HIGH POWER OPERATION WITH BEAM OF A CLIC PETS EQUIPPED WITH ON/OFF MECHANISM

I. Syratchev, R. Corsini, A. Dubrovskiy, P. Skowronski, CERN, Geneva, Switzerland
R. Ruber, Uppsala University, Uppsala, Sweden

Abstract

One of the feasibility issues of the CLIC two-beam scheme, is the possibility of rapidly switching off the rf power production in an individual Power Extraction and Transfer Structures (PETS) in case of breakdowns, either in the PETS or one of the main beam accelerating structures. The proposed solution is to use a variable external reflector connected to the PETS. When activated, this scheme allows us to gradually manipulate the rf power transfer to the accelerating structure and to reduce the rf power production in the PETS itself by a factor of 4. Recently the first operation of the Two Beam Test Stand (TBTS) PETS equipped with an ON/OFF mechanism was performed in CTF3. In this paper we will present the results of the PETS operation when powered by the drive beam up to high peak power levels (>100 MW) and compare them to expectations.

INTRODUCTION

In CLIC, each PETS provides rf power to two accelerating structures. During normal machine operation, the main accelerating structure or/and the PETS will periodically breakdown. Currently, we have little information about how the structures recover from the breakdown at a very low (about 10^{-7}) breakdown trip rate, which is why the present strategy requires local (in a single PETS) termination of rf power production in the event of any breakdown. Another important requirement is the capability of the system to provide gradual ramping of the generated power up in order to re-process the structure. It is also important that in any intermediate attenuation, neither drive the beam, nor the main beam will experience effects which can spoil the beams quality. In the past, a method based on changing the PETS synchronism with the beam frequency was proposed [1, 2]. The detailed technical analysis of this approach indicated that the system can become a cost driver for the whole PETS unit. Recently, the problem was thoroughly revised and a new compact and reliable ON/OFF mechanism concept was developed and tested at high peak rf power with beam in CTF3.

ON/OFF BASELINE STRATEGY

An external high power variable rf reflector is the key component of the system, as is illustrated in Figure 1. Providing the whole range of reflections from 0 to 1, it can fully or partially terminate the rf power transfer from the PETS to the accelerating structure. In general, the reflected rf power will be returned back to the PETS. In order to mitigate this effect, we propose to use a fixed rf reflector placed at the upstream end of the PETS, in order to establish recirculation of the rf power inside the PETS. If at the operating frequency, the electric length of such an rf circuit is tuned to $L=\lambda_0(n+1/4)$, then a destructive interference with the rf power generated by the drive beam can be achieved.

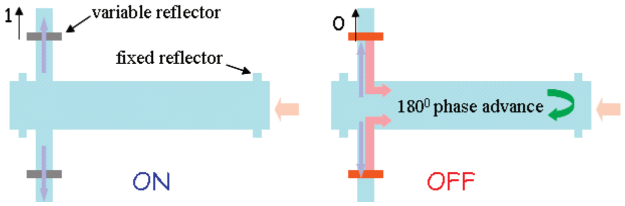

Figure 1: Schematic diagram of the PETS ON/OFF operation strategy.

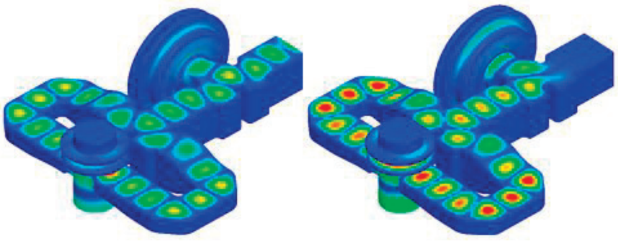

Figure 2: Electric field plots for the reflector in ON (left) and in OFF (right) positions.

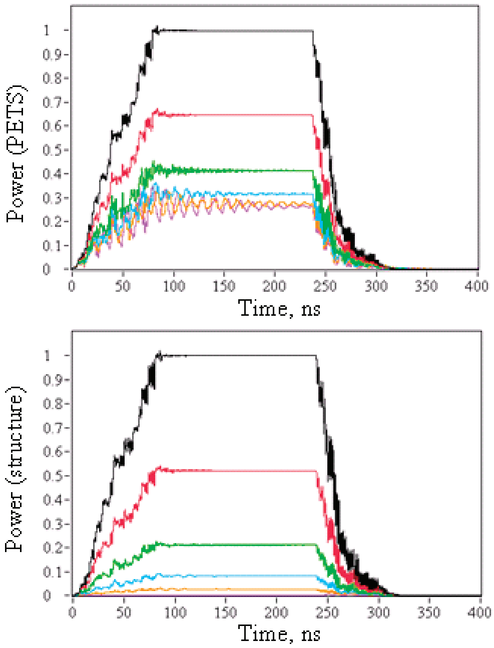

Figure 3: RF pulse envelopes at the PETS output (top) and the structure input (bottom). Here the reducing amplitudes correspond to different piston positions.

We have developed several different, mechanically driven high power variable rf reflectors [3]. Finally the preference was given to a compact (broadband) design which was integrated directly into the PETS output coupler. In this design, by displacing longitudinally the short circuit piston by 8 mm, the rf power transmitted to the structure can be progressively changed from 1 to 0. In Figure 2, the electric field plots simulated with HFSS for the two extreme positions of the piston are shown.

To study the pulse time structure at intermediate piston positions, we carried out a complete analysis of the system operation, based on the HFSS simulations of the transfer matrices for all the components, including PETS, power coupler, fixed and variable reflectors [4]. The results are summarised in Figure 3. These simulations confirmed that a gradual ramping of rf power at the structure input can be obtained in a straightforward way. In the OFF position, the rf power production in the PETS can be suppressed to 25% of its original value, which was expected to be enough to prevent or to reduce dramatically the probability of rf breakdown in the PETS.

HIGH POWER OPERATION WITH BEAM

The first prototype high rf power variable reflector was fabricated and the low rf power measurements were in good agreement with HFSS simulations, see Fig. 4. We also built a separate variable rf short circuit to enable the tuning of rf phase advance in the system.

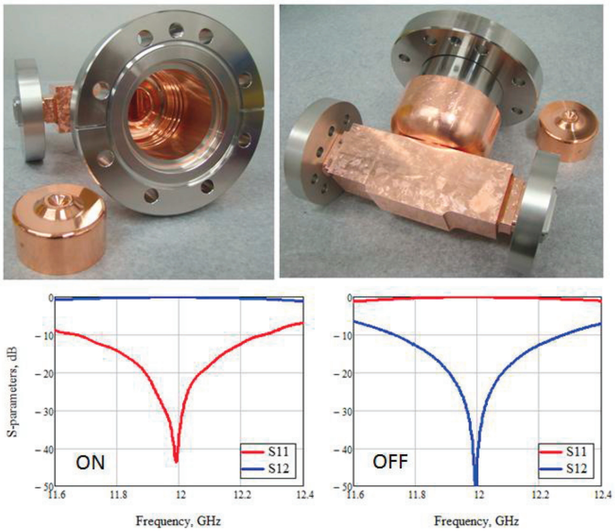

Figure 4: The general view of the variable reflector body and movable piston (up). S-parameters measured at two extreme positions of the piston.

These new components were installed on the TBTS PETS tank (see Fig. 5) in order to establish an internal recirculation rf circuit with the capability to control the coupling and rf phase advance in the loop. At the very beginning, the variable short circuit was set at the position that provided a destructive phase advance in the loop for the case of full reflection in variable reflector.

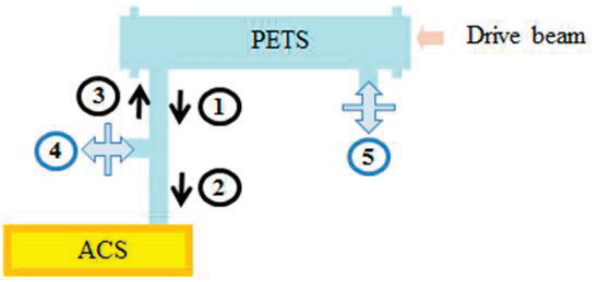

Figure 5: Layout of the PETS ON/OF setup in TBTS. The black arrows show rf power flows in the system: 1) rf power extracted from the PETS; 2) rf power transmitted to the accelerating structure; 3) rf power reflected back into the PETS. The new components are: 4) variable rf reflector; 5) variable rf short circuit.

During experiments with the beam, the variable reflector settings were changed gradually from full reflection to full transmission. The rf power produced by PETS and delivered to an accelerating structure were measured at different intermediate piston positions. The results of one of the tests are shown in Fig. 6.

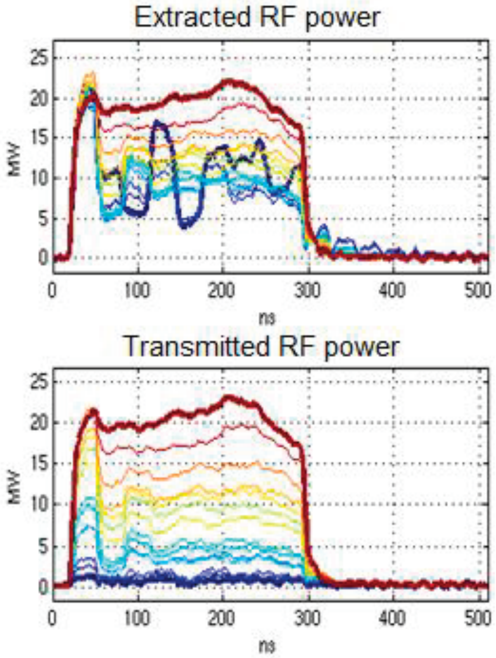

Figure 6: TBTS PETS ON/OFF demonstration with the beam. Here the line colors correspond to different settings of variable reflection. The colors are gradually changed from red (ON) to blue (OFF).

Comparing figures 3 and 6 one can observe differences in rf pulses shapes. This disagreement comes from the fact that in TBTS PETS, the round trip time is about 15 times longer than in the CLIC PETS. To benchmark our calculation methods, we have used the measured drive beam current pulse and measured S-parameters of all the rf components in a loop to reconstruct the rf pulse generate by PETS. The results are shown in Fig. 7. One can see good agreement between the prediction and the measurements.

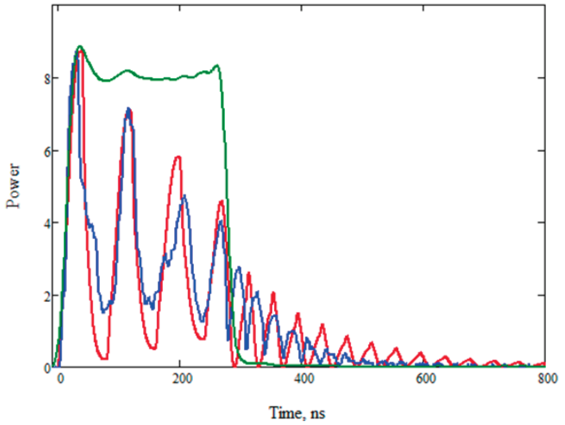

Figure 7: The simulated (red) and measured (blue) rf pulses generated by PETS in the OFF state. The direct power production (ON state) is shown in green.

One can conclude that PETS ON/OFF operational principle was successfully demonstrated in these experiments. At this time, the available drive beam current in CTF3 made it impossible for us to run the system at the nominal CLIC rf power level in direct rf power production mode. To demonstrate the power capability of the new rf components used in the ON/OFF rf circuit, we set the recirculation loop parameters to their amplification mode, similar to the setup that was routinely used in the TBTS PETS with external recirculation before [5]. The processing of the PETS with ON/OFF circuit went rather fast. In about 5 days (2x10^5 pulses) the system was conditioned up to 130 MW × 200 ns. The processing history is summarized in Fig. 8 and Fig. 9.

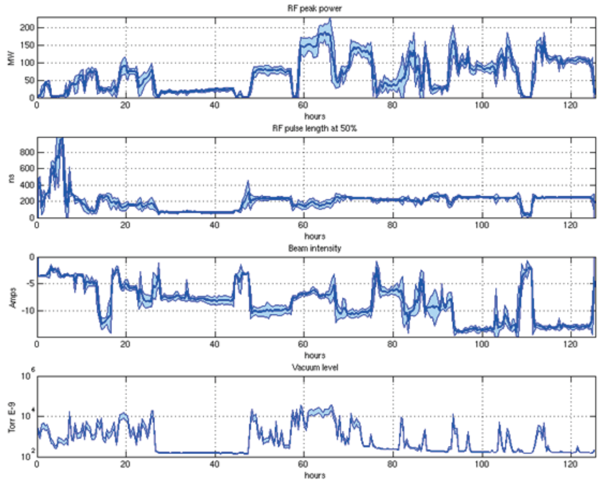

Figure 8: The PETS ON/OFF processing history. From top to bottom: peak rf power, rf pulse length, peak drive beam current and the vacuum level.

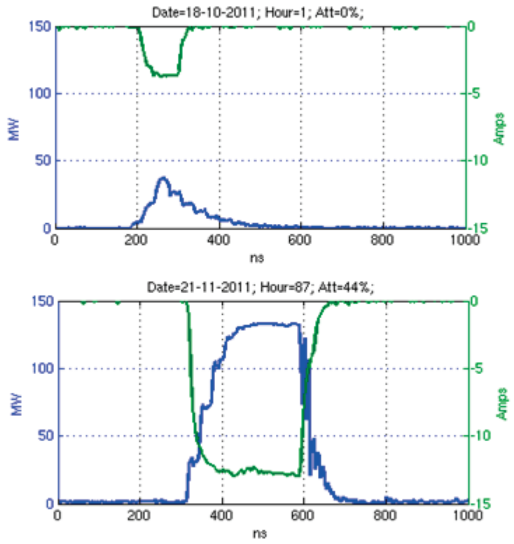

Figure 9: Typical drive beam current (green) and rf power (blue) pulses shapes at early (top) and final (bottom) stages of processing.

SUMMARY

The new high rf power variable rf reflector and variable rf short circuit were designed and fabricated. These devices have replaced the external recirculation loop which was used before as a part of the beam based rf power production in the special, 1 m long PETS installed in CTF3. The PETS ON/OFF operational principle and high peak rf power capability were successfully demonstrated in experiments with the CTF3 drive beam.

REFERENCES

[1] I. Syratchev, “30 GHz High Power Production for CLIC”, 7th Workshop on High Energy Density and High Power RF, Kalamata, Greece, June 2005.

[2] I. Syratchev and A. Cappelletti, “On-off, Options and Operation”, CLIC Workshop 2008, October 2008, CERN.

[3] I. Syratchev and A. Cappelletti, “A new High-Power rf Device to Vary the Output Power of CLIC Power Extraction and Transfer Structures (PETS)”, IPAC 2010, Kyoto, Japan.

[4] A. Cappelletti, “PETS ON/OFF and Pulse Propagation through Two-Beam rf Network”, 4th Annual X-band Structure Collaboration Meeting, May 2010, CERN.

[5] E. Adli, R. Ruber, V. Ziemann, R. Corsini, A. Dubrovskiy, and I. Syratchev, “X-band rf power production and deceleration in the two-beam test stand of the Compact Linear Collider test facility”, Phys. Rev. Special Topics - Accelerators and Beams 14, 081001 (2011).