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Status of CIEMAT work on PETS ☆

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ABSTRACT

The goal of the present CLIC Test Facility (CTF3) is to demonstrate the technical feasibility of the CLIC scheme, where the RF power extracted from the drive beam is used to accelerate the main beam. Several prototypes of the RF power extractor so-called PETS (Power Extraction and Transfer Structure) have been developed at CIEMAT for this facility. The first device was embedded in a steel vacuum tank and installed at the Test Beam Line (TBL), whose aim is to prove the beam stability during deceleration and power extraction. Presently, CERN and CIEMAT share the responsibility to build eight additional PETS for TBL. Finally, in the framework of EuCARD (European Coordination for Accelerator Research and Development) collaboration, a new PETS configuration is presently under engineering design at CIEMAT. It is based on a compact concept developed at CERN. This device will be installed in the Test Module at CTF3, in a similar configuration to that of the final two-beam scheme acceleration of CLIC. This paper describes the PETS prototype fabrication techniques used at CIEMAT, with particular attention to the production of the long copper rods which induce the RF generation and the welding and assembly procedures. The characterization of the devices with low RF power and the first tests with beam are also described.

1. Introduction

In the future collider CLIC [1], a 101 A beam will be decelerated from 2.4 GeV down to 240 MeV while converting 85% of its energy into 12 GHz microwave power. This power will be extracted by the PETS, which is a passive microwave device in which bunches of the drive beam interact with the impedance of the periodically loaded waveguide and excite preferentially the synchronous mode. The RF power produced (several hundred MW) is collected at the downstream end of the structure by means of the Power Extractor and delivered to the main linac accelerating structure (Fig. 1). The RF power travels through the opposite waveguides, because it cannot be transmitted through the beam pipe, due to the presence of a choke, which reflects it back. A single PETS consists of eight copper rods machined to high precision which are clamped together with an extraction coupler and installed in a vacuum tank (Fig. 2). The rods have periodic oscillations (cells) which induce the RF power production due to the interaction with the beam.

In order to demonstrate the feasibility of the CLIC decelerator concept, a special Test Beam Line has been implemented into CTF3 [2] at CERN to study and validate the drive beam stability during deceleration. This is one of the R&D items required by the International Linear Collider Technical Review Committee to demonstrate the feasibility of CLIC. The Line will have 16 PETS [3,4] tanks installed in its final stage. Each TBL PETS will produce the nominal CLIC power of 135 MW with a beam current of 28 A. The TBL PETS is a factor 4 longer compared to CLIC one to compensate for the lower drive beam current in CTF3. The initial energy for the CTF3 decelerator is even lower than the final energy for CLIC which makes the experiment more difficult in this respect. On the other hand, wakefield effects will be less pronounced in TBL due to the much shorter length. The emphasis for the experimental program of TBL will be on 12 GHz power production and the transport of the decelerated beam. So far, one prototype PETS tank developed and fabricated at CIEMAT in collaboration with CERN has been installed in the TBL line and the production of a series of 8 more tanks is currently under way.

2. TBL PETS Prototype Tank

The development of the first prototype for TBL PETS started at CIEMAT in 2007. The RF concept was developed at CERN [5], while the engineering design, fabrication and low power RF tests were

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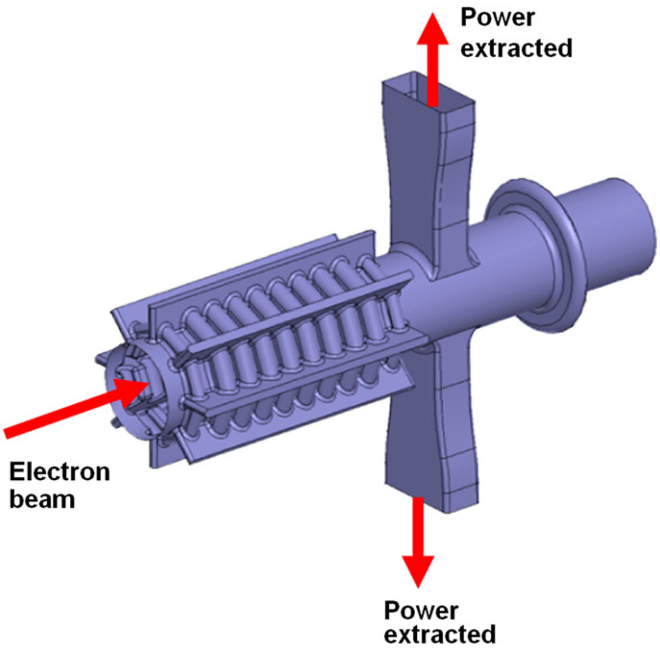

Fig. 1. RF power produced by the electron beam is extracted through two opposite waveguides (3D model of the vacuum volume inside the copper structures is shown).

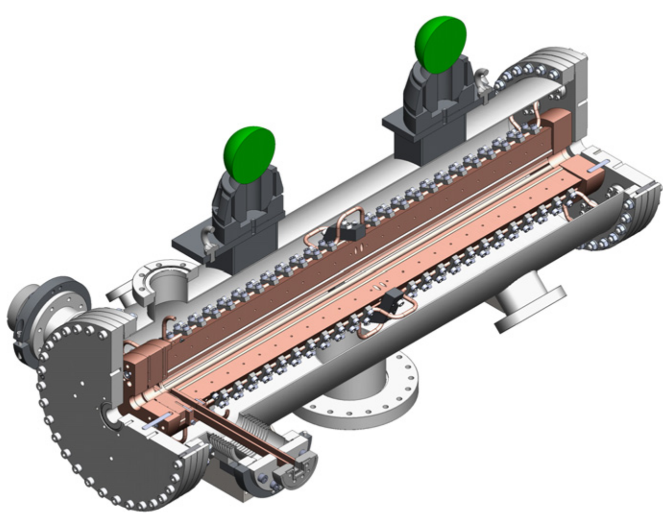

Fig. 2. Artistic view of TBL PETS structure in the stainless steel vacuum tank with two fiducials on top.

performed at CIEMAT. The RF design was optimized for the nominal CLIC frequency, that is, 11.9942 GHz. Fig. 3 shows the reflection parameter at the input port for different number of cells. Since the real number of cells of the structure is very high, 125, the numerical simulation is performed for a smaller number of cells, i.e. 5, 6, 7 and 8, in order to get 11.9942 GHz as the common operation frequency at which minimum reflection for the different cells configuration may be obtained, therefore achieving a design independent of possible phase deviations. Fig. 4 depicts the electric field map, responsible of the electron beam deceleration. It is worth to notice that no field is present beyond the choke.

2.1. Engineering design

The TBL PETS consists of eight copper rods clamped to a RF power extractor embedded in a conventional stainless steel vacuum tank (Fig. 2). The copper parts are joined by screws and dowel pins. The main advantage of this configuration is that it can be assembled and disassembled several times, as the components are not welded. The RF power generated by the beam is extracted by two opposite WR90 waveguides, whose misalignment with respect to the tank wall is absorbed by means of bellows. The electrical contact between the copper rods and the power extractor is very important for the RF performance and is guaranteed by a milled recess on the copper rods end faces. The sag of the rods due to its own weight is estimated as 19 microns in the case of a rod in horizontal position. As this value is on the order of the shape tolerance, an intermediate steel ring has been included to compensate partially this effect.

The RF copper parts are conduction cooled by cooling pipes, pressed onto the rear side of the rods with aluminium clamps. Average power generation due to RF losses is about 7 W per PETS, while estimated beam losses could be as high as 315 W. An OFE copper pipe with 1/4 inch outer diameter, 1 mm thick wall 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 small pressure drop (0.3 bar). For a convection coefficient of 5000 W/m^2K and a contact thermal resistance of 10000 W/m^2K, the expected temperature step from copper rod to water is 3 °C. Four independent cooling circuits are foreseen. Each of them cools two rods, with a very small water temperature increase, slightly above 1 °C.

2.2. Fabrication

From the point of view of fabrication, the most challenging parts are the copper rods, due to the tight shape tolerance, $\pm$20 microns, and roughness, less than 0.4 microns. They were produced by high speed milling with small ball cutters, undergoing two intermediate stress relieves at 180 °C, for one hour. The shape of the rods was checked with a 3-D measurement machine, and also with a custom RF test bench [3], providing additional valuable information about the field configuration.

A special tooling has been developed to bend the cooling pipes in two stages: the first bend to half the length of the final geometry, to fit in the size of the brazing furnace, and the latter bend, to the final shape. Different tests were also performed to determine the minimum bending radius without sealing the inner hole or inducing too high stresses in the copper wall.

Several parts have been joined by means of vacuum brazing technique since this method has several advantages such as minimum joint contamination, cleaned brazed pieces, vacuum tightness of the brazed joints, minimum piece distortion and low thermal stress. Besides, in the case of RF parts, it enhances the electric conductivity of the joint.

These joints involve copper/copper (Cu/Cu) and copper/stainless steel (Cu/SS) brazed parts. Depending on the parts to be brazed, several filler alloys (in form of wire), superficial treatments of the brazing surface and thermal cycles were selected as Table 1 summarizes. All heating, brazing and cooling steps were performed at high vacuum conditions ($<10^{-3}$ Pa) and the brazing surfaces have a superficial roughness of 0.8 μm, which has been used by other authors in the vacuum brazing of accelerating parts [6,7].

In particular, for the brazing of cooling circuits, stainless steel connectors were Ni plated with the purpose of increasing filler wettability on the stainless steel, since the chromia scale which protects steel against corrosion is even stable at the operation conditions (vacuum and temperature levels) and acts as a barrier for wetting by the molten filler alloy [8]. On the contrary, Ni plating was not necessary when 82 Au/18 Ni was selected for brazing waveguides to flanges, since brazing temperature is higher and sufficient to remove chromia scale from the stainless steel surface. After brazing, a helium leak test was carried out on