A NEW HIGH-POWER RF DEVICE TO VARY THE OUTPUT POWER OF CLIC POWER EXTRACTION AND TRANSFER STRUCTURES (PETS)

I. Syratchev, A. Cappelletti, CERN, Geneva, Switzerland

Abstract

One crucial development for CLIC is an adjustable high-power rf device which controls the output power level of individual Power Extraction and Transfer Structures (PETS) even while fed with a constant drive beam current. The CLIC two-beam rf system is designed to have a low, approximately 10^{-7}, breakdown rate during normal operation and breakdowns will occur in both accelerating structures and the PETS themselves. In order to recover from the breakdowns and reestablish stable operation, it is necessary to have the capability to switch off a single PETS/accelerating structure unit and then gradually ramp generated power up again. The baseline strategy and implementation of such a variable high-power mechanism is described.

INTRODUCTION

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 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. To maintain overall luminosity, the system reaction should be faster than 20 msec. 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 beam, nor main beam will experience effects which can spoil the beam quality. In the past, a method based on changing the PETS synchronous with the beam frequency was proposed [1, 2]. However, 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.

ON/OFF BASELINE STRATEGY

An external high power variable rf reflector is a key component of the system [2], as is illustrated in Fig. 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 fixed internal rf reflector placed at the upstream end of the PETS, and thus to establish recirculation of rf power inside the PETS. If at the operating frequency the electric length of such an rf circuit is tuned to be $L=\lambda_0(n+1/4)$, then the destructive effect of the rf power generation from the drive beam can be achieved. These processes for the cases of full transmission (ON) and full reflection (OFF) are illustrated in Fig. 2. In our simulations we have used the single bunch response of the PETS calculated with computer code GdfidL [3], whereas the reflectors were represented with idealistic dispersion-free models. Here, the gradual ramp of rf power needed for the beam loading compensation in the accelerating structure, was modelled using special modulation of individual bunches intensity [4]. In such a configuration, complete cancelation of rf power production in the PETS is not possible. However, the resulting rf pulse suppression is expected to be enough to prevent or to reduce dramatically the probability of rf breakdown in the PETS.

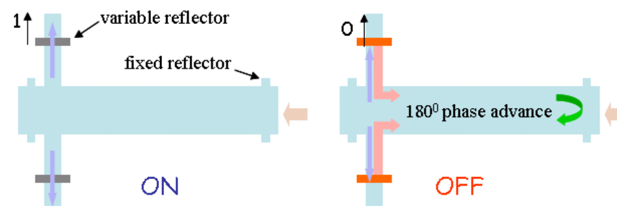

Figure 1: Schematic diagram of the PETS ON/OFF operation strategy.

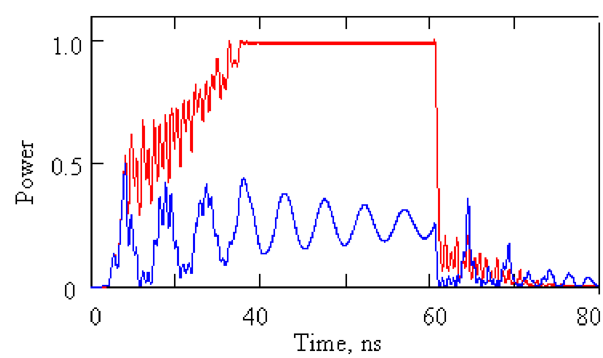

Figure 2: RF pulses envelopes at the PETS output for the ON (red) and OFF (blue) positions of the reflector.

VARIABLE RF REFLECTOR DESIGN

After numerous studies [5], the 3-port waveguide rf circuit was chosen as the baseline configuration for the variable rf reflector design. In such a device, the reflection can be varied from 0 to 1, if one of the ports is equipped with rf short circuit where the rf phase of reflection can be changed progressively by 180^0. One of the most attractive solutions for such a device has been recently developed and successfully operated at SLAC as a part of the X-band SLED II pulse compressor [6]. There, the main idea was to use the circular waveguide with a symmetric H_{01} propagating mode. In this case, the short circuit does not need to have an electrical contact with the rest of waveguide wall and can be mechanically moved in either longitudinal direction, therefore providing the necessary rf phase advance. We have studied a similar approach using the most compact design of H_{10} to H_{01} mode converter developed in KEK [7]. The rf design of such a variable reflector integrated with the PETS output coupler has been developed [8]. In Figure 3, the electric field plots simulated with HFSS [9] for the two extreme positions of the rf short circuit are shown. However the extra volume occupied with mode converter naturally limited the frequency bandwidth of the device in the ON position (see Fig. 6), as a result, due to the parasitic internal recirculation in the PETS, a transient modulation of the generated rf pulse occurs, as shown in Fig. 4.

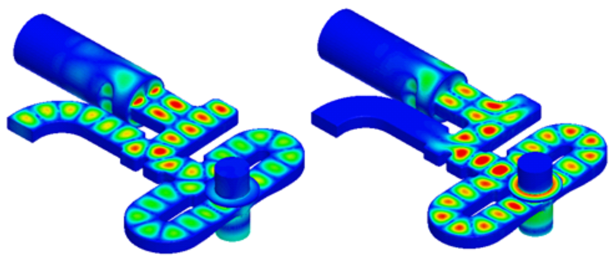
Figure 3: Electric field plots for the reflector in ON (left) and in OFF (right) positions.

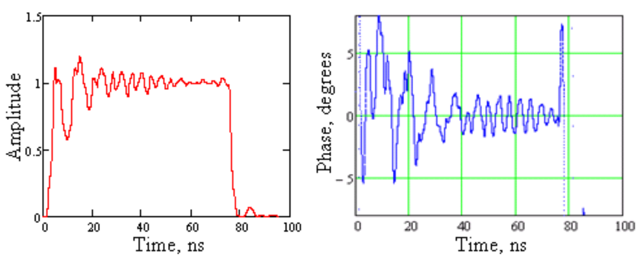

Figure 4: The generated rf pulse envelope (left) and rf phase profile (right) for the reflector in ON position.

This effect causes excessive voltage variation in the accelerating structure, thus we developed a new type of compact reflector which is arranged as a sequence of the different rf circuits, see Fig. 5. Here the rf short circuit (piston) is designed as a part of both the radial and the coaxial lines. This configuration provides the possibility for the piston mechanical movement, similar to the previous design. To prevent rf wave propagation in the coaxial part, it is equipped with an rf filter composed of the three choke reflectors with isolation better than -60 dB in a broad frequency range. Because this solution is compact, the frequency bandwidth of the device in the ON position was significantly increased (see Fig. 6), resulting in much less perturbation of the generated rf pulse, see Fig. 8. The profile of the piston face when opened towards the circular waveguide was specially optimized to reduce the surface electric field enhancement down to 80% of the maximal value in the rest of the system. In Fig. 7, the electric field plots simulated with HFSS for the two extreme positions of the piston are shown.

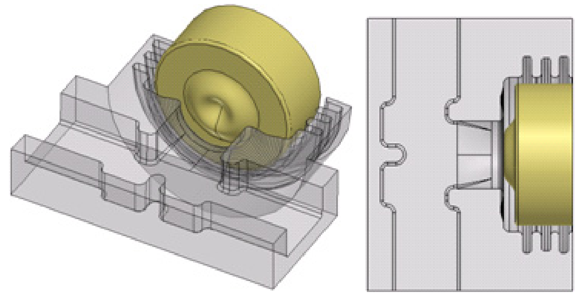
Figure 5: Artistic view of the new variable reflector.

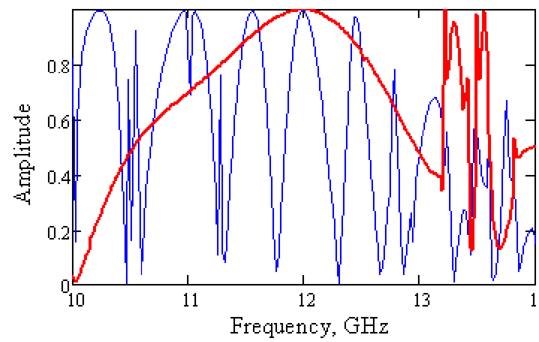

Figure 6: Transmission of the reflector in ON position. Here in blue is for the first reflector version and in red is for the new design.

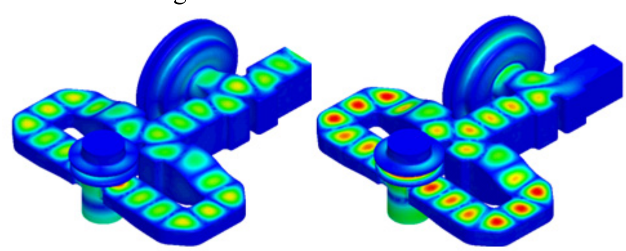
Figure 7: Electric field plots for the reflector in ON (left) and in OFF (right) positions.

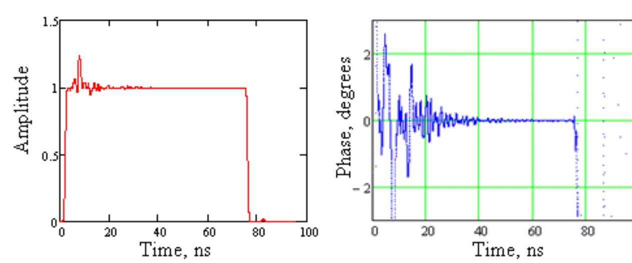

Figure 8: The generated rf pulse envelope (left) and rf phase profile (right) for the reflector in ON position.

SYSTEM OPERATION ANALYSIS

As it was mentioned earlier, the capability of the system to provide gradual ramping of the generated rf power up, in order to re-process the structure after the breakdown, is one of the key requirements. In our case, this option can be naturally implemented, because the reflection from the device is proportional to the relative position of the piston, see Fig. 9. Nevertheless, certain complications come from the fact that exact conditions for the anti-phase recirculation: $L=\lambda_0(n+1/4)$; are valid only for the piston

OFF position. At any intermediate piston position, this condition is no longer true.

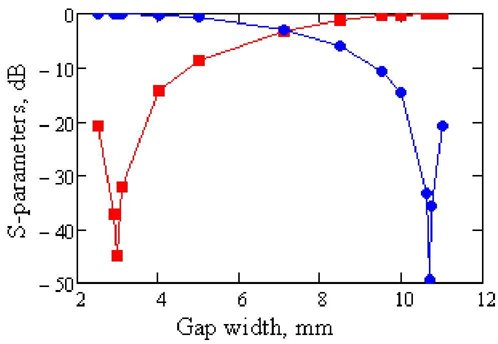

Figure 9: Reflection (red) and transmission (blue) for the different position of the piston at 12 GHz.

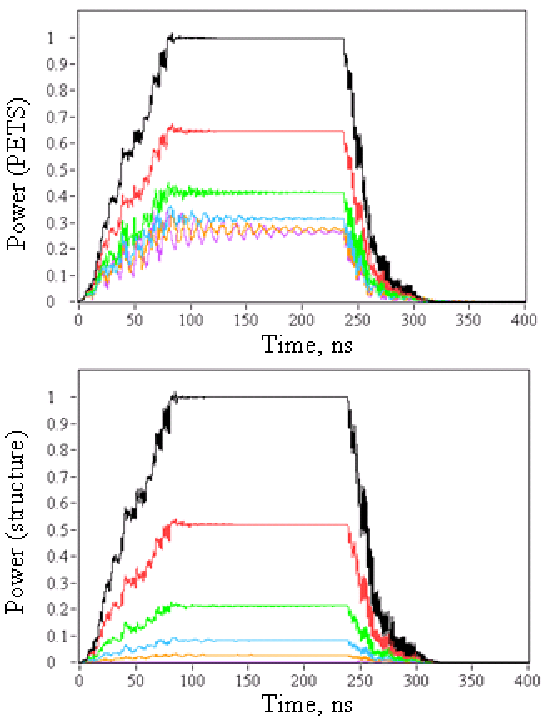

Figure 10: RF pulses envelopes at the PETS output (top) and the structure input (bottom). Here the reducing amplitudes correspond to the different piston positions.

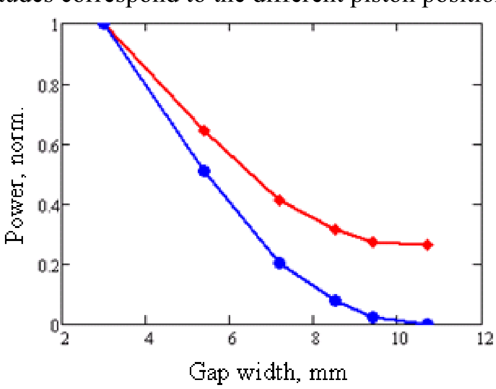

Figure 11: Normalized steady state rf power levels at the structure input (blue) and the PETS output (red) for the different piston positions.

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 [10]. As an input, we used single bunch response of the PETS calculated with GdfidL. The results are shown in Fig. 10. The rf power levels at the PETS output and at the structure input, as a function of the piston displacement, are summarized in Fig. 11. These simulations confirmed that gradual ramping of rf power at the structure input can be organized in a straightforward way. In the OFF position, the rf power production in the PETS can be suppressed down to 25% of its original value, which is expected to be enough to prevent or to reduce dramatically the probability of rf breakdown in the PETS.

TESTING PLANS

Currently, the new high rf power variable rf reflector together with the rf phase shifter, designed using a similar principle, are under fabrication. Later in 2010, these devices will replace the external recirculation loop which is now used as a part of the beam based rf power production in the special, 1 m long PETS installed in CTF3 [11]. At that time, the PETS will generate nominal CLIC rf power from 23 A drive beam and the developed PETS ON/OFF strategy will be tested.

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", CLIC08, October 2008, CERN.

[3] The GdfidL Electromagnetic Field simulator: http://www.gdfidl.de/.

[4] D. Schulte and I. Syratchev, "Beam Loading Compensation in the Main Linac of CLIC", Linac Conference, August 2000, Monterey, USA.

[5] A. Cappelletti, "Waveguide Components for the PETS ON/OFF", X-Band RF Structure and Beam Dynamics Workshop, December 2008, UK.

[6] S. Tantawi, "Test Facilities and Component Developments", 2nd Collaboration Meeting on X-Band Accelerator Structure Design and Test Program, 2008, KEK, Japan.

[7] S. Kazakov, "New Compact TE10-TE01 Mode Converter and TE01-TE02 Window", ISG-8, June 2002, SLAC, USA.

[8] I. Syratchev, "Progress in the PETS Development", CLIC09, October 2009, CERN.

[9] Ansoft Corporation – HFSS: http://www.ansoft.com/

[10] A. Cappelletti, "PETS on/off and Pulse Propagation Through Two-Beam rf Network", 4th Annual X-band Structure Collaboration Meeting, May 2010, CERN.

[11] F. Tecker, "Status of CTF3. Feasibility Studies: Experimental Program.", CTF3 Collaboration Technical Meeting, May 2010, CERN.