TESTS RESULTS OF SRF 3 GHZ BULK NIOBIUM SPUN CAVITIES

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Abstract

In the frame of a R&D program aiming at developing new fabrication techniques, three bulk Niobium 3 GHz seamless SRF cavities was produced by spinning at INFN Legnaro. These prototype cavities of different nominal thickness were tested at IPN Orsay in the temperature range 1.7 K-4.2 K. In the course of the experiments, several parameters was investigated: surface resistance R_S versus temperature T, magnetic penetration depth as function of T and Lorenz forces detuning factor K. Electromagnetic simulations were also performed. The results obtained are reported and discussed. The characteristics Q_0 vs E_{acc} of the three cavities showed field emission and the RF tests was limited by the available power. Moreover the energy gap was deduced from the R_S vs T results and compared to data previously reported on Niobium leading to a good agreement. Finally these cavities seems to be more sensitive (i.e higher detuning factor) to Lorenz forces detuning as compared to cavities of same geometry produced by deep drawing and Electron Beam Welding.

1 INTRODUCTION

The fabrication techniques and preparation methods of Superconducting RF (SRF) cavities are actually well mastered at industrial scale. However big projects like such as TESLA will use more than 22000 nine cells SRF bulk niobium cavities. For such machines cost reduction is of prime importance and constitutes a very challenging task. Up to now bulk niobium multicell cavities are produced by a well known technique : 1)deep drawing of half-cells, 2)Electron Beam (EB) welding of theses half cells at the equator and iris regions (19 EB welds needed for TESLA 9-cells cavities). This technique, which allows the production high performance SRF cavities in terms of accelerating gradient E_{acc} and unloaded quality factor Q_0, is however expensive and time consuming. Moreover for β=1 SRF cavities, EB weldings are located in high surface electrical (iris) and magnetic field regions (equator) where anomalous RF losses could occur if surface defect are presents. New fabrication technique are then needed in order to save time and reduce the production costs of RF cavities. Among the various alternative method proposed (hydro-forming, explosion bonding, spinning) the last one, which was proposed and developed at INFN, is very attractive and several muticell cavities was produced and successfully tested [1].

2 CAVITY DESCRIPTION

In the frame of TESLA collaboration Three bulk niobium spun cavities (labelled here after by the letters A, B and C were fabricated at INFN and tested at IPN Orsay (Fig. 1). Notice that the flanges of the beam tubes were EB welded at LAL.

Figure 1: 3 GHz spun niobium cavity.

Electromagnetic calculations were performed with URMEL and SUPERFISH codes : the resulting main RF parameters of the cavity are illustrated in Table 1.

Table 1: Main RF parameters of the cavity

f (MHz)	G (Ω)	B_{pk}/E_{acc} (mT/MV/m)	E_{pk}/E_{acc}
2970.56	280	4.3	1.8

3 COLD TESTS

Prior to the RF tests, the three cavities were prepared using the standard procedure : removal of a damaged layer (130 µm) by BCP, high purity water rinsing and drying in a class 100 clean room. It might be stressed that no High Pressure Water Rinsing (HPWR) was applied to the cavities : no HPWR device for 3 GHz cavities is available at Orsay/Saclay. In the course of the experiments we measured : 1) the variations of the surface resistance R_S as function of the temperature T (low field measurements), 2) the RF characteristics Q_0 vs. E_{acc} and Lorenz force detuning curve Δf vs. E_{acc} (f: resonance frequency) in the residual resistance regime (1.7 K), 3) the magnetic penetration depth λ as function of T.

3.1 Surface resistance versus T

These measurements were performed in liquid helium for T in the range 1.7 K- 4.2 K. The corresponding results are presented in Fig. 2. In order to fit the experimental data to the well-known BCS model [2] we used in these plots the parameter Y defined by :

$$Y=\frac{\left(R_s(T)-R_{res}\right)T}{f^2} \qquad (1)$$

where R_{res} is the residual surface resistance and f the fundamental mode resonant frequency (~3 GHz).

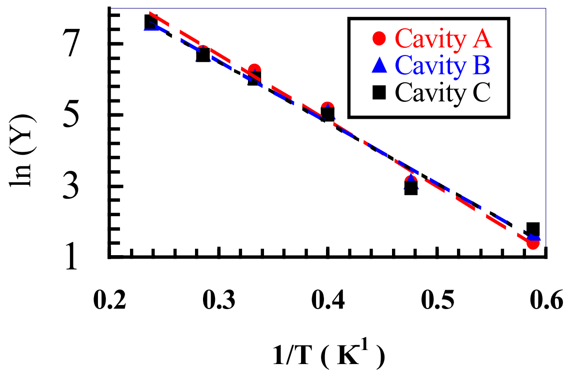

Figure 2: BCS plot of R_S vs. T.

As expected, there is a good agreement between experimental data and the BCS model. According to this model, R_S is given by the simplified formulae:

$$R_S(T)=\frac{A.f^2}{T}.\exp(-B/T)+R_{res} \qquad (2)$$

The best fit values of the parameters (R_{res}, A and B) of the BCS model are given in Table 2.

Table 2 : Values of the parameters used in BCS model

Cavity	R_{res} (nΩ)	A (nΩ.K.GHz^{-2})	B (K)
A	8	1.8 10^5	18.2
B	30	1.2 10^5	17.2
C	45	1.2 10^5	17.4

The residual surface resistance is slightly high for cavities B and C while it is a good figure for the cavity A. Moreover, we deduced the niobium reduced gap parameter Δ_r=2.Δ(0)/k_B.T_C (k_B : Boltzmann constant, T_C = 9.26 K : niobium critical temperature) from the values of B as deduced from the fit. The results are compared in Table 3 to the data previously reported: our results agree with these data and are close to the theoretical value (3.5).

Table 3 : Niobium reduced gap parameter Δ_r.

Cavity A	Cavity B	Cavity C	K. Saito et al. [3]
3.93	3.71	3.55	3.74-4.3

3.2 RF characteristics at T=1.7 K

The characteristics Q_0 vs. E_{acc} were measured (Fig. 3 and Table 2) in the residual surface resistance regime at 1.7 K. The three cavities showed strong Field Emission (F.E) and the maximum accelerating field were limited by the available RF power (~15 W). Field emission was unavoidable and is probably due to the presence of foreign particles on the RF surface. Indeed these cavities were not treated by HPWR prior to the tests : this treatment is very effective in suppressing or reducing F.E.

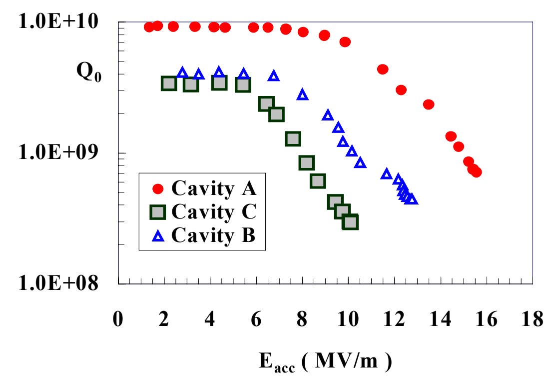

Figure 3 : RF characteristics at 1.7 K.

Table 2 : Summary of RF tests

Cavity	Low Field Q_0	F. E threshold (MV/m)	Maximum E_{acc} (MV/m)
A	9.1 10^9	7.3	15.6
B	4.1 10^9	8	12.8
C	3.3 10^9	6.5	10.1

3.3 Magnetic penetration depth λ

According to previous studies, there is a strong evidence that the normal electrons mean path l_p in superconducting niobium is much higher close to the RF surface as compared to its bulk value. Moreover RF losses depend strongly on l_p via the normal conducting niobium electrical resistivity, hence it is interesting to measure this parameter. The measurement of the magnetic penetration depth λ allows the determination of l_p in-situ (i.e. directly on a SRF cavity). The Pippard theory gives two asymptotic expressions for λ :

a) for 'dirty' superconductors (i.e. ξ>>λ)

$$\lambda_P(t)=\frac{\lambda_L(0)\sqrt{1+\frac{\xi_0}{0.8l_p}}}{\sqrt{1-t^4}}$$

b)for 'clean' superconductors (i.e. ξ<< λ)

$$\lambda_P(t)=\left(\frac{\sqrt{3}}{2\pi}\xi_0\lambda_L^2(0)\right)^{1/3}\frac{1}{\sqrt{1-t^4}}$$

where $\lambda_L(0)$ is the London penetration depth at T= 0 K, ξ_0 the BCS coherence length, t=T/T_C the reduced temperature and ξ the effective coherence length :

$$\frac{1}{\xi}=\frac{1}{\xi_0}+\frac{1}{\alpha.l_p}$$

For niobium $\lambda_L(0)$=22 nm ξ_0=204 nm. The cavity resonant frequency f depends on λ. The method consists then of measuring f(T) by a network analyser while T is increased from 4.2 K To T_C=9.26 K in a controlled way (heater and gaseous helium cooling). The variations of λ with respect to a reference value $\lambda(T_0)$ are given by :

$$\Delta\lambda=\lambda(T)-\lambda(T_0)=\frac{G}{\pi\mu_0}\frac{\Delta f}{f(T_0)^2}$$

with $\Delta f=f(T)-f(T_0)$.

The results of the tests performed on the cavity C with T_0=4.07 K are presented in Fig. 4.

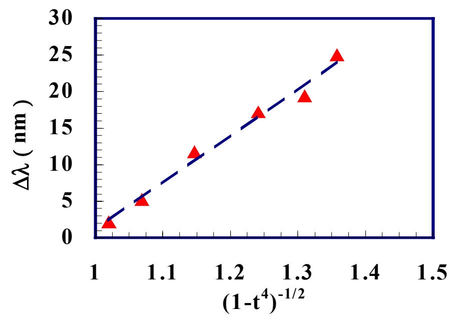

Figure 4: Penetration depth plot $\Delta\lambda$ vs. $x=(1-t^4)^{-1/2}$.

Using the theory the plot $\Delta\lambda$ vs. $x=(1-t^4)^{-1/2}$ leads to a slope b=64.3 nm and intercept $\lambda(T_0)$ = 63.2 nm. Then we deduced l_p=33.8 nm from the value of b. The resulting RRR is 12.5 is very much lower than the bulk value RRR_{Bulk} = 140-305.

3.4 Lorenz force detuning

Lorentz forces exert radiation pressure (≈ few kN/m^2 @ E_{acc}=25 MV/m for TESLA 9 cells cavities) on cavity wall leading to cells deformation in the µm range and change in their volume thus inducing a frequency shift Δf or detuning proportional to the square of the accelerating field field (i.e. Δf = -K. E_{acc}^2). In order to keep Δf lower than the cavity bandwidth, the detuning factor K must be sufficiently low for a given operating condition (i.e. external coupling Q_{ext} and E_{acc}). As K is an important parameter of SRF cavities, we performed detuning measurements on 3 GHz spun cavities. As expected the quadratic dependence of Δf vs. E_{acc} is confirmed (Table 4 and Fig. 5). Furthermore spun cavities seems to exhibit a much higher Lorentz detuning factor as compared to

Table 4: Detuning factor

Cavity	Thickness (mm)	K ((Hz/(MV/m)^2)	Method
A	2	12	spinning
B	2	13	spinning
C	1	33	spinning
LAL04-C	0.92	11	Deep drawing & E.B welding

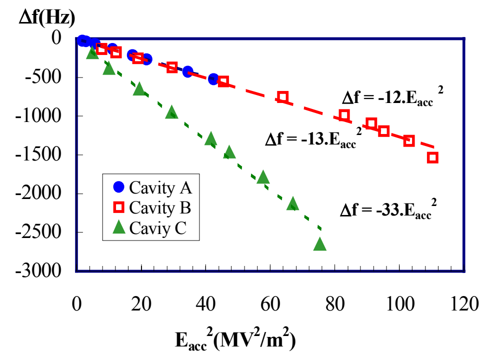

Figure 5: Lorentz force detuning of spun cavities.

conventional cavities (deep drawing + E.B welding) of same nominal thickness (factor 3).

4 CONCLUSION

Three bulk Niobium 3 GHz seamless SRF cavities was produced by spinning at INFN and tested at IPN in the temperature range 1.7 K-4.2 K. As no HPWR was used, the three cavities showed F.E and the maximum gradients were limited by RF power : one cavity reached 15.6 MV/m with low field Q_0= 9.1 10^9 at T=1.7 K. The BCS surface resistance was investigated leading to a gap value in agreement with the results reported previously. Moreover the measurement of λ was performed on one cavity and we obtained results close to literature data. Finally we studied Lorentz force detuning. A spun cavity behaves like a deep drawed cavity two times thicker. Further investigations are needed in order to understand this difference :1) precise 3D geometrical measurement of the exact cavity internal shape, 2) electromagnetic simulation with the resulting geometrical data, 3) mechanical simulation of the cavity subjected to radiation pressure and computation of the detuning. This will allow a more complete analysis of experimental results on spun cavities.

5 ACKNOWLEDGEMENT

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6 REFERENCES

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