Design of S-band high efficiency klystron

Y. A. Wang[1], Z. S. Zhou[1], O. Z. Xiao, Z. D. Zhang[1], Y. Liu[1], M. Iqbal, A. Aleem, D. Dong, Y. L. Chi, G. X. Pei[1]

Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
[1]also at University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

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

Background

The advancement of large particle accelerators necessitates increased RF power, often requiring klystron to deliver output in the megawatt range. However, this comes at the expense of high energy consumption and operating costs. Presently, S-band short-pulse klystron operate at an efficiency of approximately 40%. Hence, enhancing the efficiency of klystron can enable higher RF power generation while simultaneously reducing energy consumption and operating costs, thus promoting environment friendly and sustainable solutions. Figure 1 shows the efficiency distribution of the CEPC power source system.

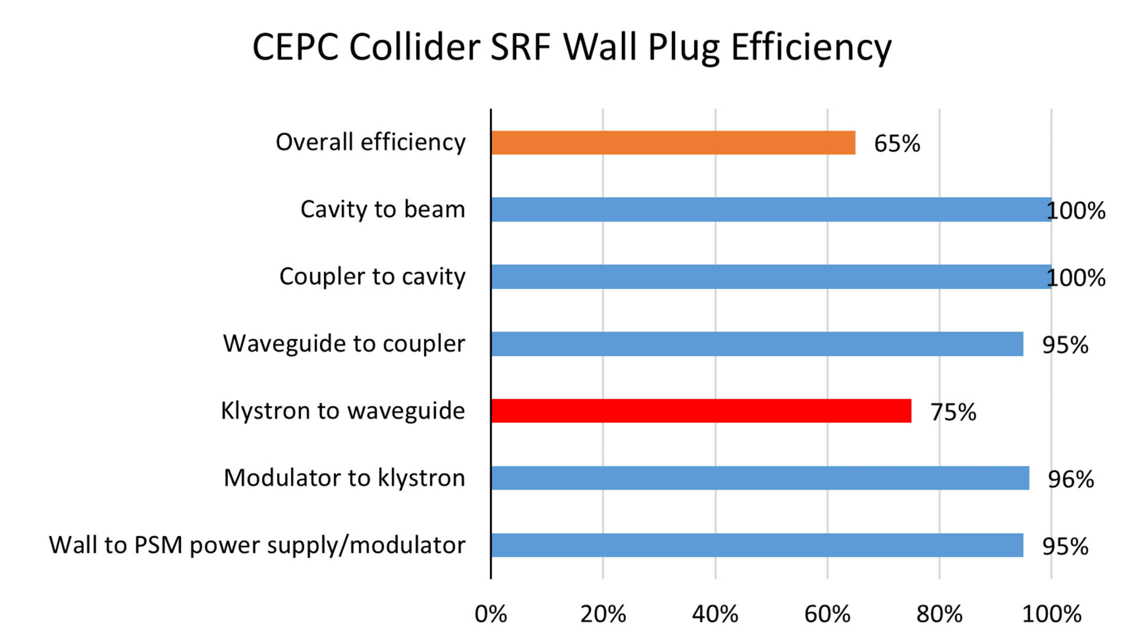

Figure 1 Overall efficiency of CEPC power source

Project Goals

- Improvement in the efficiency of the klystron from 45% to 55% by using the simulation codes
- Controlling the overall length of the klystron keeping it below 1.2 m
- Peak power enhancement up to 80MW during high power operation of the klystron

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 beam core oscillation method increases the drift length between the cavities to take advantage of the oscillation properties of electron beam plasma, allowing for the oscillation of the bunching center electrons.

Process

Currently, a selection of 8 resonant cavities has been made, with the BAC (Bunching Alignment and Collecting) method applied to the 3rd to 5th resonant cavities. Additionally, the COM (Core Oscillation Method) was utilized between the 5th and 6th cavities. Optimization was performed using the 1-D beam dynamics software AJDISK and the multi-objective genetic algorithm developed by IHEP.

A multi-objective genetic algorithm was employed for optimization, with the resonant cavity frequency and cavity spacing as the optimization variables, and efficiency and klystron tube length as the optimization objectives. Figure 2 illustrates the relationship between klystron efficiency and its length.

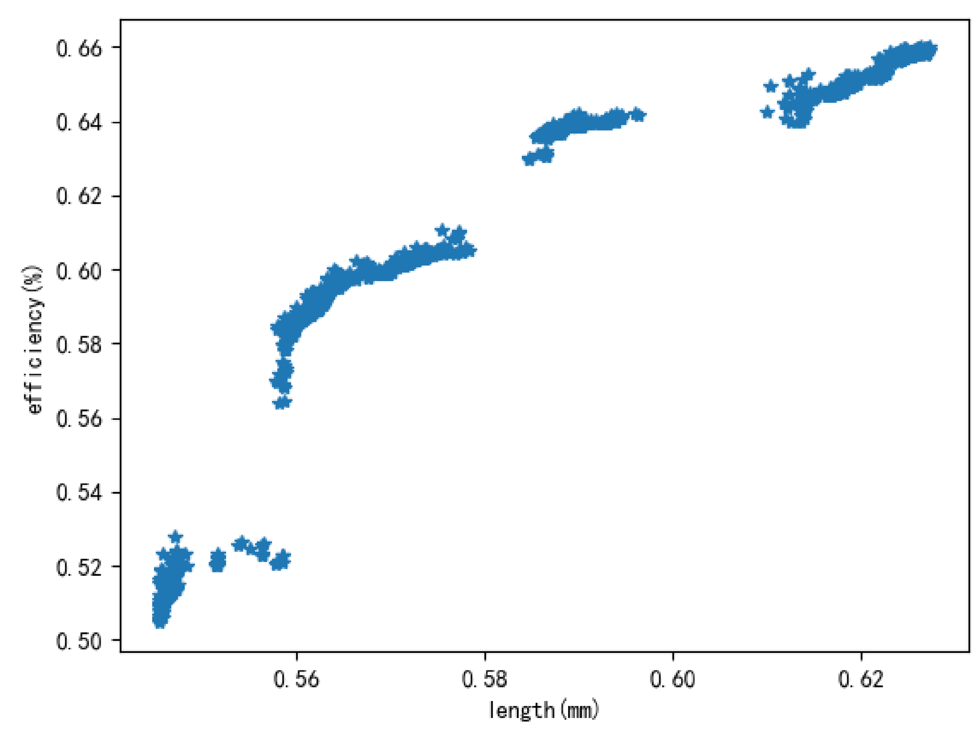

Figure 2 Relationship between efficiency and length

Figure 3 shows the 1-D AJDISK simulation results, which demonstrate the successful application of two new beam focusing methods, resulting in excellent electron beam clustering. The RF conversion efficiency of the klystron is 63.5%, and the output power is 92MW.

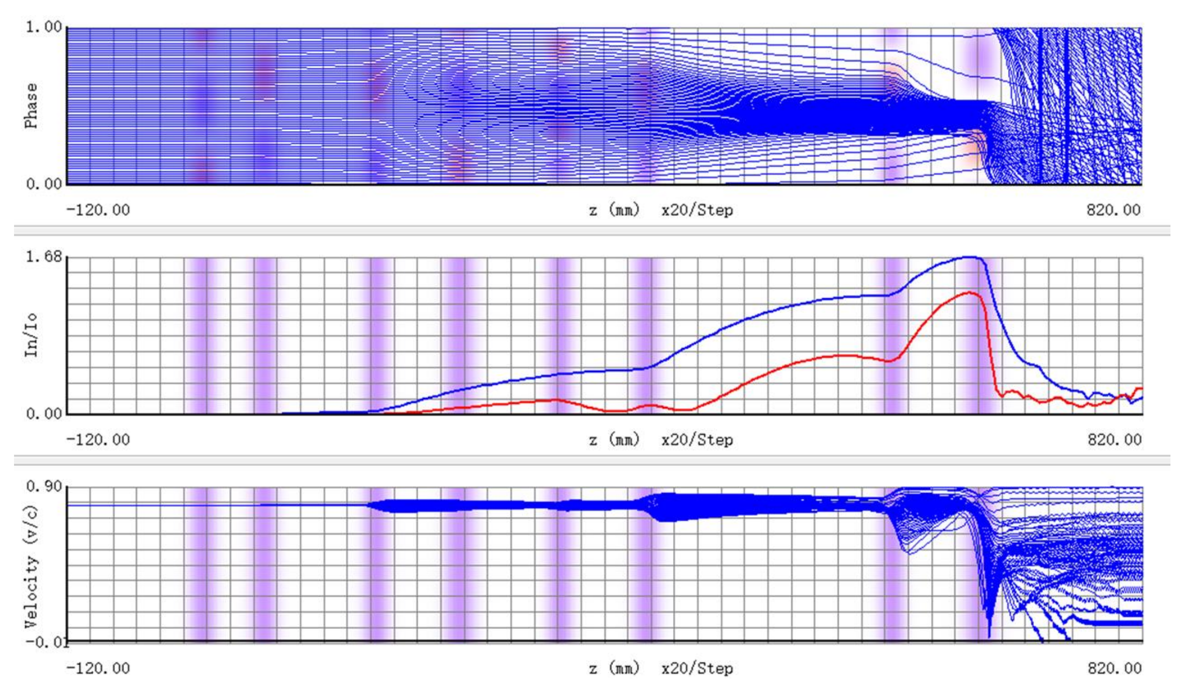

Figure 3 1-D simulation result in AJDISK

The resonant cavities were modeled in 2-D EMSYS. Beam dynamics simulations of the klystron were conducted based on the 1-D cavity spacing, and the 1-D data was cross-validated. In 2-D EMSYS, the RF conversion efficiency of the klystron was determined to be 57%, with an output power of 83MW. Figure 2 displays the beam current, energy, and current distribution of the klystron.

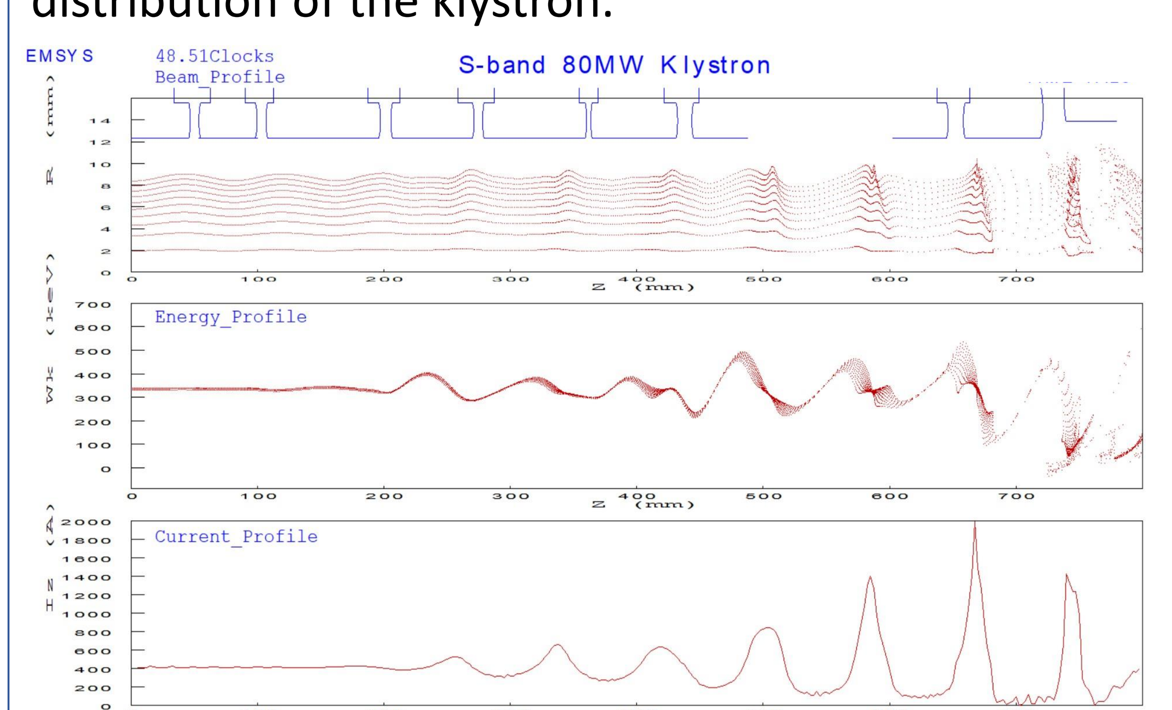

Figure 4 Beam and energy profile simulated BY EMSYS

In 2-D simulation, by varying the input power of the klystron, the output power of the klystron is simulated to obtain the transfer characteristic curve of the klystron. The relationship between the input power and the output power of the klystron is shown in Figure 5.

The output power gradually increases as the input power increases from 10W to 65W. This indicates that within the given range of input power, the klystron is capable of efficiently converting the input power into output power and exhibits good linearity characteristics.

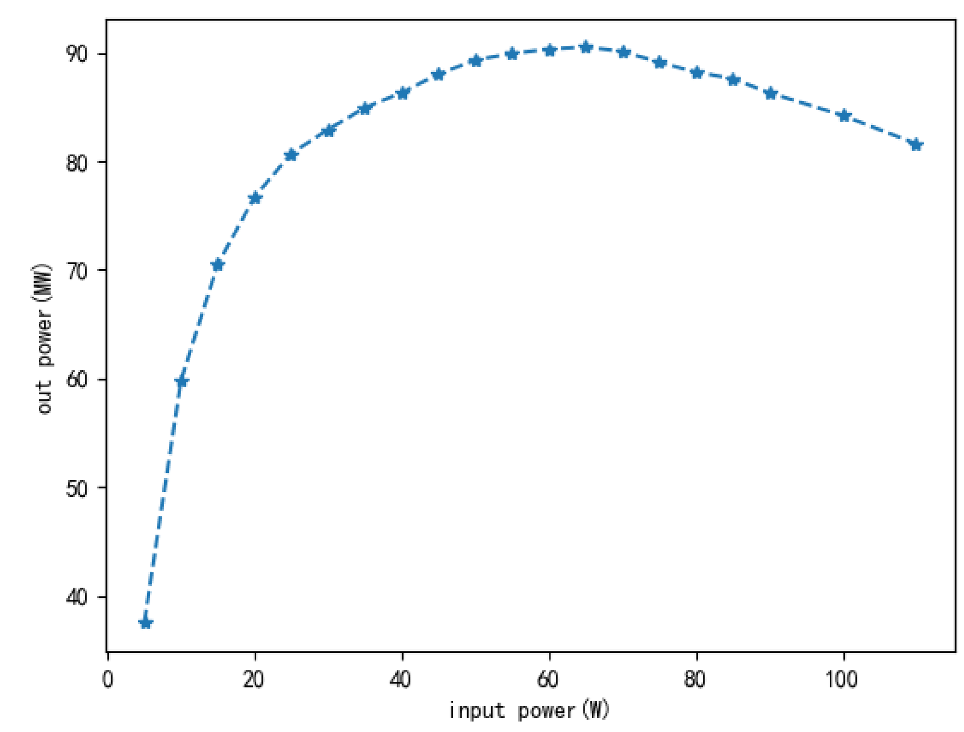

Figure 5 Power transfer characteristics

A simulation was conducted on the 1dB bandwidth of the klystron with a center operating frequency of 2856MHz. The frequency and gain curve of the klystron are shown in Figure 6. The 1dB bandwidth of this klystron is 20MHz, with a frequency range of 2850MHz to 2870MHz.

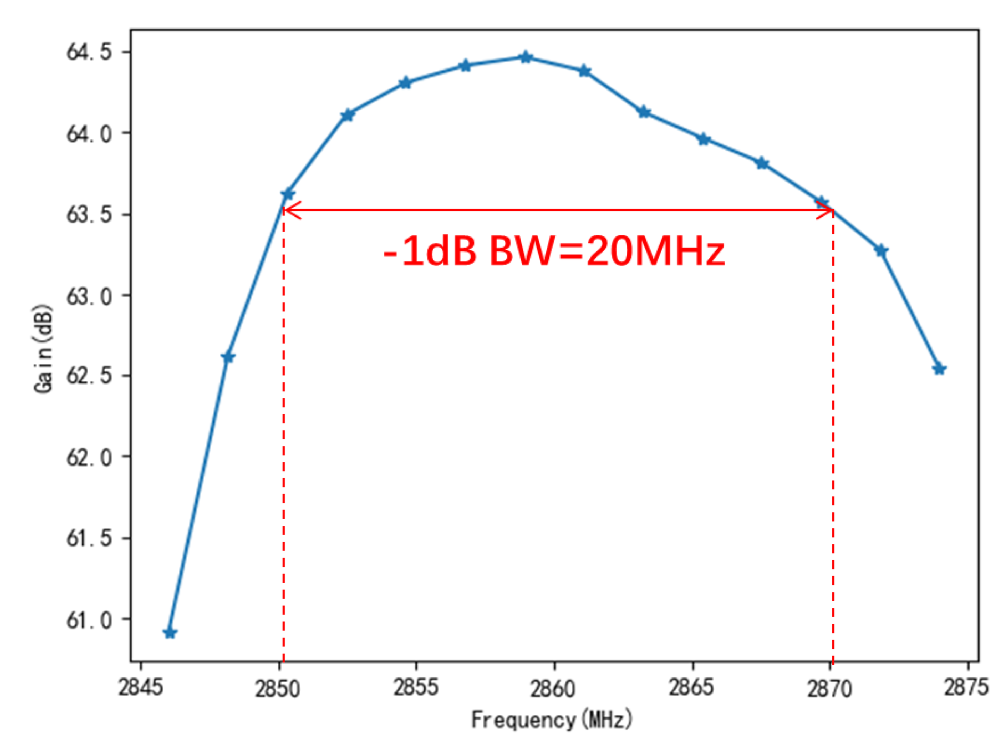

Figure 6 Relationship between frequency and gain

Conclusion

For the design of S-band high-efficiency klystrons, we have employed two novel beam focusing methods, COM and BAC. Currently, the 1-D simulation efficiency is 63.5%, while the 2-D simulation efficiency is 57%. In future, 3-D simulations using CST will be conducted to validate 1-D and 2-D results, optimizing the klystron design, to achieve the better results.

References

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† email address: zhouzs@ihep.ac.cn wangya@ihep.ac.cn