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Conceptual Design of Proton Beam Window

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Abstract

In a MW-scale neutron scattering facility coupled with a high-intensity proton accelerator, a proton beam window is installed as the boundary between a high vacuum region of the proton beam transport line and a helium environment around the target assembly working as a neutron source. The window is cooled by water so as to remove high volumetric heat generated by the proton beam. A concept of the flat-type proton beam window consisting of two plates of 3mm thick was proposed, which was found to be feasible under the proton beam power of 5MW through thermal-hydraulic and structural strength analyses.

1. Introduction

The Japan Atomic Energy Research Institute (JAERI) and the High Energy Accelerator Research Organization (KEK) have a plan to construct a MW-scale neutron scattering facility at the Tokai Research Establishment, JAERI.[1] A proton beam window is one of the key components of the neutron scattering facility, which is the boundary between a high vacuum region of the proton beam transport line and a helium environment around the target assembly working as a neutron source. Since high volumetric heat will be generated in the window, it is necessary to cool the window with water so as not to generate excessive thermal stress due to large temperature difference along the window plate and hot spots by water boiling. In this paper, we will introduce a flat-type water-cooled proton beam window proposed for a 5MW proton beam operation.

2. Conceptual Design

Figure 1 shows a concept of a flat-type beam window for applying to a 5MW proton beam operation. The dimension of the proton beam window is 330 mm in width, 235 mm in height and 65 mm in depth. Light water flowing from two inlet pipes is adjusted by using flow guides in order to distribute it's flow rate uniformly in the window section. The window section consists of two flat plates made of Inconel 718 alloy, with dimensions 200 mm wide and 60 mm high. In this concept, the thicknesses of the plate and the gap between the plates (coolant channel) are 3 mm and 5 mm respectively, but these are tentative values. We will optimize these values so as to suppress the proton beam scattering in the window section.

Figure 2 shows a detailed drawing of the beam window concept. Pillow seals are used for vacuum and helium gas sealings, which are installed at the both end of the window. Also, the window has a space to install diagnostics such as beam harrow, position and core monitors, but their types and specifications are not yet decided. This window will be fixed on an exchanging plug as shown in Fig.3, and transferred with the plug to a handling cell in order to replace a window.

3. Structural Strength Analyses

3.1 Stresses by Internal Pressure

Three dimensional analyses of structural strength were carried out using the structural analysis code, ABAQUS. The total computational grid number in the window section was 90,000, and the internal coolant pressure of 1MPa was given as the design value. As shown in Fig.4, the maximum bending stress of 254 MPa appears near the lower end of the window section. This bending stress caused by the internal pressure is less than 1/3 of the allowable bending stress of Inconel 718 alloy which gives 1.5Sm : Sm is the design intensity value of Inconel 718 alloy, 560MPa.

3.2 Thermal Stress

In order to estimate the thermal stress, it is necessary to obtain a temperature distribution in the window plate. The temperature distribution was analyzed by using the thermal hydraulic analysis code, STAR-CD, under the following conditions;

Inlet water temperature : 40 ℃

Water flow rate : 20 m³/h

Water velocity in inlet pipes : 2.5 m/s

Volumetric heat (heat density) in the window section : 960 W/cm^3

(under the 5MW proton beam operation)

Turbulent model : Standard $k - \varepsilon$ model

Total number of three-dimensional computational grid : 300,000

Boundary conditions on the outer surface of the plates : adiabatic

As for the heat density in the window section, it is available in the region of 130 mm wide and 50 mm high that is coincident with the proton beam profile. Thermal hydraulic analyses results are described in the following section.

Using the temperature distribution obtained with the Star-CD, the thermal stress was analyzed with the ABAQUS. Figure 5 shows the analytical result of the thermal stress. As seen in the figure, the maximum thermal stress of 1179MPa appears at the center of the plate, which is less than the allowable thermal stress of Inconel 718 alloy that gives 3Sm, 1680MPa. From the analytical results of the thermal stress as well as the bending stress described in Section 3.1, this concept would be feasible on the structural strength.

4. Thermal Hydraulic Analyses

Thermal hydraulic analyses were carried out under the conditions mentioned in Section 3.2. Figure 6 shows the velocity distribution. As seen in the figure, almost uniform velocity distribution of about 10 m/s is realized in the window section. Figure 7 shows the inner surface temperature distribution of the window plate. Hot spots cannot be seen in the window section. The maximum temperature is 92 ℃, which is less than the saturation temperature of 150 ℃ under the water pressure of 1 MPa. This means that the onset of flow boiling can not occur, so that it is not necessary to consider flow instability induced by flow boiling under normal operating conditions. Since the water flow rate of the inlet pipes would change in practical operations due to branch effects in the inlet pipelines etc, we also analyzed the inner surface temperature distribution under the asymmetry inlet flow condition of ± 10 %. The maximum inner surface temperature increased only 0.3 ℃ against the idealized condition without inlet flow rate deviations (the equal inlet flow rate). These results show that the proposed structure of the proton beam window would be feasible from the thermal hydraulic viewpoint.

5. Concluding Remarks

A concept of the flat-type proton beam window consisting of two plates of 3mm thickness was proposed to meet higher proton beam power (up to 5MW) from the viewpoint of the future plan of the joint project. Through structural strength analyses using a three

dimensional model, it was found that stress caused by the internal pressure and thermal stress could be below the allowable stress of Inconel 718 alloy. Also, through thermal hydraulic analyses, it was found that the water flow distribution could be kept almost uniform in the window section, so that the surface temperature of the window plate could be suppressed far below the water saturation temperature without hot spots, even under the asymmetry inlet water flow condition of ±10 %. From these analytical results, the proposed concept would be feasible from the viewpoint of structural strength and thermal hydraulic performances. We will improve the conceptual design to decrease the window plate thickness to 1.5 mm and also make clear an exchanging procedure of the beam window.

References

[1]   "The Joint Project for High-Intensity Proton Accelerators" ,JAERI-Tech2000-003(2000).
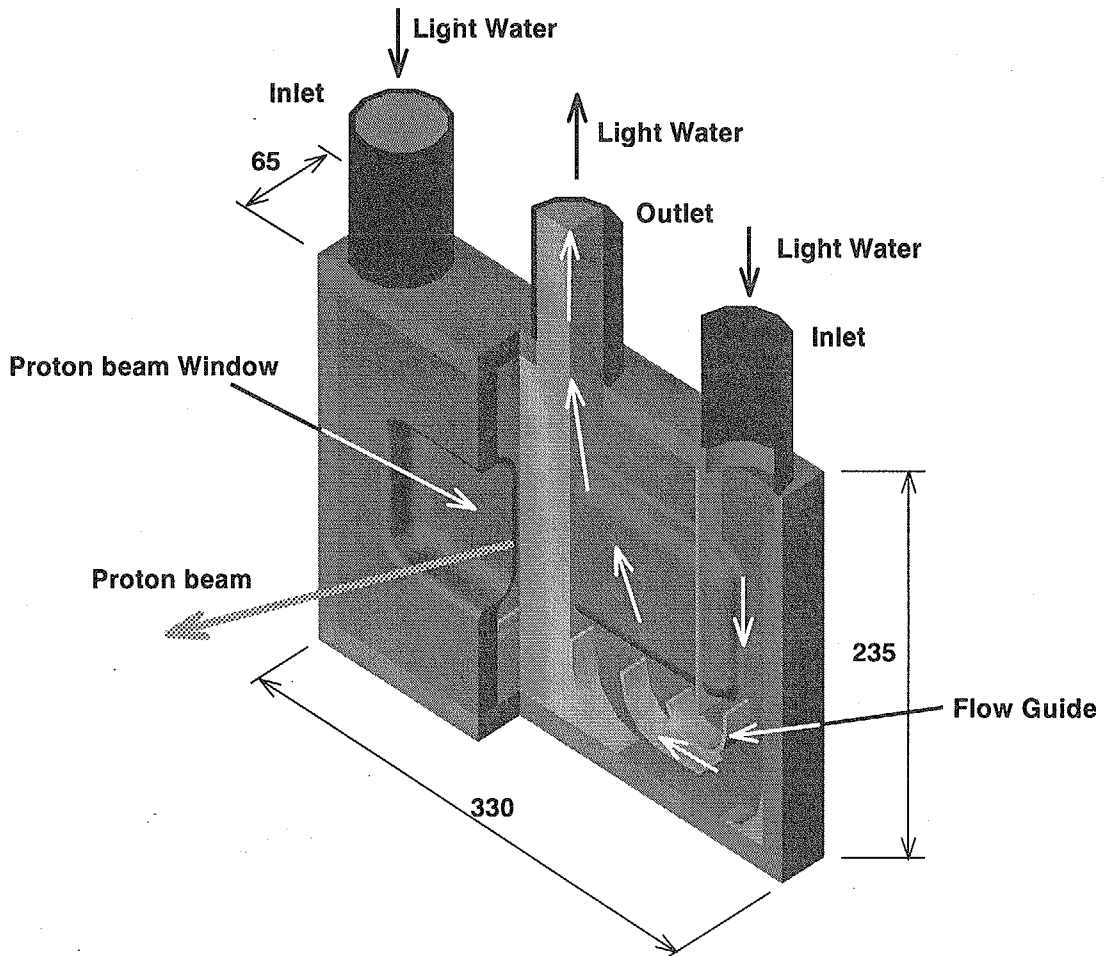

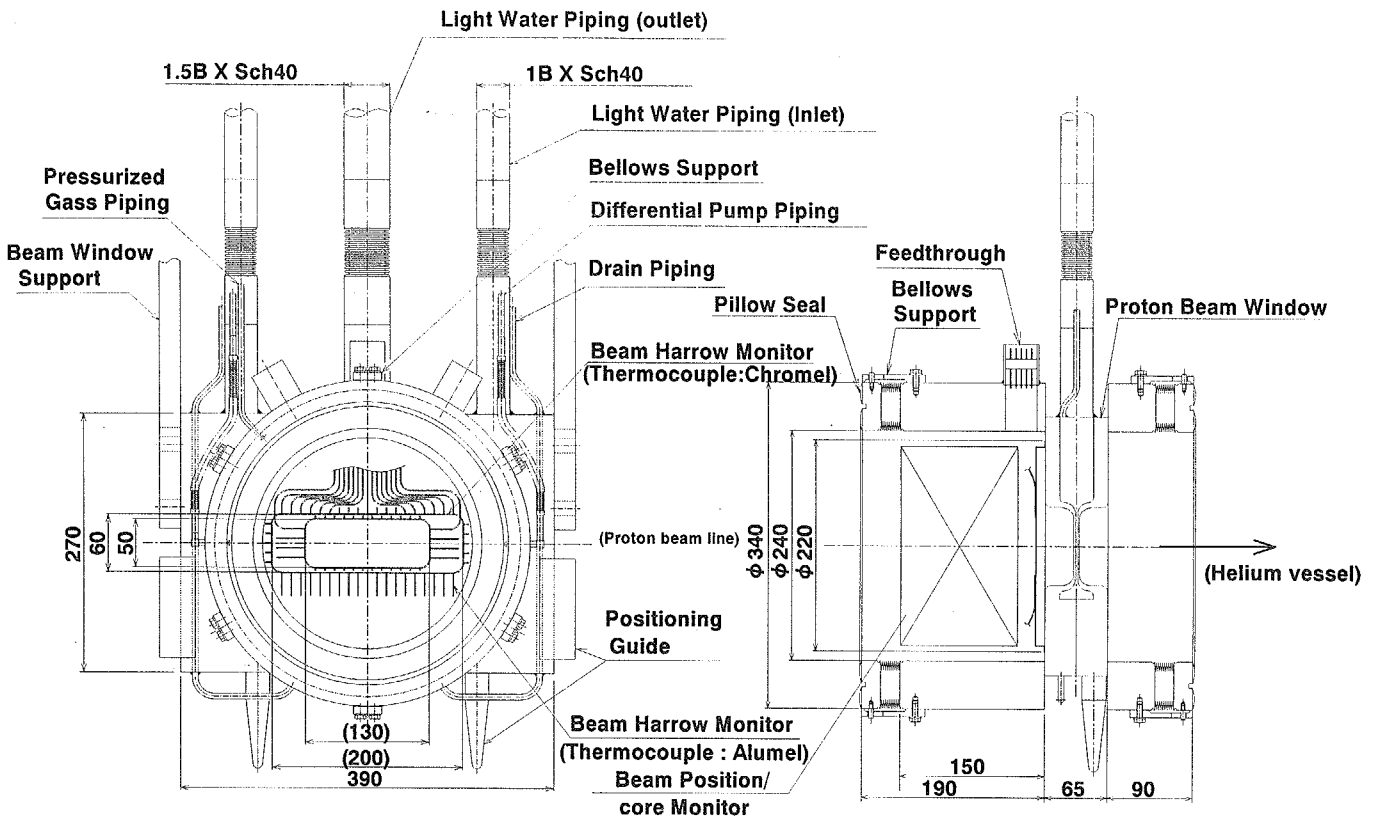Fig.1 Conceptual design of proton beam window at a 5MW proton beam operation
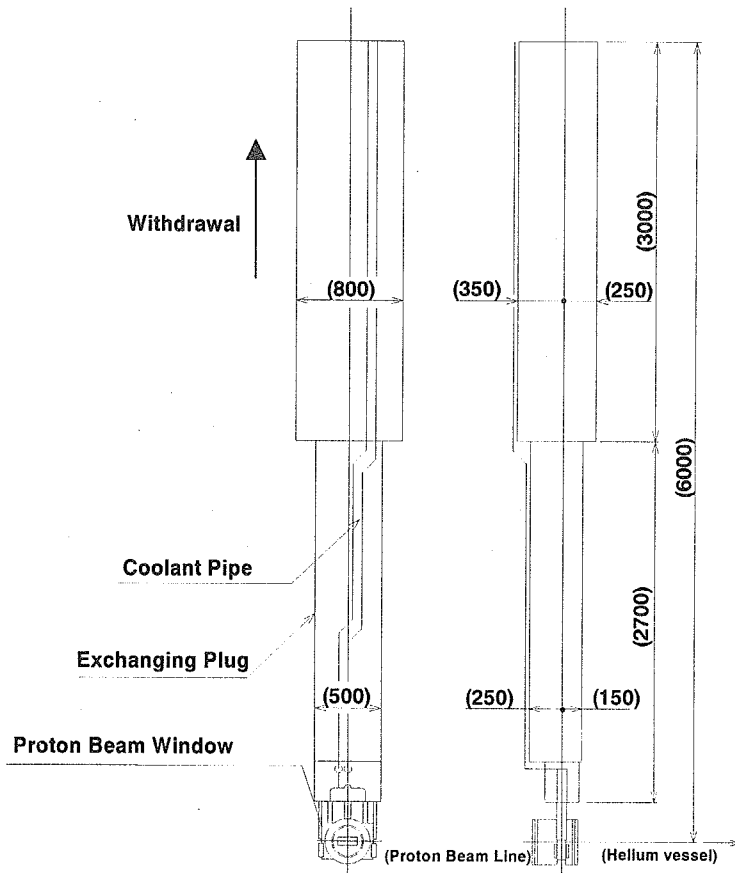
Fig.2 Flat-type proton beam window

Fig.3 Proton beam window assembly
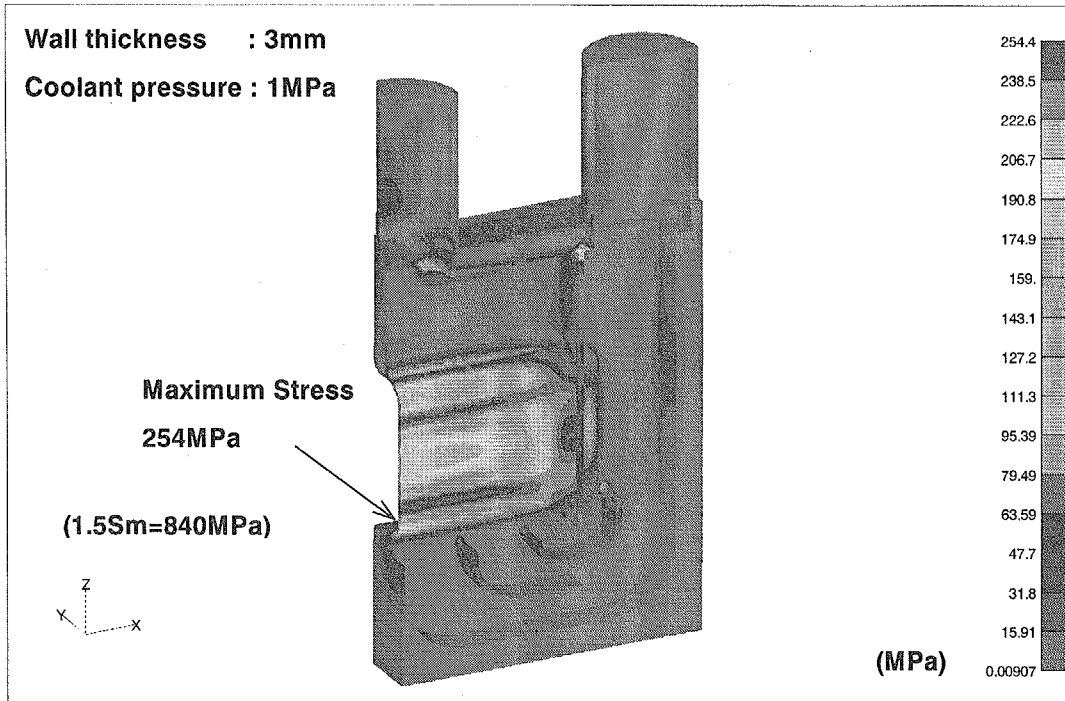
Wall thickness : 3mm

Coolant pressure : 1MPa

Maximum Stress

254MPa

(1.5Sm=840MPa)

(MPa)

Fig.4 Analytical results of stress distribution caused by internal pressure

Maximum
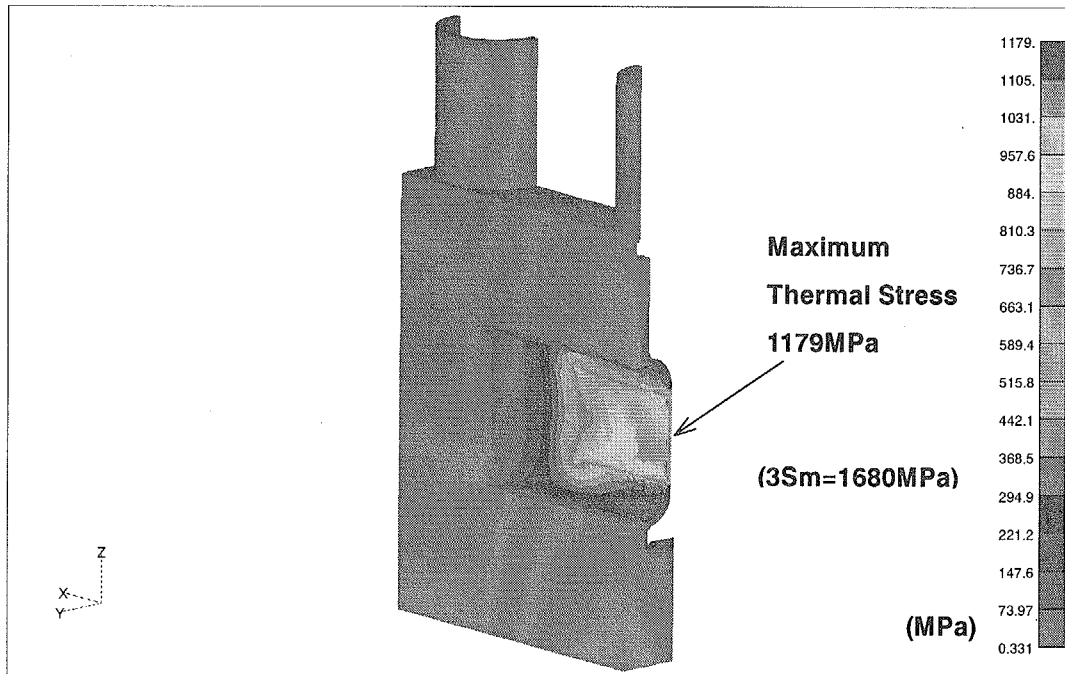
Thermal Stress

1179MPa

(3Sm=1680MPa)

(MPa)

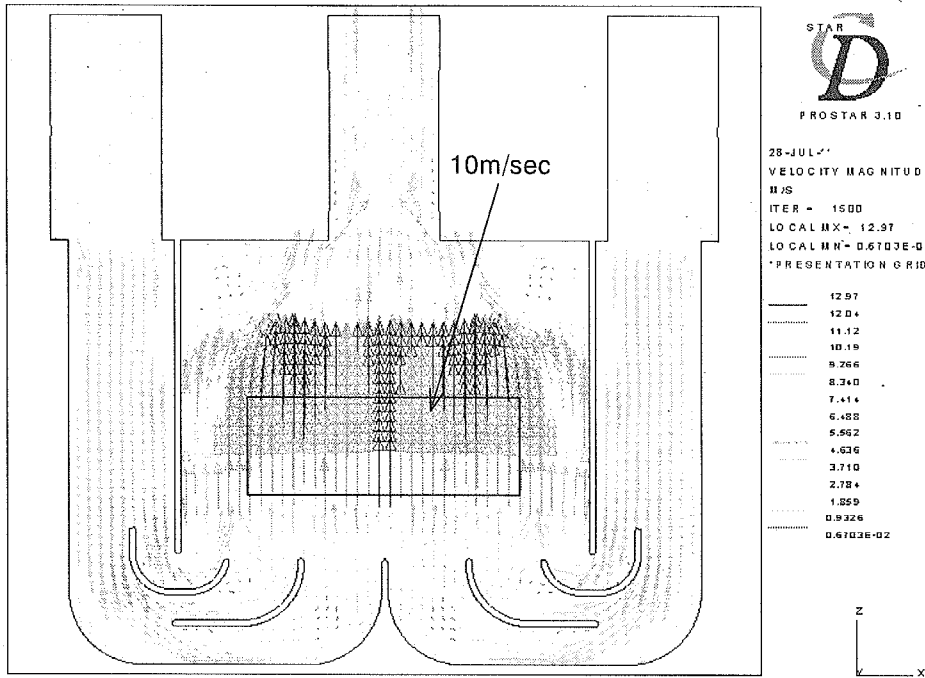Fig.5 Analytical results of thermal stress distribution caused by beam-heated

Fig.6 Thermal hydraulic analytical results of coolant velocity distribution
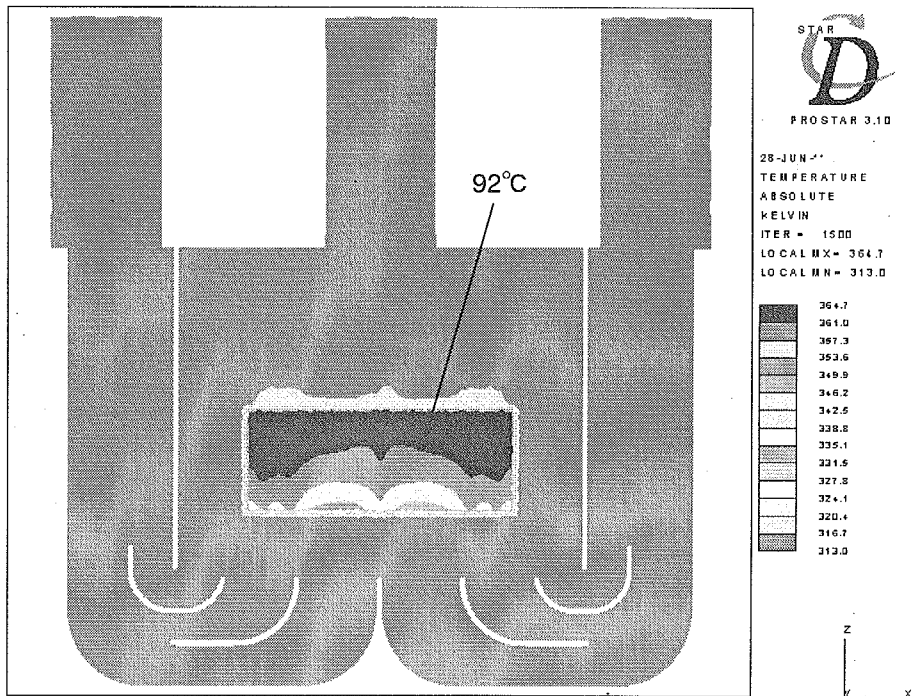

Fig.7 Thermal hydraulic analytical results of wall temperature distribution