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THE DESIGN UPDATE OF X-BAND RF PULSE COMPRESSOR WITH CORRECTION CAVITIES FOR THE CLIC 380 GEV KLYSTRON BASED ACCELERATOR

Jinchi Cai[2] and Igor Syratchev[1]

[1]European Organization for Nuclear Research, Geneva, Switzerland
[2]Lancaster University, United Kingdom

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Abstract

The X-band RF Pulse Compressor (PC) with Correction Cavities was selected as a base line option for the CLIC 380 GeV klystron based accelerator. The recent detailed studies of this system were done few years ago. Since then, the parameters of the accelerating structure have been re-evaluated to improve the accelerator performance. Consequently, the update of the pulse compressor (PC) design is needed to adopt it to the new CLIC accelerating structure requirements. The results of PC optimisation adopted to the new structure parameters are presented in this note.

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The design update of the X-band RF pulse compressor with Correction Cavities for the CLIC 380 GeV klystron based accelerator.

J. Cai (1) and I. Syratchev (2)
(1) Lancaster University, UK
(2) CERN, Geneva, Switzerland

1. Introduction

The X-band RF pulse compressor with Correction Cavities [1, 2] was selected as a base line option for the CLIC 380 GeV klystron based accelerator. The recent detailed studies of this system are presented in [3, 4]. Since then, the parameters of the accelerating structure have been re-evaluated [5] to improve the accelerator performance. Consequently, the update of the pulse compressor (PC) design is needed to adopt it to the new CLIC accelerating structure requirements. The basic input information for such design update are RF pulse length and RF pulse shape (see Fig. 1) that were optimized for the accelerating structure that provides optimal combination of the machine luminosity, cost and power consumption efficiency. Another input parameter, the klystron pulse length before the PC (2000 ns), was kept similar to the original design. Such a pulse length was selected originally as a compromise between klystron/modulator constrains on the peak/average power and PC efficiency [6]. To improve the system efficiency further, it was decided to introduce the RF driving power during the rise time of the modulator HV pulse. In this case, with proper RF phase compensation, the klystron will produce effectively longer (~15%) pulses, which will increase the compressed power level after the PC. Another improvement considered the design methodology. This time, we introduced the complex transfer function of the klystron amplifier based on the klystron simulations using CERN made computer code KlyC [7]. In general, such approach allows simulating klystron response in the presence of time dependent RF reflection from the load, like RF breakdown in accelerating structure for example. The RF network itself, including storage and correction cavities, was characterized in a frequency domain. Thus, the simulation can include complex transfer functions of all the RF components that comprise RF network. With this method, the frequency bandwidth limitations of all the RF components can be accounted for and will contribute to the RF pulse shape distortion. However, the results presented in this note are based on the simulations with PC connected to the matched RF load.

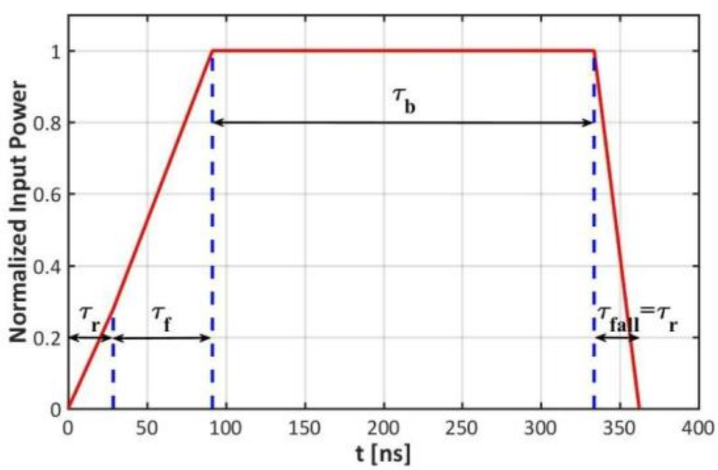

Figure 1: Schematic shape of the input pulse for the CLIC-K accelerating structure. Flat top 244 ns [5].

2. PC optimization results.

The PC optimization was targeted to find the compromise between compression efficiency (power gain) and the cost (number of correction cavities). The initial study employed the intrinsic quality factors of correction cavity ($4.5x10^4$) and storage cavity ($1.77x10^5$) identical to the ones used in [3 and 4]. These quality factors have been demonstrated in experiments and can give an accurate estimate of the PC performance based on the measured data. In the PC with a finite number of correction cavities, the compressed pulse contains the residual modulation of the flat top, which oscillation frequency and amplitude depend on the cavities number. To flatten the pulse, the accepted strategy is to use klystron pair with individual phase modulation connected through the 3dB hybrid. Thus, the resulting pulse amplitude can be pre-modulated and compensate for the compressed pulse flatness. In this process, the modulated part of the pulse will be removed and efficiency will be reduced. In Fig. 2, the power gain curve optimized for the different number of correction cavities is shown. The example of RF pulses with six correction cavities is shown in Fig 3.

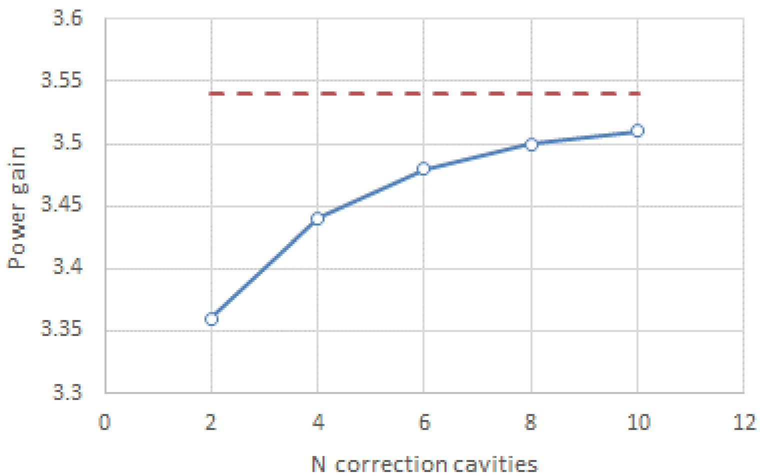

Figure 2: The power gain on the flattened pulse top for the different number of correction cavities (Q_{BOC}=$1.77x10^5$ and Q_{CC} =$4.5x10^4$; Δf_{cc}=±m×2.8MHz and T_{Kl}=2000ns). Dash line corresponds to the average power gain (3.54) in a system without pulse top flattening, which is also equal to the flat top pulses with infinite number of the correction cavities.

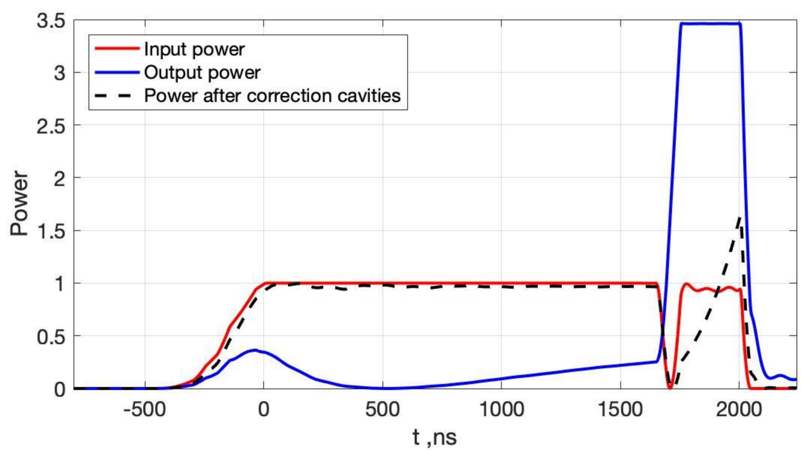

Figure 3: The voltage envelopes of the pulses for 6 cavities in the correction chain (Q_{BOC}=$1.77x10^5$; β=5, and Q_{CC} =$4.5x10^4$; β=1.35). Flat top 244ns.

From this study, we may conclude that compression efficiency is almost saturated when the number of correction cavities $N_{CC} \geq 6$ (Pg_6=3.48). Such a result comes from the significant reduction of the compress pulse spectral bandwidth due to the long (90ns) RF pulse rise time (Fig. 3), which is needed for the beam loading compensation. In the case with low beam current (no beam loading), the flat top shall be increased from 244ns to 300 ns. In this case, the longer flat top, together with fixed frequency tuning of the correction cavities will reduce the power gain from 3.48 to 3.18 (see Fig 4). This power gain is still above the conservative value of 2.2 that is needed to maintain the designed accelerating gradient in the structure without beam loading effects.

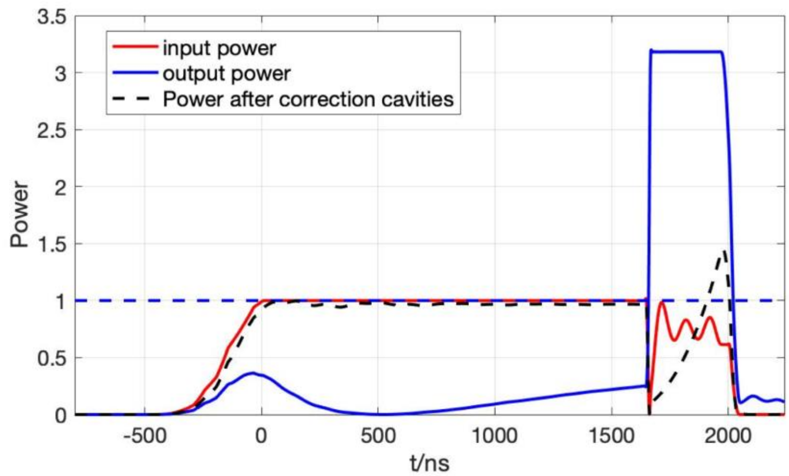

Figure 4: The voltage envelopes of the pulses for 6 cavities in the correction chain (Q_{BOC}=1.77x10^5; β=5, and Q_{CC} =4.5x10^4; β=1.35). Flat top 300 ns.

Next, we investigated the possibility to improve compression efficiency in a system with 6 correction cavities by increasing the quality factor of the storage cavity from 1.77x10^5 up to 2.6x10^5 for two different values of the correction cavity quality factor: 4.5x10^4 and 6x10^4. The results are summarized in Fig. 5. As expected, the efficiency of compression is improved with increasing Q factors. It is suggested that Qcc=6x10^4 (β=1.48) and Q_{BOC}=2.4x10^5 (β=6) is a good compromise that increases power gain by 7.5% compared to the initial design: from 3.48 to 3.74.

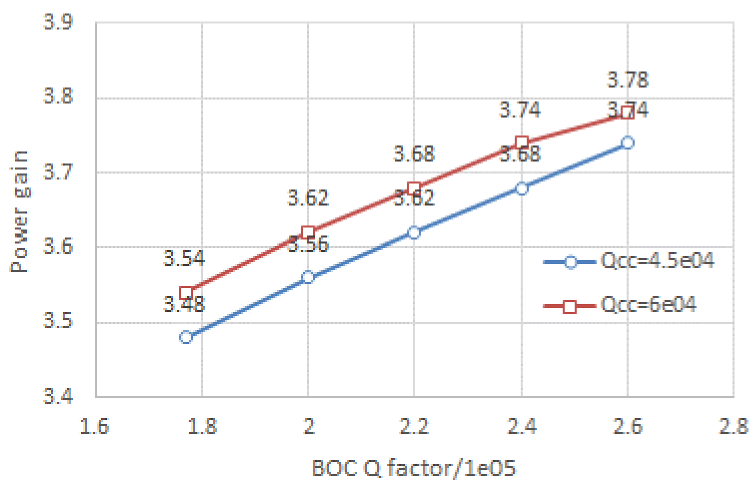

Figure 5: The power gain for the different values of the quality factors of the storage and correction cavities.

The power gain of 3.74 can be used now to determine the klystron peak RF power requirements. In the present CLIC-K module layout the two klystrons deliver RF power to eight accelerating structures. With 40.6 MW [5] peak RF power needed to drive the individual accelerating structure and simulated 84% of the waveguide circuit transmission efficiency, the single klystron shall produce 51.7 MW, 2000 ns pulse at the repletion rate of 50 Hz. The high efficiency 50 MW klystron was recently designed at CERN in collaboration with CPI [8]. This klystron, operated in saturation with 190 A beam at 400 kV is expected to deliver 52.4MW with efficiency of 69%, see Fig. 6.

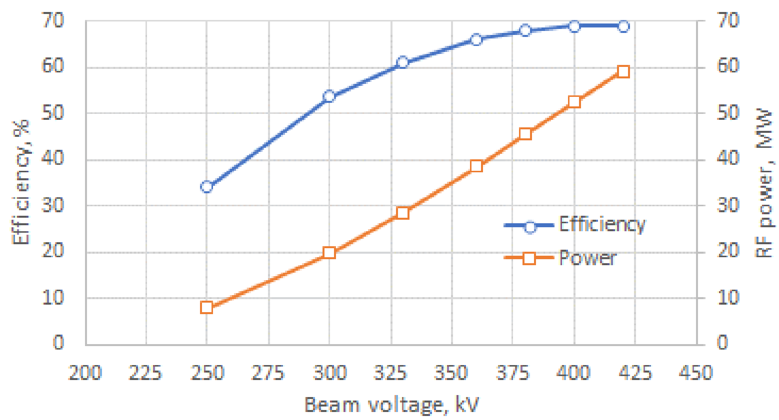

Figure 5: Peak RF power and efficiency vs. beam voltage in the high efficiency X-band klystron designed at CERN.

To calculate the overall efficiency of the system, the efficiency of the modulator and power consumption in the klystron solenoid shall be accounted for. Recently, the first prototype of the HTSC solenoid for the 50 MW X-band commercial klystron was fabricated and tested in industry [9]. In the CLIC-K module, the twin solenoid with a single current feedthrough will be used. In this configuration, the solenoid power consumption per klystron is expected to be about 1.2 kW. The measured power efficiency of the modern solid-state high power pulsed modulator is 80% [10]. Therefore, at 50 Hz repetition rate, 2 μsec long pulses and 76 MW peak beam power, the average power delivered from plug to modulator is 9.5 kW. Additional 0.8 kW is attributed to the klystron cathode heater, RF driver and LLRF system. In total, the RF power source consumption/klystron from plug builds up to 11.5 kW. The average RF power used for acceleration in four structures is 2.1 kW. Finally, the overall efficiency of the RF power production and delivery in CLIC-K module is 18.2%.

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