SRF CAVITY STIFFENING BY THERMAL SPRAYING

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Abstract

In this paper, we report on the advances in the new stiffening method using a thermally sprayed copper layer onto bulk niobium cavities. This technique could be used either for replacing the actual EB welded stiffening rings in TESLA cavities, or to fabricate Superconducting Radio Frequency (SRF) proton cavities at low β with reduced niobium thickness. The latest measurements performed on samples to characterise the mechanical and thermal properties of the copper coating are presented and the plasma spraying method used is detailed.

1 INTRODUCTION

Mechanical stability of SRF cavities is an important issue for electrons or protons accelerators operated in the pulsed mode like TESLA [1], ESS or multi-purpose projects. The most important source of SRF cavities frequency shift (Δf) is due to Lorentz forces. The surface electromagnetic fields generate a radiation pressure on the cavity wall and alter the cavity geometry. A variation of only 1 µm of one cavity dimension could induce a frequency shift of several hundreds of hertz. The consequence of the detuning is a decrease of the accelarating field E_{acc} in the cavity. RF feedback is used to compensate the E_{acc} decrease by increasing the input RF power. The additional available RF power is usually limited to 10 % of the nominal power. Consequently, the cavity detuning has to be small enough in order to be compensated with the RF feedback. Additional stiffening is then needed to improve the cavity mechanical stability and reduce the frequency shift. Actual solutions based on Electron Beam (EB) welded stiffening rings between the cells are used, but this technique is not sufficient for high fields (TESLA energy upgrade at 800 GeV, with E_{acc} = 34 MV/m and Δf_{max} = 425 Hz). Moreover it is difficult to weld these rings on the low β proton cavities due to the tight space between the cells.

An alternative stiffening method based on thermally spraying a copper layer onto the cavity outer walls has been presented in previous papers [2-5]. This study is leaded in a close collaboration between 3 french laboratories (LAL, CEA and IPN). Different spraying techniques have been tested for this application. The main conclusion was twofold: the porosity rate of the copper layer has to be as lowest as possible to obtain a coating with mechanical properties good enough, and the copper oxidation during the process has to be avoided in order to insure good thermal characteristics. Measurements of thermal and mechanical properties of the coating performed on samples are compared with the analysis of copper coated cavity RF tests and show good agreement. Among all the techniques investigated, the best spraying method to reach these objectives is the Inert Gas Plasma Spraying (IGPS): the first results on samples are presented in this paper. The principle of the IGPS technique [6] is to create a plasma by an electric arc discharge initiated in a gas (usually Ar/He). The copper powder is injected in the high temperature plasma and the molten particles are sprayed out of the plasma gun. The spraying environment is an inert gas (Argon). The main advantage of IGPS is to avoid any oxidation of the coating during the deposition process. This stiffening method could be used either for TESLA cavities or low β proton cavities. This solution is also very complementary with seamless cavities (spinning or hydroforming) [7].

2 RF TESTS AND SIMULATIONS

Two 1.3 GHz monocell cavities have been already coated with copper using two different thermal spraying methods. The first cavity was coated using a non-optimized Atmospheric Plasma Spraying (APS) process (manual procedure, use of an intermediate Al/Cu bonding layer). The same Qo vs Eacc after and before copper deposition was obtained [3,8]. Thermal measurements on samples showed that the copper layer increases the overall thermal resistance by 4.10^{-4} $K.m^2/W$ at 2 K (Cu thickness = 2 mm). This slight increase of the thermal resistance showed that the cavity thermal stability is not affected. This result is a proof of the high porosity of the copper layer (about 20%) and the penetration of the superfluid helium into the copper layer. As described by Spigg's law, the Young modulus is lowered when the porosity increases. The measurement using different methods gives 25 GPa for the copper layer Young modulus, a value too low for an efficient cavity stiffening at high fields. The frequency shift induced by Lorentz forces was measured on the cavity. As theoretically expected, the detuning depends quadratically on the accelerating field: $\Delta f = -K.E_{acc}^2$, with K a constant called the detuning factor. The stiffening efficiency of the APS Cu coating is given by means of the Δf vs E^2_{acc} curves for the bulk Nb cavity and the copper coated cavity. The K factor is decreased by 35 % with the copper stiffening. However, numerical simulations showed that this would not be sufficient for high fields (above 30 MV/m) [3,8,9].

The second cavity was copper coated using the High Velocity Oxy-Fuel (HVOF) process, performed by the LERMPS laboratory, located in Sevenans (France). The measured cavity detuning curve (i.e $\Delta f = -K.E_{acc}^2$) is very good [Fig 1] thanks to the copper layer low porosity (2.6%) obtained with this process [4]. The measured Young modulus was 66 GPa. The detuning factor of the coating cavity is drastically reduced by a factor 4.2. But the drawback is the very high overall thermal resistance of the HVOF Cu coating: >$1.43.10^{-3}$ Km^2/W at 2K (thickness: 3 mm), resulting in a strong reduction of the quench field from 31 MV/m to 20 MV/m [Fig 2].

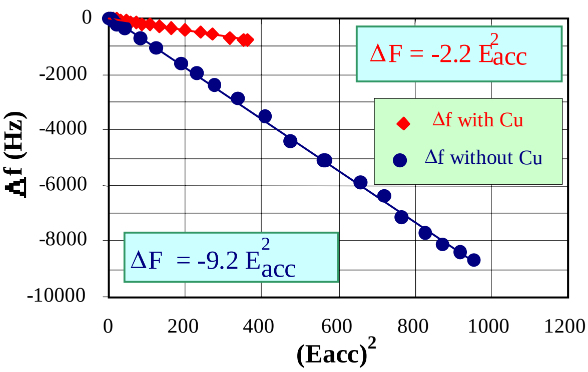

Fig 1 : Δf vs E_{acc}^2 with and without HVOF Cu.

A cavity thermal behaviour simulation based on a simple model (defect free case) [Fig 3] proved that this Eacc degradation is due to the overall thermal resistance increase [Fig 2]. The important copper oxidation during the deposition process seems to be responsible of the poor thermal properties of the coating.

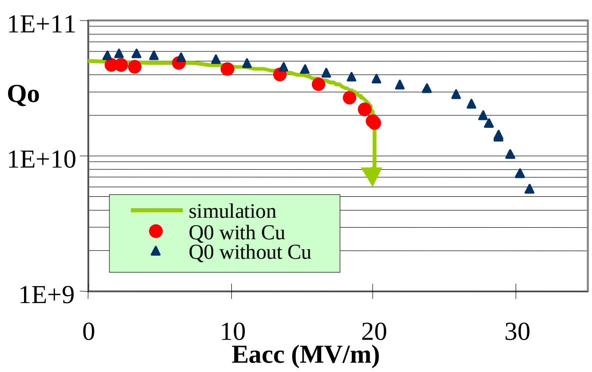

Fig 2 : Qo=f(E_{acc}) with and without HVOF Cu and simulation with HVOF Cu.

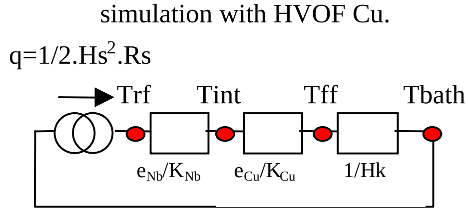

Fig 3 : Equivalent circuit for the thermal simulation

The principle of the calculation used to determine the RF surface temperature (Trf) is the following: the cavity cold surface temperature (Tff) is set and then the heat flux density q is calculated using the equation q=Hk.(Tff-Tbath). Here, Hk is the Kapitza conductance between copper and helium, which is given by $Hk(W/K.m^2)=450.Tbath^{3.5}$. The temperature at the copper/niobium interface Tint is easily calculated considering a linear dependence of the copper thermal conductivity k(T) on the temperature. The same approximation is applied to the niobium thermal conductivity, leading to Trf. Then, the surface resistance Rs is given by

$$Rs(n\Omega) = \frac{10^5 . f^2 (GHz)}{Trf} . \exp\left(-\frac{18}{Trf}\right) + Rres$$

and the surface magnetic field Hs determined by $Hs = \sqrt{2.Rs/q}$.

Finally, using the relations Qo = G/Rs, remembering that E_{acc} is proportional to Hs, and varying T_{FF}, the Qo = f(E_{acc}) [Fig 2] and Trf = f(E_{acc}) [Fig 4] curves can be plotted .

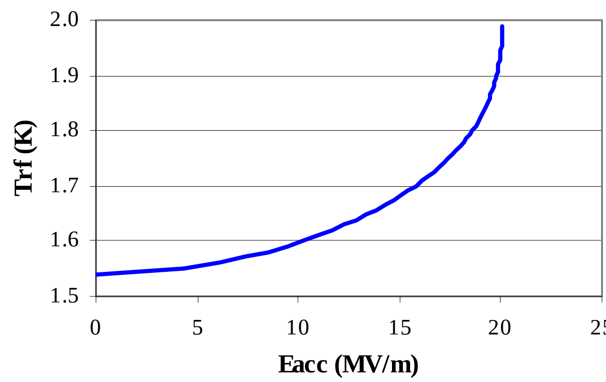

Fig 4: Simulation of Trf vs E_{acc} with HVOF Cu

3 MECHANICAL AND THERMAL MEASUREMENTS

An automated system was developed at the IPN Lab. for the Young modulus measurement, using the 3 points bending method. The sample is a rectangular slab (L:55mm x W:10mm), of variable thickness (th). A motor, controlled by a PC with Labview, exert a force (F) on the sample via a force sensor. The sample deformation (d) is measured by means of a displacement gauge. The Young modulus (E) is deduced using the formula $E=F.L^3.(4.d.W.th^3)^{-1}$ [9]. The results for the different samples are given in Table 1. The Young modulus (72 GPa) of the IGPS coating is very good and the highest of the Cu coating obtained up to now with different spraying methods.

Method	Young modulus
APS (Mallard)	25 GPa
APS (Evry)	63 GPa
HVOF (sevenans)	66 GPa
IGPS (Evry)	72 GPa

Table 1: Measured young modulus of copper coatings for different spraying process (130 GPa for bulk copper).

Thermal properties are measured on Nb/Cu samples according to the method described elsewhere [2,10]. The thermal resistance of the copper layer deposited with the IGPS process is very low, only $4.7.10^{-4}$ K.m^2/W at 2 K (it includes the contribution of the Cu conductivity and the Cu/He Kapitza resistance) for a 3.5 mm thick copper coating. On the Fig 5 is plotted the overall thermal resistance Rg for a 1 mm thick Nb sample (RRR 140) and for the same sample covered with 3.5 mm of copper. The difference between the two of them is only a factor 2.2. From the thermal resistance point of view, the Nb/Cu sample (1 mm Nb + 3.5 mm Cu) is equivalent to a 3.1 mm thick bulk Nb sample (same RRR). This very good result is explained by the absence of copper oxidation.

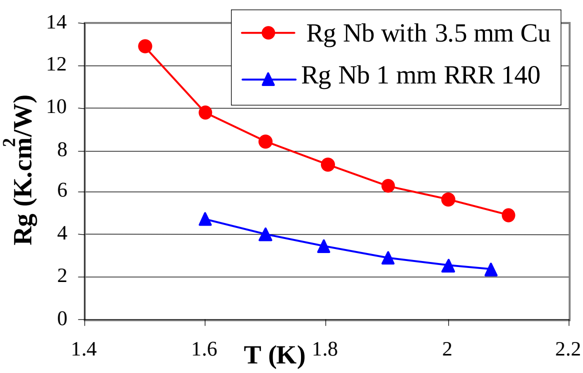

Fig. 5: Overall thermal resistance measurement on a Nb/cu sample obtained with the IGPS process.

The copper layer thermal resistance measurements have been used to simulate the Qo=f(E_{acc}) curve for a TESLA cavity (Nb 2.5 mm thick) coated with copper deposited by the same IGPS method. As shown [Fig 6], the Qo degradation at 34 MV/m is acceptable for a 5 mm thick Cu coating. Only 2 mm at the equator and 20 mm at the iris are necessary for an efficient stiffening at 34 MV/m.

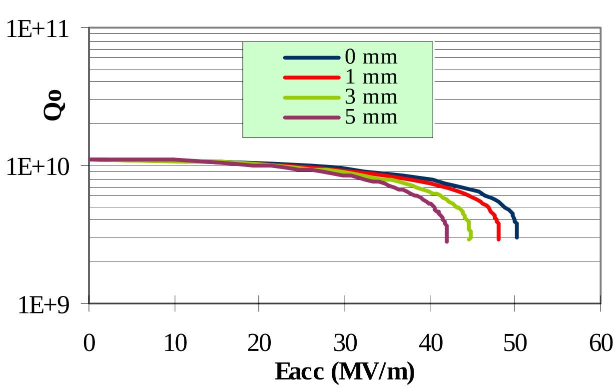

Fig. 6: Simulation of Qo vs E_{acc} at 2 K for different copper coating thickness (IGPS process).

4 CONCLUSION AND FUTURE

A new stiffening method for SRF cavities is presented. The principle is to stiffen niobium cavities with a copper layer deposited by thermal spraying. Comparison of RF performances obtained with the first cavities tested before and after copper deposition showed that the quench field is not affected when the thermal resistance is low, while frequency detuning measurements showed that the stiffening effect was sufficient for a Young modulus around 70 GPa. These results prove the interest of the method. The test on samples produced by IGPS at Ecole des Mines de Paris (Evry) showed that both good thermal properties and good mechanical properties are obtained: a high Young modulus (72 Gpa) and a low thermal resistance. The explanation lies in the absence of oxidation and the low porosity.

Cavity stiffening using copper thermally sprayed seems to be a solution now ready to be used on TESLA 9 cells cavities, TESLA superstructure or proton cavities. We plan to test a monocell 1.3 GHz cavity with IGPS Cu coating and to perform mechanical measurements on specific specimen (two half cell welded at the iris) to definitively check if the mechanical characteristics are good and the process suited for our application. The cost, depending on the spraying method, can also be evaluated for big scale production.

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