HIGH-POWER TESTING OF X-BAND CLIC POWER GENERATING STRUCTURES

I. Syratchev, E. Adli, A. Cappelletti, S. Doebert, G. Riddone, W.Wuensch
CERN, Geneva, Switzerland
R. Ruber, V. Ziemann, Uppsala University, Sweden
S. Tantawi, V. Dolgashev, J. Lewandowski, SLAC, Stanford, CA, U.S.A.

Abstract

A fundamental element of the CLIC concept is two-beam acceleration, where RF power is extracted from a high-current and low-energy beam in order to accelerate the low-current main beam to high energy. The power extraction occurs in special X-band Power Extraction and Transfer Structures (PETS) [1]. The structures are large aperture, high-group velocity and overmoded periodic structures. Following the substantial changes of the CLIC baseline parameters in 2007, the PETS design has been thoroughly updated along with the fabrication methods. Two PETS prototypes have been fabricated and high power tested. Test results and future plans are presented.

PETS TESTING PROGRAM

The main objective of the PETS testing program [2] is to demonstrate the reliable production of the nominal CLIC RF power throughout the deceleration of the drive beam. Following the recently adopted changes of the CLIC parameters [3], the PETS must generate 135 MW, 240 ns 12 GHz RF pulses from the 100 A drive beam with a breakdown rate as low as in the accelerating structure: 10^{-7}/structure. In order to investigate the high power performance of the PETS, testing programs are underway at the ASTA at SLAC and at the TBTS* at CERN.

PETS Testing at SLAC

The Accelerating Structure Test Area (ASTA) was recently constructed and commissioned at SLAC [4]. This is a new generation, general purpose high power RF test stand, which will allow processing of the various types of the high power RF equipment at X-band.

The test area is powered by two 50 MW klystrons, whose 1.5 us pulses are combined and compressed using SLED II RF pulse compressing system. Schematic view of the ASTA layout is shown in Fig. 1. The facility can provide a very versatile combination of pulse length and output power: from 100 MW×1500 ns to 530 MW × 64 ns. Testing PETS in ASTA gives a unique opportunity to understand the limiting factors for the PETS ultimate performance. It is the only place, where the long term, high RF power operation at a high (60 Hz) repetition rate can be currently investigated. To do this test, the 11.424 GHz scaled version of the 12 GHz PETS was designed, fabricated and installed in the ASTA test bunker in November 2008 (see Fig 2).

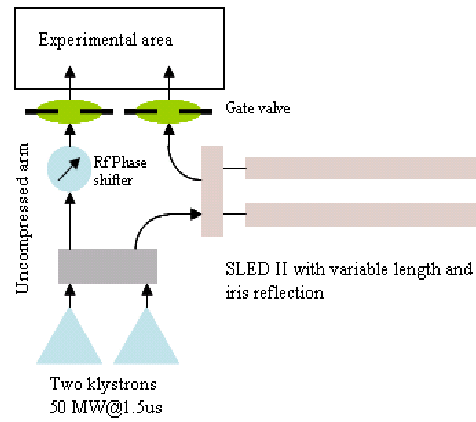

Figure 1: ASTA schematic layout.

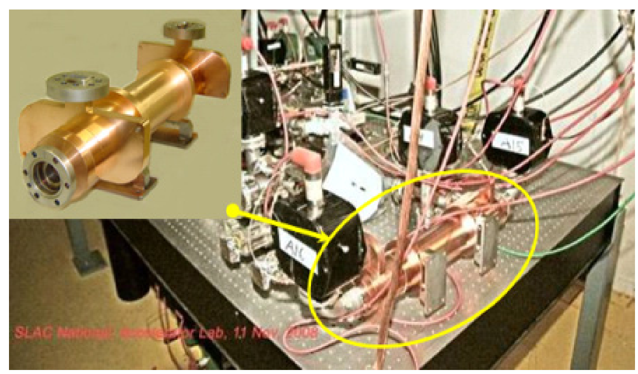

Figure 2: PETS installed in the ASTA bunker.

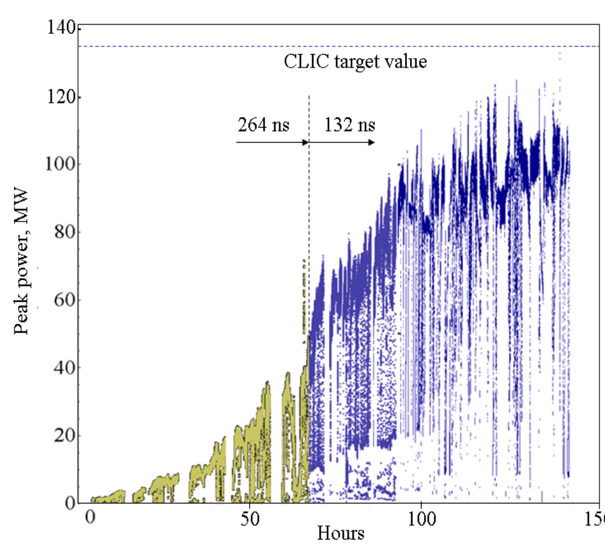

Figure 3: The PETS processing history in ASTA.

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During the winter of 2008/09 the PETS was tested in two few-week runs. The processing speed was slow compared to accelerating structures and was mostly limited by heavy out gassing of the PETS. The gas may have come from surface contamination because the PETS was not heat treated, in order not to deform it. After about 120 hours of operation, the processing had practically saturated as shown in Fig. 3 (typical pulse shape in ASTA is shown in Fig. 4). It was still limited by the vacuum interlocking of the ion pumps. At power levels above 100 MW the reason for such saturation was probably due to the vacuum activity inside the ion pumps themselves. It is possible that some RF power leaked out through the PETS power couplers into the pumps. To eliminate this potential problem, the PETS was removed and special RF screens were installed at the PETS extremities. At the moment of writing the paper, the modified PETS setup was reinstalled into the ASTA test bunker and the testing will be restarted soon.

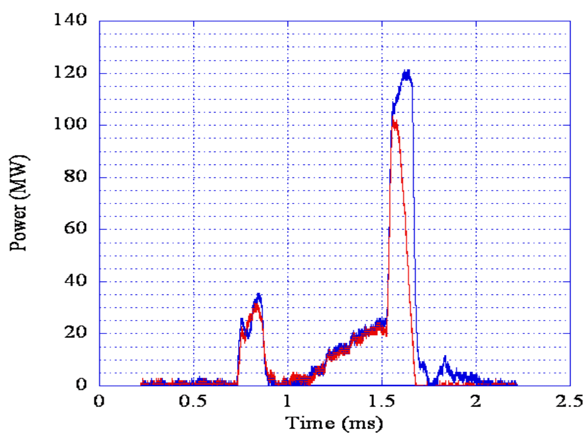

Figure 4: Typical transmitted RF pulse in ASTA (blue) and the pulse with breakdown event in the PETS (red).

PETS Testing at CERN

12 GHz PETS power production from a drive beam recently have been started at CERN, in the CTF3. The new CLIC experimental area (CLEX) has been partially completed as part of the CTF3 [5]. When fully equipped, the CLEX will comprise a number of experiments. One of them is the Two Beam Test Stand (TBTS). The TBTS is unique and versatile facility where the two-beam acceleration is planned to be demonstrated in 2009. The drive beam current available in CTF3, even with full recombination, will be about four times lower than the CLIC design; therefore, the TBTS PETS design was modified to be able to generate the nominal CLIC RF power. To recover the lack of current, the active PETS length was significantly increased from original 0.215 m to 1m. The TBTS PETS power production capability for the different CTF3 modes of operation is summarized in a Table 1. The fully assembled, 1 meter TBTS PETS equipped with water cooling channels and power couplers on it its girder, ready for the installation into the vacuum tank, is shown in Fig. 5. Mode 1 of the PETS operation should provide peak RF power levels well above the CLIC nominal values. Unfortunately, the pulse length of 140 ns is shorter than the CLIC nominal pulse of 240 ns. To lengthen the pulse and to increase the peak power the same time, it was decided to implement a different PETS layout – PETS with internal re-circulation [2]. In this case, the PETS will operate in the amplification mode, similar to that in the classical resonant rings. The only difference is that now we have a beam as an internal source of the RF power.

Table 1: The TBTS PETS Power Production Modes

Operation mode	1	2	3
Current (max.), A	25	14	4
Pulse length, ns	140	<240	<500
Beam frequency, GHz	12	12	3
PETS power, MW	200	61	5

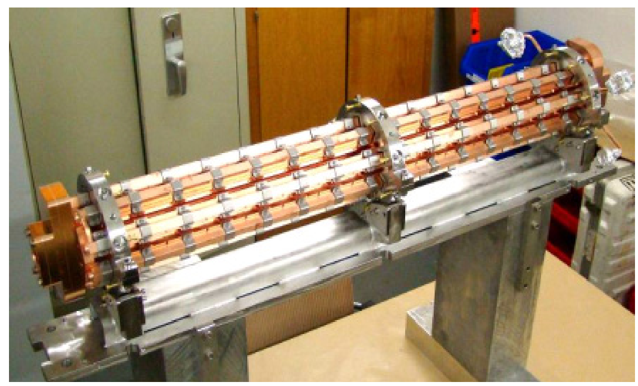

Figure 5: The TBTS PETS general view.

Providing enough peak power and pulse length, the PETS operation mode 3, together with re-circulation was fixed as a starting point for the PETS power production testing program. In October 2008, the PETS tank equipped with all the RF components was installed into the drive beam line in the TBTS experimental area, as is shown in Fig. 6.

Figure 6: The PETS tank installed in the TBTS test area.

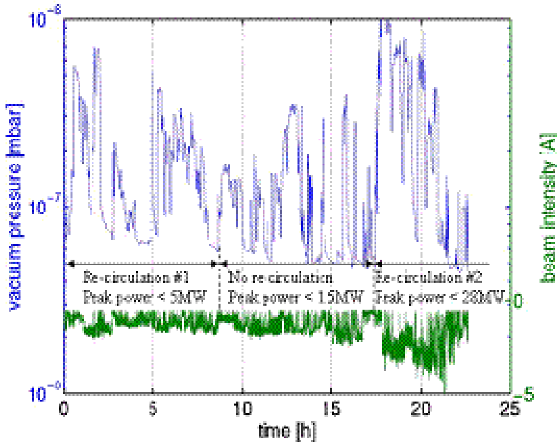

Figure 7: The vacuum and drive beam current history together with a brief summary of the system settings.

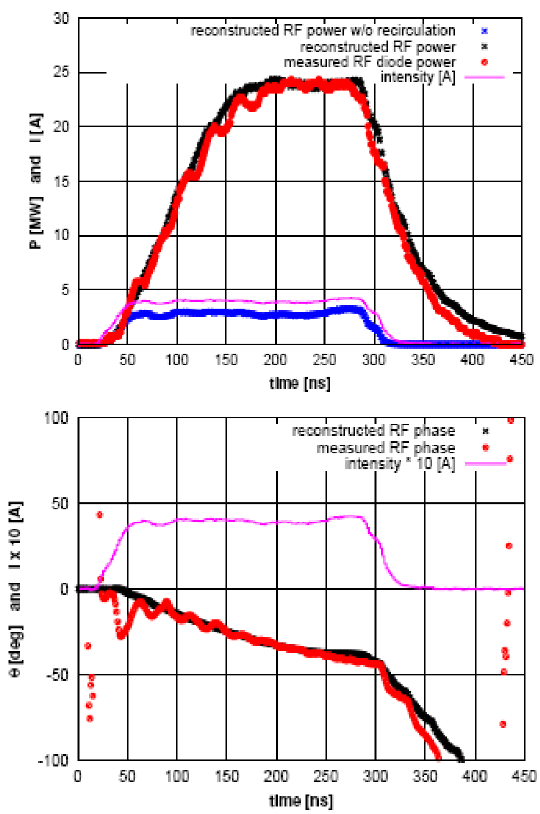

Figure 8: The measured (red) and reconstructed (black) RF power pulses (upper plot) and RF phases (low plot). The drive beam current (magenta) and expected power production without re-circulation (blue) are given for reference.

RF power production in the PETS started in November 2008. From the beginning of the run to the CTF3 winter shut down, the PETS was operated in total about 24 hours with the drive beam at 1 Hz repetition rate. During this period, the pulse length was kept about 250 ns. The vacuum and drive beam current history, at the time when the PETS was producing RF power, is shown in Fig. 7. The drive beam current was measured at two locations just before and after the PETS tank. There were no beam losses observed during the entire processing period. We have used few different re-circulation settings to learn about the system operation. The re-circulation was also switched off to confirm the direct PETS RF power production and the signal calibrations. The maximal available drive beam current was 4 A. Together with re-circulation, the RF peak power reached ~ 30 MW, which corresponds to about factor 7 in amplification. At the power levels above 20 MW peak, a number of the RF breakdowns was first registered. To analyze the PETS RF power generation, the special computer models have been developed [6, 7]. The measured drive beam current pulses were used then to make reconstruction of the produced RF power. The measured and reconstructed RF signals are shown in Fig. 8 and one can see good agreement between the two.

The next experiments in the TBTS will start early summer 2009. Meanwhile, the TBTS PETS instrumentation was upgraded. Two RF pick-ups were installed into the damping slots. This will allow monitoring of the beam position inside the PETS and, if happened, to measure RF signals in the slots during breakdown event. Also the quartz window was installed on the PETS tank to register the light emission during breakdown event.

SUMMARY

The two PETS prototypes have been fabricated and installed in the TBTS tests area at CERN and ASTA at SLAC. The processing of the scaled 11.4 GHz PETS has been started at SLAC. To date, the structure arrived at 110 MW x 132 ns (cf. 135 MW x 240 ns in CLIC). The tests are underway. The 12 GHz power generation in the PETS with re-circulation has been first demonstrated at CERN, yet at a moderate RF power level. The new drive beam will be available in TBTS early summer 2009.

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