Design of periodic permanent magnet for S-band high efficiency klystron†

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ABSTRACT

The efficiency of klystrons is critical in determining the operational costs of particle accelerators. This study introduces the design of an S-band 50MW high-efficiency klystron, utilizing permanent magnet focusing technology. We emphasize innovative design methodologies aimed at improving klystron efficiency through advanced magnetic field configurations and the optimization of cavity string structures.These innovations not only enhance operational performance but also facilitate the integration of permanent magnets, maximizing spatial efficiency within the klystron design. The development of this high-efficiency S-band klystron marks a significant advancement in klystron technology, providing a sustainable and cost-effective solution for high-power applications. By enhancing performance and reducing power consumption, this design aligns with broader objectives of energy efficiency and cost reduction in accelerator technology.

INTRODUCTION

High power and high efficiency are critical areas of focus in klystron research. The development of large scientific facilities such as the International Linear Collider (ILC), Compact Linear Collider (CLIC), Future Circular Collider (FCC), and Circular Electron Positron Collider (CEPC) underscores the significance of high-efficiency klystrons as essential technologies for these endeavors. Improving klystron efficiency involves effectively bunching peripheral electrons and minimizing velocity dispersion. Common strategies to achieve this include reducing electrical conductivity and employing second harmonic cavities.

The adoption of permanent magnet focusing technology offers several advantages: it reduces power consumption associated with focusing coils, decreases the overall size and weight of the klystron, and eliminates the need for coil power supplies and cooling systems. These enhancements are crucial for achieving klystron miniaturization and operational simplicity.

This study presents a design that integrates high efficiency with permanent magnet focusing, aiming to enhance klystron performance while facilitating system miniaturization.

PERIODIC PERMANENT MAGNET FOCUSING

The periodic permanent magnet (PPM) focusing system consists of a positive and negative periodic arrangement of axially magnetized permanent magnet rings. Within this periodic magnetic field, the beam can still maintain the focus, but there is a fluctuation in the envelope, and the fluctuation increases with the decrease of the beam voltage, and the beam is completely divergent below a certain voltage. The periodic magnetic field enhances the utilization of the reverse magnetic fields adjacent to the permanent magnet rings, resulting in a more compact and lightweight focusing system.

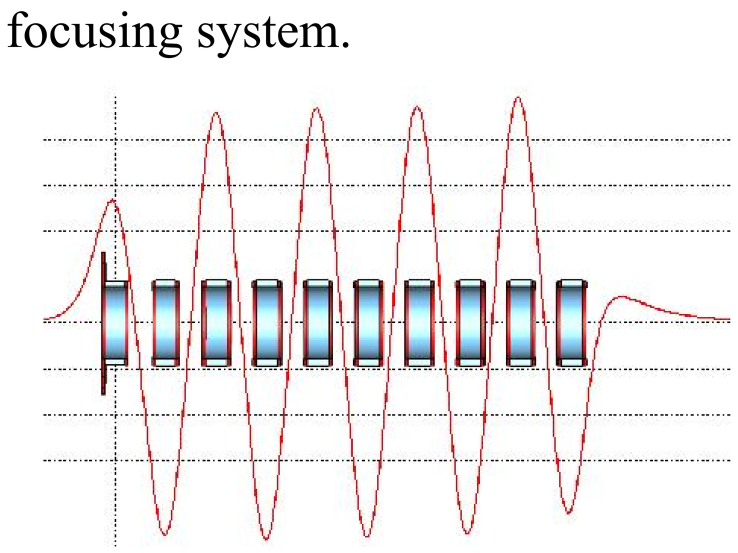

Figure 1 Periodic permanent magnet focusing structure

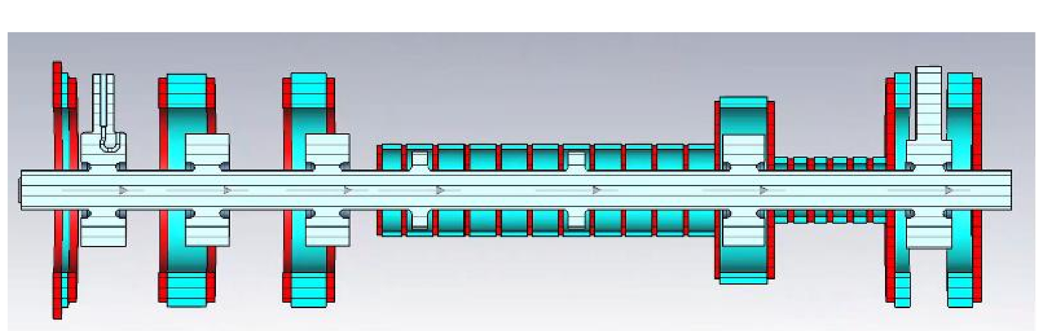

Figure 2 Focusing structure and vacuum inside the klystron

FOUNDATION DESIGN

This design uses 7 cavities, including 2 second harmonic cavities. The two second harmonic cavities are placed adjacent to each other in an unconventional manner. The first cavity corrects the velocity, while the second cavity collects peripheral electrons and provides spatial convenience for the focusing structure.

The focusing structure is mainly divided into three sections. The first section has a small fundamental current of the beam and is designed as a long-period magnetic field that is easy to process. At the same time, considering the water cooling space, a large inner diameter magnetic ring is used. In the second section, the pole shoe extends into the vacuum inside the klystron, and considering the cavity size, it is designed as a medium-period medium inner diameter structure. The third section has a large fundamental current and is designed as a short-period small inner diamete structure.

Table 1 Main parameters of klystron

Frequency	2856Mhz
Output power	50MW
Voltage	373kV
Current	245A
Beam radius	7.1mm
Drift tube radius	11.8mm
Efficiency	55%

ELECTRON OPTICS

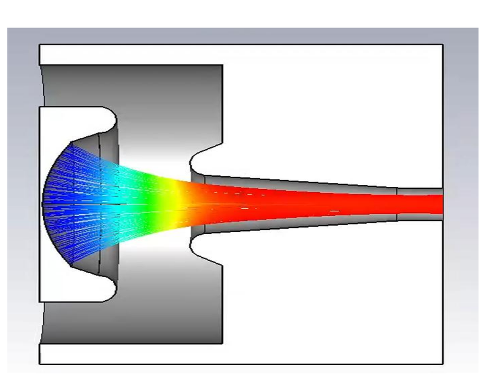

Figure 3 The electron gun in CST

In CST simulation, the electron gun current is 245A, the waist radius is 6.6mm, the minimum period length of the focusing structure is 24mm, and the maximum magnetic field along the axis is 1703Gs.

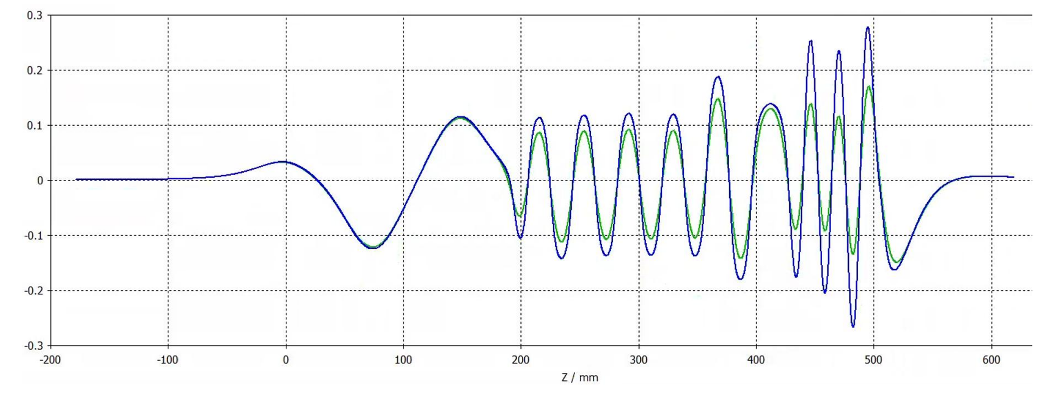

Figure 4 Magnetic field distribution at the axis and beam radius

BEAM DYNAMIC

In CST simulation, the performance of cavities was optimized and the field asymmetry caused by the output cavity coupling port was reduced by off-axis. The final output power in PIC simulation is 50MW with an efficiency of 55%.

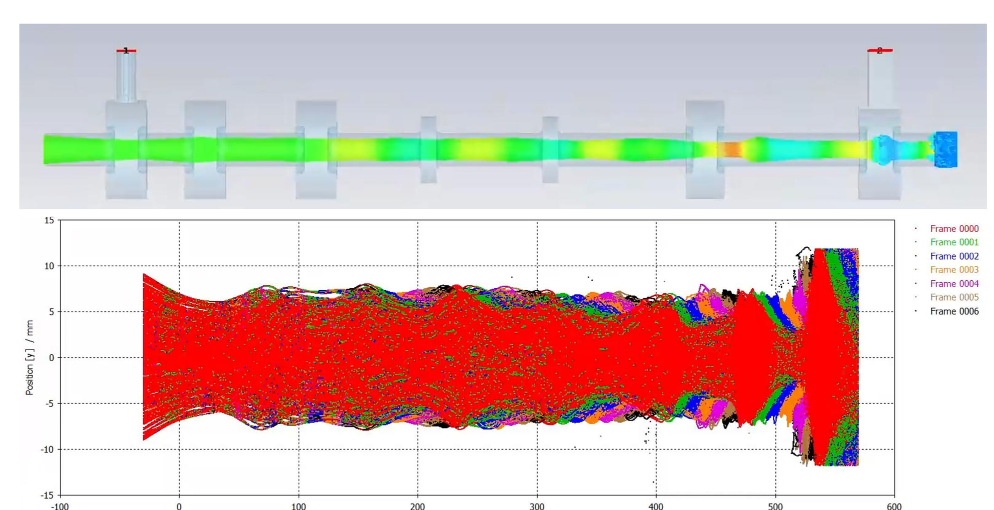

Figure 5 Beam envelope in PIC

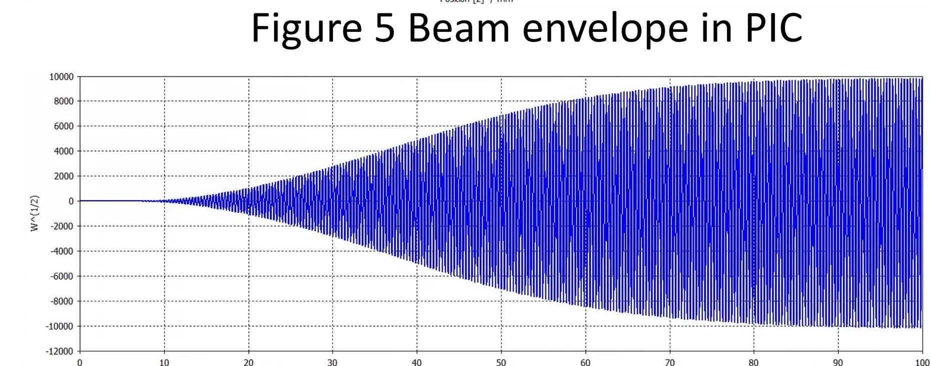

Figure 6 Output power in PIC

SUMMARY AND OUTLOOK

This study presents the design of an S-band 50 MW high-efficiency permanent magnet klystron, featuring adjacent second harmonic cavities and segmented periodic permanent magnet focusing. This configuration offers the benefits of high efficiency, simplicity, and compactness. CST simulation results indicate an output power of 50 MW with an efficiency of 55%.

The next step is to reduce the voltage requirement of the tube while maintaining this efficiency.

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