RF SUPERCONDUCTIVITY ACTIVITIES AT LAL[*]

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Abstract

Present activities at LAL on Superconducting RF are dictated by the collaboration on TESLA and TTF. In this frame a local french collaboration between LAL(IN2P3), IPN(IN2P3) and DAPNIA(CEA) was set up and signed about 3 years ago and for a duration of 4 years.
The involvement of LAL has been essentially in the development of high power input couplers for the TTF cavities, in the new cavity fabrication technologies including cavity stiffening and in the experimental search for gradient limits (Super Heating Field) on 3 GHz single cell cavities powered from a short pulse (~ 4.5µs),high peak power (~ 35 MW) existing klystron.

1 INTRODUCTION

The CEA and the IN2P3 decided early in 1997 to combine their efforts on SCRF R & D within the TESLA project.The collaboration was set up for an initial period of 4 years.
The specific LAL contributions which will be reported here can be summarized as follows:

- cold and hot forming of seamless Nb cavities,
- copper plasma spray for cavity stiffening,
- high power input coupler developments,
- experiments on high gradient limits and London depth.

The latter was launched in view of the possibility of using an existing short pulse, high peak power RF source at 3 GHz. It was also considered as an interesting way of training LAL engineers and technicians in the domain of superconducting RF and cryogenics. A specific contribution on this subject will be presented during the workshop [1].

2 FORMING OF SEAMLESS NIOBIUM CAVITIES

In view of the production of 20000 nine-cell cavities for the TESLA project, a large amount of R&D effort on the manufacturing processes of these items is necessary, especially when considering the cost of such a project.
The LAL contribution was done with very modest financial investment. The main idea was to use existing industrial equipments (ex: bellow fabrication) to assess the main parameters of importance in forming seamless Nb cavities ,so as to avoid expensive electron welding procedures. Two approaches have been studied; hydroforming and hot forming from Nb sheets [2].

2.1 Hydroforming

We have done some tests with SIBB, a french firm specialized in hydroforming for the automobile industry.
We provided them with niobium tubes of RRR 40, and of internal diameter 51.7 mm and thickness 2 mm. These tubes were annealed at 900 °C for 2 hours in the LAL furnace before delivery ,thus prior to any deformation.
These tubes were deformed to produce 3 GHz twin-cell cavities with an equator to iris ratio of 2/1. In order to succeed, a second annealing (800°C – 2 hours) was necessary after a first step at 40 % deformation. Two cavities have been produced (Fig.1)and after chemical and thermal treatments at CEA – Saclay they will be tested at low RF power level at the IPN – Orsay.

Figure 1: hydroformed 3 GHz bicells Nb cavities

As far as we know these cavities are the only multicell hydroformed cavities in the community.

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2.2 Hot forming

Superplastic forming is a well known process in some industries (especially in aeronautics) for the fabrication in one step of very complicated parts.(mainly of titanium or aluminium with deformation rates between 200 and 1000 %).

Hot forming (or even superplastic forming) of seamless niobium cavities seemed ,at first, a promising idea, with the hope of forming seamless cavities in a single step .

However the obvious questions that arise are : what are the mechanical characteristics of niobium at high temperatures ? Can niobium be hot formed with 300 % deformation (Equator/Iris ratio of TESLA cavities : 3/1) ?

Therefore, we have decided to characterize the rheological behaviour of niobium at high temperatures and then to perform numerical simulations of the industrial hot forming process.

The first problem was to choose the most appropriate temperature at which to do the measurements.

A bibliographic review allows us to foresee two preferential temperature ranges for large niobium deformations : between 700 and 900 °C and above 1300°C.

The study focused on six temperatures : 700, 800, 900°C (industrial temperatures) , 1300, 1400, 1500 °C (very high temperatures) and was applied to niobium sheet samples from the company Heraeus with measured RRR 135 and thickness 1 mm.The measurements were done under a contract with SEP, a french company in the field of space rockets propellers.

At first we made some tests with a strain rate jump method in order to know the temperatures and speeds of deformation where niobium is the most ductile (i.e. where the m coefficient of speed sensitivity is the biggest).

We found that the best values were obtained at 900 and 1400 °C, with a strain rate of 0.1 % of deformation per second in both cases.

After that we made some classical tensile tests at these temperatures and strain rates in order to get the mechanical behavior $\sigma = K\,\varepsilon^{n}$ of the niobium (Table 1).

Table 1 : Mechanical behaviour of niobium

	$\sigma = K\,\varepsilon^{n}$	**ε max (breaking)**
Room Temperature	-	40 – 50 %
900 °C	$\sigma = 110\,\varepsilon^{0.3}$	80-100 %
1400 °C	$\sigma = 30\,\varepsilon^{0.25}$	70 – 120 %

These values of deformation were too low (and too erratic) to let us hope that numerical simulations of the manufacturing process would give us additional interesting information. It was concluded that hot forming of TESLA cavities is not possible with that kind of niobium.

However these low values can be explained by a coarse grain structure (70 to 150 microns) that prevents efficient slipping of the grains in the material.

We have decided to stop our R&D effort on this topic as further research in this field would be rather expensive. That next step, according to our experience and to metallurgy experts, would consist in the

the study (together with niobium providers) of thermo-mechanical treatments to produce niobium with much smaller grains (10 to 30 microns instead of 50 to 150 microns average diameter).

2.3 Copper Plasma Spray on Niobium Cavities

We are involved with IPN Orsay on thermal plasma spraying of copper on to niobium cavities for mechanical stiffening (contribution of IPN-Orsay to this workshop).

Presently single cell cavities are stamped and electron beam welded at LAL,with 3 GHz geometries and different thicknesses (1 to 2 mm). The copper plasma spray is done in industry and the low level RF tests together with thermal conductivity tests,are made at IPN-Orsay. Soon 1.3 GHz single cell cavities of the TESLA shape will be also produced this way.

3 HIGH POWER COUPLERS

The development of a high power coupler for the TESLA superconducting cavities must fulfill the requirements set by the cryogenic environment and by the necessity to reduce the cost of such a device. For the coupler itself some points are already well established: a coaxial structure is the best way to couple to the cavities and is well suited to the thermal constraints while the separation between the cavity vacuum and the gas pressure in the RF network is made by using two ceramic windows, one near the cavity (cold window) the other one in the RF network (warm window) .

To match the coaxial line to the RF network, we have studied a new type of transition, different from the classical doorknob type [3]. Our first goal was to design a transition working under neutral gas pressure; that led us integrate the warm ceramic window in the transition itself. Considering that the cost of the device was also a point of major importance, we tried to relax on the mechanical tolerances. In order to remove any possible remaining multipactor, the design also offers the possibility to apply a DC voltage on the inner conductor of the coaxial line. Finally, to avoid RF breakdown, the amplitude of the electric field in the transition has been kept as low as possible.

Figure 2 shows the general structural layout of the transition after optimization using the 3D electromagnetic code HFSS.

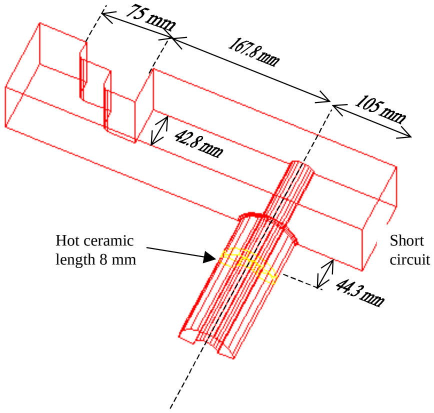

Figure 2: Rectangular to coaxial transition

The 50 Ohm coaxial line fully penetrates into the short-circuited WR 650 waveguide. The warm ceramic window is integrated into the design of the transition: a thin 8 mm cylindrical ceramic window brazed in the coaxial line separates the gas pressure from the coupler vacuum. The transition is matched at 1.3 GHz by using two short lengths of reduced height waveguide; their location fixes the centre frequency while their heights minimize the reflection coefficient. Figure 3 gives the reflection coefficient, seen from the waveguide, versus frequency.

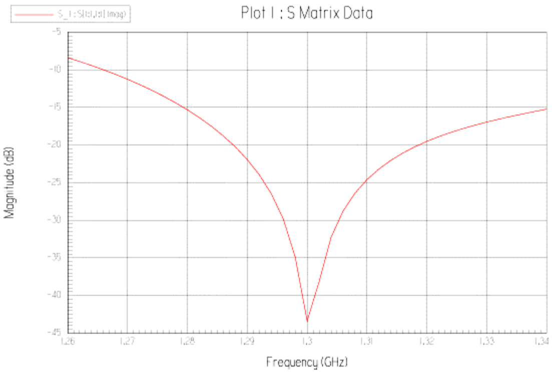

Figure 3: Reflection coefficient vs frequency

Figure 4 is an example of the low sensitivity of this transition to mechanical errors: here, one can see that a large shift of the position of the short-circuit does not affect significantly the centre frequency.

This transition appears to be very simple in comparison to the standard doorknob. Avoiding the need for a high vacuum in the transition, relaxing on mechanical tolerances and using a very simple ceramic window may lead to a significant reduction of the coupler cost.

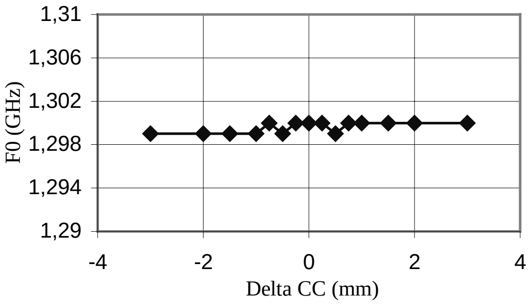

Figure 4: Central frequency vs short circuit position

If a DC voltage is required to remove multipactor in the coaxial line, this transition can be easily DC biased using a version based on the simple structure shown in Figure 5. A RF choke surrounds the inner conductor of the coaxial line and acts as a short-circuit separating the DC access from the RF power.

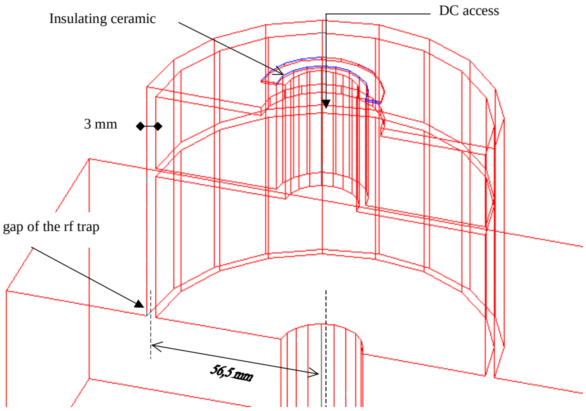

Figure 5: Biased transition

The coupling gap of the choke is located at the top of the rectangular waveguide at 56.5 mm from the axis of the coaxial line; this location is chosen to give a very small coupling. The length of the trap is near 10 cm to operate at 1.3 GHz and the width can be chosen between 3 to 5 mm without significant effects on the matching of the transition. A thin ceramic insulates the DC access from the rest of the transition. The electric field (calculated at 1.3 GHz for 1 W of incident power in travelling wave regime), plotted in Figure 6 shows a reasonable amplitude in the transition, and because of its low coupling to the waveguide the RF choke contains nearly zero electric field.

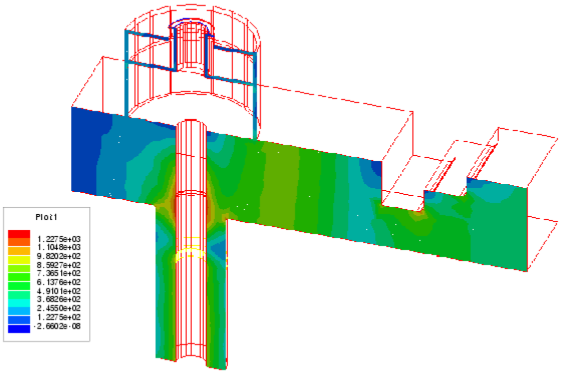

Figure 6: TW electric field at 1.3 GHz

Presently, a first prototype transition,without the DC biased scheme, is being fabricated. We will vary several dimensions (like the location and penetration of the reduced waveguides) in order to validate the structure during low level measurements. In a second step, measurements will be performed up to 1 MW on the high power test bench installed at Saclay in collaboration with the CEA.

4 EXPERIMENTS ON GRADIENT LIMIT AND LONDON DEPTH

In view of the TESLA collaboration it seemed obvious that the accelerator activities at LAL should also include in house R&D on superconducting RF. That motivation led us to collaborate with the University of Genoa, Italy, to set up a low cost experiment (Fig. 7) using existing equipments (high power RF source from LAL; cryostat and He tank from Genoa, but formally from CEBAF). Since the RF peak power is too high a 7 dB coupler has been inserted.

The experiment was dedicated to testing 3 GHz single cell cavities under short pulse, high peak power . By strong overcoupling of the cavities it is possible to feed them with large amounts of stored energy, hence achieve high gradients (magnetic quench) without being limited by thermal quenches. It also permits one to operate at 4 K with lower Q_0. With present operating conditions a coupling factor of 30,000 has been chosen to provide an energy transfer efficiency of 80%.

Particular effort has been put on the instrumentation which led to precise measurements of the London depth by measuring the frequency shift as a function of temperature.

The first cavities tested were fabricated by Genoa University, chemically cleaned in Saclay and tested at LAL, both at low power and high peak power. Gradients up to 40 MV/m have been measured while the London depth measurement has illustrated the poor quality of the Nb with RRR of about 30.

In the near future it is intended to test 3 GHz single cell cavities stamped and electron beam welded at LAL, with and without copper plasma spray.

Details of the experimental set up together with experimental results are presented at this workshop [1].

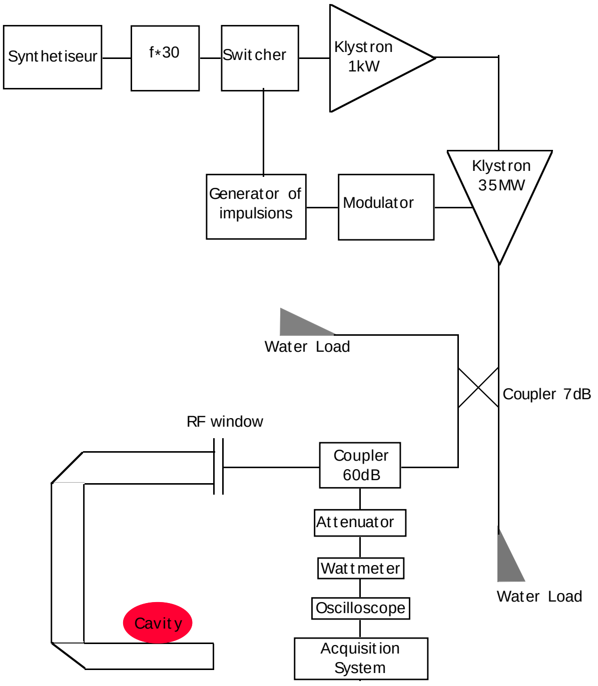

Figure 7 : Schematic of experimental set-up

5 ACKNOWLEDGEMENT

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6 REFERENCES

[1] C.Thomas, Accelerating Field Measurements in 3 GHz Pulsed Cavities,Contribution to this workshop

[2]L.Grandsire, Status of cavities R&D at LAL-Orsay ,TESLA Meeting, March 1-3, 1999 at DESY.

[3] P. Lepercq, private communication.