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DESIGN STUDIES OF OUTPUT WINDOW FOR CEPC KLYSTRON

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Abstract

A high power and high efficiency klystron for the Circular Electron Positron Collider (CEPC) is developed at IHEP. This paper presents the design and simulation for a high-power coaxial window of the 650MHz, 800kW CW klystron, and the coupler design for high power test of window are also included. CST, ANSYS and Multipac 2.1 are used for design of window microwave performance, thermal analysis and multipacting effect. The simulation results of the coaxial window S-parameter analysis, shows a low reflection at the desire frequency of 650 MHz after optimized. The E-field and thermal simulation shown a good temperature distribution and maximum temperature has been found to be 36 Celsius degree at ceramic with water cooling in the inner and outer conductor. And the multipacting simulation for the window shows that multipacting has less chance to occur on the surface of ceramic.

INTRODUCTION

The Institute of High Energy Physics (IHEP), Chinese Academy of Sciences (CAS), has proposed a future plan of Circular Electron-Positron Collider (CEPC), which will be the biggest electron-positron collider in the world. Klystron is a critical component for an operation of accelerator. As RF power sources, more than 200 high efficiency klystrons with a frequency of 650 MHz and CW 800 kW output power are required. Those klystrons are designed at IHEP and the first prototype klystron is going to manufacture in China. The specifications of CEPC klystron are listed at Table 1 [1], we aim at more than 65 percent of the efficiency for the first klystron and more than 80 percent for the future plan to reduce the operation cost.

Table 1: CEPC Klystron Design Parameters

Frequency(MHz)	650
Output Power(kW)	800
Beam Voltage(kV)	81.5
Beam Current(A)	15.1
Efficiency (%)	>65

For successful operation of CEPC, the stable operation of klystrons is crucial, and an output window used in the klystron is one of the key components. Output window is a critical part of transmitting high RF power from klystron vacuum side to the external atmosphere, therefore a low power dissipation and no breakdown is important for window.

We had made a strategy to manufacture a reusable klystron with two steps or more as shown in Fig. 1. Before build the tube, the window itself must be manufactured and evaluated by using the existing RF power source to ensure the power handling capability.

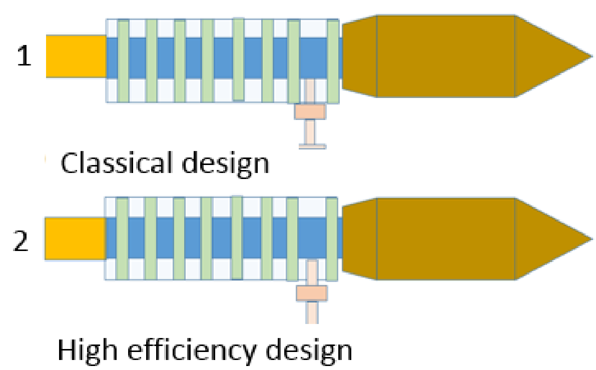

Figure 1: Klystron development strategy.

WINDOW DESIGN

WR1500 (381 mm×190.5 mm) waveguide is used to transmit 650 MHz RF power from klystron to accelerator, but it is difficult to use the pill-box window with rectangular waveguide to the klystron output cavity because of its big size. The pill-box window has a difficulty in cooling the center of ceramic so the high temperature may cause a high thermal stress that possibly may cause ceramic window breakdown.

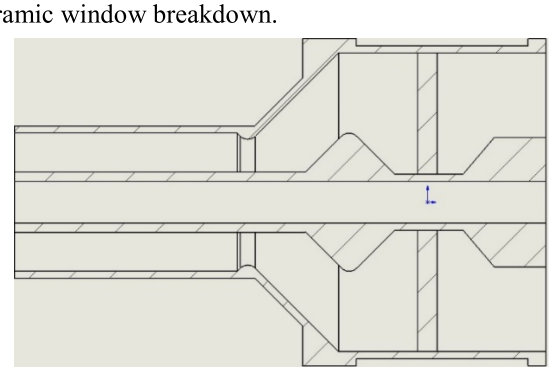

Figure 2: Schematic drawing of CEPC klystron output window.

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Therefore, we use the coaxial structure coupling to the output cavity and then transfer the power to WR1500 waveguide. Schematic drawing of CEPC 650 MHz klystron window is shown in Fig. 2 [2]. The microwave design of window was carried out by CST Microwave Studio [3]. The thickness of ceramic is about 11 mm. With high purity alumina (99.7%) we obtained -85 dB of return loss at the 650 MHz and less than -30 dB at 50 MHz bandwidths as shown in Fig. 3. At actual operation, the required VSWR of the window is less 1.05 (-32.3 dB), so S-parameter in our design satisfies this requirement.

Figure 4 shows the electromagnetic field (E-field) calculated by CST CODE. The maximum of E-field is around 9×10^5 V/m, and the maximum of H-field is about 2000 A/m at 800 kW operate condition. We obtained the similar results for ANSYS CODE. The E-field in this type of RF window shows small concentration on ceramic surface.

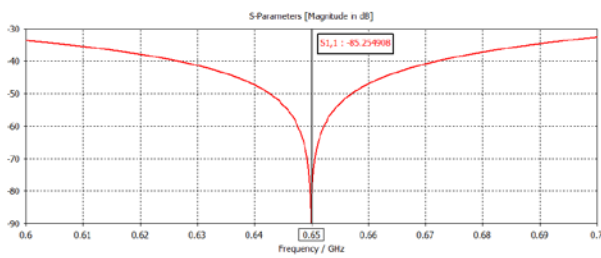

Figure 3: Return loss (S11) and insert loss (S21).

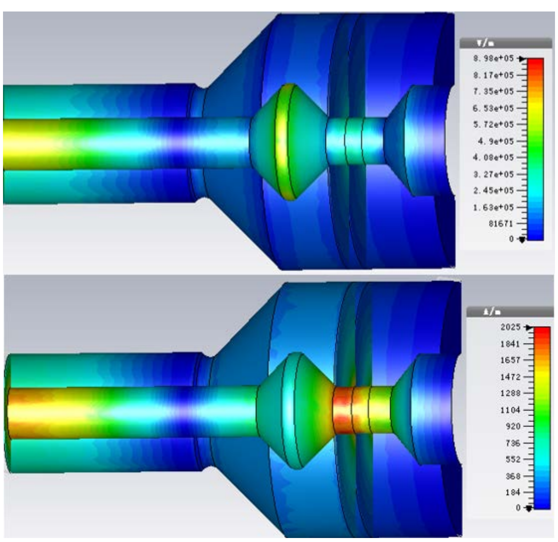

Figure 4: Electromagnetic field simulation by CST. Upper is electric, lower is magnetic field.

THERMAL ANALYSIS

Water cooling was prior to be considered because of its cooling power capability for 800 kW operation. The thermal loss of the window was evaluated to be about 800 W. Most of the loss are mainly generated on the inner conductor, and these losses resulted in several hundred degree Celsius. So only the forced air cooling might not be enough.

Water cooling of the inner conductor is important but since it is difficult to make a water channel from the output cavity of the klystron, the water is introduced from waveguide transition side (air side). In order to obtain better cooling, double piping structure is adopted after negotiated with TETD (Toshiba Electron-Tube Division), so the water directly flow by the ceramic inner thin copper surface to obtain the good cooling for the humps and inner conductor. The outer conductor of ceramic window part is also cooled by water.

Thermal simulations in ANSYS CODE [4] are carried out by calculating the convective heat transfer coefficient and radiation coefficient, but since the radiation effect was too small to consider in this temperature range which was enough to consider the thermal convection.

The thermal simulation results are simulated under the normal steady-state condition. Figure 5 shows the simulation results when water cooling is supplied in inner conductor and outer conductor. As shown in Fig. 6, the difference between the maximum and the minimum temperature in ceramic plate is about 10 ℃ and the maximum thermal stress caused by temperature difference is about 25 MPa, which much less than 99.7% purity alumina stress capacity of 320 MPa. And the structure deformation by temperature difference is in negligible. Since the conductivity of copper is enough to transfer the heat from conductor to the cooling water, the cooling of overall window is sufficient even in the case of the maximum temperature on the surface of ceramic which is about 36℃.

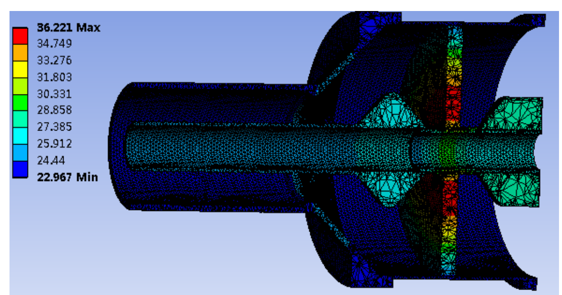

Figure 5: Thermal Simulation in ANSYS.

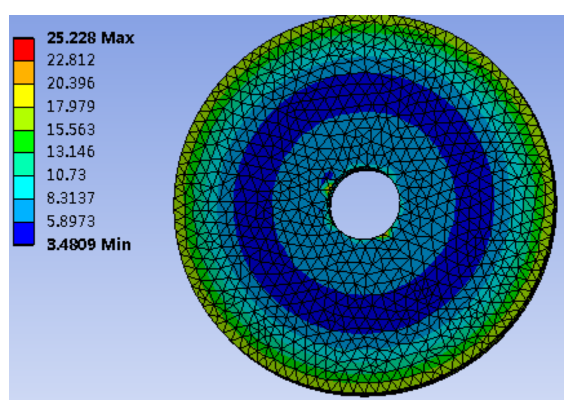

Figure 6: Thermal stress on the ceramic surface.

MULTIPACTING

Destruction of klystron output ceramic windows were

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often caused by multipacting [5]. Multipacting directly results in surface local overheating of alumina ceramic and ceramic cracking or melting, the vacuum leak of the tube subsequently. In this chapter, multipacting phenomena is studied.

Multipacting is a common phenomenon in the high-power operating ceramic window, in some cases it causes serious damages. Therefore, avoid serious multipacting was achieved by not only the designing of structure but also by choosing a low SEY (Secondary Electron Yield) ceramic surface.

The ceramic coating with thin coating of low SEY characteristic materials such as TiN is a common way to suppress secondary emission. The SEY can be as high as 6 in maximum value for high purity alumina ceramic if has no coating on the surface of ceramic. Since TiN is resistive material and thick film increases loss, there is an optimum thickness to suppress the secondary electrons and with low loss. TiN coating thickness is about 5 nm from the past experience as described in Ref. [6]. With so many high-power klystrons employ TiN coating on the ceramic, therefore this process is simulated to confirm if the TiN coating effect.

The multipacting simulation is performed using the code Multipac [7] as shown in Fig. 7. In this code, initial electron source is automatically distributed along the setting boundary of window. The c_0 is initial free electron number in the boundary and c_{20} is the free electron number after 20 impacts. Ef_{20} is the average impact energy of the last impact in eV, e_{20} is secondary electron number after 20 impacts. The simulation results are shown in Fig. 7 when the ceramic surface in vacuum side is coated with TiN. In this figure, horizontal axis shows average incident power in kW. If Ef_{20} is in the range of high SEY area, multipacting may be serious. In the case of TiN coating of 5nm, though the impact energy is also between 100 eV and 1000 eV where SEY is larger than 2, the secondary electrons number is quite low and hard for multipacting or electron avalanche to continue.

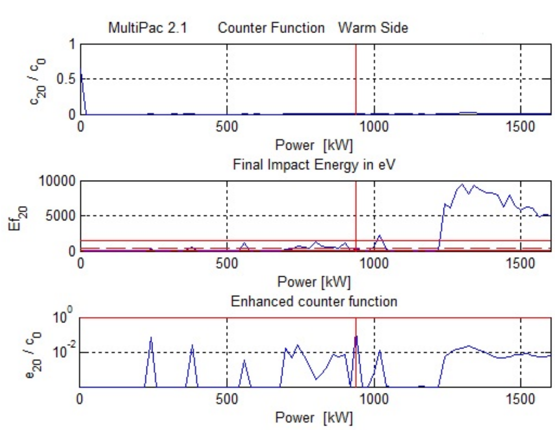

Figure 7: Secondary electron emission on the ceramic with 5 nm TiN coating simulation result in multipacting.

From this result, it is concluded that secondary electron may even exist with coating, but multipacting has less chance to be happened on the surface of ceramic

HIGH POWER TEST PLAN

Since this window is going to be used in the klystron, so one side of the window is evacuated. Therefore, in vacuum two windows which are connected by the waveguide structure required to be evaluated its performance similar with the window of the klystron. To achieve the water cooling for inner conductor, doorknob coupler has designed. The inside pressure should be as low as that of klystron pressure, which is about 10^{-7} Pa. Before testing, the window and coupler will be baked.

Proper cooling system with inlet and outlet of water supplied from the doorknob side through double piping structure is necessary for the hot test including high power capability of ceramic window.

Power will be increased step by step same as in klystron high power test. A solid-state amplifier (SSA) with CW 150 kW is available for this test at IHEP. Firstly, the power transmission test with load is planned and then by changing the phase full reflection test is followed. We can evaluate the power capability of 600 kW equivalently with this test.

The ceramic coating is very important, so the windows manufactured by TETD having coated with 5nm TiN (O) film on the surface of ceramic. In order to detect the multipacting or arcing problems, the viewport and arc-detector are used.

CONCLUSION

We have finished simulation of RF coaxial output window to be used in the CEPC 650 MHz, 800 kW, CW klystron. RF design is fulfilled, and the S-parameter have been optimized. The thermal loss and multipacting in ceramic have also been considered at the high-power operation. Good window cooling was successfully introduced after the thermal analysis. After the simulation using MultiPac, it was successfully shown that suppression of the multipacting with 5nm TiN coating is achieved. We have finished the mechanical design and started to manufacture it. The high-power test plan is also described.

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