RF DESIGN OF A COMPACT X-BAND TWO-STAGE PULSE COMPRESSION SYSTEM

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Abstract

This paper presents the design of a compact X-band two-stage pulse compression system featuring bowl-shaped open cavities, developed for a newly acquired 6-MW X-band klystron. The system consists of a correction cavity chain, a first-stage and a second-stage storage cavity. By employing bowl-shaped geometries, which have an unloaded quality factor (Q_0) higher than those of spherical cavities, the system significantly enhances both power gain and compression efficiency. With an input pulse of 5-µs from the klystron, the first-stage pulse can be flattened, generating a two-stage compressed pulse of 200 ns with exponentially decaying waveforms, thereby achieving a total peak power gain of ≥ 10.

INTRODUCTION

To meet the demanding power requirements of modern linear accelerators (linacs), advanced pulse compression techniques have become increasingly vital. The pulse compressor is a RF component that converts a long input pulse into a shorter, higher-amplitude pulse, reducing dependence on high-power klystrons [1, 2]. Due to inherent physical limitations, the peak power gain of a single-stage pulse compressor is typically capped at a threshold of 9 [3].

To achieve a higher power gain, this paper proposes the design of a two-stage pulse compression system, which incorporates a correction cavity chain (CC), a first-stage storage cavity (SC1), and a second-stage storage cavity (SC2). Due to the energy discharge process within the resonant cavity, the waveform generated by a single-stage pulse compressor exhibits a characteristic exponential decay. However, a flattop output is preferable, as it facilitates the acceleration of multiple bunches while effectively reducing the maximum surface fields of the structure. The correction cavity chain is an efficient method to compensate for the exponentially decaying output pulse from the first-stage pulse compressor [4]. The correction cavity consists of 6 resonant cavities, which are designed to create periodically spaced resonant peaks centered around the operating frequency of the storage cavities. The input pulse is modulated by the correction cavity chain into a rising-edge pulse. This shaped waveform compensates for the decaying pulse released by the first-stage storage cavity, ultimately resulting in a flattop output pulse. This output pulse is imperfectly flat because of the limited number of correction cavities and has some ripples at the top. Both the correction cavities and storage cavities employ the bowl-shaped geometry proposed in Ref. [5]. This specific cavity has a high unloaded quality factor (Q_0) while maintaining a compact physical size. After optimization, the proposed two-stage pulse compression system achieves a theoretical peak power gain of 16.95. Table 1 summarizes the main parameters of the two-stage pulse compression system.

Table 1: Parameters of the Two-stage Pulse Compression System

Parameters	Value
Input pulse length	5 µs
Output pulse length	200 ns
Number of correction cavities	6
Peak Power Gain	16.95
Unloaded quality factor of CC	1.7×10^5
Unloaded quality factor of SC1	2.5×10^5
Unloaded quality factor of SC2	2.4×10^5
Coupling factor of CC	2.0
Coupling factor of SC1	2.8
Coupling factor of SC2	28.4

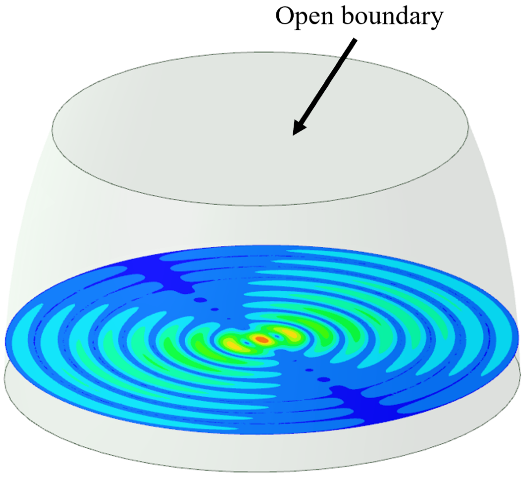

Figure 1: The electric field distributions of the working mode of $TE_{1,2,9}$.

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RF DESIGN OF THE CORRECTION CAVITIES

The bowl-shaped cavity work in the mode of $TE_{1,2,i}$, which is a dipole mode. The electrical field of the working mode in the top area is very small, thus the top of the cavity can be kept open. Furthermore, the symmetric geometry and open-top boundary of the cavity facilitate fabrication by eliminating the requirement for brazing, thereby significantly reducing manufacturing costs while enhancing precision.

The correction cavities work in the mode of $TE_{1,2,9}$, with a radius of around 118 mm. The electric field distributions of the working mode of $TE_{1,2,9}$ in a bowl-shaped cavity is shown in Fig. 1. While the working mode exhibits a negligible electric field at top boundary of the cavity, the parasitic modes may cause high field distribution in this region, leading to significant power losses at the open boundary. RF design of the coupling iris is shown in Fig. 2. Through optimizations of the coupling iris, the ratio of power dissipation at the open boundary to that on the cavity walls (R_{loss}) has been successfully reduced to 0.21%.

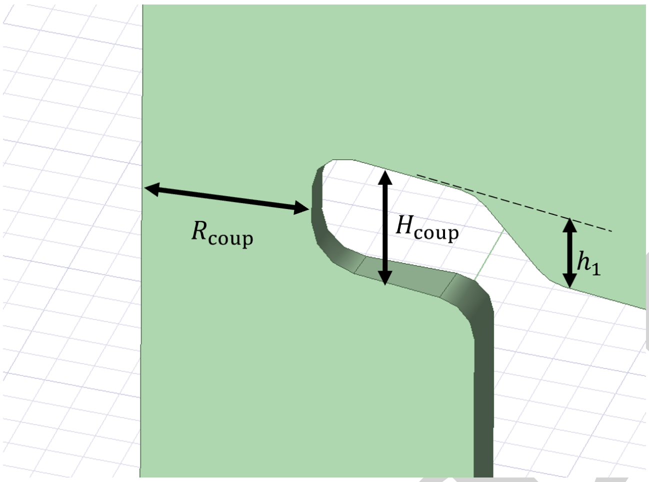

Figure 2: RF design of the coupling iris.

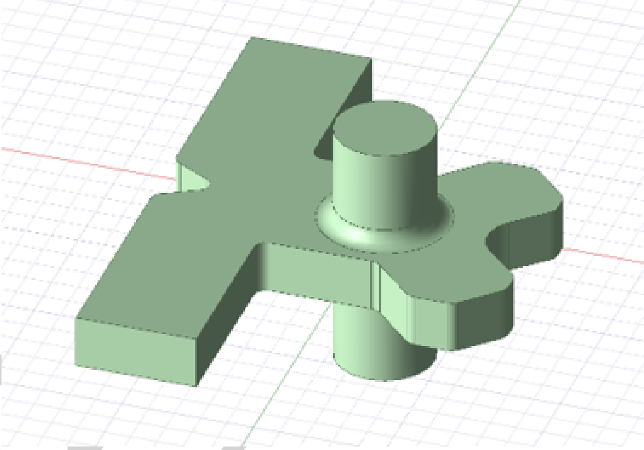

Figure 3: RF design of the expanded dual-mode polarizer used for correction cavities.

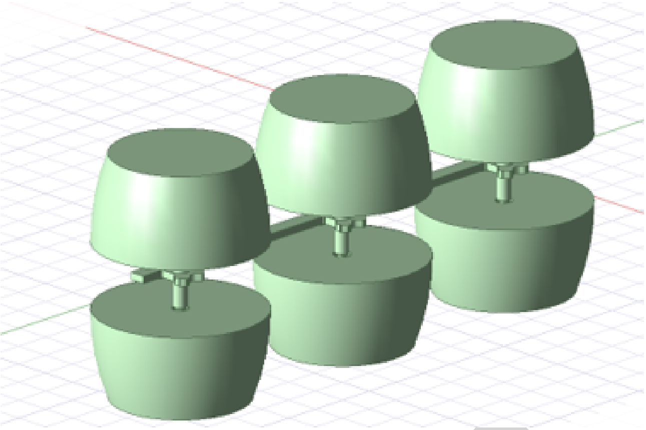

Figure 4: RF design of the correction cavity chain.

Figure 3 shows the expanded dual-mode polarizer used to excite the rotating mode in the correction cavities [6]. The circular waveguides situated at the top and bottom of the dual-mode polarizer can be interfaced with correction cavities of different resonant frequencies. This integrated configuration enables a single polarizer to serve two distinct cavities, thereby halving the total number of required dual-mode polarizers within the system.

The correction cavity chain is shown in Fig. 4, comprising 6 bowl cavities and 3 expanded dual-mode polarizers.

RF DESIGN OF THE STORAGE CAVITIES

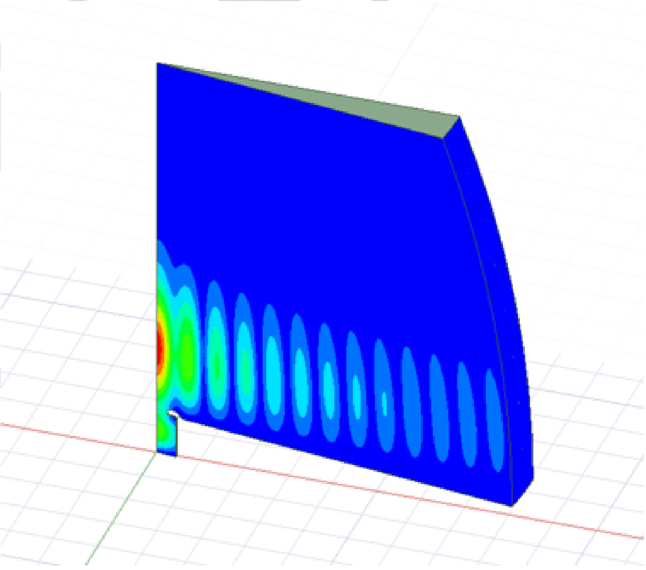

Figure 5: The electric field distributions of the working mode of $TE_{1,2,13}$.

The storage cavities work in the mode of $TE_{1,2,13}$, with a radius of around 171 mm. The electric field distributions of the working mode within the bowl-shaped cavity is illustrated in Fig. 5. Similar to design of the correction cavities, through meticulous optimization of the coupling irises, R_{loss} for the two storage stages have been successfully reduced to 0.26% and 2.1%, respectively. As the power loss at the open boundary increases with the coupling coefficient, Q_0 of SC2 is slightly lower than that of SC1. The dual-mode polarizer introduced in Ref. [7] is used to excite the rotating mode in the storage cavities, as shown in Fig. 6.

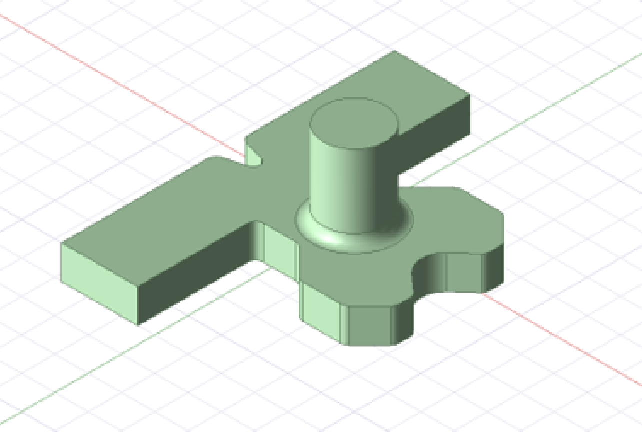

Figure 6: RF design of the dual-mode polarizer used for storage cavities.

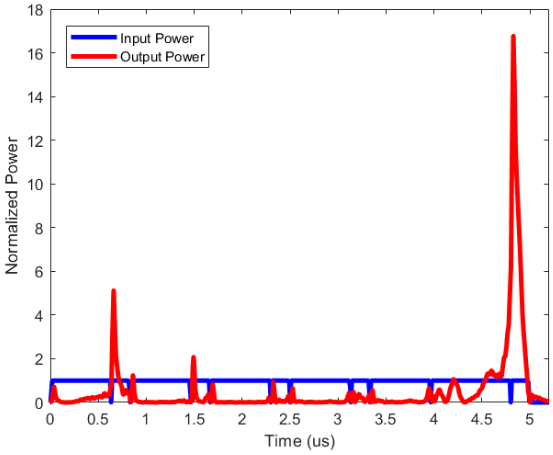

Figure 7: The calculated waveforms of the two-stage pulse compression system using the simulated transmission spectrum.

Figure 7 illustrates the time-domain waveforms of the two-stage pulse compression system, derived from the simulated transmission spectrum.

CONCLUSION

In this paper, a two-stage pulse compression system employing the bowl-shaped open cavities for both correction and storage has been developed. After optimization, the system achieves a peak power gain of approximately 16.95. This two-stage pulse compression system is currently under fabrication. The cold measurements and high power test results will be presented in the future.

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