A NEW FABRICATION AND STIFFENING METHOD OF SRF CAVITIES

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ABSTRACT A new fabrication and stiffening method of SRF cavities is proposed. The principle is to spray a copper layer onto a thin wall niobium cavity. The main advantages of this technique are fabrication cost reduction and stiffening method simplification. Numerical simulations were performed to demonstrate the efficiency of the proposed stiffening scheme on the reduction of the cavity frequency shift due to Lorentz forces. A first series of cavities (3 GHz) were fabricated and the corresponding cold RF tests are presented. Finally, the overall thermal resistance of different samples was measured and the results are discussed.

1 PLASMA SPRAYING PROCESS

The plasma generator [1] consists of a copper anode and a thoriated tungsten cathode. The electric arc discharge heats up the working gas (mixture of Ar (or N_2) with H_2) at temperature in the range 15000 K - 30000 K. The copper powder (particles size $\approx 50\mu$m) is injected into the plasma flame. These copper particles, which are accelerated (velocity≈Mach 1-2) and melted in the plasma, impact the cold substrate (Nb) resolidify hence forming the copper layer coating. The actual process is realized under normal atmosphere (Atmospheric PS : APS) but plasma spraying is also possible in presence of an inert gas (i.e Ar: Ar PS). In the case of APS, the substrate surface is roughned and a bronze/aluminium thin layer is sprayed onto niobium prior to copper layer deposition so as to achieve a high bonding strength.

2 CAVITY COLD TEST RESULTS

Five 3 GHz cavities were fabricated. The five cavities are made from RRR =40 Nb sheets of 0.5 mm thickness. The cavities are prepared according to the procedure described elswhere [2]. Out of these series, two 3 GHz cavities (#4 and #5) have been successfully tested before and after Cu deposition. The maximum E_{acc} reached was limited by a quench for these two cavities. The corresponding results are summarized in Table1. After Cu deposition, E_{acc} max is the same (#4) or slightly decreased by 7% (#5). The resulting Q_0 vs E_{acc} curves of the cavity #4 recorded at a bath temperature T_{bath} =1.8 K are displayed in Fig.1. The observed Q_o difference between the two tests presented is only due to a change of the cavity location inside the cryostat relative to the magnetic shielding, resulting in a different residual earth magnetic field.

	before Cu deposition	With Cu
cavity#4	$E_{acc}max$=**16.5MV/m**	$E_{acc}max$=**16.5MV/m**
cavity #5	$E_{acc}max$=**14.5MV/m**	$E_{acc}max$=**13.5MV/m**

Table 1: Maximum electric field in cavities #4 and #5

As the Cu deposition process was not yet optimized (see section 4) to achieve the best thermal characteristics suited for accelerating cavities, these first results are very encouraging and the technique is still promising.

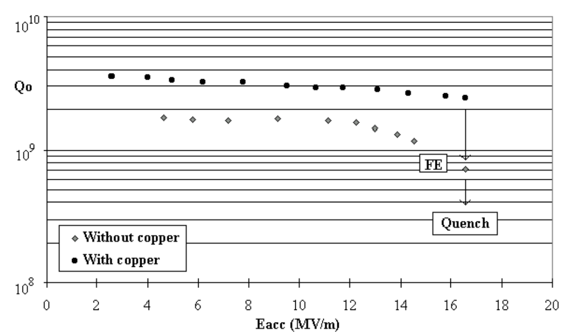


Figure 1: Cavity #4 RF performance at 1.8 K

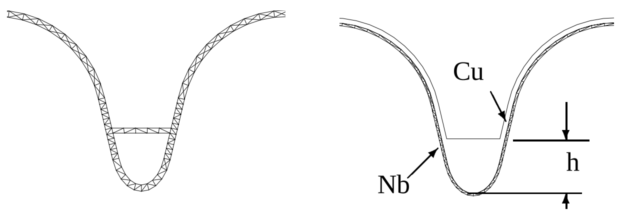
3 EFFECTS OF THE LORENTZ FORCES

As TESLA cavities work at high accelerating gradient, the mechanical stability may be critical for RRR>300. A stiffening system is necessary to reduce the detuning induced by Lorentz-force: the frequency shift Δf must be lower than the cavity bandwidth . First the resulting cavity shape change is computed for a given stiffening scheme with the finite element code "CASTEM 2000 " [3] then a special module developped is used to compute the cavity volume change ΔV and the resulting frequency shift according to Slater's formula:

$$\frac{\Delta f}{f_0} = -\frac{1}{4W} \iiint_{\Delta V} (\mu_0 H^2 - \epsilon_0 E^2) dV \qquad (1)$$

where: W is the total electromagnetic energy stored in the resonator, E and H are the electromagnetic surface fields and f_0 is the fundamental mode of the unperturbed cavity.

A comparison between the actual stiffening method using the Nb welded stiffening ring (Fig.2 a) and the new method with a PS copper layer(Fig.2 b) has been made.



a) Nb welded stiffening ring b) sprayed Cu layer

Figure 2: Stiffening methods between cells

Numerical simulations were performed, it has been proved analytically and numerically that for small pertubations, the frequency shift is proportional to ${E_{acc}}^2$ [4]. The computed frequency shifts versus ${E_{acc}}^2$ for differents stiffening methods are presented in Fig.3. The results point out clearly the efficiency of the new stiffening system and the possibility to reduce the Nb wall thickness and hence its cost in terms of material mass. The actual stiffened TESLA

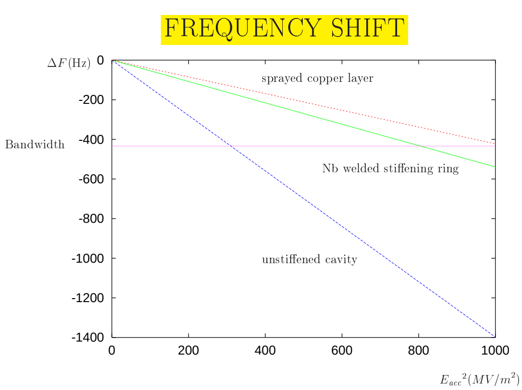


Figure 3: Computed Lorentz force effet

9 cells cavity has been designed for E_{acc}=25MV/m and a Nb wall thickness of 2.5mm. Comparison between differents simulations results and measurements for actual stiffened cavity has been made and a good agreement has been observed [4].

The Table2 summarize the computed frequency shifts of the two stiffening systems for differents configurations, for E_{acc} =25MV/m, with brick elements, Young modulus = 130GPa, Poisson ratio=0.34, the adherence between sprayed copper and niobium has been supposed perfect. Note that the bandwidth is $434Hz(Q_{ext} : 3.10^6)$. The Table2 clearly show that we can reduce the Nb wall thickness down to 1mm, and simplify the stiffening method.

The new stiffening system has two options: homogeneous copper layer or inhomogeneous copper layer (thicker layer at the iris). We can then chose the thickness of the homogeneous copper layer and/or the height of the stiffening

configuration	Δf(Hz)
Nb2.5mm without stiffening	−834
Nb2.5mm with Nb welded ring	−337
Nb2.5mm,Cu2mm homogeneous	−345
Nb2.5mm,Cu2mm iris stiffening	−140
Nb1mm,Cu2mm iris stiffening	−264

Table 2: frequency shifts

in iris region for $E_{acc} \geq 25$MV/m. An optimization of the iris stiffening height (h) is made to minimize the frequency shift, Fig.4. It seems that an optimum heigth(h)

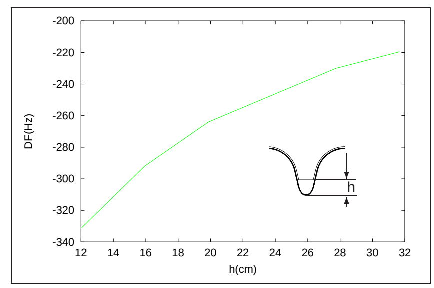


Figure 4: Δf vs copper depth at the iris(h)

compensate the decrease of Young modulus due to the material porosity [4].

4 THERMAL RESISTANCE MEASUREMENT

The purpose of this experiment is to measure and compare, by a differential method, the overall thermal resistance between the hot niobium surface and superfluid helium. The new dedicated overall thermal resistance experimental cell already described elswhere[5], consist mainly of a stainless-steel cylindrical "cavity" filled by He II via two capillaries. This "cavity "is closed at its two extremities by a pair of the test-samples to be tested. We used to kinds of specimens : bulk niobium samples (Nb) and niobium samples coated with a 2.5 mm thick PS copper layer (Nb/Cu). Finally, the external surface of each test-sample is cooled by a He II thermostated bath (temperature: T_{bath}). The principle of the method is to heat the He II inside the cavity and to record in steady-state, the resulting temperature difference ΔT between the hot He II and the He II thermostat as function heat flux density q. As each pair of test-samples is machined from the same Nb sheet, and their surfaces prepared according to exactly the same process, the slope of the curve ΔT vs. q is simply R_O/2, where R_O is the sample overall thermal resistance. In the case of Nb samples and for small heating (i.e $\Delta T \ll T_{bath}$), R_O is the sum of two contributions: 1) the bulk niobium thermal resistance $R_{Nb} = e_{Nb}/k_{Nb}$ where e_{Nb} and k_{Nb} are respectively the Nb thickness and thermal conductivity, 2) twice the Kapitza resistance ${R_K}^{Nb}$ at Nb-He II interfaces. In the case of the Nb/Cu samples the resulting overall thermal resistance has five contributions: 1) the bulk alloy niobium thermal resistance R_{Nb} , 2) the Kapitza interfacial thermal resistance ${R_K}^{Nb}/Alloy$ between the niobium and the bronze-aluminium alloy, 3) the bulk thermal resistance $R_{Alloy} = e_{Alloy}/k_{Alloy}$where e_{Alloy} and k_{Alloy} are alloy thermal thickness and conductivity, 4) the Kapitza interfacial thermal resistance ${R_K}^{Nb}$/Cu between the alloy and the copper, 5) the equivalent thermal resistance of the copper layer which includs the He II microchannels effective thermal impedance and the Kapitza resistance at Cu-He II interfaces. All the experimental runs were performed in the temperature range 1.5 K-2.1 K. The experimental data hence measured are presented in Fig.5.

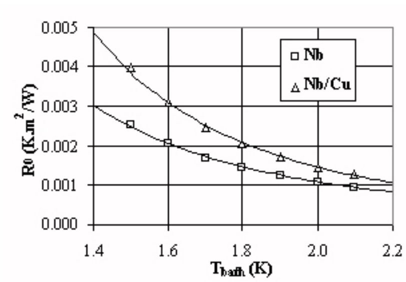


Figure 5: Overall thermal resistance variations with T_{bath}

These results clearly show that the APS coating , which includ the bronze-aluminium alloy and the copper layer increases significantly the overall sample thermal resistance R_O. For example, at the TESLA working temperature T_{bath}=2 K, the APS copper coating with the bronze-aluminium alloy increases R_O by 36%. Moreover, the actual R_O experimental data could be fitted by the following empirical power laws:

$${R_O}^{Nb}(\frac{K.m^2}{W}) = 8.110^{-3}{T_{bath}}^{-2.92}$$

$${R_O}^{Nb/Cu}(\frac{K.m^2}{W}) = 1.5310^{-2}{T_{bath}}^{-3.4}$$

The theoretical solid-solid interfacial thermal resistance ${R_I}^{Theo}$ could be estimated with a good precision according to Little theory[7] and we finded[5] the following theoretical expression:

$${R_{Nb/Cu}}^{theo}(\frac{K.m^2}{W}) = 2.10^{-4}{T_{bath}}^{-3}$$

The use of the previous expression leads to a theoretical interfacial thermal resistance in the range $2.310^{-5} - 6.010^{-5}$ K.m2/W for T varying from 2.1K down to 1.5K. However the experimental data shows an overall thermal resistance variations (i.e Nb vs. Nb/Cu samples) of $3.210^{-4} - 1.4410^{-3}$ K.m2/W in the same temperature range. One could then conclude, that the observed R_O increase should not be explained by the solid-solid bound-Sary resistance. Moreover if one considers now the alloy bulk resistance contribution to R_O, we estimate a value of $R_{Alloy} \cong 210^{-4}K.m^2/W$ at T_{bath} = 2 K (we used $e_{Alloy} \cong 0.2mm$) and a typical value of a dirty metal thermal conductivity $k_{Alloy} \cong 1W/m.K$. The actual results confirm the R_O experimental data we have reported previously [2]. Notice that the previous results were obtained with a completly different test-cell. One could then conclude that the Alloy thermal resistance should dominate the heat transfer from Nb to superfluid helium.

5 CONCLUSION

A new fabrication method for SRF cavities is presented. The comparison of the RF performances obtained with the two first cavities tested before and after copper deposition showed that the maximum accelerating field reached was not (or very slightly) decreased. The mechanical behaviour of such cavities was thoroughly studies by numerical simulation. The new overall thermal resistance test cell has been operated succesfully. In order to improve the mechanical and thermal properties of the plasma sprayed copper layer, the influence of the main deposition parameters will be studied on samples: spraying methode(APS and ArPs) copper powder particle size, substrate surface state, pretreatment before plasma spraying and substrate temperature during spraying. Different physical parameters like RRR, mechanical properties, adherence, thermal conductivity, porosity and permeability will be measured on samples. Once optimum deposition parameters are determined, several 1.3 Ghz monocell and multicell cavities will be fabricated from RRR=200, 1 mm thickness Nb sheets and stiffened with the plasma sprayed copper layer.

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