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

Yu Liu[1,2], Zusheng Zhou[1,2†], Fei Li[1], Ouzheng Xiao[2], Yiao Wang[1,2], Munawar Iqbal[1], Abid Aleem[1], Han Xiao[1,2], Wenbing Gao[1,2], Fanyu Wang[1,2], Noman Habib[1], Yunlong Chi[1,2]

1Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049

2University of Chinese Academy of Sciences, Beijing 100049, China

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

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 traveling-wave tube(TWT) and klystron for TV communications. 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 describes 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. Currently, the mechanical fabrication and the setup of the testing platform have been completed. 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%. Fig. 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 a little research on depressed collector technology of 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 step-down 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 complete the design of energy recovery verification device. The mechanical machining was completed, and preliminary tests were conducted.

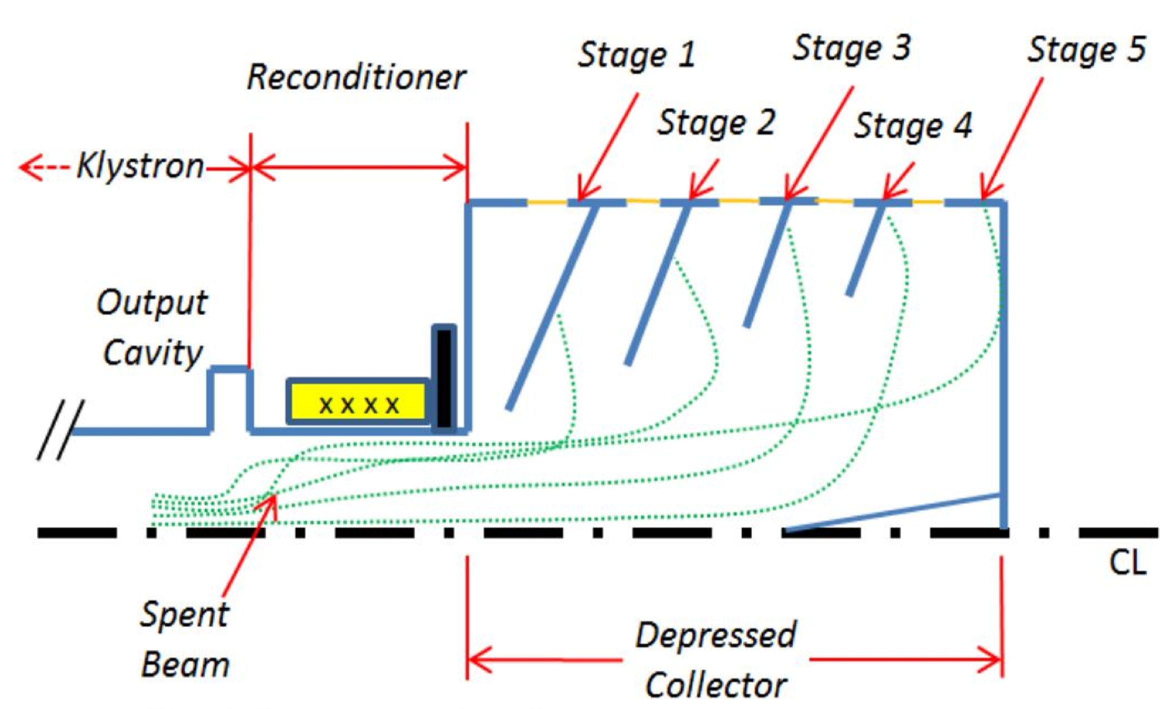

Fig.1.Depressed collector structure

DEPRESSED COLLECTOR PRINCIPLE

The recovery power of depressed collector is related to 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 will be decelerated by the electric field force 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 tube 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: 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 collecting pole waste electron is shown in Fig. 2.

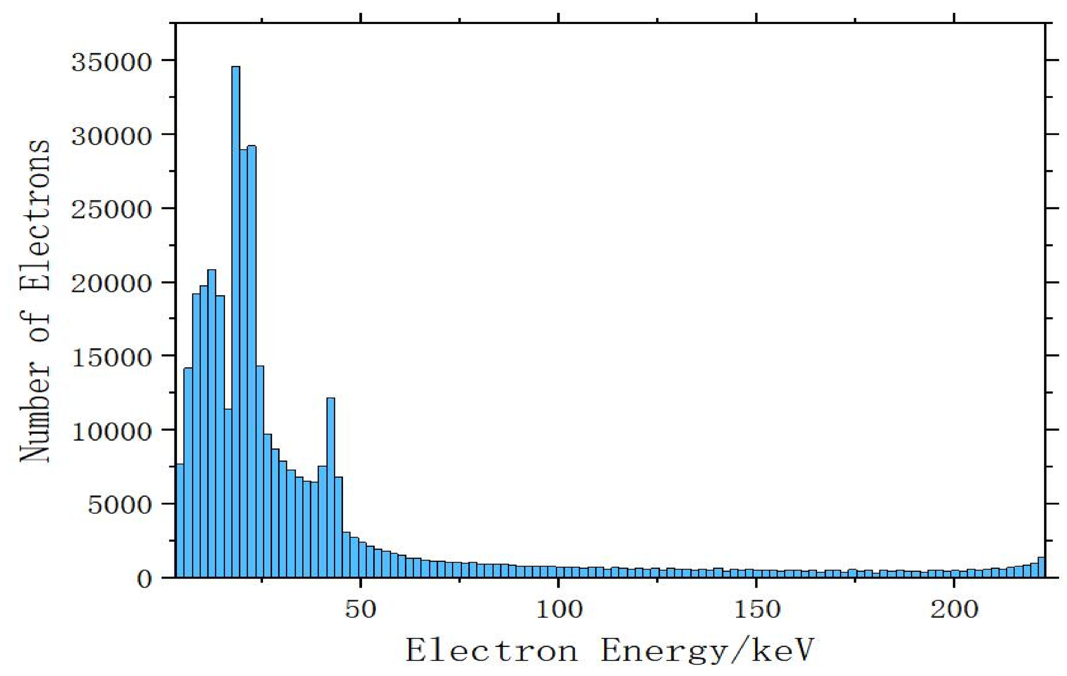

Fig.2.Energy distribution of waste electrons

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

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

where Jwaste is the probability density function of electron energy distribution. We can calculate the relationship between the klystron efficiency of depressed collector and the number of electrodes, and the result is depicted in Fig. 3.

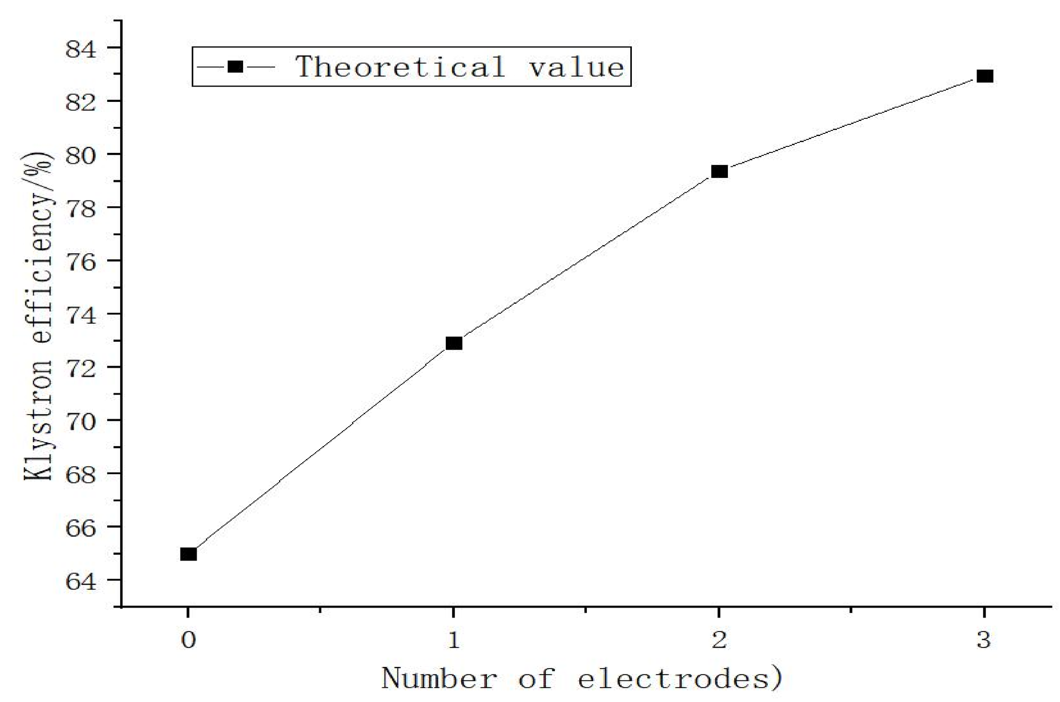

Fig.2.Number of electrodes vs efficiency

VERIFICATION DEVICE

Before processing the depressed collector klystron, we use the energy recovery verification device to verify the key technology. The basic structure and machining of the verification device are shown in Fig. 3 and Fig. 4.

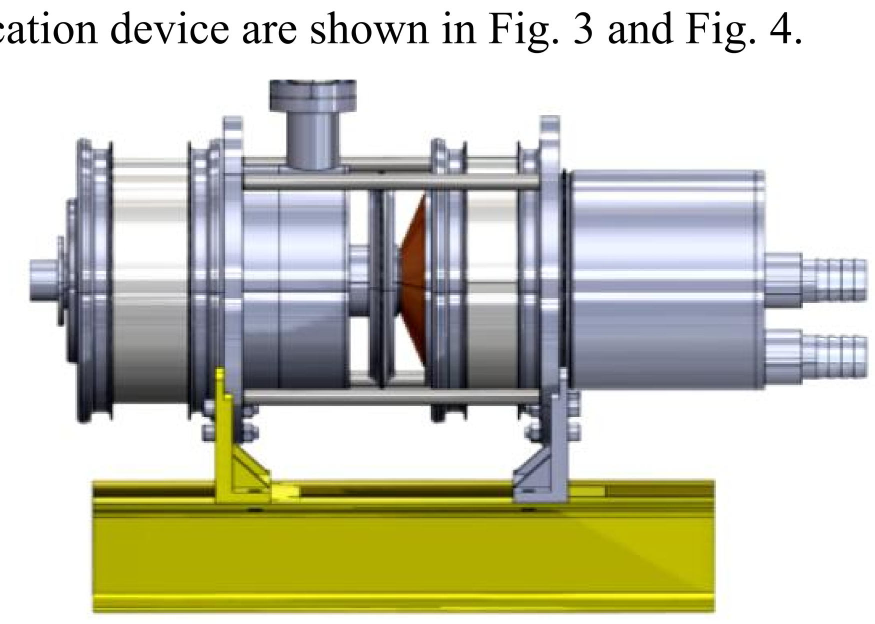

Fig. 3. Structure of energy recovery verification device

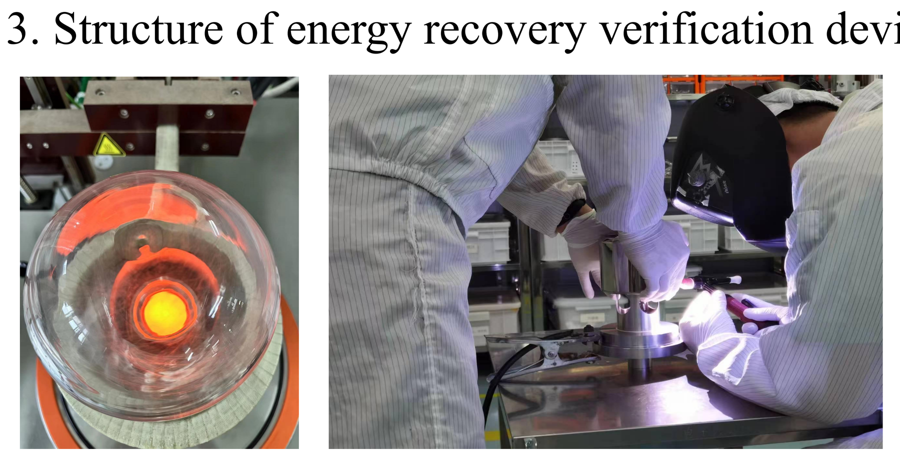

Fig. 4. Mechanical machining

After the mechanical machining was completed, we proceeded with the setup of the test platform, as shown in Fig. 5. Additionally, ceramic pressure resistance tests were conducted, as shown in Figure 6. The verification device is expected to undergo high-power testing by the end of this year.

Fig. 5. Test platform

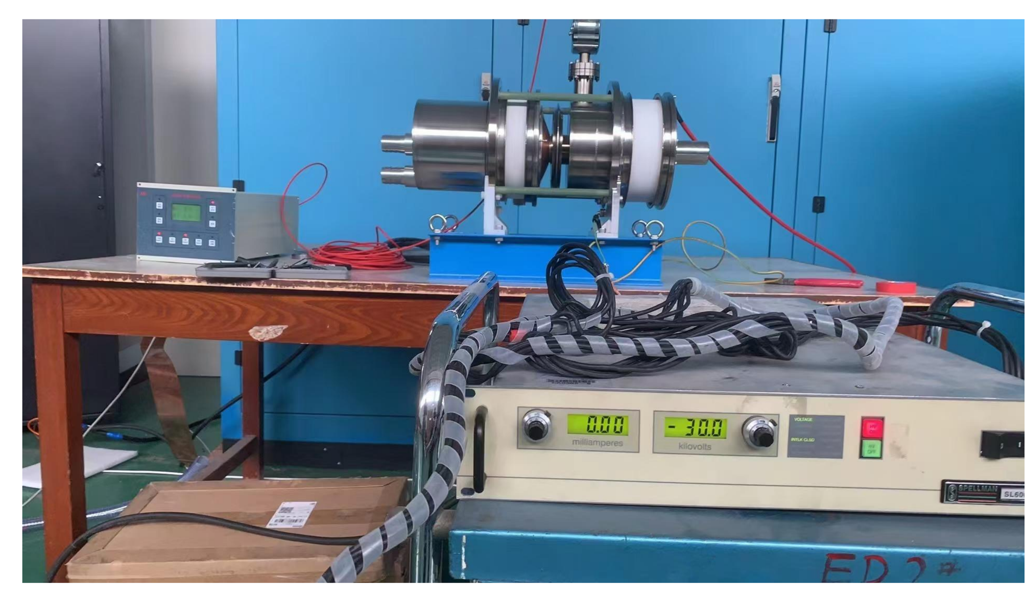

Fig. 6. Ceramic pressure testing

SUMMARY AND OUTLOOK

This paper focuses on the high-efficiency CEPC klystron and conducts a theoretical analysis of the collector suppression, determining the electrode parameters. To validate the key technologies of the energy recovery klystron, an energy recovery verification device consisting of an electron gun and a collector was designed and fabricated. After completing the high-power testing, we will proceed with the design of a high-efficiency klystron with a depressed collector, aiming to increase the efficiency from 65% to over 75%.

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† email address: zhouzs@ihep.ac.cn