PROGRESS ON THE π-MODE X-BAND RF CAVITY FOR SPARC

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Abstract

The Frascati photo-injector SPARC (Pulsed Self Amplified Coherent Radiation Source) will be equipped with a X-band RF cavity for linearizing emittance to enhance bunch compression and for reducing bunch longitudinal energy spread. The nine cells standing wave cavity prototype made of separated cells has been already built and measured. In this paper we report on characterisation of the first brazed prototype. Heat load studies have been performed as well to design the cooling system for the final device.

INTRODUCTION

The X-band structure operating at $11.424GHz$, designed to obtain $42MV/m$ accelerating gradient, is a 9 cells π-mode structure fed by a central coupler. The sketch of the cavity profile with dimensions is reported in Fig. 1. The design of the structure, the cavity parameters, and the field measurements made on a non brazed copper prototype is reported in [1]. In this paper we report on the characterisation of the brazed copper prototype [2].

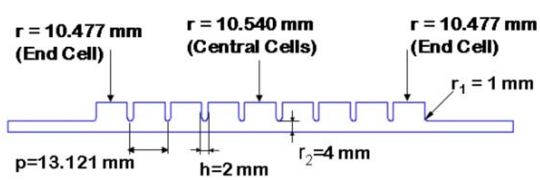

Figure 1: 2D profile of the X-band structure.

BRAZED PROTOTYPE

The prototype geometry has been properly studied to allow a good brazing process and to avoid the diffusion of the brazing alloy inside the cavity volume. For this reason some special grooves have been machined on the contact area between contiguous cells. As Fig. 2 shows, REGION 'A' is the contact area, REGION 'B', that has a vertical dimension of a few tens of micron, will receive the liquid alloy coming from the adjacent $0.6mm$ alloy wire that is initially located in a groove $0.7mm$ deep and $0.8mm$ wide (REGION 'D'). The last area, REGION 'C', that is $0.5mm$ deep, is necessary to obtain vacuum inside the cavity and to avoid that melted alloy escapes towards outside. The material used to made the RF cavity is Cu/OF, UNI 5649/71, and the brazing alloy is eutectic Ag/Cu 72/28, $0.6mm$ wire whose melting point is $780°C$. After cleaning procedure, the structure to be brazed is mounted inside the oven with its axis of symmetry in vertical position. The contact pressure among the cells is obtained only with $0.5kg$ weight, without using tie rods. Our tests have demonstrated that: the total length of the structure, as well as its coaxiality, are not modified by the brazing operation, the use of weight instead of tie rods to keep in contact the cells during the brazing is simple and effective, the working pressure during the brazing operation, roughly $10^{-5}mbar$, is sufficient and the results of the vacuum leak checking procedure are fully satisfactory.

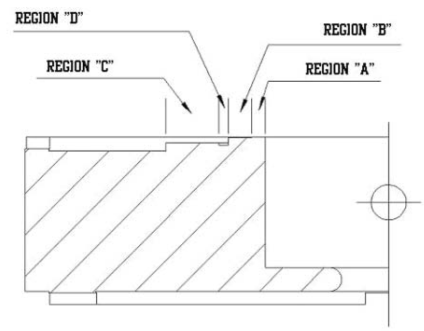

Figure 2: Brazing profile.

Frequency and Q-factor measurements

The transmission coefficient between the small antenna, fixed on the lateral cell, and the central coupler compared with the one of the non brazed prototype is reported in Fig. 3. The brazing procedure has reduced the visibility of the unwanted modes having a zero field in the central cell, as we can see. The measured dispersion curve before

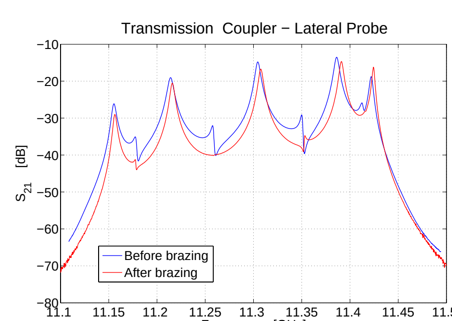

Figure 3: Transmission coefficient between the lateral antenna and the central coupler.

Table 1: Quality and form factors measured before (I) and after (II) brazing on the prototype compared with the numerical results

	HFSS	Superfish	Meas I	Meas II
$f_0(GHz)$	11.4244	11.4240	11.4239	11.4244
Q_0	8500	8070	7900	8066
$R/Q(\Omega/m)$	9138	9232	9440(90)	9070(20)

and after brazing, is compared with the one from HFSS in Fig. 4. The quality factor of the operating π-mode has been

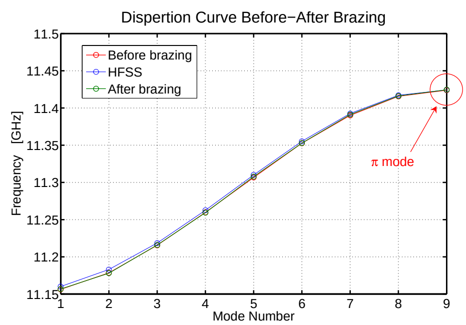

Figure 4: Dispersion curve before and after brazing.

measured on the brazed structure and compared with both the one measured on the non brazed cavity and the one calculated by HFSS and SUPERFISH code (see Tab. 1). The results point out that the brazing process brings improvements in terms of the quality factor.

Field measurements

With the bead pull technique we measured the electric field on axis. To calculate the R/Q we have calibrated the bead form-factor comparing the perturbation induced in a pill-box cavity with analytical results. The measured longitudinal electric field on axis, for the brazed prototype, compared with the one of the non brazed cavity, is plotted in Fig. 5. Tuning the brazed structure has been

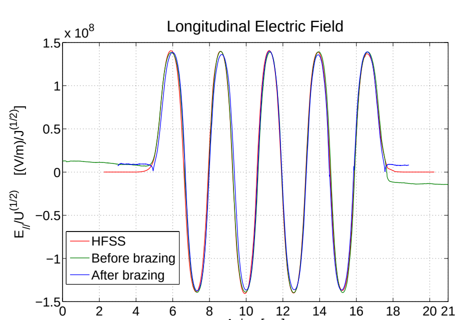

Figure 5: Measured longitudinal electric field on axis.

proved to be more difficult with respect to the structure made by separated cells due to reduced RF losses.The field-flatness is of the order of 4% at the measured frequency of $11.4244GHz$. The measured R/Q per unit length is reported in Tab. 1.

HEAT LOAD AND COOLING SYSTEM DESIGN

One of the most important requirements for an RF cavity is to have a high accelerating field. Unfortunately an upper limit for the axial electric field is given by the maximum value of surface field possible before breakdown. Experimental tests prove that a possible way to raise this breakdown limit is to use different materials for the inner surface of the structure containing the cavity. We have decided to consider, study and compare three different constructive solutions: structure totally made out of copper; structure with irises made out of Molybdenum (**Mo**) and structure with only half of the irises (the nose) made out of **Mo**, and outer half made out of **Cu**. An electromagnetic analysis of the π-mode operating structure has been performed for each one of the three cases above with SUPERFISH code, the obtained results have been used as input for subsequent thermal simulation performed with ANSYS [3] code. The main RF parameters are reported in [4].

ANSYS thermal simulations

The use of **Mo** surely brings advantages in terms of the electromagnetic behaviour of the cavity since it allows to operate with higher accelerating fields, at the price of a greater power loss due to higher surface resistance, and a more difficult heat evacuation because of the lower rate of heat transfer, therefore we expect to have higher temperature gradients, greater thermal expansion and thus greater frequency variations.
In order to reduce and simplify the model to be analysed, we have considered only one full and one half cell, applying all the necessary boundary conditions (See [4]). Numerical simulations performed with ANSYS show that the maximum temperature variation within the structure, in the classical solution (all copper), is less than $2°C$. The maximum temperature variation goes up to more than $7°C$ in the case of using **Mo** for the entire irises. The mixed **Cu-Mo** solution appears to be the best since it has both the advantages of allowing higher accelerating fields and small temperature variation (3%)as shown in Fig.6.

The cooling system design

In order to materially obtain the temperature boundary condition on the external surface of the structure we need to supply the accelerating structure with a cooling system. This will be a closed water device with 4 tubes (of diameter $6mm$), parallel to the axis of the cavity, positioned on the outer surface of the structure. The results [4] show that the temperature distributions do not differ much from the previous analysis obtained with the approximation of consid-

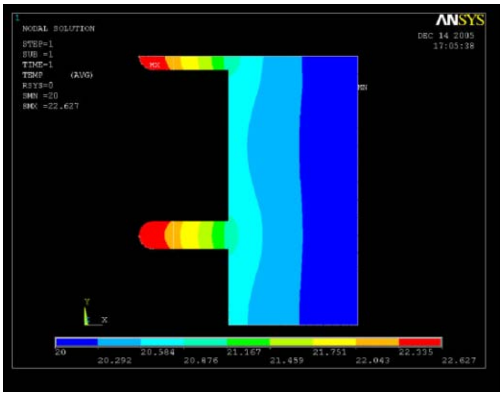

Figure 6: Thermal field in the π-mode cavity.

ering a constant temperature on the whole external surface. The highest temperature value obtained, even in the most critical conditions (duty cycle $5E-5$ with tubes at $30°$),is not greater than $42°C$, and the maximum temperature variation within the structure is less than $2°C$ as we can see in Fig. 7.

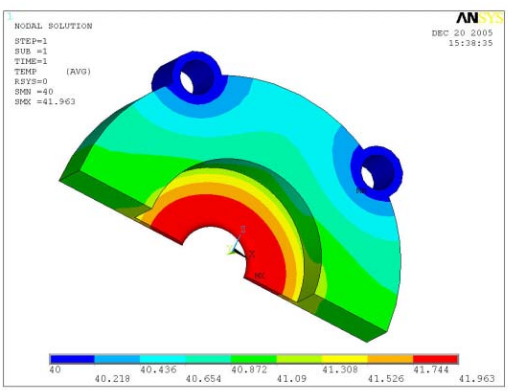

Figure 7: π-mode cavity with tubes at $30°$ working on duty cycle 2 ($5E-5$).

Cooling system calculations

In the previous simulations we have considered a steady value for the wall temperature of the tubes, so we have approximated the cooling system as a perfect heat absorber. Actually it is not so, and it is necessary to calculate the needed speed and temperature for the water, in order to have a good efficiency for the cooling system. A first approximation of the water flow rate may be given by the following:

$$W = P \cdot \delta \cdot c \cdot \Delta T \qquad (1)$$

in which W is the heat transferred to the water per unit time, P is the volumetric water flow rate, δ is the water density, c is the specific heat and ΔT is the difference of the water temperature from the beginning to the end of the tubes. With equation (1), it is possible to establish an approximate value of the flow rate necessary. Once the speed of the water has been established we can evaluate the water temperature with the equation of convection heat transfer:

$$W = h_c \cdot S \cdot (T_w - T_b) \qquad (2)$$

where h_c is the convection film coefficient, S is the total exchange surface, T_w is the wall temperature and T_b is the bulk temperature. The film coefficient has been calculated [4]. Temperature difference between inlet and outlet and between wall and bulk, corresponding to different values of water volumetric flow rate are shown in Fig. 8.

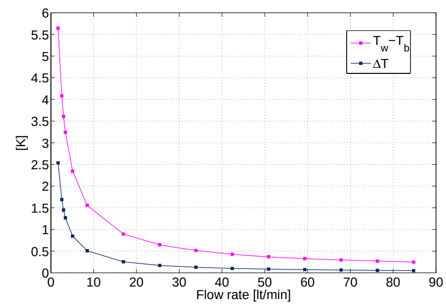

Figure 8: Thermal gradient behaviour in the cooling system.

CONCLUSIONS

A π-mode cavity has been realised and brazed. Experimental tests have given satisfying results. The electromagnetic behaviour, in terms of E field on axis, Q factor and R/Q form factor does not show substantial variations. The brazing procedure has been successfully studied and carried out. Alternative solutions to reduce the peak surface field and thus to allow higher accelerating gradients have been considered and analysed. A cooling system has been designed and calculated and simulations prove that it works correctly.

ACKNOWLEDGEMENTS

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