Design of S-band high efficiency klystron

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Abstract

This paper focuses on designing S-band klystrons with higher efficiency to reduce energy consumption and costs in particle accelerators. Two novel bunching methods, Core Oscillation Method (COM) and Bunching Alignment and Collecting (BAC), have been applied to the S-band klystron at the Beijing Electron Positron Collider II (BEPCII). These methods have increased the klystron's efficiency from 45% to 55% and its output power to 80 MW. The design has been optimized using 1-D, 2-D, and 3-D simulation codes, which have improved electron injection and RF conversion efficiency. This design aligns with the goal of reducing energy consumption and promoting environmental sustainability.

Background

The development of large particle accelerators necessitates klystrons capable of providing megawatt-level power, which results in high energy consumption and operational costs. Therefore, enhancing the efficiency of klystrons can enable higher RF power generation while simultaneously reducing energy consumption and operating costs, thereby promoting environmentally friendly and sustainable solutions.

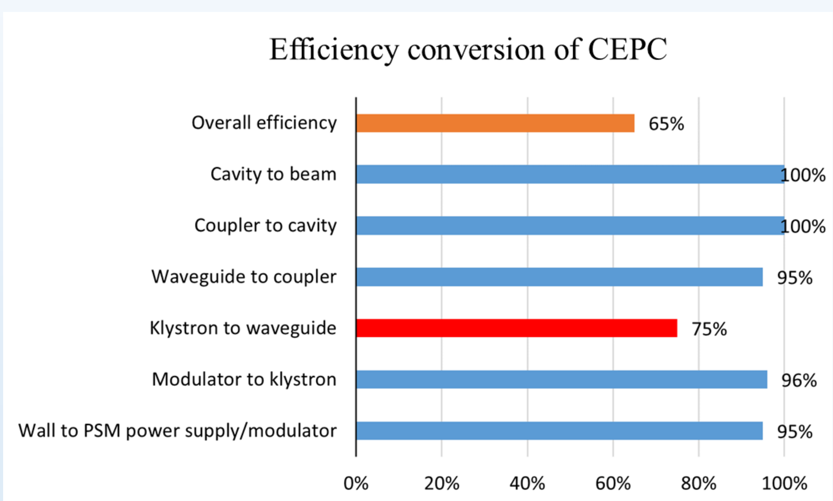

Figure 1 Overall efficiency of CEPC power sources

Method

The BAC method utilizes a resonant cavity to generate oscillations at the bunching center, reducing the length of high-frequency interactions. This leads to improved RF conversion efficiency and reduced energy losses. In contrast, the COM increases the drift length between the cavities to leverage the oscillation properties of the electron beam plasma, allowing for the oscillation of the bunching center electrons.

Design of electronic optical system

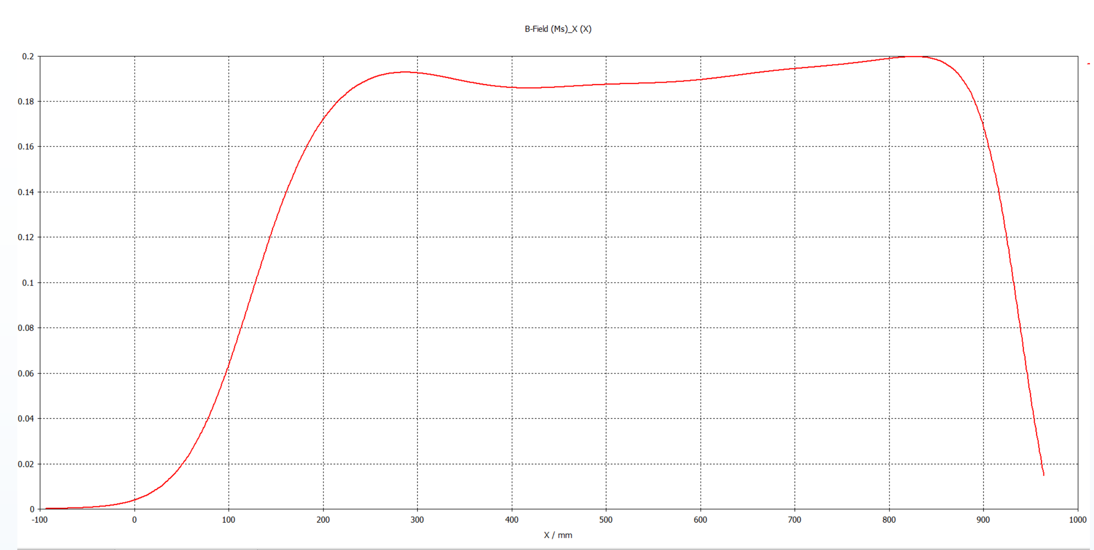

Figure 5 Magnetic field distribution in CST

The electron gun is verified in CST to achieve a current of 415 A, a maximum beam radius of 8.67 mm, and a beam fluctuation rate of 5.1%.

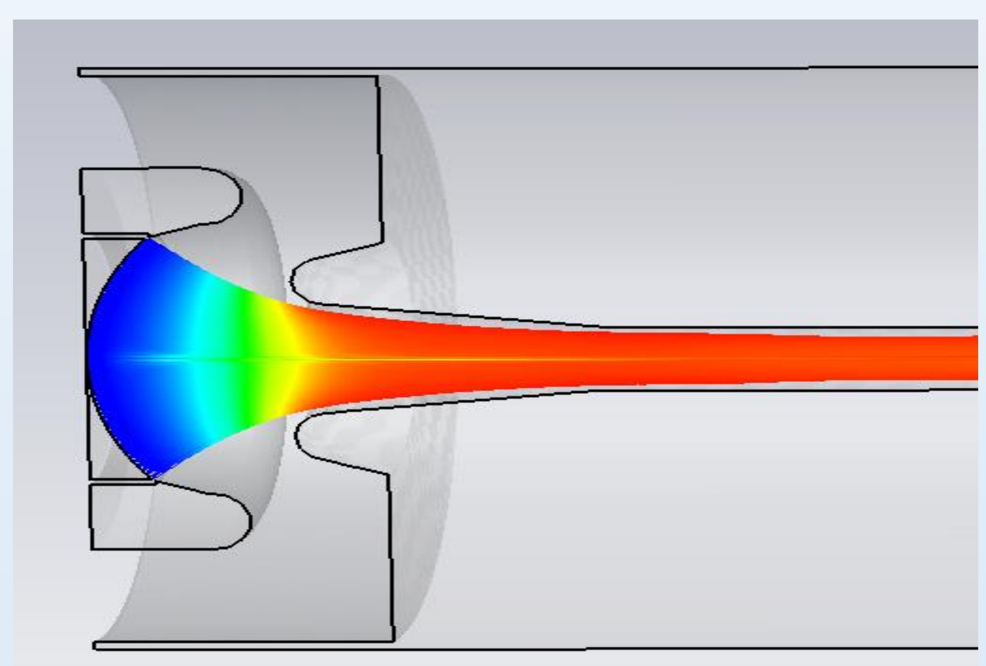

Figure 6 The electron gun in CST.

Beam dynamic

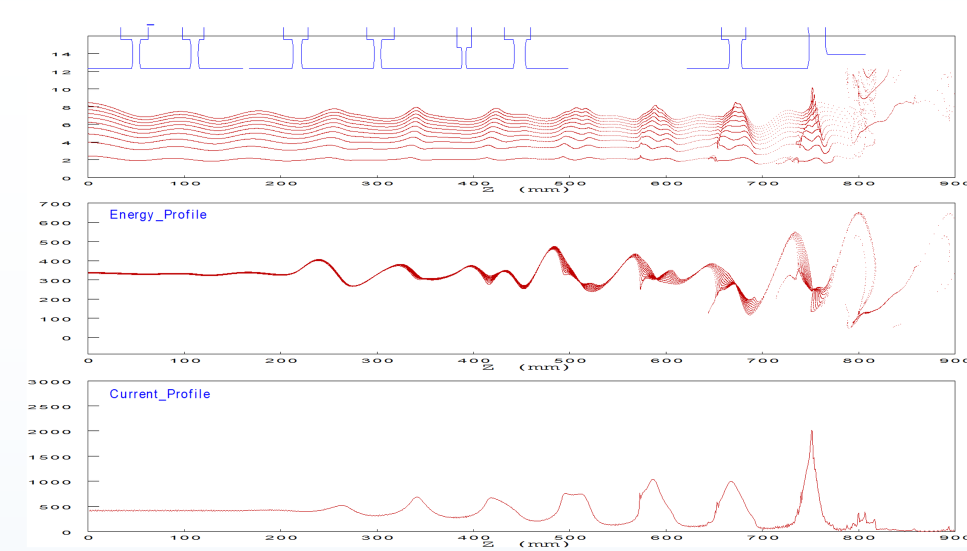

Figure 9 Beam and energy profile simulated by EMSYS

In 3-D CST, the RF conversion efficiency of the klystron was determined to be 55%, with an output power of 80 MW.

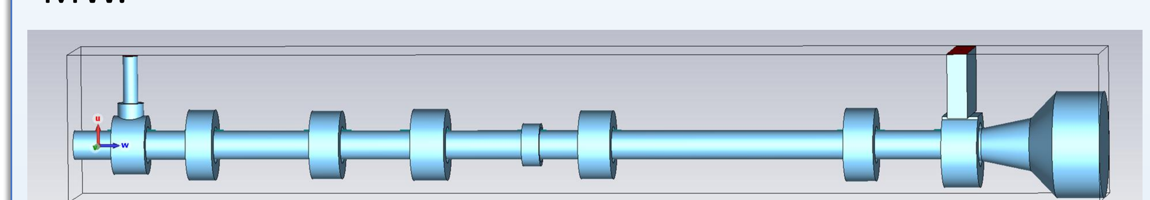

Figure 10 Structure of the klystron

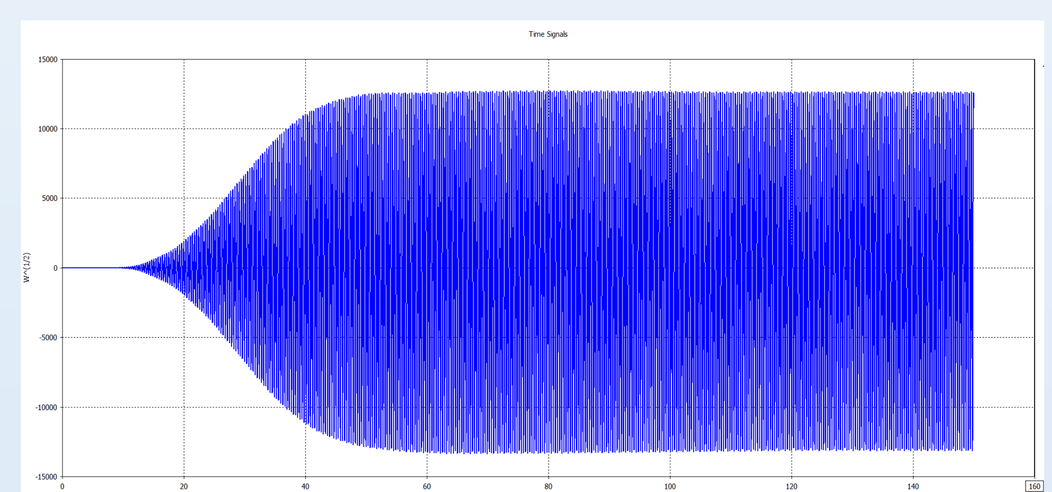

Figure 11 The power output in CST

Design of electronic optical system

The required parameters for the electron gun in this design are a voltage of 350 kV, a current of 415 A, and a beam radius of 8.65 mm. The electron gun is modeled in DGUN based on Pierce electron gun theory.

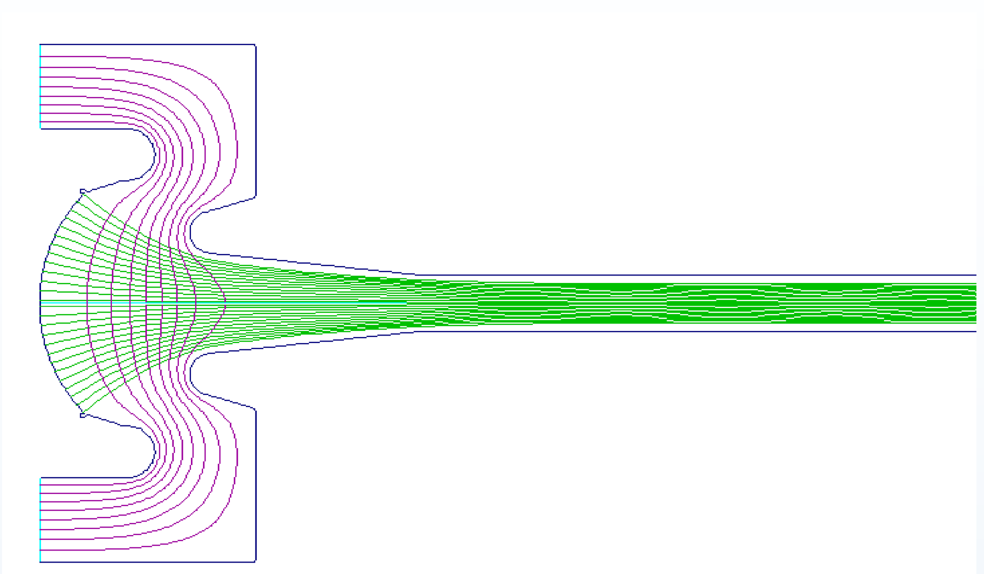

Figure 2 The electron gun in DGUN

The focusing magnetic field for the electron gun is provided by the coil structure designed using Poisson.

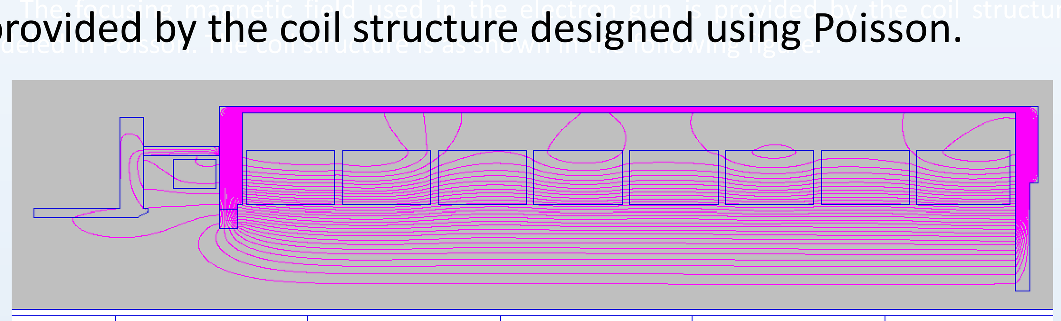

Figure 3 The coil structure in Poisson

The coil structure and magnetic field distribution are verified in CST.

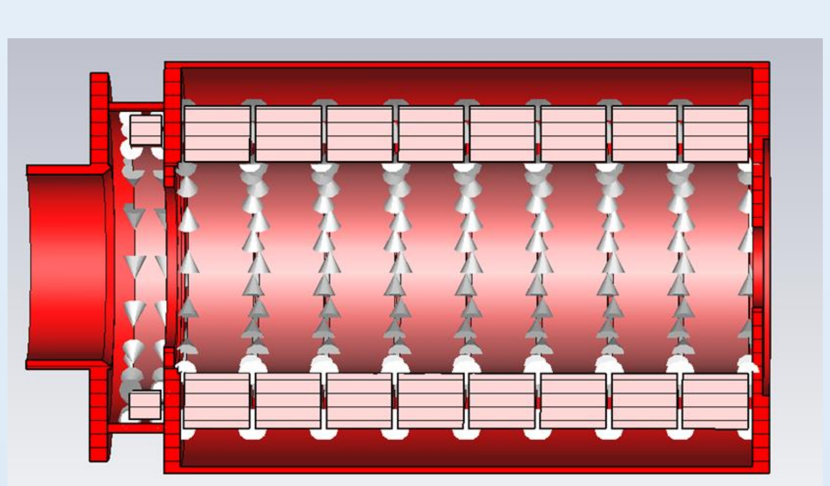

Figure 4 The coil structure in CST

Beam dynamic

Using 8 resonant cavities, the resonant cavity array is designed using the BAC and COM methods. The fifth resonant cavity is a second harmonic cavity.

By optimizing the parameters of the resonant cavities and the distances between them using a genetic algorithm, the relationship between efficiency and the length of the klystron can be determined.

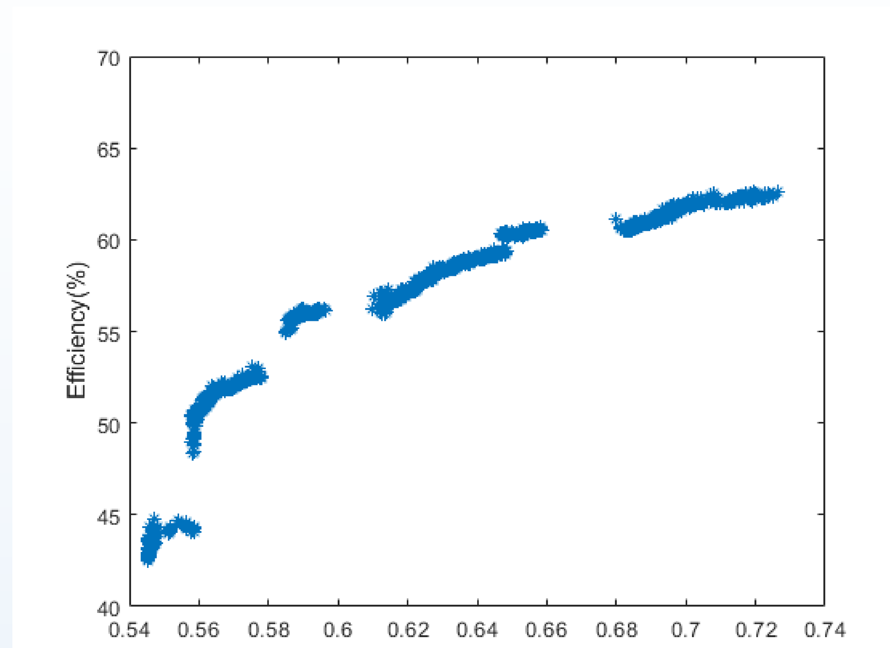

Figure 7 Relationship between efficiency and length

The parameters of the 8 resonant cavities are simulated in 1-D AJDISK. The RF conversion efficiency of the klystron is 61.5%, and the output power is 89 MW.

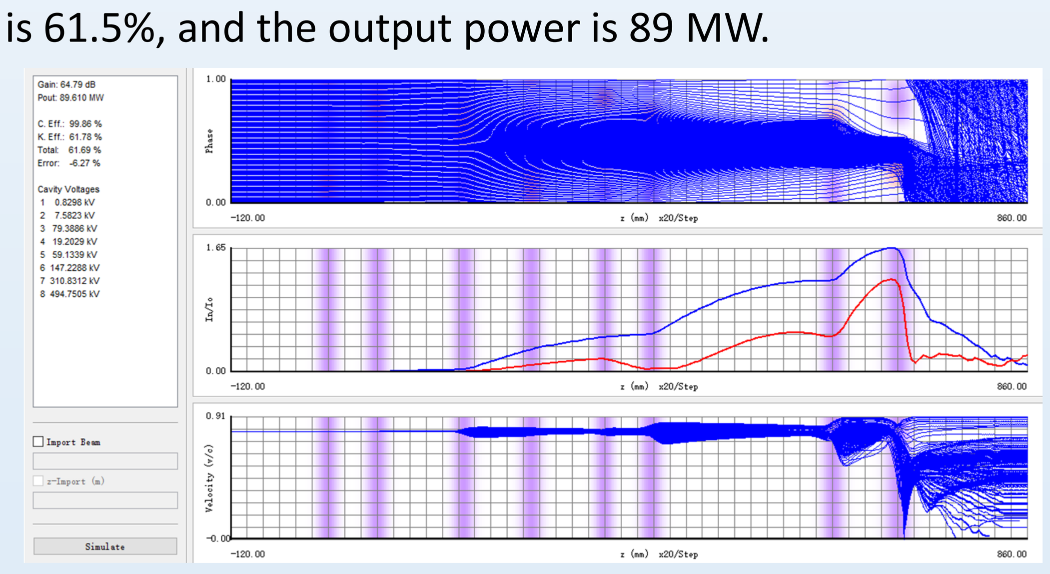

Figure 8 1-D simulation result in AJDISK

In 2-D EMSYS, the RF conversion efficiency of the klystron was determined to be 58%, with an output power of 84 MW. Figure 9 displays the beam current, energy, and current distribution of the klystron.

Conclusion

The electron gun is modeled and optimized based on Pierce electron gun theory for the electron optical system. The electron gun structure is optimized using 2-D DGUN and 3-D CST, while the coil structure is optimized using 2-D Poisson and 3-D CST. Currently, the electron beam current, beam radius, and beam fluctuation rate all meet the design requirements.

For the design of S-band high-efficiency klystrons, two novel beam focusing methods—Core Oscillation Method (COM) and Bunching Alignment and Collecting (BAC)—have been employed. The 1-D simulation efficiency is 61.5%, the 2-D simulation efficiency is 58%, and the 3-D simulation efficiency is 55%.

In the future, overall optimization, thermal analysis, and cooling system design will be carried out. After the design is completed, mechanical machining and high-power testing will be conducted.

References

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* **Work supported by Dr. Yifang Wang's Science Studio of the Thousand Talents Project**

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