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# RF CHARACTERIZATION OF SMALL SCALE CAVITIES

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The RF characterization of samples is an useful diagnostic tool to accurately investigate local properties of superconducting materials. However the most common limitation of systems used for this, consists often in the difficulty of scaling the measured results to the real resonator. The most direct way for measuring material RF properties would be the use of micro-cavities completely equal in shape to the real scale model. Using the spinning technique, it becomes feasible to produce small scale resonators in little time, negligible cost and in large quantity. Therefore we provided 6 GHz cavities and developed a suitable RF test "plug and measure" bench. The emphasis is placed on the cryogenic and RF facilities as well as the first results obtained on bulk niobium spun cavities.

*Keywords:* Superconductivity; Radiofrequency; Cavities; Surface impedance

## 1 INTRODUCTION

Niobium is largely used in superconducting particle accelerators as metal sheet in the Jefferson Laboratory 1.5 GHz linear accelerator, in 1.3 GHz cavities tested at T.T.F.[1] (Tesla Test Facility) for the Tesla project or as a sputtered film on a copper substrate in the LEP2 collider at CERN... etc. Pushing forward the performances of high gradient accelerating cavities requires in addition to the high care in the production process, a better knowledge of surface superconductivity and

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numerous tests on samples to study the involved parameters. Many advantages of a direct method account for the choice of using a small scale cavity as a sample and this paper intends to show the feasibility. To be a valuable method for niobium characterization, we would like to achieve a residual surface resistance in the nano-ohm range.

## 2 EXPERIMENTAL SET-UP

### 2.1 Geometry: Advantages and Drawbacks

Six GHz cavities have a 115 mm total length and a 45 mm diameter cell (Figure 1): they are therefore light and easy to handle; they can be fastly substituted and cooled down directly by immersion in a Dewar of Helium. As a comparison, let us consider the triaxial cavity[1,2] in which the sample to study is part of the wall of a complex resonant cavity. The size and position of the sample are critical since its center should be in an intense field zone to maximize sensitivity, whereas its edges should see nearly zero field to minimize losses at the seal. Hence it would require a fine tuning of the cavity and very fine mechanical tolerances, high cure when mounting the sample avoiding contamination since the cavity contribution is supposed to be known. This is also valid for the pill box cavity excited on the TE011 mode.[3] An over-heating might cause irreversible deformation and destroy the host cavity itself. The losses on the flange must be calibrated. However the evaluation of these resistive losses remains difficult as they are statistical and thermal measurements are critical. With the whole cavity as a sample, we do not encounter these drawbacks; furthermore, the cylindrical symmetry of our cavity is in favour of minor multipactoring.

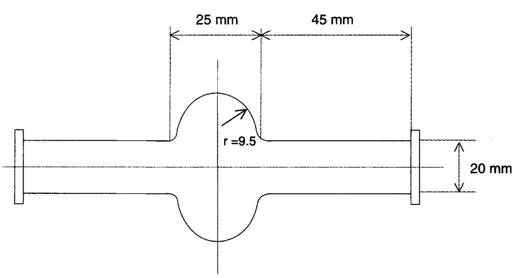


FIGURE 1 An RF cavity. Geometrical factor (superfish program) $G = 295\,\Omega$.

However indirect the losses' evaluation is, flat samples are suitable for further surface analysis or for special crystal film growth. Since it was possible to spin a 0.3 mm thick niobium sheet, it opens the possibility to study a multilayer cavity (e.g.: Nb/Cu). The geometry of our samples scales the accelerating cavities and simulates the effects of material stresses.

## 2.2 Cryogenic Infrastructure

The cryogenic power consumption is also significantly reduced, avoiding any loss during a transfer into a cryostat: One measurement at 4.2 K requires roughly 30 l of liquid helium. We could achieve 2 K by pumping directly over the bath, consuming another 70 l to complete the measurements at low temperature. We could benefit from the same pumping equipment used for 1.5 GHz cavity tests. The insert was designed on the dimensions of a 450 or 250 l Dewar. As it must enter the Dewar's neck, it is very compact: On the cylindrical top part, the insulation with external environment is realized by successive thermal screens, letting pass through the two RF cables, a thermal probe, one translating axis, which is forseen for future moving input coupler.

The cavity is closed by two stainless steel flanges (Figure 2), on which are welded the RF SMA connectors. A 1.2 mm diameter indium wire is squeezed between a packing groove carved on the flange and the cavity flat border with two stainless steel half moons, screwed on the flange.

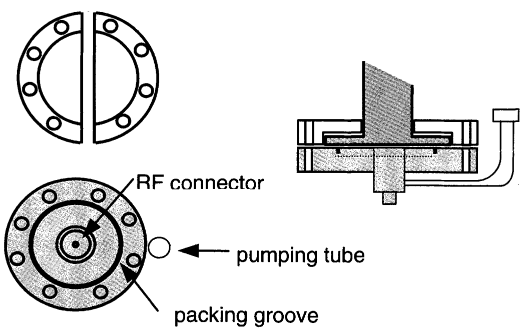


FIGURE 2 Cavity closing.

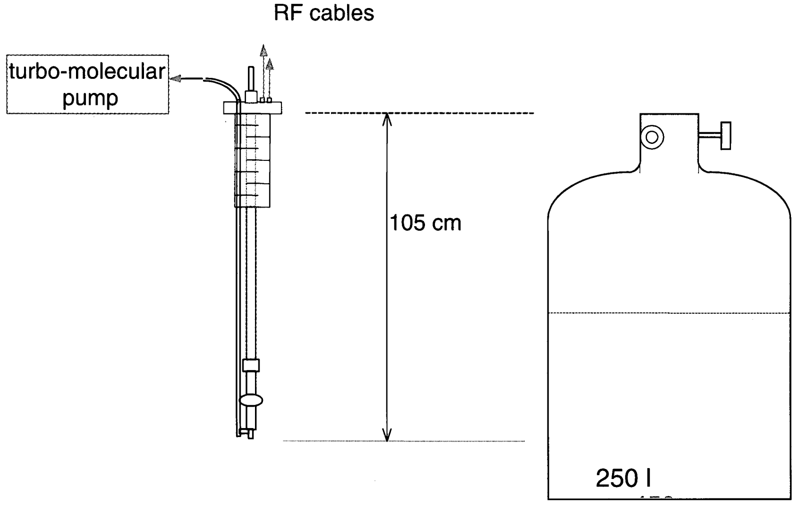


FIGURE 3 Insert.

A 5 mm diameter pumping tube is welded from one side on the pick-up RF connector and is mounted at the other side by a Swagelock assembly. One external valve keeps under vacuum a tomback, linking the insert (Figure 3) to the turbo-molecular pump.

### 2.3 RF Measuring Bench

We could benefit from instruments we already had for 160 MHz quarter wave resonator test and 1.5 GHz cavity test, inserting a new phase lock loop and a power amplifier running at 6 GHz. The same generator, frequency-meter, directional couplers, power dividers, power measurement heads could be used. Most of instruments are computer controlled. The RF test bench is also very compact (cf. the scheme in Annexe I). Very few modifications in the program were necessary to carry out tests at this new frequency.

## 3 FIRST RESULTS

Three cavities K1, K2, K3 were spun on an aluminium mandrel, dissolved later on in a sodium hydroxide solution. Their preparation is

TABLE I Samples preparation

| *Name* | *Wall thickness* | *Chemistry* | *Heat treatment* | *Remarks* |
|---|---|---|---|---|
| K1 | 2 mm | 1 : 1 : 1 | 10′ | $H_{earth}$ not screened |
| K1_b | | 1 : 1 : 1 | 10′ + 30′ | $H_{earth}$ not screened |
| K1_c | | 1 : 1 : 1 | 10′ + 30′ | $H_{earth}$ screened |
| K2 | 3 mm | 1 : 1 : 1 | | — |
| K3 | 2 mm | 1 : 1 : 2 | | — |

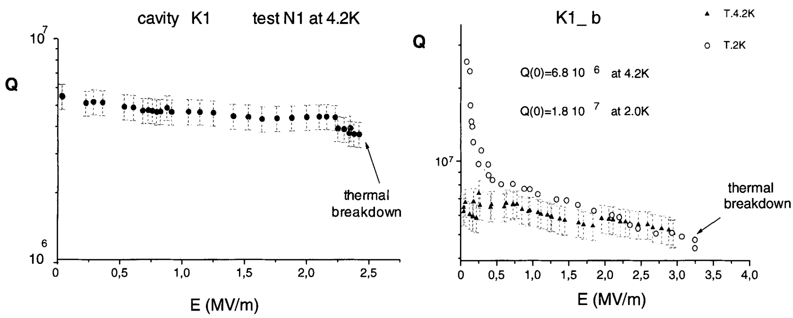


FIGURE 4 First two results on cavity K1 without earth magnetic field shielding.

summarized in Table I. Niobium chemical treatment is the common $HNO_3$, $H_2PO_4$, HF mixture. The RF measurements have been performed without screening the earth's magnetic field (Figure 4). In a screened area, we expect the BCS surface resistance as the residual surface resistance to be proportional to the frequency square, hence a quality factor around $3.5 \times 10^7$ at 4.2 K whereas the expected value at the lowest temperatures is $2 \times 10^9$.

In order to avoid parasitic dissipation, due to fluxons trapped during cooling down in the presence of the terestrial magnetic field, it was made into a cylinder of $\mu$-metal (CONETIC AA), 77 mm diameter and 500 mm high. It was necessary to heat treat it at 1121°C/3 h to recover its magnetic properties: After this treatment, the maximum residual field measured in the cavity axis $B_{\|}$ and in the orthogonal plane $B_{\perp}$ is:

$$B_{\|} = 0.3\,\mu\mathrm{T} \pm 0.1\,\mu\mathrm{T},$$
$$B_{\perp} = 0.0\,\mu\mathrm{T} \pm 0.1\,\mu T,$$

at the cavity cell's height and still 200 mm above the cell.

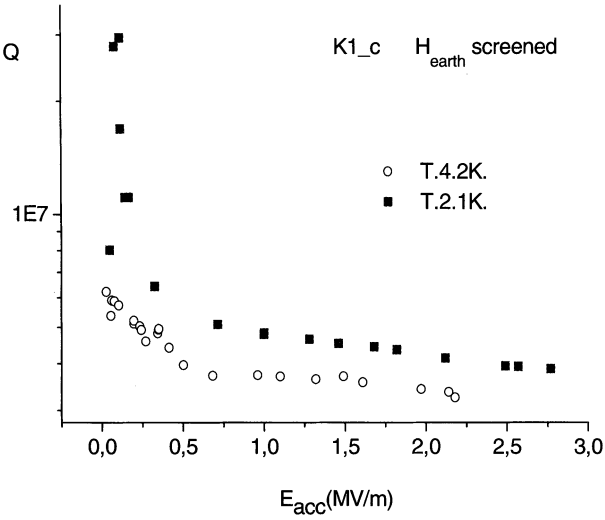


FIGURE 5 Temperature dependence in screened case.

The screen hangs on the insert by four stainless steel wires.

The same cavity K1 remained under vacuum and was tested again with the screen around (Figure 5): The surface resistance did not show any change under better environmental conditions.

The residual surface resistance is not dominated by the trapped earth field fluxons. After 2.5 MV/m a real thermal quench was not observed but rather thermal instabilities at the maximum available power (14 W input). Actually the reflected power started to rise and limited the presicion with the coupling we had.

A next step is a thermal treatment under vacuum, using a titanium network as a getter material in order to reduce significantly the residual surface resistance.

## 4 CONCLUSION

We proved this can be a suitable tool to investigate material properties with a wider sensitivity, once a low surface resistance can be obtained. Many kinds of surface treatment can be studied, from the point of view of surface resistance modifications. It also allows to investigate other materials such as $Nb_3Sn$, NbTiN or multilayered materials.

## *References*


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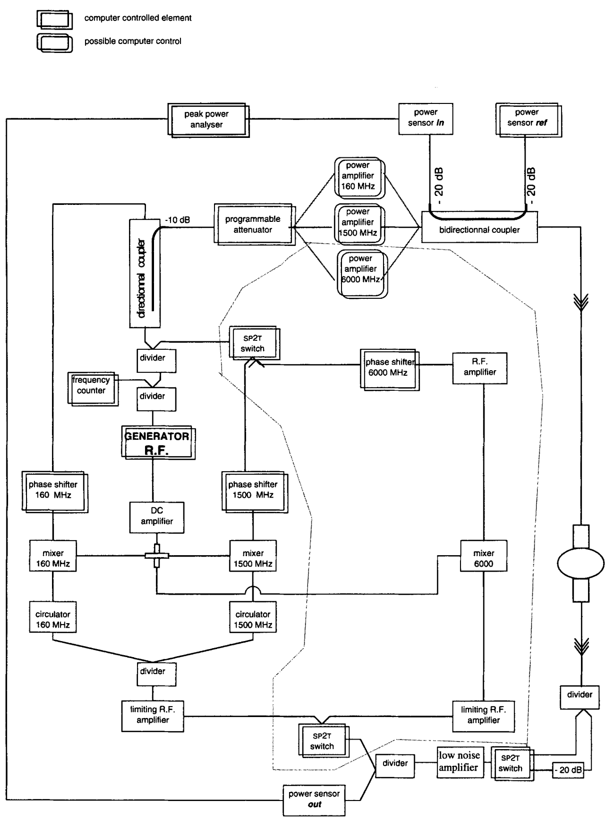
## ANNEXE I




SCHEME 1 RF test bench.