PRELIMINARY DESIGN OF A STAINLESS STEEL HELIUM TANK AND ITS ASSOCIATED COLD TUNING SYSTEM FOR 700 MHZ SCRF CAVITIES FOR PROTON.

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Abstract

For the R&D program on 700 MHz SCRF cavities for proton, we study the helium tank attached to a 5-cells cavity and its cold tuning system. Our work is orientated to a stainless steel helium tank, mainly for cost reduction. We present in this paper preliminary tests and results giving good arguments on the feasibility of a stainless steel helium tank brazed on the cavity cut off. Then we describe the helium tank design and the mechanical cold tuning system based on the "Soleil" principle designed at CEA Saclay.

1 INTRODUCTION

The purpose of the paper concerns the whole mechanical structure composed by the cavity, the helium tank and the cold tuning system (CTS). These elements, as shown below, are strongly connected in term of mechanical design as the helium tank gives, associated with the cold tuning system (CTS) , a parallel stiffness to the cavity. This stiffness is linked to several cavity characteristics as cavity stiffness, static Lorentz forces and the CTS stiffness and mechanical resolution.

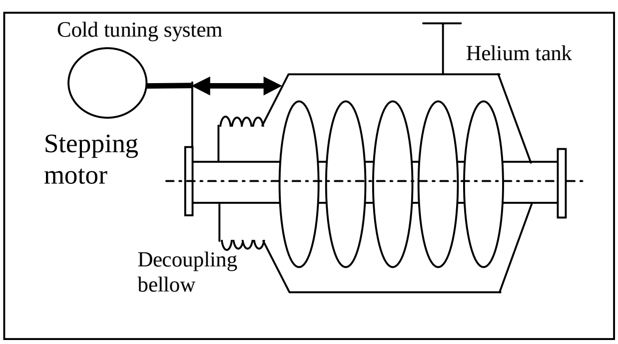

Figure 1 Principle layout of the cavity cold tuning

The compensating bellow, decouples the cavity to the rest of the structure allowing the CTS to pull or push the cavity. Therefore the frequency shift caused by the lorentz longitudinal component forces depends on the stiffness of the CTS/Helium tank ensemble.

In our case the use of Stainless Steel (SS), instead of titanium, for the helium tank and the CTS reduces considerably the manufacturing costs. The draw back is either great thermal stresses on the cavity, either a large stroke for the CTS. Further more the technological feasibility of this solution remains to be proven.

The paper describes preliminary tests on the feasibility of a SS helium tank, the design of the helium tank and the Cold tuning system.

2 PRELIMINARY TESTS

Brazing a stainless steel helium tank on the niobium cavity cut off stands several technological difficulties.

A first optimistic foreground was given by the CERCA French company who brazed with copper stainless steel CF flanges on some cavities cut off of the former APT project. Several tests and simulations were performed on various technological aspects and consequences of using SS helium tank.

In the case of the helium tank, super fluid helium is directly in contact with the brazed interface which would emphasis the gaseous flux inside the cryostat insulation vacuum in case of leaks. This risk of leak is improved by the great thermal hoop stresses taking place at cool down between SS and Niobium. A first experiment was stand to verify the tightness of the brazing on a mock up at super fluid helium.

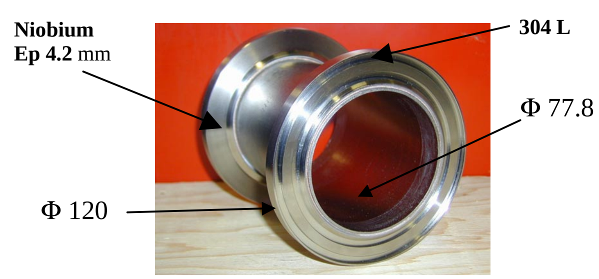

Figure 2 Niobium / SS Mock-up

This mock up consists in a Niobium tube where stainless flanges are brazed at extremities. There is similarity of the maximal thermal stresses at the brazing area between the mock up and the final design of the tank which are respectively about 150, 80, 60 N/mm^2 for the Niobium tube, the copper interface (70 µm thick) and the SS flange.

An additional longitudinal load of about 5000 N for each flanges was added to simulate forces generated by the CTS.

No leak at 2 K was detected, after 10 thermal cycles at 80 K, with a sensibility better than 2 10-9 mbar l/s.

Even if the EB welding heats locally the bounded parts we may have over heating in a small area. In our case, on the main coupler side the brazed helium tank is close to the EB welding of the first cavity Iris. Risks of migration and diffusion of copper may occur. It effects pollution of the RF surfaces or the EB welding itself causing leaks.
Samples were analysed for different distance between the copper brazed interface and the EB welding. Conclusions were that the diffusion is negligible but for distances about 3-4 mm the copper is melt and may flow toward the EB welding area. A minimal distance of 9 mm, taking into account the tests samples and thermal simulations, was chosen for the design of the tank

Effects of the residual magnetic field in stainless steel is to be tested in the "CRYHOLAB" horizontal cryostat with a first 700 MHz mono-cell (fig. 3) equipped with its whole SS helium tank. A first test of this mono-cell equipped with only its 316 LN extremity caps has been performed in a vertical cryostat and shows very good RF performances ($Q_0 \sim 4\ 10^{10}$, 25 MV/m before quench).

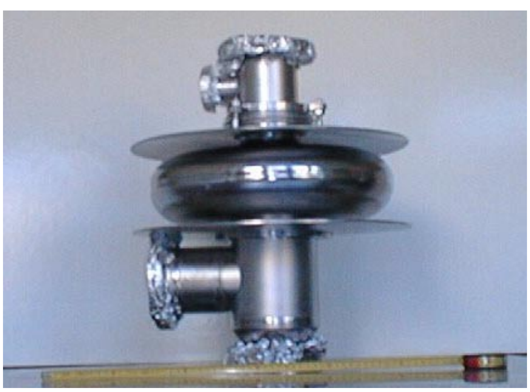

Figure 3 700 MHz mono cell w. SS helium tank end caps

3 MECHANICAL TUNING

As said above the CTS and helium tank designs are subjected to cavity mechanical parameters. This parameters are also needed to set up the fundamental frequency the cavity must have before cool down.

3.1 Cavity tuning parameters

The parameters presented below were calculated for a 5 cell 700 MHz cavity [1].

Longitudinal frequency sensitivity $\delta f/\delta l$	~ 250 kHz/mm
Longitudinal cavity stiffness $\delta F/\delta l$	~ 1592 N/mm
Band width for Ip ~ 20 mA Δf	~ 500 Hz
Static longitudinal Lorentz Force $F_{Lorentz}$	13.86 N
Thermal differential contraction $\Delta L_{Helium\ Tank} - \Delta L_{cavity}$	~ 1.6 mm/m @ 4 K
Frequency shift due to cool down $\Sigma \Delta f_{CD}$	To be measured
Incertainity on $\Sigma\ \Delta f_{CD}$ ε_{CD}	~ 300 kHz Arbitrarily set !!

Table 1 : Cavity tuning parameters

Several design numbers can be evaluated :

- The mechanical resolution of the CTS is taken as

$$\frac{\Delta f}{20} = 25Hz \triangleright \frac{25}{\delta f / \delta l} \approx 0.1\mu m$$

- The frequency shift caused by the static lorentz force must be inside the bandwidth. It means that the stiffness of the Helium tank CTS ensemble should be :

$$K_{\tan k+CTS} > \frac{F_{Lorentz}}{\Delta f} \cdot \frac{\delta f}{\delta l} \approx 7000 N/mm$$

- When acting the CTS a part of the deformation goes to the helium tank and the CTS parts. We want to have 90 % at least of the CTS displacement going to the cavity :

$$K_{\tan k+CTS} > \frac{\frac{\delta F}{\delta l}}{1/90\% - 1} \approx 15000 N/mm$$

- The design value taken for the helium tank / CTS stiffness is $k_{\tan k/SAF} \approx 20000 \cdot N/mm$

3.2 Warm frequency

The different fabrication steps of the cavity modify its fundamental frequency [2] (fabrication incertainities, chemical preparation…). The warm tuning (field flatness adjustment) being the last process affecting the cavity shape is used to adjust the frequency to the good value. This value is connected to the frequency shift during cool down and the maximal range of the CTS.
The CTS can operate in only one direction (pulling or pushing) to avoid discontinuity of the motor's steps

/cavity deformation relation due to backlash in the CTS mechanical parts.
Assuming this we can give the relation between the warm frequency before cool down and the maximal range of the CTS.
Two cases are possible.

- Case 1

The cold tuning system is attached to the cavity and the helium tank. At 2 K the cavity is compressed by 1.6 mm/m.

The target frequency f_0 must be outside the cold frequency band $f_C \pm \frac{\varepsilon_{CD}}{2}$ to avoid the CTS to act either by pushing or pulling on the cavity. In this case the CTS only stretch the cavity.

Δf_W corresponds to a pre stress applied at 300 K by the CTS to limit the compression stress on the cavity at 2 K.
The warm frequency before cool down is then :

$$f_w = f_0 - (\sum \Delta f_{CD} + \frac{\varepsilon_{CD}}{2} + \Delta f_{Lorentz}) - \Delta f_W + (\Delta l_{tank} - \Delta l_{cav}) \times \frac{\partial f}{\partial l}$$

Maximal cavity compression : $\Delta l_{Tank} - \Delta l_{cav} - \Delta f_w \times \frac{\partial l}{\partial f} < 1.6mm$

Maximal tuner range : $(\varepsilon_{CD} + \Delta f_{Lorentz}) \times \frac{\partial l}{\partial f} < 1.3mm$

This case facilitate the fixture conception of the CTS on the rest of the structure but high stresses may appear on the cavity walls (~ 25 N/mm^2) and on the CTS. The reproducibility of the frequency after cool down depends here on the dimensional tolerance of the CTS which would cause more scattering from one equipped cavity to the other. On the other hand the stroke of the CTS is low, about 1.3 mm.

CASE 2

The CTS is not attached to the cavity during cool down. The cavity contracts freely at 2 K and receive no thermal stresses.

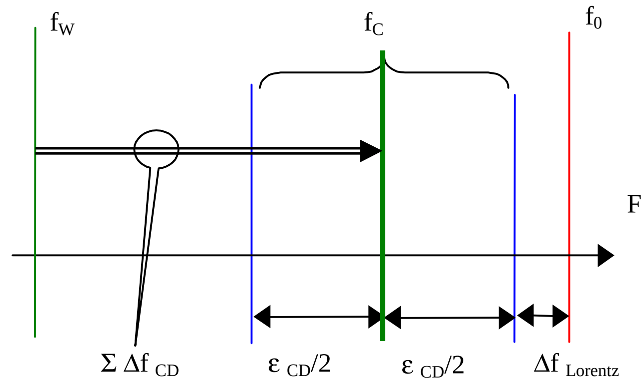

Figure 4 Frequency history during cool down-case 2

$$f_w = f_0 - (\sum \Delta f_{CD} + \frac{\varepsilon_{CD}}{2} + \Delta f_{Lorentz})$$

Maximal cavity elongation : $(\varepsilon_{CD} + \Delta f_{Lorentz}) \times \frac{\partial l}{\partial f} < 1.3mm$

Here the CTS must recover the differential thermal contraction between the tank and the cavity before stretching the cavity to its target frequency. Its maximal range is then :

$$(\varepsilon_{CD} + \Delta f_{Lorentz}) \times \frac{\partial l}{\partial f} + \Delta l_{Tank} - \Delta l_{cav} < 3mm$$

For this case the structure receive no longitudinal thermal stress and the cold frequency f_C depends only on the cavities shape dispersion. The back draw is the more complicated conception of the CTS fixture and a greater required stroke.

4 HELIUM TANK DESIGN

The helium tank [3] plays the role of a cryogenic fluid container as well as a stiff mechanical structure. The

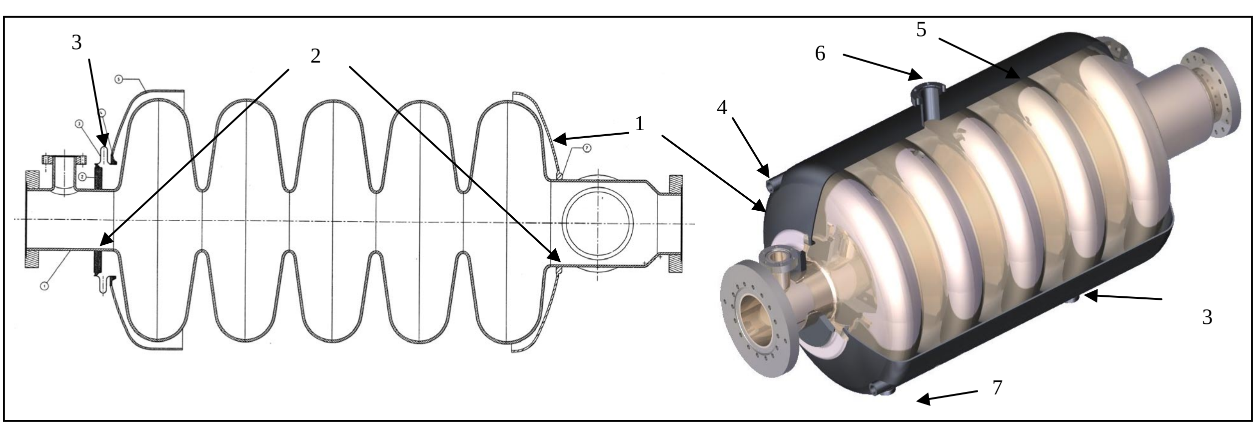

Figure 5 Helium tank design

design presented below is for a 700 MHz β= 0.65 5 cell cavity being currently manufactured.

The extremities, normalised 3 mm thick and 400 mm diameter domed cups (1), give a better stiffness than conical ends. For a load applied on the beam tube the longitudinal stiffness can reach about 55 kN/mm, which gives, associated with the cylindrical part of the vessel a total stiffness of about 50 kN/mm.

The SS parts (2) are brazed on the Niobium cut off at a minimal distance of 9 mm from the nearest EB welds.
The thickness of these rings is 15 mm to reduce the hoop thermal stresses at the copper interface without over stressing the niobium tube .
The de coupling bellow (3) allows 6 mm displacement.
Four supports (4) are welded close to the external diameter of the cups (where the tank stiffness is higher) to fix the CTS.

The vessel (5), 400 mm diameter, is as close as possible to the cavity equators to limit the volume available for helium inventory. A 40 mm CF cryogenic port onto the tank (6) is used for the feeding of super fluid helium from an auxiliary pot. Two 16 mm CF ports (7, 8) at the bottom of the tank are respectively dedicated to the cool down of the cavity and the relation to the auxiliary pot for LHe level measurements.

5 COLD TUNING SYSTEM DESIGN

We designed a CTS able to work in the case 2 mechanical tuning seen above. This involves a great stroke which is not incompatible with the rather high mechanical resolution required. Therefore a mechanical system with rolls compatible with vacuum and cryogenic temperature has been chosen.

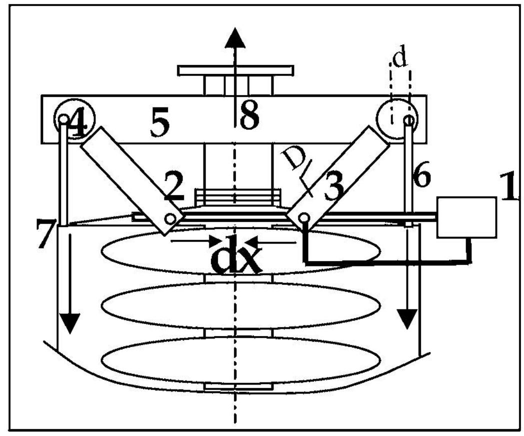

Figure 6 CTS Principle layout

We also give us the ability to insert in this system piezo electric actuators to achieve finer resolution and dynamic tuning for possible pulsed beam operations.
The CTS principle used was designed at CEA Saclay for the "SOLEIL" project [4].

It is typically constituted of a cold stepping motor (1) with 200 steps by turn associated with a gear reduction of ratio r = 1 : 50 . The engine torque and rotation (C_m and α_m) are transmitted to a screw /bolt mechanism (2) with a thread p. The two arms (3) rotate around the axis (4), loading symmetrically the beam tube flange (8) and the helium tank (7) with eccentric rods (6).
The lever arm has a ratio h given by the length of the arms (3) and the eccentricity of the rods (6) : h=D/d.
The cinematic and static relations are :

$$dx_{CTS} = \frac{p}{r \cdot 2 \cdot h} \cdot \frac{\alpha_m}{\pi} \quad \text{and} \quad F_{CTS} = \eta \cdot \frac{2 \cdot \pi}{p} \cdot h \cdot r \cdot C_m$$

and : $dx_{cav} = dx_{CTS} - F_{CTS} \cdot \dfrac{1}{k_{CTS/\tan k}}$

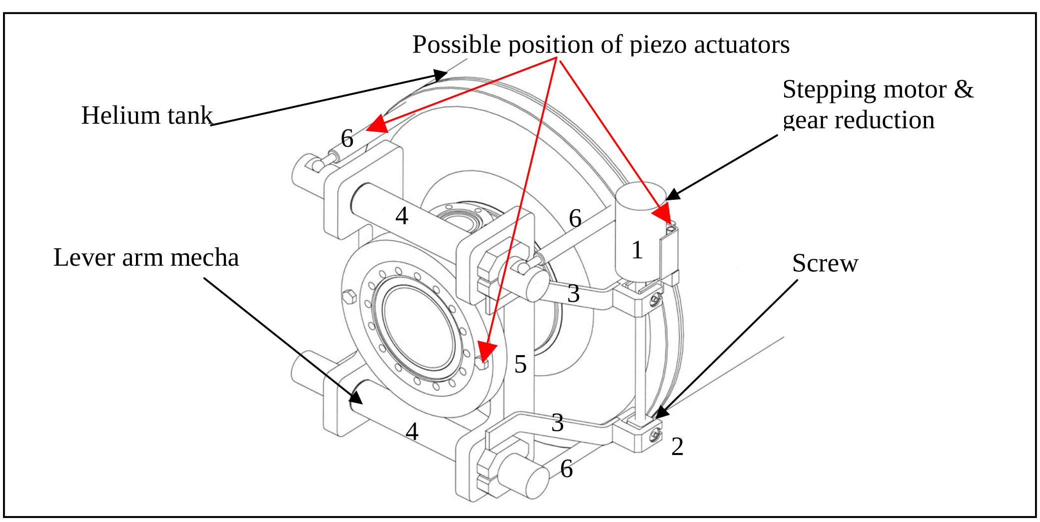

Figure 7 CTS design

The theoretical mechanical resolution is then :

$$rés < \frac{p}{r \cdot 2 \cdot h} \cdot \frac{\alpha_{\min i}}{\pi}$$

The lever arm ratio has been taken to 10 mainly to limit the load (about 600 N max.) on the screw/bolt mechanism which is the weak part in term of friction and wear. It leads to a designed resolution of about 25 nm. The designed CTS longitudinal stiffness is about 35kN/mm, which leads to an overall stiffness of the CTS/helium tank structure of 20kN/mm.

As the cavity contracts freely the CTS will receive no tensile stresses during the cool down of the structure. Further more the pressure loads on the CTS occurring during the cryogenic processing are limited by the stiffness of domed cup and the use of a small diameter compensating bellow. Therefore It makes possible the insertion of piezo actuator with few tensile loads and no sensible stress induced loss of stroke. These piezo would be used as well as sensors, to validate simulations of dynamic Lorentz forces effects in pulsed mode and measure external vibration disturbances, and actuator to perform fast fine tuning and dynamic compensation of the frequency shifts.

6 SUMMARY

The design of a 5 cell β = 0.65 700 MHz SCRF cavity helium tank and its associated Cold Tuning System have been described. The feasibility of the use of Stainless Steel for the helium tank is to be proven with the test of an equipped mono cell in the horizontal “CRYHOLAB” cryostat before the end of the year. In parallel the CTS is to be manufactured and efforts on the characterization and use of piezo actuators at 2 K are performed.

7 REFERENCES

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