

ENGINEERING DESIGN OF A PETS TANK PROTOTYPE FOR CTF3 TEST BEAM LINE *

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Abstract

In the CLIC concept, PETS (Power Extraction and Transfer Structure) role is to decelerate the drive beam and transfer RF power to the main beam. One of the CTF3 test beam line (TBL) aims is to study the decelerated beam stability and evaluate PETS performance. The PETS core is made of eight 800 mm long copper rods, with very tight tolerances for shape (± 20 micron), roughness (less than 0.4 micron) and alignment (± 0.1 mm). Indeed, they are the most challenging components of the tank. This paper reports about the methods of fabrication and control quality of these bars. A special test bench has been designed and manufactured to check the rod geometry by measuring the RF fields with an electric probe. Other parts of the PETS tank are the power extractor, the waveguides and the vacuum tank itself. Industry is partially involved in the prototype development, as the series production consists of 15 additional units, and some concepts could be even applicable to series production of CLIC modules.

INTRODUCTION

CTF3 [1], the third CLIC test facility, will demonstrate the feasibility of the essential parts of the CLIC drive beam generation scheme. The aim of the experiment so-called TBL [2] is to extract as much energy as possible out of the CTF3 beam and to demonstrate the stability of the decelerated beam and the produced RF power in the PETS. The main issues are the transport of a beam with a very high energy spread with no significant beam losses and the wakefields suppression. Additional goals are the test of alignment procedures and the study of the mechanical layout of a CLIC drive beam module with some role of industry to build components which finally should be produced in large series.

PETS LAYOUT

The TBL PETS consists of eight identical copper rods with shallow corrugations separated by 2.2 mm wide slots filled with absorbers for the damping of the transverse high order modes (see Fig. 1). Ceramics, such as silicon carbide and aluminium nitride, from several companies, have been characterized (loss tangent and permittivity measurements), but results are not optimal, so the selection process is still open.

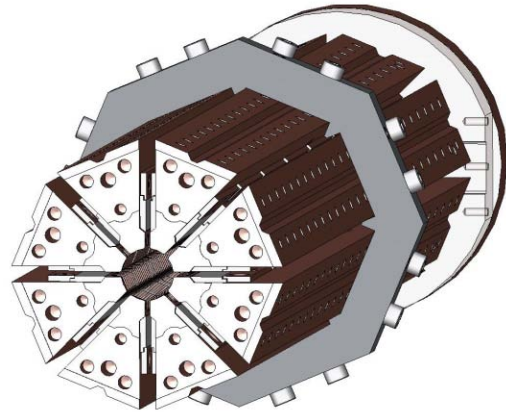


Figure 1: Copper rods with absorbers in the slots.

The rod profile must be machined with great accuracy (± 20 microns) and low roughness (lower than 0.4 microns). After several tests in short probes, high speed milling was the only conventional method that could achieve those tight tolerances. Two intermediate heat treatments are necessary for stress release. Finally, rods are being machined in a Spanish company, Utillajes Huerta. The validation of these rods is described in the next Section.

At both ends, the rods are supported by copper blocks, referenced by pins, to get the required alignment tolerance of ± 0.1 mm. The electrical contact between the tip of the bars and the blocks is necessary for proper surface current flow. It is guaranteed by a machined recess and a screw between the pins to press the bar against the copper block. Besides, all the rods are machined simultaneously to perform the same length.

The sag of the rods due to its own weight is not negligible. In the most unfavourable case, for a horizontal rod, it is about 19 microns, in the order of shape tolerances. An intermediate steel ring has been included to get profit from the fact that the sag for a vertical rod is only 10 microns, and to correct other possible misalignments.

The beam generates RF power in the structure, which is extracted by two opposite waveguides attached at one of those copper blocks, which is known as power extractor (Fig. 2). It is equipped with a choke (round slot) to reflect the travelling RF power backwards. It must be split into three parts for machining. They are brazed to enhance the electrical contact and to avoid virtual leaks. Waveguides are WR90 size with thick walls (3.17 mm) to enhance heat transfer of RF losses.

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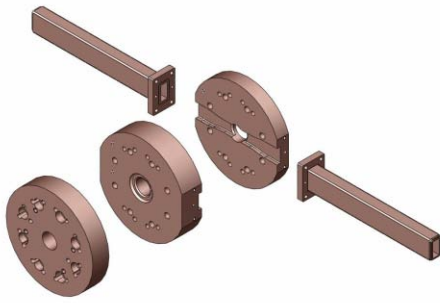


Figure 2: Exploded view of power extractor.

Copper rods are water cooled to avoid the frequency shift due to thermal deformation originated by induced currents and beam losses. Pulsed heat deposition can be converted in an averaged steady heat source to evaluate the heat transfer efficiency. Mean power generation due to RF losses is about 7 W, while beam losses could be as high as 315 W (assuming 10% of CLIC-type beam loss).

An OFE copper pipe with 1/4 inch diameter is chosen. Custom vacuum tight connectors with Helicoflex seals are designed. Assuming water speed of 1 m/s, turbulent flow is achieved (Reynolds number is 5100) for a sensible pressure drop (0.3 bar). For a convection coefficient of 5000 W/m²K and a contact thermal resistance of 10000 W/m²K, the expected temperature step from copper rod to water is 3°C. Four independent cooling circuits are foreseen. Each of them will cool two rods, with an estimated water temperature increase slightly above 1°C. In this first prototype, alternative rods will be equipped with temperature sensors (bolted PT-100).

The set of copper rods and blocks is introduced in a large vacuum tank (Fig. 3) with several ports for pumping and diagnostics. Fiducials are based on Taylor-Hobson spheres. Three adjustable legs are used for alignment. The position of the copper rods is accurately transferred outside by means of reference pins on the endplates.

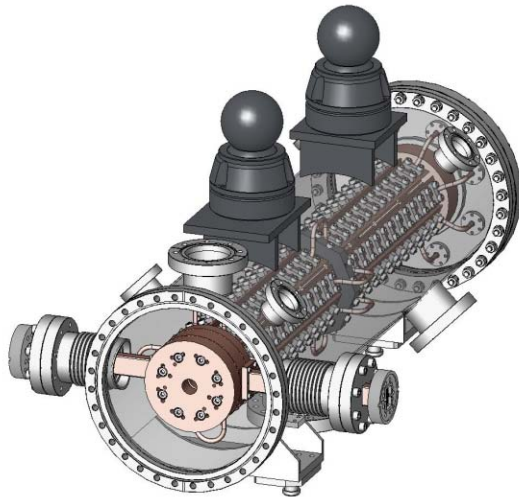


Figure 3: PETS structure in the vacuum tank.

VALIDATION TESTS OF PETS

Single Bar Test Bench Design

In order to detect any geometric error and to know specifically what is wrong (matching cells, shape profile, etc) in the produced copper rods, a custom device has been designed. These rods are by far the most demanding and restrictive PETS components. Geometry is also checked with a 3-D measuring table, but this test bench will provide additional valuable information about the field configuration. It consists of two side blocks made of copper that will be in contact with the copper rod itself (Fig.4). There are tapers at both ends of the device that couple the geometry of a WR90 waveguide to the cavity defined by the copper rod and the side blocks (Fig. 5).

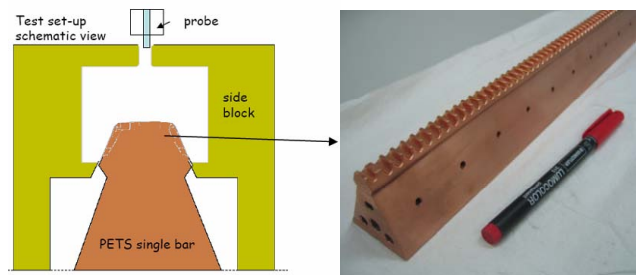


Figure 4: Schematic cross section of the RF test device.

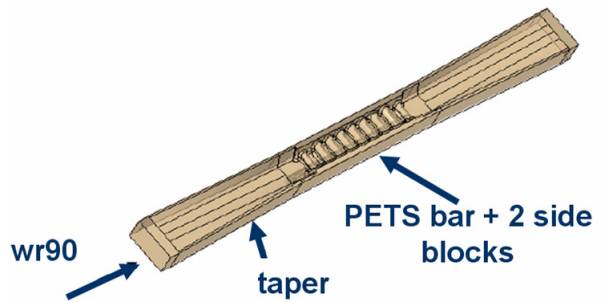


Figure 5: Vacuum volume in the device 3-D model.

This test bench is able to create a TE₁₀-like mode with the same phase advance per cell, electric field on the surface and group velocity than the decelerating mode TM₀₁ that will exist in real PETS. The design is optimized (S11 < -60dB) for the PETS working frequency, 11.9942 GHz, with 350 MHz bandwidth. Electric field is shown in Fig. 6.

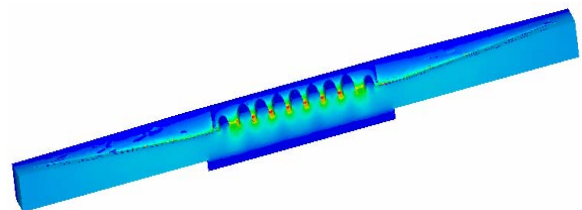


Figure 6: Electric field modulus in the 3-D model.

An electric probe will be introduced to measure phase shift per cell. Simulations have been done (Fig. 7) to check out the effect of this antenna and to calculate the optimal position to get accurate measurements without perturbing the field inside the device: the antenna tip must be placed into the slot, nor more than 0.5 mm away from the slot end. This probe will be moved along the device while using an electronic ruler (Fig. 8) to measure positions of the coaxial port with high accuracy (10 μ m).

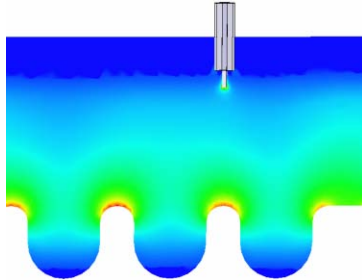


Figure 7: 3-D model of the probe antenna.

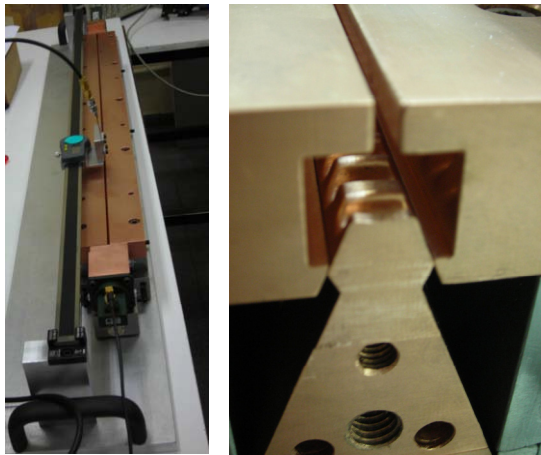


Figure 8: a) Full device b) End view of device with PETS bar placed inside.

Single Bar Test Bench Measurements

The first 800 mm long bar has been already measured with the RF test bench. Input power from the network analyzer comes into one taper and a matching load is connected to the other taper. Figure 9 shows transmission parameter S21 to the antenna for different positions along the PETS bar. It can be seen that there is a -121° phase slip after 800 mm (123 cells) displacement, which yields approximately 89° phase shift per cell, very close to the theoretical value, 90° .

This phase slip would yield a shift in nominal operation frequency of 68 MHz which would produce a 13% loss of power extracted from PETS. Nevertheless, actual power loss is expected to be much lower because the geometric errors of the test bench itself cannot be distinguished from those of the copper rod. Even more, the sharp edges of the side blocks are supposed to provide electrical contact with the bar for the whole length but, looking at Fig. 8b, one can easily notice that due to low stiffness of copper, these

tips are slightly deformed after several uses. In the future, it would be useful to design a new device to test PETS bars without the requirement of electrical contact between bars and device to avoid deformations.

In conclusion, the first prototype copper rod was accepted after being checked with the standard 3-D measuring machine and the custom RF test bench.

Another bench is under design for the RF test of the complete PETS before the final assembly with the vacuum tank. The eight copper rods with end blocks will be placed in vertical position, and a probe will be introduced along the slots to measure the electric field profile. This new test bench will produce the same TM_{01} mode that will operate finally in TBL PETS. Custom mode launchers have been designed to couple the WR90 waveguides and the PETS.

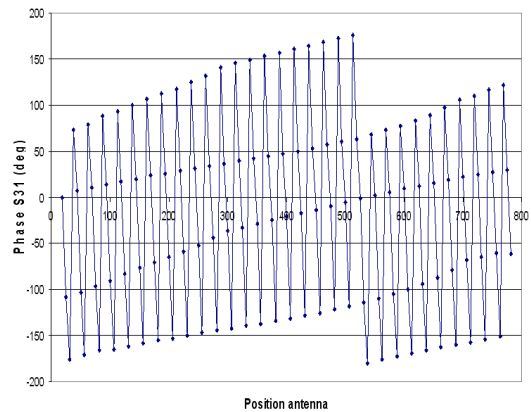


Figure 9: S21 phase for different antenna positions (mm).

ASSEMBLY

Once the PETS have been tested, they will be placed on top of the endplate opposite to the waveguides (Fig. 3), referenced by pins. Then, cooling pipes and temperature sensors will be fixed and the tank wall will surround the assembly. Finally, waveguides will be introduced through the flanges and bolted, closing the vessel with the second endplate equipped with reference pins as well. RF screens are foreseen at the endplates bore to avoid beam losses.

CONCLUSIONS

A first prototype of PETS tank for TBL is being designed. The most challenging component is the set of eight long copper rods with very tight tolerances. A custom test bench has been developed to successfully characterize the RF behaviour of the first machined copper rod. The set of rods and other components are under fabrication.

REFERENCES

- [1] G. Geschonke and A. Ghigo, "CTF3 Design Report", CERN/PS 2002-008 and LNF-02/008, 2002.
- [2] S. Doebert et al., "Progress on the CTF3 Test Beam Line", EPAC'06, MOPLS097, <http://www.jacow.org>