, complete with couplers and cryostat.

Fabrication procedures

As mentioned elsewhere[1], the technology used for cavity fabrication has some influence on the nominal cavity dimensions. Moreover the achievable mechanical tolerance and reproducibility, also dependent on the fabrication technique, are essential for the quality of the SC cavity.

To get some insight on the problem of tolerances let us make some general considerations.

In our type of cavity the resonant mode used for acceleration is the $TM_{010\text{-}\pi}$, in which the accelerating field in two adjacent cells has the same amplitude but opposite sign. To have this mode at the nominal frequency, with almost the same field amplitude inside each cell (field flatness of few per cent), each cell - with its real boundary conditions determined by the adjacent cells and the cut-off tubes - must resonate at exactly the same, desired frequency. The sensitivity is of few kHz per percent of field flatness.

From a purely mechanical point of view this means that the shape of each cell should be identical to the ideal one to the order of a few hundredths of a millimetre; in practice however the resonant frequency is an integral property of the cell volume. The way the resonant frequency depends on the cell geometry can be better understood by looking at Fig. 1 that shows the sensitivity curves (for the $TM_{010\text{-}\pi}$ mode) for a 500 MHz half cell, scaled from the LEP design. The sensitivity is expressed as the frequency variation, in kHz, for a change of one cm^2 in the area of the cell equatorial cross section[2].

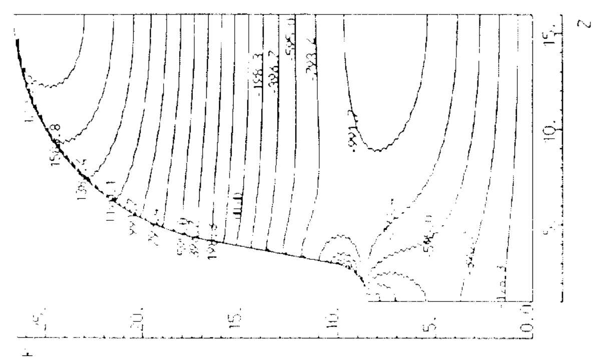

Fig. 1 - Sensitivity curves (for the $TM_{010\text{-}\pi}$ mode) for a 500 MHz half cell. The sensitivity is expressed as the frequency variation, in kHz, for a change of one cm^2 in the area of the cell axial cross section. All dimensions are in cm.

It can be seen that :

- standard mechanical tolerances are at least one order of magnitude too large: the sensitivity on the value of the equatorial diameter is of the order of 1MHz per millimetre when a frequency accuracy of less than ≈ 1 kHz is desired;
- using the degree of freedom afforded by the axial position of the actual profile, a volume compensation is possible, with respect to the $TM_{010\text{-}\pi}$ accelerating mode, which gives a good equivalence, between the real translated geometry and the theoretical one.

A technique to manufacture cells that are identical from the electromagnetic point of view, in spite of mechanical tolerances, has therefore been implemented in collaboration with the ANSALDO firm. It consists essentially in measuring the profile of each half cell and then cutting it so that an equivalent shift of the cell profile in the axial direction - and a consequent electromagnetic compensation, according to the concept of volume equivalence mentioned above - are produced.

This technique has been successfully tested on a number of Cu and Nb half cells, produced by spinning. As a further improvement, it has been decided, for the ARES cavities, to change the fabrication technology, from spinning to deep-drawing. The reason is mainly that deep-drawing is intrinsically more reproducible, so that the need for costly compensation procedures is drastically reduced. Moreover, because cells obtained by deep drawing and electron beam welding, once tuned to the proper frequency, are mechanically almost identical to each other, the actual field distribution of higher order modes (HOM) is much better known and HOM couplers can be rendered much more efficient. A comparison of the results obtained at KEK[3] , where deep-drawing is used, with those of

DESY[4] and CERN[5] , where half-cells are spinned, confirms that our choice can be advantageous. The major modifications with respect to the CERN scaled cavity are the shape of the cut-off tubes, the position and dimension of the coupling ports and, finally, the cell diameter. As discussed elsewhere[1], each modification has a rationale dictated by experience or suggested by the specific ARES parameters.

The deep drawing of the half cell has been selected after some attempts with the late spinning process, because of the higher reproducibility.

Chemistry

With respect to the necessary chemical etching of the Niobium surface - after the forming and welding processes - we adopted the electrochemical etching (EP), mainly because of the Italian safety rules on waste disposal do not allow to handle the required quantity of the HF HNO_3 H_3PO_4 mixture used for the chemical polishing (CP) of multicell cavities.

The chemical plant has been set-up at ANSALDO and some single cell Nb cavities have been etched with the standard H_2SO_4 HF mixture in order to investigate the effect of hydrogen contamination on the niobium.

In particular, because of the easier handling, we realized four C-band single cell cavities made of Nb sheet. These cavities were exposed to a very high flow of hydrogen ions in an electrolytic cell and their Q_0 was measured as a function of the increasing H^+ dose.

After that shock treatment, resulting in Q_0 values as low as 10^6, the cavities were fired, at different temperatures, in a UHV furnace and measured again to recover the high Q_0. In that way we succeeded to get an improvement of three orders of magnitude for the residual losses, recovering highly contaminated cavities.

We also investigated the effectiveness of the heat treatment in reaching high accelerating fields. After firing, the C-band cavities were able to hold fields up to 20 MV/m without any conditioning, the ultimate limit being set by the equatorial weld.

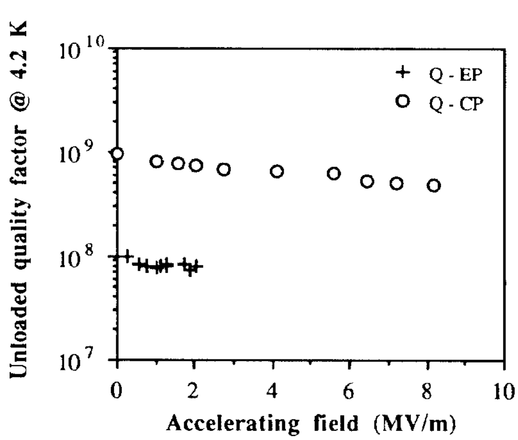

Fig. 2 - Q_0 vs accelerating field for two 500 MHz single cell Nb cavities (see text for details).

Two single cell, 500 MHz, Nb cavities have been also realized by spinning and EB welding from inside. One was CP (courtesy of CERN), and the second was EP. The result of the Q_0 vs E_{acc} is shown in Fig. 2. The data reported were measured in the actual vertical cryostat which is not provided of magnetic shielding. The field achieved in the EP cavity was power limited.

The very different behaviour between these two cavities reproduces the results obtained at KEK, thus indicating the presence of Hydrogen contamination during the EP. Work is now in progress to perform a vacuum furnace treatment, with a titanium box, in order to improve the quality factor of the EP cavity.

Copper coated cavities

Following the CERN experience, we also started to develop the sputtering technique to coat copper cavities with superconducting materials. The underlying idea[6,7] is that the RF electromagnetic fields do not penetrate within the bulk material, thus the use of a superconducting thin film deposited on a copper cavity should realize a superconducting cavity having the good thermal conductivity of copper. Moreover this line opens the possibility to apply different superconducting materials, having in principle better performances than pure niobium.

In the context of the collaboration with the Italian industry mentioned above, work is in progress to realize, both at ANSALDO and at Europa Metalli-LMI, a facility to sputter Nb on copper multicell cavity.

The system adopted is the same developed at CERN, i.e. magnetron sputtering from a coaxial Nb tube placed into the cavity.

Meanwhile the necessary equipment both to weld the cavities from the inside and to prepare the copper surface for Nb coating have been acquired.

The first single cell cavities will be sputtered in the next few months and we expect to be able to test the first prototype of a multicell cavity, according to the ARES design, during February 1991. The mechanical procedure to fabricate the copper cavity is identical to that used for the bulk niobium, except for the parameters chosen to set the deep drawing and EB welding machines.

Moreover Europa Metalli-LMI is developing the technology of hydroforming copper cells and several 500 MHz single cell cavities have been realized successfully, without any equatorial welding, using ETP copper. Attempt to realize by hydroforming 500 MHz and 350 MHz cells with Cu OFHC is now in progress.

Work in progress on thin film superconductors

The application of superconducting cavities to TeV colliders, requiring high accelerating fields, suggest the use of superconductors having a higher critical temperature, T_c, and a higher critical magnetic field, B_c, with respect to those of niobium. We have therefore also started an activity - in the context of a collaboration with CERN and a number of Italian groups operating in different laboratories and Universities - to develop alternative superconductors.

At present, we have obtained at the Frascati Laboratory (LNF) several superconducting thin films, using an equipment based on the Leybold L 560 thin film fabrication plant, equipped with a 3" Nb cathode. Although the system allows for both RF and DC magnetron sputtering, we normally use the last one, because of the better results obtained at CERN in the SC cavity production[7].

The pumping system allows to reach a final pressure of $\approx 10^{-7}$ mbar in few hours. All samples have been deposited through a steel mask to get a linear strip - either on Corning 7059 glass or on sapphire substrate - without any substrate heater. Film growth is monitored using a quartz thickness monitor (Inficon XTC) and measured with a profilometer (Alpha Step 200). Fig. 3 shows a typical resistivity vs temperature curve for the Nb thin films deposited at LNF. The measured transition temperature is 9.18 K, for RRR > 9. This RRR value is obtained without heating the substrate during the deposition, which rate is > 10 Å/s. The Nb properties have also been studied from the point of view of critical field, as reported elsewhere[8].

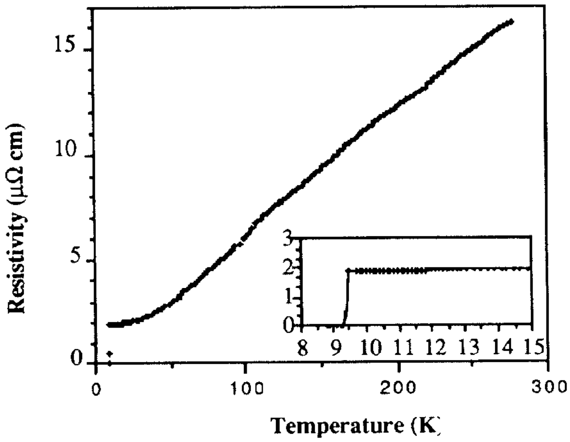

Fig. 3 - Typical resistivity vs temperature curve for the Nb thin films deposited at LNF. The transition region is magnified in the inset.

The measured residual resistivity of 2 μΩ cm, together with a $T_c \approx 9.2$ K gives a theoretical BCS value of $R_s \approx 64$ nΩ for the surface resistance @ 4.2 K, which corresponds to a $Q_0 > 4 \cdot 10^9$.

We have also started to investigate the potential application of different superconducting materials. The first one was the NbN compound, obtained by reactive sputtering. Several samples have been sputtered to get the right superconducting phase, the process being performed without heating the substrate, that is in a condition similar to that required for SC cavities production.

In Fig.4 the typical resistive behaviour of the NbN samples is reported . Nevertheless, in spite of the high T_c, quite high residual resistance was found, due to the granularity of the superconductor[9]. The behaviour of the critical temperature in the presence of high magnetic field is also reported in the inset of Fig. 4. We note that the measured critical field at 9.0 K was as high as 4 Tesla.

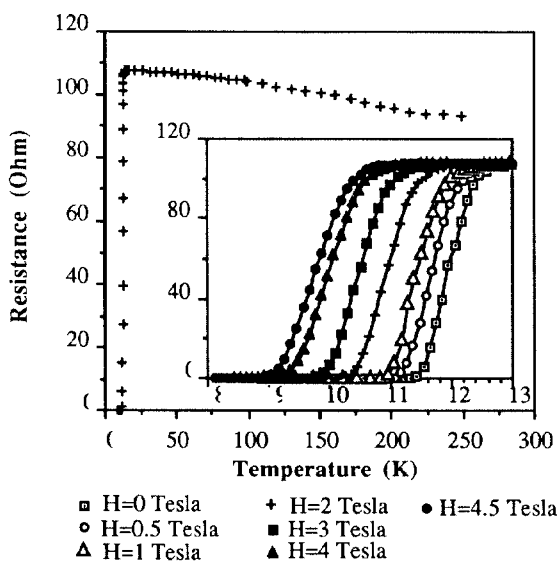

Fig. 4 - Resistive behaviour of NbN films. The inset shows the magnified transition temperature in the presence of a parallel magnetic field.

Further investigation are in progress on Nb alloys, following the suggestions of different authors[10]. Our attention is now devoted to NbZr, whose reported critical temperature is ≈10.5 K. We produced several samples of Nb(75%)Zr(25%) thin films by sputtering. The samples were very reproducible, showing the same T_c and resistivity for a wide range of sputtering parameters. Moreover we get a better metallic behaviour if compared with NbN films. As showed in Fig.5 the critical temperature was higher than 10 K.

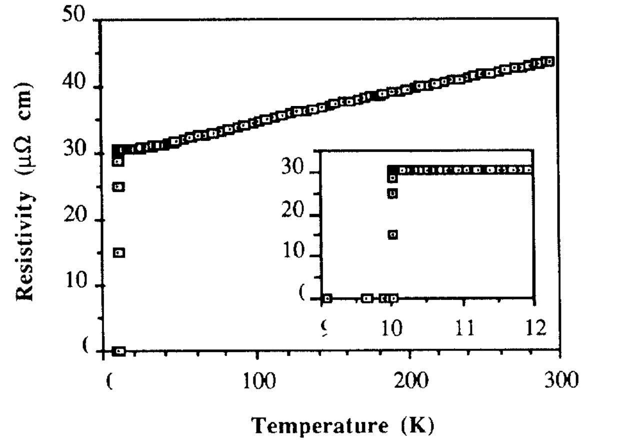

Fig. 5 - Resistivity Vs temperature for a NbZr thin film; the inset shows the magnified transition region.

At present the expected BCS surface resistance at LHe temperature is ≈128 nΩ, which leads to a $Q_0 > 2 \cdot 10^9$. The NbZr film has been also investigated from the point of view of its behaviour in a magnetic field. The experimental results show a critical field higher than that of Nb.

Conclusion

The preliminary work presented has to be considered as the starting point of the R&D needed for the ARES project. As mentioned above, we expect to have the first results on multicell cavities, in bulk Nb and sputtered, at the end of this year. At that time a facility to test multicell cavities will be completed, including the diagnostics, in the new technological area built in the context of the LISA project.

References

[1] The ARES Superconducting LINAC, C. Pagani, S. Tazzari Eds, Rep. LNF-90/035(R), Frascati, May 1990.

[2] L.Serafini, S.Gustafsson, C.Pagani, Proc. 11th Int. Conf. on Cyclotrons and Their Appl., Tokyo, October 1986, Ionics Pub., Tokyo, 370 (1987).

[3] T.Tajima, T.Furuya, T.Suzuki and Y.Iino, "Pre-tuning of TRISTAN Superconducting RF Cavities", Proc. 4th Workshop on RF Soperconduc., KEK, Japan, August 1989.

[4] B.Dwersteg et al. "Superconducting Cavities for HERA", Proc. 3rd Workshop on RF Superconductivity, ANL, Argonne, Illinois, September 1987.

[5] Ph.Bernard et al., "Superconducting RF Cavities for LEP", Proc. 1st European Particle Acc. Conf., Rome, Italy, June 1988.

[6] C. Benvenuti, N. Cirelli, M. Hauer, W. Weingarten, "Superconducting 500 MHz accelerating copper cavities sputter coated with Niobium films", Proc. 2nd Workshop on RF Superconductivity, H. Lengeler Ed., Geneva, July 23-27, 1984

[7] C. Benvenuti, D. Bloess, E. Chiaveri, N. Hilleret, M. Minestrini, W. Weingarten, "Preparation of Niobium coated Copper superconducting RF cavities for the Large Electron Positron collider", Proc. 1st EPAC Conf., Rome 7-11, 1988, Ed. World Scientific.

[8] D. Di Gioacchino, U. Gambardella, P. Gislon, G. Paterno', C. Vaccarezza, INFN report LNF 89/064 (R), (1989)

[9] R. Parodi, et al., Journal of Ap. Physics, December 1989.

[10] R. di Leo, A. Nigro, G. Nobile, R. Vaglio, "Niobium-Titanium Nitrade thin films for superconducting RF accelerating cavities", to appear in Journal of Low Temperature Physics