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*Preliminary design of energy recovery scheme for high-power klystron**

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Based on the high efficiency klystron scheme of circular electron positron collider (CEPC), the depressed collector design is proposed to improve the overall efficiency of RF power source. The depressed collector technology has been applied in low power microwave electronic vacuum devices such as TWT and TV communication klystrons. The velocity of electrons entering the klystron collector is scattered, and it is difficult to use the depressed collector to sort the velocity of electrons. This paper will carry out a detailed theoretical analysis of the depressed collector and determine its basic design scheme for CEPC high efficiency klystron. In order to verify the klystron energy recovery scheme, an energy recovery verification device is designed. DGUN and CST codes are used for design optimization of verification device beam. ANSYS thermal analysis is carried out on the depressed collector to determine the electron gun and depressed collector design scheme. The verification device is expected to be completed by the end of the year to carry out high-power experiments.

INTRODUCTION

The depressed collector is an important method to improve the efficiency of microwave tubes by recovering the energy of waste electrons. This technology has been widely used in TWT, and its collector recovery efficiency is more than 70%. Figure 1 shows the basic principle of an energy recovery device. At present, the application of depressed collector on klystron is mainly used in low power klystron for TV and communication, but there is little research on depressed collector technology on high power klystron. The characteristics of klystron bring some difficulties to the design of depressed collector. The proposal of depressed accelerator puts forward higher demand for high power klystron efficiency. The application of depressed collector technology in high power klystron further improves the overall efficiency of power source system. In order to verify the feasibility of klystron energy recovery scheme, we have completed the design of energy recovery verification device. The design scheme and corresponding simulation results are presented.

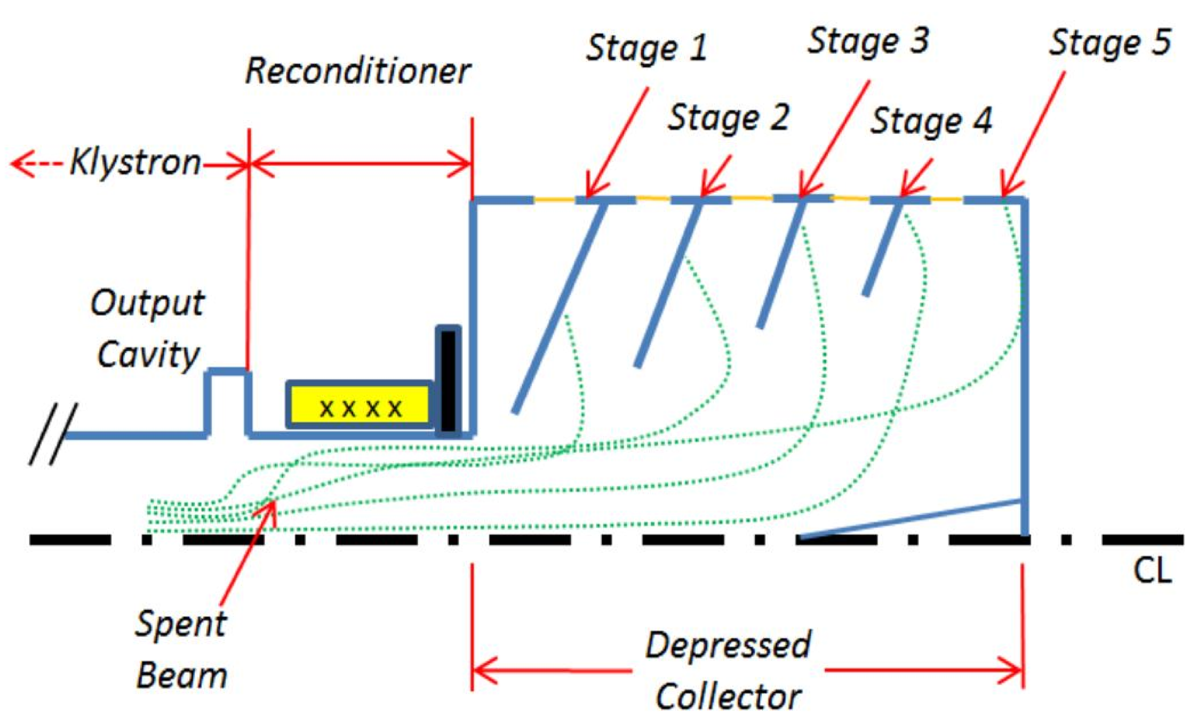

Figure 1:Depressed collector structure

DEPRESSED COLLECTOR PRINCIPLE

The recovery power of depressed collector depends on the selection of collector potential. A deceleration field is established in space by providing the collector with a lower potential than the tube body, after which the waste electrons are decelerated by the electric field upon entering the collector. The efficiency of the klystron is improved by the energy recovery on the electrode, and the heat dissipation pressure of the collector is also reduced.

Based on the high efficiency klystron of CEPC, the depressed collector scheme is designed. The high efficiency klystron has a saturated output power of 800kW and a design efficiency of more than 75%. The main design parameters of the high-efficiency klystron are shown in Table 1.

Table 1: High efficiency klystron parameters of CEPC

Operating frequency	650 MHz
Output power	≥800 KW
Beam voltage	113 kV
Beam current	9.5 A
Beam perveance	0.25 μP
Efficiency	≥75%

Due to the need of low-level feedback control, the klystron usually works in the approximately linear region, and its output power is based on 700 kW. The probability distribution of its energy entering the collector pole waste electron is shown in Figure 2.

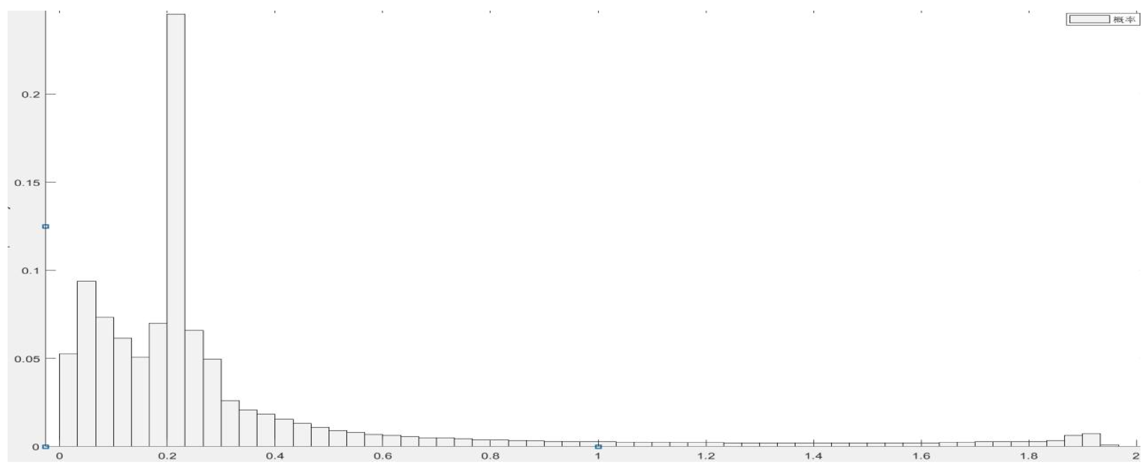

Figure 2 Energy distribution of Klyc waste electrons

The following formula is used to obtain the recovery power of the multi-stage depressed collector :

$$P_{rec} = \sum_{1}^{N-1} \int_{Vi}^{Vi+1} J_{waste}(V) I_0 V_i dV + \int_{V_N}^{\infty} J_{waste}(V) I_0 V_N dV$$

DESIGN OF VERIFICATION DEVICE

Before processing the depressed collector klystron, we use the energy recovery verification device to verify the key technology. The basic structure of the verification device is shown in Figure 3.

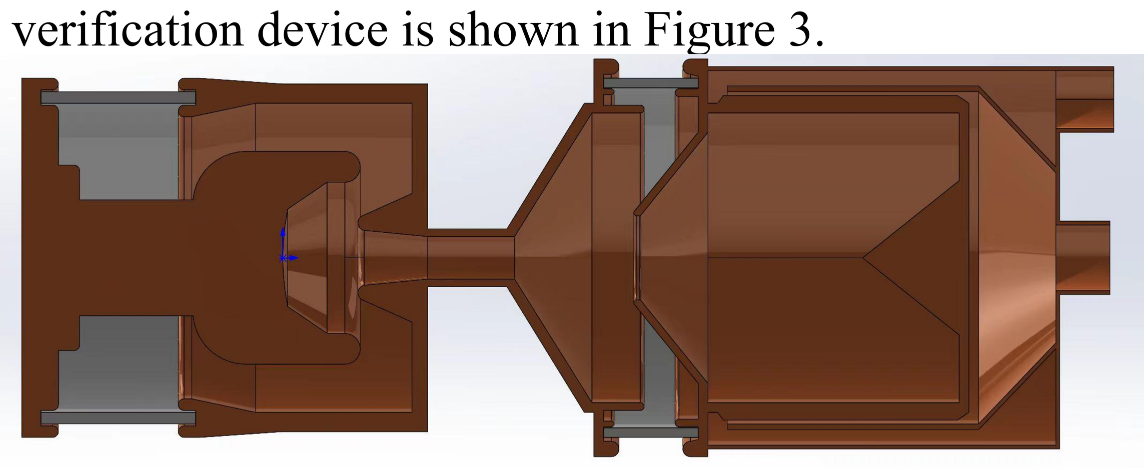

Figure 3:Structure of the device

Based on the CEPC high efficiency klystron single-pole depressed collector parameter, the electron gun voltage is 30kV, the current is 4.5A, and the depressed collector voltage is 27kV. Figure 4 shows the results of the gun in DGUN and CST. The depressed collector adopts axisymmetric structure, as shown in Figure 5. The structure has two electrodes, the first electrode is consistent with the potential of the tube, and the second electrode applies a negative high voltage to slow down the electrons and to recover energy. In the case of considering secondary electrons, the waste electron reflux rate is low, and the results meet the requirements.

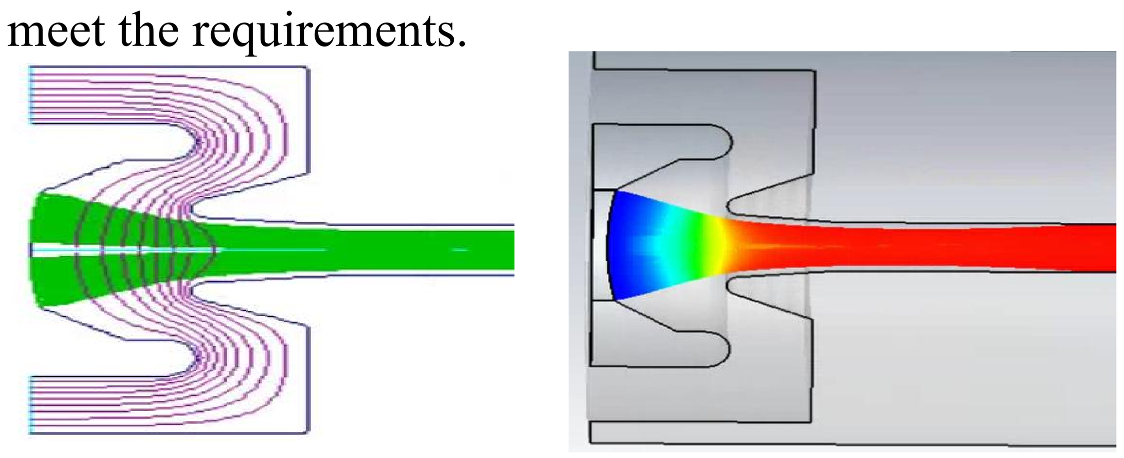

Figure 4: Beam optic simulation results in DGUN and CST

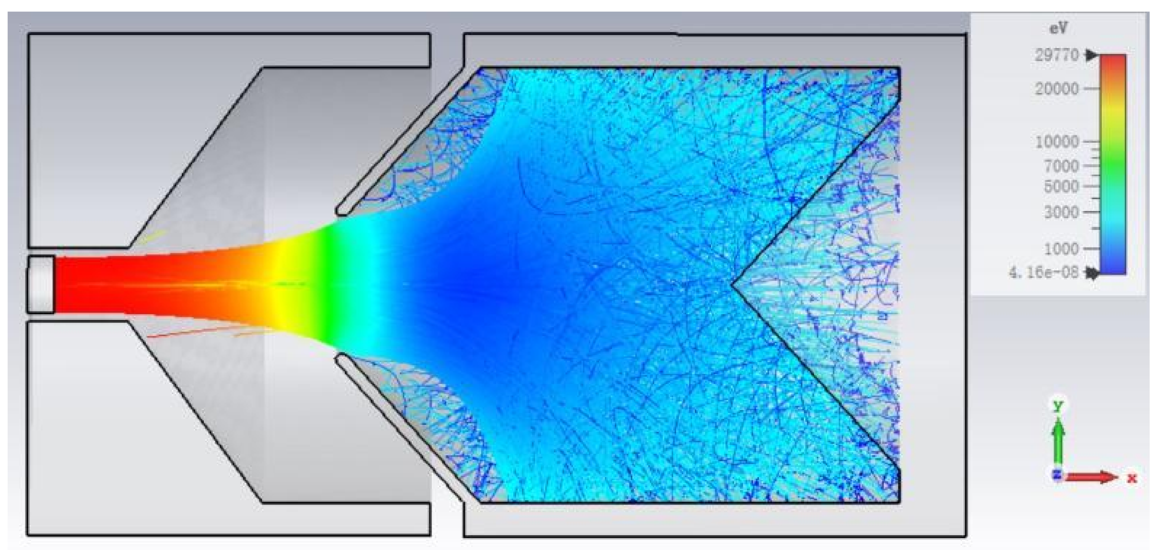

Figure 5 Electron trajectory in the collector

THERMAL SIMULATION

The structural model was established in ANSYS, and the grid was divided when the calculation accuracy was met. Thermal load was added to the model, boundary conditions (ambient temperature 293K) and heat transfer mode were set, and thermal analysis was carried out using ANSYS Workbench module. Figure 4 shows the temperature distribution on the collector section, with a maximum temperature of 363K. The results can provide reference for the next water cooling design.

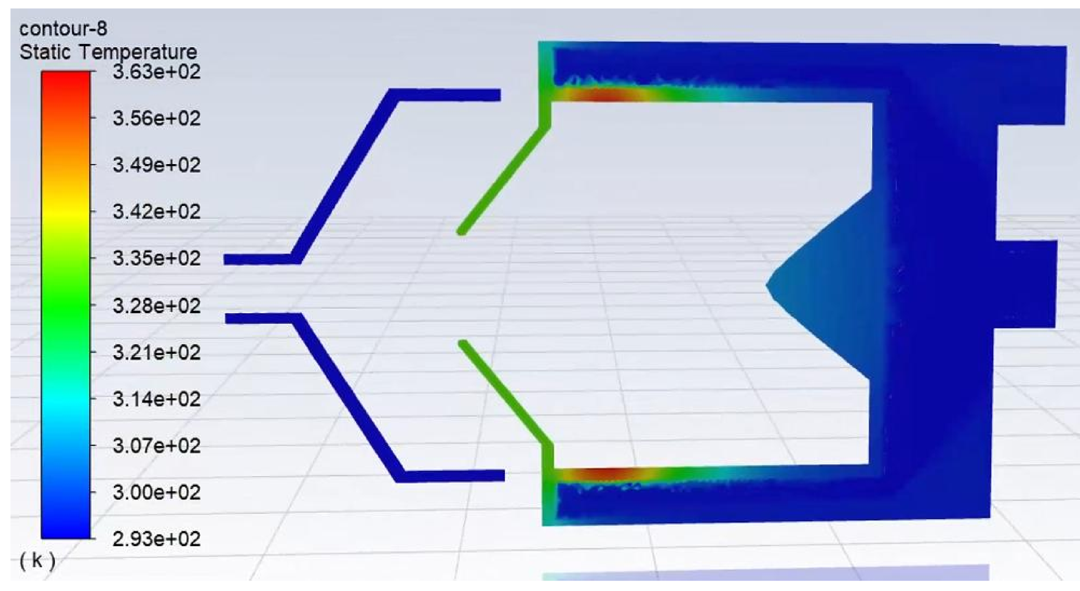

Figure 4:Collector temperature distribution by ANSYS

SUMMARY AND OUTLOOK

In this paper, we take the high efficiency CEPC klystron as a research object. The depressed collector is theoretically analyzed, and the electrode parameters are determined. In order to verify the key technology of energy recovery klystron, we designed an energy recovery verification device composed of gun and collector. The beam optics were simulated in DGUN and CST, and thermal analysis of the collector was performed using ANSYS. The structural design of gun and collector is completed. The simulation results show that the electron trajectory and thermal analysis of the collector meet the design requirements.

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