RRR MAPPING OF SRF CAVITIES BY A MAGNETOMETRIC METHOD

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ABSTRACT

We propose, here, a non destructive method for measuring the electrical conductivity of niobium superconducting cavities. This RRR measurement is made by a movable arm's sensors which cover all the cavity. Each sensor is a set of two coupled inductances powered by an electromagnetic sinewave. We access to the fluctuations of the RRR by measuring the mutual inductance variations. The process of datas is made by the LABVIEW SYSTEM, and we obtain RRR map of SRF cavities.

1. INTRODUCTION

Niobium purity is a major issue for the technology of superconducting cavities. A clear correlation between cavity performance and material purity has been established (ref.1). In this context, tools enabling the caracterization of this purity are especially useful. So far, the most convenient criterion for the evaluation of niobium purity is the residual resistance ratio (RRR) defined as RRR = ρ_{300K} / ρ_{4K}. The room temperature resistivity of niobium is a constant ($\rho_{300K} = 1.45\ 10^{-7} \Omega.m$) and the residual resistivity ρ_{4K} depends primarily of the material purity and, to a lesser extent, of its cristalline state (ref.2). In practice, for niobium, the low temperature resistivity is not measured at 4K, but at 10K, in order to avoid the onset of superconductivity. ρ_{10K} is not very different from ρ_{4K}, and appropriate corrections can be applied to deduce the true RRR from ρ_{10K}.

Usually, the Niobium RRR is measured by " 4 wires " resistivity measurements from elongated metal strips at cryogenic temperature. This very widely used technique has two severe drawbacks : it's non local, since the measured quantity is the resistance averaged over the sample length (typically 5 to 10 cm). Moreover, it's destructive, since the measured strip has to be cut out from the bulk. This practically precludes the application of the method to build cavities, even though RRR measurements on finished accelerator structures would be most valuable.
In order to cure these shortcomings, we developed a new method for measuring the RRR value of Niobium, using low frequency induction.

2. PRINCIPLE OF MEASUREMENT

The mutual inductance of pair of coils can be modified by the presence of a neighbouring piece of metal. The modification's magnitude depends upon the geometry's details and metal conductivity.
In the present case, the pair of coils is placed close to the Niobium surface (Fig .1)

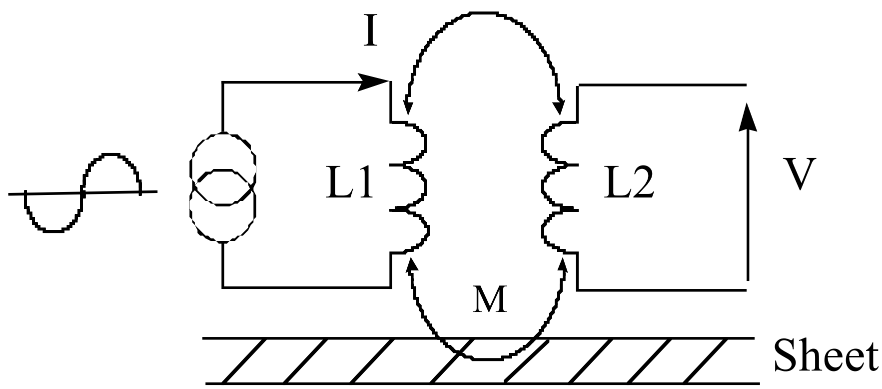

Fig.1 Electrical set-up

A known AC current is injected in the primary coil. The AC voltage V induced in the secondary coil is measured. In order to minimize systematic errors, V is measured both with the Niobium sheet in the normal conducting state at 10K (V_{10k}) and in the superconducting state (V_s). The measurement in the superconducting state (V_s) being used as reference, the ratio V_{10k} / V_s is plotted as a function of frequency (Fig.2)

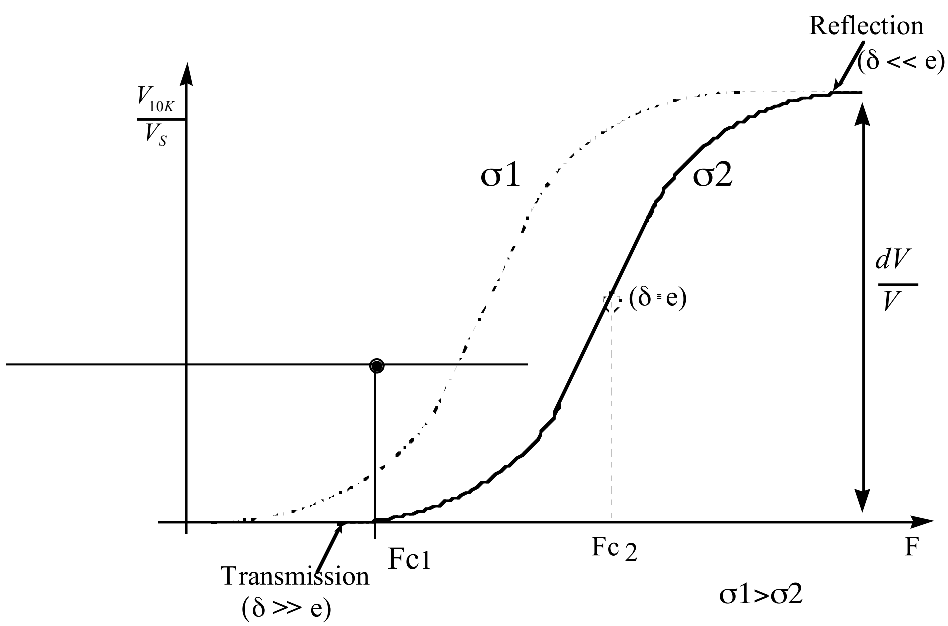

Fig. 2 Plot of ratio V $_{10k}$ / V_S versus frequency (F in log scale).

In the normal conducting state, the eddy currents induced in the Niobium sheet circulate on a skin depth :

$$\delta = \sqrt{\frac{2}{\mu_0 \sigma \omega}} \qquad \text{(eq.1)}$$

for $\delta \cong e$, we define a characteristic frequency :

$$F_c = \frac{1}{\pi \mu_0 e^2 \sigma} \qquad \text{(eq.2)}$$

In the superconducting state, the currents circulate in the negligibly small superconducting penetration depth λ . The ratio V_{10}/V_s thus approaches 1 for relative high frequencies, and tends to a constant value for very low frequencies.In this latter case, the skin depth becomes larger than the niobium sheet thickness, and the sheet becomes transparent to the AC electromagnetic field (fig.3).

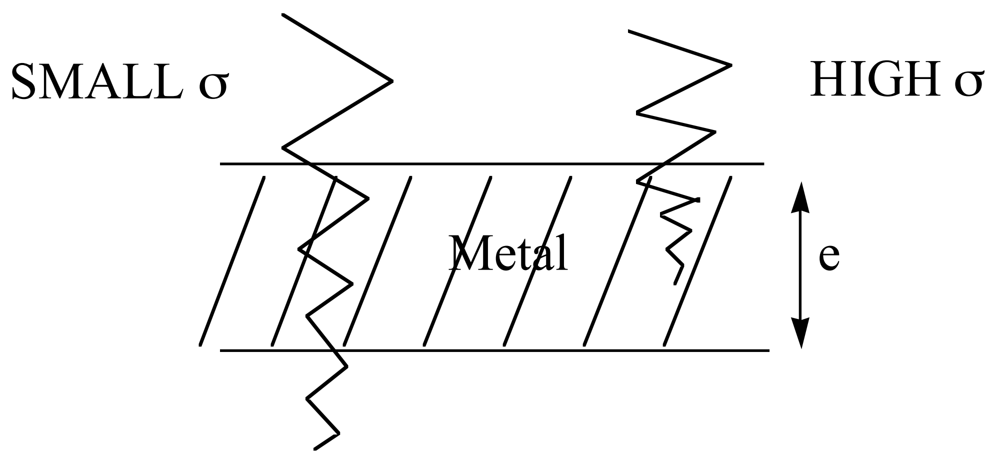

Fig.3 Depth penetration δ of a sine wave with conductivity in a metal sheet

Between these two extreme limits, the curve V_{10K} / V_S f(F) (fig.2) has an inflexion point for a frequency Fc such that the skin depth δ approaches the sheet thickness **e**. For a given coil geometry and sheet thickness, the curve V_{10k} / V_s f(F) depends only upon the material RRR. Considering two metal sheets of equal thickness with conductivity σ_1 and σ_2 respectively, it can be seen from eq.2 that the skin depth is the same in both sheets for two different frequencies F_{c1} and F_{c2} such that :

$$\frac{F_{c1}}{F_{c2}} = \frac{\sigma_2}{\sigma_1} = \frac{\rho_1}{\rho_2}$$

Instead of two differents sheets, on single metal sheet can also be measured at 300K and at 10K. We plot the curve V_{300K} / V_0 f(F) (Vo is the output signal without metal sheet) and the curve V_{10K} / V_S f(F) . The frequency ratio between these curves then yields ρ_{300K} / ρ_{10K} . From the law :

$$\frac{\rho(T)}{\rho_{300K}} = A + BT^3$$

we obtain ρ_{4K} by extrapolation and we define the $RRR = \frac{\rho_{300K}}{\rho_{4K}}$

3.EXPERIMENTAL SET-UP

Choice of the coils and geometrical arrangement.

Two key components of the device are the primary and secondary windings ; Special care was taken in the choice of these coils. The following criteria were used :

- small coils, for a good spatial resolution
- the useful part of the field created by the coils is the one located close to the Niobium surface. The stray field must thus be a large as possible, for both primary and secondary windings. Flat coils were chosen to this end.
- The voltage induced in the secondary coil is proportional to its inductance L. For a large signal to noise ratio, L should be as large as possible.
- L may also vary with temperature, causing variations in the voltage induced in the secondary coil. The choice of a coil having a low temperature coefficient is important.

The chosen coils (reference SIGMA 289.85880, L = 1mH, R(300K) = 37 Ω, R(10K) = 1Ω,, length 10mm, diameter 4mm) meet these requirements, and have the additional advantage of being commercially available at low cost. For simplicity, the same component was used for the primary and the secondary coils.

The coils have to be on the same side of the sheet. This arrangement is desirable if one wishes to use the device on cavities. The geometrical disposition of the coils with respect to the sheet was chosen so as to maximize the influence of the metal sheet. Several arrangements were tried, with coil axis perpendicular or parallel to the sheet plane, and coaxial or parallel coils. A satisfactory arrangement was found with parallel coils, with their axis parallel to the niobium surface, the coils lying as close to each other as possible. In this geometry, a crucial parameter is the distance between the coil doublet and the niobium surface. In order to maximize the influence of the underlying metal, this distance should be maintained as small as possible. The influence of this distance has been investigated. As can be seen from fig.4, the output signal decreases when the coil-sheet distance **d** increases.

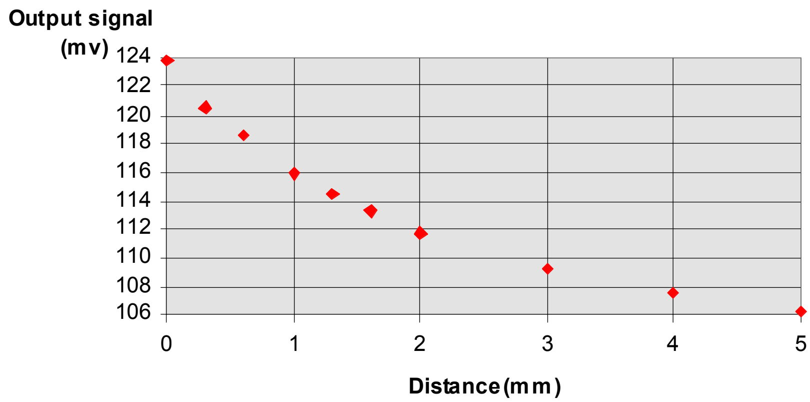

Fig.4 V output variation versus distance d

Excitation of the primary coil was made with an AC generator (ref. HWP.3325B,10 volts output level). The detected voltage across the secondary coil was of the order of 0.1 mV at low frequency and 300 mV at high frequency. For the RRR mapping of SRF cavity , we have built a movable arm with 9 sensors like the one previously described (fig.5 and 6). We rotate this arm step by step (30° or less). For each arm's position, we plot signal ratio curves versus frequency like fig. 7 and 8. From these curves,we deduce and calculate the resistivity ratio :

$$RRR = \frac{\rho_{300K}}{\rho_{4K}}$$

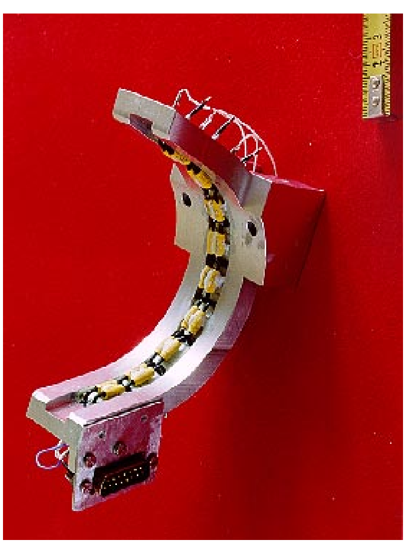

fig.5 :Arm's sensors

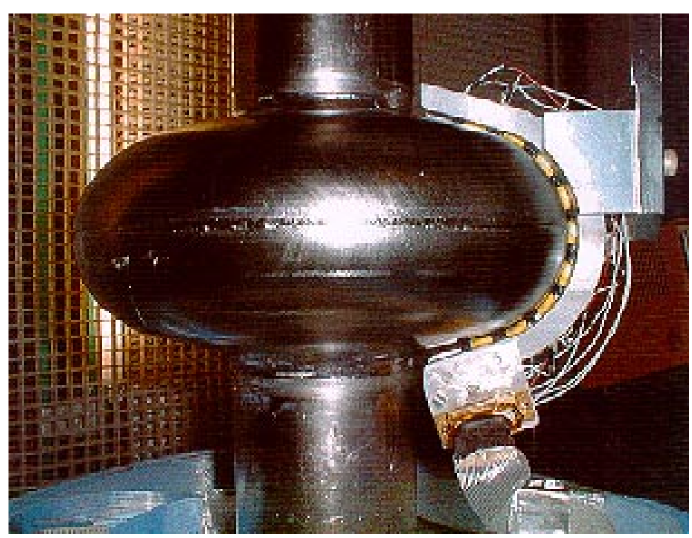

fig. 6 :Movable arm's sensors on the cavity

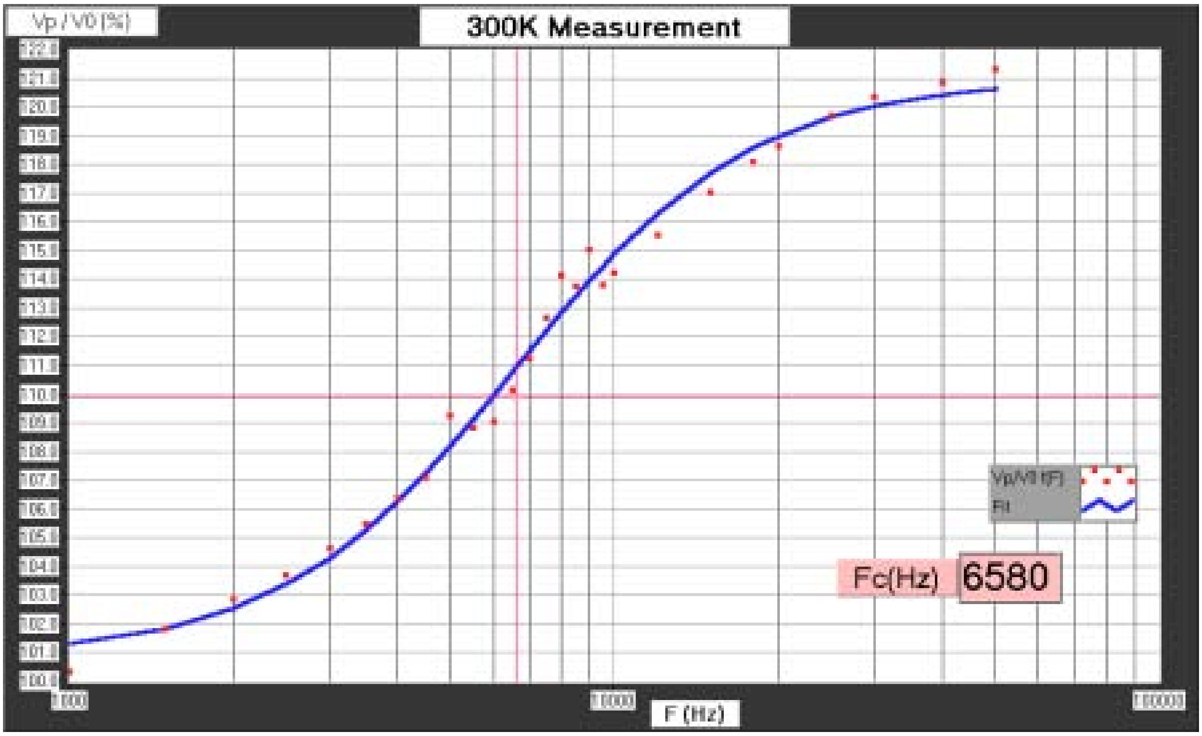

Fig.7 :Typical Curve obtained by fit with Niobium sheet at 300K

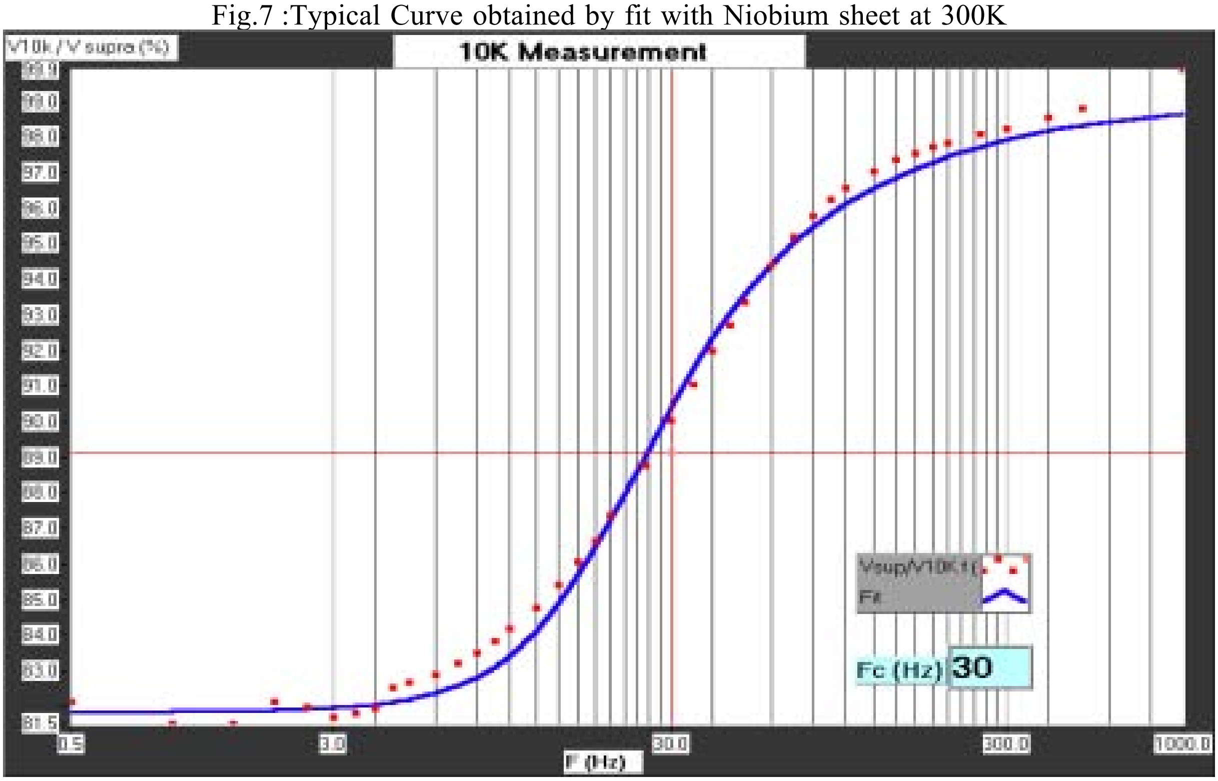

Fig.8 :Typical Curve obtained by fit with Niobium sheet at 10K

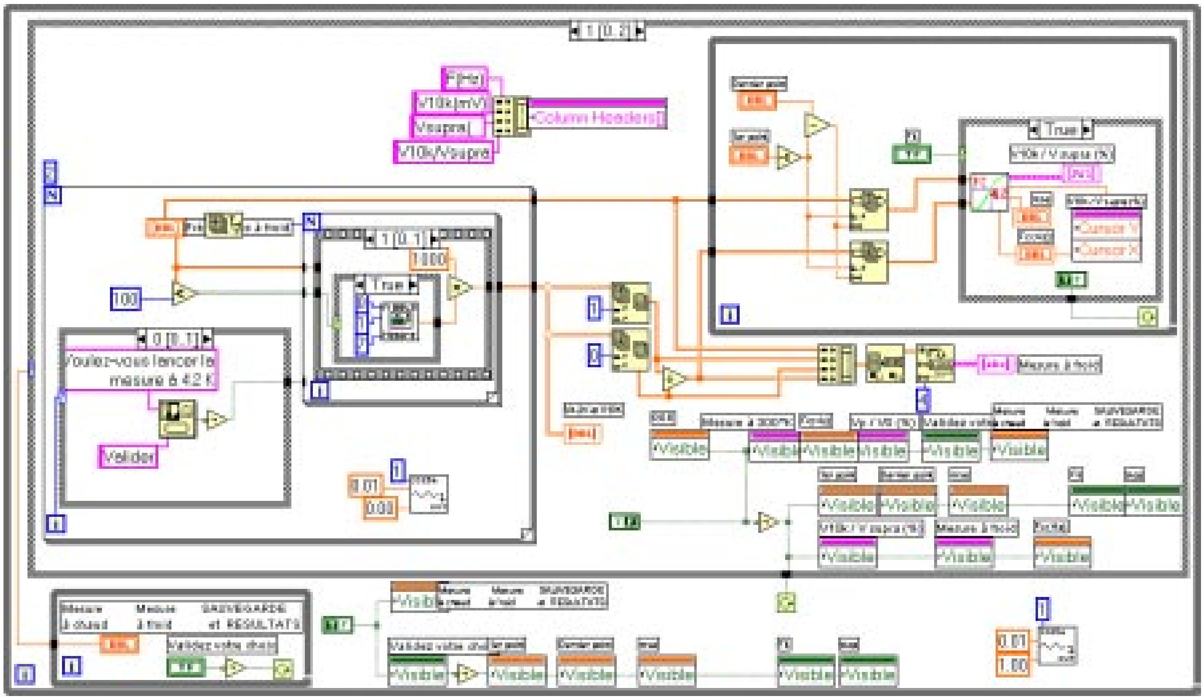

Fig.9 : Labview Process

By the LABVIEW SYSTEM (fig. 9), we process the set of datas (10000 pts and 130 curves) and we obtain RRR maps of cavities (fig.10 and 11).

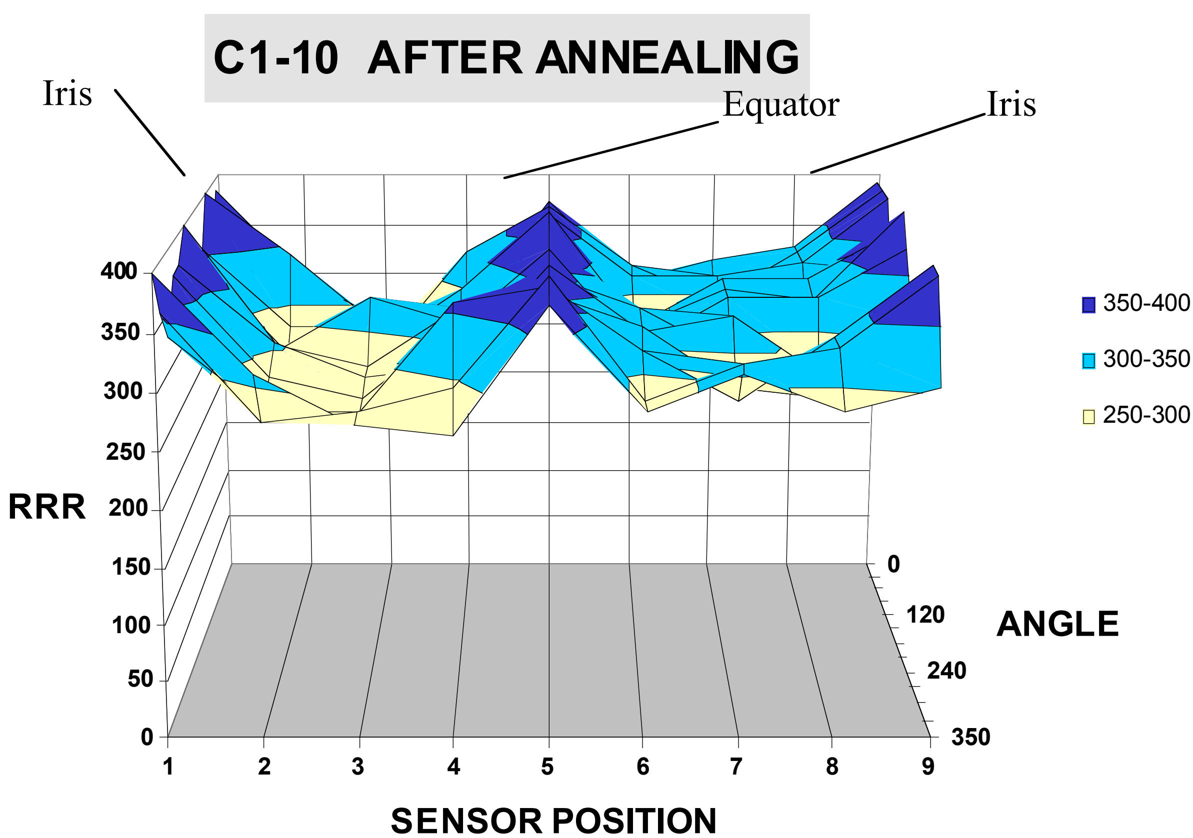

Fig.10 RRR map of a SRF cavity (high RRR)

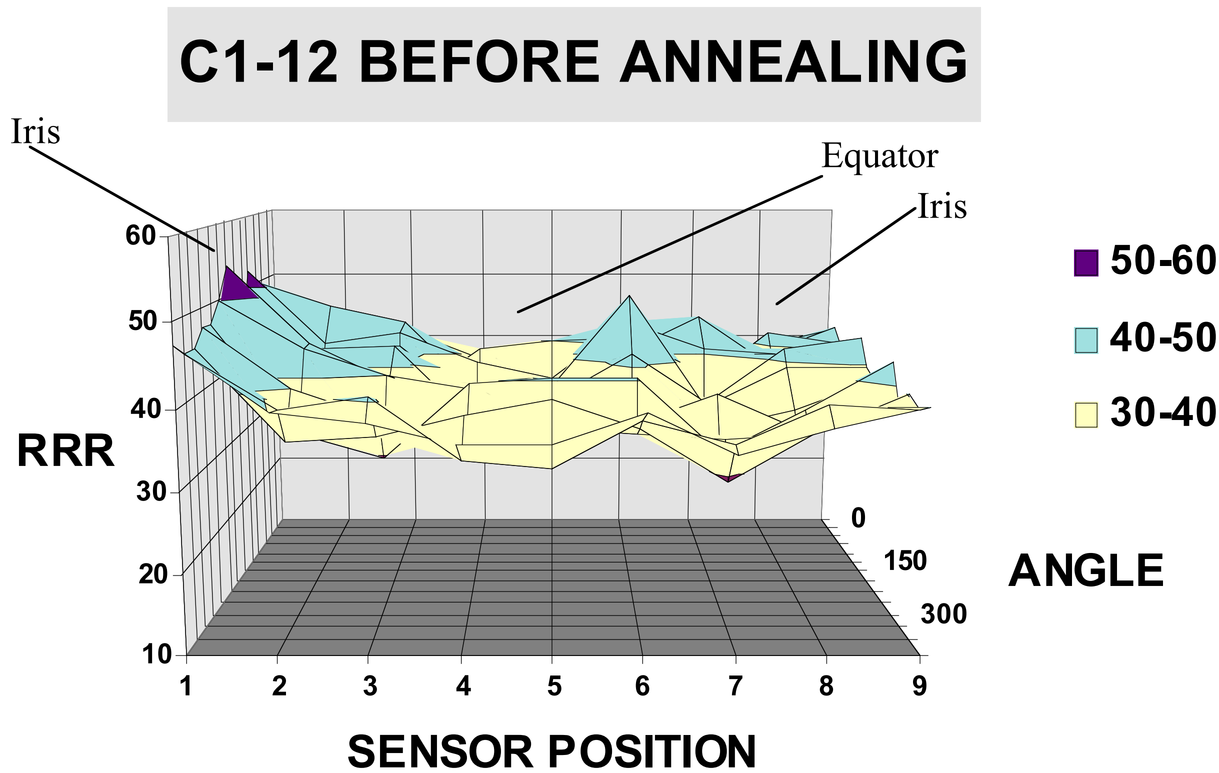

Fig.11 :RRR map of a SRF cavity (low RRR)

ACCURACY

Sensitivity of RRR measurements :

- To apparatus

  We estimate the error to the microvoltmeter and frequencemeter at 2%.
- To temperature system

  The relative variation of resistivity ρ_n (T), about 10K, varies with temperature as follows :

$$\frac{d\rho_n}{\rho_n} = -\frac{dRRR}{RRR} = 1{,}2.10^{-6}.T^2.RRR.dT$$

The temperature of the sheet is controlled with a typical precision of less than 1K. This corresponds to a relative error of 2 or 3% on the RRR-value.

- To systematic error

  For an eventual distance variation of 1mm between sensors and metal sheet,we estimate the RRR error at 5% (Fig. 4).

- Reproductibility

  The same sample was measured three times in the same conditions . We obtain 5% for the results dispersion. So, if we consider a quadratic contribution of the overall errors, we estimate the final relative RRR error at 10%.

CONCLUSION

- A local, non destructive, magnetometric measurements of the conductivity of a metal as been demonstrated.
- From cold measurements, RRR can be deduced. Results are validated by standard resistive 4 wires method.
- Estimated relative error is roughly 10% for RRR 200.
- We can, at this time, map the RRR of superconducting cavities in niobium.

Ref.1 : H. Padamsee, K. W Shepard and R. Sundelin, Ann. Rev. Nucl. Part. Sci. 43 (1993) 635
Ref.2 : K. Schulze, Metals, 33 (5) (1981) 33
Ref.3 : M.Bolore, B.Bonin, Y. Boudigou, S. Heuveline, E. Jacques, S. Jaidane, F. Koechlin, H. Safa, Procee.7th Workshop SRF /T3/ Oct. 1995.