Transient thermal analysis of HCCR test blanket module during a loss of flow accident

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1. Motivation

When the loss of off-site power (LOOP) accident occurs in the ITER, the plasma and the related auxiliary facilities will be stopped. For the HCCR TBM, thermal load coming from the plasma facing surface will disappear and the coolant flow will be stopped, which is called the loss-of-flow accident (LOFA). In this case, the temperature of the TBM may increase due to the decay heat without cooling. Actually, there is an emergency circulator for investment protection (IP) in this case and it will take 90 s to start. Therefore, transient analysis was performed to investigate the TBM temperature whether or not it could affect the integrity and safety.

2. Model and assumptions

The model in the conceptual design of HCCR-TBM was used as shown in Fig. 1 [1]. The HCCR-TBM consists of four sub-modules, and the main components are first wall (FW) and breeding zone (BZ) in each sub-module and common BM. In HCCR-TBM, the reduced activation ferritic/martensitic (RAFM) steel is used as structural material, and the lithium ceramics, beryllium and graphite are used as functional materials such as breeder, multiplier and reflector, respectively. The BZ comprises total seven layers, i.e. three breeder layers, three multiplier layers and one reflector layer. Between the layers, BZ cooling plates with cooling passage inside are located to cool each layer within the temperature limit. In the conceptual design phase, the steady-state thermal analysis for integral module (INT-TBM) was performed [2], and this model and input for CFD code were used in the present analysis [3].

Total analysis time was 1200 s after LOOP accident, in which the IP circulator starting time, 90 s can be used for inferring the temperature evolution assuming the circulator replacement. The initial temperature condition was used from the results of the steady-state analysis of INT-TBM. There is no helium coolant in the cooling channel of the structure due to the LOFA and it was assumed to stay in a stationary state. Radiative cooling is not considered for the conservative approach. The thermal load on the plasma-facing surface of FW from the plasma is assumed to disappear right after the LOOP accident. Decay heat for each structure was used as the heat source from the neutronics analysis.

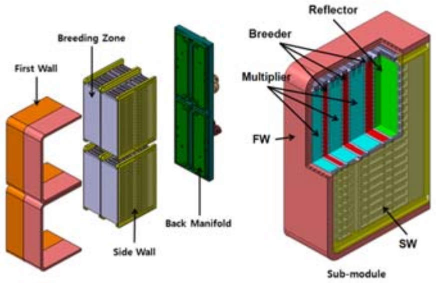


Fig.1. Exploded and internal view of the conceptual design of HCCR-TBM

3. Transient analysis results

Figure 2 shows the maximum temperature evolution at each component after LOOP accident. Due to the thermal equilibrium state between the lower and higher temperature regions, breeder and multiplier temperatures decrease sharply but the RAFM structure temperature increases. All functional material temperatures were lower than the requirements but that of structure was higher than the material limit (600 oC) for 350 s. For the RAFM steel, the lower limit is 300 oC because the DBTT (Ductile Brittle Transition Temperature) becomes lower below the limit. The higher limit is 600 oC because the strength rapidly decreases with neutron irradiation above the temperature. And the operating temperature was selected to be 300 oC and 550 oC considering thermal margin. However, when the IP circulator starts at 90 s, the structure temperature did not exceed the limit temperature. When the IP circulator is running and helium coolant flows accordingly, the temperature of the TBM-set will drop instantly.

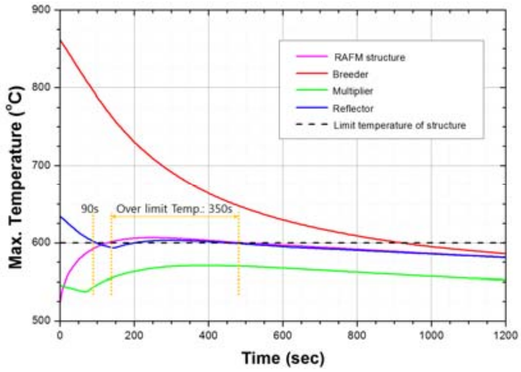
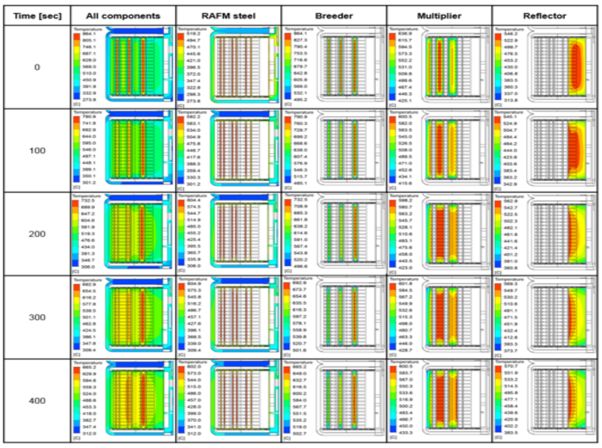
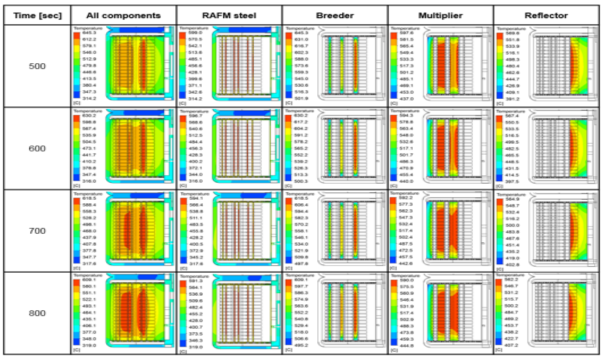


Fig. 2. Temperature evolution at each TBM component

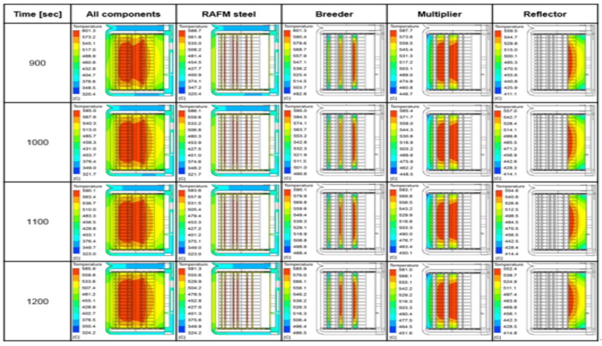
Figure 3 shows where the maximum temperature region of each material occurs in 100 second increments on the cross section of TBM. The breeder is the component with the highest temperature in its initial state. Breeder continues to transfer its heat with the multiplier and the RAFM steel in contact with each other. At the 1200 second point, the maximum temperature of the three materials becomes equal. In the case of the Multiplier, the heat is transferred to the RAFM steel which is in contact because the temperature of the multiplier is higher than that of the RAFM steel at the initial state. However, after the temperature of the RAFM steel is higher than the multiplier, the tendency of the temperature change for the multiplier is same with the RAFM steel. In the case of the reflector, the value of the rising temperature is small because there is no direct contact with the breeder and the generated decay heat is small.



(a) Time range: 0 ~ 400 second



(b) Time range: 500 ~ 800 second



(c) Time range: 900 ~ 1200 second

Fig. 3. Time-temperature history of TBM components

Table 3 shows the power required for each component to increase temperature 0.01 degree. The physical and thermal properties of the 500 ^{o}C for the materials were used in the calculation [4]. It was confirmed that the relatively small value of the decay heat occurred at all times. These values of the decay heat do not have a significant effect on raising the temperature of each component. The initial temperature of the contacting components is an important factor to determine its own temperature after the loss-of-flow accident.

Table 3. Power density to raise the 0.01 degree for material

	Power density [W/cm^3]
RAFM steel	5.35E-02
Breeder	3.06E-02
Multiplier	3.19E-02
Reflector	1.73E-02

4. Conclusions

Transient thermal analysis of HCCR-TBM was performed for the LOFA induced by LOOP accident. The maximum temperature of the RAFM steel is kept below 600 oC for 90 s. The maximum temperature of the structure was analysed as 610 oC over the design limit during 350 s even considering no operation of the IP circulator. The degradation of the mechanical properties is unlikely to occur at the LOFA due to the relatively low maximum temperature and the short duration time.

Acknowledgment

This work was supported by the R&D Program through the National Fusion Research Institute (NFRI) funded by the Ministry of Science and ICT of the Republic of Korea (NFRI-IN1703)

REFERENCES

[1] M.Y. Ahn et al., HCCR-TBS Conceptual Design Description (QQ2R5R v1.0), 2014
[2] D.W. Lee et al., HCCR-TBS CD Thermal-hydraulic Analysis Report for TBM-set (QQ3KQS v1.0), 2014
[3] ANSYS 17.0, 2016, User Manual, ANSYS
[4] D.W. Lee et al., HCCR-TBS Material Data Summary for the Design and Analysis of CDR (QABFQ5 v1.0), 2014