THE STRUCTURE DESIGN AND ANALYSIS OF PROTON BEAM WINDOW FOR CSNS

H.J.Wang, D.H.Zhu, H.M.Qu, L.Kang, R.H.Liu, IHEP, Beijing, People's Republic of China

Abstract

The proton beam window (PBW) is one of the key devices of China Spallation Neutron Source (CSNS). In this paper, a new designed PBW structure called single-double layer structure is discussed. The new structure will be used in CSNS, and it is designed based on the beam characteristic of CSNS, which power is 100 kW. The structure design and thermal-analysis are presented, and the convective coefficient of cooling water is calculated. Besides, the radiation damage is discussed to assure there is no danger of radiation lifetime of PBW.

INTRODUCTION

CSNS is now under construction and will be completed in a few years[1]. As one of the key devices, the PBW will be installed and checked before 2015. The PBW is the boundary of the high vacuum region of the transport line and the helium region of the target. There are several design demands of PBW, such as scattering effect, energy deposition, radiation damage, cooling method, mechanical strength and so on[2-5].

A5083-O was chosen as the material of PBW due to its stability, low effect on beam scattering, low energy deposition. The beam used for calculation is 2D Gaussian distribution, and the beam power is 100kw. According to the beam character, single-double layer structure was first proposed, and the relative calculation were done[6]. During the technological design process, we modified the structure for safety and difficulty consideration, then some necessary check computations are done, including the thermal-stress analysis and convective coefficient. Besides, the radiation damage calculation is presented, which shows the PBW has no danger in radiation lifetime design.

Table 1: Beam character of CSNS

Beam Power	100 kW
Beam Energy	1.6 GeV
Beam Distribution	2D Gaussian distribution σ(27mm,6.3mm)
Repetition Frequency	25Hz
Population per pulse	1.56×10^{13}
Operating time	5000h/y

STRUCTURE MODIFICATION

Single-double layer structure was first proposed and will be used in CSNS, the section view of which is showed as Fig. 1. This new structure own both the advantages of double layer structure and single layer structure[6]. It has low beam scattering effect, low energy deposition and low activation of cooling water, and the temperature and stress can meet the material allowable value well.

The original structure of PBW is a window plus two water blocks, and the three were welded together. The two location columns were also designed to be welded to each water block. To reduce the effect on the thin window produced by welding, a wholistic window was designed, then the welding lines are far away the middle of the window. Besides, the welded location columns are modified to be pin jointed, in order to improve the machining precision. The wholistic PBW will be produced in a few months, and the prototype is in fabrication, which is showed in Fig. 3.

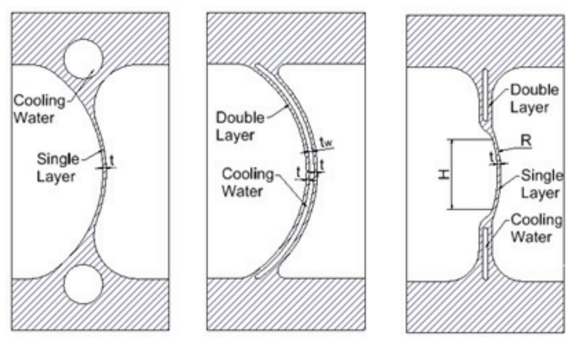

Figure 1: Section views of three structures (L: Single layer structure; M: Sandwiched structure; R: Single-Double Layer Structure).

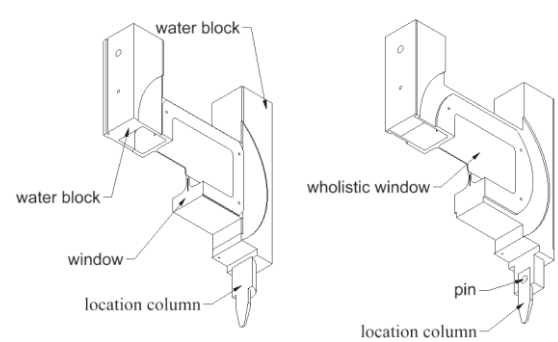

Figure 2: The modification of PBW (L: original design; R: modified design).

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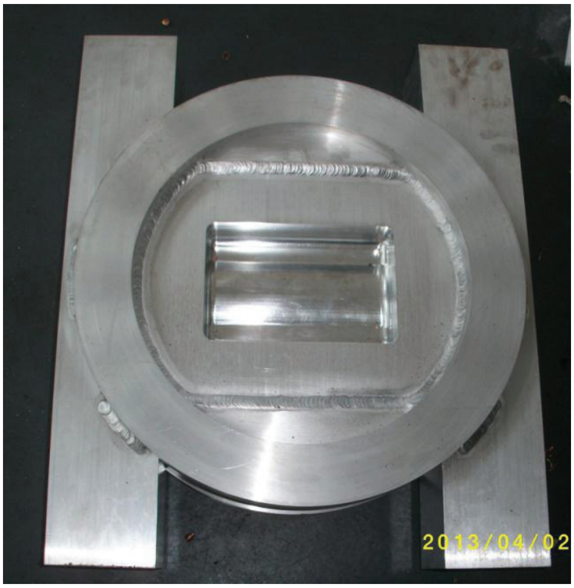

Figure 3: The prototype of PBW.

THERMAL-STRESS ANALYSIS

After the structure modification, the temperature and stress of PBW was recalculated using ANSYS code. Figure 4 presents the results and Table 2 shows the contrasts of the results of wholistic window and that of the original window. In spite of structure change, the results are almost the same. The slight difference can due to different element divisions. The results mean it is unnecessary to examine other calculation, such as transient analysis and safety confirmations. All of these are discussed in the previous work[6].

Table 2: Contrast between the results of the two model

Structure	Highest temperature	Highest Von Mises stress	Biggest displacement
wholistic	72.5℃	60.4Mpa	0.04mm
original	72.6℃	59.4Mpa	0.04mm

CONVECTIVE COEFFICIENT CALCULATION

When the convective coefficient is over 3500 W/(m^2·℃), the highest temperature and stress hardly vary[6]. The convection coefficient is related to temperature, water speed and the geometrical shape of water tube. The shape of water tube is showed in Fig. 1. It is 3mm wide and 40mm tall. The convective coefficient can be calculated by empirical equations. The environment parameters are listed in Table 3, then the convection coefficient K can be calculated.

$$Re = \frac{V \cdot d_s}{\nu} \quad (1)$$

$$Pr = \frac{Cp \cdot \mu}{\lambda} \quad (2)$$

$$N_\mu = \frac{K \cdot d_s}{\lambda} = cRe^n Pr^m \quad (3)$$

Table 3: Environment parameters of cooling water

Parameter	Value	Symbol
Temperature	30 ℃	--
Kinematic viscosity	0.805×10^{-6}m^2/s	ν
Specific heat capacity	4200J/(kg·℃)	Cp
Dynamic viscosity	0.8×10^{-3}Pa·s	μ
Thermal conductivity	0.6113W/(m·℃)	λ

Re is Reynods number, V is water speed, Pr is Prandtl number, $N\mu$ is Nusselt number, and c, n, m are constants of forced convection in tube without phase change.

The designed water speed is 1.5m/s, the calculated convective coefficient is 8115 W/(m^2·℃). And the water flow can be accommodated according to water speed by valve.

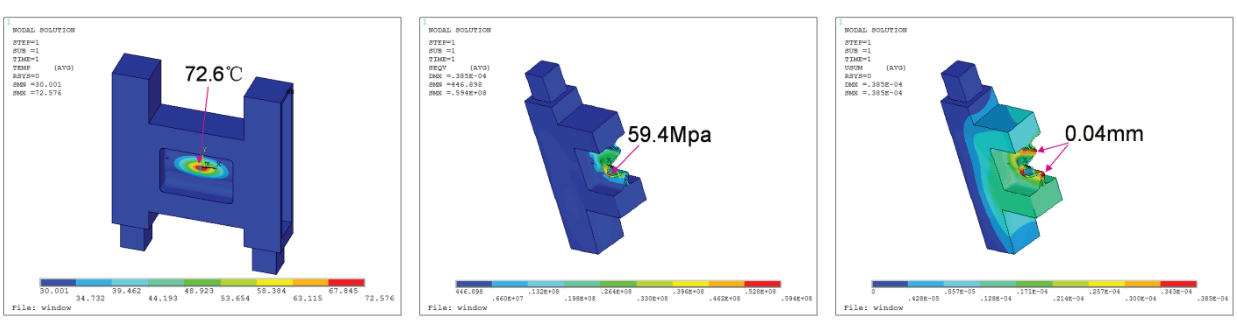

Figure 4: Thermal-stress results of modified structure(L: temperature; M: Von Mises stress; R: displacement).

RADIATION DAMAGE ANALYSIS

The lifetime of PBW mainly includes radiation lifetime and mechanical lifetime. As discussed in previous work, the mechanical lifetime has no problem[6]. The radiation lifetime is discussed based on DPA (displacement per atom), and the Monte Carlo program FLUKA is used to calculate the DPA of the PBW. The composition of A5083 is list in Table 4, as well as the damage threshold energy (E_{th}) of each element[7-9]. The PBW is simplified as a flat with the size of 180mm×60mm×2mm, the beam character is listed in Table 1. In the calculation there are five statistically independent runs, each one made of 1e8 histories, and the maximum DPA is 0.57/y. The DPA distribution is coincide with the beam distribution, which is showed as Fig. 5. We set the maximum acceptable DPA of A5083-O is 10 [9], thus there has no danger of radiation lifetime.

Table 4: The composition of A5083 and Eth of each element

element	Si	Fe	Cu	Mn
Mass fraction/%	0.14	0.19	0.01	0.66
E_{th}/eV	25	40	40	40
element	**Mg**	**Cr**	**Ti**	**Al**
Mass fraction/%	4.62	0.11	0.01	94.26
E_{th}/eV	20	40	30	27

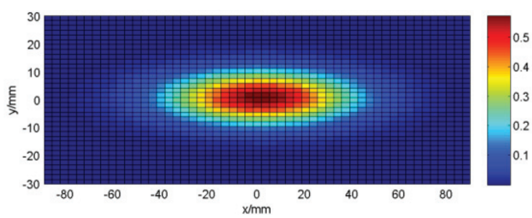

Figure 5: DPA distribution of PBW.

CONCLUSIONS

The proton beam window is very important to CSNS. A single-double layer PBW was first proposed according to the beam character of CSNS and will be used. During the technological design, the original structure has been modified to a wholictic one. The thermal-stress analysis showed there is slight differences between the two structure, and the working condition can meet the material demands well. Besides, the DPA is presented to assure the radiation lifetime has no problem. The prototype is now in process, the next work will be prototype checking and PBW machining.

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