PRELIMINARY ANALYSIS OF LBE COOLED INTEGRATED TARGET IN ADS

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Abstract

The design of the spallation target is a challenging task in Accelerator Driven subcritical System (ADS), as the target operates under high neutron and proton irradiation, high temperature and high corrosion-erosion conditions. For the very low neutron capture and low melting point, the lead-bismuth eutectic (LBE) liquid target is the reference target for ADS application. To provide good neutron economy, the target unit in ADS is as compact as possible. In this paper, An integrated target concept and preliminary analysis of LBE cooled integrated target was presented with the fluid-structure coupling method by using ANSYS code. This LBE cooled integrated target is a clamped-sliding pin type target, and all the components in the target are connected only on the top of reactor cover. the proposed target can achieve an easy intervention scheme for maintenance and repair. The preliminary analysis of this target is performed under an adequate earthquake loading to assess the feasibility, including the fluid effect and contact between inner tube and sleeve. The result shows that the proposed LBE cooled integrated target can satisfy the requirements under design condition. As the strong convenience in maintenance and repair, and the feasibility in operation, the proposed LBE cooled integrated target may be a valuable reference for spallation target design in ADS.

Introduction

The Accelerator Driven subcritical System (ADS) has very attractive advantages such as its potential ability to achieve long-lived radioactive nuclear wastes transmutation, fission fuel breeding and energy production etc. Chinese Academy of Sciences (CAS) had launched a Strategic Priority Research Program of "the Future Advanced Nuclear Fission Energy-ADS transmutation system" to develop ADS in China since 2011 (Zhan et al., 2012). Based on years of the research in the field of advanced neutronics software(Wu et al., 1999, 2009a, 2014a), heavy liquid metal operation(Wu et al., 2009b, 2012;), low radioactivity material(Huang et al., 2007,2013), and advanced nuclear system design(Wu et al., 2002, 2006, 2011,2014b), Institute of Nuclear Energy Safety Technology(INEST) undertakes the R&D of the lead-bismuth eutectic(LBE) cooled reactor design and technology(Y. Wu, 2014b).

In previous study, many projects put forward their window target design, like JAEA-ADS(Kikuchi,2009), HYPER(Song and Tak., 2003), FASTEF(H.Abderrahim,2012), THREE BEAM CONCEPT(Knebel et al., 2000), XADS(D. Coors et al.) and MYRRHA (A.G.Class, 2011). In convential target concept, the cylindrical tube welded on the support will suffer damage at the level of 5dpa a year. The estimated operational life time is similar to the windowless target (about 3 years). (OECD, 2005) Compared to the reactor design life (about 30 years), the target unit in the core regions must be replaced. By extending on this basis, an integrated target unit is newly proposed in this paper

Integrated target concept

Exposed to high intense irradiation and thermal load, the spallation target is the life time limiting component. Thus, the configuration of the target components must match the requirements with respect to replaceability and feasibility. An integrated target concept is presented in this paper.

The target unit is a clamped-sliding pin type target, only fixed on the reactor cover by flange, as shown in Figure 1 . All the components of the target can be replaced flexibly and separately from the top of the reactor. And this configuration can provide free space for differential expansion to reduce the thermal stress. In addition, a sudden expansion channel in the spallation area will enhance the heat transfer of the beam window.

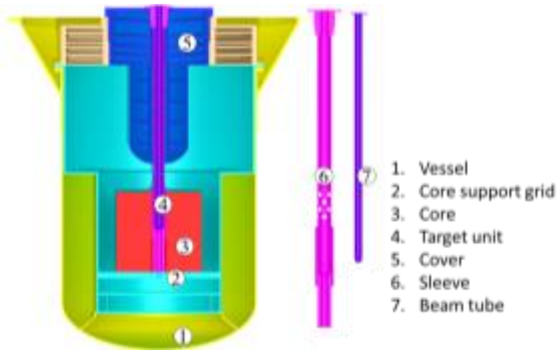

Figure 1. Overall views of the integrated target concept

For a detailed configuration, the target flow channel, as shown in Figure 2, is divided into three zones, from bottom to top, the feeder line, the spallation area, and the return line. The three zones have similar cross- section area to minimize pressure loss. The vertical section of the spallation area is inverted cone sharp. It allows minimizing the inactive volume of LBE in the target flow channel and increasing the window surface heat transfer.

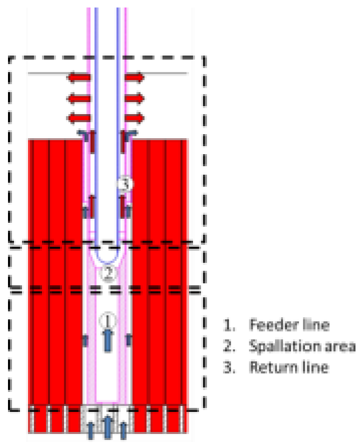

Figure 2. Thermal hydraulic schematic view of the integrated target

Thermal-hydraulic analysis

Due to the high intensive deposited heat in the spallation area, the thermal-hydraulics performance of the LBE cooled integrated target is simulated to demonstrate that the target would be cooled adequately. Due to the corrosion and the compatibility, two criteria is set regarding the thermal-hydraulics: 1) the temperature of the structure material should not exceed 550℃; 2) the flow velocity of LBE should not exceed 1.5m/s.

The temperature distribution in the target is shown in Figure 3. The maximum temperature occurs near the outer boundary of the proton beam, and is 549℃. That means this scheme can provides adequate cooling for the structure material. The distribution is very non-uniform, and the structure nearby will become thermally stressed as a consequence of larger local temperature gradient. It will be considered in the structural analysis.

Figure 4 shows the velocity distribution in the fluid domain. The maximum velocity is 0.879m/s which is less than the material limit (1.5 m/s). Moreover, it is obvious that a stagnation point occurs below the center of the window. In this area, it is difficult to improve the heat transfer of the beam window.

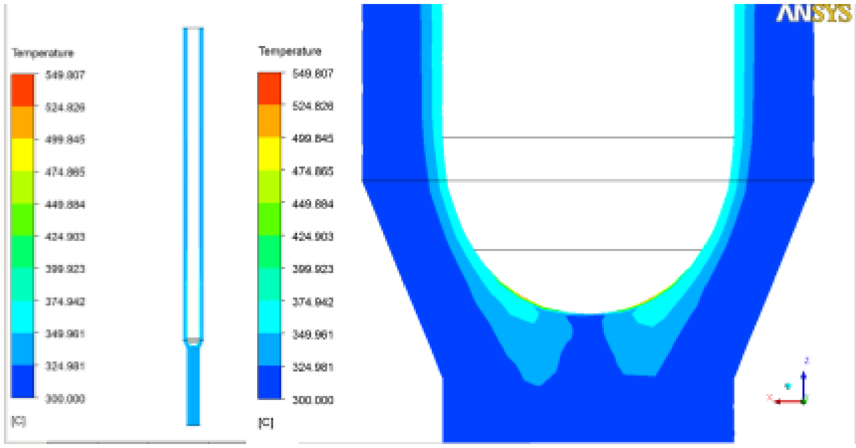

Figure 3. The temperature distribution in target

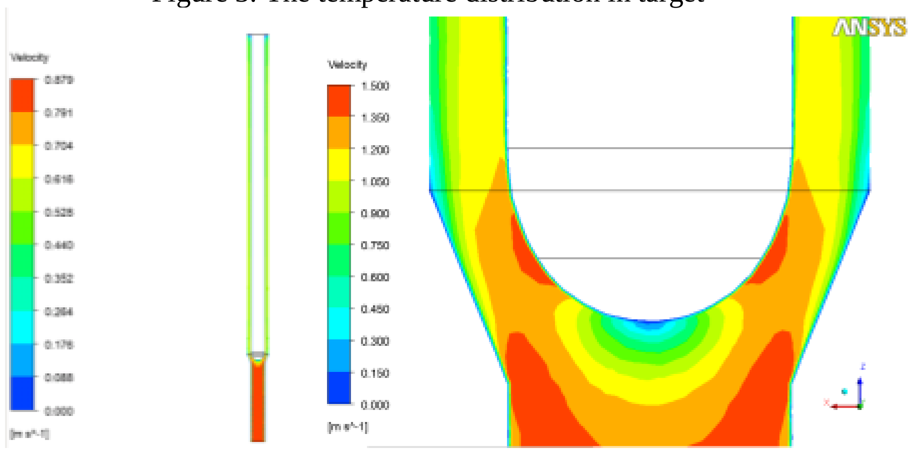

Figure 4. The velocity distribution in target

Structure analysis

In order to evaluate the mechanical behaviour of the LBE cooled integrated target, static structural analysis and dynamic analysis of the target unit are performed to obtain the von Mises stresses.

In static structural analysis, the von Mises stress of the target unit is shown in Figure 5. The maximum von Mises stresses on the beam window occur close to the intersection of the proton beam boundary on the outer surface, about 58MPa. And the maximum stress on the sleeve occurs on the spring connection, and is 69Mpa. It maybe arises from the bulking effect. In static structural analysis, the maximum von Mises stresses are lower than allowable stress of the structure material(Beam tube and window : T91, 102MPa; Sleeve: AISI 316L, 88MPa).

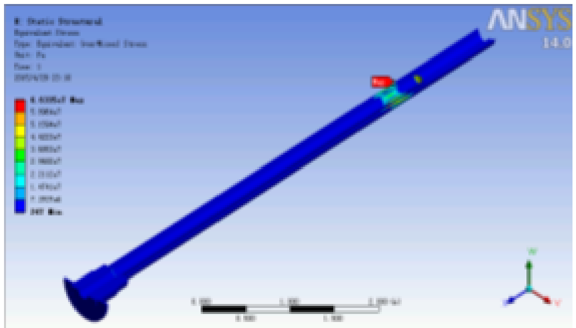

Figure 5. The von Mises stress configuration by two schemes in static structural analysis

In dynamic analysis, the von Mises stress of the target unit is shown in Figure 6. On the beam tube, the stress of beam tube is about 0.7Mpa. The maximum stress occurs on the connection between the tube and the top flange. The maximum von Mises stress on the sleeve occurs at the bottom. And it also have large safety margin.

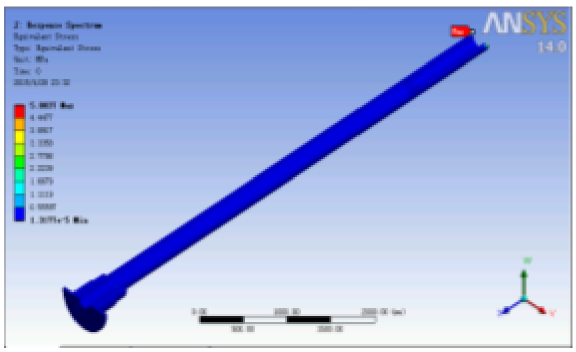

Figure 6. The von Mises stress configuration by two schemes in dynamic analysis

Conclusion

In present stage, the design of an integrated target which is simply and can be easily replaced is presented. The thermal-hydraulic and structural analysis are performed aiming to assessment the feasibility of the integrated target. The result shows that the hotspot of this target is near the material limitation; and the stress of the structure have enough safety margins. In the next step, we may find some ways to enhance heat transfer of target window and reduce the thermal loads and dynamic load.

Acknowledgements

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