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DESIGN AND THERMAL ANALYSIS OF ADS BEAM STOP

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Abstract

ADS beam stop is an important device which required for the commissioning and accelerator tests of Accelerator Driven Sub-critical System (ADS), it is used to stop the beam which power is about 100kW and consume energy of the beam. This paper will present a triangular prism structure of the ADS beam stop, its mechanical design is described in detail, and there are numerous grooves and ribs in the cooling plates which is the core component of the beam stop. The thermal analysis is performed and its result proves that the triangular prism structure meet the design requirement.

INTRODUCTION

The China Accelerator Driven Sub-critical System(C-ADS) program is an important strategic research for solving nuclear waste and nuclear fuel problems. The Institute of High Energy Physics (IHEP) is responsible for Injector I which based on 325MHz RFQ and spoke cavities [1]. The driven accelerator works with an average beam current of 10mA. The ADS beam stop is an important terminal device of accelerator which used to stop the beam and consume energy of the beam, as no target is planned for the accelerated beam, so the ADS beam stop is required for the commissioning and accelerator tests. Table 1 Shows some design parameters of ADS beam stop.

Table 1: Design Parameters of ADS Beam Stop

Item	Result
Beam power	100kW
Beam current	10mA
Beam energy	10MeV
Beam diameter	200mm
Design water pressure	10kg/cm^2
Water velocity	2m/s
Water temperature	20°C
Vacuum pressure	6.67×10^{6} MPa
Vacuum leak rate	2.67×10^{3} MPa· m^3/s

MECHANICAL DESIGN

Material and Structure Choice

As the temperature, thermal gradients, and stress field in the beam stop material are directly dependant on the power density profile [2], therefore, it is an effective means by reducing the power density. The reduction of this power density is achieved by defocusing the beam to increase its size and by using a very low incidence angle in the beam stop thus maximizing the material surface area hit by the beam [3]. So the beam, which has a circular cross profile, is expanded to diameter 200mm at the beam stop entrance. In addition, use a smaller angle in order to increase the material surface area hit by the beam is another mean to reduce the power density. The Oxygen-free Copper (OFC) is chosen for the main material of the core component because of its thermal properties and activation criteria.

The triangular prism structure is used for the beam stop (Figure 1), the material surface area hit by the beam is changed with the angle of the two OFC plates, the angle of the two OFC plates should be properly chosen, avoiding large angle, which would produce high power density, and too small angle, which would increase the overall length of the beam stop. Besides, this structure is more convenient for processing.

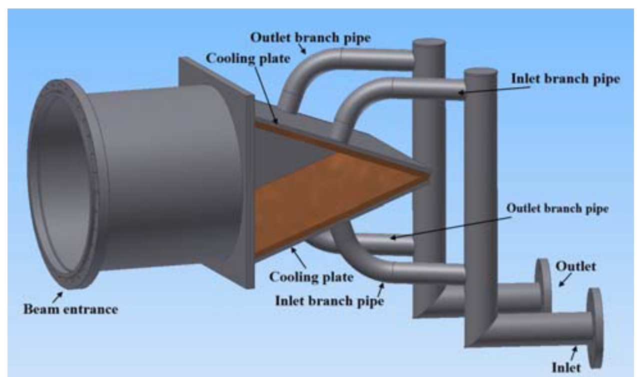

Figure 1: The structure of the ADS beam stop.

Cooling System

Due to the heat flux (or the power density) is very high, water is chosen as coolant of the cooling system. There are a number of long grooves (Figure 2&3) and ribs in the back of the OFC plates which opposite to the beam hit surface. The cooling water flow through the long groove from one side to another side, in this process, the heat exchange is performed and the heat is taken away by cooling water. The coolant channel geometry is chosen to provide adequate velocity in the high power density zone, avoiding high values, which would produce vibrations and material erosion, and too low values, which would not provide enough heat transfer [3]. Therefore, as a matter of past experience and calculation, the cooling water enters at a high velocity (2m/s), and the water pressure is 10kg/cm2.

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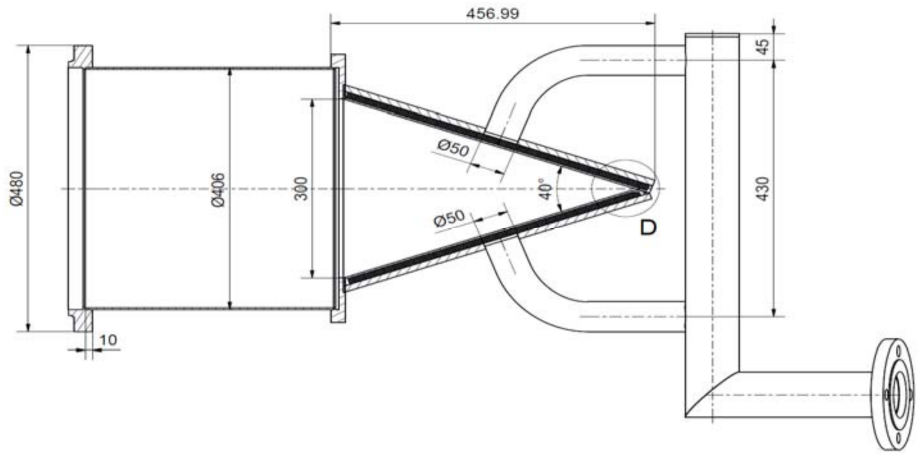

Figure 2: The structure and the assembly of the beam stop.

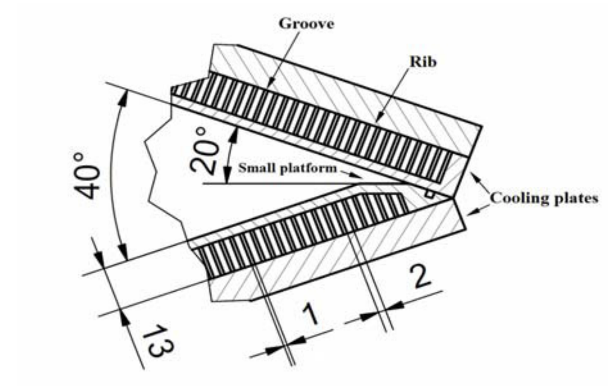

Figure 3: The long grooves of the ADS beam stop.

Taking account of the temperature of the zone near the interface of the two OFC plates is probably higher，a small platform is designed where the tip of the two OFC plates (Figure 3), which parallel with the direction of the beam. Consequently, several grooves is increased in the tip, and more heat can be taken away avoiding the high temperature of the tip and even the destroy of the copper plates.

Beam Stop ayout

Figure 2 shows the main structure and the assembly of the beam stop. A cooling plate and the coolant channel formed after the OFC plate and a stainless steel plate welded, moreover, the OFC plate is strengthened by the stainless steel plate. The cooling water enter the cooling system from the inlet (Figure 1), and separated by two inlet branch pipes, flow into the cooling plates through the grooves, and cooling the beam stop, then the heated cooling water go into other two outlet branch pipes, finally converges in the outlet. This process is continuous when the beam stop is working.

THERMAL ANALYSIS

Because of the fact of that the beam enter the beam stop is nearly homogenized, so the heat flux is assumed to be a constant which simplify the thermal analysis. And the heat flux of a 100kW beam on the cooling plate is calculated using Eq.1,which is 1.12×10^6 W/m^2 , heat transfer coefficient is calculated using Eq. 2, which is 1.06×10^4 W/m$^2\cdot$K. The cooling water velocity is 2m/s, water initial temperature is 20°C.

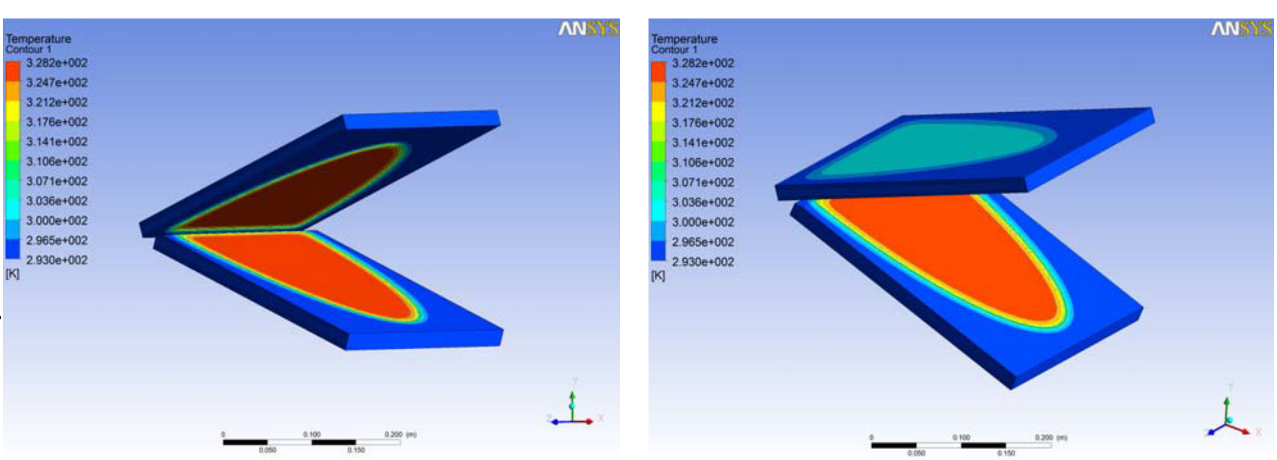

Figure 4: The contours of the two cooling plates .

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$$q = \frac{\phi}{A} \tag{1}$$

$$Nu = 0.023\mathrm{Re}^{0.8}\cdot\mathrm{Pr}^{n} = \frac{hd}{\lambda} \tag{2}$$

Φ is heat transfer rate, A is the beam hit area on the cooling plate, q is the heat flux, Nu is Nusselt number, Re is the Reynolds number, Pr is the Prandtl number, h is the heat transfer coefficient, d is the equivalent diameter, λ is the thermal conductivity, n is 0.4(when the fluid is heated).

According the calculation of the parameters and nominal conditions above -mentioned, the thermal analysis of the two cooling plates of the beam stop has been performed, meanwhile the distribution of temperature field of the two cooling plates is calculated when the angle of the cooling plates is 40 degree. Whether this beam stop structure can meet the heat exchange requirement is validated by the result of the thermal analysis. The standard is the maximum temperature of the cooling plates must below 100°C, and the cooling water must avoid boiling. Figure 4 shows that the contours of the two cooling plates, Figure 5 shows that the contours of beam hit surface of the upper cooling plates(left) and lower cooling plates(right), and Figure 6 shows that the contours of opposite surface to the beam hit surface of the upper cooling plates(left) and lower cooling plates(right). From the figures, the maximum temperature of the cooling plates is 328K(55°C), so this structure meet the design requirement.

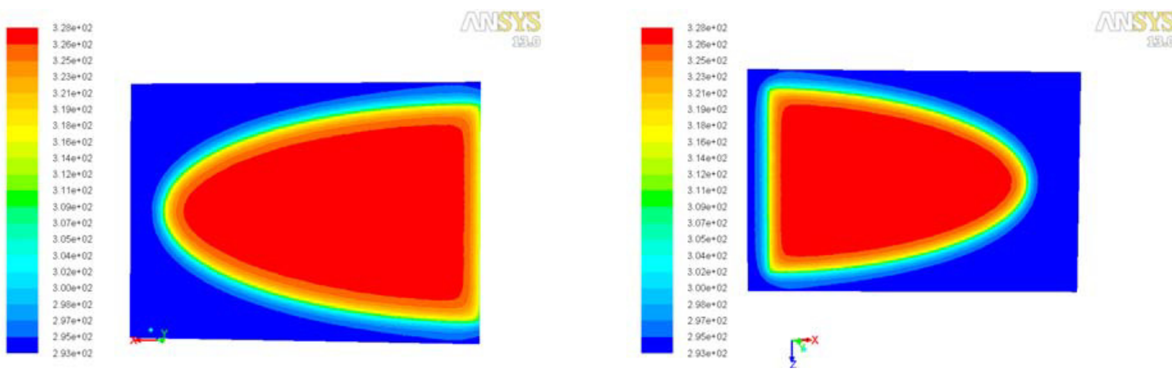

Figure 5: The contours of beam hit surface of the upper cooling plates and lower cooling plates.

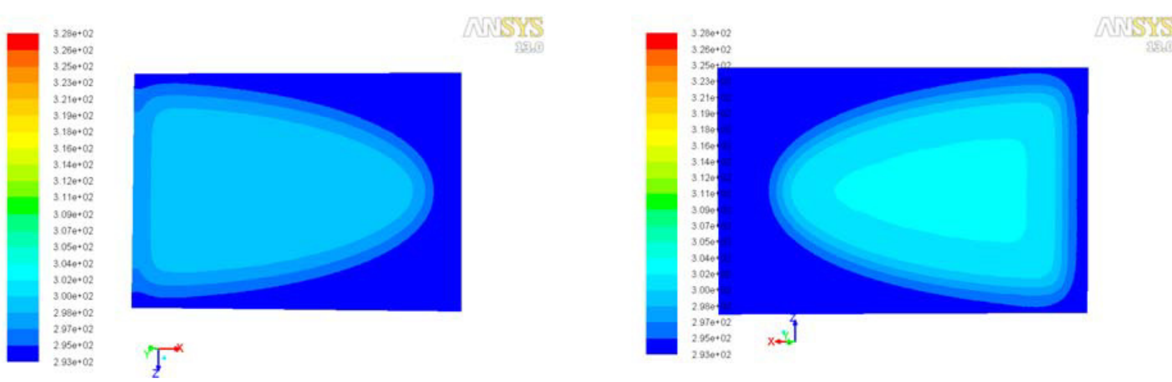

Figure 6: The contours of opposite surface to the beam hit surface of the upper cooling plates and lower cooling plates.

CONCLUSION

A triangular prism structure is used for the ADS beam stop, this is a structure of innovation, and all the mechanical design is completed. In addition, the thermal analysis of the cooling plates of the ADS beam stop is finished, the result of the thermal analysis proves that the triangular prism structure meet the design requirement.

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