SRF ACTIVITIES AT IPN ORSAY

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Abstract

R&D activities on RF superconducting cavities have continued at IPN Orsay during the last two years. These activities concern mainly four major topics : basic studies on cavities thermal and mechanical behavior including material characterization, development of a new fabrication technique of SRF cavities based on thermal spraying, design of 5 cells 700 MHz superconducting cavities prototypes for high intensity proton linacs and finally design of an horizontal cryostat (CRYHOLAB) dedicated to the test of 1. 3 GHz and 700 MHz multicell cavities equipped with their auxiliary components. In this paper we report on the recent progress achieved in the above topics.

1. INTRODUCTION

Our involvement on RF Superconductivity was actively pursued during the last two years. The two main goals were to continue the improvement program of 1.3 GHz cavities for electrons (TESLA project), and more recently, the start of a R & D program on 700 MHz cavities, which are now of great interest for the high intensity proton accelerators. The activities concerning the cavities for electrons (TESLA type), were closely related to the studies on new fabrication methods , where performance improvement associated to cost reduction are the main challenges [1]. In a joint effort with two other french laboratories (CEA Saclay and LAL Orsay), and in close connection with several other laboratories of the TESLA collaboration, we started 3 years ago a program for the study and development of a new stiffening method using thermal spray techniques. The Lorentz forces acting on the walls of high gradient cavities produces important detuning and leads to mechanical and RF control solutions which are considered to be technically complex and expensive. Coating the cavity wall with a copper layer can solve the stiffening problem at moderate cost. This technique could also be considered in the case of spunned cavities made from thin Niobium sheets. For 700 MHz cavities for protons, this technique could be interesting for the enhancement of the mechanical stability in low β cavities ($\beta \leq 0.5$) where the cell shape could be incompatible with the stress generated by the vacuum inside the cavity.

The start of a R & D program on cavities for high intensity proton accelerators was a more recent decision [2]. This program was launched in strong collaboration with the two french laboratories mentioned above, and enlarged to other laboratories actively working on this field: INFN Milano (Italy), LANL (USA), etc. Within the franco-italian collaboration, R & D work is performed in order to propose an accelerator for high intensity proton beams. It includes an injector, low energy sections, and high energy sections with RF superconducting cavities.The field of applications of this accelerator is rather large, covering the nuclear energy and waste transmutation, the neutron spallation sources, and several new proposals for fondamental physics research in the field of muon colliders, neutrino factories, and radioactive nuclear beams. The first sudies on this subject are related to the mechanical design of new cavities, and the preliminary conceptual studies on cryogenic systems and equipments needed for this kind of accelerator.

Finally another important task was the construction of a new facility to test SRF cavities: the CRYHOLAB project.It started three years ago, as a joint project of the french laboratories, with the support of the "Conseil Regional de l'Ile de France". This project is now in its final construction stage: the horizontal cryostat, the cryogenic infrastructure, and the RF powering and measuring systems, are now near completion, with a close milestone in the middle of the next year for the first tests in the CEA Saclay site. 1.3 GHz and 700 MHz multi-cell cavities will be tested in this facility together with all its major components: couplers, Helium tanks, cold tuners, etc.

2. THERMAL SPRAYED CAVITIES

At the beginning of this study we found the need of an improved stiffening system for 1.3 GHz TESLA cavities. The cavities can operate at high gradients, close to 25 MV/m, in pulsed mode (1ms pulse length at 5 Hz) and the Lorentz forces acting on the cavity walls lead to important transient detuning which is not compatible with a high stability in field amplitude and phase, as required for high luminosity beams in an e^+e^- collider. The actual stiffening method consists of Niobium rings welded between the cells. Combined with the mechanical structure of the Helium tank, it gives a detuning factor of around 1 $Hz/(MV/m)^2$. A sophisticated RF control system was needed to operate the cavities within its frequency bandwidth at gradients ranging between 15 and 20 MV/m [3].

We have proposed in several papers [4] [5] [6], an alternative stiffening method based on thermal spray of a copper layer onto the Niobium wall. We have considered that three major challenges have to be met in order to reach our goal:

1) Reduction of fabrication costs: less Niobium will be needed if a thinner wall is used, and less EB welding as compared to the actual stiffening technique.
2) High mechanical stability which solves the problems created by the Lorentz forces at high gradient in pulsed mode.
3) High heat transfer between the inner Niobium wall and the Helium bath, needed to operate the cavities under the thermal quench limits.

In a first attempt, Finite Elements model calculations give us some preliminary confirmations about the potential performances of the mechanical stability. Fig. 1 shows a possible coating layer profile, and Fig. 2 shows the calculated detuning (steady state regime) as a function of the accelerating field. A variable thickness Copper layer over the cavity surface could allows to reduce the detuning, but the layer have to exhibit good mechanical properties: high Young modulus, high bond strength, high UTS, and good elongation behaviour. All of them must contribute to a final stiffened cavity able to handle both the thermal and mechanical stress encountered during the mounting, tuning and cooling procedures.

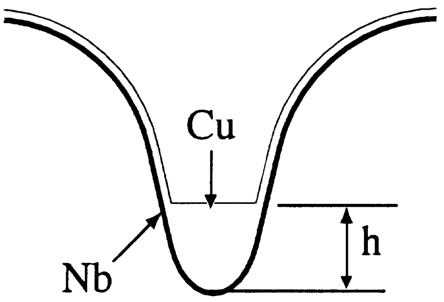

Figure 1 : Profile of the copper layer over the Niobium cavity wall

Thermal model calculations show also that the heat transfer between the cavity wall and the HeII bath has to stay within reasonable limits, in order to not degrade the high gradient performances of the cavities (quality factor and thermal quench limit).

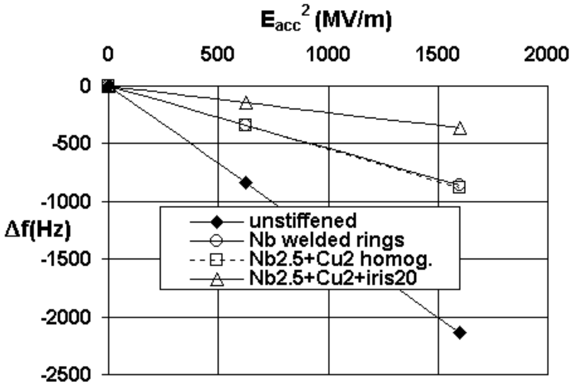

Figure 2 : Model calculations of the Lorentz forces detuning of a 9 cell cavity

Concerning the quench originated by surface defects in the inner side of the Niobium wall, the added thermal sprayed layer do not play an important role. The quench limit is strongly dependent on the high conductivity of the Niobium wall, and only the very close volume around the defect location is concerned by the defect heating. On the other hand a defect free cavity, is limited by the overall thermal resistance (thermal resistance of the wall and Kapitza resistance between the external side of the wall and the Helium bath). In this case the thermal resistance of the additional layer can play an important role. The model calculations show that the whole thermal resistance of this layer (including the Kapitza resitance) must to be less than 5 times the typical Kapitza resistance of a naked Niobium wall at 2K. This value allows to operate the cavities at gradients $E_{acc} \leq 35$ MV/m, which can be considered a good safety margin for the TESLA project [7].

The coating work, associated to an important counsel support, was made by two specialized laboratories in France: LERMPS (Institut Polytechnique de Sevenans, Belfort, France), and Centre des Matériaux (Ecole de Mines de Paris). The mechanical characterization was performed in different sites (ENSAM Paris, LAL Orsay and IPN Orsay), and the thermal characterization was performed at IPN Orsay. Table 1 shows the results obtained with different depositions methods: Atmospheric Plasma Spray (APS), Controlled Atmosphere Plasma Spray (CAPS), and High Velocity Oxy-Fuel (HVOF). The coating Young modulus is rather low if compared to bulk Copper (≈130 GPa), its value depends on the porosity and, possibly on the oxides content. The thermal properties are well represented by the thermal resistance added by the coating (ΔR_g), and by the ratio between this added resistance and the typical value of the Kapitza resistance of Niobium at the same temperature

Table 1 : Mechanical and thermal characterisation of coatings

Process	Mechanical Properties			Thermal Properties	
	Young modulus (GPa)	UTS (Mpa)	Porosity	ΔRg @ 2K ($K.m^2/W$)	ΔRg/Rk
Cu APS (industry)	25 - 40	75	≈ 20/30%	$4.0\ 10^{-4}$ (2 mm)	3
Cu APS (laboratory)	41 - 63	80-120	1-2 %	> $1.8\ 10^{-3}$ (3 mm)	> 16
Cu CAPS	60	100	9.8 %	$3.9\ 10^{-4}$ (2 mm)	3
Cu HVOF	41 -54.5	60 -152	2.6 %	> $1.43\ 10^{-3}$ (3 mm)	> 10
Ti APS	18	-	≈ 20/30%	$5.0\ 10^{-4}$ (2 mm)	3.5

($\Delta R_g/R_K$). The picture in Fig. 3, was taken during the spray process of a monocell 1.3 GHz cavity using the HVOF method at the LERMPS laboratory.

Figure 3 : HVOF spray of a monocell 1.3 GHz cavity

These results show that mechanical and thermal requirements are closely correlated and could lead to a contradictory result. Good thermal resistance seems to be related to high values of porosity, and this parameter has to be lowered for a good mechanical behaviour of the layer. Moreover, highly optimized deposit methods which offers low porosity, gives high oxidation of the layer which in turn is responsible of high thermal resistance and rather fragile and brittle material. Having in mind these preliminary conclusions, we are entering now in a new phase of our study, and we are looking to explore the properties of coatings obtained using Vacuum Plasma Spray (VPS), or Controlled Atmospheric Plasma Spray (CAPS). Both techniques offer less oxidated layers while keeping good mechanical properties. We expect to conclude the first stage of this work during the next year, at this time we hope to be able to propose an industrial deposit technique with good performances. A second phase could start at this moment, with the construction of the first multicell cavities using this stiffening method.

Several contributions to this conference offer a more detailed presentation of this study: an overall presentation of the thermal spray method , including the results with monocell prototype cavities [8], the mechanical results [9], and the thermal results [10].

3. 700 MHz CAVITIES FOR HIGH INTENSITY PROTON ACCELERATORS

The interest for this kind of accelerator, started several years ago in different laboratories around the world. In France, a R & D program was launched to study the main components of an accelerator delivering a proton beam of high intensity (10 mA), with final energy in the range of 500 MeV to 1 GeV. This design includes a high intensity c.w. proton source (IPHI), which is now under test and delivers a 100 mA beam at 100 keV, a copper RFQ (350 MHz) with final energy of 5 MeV, which is now under construction, a copper linac section (350 MHz Drift Tube Linac), and, finally a superconducting linac using 700 MHz cavities. This SRF linac would accelerate protons between an input energy of 90 MeV and a final energy of 500 MeV (1 GeV) using two (or three) different sections with beta values: β_1=0.5, β_2=0.65 (and β_3=0.85).

In the frame of a close collaboration between the french laboratories (CEA-CNRS) and the INFN from Italy, the design of the superconducting linac has actively progressed in the last months. The geometry specifications of both the β_1=0.5 and the β_2=0.65 cavities are completed and several monocell cavities have been tested [11]. Several important steps are foreseen for the next 4 years: 1) construction and test of several multicell cavities, 2) study, construction and test of a new power coupler (P > 100 kW), 3) study, construction and tests of the first cryomodules.

At the IPN Orsay, we have started this program taken in charge the first mechanical calculations of multicell cavities. Finite element model calculations were performed to verify the mechanical stability of β_2=0.65 cavities. Fabrication of multicell cavities using Niobium sheets of thickness 4 mm is possible. The stress created by pressure difference up to 2 bars, can be handled with this thickness value. Calculation of Lorentz forces at accelerating fields ranging from 10 to 15 MV/m, and study of vibrational modes are now progressing. The effect of Lorentz forces on the tuning frequency has to be carefully studied in order to consider the case of operation with pulsed beam, such as it is proposed for spallation neutron sources. For lower beta cavities (β_1=0.5) the study is performed by our partners in Italy, the firsts results show that mechanical stability can be reached by either increasing the wall thickness, or using an additional stiffener. We have also started the preliminary design of cryomodules and associated cryogenic equipments: Helium tank, cold tuner, etc. The initial goal is to prepare the tests in an horizontal cryostat (CRYHOLAB facility), followed by the final assembly of two cavities in the first cryomodule. In a more general approach we are also participating with our partners to the conceptual design of the cryogenic plant and the cryogenic fluids distribution in a future accelerator

4. CRYHOLAB FACILITY

The aim of this project is to provide a flexible and complete facility for testing and measuring, at nominal power, different types of SRF cavities. The cavities will be operated in an "accelerator" environment, with all its associated RF and cryogenic equipments. Fig. 4 shows the main components of this facility. All of them are now in its final construction phase at the three french laboratories collaborating in this project: CEA (Saclay), IPN and LAL (Orsay). All the components will be assembled at the final site in Saclay, during the first quarter of the next year, and a complete cryogenic test must take place during the second quarter.

The cryoplant installed at CEA Saclay can deliver 120 l/h of Lhe, in liquifier mode, to a 2000 l dewar used as intermediate storage during the experiments. A 30 m transfer line is under construction to supply LHe to the cryostat. Low presure helium gas is recovered through a heater and transferred to the pumps by a pumping line of 40 m length.The capacity of pumps allows a mass flow of 4 g/s at 13 mbar (8 g/s at 26 mbar).

The cryostat and the associated cold box must operate at a maximum power of 60 w (1.8 K) in order to test cavities at full RF power [12]. The dimensions of the cryostat allow the test of 700 MHz and 1.3 GHz multicell cavities completely equiped: Helium tank, cold tuner, power and HOM couplers, etc. A radiation shield, cooled by LN_2, operates at 80 K. A 4 K loop is also provided to cool the cavity support table and eventually, other components of the cavity (i.e. couplers). The cryostat is now in its final assembly phase (Fig. 5) and will be tested in a preliminary cryogenic configuration before the end of this year. The test with the liquefier, pumping system and associated cold box will take place next April 2000.

Two RF test modes are possible with the CRYHOLAB facility: 1) low power RF tests using a 250 W wideband amplifier (700 MHz - 1500 MHz) and a phase locked loop with all the RF measurement and control systems. 2) high power RF tests at 1.3 GHz using a TH2086 Klystron with its High Voltage Modulator: 300 kW (2 ms pulse length, 10 Hz) or 1.5 MW (500 µs, 1 Hz). All the low level RF systems (700 MHz and 1.3 GHz), and the 1.3 GHz power source are constructed and will be assembled at the beginning of the next year. A c.w. power source of 300 kW at 700 MHz will be installed later.

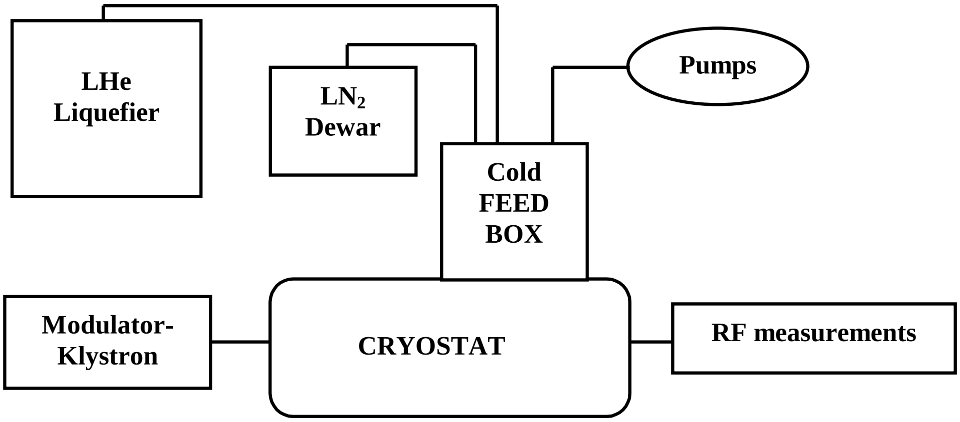

Figure 4 : CRYHOLAB facility for 700 MHz and 1.3 GHz cavities tests

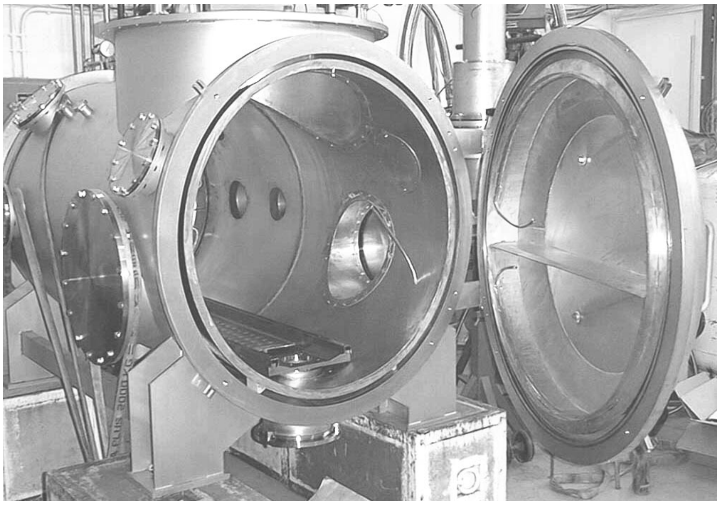

Figure 5 : View of the CRYHOLAB cryostat during assembly

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