DESIGN STUDY OF COLLECTOR FOR CEPC 650 MHz KLYSTRON

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Abstract

This paper presents the design and simulation of collector for CEPC 650 MHz high-power CW klystron. Power dissipation in collector is optimised by universal beam spread curve and EGUN code, beam trajectory in collector is verified by Magic code. The thermal analysis is done by ANSYS-CFX, and groove number and water flow rate are optimized by fluid-solid coupled heat transfer simulation.

INTRODUCTION

Future Circular Electron-Positron Collider (CEPC) project requires hundreds of high efficiency klystrons working at a frequency of 650 MHz and a CW output power of 800 kW [1]. A single beam triode type electron gun is designed for CEPC 650 MHz klystron [2][3]. The gun operates under a voltage of 81.5 kV and a current of 15.1 A, corresponding to a beam micro-perveance of 0.64 μA/V$^{3/2}$. The total beam power is 1.23 MW.

As described in ref. [2], concerning with the choice of specification for cooling the collector, there are two way; being durable for a full beam power without any RF drive (~1.2 MW) and for a reduced beam power under having an RF drive (~less than 400 kW). There are choices for cooling way of a collector such as a pure water cooling, a semi-vapour cooling and a pure vapour cooling. From the simplicity of cooling and analysis, we choose the full-power dissipation at the collector without RF drive employing the pure water cooling. In order to examine the collector design and its feasibility, a gun-collector test module is planned to be manufactured and tested before fabrication of a klystron prototype. Various data to evaluate the collector specification will be accumulated by using this beam tester. This project will go to the next step to build the assembly comprised of a gun, an interaction region with output window and a collector to evaluate the RF interaction design [4].

This paper mainly presents the collector design under the given conditions mentioned above. The power dissipation in a collector is optimised both an analytic and a numeric way. The peak power dissipation density is optimized not to exceed the very conservative value of 200 W/cm^2. The collector outer surface is grooved to enhance cooling efficiency. Number of grooves, water flow rate and other parameters are optimized by a fluid flow and coupled heat transfer simulation. Due to a possible furnace size problem in China, we need to reduce the collector size to have a whole length of a gun-collector test module within 2 m at first [2]. Therefore, the design of a size reduced collector is also presented.

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POWER DISSIPATION OPTIMISATION

In designing the collector, how to choose the average collector dissipation on the surface of the collector is a key issue. In ref. [5] and [6], maximum power dissipation should be less than 1 kW/cm^2. Another reference [7] gives the 0.7~1 kW/cm^2. In our case, since we made this CW tube at the first time, the very conservative value of 200 kW/cm^2 is chosen as the first step, and we will evaluate this choice in a beam test tube.

Collector dissipation analysis and determination of collector shape was performed in three steps. At first, using the universal spread curve and an analytic formula for the collector dissipation of eq. (1), the rough shape was analysed. Suppose the uniform laminar flow having a perveance of P_μ with a radius b, starts diverging and hits to the collector wall. The beam-let at the radius from r_0 to r_0+dr at the first, diverges to hit to the wall of radius r_a. At the taper part of a collector, θ is an angle of a collector wall to axis. The contribution of this beam-let to the total dissipation, H, is expressed as follows [8],

$$H = \frac{r_0^{\ 2}}{r_a^{\ 2}} \cdot (\sin\theta + 174\frac{r_0}{b}\sqrt{P_\mu}\cos\theta \cdot \sqrt{\ln\frac{r_a}{r_0}}) \qquad (1)$$

By using universal beam spread curve and related formula (1), maximum intercepted power density of 200 W/cm^2 under a full beam condition was derived. With this conservative peak power density value, resulted collector radius reaches 210 cm, which was 12 times larger than the beam radius in the drift tube and the collector length reaches up to 2 m. Then the result was checked by using EGUN code [9] to simulate a beam trajectory in a collector and calculate power density in the same approach with the analytic way. We obtained almost similar result. Since beam perveance is low as 0.64 μA/V$^{3/2}$, the beam diverged slowly and then resulted in larger and longer collector.

The analysis was performed in the magnetic field free space, while considering solenoids field which ended at the entrance of the collector, the peak power density could drop to 150 W/cm^2 with the same collector radius, since the beam diverged quickly and wider area of collector surface than the case without solenoids field.

Beam trajectory in the collector was cross-checked by PIC code MAGIC 2D [10], and the result obtained was similar as the other simulation code. Figure 1 shows the collector shape, the beam trajectory and the power dissipation density for the EGUN code and MAGIC 2D code.

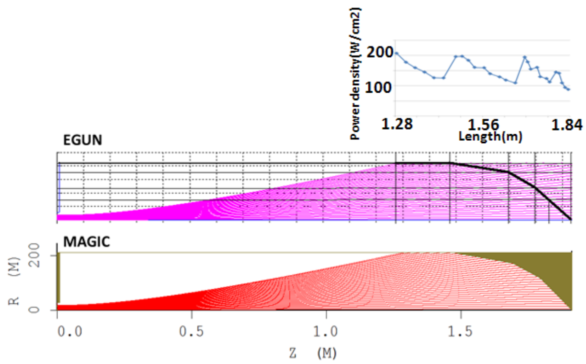

Figure 1: Upper dissipation curve and middle trace is derived by EGUN and bottom is derived by MAGIC 2D.

COLLECTOR THERMAL ANALYSIS

Cooling Structure Optimization

Thermal analysis to dissipate 1.2MW power is performed using ANSIS-CFX [11]. This simulation is based on the water cooling, with forced cooling water flows though grooves on outer surface with a high Reynolds number. So far, the analysis involving the vapour cooling and related flow is not performed. Employing a fluid flow and a coupled heat transfer simulation, the groove number was optimised under the condition of keeping the water flow rate constant. The groove dimension (the width to height ratio) of 1:2 was employed compromising the cooling efficiency and geometrical factors. In this case, the water flow velocity was chosen to be 4 m/sec. Figure 2 shows CFX simulation result of the maximum temperature of a collector inside with a function of a groove number and the same one with a function of a water flow rate. 180 grooves and 1400 litre/min water flow rate was finally chosen with compromising the fin size limit and water pressure loss.

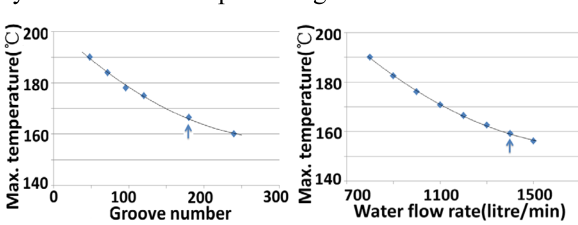

Figure 2: (a) Chart of temperature vs. groove number while keeping constant total flow rate (b) Chart of temperature and vs. water flow rate. Arrows show our operation point.

CFX result was checked by ANSYS-Multiphysics, the results have 3% discrepancy since analytic calculation of coefficient of wall heat transfer on the interface of water - copper is slightly lower than CFX's prediction (Figure 3).

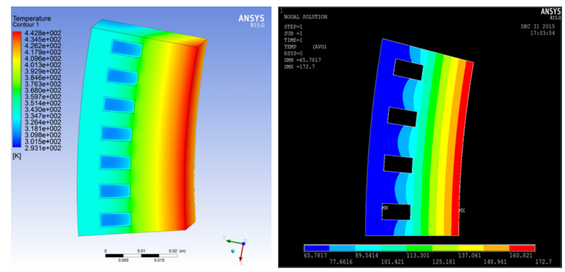

Figure 3: Contour of temperature in ANSYS_CFX (left) and ANSYS-Multiphysics (right).

Thermal Analysis Including Collector Tapered Part

A whole collector structure including an outer water jacket is shown in Figure 4, and CFX thermal analysis of one slice of collector is also presented with the condition of a constant flow rate of 1400 litre/min and a temperature of 20℃ on the water inlet boundary. The result shows that the maximum temperature on an interface of copper and water is under 100℃ and water boiling was avoided.

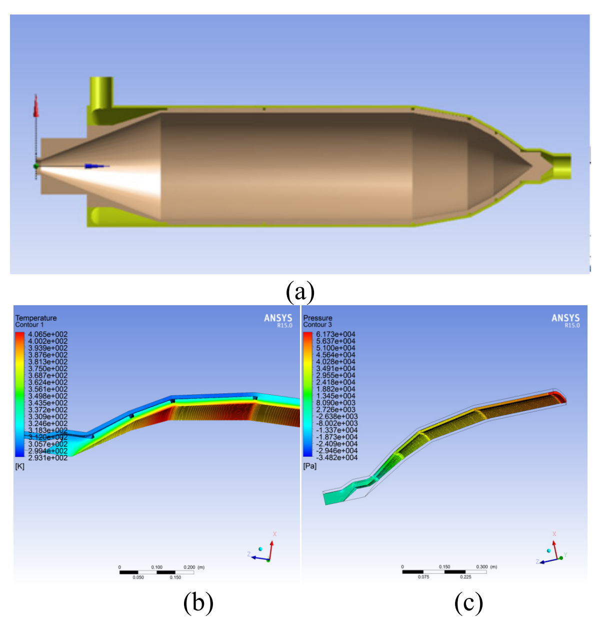

Figure 4: (a) Whole collector structure, (b) Contour of temperature of collector, (c) Contour of water pressure loss.

REDUCED SIZE OF COLLECTOR

The resulted gun-collector test module including a short drift tube has a total length of 2.7m, which exceeds the currently available baking furnace in China. For quick

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needs to proceed the beam test, the total length should be reduced to less than 2m. Therefore a reduced size of collector was also designed to adapt to this requirement. In this simulation, maximum limit of the average power dissipation density is raised to 500 W/cm^2, and this gives the ratio of 2.5 times larger than the conservative design value mentioned above. Figure 5 shows a reduced collector outer frame.

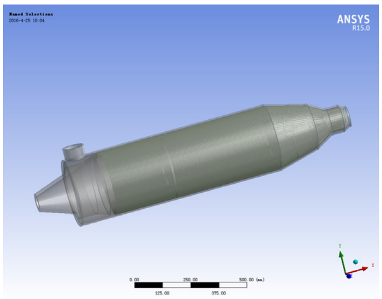

Figure 5: Outer frame of the size-reduced collector.

BEAM TEST MODULE

As described in INTRODUCTION in this paper and reference [2] and [3], the beam test module employing a modulated anode (MA) gun will be manufactured and tested. In the operation of this test module, some of the basic parameters are evaluated. The MA gun enables us to evaluate not only the gun performance but also the other part design parameters. The pulse operation of MA gun gives different pulsed power to the structure, and especially it is important to evaluate the performance of a collector. At first, we must start from the smaller-sized collector, therefore it is important to take a data for the different averaged beam power dissipation.

Plenty of thermo-coupling sensors will be installed on groove bottoms of collector and record the temperature rise under the operation. Figure 6 shows the beam trajectory in the reduced gun-collector test module. As described above, the maximum peak power dissipation density for the full beam power exceeds 500 W/cm^2 to this size-reduced collector. In the case of pulse operation of which pulse duty is 0.4, the maximum peak power dissipation density is to be 200 W/cm^2: higher duty, higher the maximum peak power dissipation density, approaching to 500 W/cm^2 at CW operation. We have been assuming that the limit of the thermal interface temperature is 100 ℃ tentatively through this simulation, but

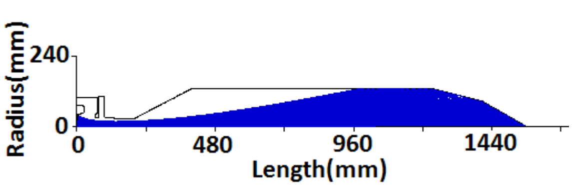

Figure 6: Beam trajectory of reduced gun-collector test module.

when the pulsed duty reaches 0.6 , the thermal interface temperature exceeds 100 ℃. From this point, the assumption of CFX is not right; vaporization starts, and the experimental result will be important to judge the feasibility of the collector performance. In this case, cooling characteristics are controlled by the nature of so-called transition zone (Nukiyama curve) and is known as the principle of Vapotron^{TM}. Through the test experiment of the beam tester, we can study the possibility to introduce a smaller collector than the one described before.

As described in ref. [3], the MA cathode has a ϕ10 hole to avoid the ion bombardment heating, and the beam trajectories shown in Figure 1 and Figure 6 are slightly different.

SUMMARY

Collector for the CEPC 800kW/650Hz CW klystron has been designed. Computer simulation tools of EGUN, MAGIC 2D, CFX and ANSYS-Multiphysics are used to design the collector. Gun-collector test module will be manufactured this year to evaluate the collector.

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