RF DESIGN OF THE PULSE COMPRESSION SYSTEM FOR THE KLYSTRON-BASED CLIC MAIN LINAC

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Abstract

A pulse compression system based on double-height waveguides was designed for the Klystron-based CLIC main linac. The system has been optimized to achieve a power gain of 3.81 with the specific pulse shape required for the CLIC-K accelerating structure. This pulse compression system is composed of a main pulse compressor based on the Barrel Open Cavity (BOC) design and 4 correction cavities based on the bowl cavity design. The BOC pulse compressor operates in the $TM_{1,1,32}$ mode and has a Q_0 of 2.35×10^5 and a β of 6.6. To simplify the machining process, a novel coupling waveguide network was designed for the BOC pulse compressor. The correction cavities are based on the bowl cavity operating in the $TE_{2,2,3}$ mode, with a Q_0 of 7.5×10^4 and a β of 1.95.

INTRODUCTION

The Compact Linear Collider (CLIC) based on klystrons and a novel pulse compression system was proposed in Ref. [1]. In this scheme, the pulse compression system plays a crucial role in increasing the peak RF power in the RF module. This pulse compression system consists of an X-band SLED-type pulse compressor (SLEDX pulse compressor) and a correction cavity chain with 8 correction cavities [2]. The spectrum of this pulse compression system is similar to the spectrum of the SLED-II pulse compressor, which generates flat output pulses. However, the SLEDX pulse compressor alone generates RF pulses with decaying shape that is only suitable for single bunch acceleration. To compensate for this, the correction cavity chain modulates the amplitude of input pulse and generates RF pulse with a triangle shape. This process corrects the decaying shape of the SLEDX pulse compressor. Nevertheless, the RF pulse is imperfectly flat because of the limited number of correction cavities and has some ripples at the top. An RF rotator is used for the correction cavity chain to excite two polarized modes in the resonant cavities, which is a technique widely used in RF pulse compressors based on a single resonant cavity. We fabricated and tested the pulse compression system to demonstrate the principle [3], after which the parameters of the klystron-based CLIC were studied in detail and updated in [4]. In particular, a new accelerating structure named CLIC-K, the application of high-efficiency X-band klystron, and the RF network based on a double height weveguide were proposed. The available peak RF power of the X-band klystrons is assumed to be 50 MW, requiring a power gain of more than 3.8 [5]. To achieve this goal, we need larger unloaded quality factors for the resonant cavities of the pulse compression system. The pulse compression system should generate the RF pulse with specific shape compensating for beam loading of the CLIC-K accelerating structure. The required pulse shape is detailed in Ref. [6]. To achieve this goal, we propose a strategy to optimize the output RF pulse for the pulse compression system.

In this paper, we present a new pulse compression system with a power gain of 3.81 and a specific output shape satisfying the requirements of the klystron-based CLIC. We discuss the optimization strategy of the output pulse and provide details of the RF designs of the resonant cavities.

WAVEFORM OPTIMIZATION

Figure 1 shows the normalized input and output waveforms, as well as the input and output phases, of the pulse compression system. The flat input pulse (represented by the blue dashed curve) generated by the klystron is compressed by the pulse compression system, which results in an output pulse with several ripples. To obtain a flat output pulse, the amplitude modulation is applied to the input pulse, which generates the input pulse with the ripples (represented by the blue solid curve) as shown. During this amplitude modulation process, the beam time, filling time and power level at the beginning of the filling time are all taken into account. A detailed explanation of the these parameters can be found in Ref. [6].

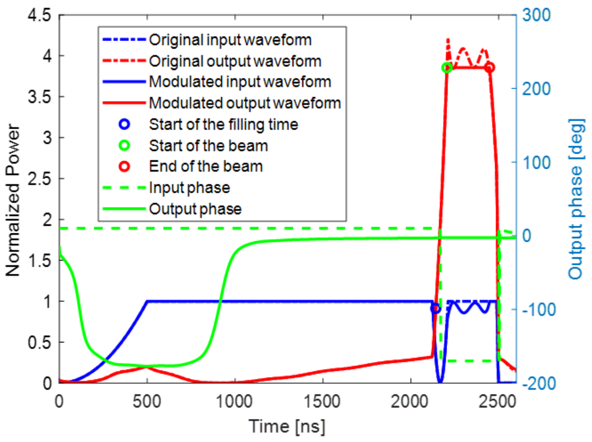

Figure 1: normalized input and output waveforms as well as the input and output phases of the pulse compression system.

The pulse compression system were analyzed using the optimization approach described earlier. Specifically, the rising and falling times of the input RF pulse were analyzed, in addition to the unloaded quality factors and coupling factors of the resonant cavities. Furthermore, We considered

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the RF losses that occur within the RF network for the resonant cavities. The optimized parameters of the new pulse compression system are presented in Table 1.

Table 1: Parameters of The Pulse Compression System

Parameters	**Values**
Power Gain	3.81
Unloaded quality factor of SC	2.35×10^5
Unloaded quality factor of CC	7.5×10^4
Coupling factor of SC	6.6
Coupling factor of CC	1.95
Number of correction cavities	4

RF DESIGN OF THE BOC PULSE COMPRESSOR

The pulse compression system's resonant cavities can be classified into two types: a single storage cavity (SC) and multiple correction cavities (CC). In principle, it is only the SC that requires a large unloaded quality factor, while the CCs require a relatively lower value. This explains why the pulse compression systems based on individual cavities can be very compact.

The pulse compression system' power gain is significantly enhanced by the large unloaded quality factor of the SC. Nevertheless, a large quality factor entails a sizable resonant cavity with small mode separation, complicating the design of the RF coupler. The Barrel open cavity (BOC) pulse compressor offers an advantage in this regard, featuring numerous coupling holes on the cavity [7]. We designed a new BOC pulse compressor for the klystron-based CLIC as demonstrated in the Fig. 2. This design incorporates a barrel open cavity and an innovative RF coupler utilizing a double height waveguide. Employing the double-height waveguide reduces the RF coupler's surface fields by 30% and its RF loss by 40%, addressing the primary constrains of the BOC-type cavities in high-power and high-efficiency pulse compression systems.

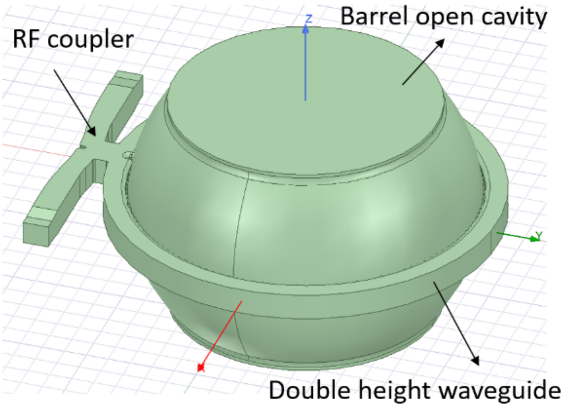

Figure 2: RF design of the BOC pulse compressor.

The electrical field pattern of the BOC pulse compressor is shown in the Fig. 3. The mode of the BOC pulse compressor is $TM_{1,1,32}$, excitable by 128 coupling holes located on the equatorial plane of the cavity.

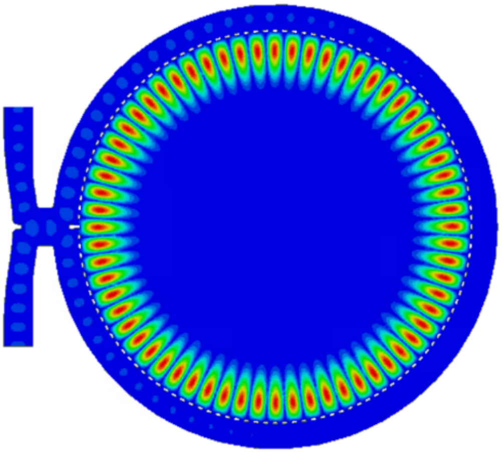

Figure 3: $TM_{1,1,32}$mode of the BOC pulse compressor.

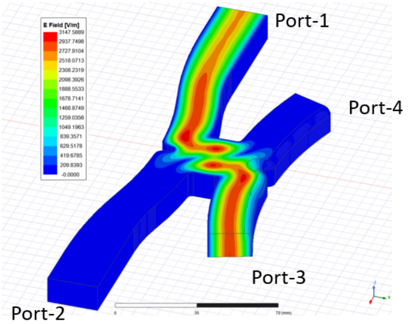

Figure 4: Core part of the RF coupler.

Figure 4 displays the core component of the RF coupler, which is a 4-port RF device. The RF power transmitted from Port-1 is directed to Port-3, while Port-2 and Port-4 are isolated from the Port-1. Connecting the Port-3 and Port-4 yields the full RF coupler with two ports, as shown in Fig. 5. In this case, the RF power from Port-1 goes to the Port-2 with minimal reflection, as shown in the Fig. 6. The traditional BOC pulse compressor has a thin wall between the input and output waveguides [7]. In the case of a double height waveguide, the thin wall is challenging to fabricate. The novel RF coupler can solve this problem as the input and output RF power share the core component.

RF DESIGN OF THE CORRECTION CAVITY CHAIN

For correction cavities, the bowl cavity was proposed in Ref. [8]. The working modes of the bowl cavity are two polarized $TE_{2,2,3}$ modes, as shown in Fig. 7. One notable feature of the bowl cavity is the low fields on the top of the

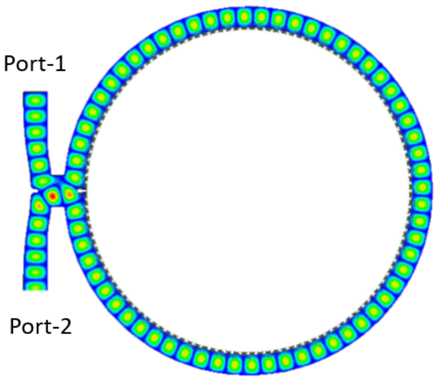

Figure 5: The RF design of the RF coupler.

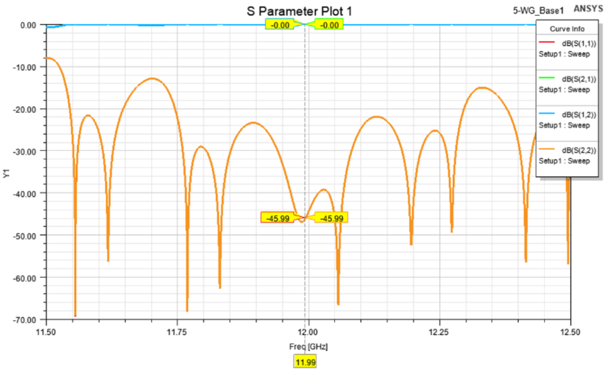

Figure 6: S-parameters of RF coupler.

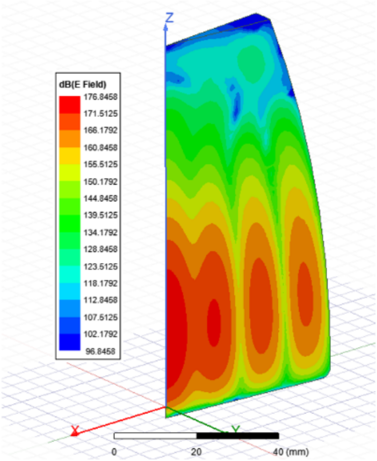

Figure 7: RF design of the bowl cavity with $TE_{2,2,3}$ mode.

cavity, which allows the top of the cavity to remain open for use in cavity machining and evacuation.

Figure 8 shows the RF rotator used to excite the rotating mode in the correction cavities, which is similar to that used for the first prototype of the correction cavity chain [2]. To reduce the surface fields and the RF loss, the RF rotator's height was increased from 10.16 mm to 12 mm. A new method to use the RF rotator was introduced in Ref. [9]. Based on this new method, two correction cavities can share the same RF rotator. This reduces the number of the RF rotators required for the correction cavity chain by half. The compact size and reduced RF loss of the correction cavity chain are benefits of this reduction in the number of the RF rotators.

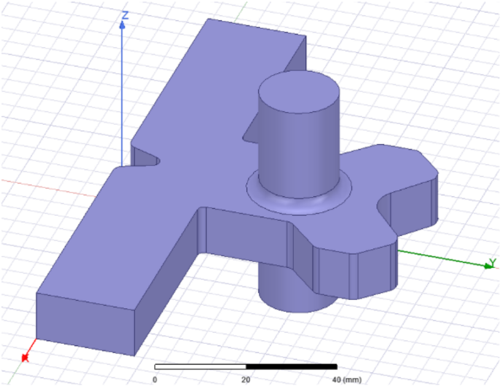

Figure 8: RF design of RF rotator with height of 12 mm.

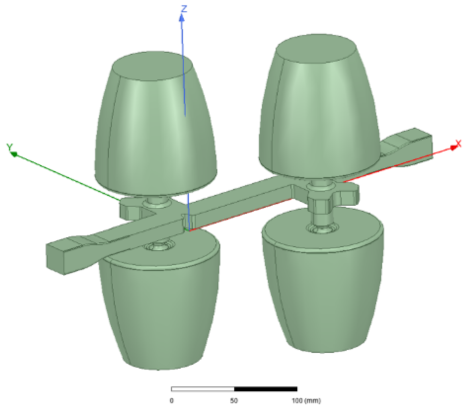

Figure 9: RF design of correction cavity chain.

The correction cavity chain is shown in the Fig. 9, comprising four bowl cavities and two RF rotators. Two tapers are utilized to transform the the waveguide height from 12 mm to 20.32 mm.

CONCLUSION

We have designed a new pulse compression system based on the new BOC pulse compressor and bowl cavities. The main parameters of the pulse compression system are listed in Table 1. The prototypes of the BOC pulse compressor and the bowl cavity are currently under fabrication. The cold measurements and high power test results will be presented in the future.

ACKNOWLEDGEMENTS

The authors thanks Igor Syratchev and Jinchi Cai for the discussion on waveform calculations.

REFERENCES

[1] M. J. Boland *et al.*, “Updated baseline for a staged compact linear collider”, 2016. `doi:10.48550/arXiv.1608.07537`

[2] P. Wang, H. Zha, I. Syratchev, J. Shi, and H. Chen, “Rf design of a pulse compressor with correction cavity chain for klystron-based compact linear collider”, *Phys. Rev. Accel. Beams*, vol. 20, p. 112001, Nov. 2017. `doi:10.1103/PhysRevAccelBeams.20.112001`

[3] Y. Jiang et al., “Demonstration of a cavity-based pulse compression system for pulse shape correction”, *Phys. Rev. Accel. Beams*, vol. 22, p. 082001, 2019. `doi:10.1103/PhysRevAccelBeams.22.082001`

[4] M. Aicheler *et al.*, *The Compact Linear Collider (CLIC) –Project Implementation Plan*, Geneva, Switzerland, CERN Yellow Reports, CERN-2018-010-M, 2018.

[5] J. Cai and I. Syratchev, “The design update of the X-band RF pulse compressor with Correction Cavities for the CLIC 380 GeV klystron based accelerator”, CERN, Geneva, Switzerland, Rep. CERN-ACC-2020-0031, Oct. 2020.

[6] J. Liu and A. Grudiev, “RF design of accelerating structure for the main linac of the klystron-based first stage of CLIC at 380 GeV”, CERN, Geneva, Switzerland, Rep. CERN-ACC2018-0034, Oct. 2018.

[7] V. E. Balakin and I. V. Syrachev, “Status of VLEPP RF Power Muliplier (VPM)”, in *Proc. EPAC’92*, Berlin, Germany, Mar. 1992, pp. 1173–1176.

[8] X. Wu and A. Grudiev, “Novel open cavity design for rotating mode rf pulse compressors”, *Phys. Rev. Accel. Beams*, vol. 24, p. 112001, 2021. `doi:10.1103/PhysRevAccelBeams.24.112001`

[9] X. Lin *et al.*, “X-band two-stage rf pulse compression system with correction cavity chain”, *Phys. Rev. Accel. Beams*, vol. 25, p. 120401, 2022. `doi:10.1103/PhysRevAccelBeams.25.120401`