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CFD Analysis on HYPER Spallation Target under Beam Transients

Nam-il Tak, Chungho Cho, Tae Yung Song
KAERI, 150 Deokjin-dong, Yuseong-gu, Daejeon 305-353, Korea, takni@kaeri.re.kr

1. Introduction

One of the innovative systems in an accelerator-driven system (ADS) is a spallation target, which is a physical and functional interface between an accelerator and a reactor core. The operating experience of existing accelerators shows that beam transients occur very frequently. Analysis of thermal hydraulic behavior of a target system under beam transients is important since a beam window is very vulnerable to failure under beam transients.

This paper presents thermal hydraulic analysis on the HYPER spallation target under beam transients, focusing on the window temperature. Two transient scenarios, i.e. beam interrupt and beam focusing events, are primarily analyzed using a computational fluid dynamics (CFD) code.

2. Numerical Approach

The HYPER target with a dual injection tube (recently proposed in [1]) is considered in this paper. For the present CFD analysis, CFX 5.7 [2] was adopted. Fig. 1 shows the computational domain and boundary conditions. An axi-symmetrical two-dimensional computation domain was chosen due to symmetric conditions. The standard k-ε turbulence model with the scaleable wall function was applied.

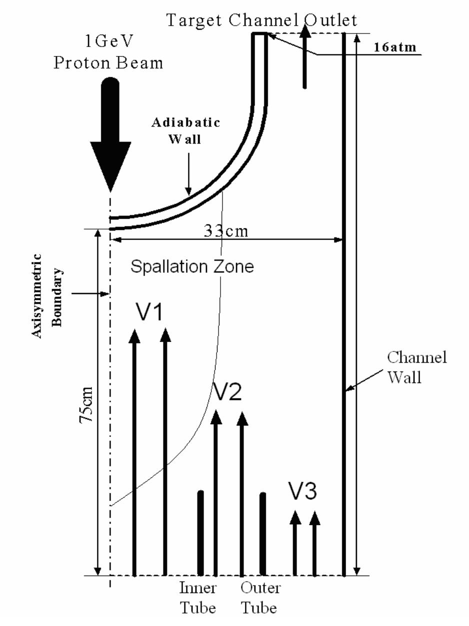


Figure 1. Computational domain and boundary conditions.

2.1 Boundary Conditions

The spallation heat distribution calculated by neutronic analysis was applied as a volumetric heat source. The inlet LBE temperature entering the target channel is 340 ^{o}C, which is the same with that of the core inlet. The injection velocities from the tubes (V1, V2, V3) are 1.8, 0.3, 0.01 m/s, respectively. The dimensions of the injection tubes and the injection velocities are optimized by parametric studies [1]. The reference beam current is 19.6 mA.

2.2 Initial Conditions (Steady State Behavior)

The results of the steady state calculation [1] were used for the initial conditions of the present analysis. The initial window temperature is shown in Fig. 3. The maximum temperature of the window is located near the edge of the beam (Position A) and is as high as 513 ^{o}C.

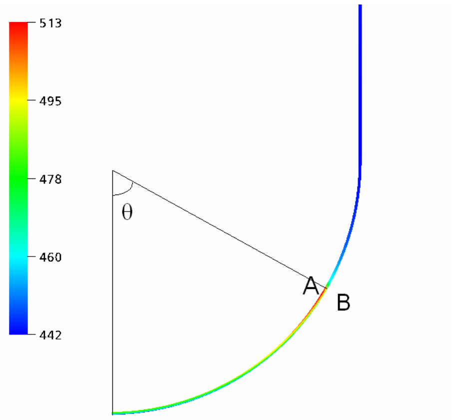


Figure 2. Steady state window temperature (in ^{o}C).

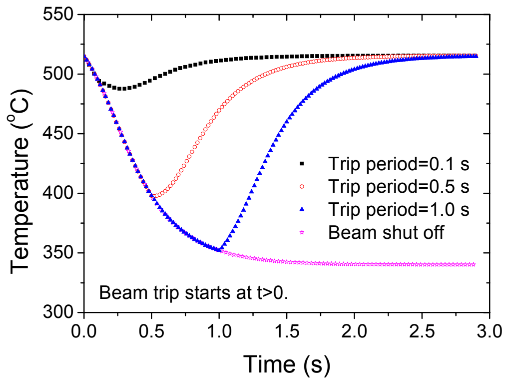
3. Transient Results

Two points (A and B) are selected to investigate the transient behavior of the window. The point A represents the position where the maximum window temperature exists under steady state conditions (See Fig. 2.). The point B is aligned with the point A with the same angle ($\theta = 59^{o}$). These two points are located at the inner and outer surface of the window, respectively.

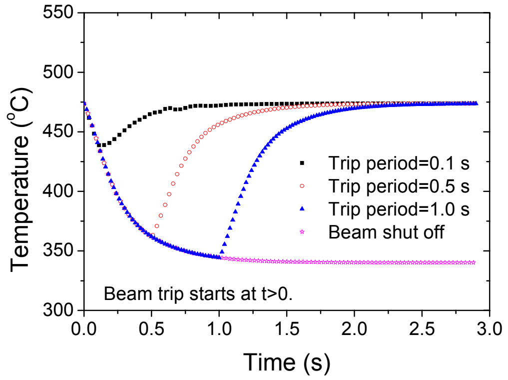
3.1 Beam Interrupt

Beam trips with three different interrupt durations, i.e. 0.1, 0.5, and 1 second, were investigated in this study.

Fig. 3 presents the predicted temperatures at the positions A and B under beam trips. For a better understanding, the case of beam shut off was also simulated and presented. As expected, beam trips with a smaller trip period result in a smaller temperature drop. The window undergoes a temperature drop up to 163 ^{o}C for the trip period of 1 s, whereas the maximum temperature drop is only 27 ^{o}C for the trip period of 0.1 s. The maximum temperature change rate is predicted as high as 355 ^{o}C/s, at the point B. This maximum temperature change rate occurs at 0.1 s after the beam interrupt.



(a) Position A



(b) Position B

Fig. 3 Temperature behavior under beam interrupts.

3.2 Beam Focusing

A beam focusing event can be initiated by failure of rastering magnets. There are 4 rastering magnets for beam scanning in the HYPER accelerator and one pair of magnets covers each axis of the footprint of the beam (i.e., circle with a radius of 15 cm). Therefore, if one of the rastering magnets fails, the proton beam will cover only the half of the entire footprint with the same beam power. It means that the beam intensity becomes double for one half of the target in case of one rastering magnet failure. An accident initiated by the failure of one rastering magnet was simulated. To simplify CFX 5.7 analysis, the computational model and boundary conditions used for the steady state analysis were unchanged except the beam current, which was increased to 39.2 mA from the reference value (= 19.6 mA). Based on the existing results of material tests [3] and the previous stress analyses, 800 ^{o}C is chosen used as a rough estimate for the temperature, at which the window failure occurs. However, Fig. 9 shows that the maximum window temperature does not reach 800 ^{o}C after beam focusing.

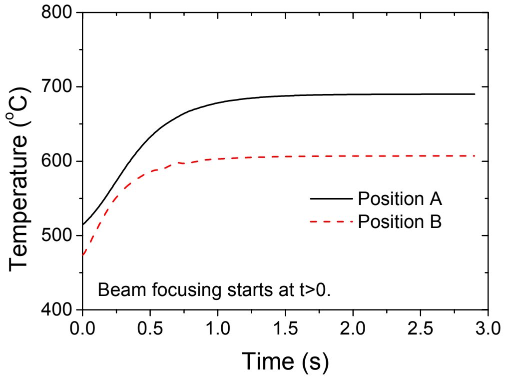


Fig. 4 Temperature behavior under beam focusing.

4. Conclusions

The transient behaviors of the HYPER target under two beam transient scenarios were investigated using the CFX 5.7 code. At beam interrupt transient, a temperature drop of 163°C is obtained in case of a trip period of 1 s. For all beam trips analyzed, the maximum temperature change rate is predicted as high as 355 ^{o}C/s. In case of beam focusing, the window failure is not expected in the HYPER target. It means that beam focusing is not serious concern in the HYPER target in contrast to the results in [4].

ACKNOWLEDGMENTS

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