MANUFACTURING AND TESTING OF A TBL PETS PROTOTYPE*

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Abstract

The goal of the present CLIC Test Facility (CTF3) is to demonstrate the technical feasibility of the CLIC scheme. The Test Beam Line (TBL) is used to study a CLIC decelerator focusing on 12 GHz power production and the stability of the decelerated beam. The extracted CTF3 drive beam from the Combiner Ring (CR) features a maximum intensity of 28 A and 140 ns pulse duration, where the Test Beam Line consists of 16 cells, each one including a BPM, a quadrupole on top of a micrometer-accuracy mover and a RF power extractor so-called PETS (Power Extraction and Transfer Structure). This paper describes the first prototype fabrication techniques, with particular attention to the production of the long copper rods which induce the RF generation. A special test bench for the characterization of the device with low RF power measurements has been developed. Performed measurements of the scattering parameters and the electric field profile along the structure are carefully described. Finally, the prototype has been installed at CTF3. First measurements with beam are also reported.

INTRODUCTION

The third CLIC Test Facility, CTF3 [1], aims to demonstrate the technical feasibility of the CLIC drive beam generation scheme. The objective of the TBL experiment is to extract as much energy as possible out of the CTF3 beam and to prove the stability of the decelerated beam. The RF power is extracted by the PETS [2]. Each device consists of eight identical copper rods with shallow corrugations attached to a copper coupler with two opposite transverse waveguides for power extraction. The copper rods are 800 mm long, roughly three times longer than the analogous CLIC rod. The additional length allows reaching the nominal CLIC RF power production with a less intense beam, as the CTF3 one. The complete assembly is enclosed by a vacuum tank.

FABRICATION CHALLENGES

From the point of view of fabrication, the most challenging parts are the copper rods, due to the strict shape accuracy, +/- 20 microns, and roughness, less than 0.4 microns. They were produced by milling with two intermediate stress relieves at 180ºC, for one hour. The rods shape was controlled with a 3-D measuring machine. Some problems were detected with the repeatability of the measured points at surfaces with small curvature radius, i.e. the teeth peak. As the rods were not bolted to the support, an average of 0.13 mm sag was measured (see Fig. 1). This deformation can be compensated in the assembly by the central support ring. Concerning the position of the regular cells, there is an error of about 0.1 mm from the first to the last cell position. It is assumable because the profile shape of each corrugation is within tolerances.

The shape of the first prototype rod was also checked with a custom RF test bench [2], which has not been used for the rest of rods because of the excessive pressure necessary to get a good RF contact between the rod and the bench parts. Nevertheless, it proved to be an accurate device. It could be used in the future for testing PETS rods with some modifications oriented to avoid electrical contact between the device and the copper rods.

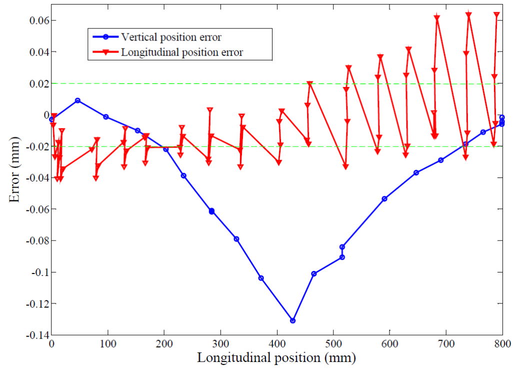

Figure 1: Average measurements of the eight copper rod shapes: vertical position of selected teeth peak (blue) and longitudinal position of some teeth wall (red).

A special tooling has been developed to bend the cooling pipes in two steps: the former, with half the length, to fit in the size of the brazing furnace, and the latter, to get the final shape for assembly (Fig. 2). Brazing of power extractor was especially demanding: tight tolerances of the choke geometry must be kept to avoid RF transmission along the beam pipe, good RF contact is necessary at the waveguides and beam aperture, and virtual leaks will not appear if joint is properly done.

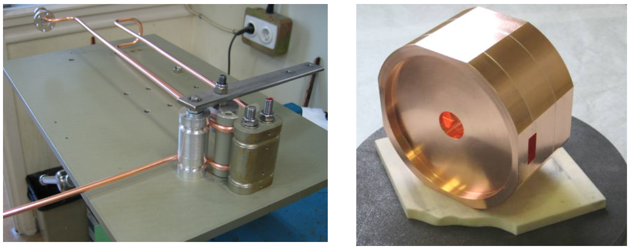

Figure 2: Custom tooling to bend cooling pipes (left). Brazed power extractor (right).

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* Work partially supported by the Spanish Ministry of Science and Innovation under project FPA2007-29109-E

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ASSEMBLY PROCESS

The assembly starts with the positioning of the copper rods at the end support (see Fig. 3 left). Once all the copper parts are positioned, the distance between the back flat sides of opposite rods was checked. The mean value was 112.99 mm, compared to nominal one of 113.00 mm.

Afterwards, the complete copper assembly was lifted with a crane, to position the tank endplate below, referenced to the copper by dowel pins. Then, the cooling pipes were fixed with aluminium clamps to guarantee the good thermal contact necessary for the conduction cooling. Temperature sensors (PT-100 type) compatible with UHV conditions were bolted to alternative rods.

Finally, tank wall was introduced and the waveguides fixed with the help of special tools due to the difficult access to the screws (see Fig. 3 right). Bellows are placed in the waveguide ports to cope with any misalignment between the waveguides and the tank wall. Leak test was done showing a leak rate below 10^{-10} atm·l/s.

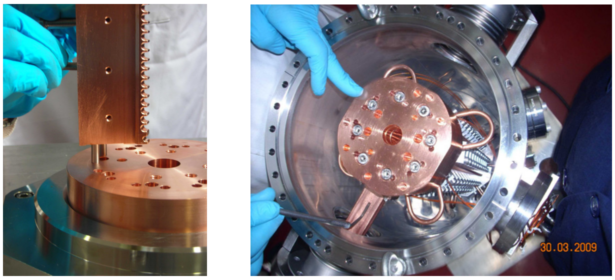

Figure 3: Positioning of first copper rod with dowel pins (left). Waveguide assembly (right).

RF VALIDATION TESTS

Measurements of Individual Parts

In order to test the complete assembly, two custom input couplers have been designed using HFSS software. Their function is to create the nominal TM01-like mode inside the PETS while they are fed by the network analyzer using an adaptor from coaxial wire to rectangular waveguide WR90 (see Fig. 4). The S-parameters were measured and matched the calculated values.

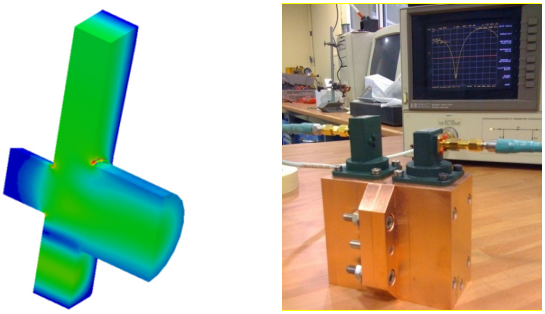

Figure 4: Electric field map (left) and measurement of S-parameters (right) of the input couplers.

Next step is the acceptance of the power extractor once brazed. The input couplers were used as feeders at the test bench. The S11 parameter depicted in Fig. 5 shows the broadband characteristics of the power extractor.

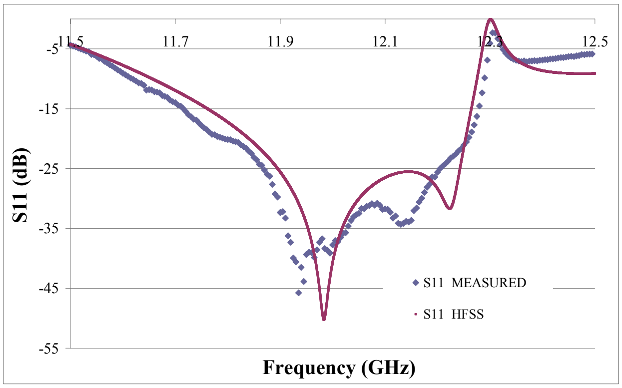

Figure 5: Calculated (dots) and measured (diamonds) values of S11 parameter of power extractor vs. frequency.

Measurements of Complete Assembly

The RF characterization of the complete assembly has been done using a custom test bench (see Fig. 6). An antenna made with coaxial wire was moved along the slots between the copper rods, hold by a digital ruler, which provides the longitudinal position with an accuracy of 0.01 mm. The antenna is introduced till the measured transmission from the input couplers is about -40 dB. As the test bench is in vertical position, the distance between the antenna and the assembly centre keeps constant. Measurements have been done in different slots, with good repeatability, as expected.

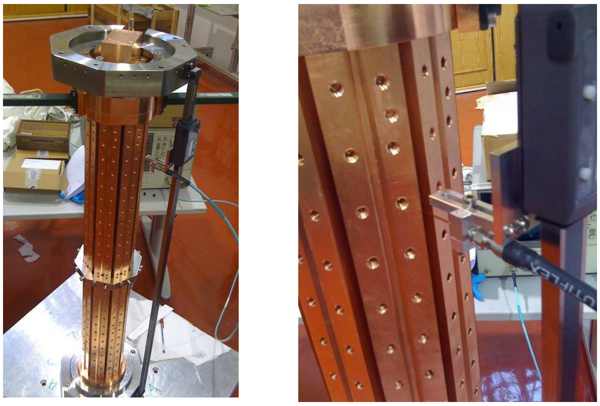

Figure 6: Custom RF test bench for complete assembly.

Figure 7 shows phase shift values from the input coupler to the antenna for different frequencies as function of the longitudinal position of the antenna. Measurements are interrupted at the mid-plane because of the stainless steel ring for alignment. As nominal phase shift per period is 90º and measurements have been done every two periods, a horizontal line should be depicted for the frequency at which the PETS are tuned. In this case, the horizontal line is found about 40 MHz below the nominal frequency (11994 MHz).

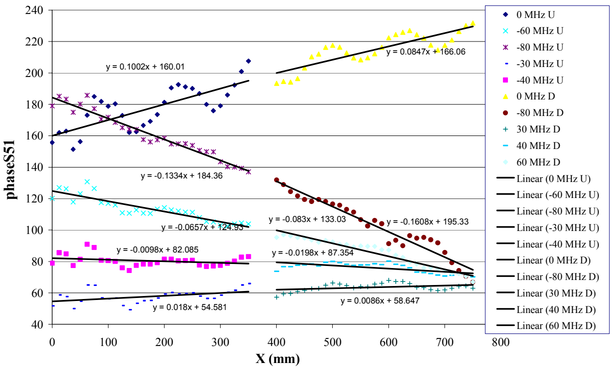

Figure 7: Phase shift measurements on complete PETS assembly for different frequencies.

A sensitivity analysis was performed to find the origin of that frequency mismatch. The design is not sensitive to the variation of the curvature radius of the teeth peak (see Fig. 8), which changes frequency as -2 MHz/mm. Higher sensitivities are produced by the variation of the valley depth D_v, with a rate of -1.1 MHz/µm, and the distance R_a to the beam axis, with -0.2 MHz/ µm. This last parameter is the only one easy to be changed, by shimming at the intermediate support ring, but sensitivity is too low.

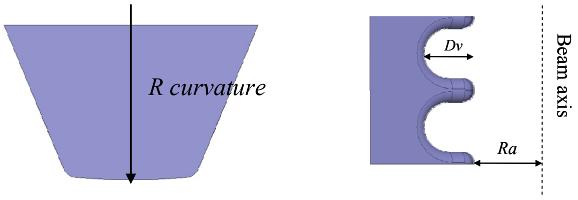

Figure 8: Parameters used for the sensitivity analysis.

On the other hand, as the PETS must be synchronized with relativistic electrons, that is not the real detuning. Figure 9 depicts the PETS dispersion curve and the speed of light line. The former is computed as the phase shift per cell, dividing the total PETS phase advance (see Fig. 7) by the number of cells.

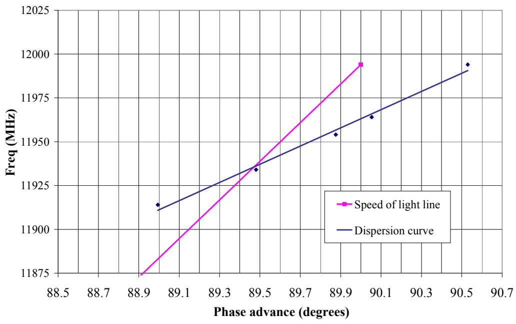

Figure 9: PETS dispersion curve and speed of light line.

The point at which both lines cross will be the operation point. The real detuning in this case is about -60 MHz. In the worst case, a maximum of 10% power loss is expected, which is compatible with TBL experiment. Nevertheless, in the first measurements, done with a 10 A, 280 ns pulsed beam, up to 20 MW (see Fig. 10) are obtained without any sign of power loss, assuming a form factor of 0.9. Instrumentation accuracy is in the range of few percent, so no definitive conclusions can be arisen with the present power level.

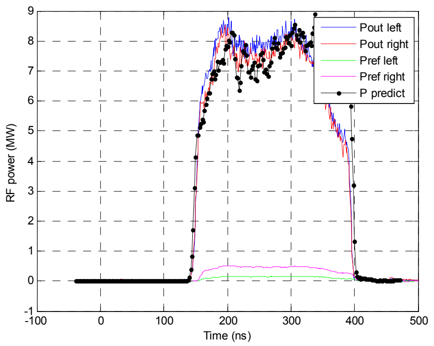

Figure 10: RF power produced at each waveguide.

CONCLUSIONS

This paper has described the main steps of the fabrication and assembly of the first prototype PETS tank for TBL experiment. The most difficult parts to produce were the copper rods, whose mechanical measurements were at the limit of the requested tolerances. RF measurements of individual parts were satisfactory. A custom test bench has been used for the RF measurement of the complete assembly. A detuning of -40 MHz has been found, which leads to a maximum expected 10% of power loss. Once installed in the TBL, first power measurements agree with the calculations.

The production of a series of eight tanks has been started as a collaboration of CERN and CIEMAT, to make possible beam stability studies during RF power generation by beam deceleration.

ACKNOWLEDGEMENTS

The authors thank warmly the numerous people involved in the production: Utillajes Huerta for the copper parts machining, S. Mathot (CERN) for the power extractor brazing, CIEMAT workshop and Utillajes Jucar for steel and aluminium parts, J. Sotelo (AIMEN) for the cooling pipes and waveguides brazing, and Trinos Vacuum Projects for the vacuum tank.

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