THE DESIGN AND ANALYSIS OF PROTON BEAM WINDOW FOR CSNSIII

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Abstract

The proton beam window (PBW) is one of the key devices of China Spallation Neutron Source (CSNS). When the beam power of CSNS upgrades from 100kw to 500kw (CSNSIII), the present single-double layer structure of PBW cannot meet the demands. The PBW will be changed to other structure. This paper discusses sandwiched structure and multiple pipe structure, and the later one is chosen as the PBW of CSNSIII. An appropriate convective coefficient of cooling water is chosen, based on which the detailed thermal-stress analysis is presented. Besides, the lifetime is estimated. All these analyses show the designed PBW can work well in CSNSIII.

INTRODUCTION

CSNS is now under construction in China. The beam power of CSNS is 100kw and will be upgraded to 500kw in CSNSIII [1]. A single-double layer structure PBW made of A5083-O was designed and will be used in CSNS, but it cannot accommodate the beam power of CSNSIII. This paper presents two double layer structures, sandwiched type and multiple pipe type. The multiple pipe type can be made with thinner walls, which has advantages on beam quality and window temperature, so it is chosen as PBW structure of CSNSIII. The material is still A5083-O for its stability, low effect on beam scattering and low energy deposition. The allowable temperature and stress are respectively 82.5℃ and 72Mpa [2]. The beam used for calculation is 2D Gaussian distribution, with the same beam profile of CSNS (Table 1). A proper convective coefficient is chosen, and detailed thermal-stress analysis is done using ANSYS code. The lifetime is estimated, mainly considering the mechanical fatigue and radiation damage.

Table 1: Beam character of CSNSIII

Beam Power	500 kW
Beam Energy	1.6 GeV
Beam Distribution	2D Gaussian distribution σ(27mm,6.3mm)
Repetition Frequency	25Hz
Operating time	5000h/y

STRUCTURE ANALYSIS

The single-double layer structure PBW of CSNS is only suitable for low power accelerator. When the beam power is quintupled, the calculated temperature is over 200℃, that is too high for the material. Thus double layer structure is a good choice. There are mainly two kinds of double layer structure, sandwiched type and multiple pipe type [3-5]. J-PARC and SNS used sandwiched PBW and ESS will use the later one, the single-double layer structure used in CSNS and the two double layer structures are showed in Fig. 1.

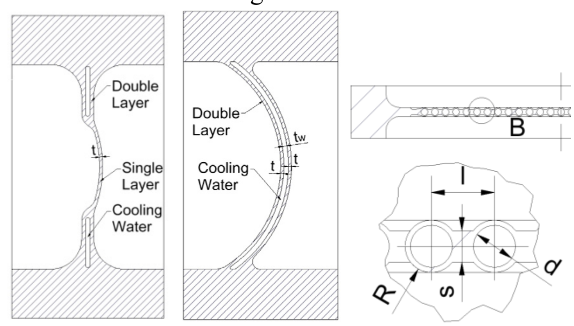

Figure 1: The cross section the three structures of PBW (L: single-double layer type, M: sandwiched type, R: multiple pipe type).

When passing through PBW, the beam scattering effect and energy deposition are mainly depend on material and the thickness. Since the material is determined, the thickness of PBW became the major factor. Take sandwiched structure for example, the highest temperature and stress variation with thickness can be calculated using ANSYS, which is shown as Fig. 2. Here the energy deposition used for calculation is obtained by SRIM code, and the cooling water is 30℃, with the convection coefficient of 5000 W/(m^2·℃).

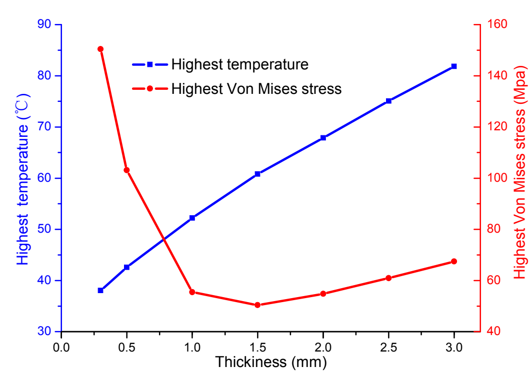

Figure 2: Temperature variation with thickness.

Figure 3 shows the scattering effect variation with thickness[6]. Both the scattering effect and temperature variation suggest that the PBW with a thinner wall is preferred. For the sandwiched PBW, if the PBW wall is thinner than 1mm, the capability of affording the pressure of water and Helium at target became rapidly worse, and it is too hard for fabrication. For the multiple pipe type, it

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has the advantages of resistance of pressure and manufacturability.

A primary design of multiple pipe PBW is done, as showed in Fig. 1, the parameters *R*, *s*, *d*, *l* are respectively 2.5mm, 3mm, 4mm, and 6mm. The relationship between highest temperature and Von Mises stress and the convective coefficient is presented in Fig. 4. It is indicated that when the value of convection coefficient is over 5000 W/(m^2·℃), the operating condition hardly varies. The water speed of 1.5m/s is taken as the designed speed, the corresponding convective coefficient is 8115 W/(m^2·℃), thus the water flow can be determined, which can adjusted by valve. Figure 5 shows the distribution of temperature, Von Mises stress and displacement, these value can meet the permitted value well.

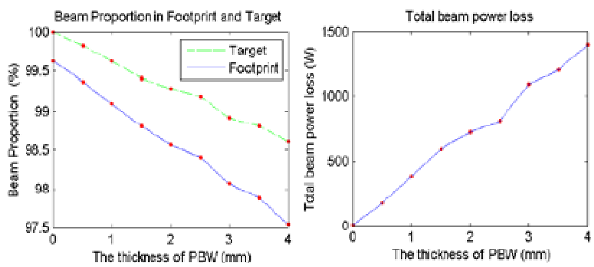

Figure 3: Scattering effect variation with thickness.

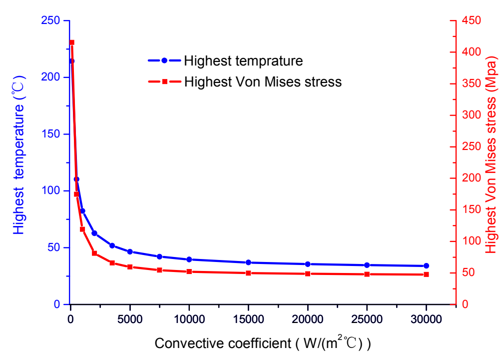

Figure 4: Temperature and stress variation with convective coefficient.

LIFETIME ESTIMATION

The lifetime of PBW mainly refer to mechanical lifetime and radiation lifetime.

The highest temperature and stress of PBW has no problem to meet the demands of the material, and the temperature is low, the stress produced by temperature change is a small part of the whole stress. Transient calculation was done considering the fatigue effect. Figure 6 shows the highest temperature variation with time. When balanced, the temperature switch is about 2℃ per pulse. The vary is small and the fatigue effect can be ignored.

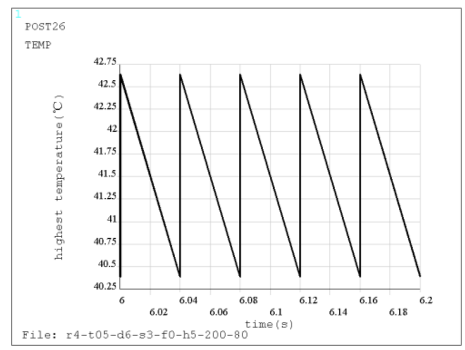

Figure 6: Highest temperature variation with time.

DPA (displacement per atom) is a main index of radiation damage. As the beam power is high and the thickness is little, the effect of thickness and shape is ignored. The DPA is related to beam character and material. The composition of material is the same as that of CSNS[7], and the beam profile is also the same, the DPA distribution is similar to that of CSNS, only the value changes. The PBW is simplified as a flat with the size of 180mm×60mm×2mm, the maximum DPA is 2.85/y, and the allowable DPA is 10, then the lifetime of PBW is two years, considering a safety factor of 1.75. The DPA distribution is presented in Fig. 7.

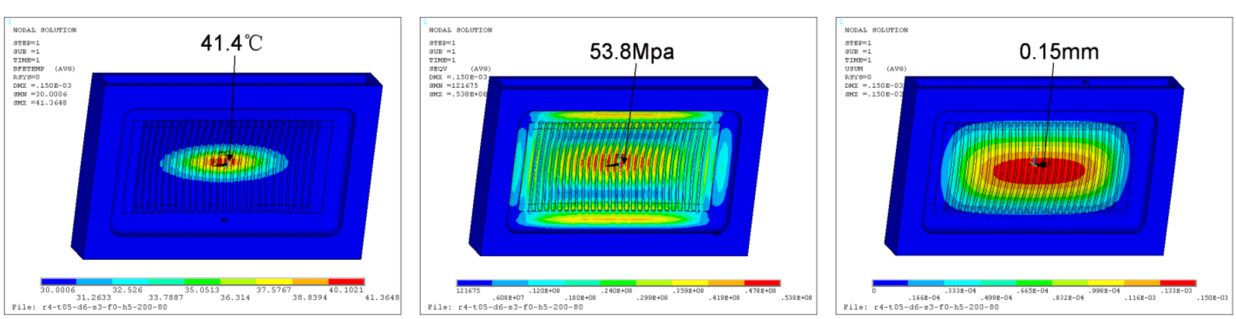

Figure 5: Calculation results of primary designed PBW (L: temperature distribution; M: Von Mises stress distribution; R: displacement distribution).

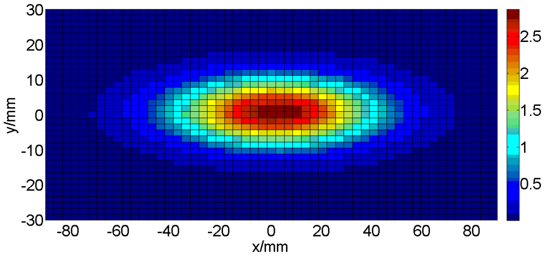

Figure 7: DPA distribution of PBW.

CONCLUSIONS

The beam power will be upgraded from 100kw to 500kw in CSNSIII, the present designed structure is not applicable. Two double layer structures are contrasted and the multiple pipe type is chosen, because its wall can be made thinner, then the scattering effect and operating temperature can be lowered. From the analysis of convective coefficient, the water speed of 1.5m/s is chosen and based on which the detailed thermal-analysis is done, the highest temperature and stress can meet the material demands well. Because there is little flutter of temperature per pulse, the fatigue effect is ignored. The DPA is calculated to estimate the radiation lifetime, which shows the PBW can operate 2 years with a safety factor of 1.75. The next work is the structure optimization and fluid analysis.

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