BETA TUNABLE 700 MHz INSERT WITH NATURAL CONVECTION PRECOOLING

D. Barni, C. Gesmundo, C. Pagani, G. Varisco

INFN-Milano, LASA- Segrate 20090 ITALY

Abstract

A cryostat insert to study and measure RF cavities above 700MHz, at different beta, is under development. The insert is separated into different parts, in order to make the assembly easier and cleaner. A system for temperature mapping during the cold test allows the control of the hot spots in the cavity walls. The temperature mapping system can be adapted to the different betas shapes. A sliding antenna allows to optimize the RF coupling to the system, keeping the cavity always in vacuum and clean conditions. The insert is designed to fit into an existing larger cryostat by means a reduction chamber. The vacuum space between the vessels is used for the liquid nitrogen pre-cooling phase, when the insert is cooled by free convection of pressurized Helium gas.

1 INTRODUCTION

In the framework of the Italian Project TRASCO[1], in collaboration with the ASH French program[2], a test facility for measuring superconducting cavities at 700 MHz is under construction and commissioning at LASA (Laboratory of the INFN-Milan). The program will test cavities for a high energy proton linac with beta in the range of 0.46 to 0.85. The laboratory is being prepared to operate such tests[3].

2 THE TEST FACILITY

In order to accomplish the necessities of the TRASCO project the LASA experimental area is going to be adapted as a RF test facility for cavity power testing. A vertical cryostat, 4090 mm depth and 700 mm diameter, for the test of 500 MHz cavities already exists in a bunker with the ancillaries for Radio-protection and Gas control.

2.1 General layout

The SC-cavities power test facility (Fig. 1) has been adapted to the new necessities; a 500 W amplifier (UHF Band) has been installed. Helium and Nitrogen transfer lines and the pumping system are almost ready. The original system was designed to test 500MHz SC cavities for another INFN project and now it has been adapted to the TRASCO needs. In order to reduce the helium consumption an inner, smaller, helium tank has been designed (ϕ=580 mm) to fit the dimensions of the smaller 700 MHz cavities. The new vessel reduces by about 500 liter the liquid He needs for a typical test. Due to our
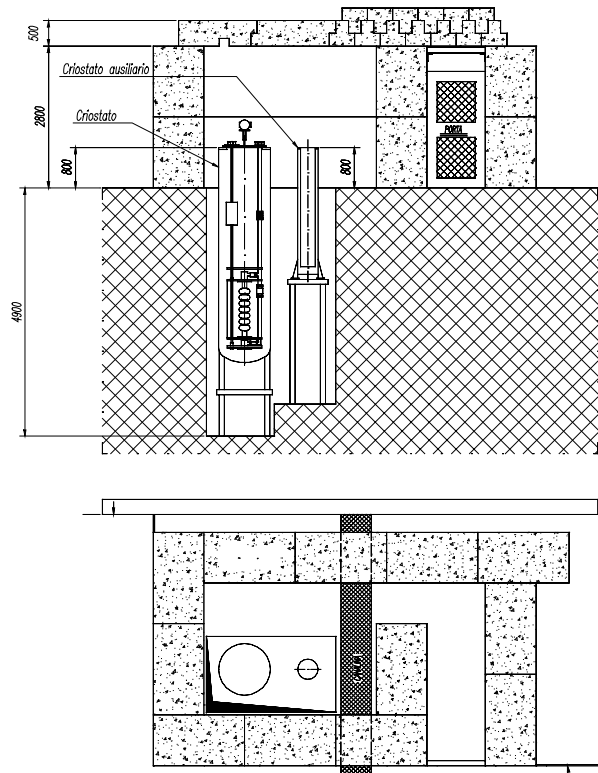

Figure 1: General layout of the bunker where the vertical cryostat has been installed .

liquid He plant capacities we have to fill the helium vessel using one 1000 liter dewar and a few small 500 liter dewars. A typical test will consume about 3000 liters, The 500 liters reduction amounts to 16 % of the inventory.

The new vessel has also the possibility to use a different precooling procedure with a separated liquid nitrogen circuit and free convection on pressurized Helium gas, without gas mixing and reducing the dangers of liquid nitrogen icing during the final cooldown. This argument is discussed in the second part of the paper.

2.2 The Insert

In order to measure cavities with different geometrical beta and with different number of cells, the new insert has been designed so to be compatible with the TRASCO requirements. The different measurements necessities have been summarized in Table 1.

The insert has been designed to fit the reduced helium vessel and Teflon sliding pads have been fixed for an easier assembling and a less critical operation during the insertion in the vessel.

The insert, shown in Figure 2, is divided into 2 section for easier handling. The upper part is the real insert with a large stainless-steel flange with pass-trough for electrical connections, RF input and output, and vacuum pumping.

To standardize the system all connection are done by KF40 flanges welded on the stainless steel upper flange. The connections have been divided into logical groups: electrical, vacuum system, RF-input and output and cryogenic connection; each group has the minimum number of flanges, with the option of "multiplying" them with extensions.

Table 1: Insert length acceptance necessities

Type	Beta	Length
Cavity	0.5	900 mm
Monocell	0.5	400 mm
Cavity	0.65	1100 mm
Monocell	0.65	440 mm
Cavity	0.8	1480 mm
Monocell	0.8	480 mm

The lower part of the insert, that holds the cavity, is connected by M20 screws to the upper part by an aluminum plate. The cavity is supported by its lower flange and clamped by two annular pieces (Fig. 3). The upper flange of the cavity can be guided or fixed according to necessity; the two options are obtained by reversing the same fixer. To allow different cavity lengths the plate fixing the upper flange of the cavity is sustained by four stainless steel rods, using clamping fixtures. Similar fixtures support the apparatus for thermal mapping during the power test. The clamping fixtures are stainless steel blocks tied by small screws over the rods, friction forces guarantee the stability of the position during cooldown and operation.

The connection to the cavity vacuum pumping system is done on the lower flange by two valves that close both the pumping tube and the cavity during assembling (Fig. 3). The assembling procedure assumes that the cavity, already clean and under vacuum, is fitted in the insert (all the assembling are done keeping the cavity vertical) with the pumping line already under vacuum.

Under a laminar flow system the external flanges of the valves are cleaned and connected, the interconnection is then pumped by the pumping line. The cavity valve is opened when vacuum conditions on both sides have been reached, in order to minimize dust deposition in the cavity during the test. The RF antenna is mounted over a bellowed system to allow variations of the coupling without changing the antenna.

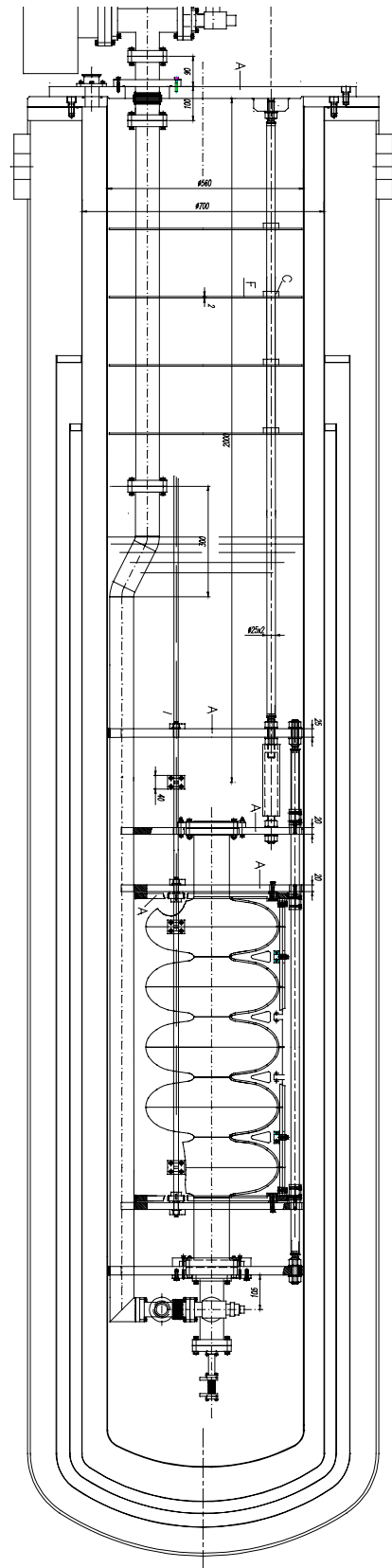The temperature measuring system is driven by two gear disks connected to a computer controlled motorized shaft.

Figure 2: Vertical cross section of the insert with a schematical 5 cell cavity at beta = 0.65   Temperature monitoring can be seen.
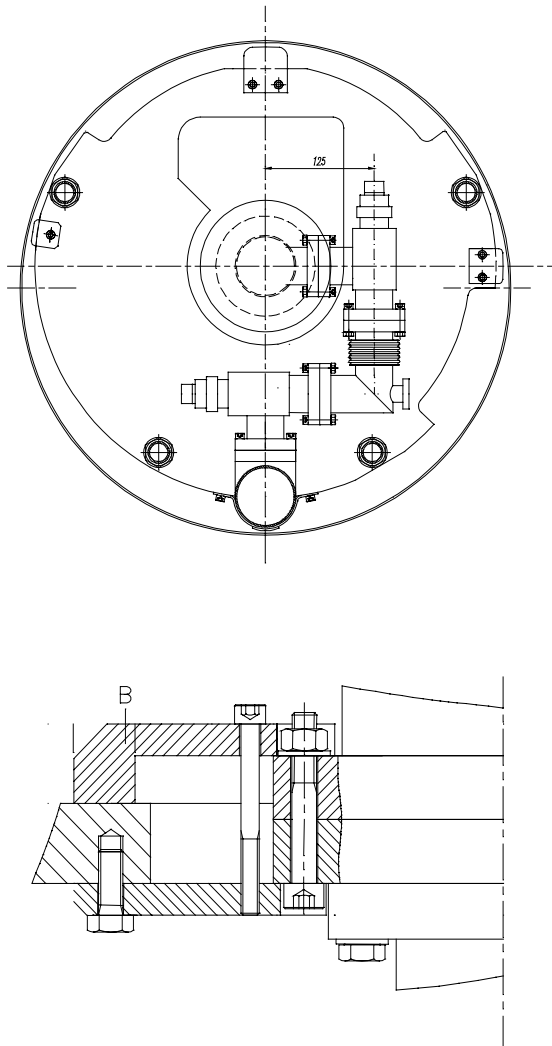
The flow can be considered laminar if:

$$Gr(T, T_C) \cdot \Pr(T) \geq 10^9 \qquad (6)$$

Using condition (6) the convection heat exchange is univocally defined.

The dynamic system has two state variables: the Helium temperature(T_{He}) and the cavity temperature(T_{Nb}). No temperature distribution is consider along the cavity wall.

$$V \cdot (\rho(T_{He}) \cdot Cp(T_{He}) - \beta \cdot C_{rt} \cdot (300K - T_{He})) \cdot \frac{\partial T_{He}}{\partial t} =$$
$$h(T_{He}, T_{LN}) \cdot (T_{He} - T_{LN}) \cdot S_{He} - \qquad (7)$$
$$h(T_{Nb}, T_{He}) \cdot (T_{Nb} - T_{He}) \cdot S_{Nb}$$

$$P \cdot C_{Nb} \cdot \frac{\partial T_{Nb}}{\partial t} = h(T_{He}, T_{Nb}) \cdot (T_{He} - T_{Nb}) \cdot S_{Nb} \qquad (8)$$

where:

- V: vessel free space
- P: Cavity and ancillary weight
- rt Room Temperature
- C_{Nb} Niobium specific heat

Equation (7) drives the helium temperature transitory, the helium gas (1st line, first term) is cooled by the LN wall (2nd line), it is warmed by the cavity wall (3rd line) and it is also warmed by the helium gas injected by the pressurization system (1st line, second term).

Equation (8) describes the cooling effect on niobium by the helium gas.

Using data extracted from the geometry of the new insert, a numerical solution of the system has been run. In order to take into account all the ancillaries the cavity weight has been doubled.

The helium and niobium temperature are plotted in Fig. 4 as a function of the cooldown time, assuming time = 0s when the cold vessel surface is at the LN temperature. The results are very interesting and a few things should be remarked:

- The helium temperature history shows two time constants: the first is very fast (few seconds) and is related to the gas cooling at about 100 K, then a second time constant, related to the heat exchange with the cavity surface, drives the final cooldown
- The convective heat exchange coefficient jumps between turbulent and laminar in the first part of the transient due to the high temperature drop in the system.
- The cavity cooldown follows with its inertia the helium temperature, the slope variation can be interpreted by the temperature dependence of the niobium specific heat
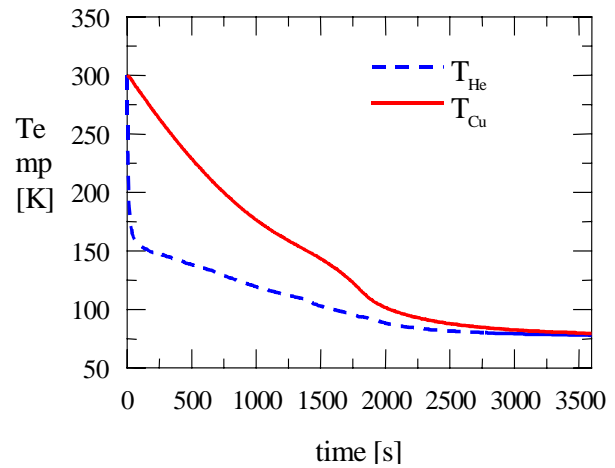

Figure 4: Transient cooling of the insert by free convection. The Helium temperature (T_{He}) drive the cooldown of the cavity (T_{Cu}).

3.1°Model test

To check and to validate the numerical model used to study the insert pre-cooling by free convection, a small equivalent system has been manufactured and monitored during a cool-down. The system consists of a small stainless steel vacuum chamber (100 mm diameter) with an isolated G10 support keeping a copper cylinder (with an height of 20 mm and a diameter of 40 mm).
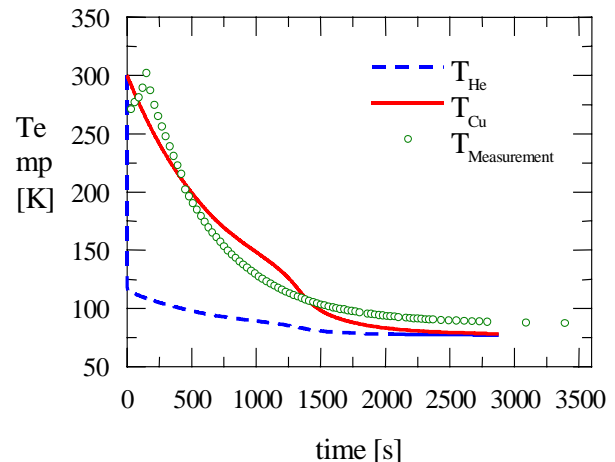
Figure 5: Cross check between the experimental measurements (open circles) and calculations from the dynamic model. Only the Copper temperature has been monitored.

A calibrated temperature sensor monitors the copper and helium temperatures. A cryogenic pipe (about 1 m long) connects the vessel to a box chamber, that can be pumped or filled by pressurized helium gas. To have a reference of the background heat exchange a measure has been run with the system in vacuum. The measure ran for about 4 hours with a temperature decrease of just few K, corresponding to a thermal losses that are absolutely

negligible with respect to the free convection case. This consideration drives us to neglect background contribution by radiation and by heat conduction through the G10 supports and sensor cables.

Using the geometrical data from the test configuration a numerical integration of the analytic system has been run, and the results are plotted in Figure 5.

Only the copper block temperature has been checked, but the simulation follows very well the experimental data. The calculations exclude in this geometry the possibility of "turbulent" heat exchange. The main difference between the simulation results and the experimental data is the "bumpy" behavior of the simulation. This effect is due to the copper specific heat temperature dependence. The simulations neglect the spatial temperature distribution of the sample, and hence of the copper specific heat. The final effect is that the real transient is faster at the beginning of the cooldown and slower at the end but on the average is following the calculated curves.

Another difference is in the final temperature: the calculation made the hypothesis that the free convection process is always occurring, but when the temperature drop is a few K the gas movement stops and the heat exchange is driven by the conduction effect thought the helium gas.

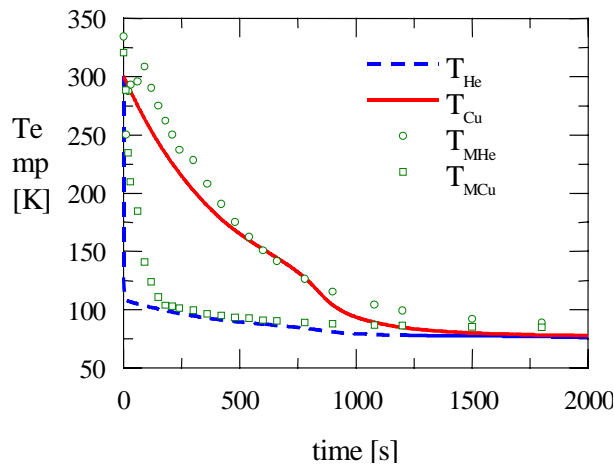The final measured temperature is about 85 K.

Figure 6: Experimental data and calculation in the second test. Box are measures while line are the calculations for both copper and helium temperature.

To check if the parameters dependence of the model is correct, a different sample has been inserted in the chamber. The new sample, again made by copper, is a cylinder with an height half of the previous one (10 mm, and the same diameter of 40 mm). The new sample has a different ratio between volume (the mass to be cooled) and external surface (the cooling surface), hence the results should be different. In this test also the He temperature has been monitored. The results are shown in Figure 6.

The calculation reproduces well the new situation and also the He temperature is well described. The effect of the temperature distribution in the copper block is less evident (the block is about twice smaller) and the cooling time are reduced by about a factor of two.

Also in this case the final temperature for both Helium and copper is about 85 K, when the temperature drop is too low to maintain the free convection system.

3.2 Final considerations

The test studied have demonstrated that free convection on a pressurized helium vessel can be studied using standard numerical correlation and that the model developed can follow the complexity of the problem.

The results presented suggest us that free convection is a good heat exchanger that will drive the cavity cooling without introducing time delays. The helium and nitrogen gases will never be mixed, avoiding every possibility to ice nitrogen in the helium vessel.

In the test apparatus the helium from the pressurized line is injected from the above of the system, in the real insert the helium gas is injected from below. Helium at room temperature from the line is lighter and moving on the upper side of the insert will enhance the gas movement.

4 CONCLUSION

An insert with the possibility of measuring cavities and monocells at 700 MHz and at different beta has been presented. The system will be used in an existing larger vertical cryostat, using a reduction vessel to minimize the helium consumption. The presence of a vacuum space between the two vessels suggested the possibility of using it during the precooling to the LN temperature, by means of pressurized helium acting as the heat exchanger between the liquid nitrogen and the cavity. To test the model used for the calculations a mock up of the system has been built and monitored. Experimental data are well represented by the calculations made with the numerical model, confirming that free convection by pressurized helium is a good heat exchanger.

5 REFERENCES

[1] C. Pagani, "Activities on the High Current SC Proton Linac for the TRASCO Project", OECD/NEA Workshop on Utilization and Reliability of High Power Accelerators, Tokai-Mura, Japan, October 1998.

[2] H. Safa, "Superconducting Proton Linac for Waste Transmutation", these Proceedings, Contribution WEA005.

[3] C. Pagani, "Superconducting RF activities at INFN LASA", these Proceedings, Contribution MOP008

[4] J.G. Weisend, "Handbook of Cryogenic Engineering", Taylor & Francis 1998