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Simulation Results of High Heat Flux Test Conditions for ITER Neutral Beam Duct Liner Mockup

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1. Introduction

An ITER Neutral Beam Duct Liner (NBDL) is located inside the NB port structure of a vacuum vessel (VV). The main functions are to protect the port wall from the high-power neutral beam, to limit the beam dimension, to contribute to the radiation shielding of the TF coil, and in particular, to provide a higher cooling performance [1,2]. The NB liner consists of two main components, the neutron shield of the double wall structures with cooling paths, and the cooling module utilizing copper alloy as a heat-sink material. In Korea, as a procurement country for NBDL, to verify the manufacturing processes of the cooling module of the ITER NB duct liner, simplified full-scale mock-ups with 6 holes have been fabricated and we have prepared a high heat flux test for verifying the cooling and instrumentation performance, in which 4 types of thermocouples will be installed and their measurement capability tested through a high heat flux test. In order to determine the optimized test conditions and thermocouple locations, a thermal-hydraulic analysis was conducted considering the neutron beam profile in the previous study [3].

In the present study, we performed the analysis with ANSYS-CFX and make optimum test matrix to negotiate the reduced test sets proposed by ITER Organization (IO), which have 8 test sets currently.

2. Review of the ITER operation conditions and IO proposed test conditions

From the contract document by IO [4], reference analysis was reviewed. IO analysis shows the maximum temperature of duct liner is 248 ^oC when using the following operation conditions;

- power density profile with peak : 1.5 MW/m^2
- no coolant simulation : HTC 30 kW/m^{2}K
- assuming 100 ^oC and 3MPa water coolant
- heat flux 1.5 MW/m^2 with volumetric heating of 5 MW/m^3

Considering the ITER operation conditions in NBDL, IO proposed 8 sets of test as shown in Table 1. In every test set, heat fluxes and transient heating time were proposed for 0.1, 1.0, and 2.2 MW/m^2 and for 1, 10, and 60 sec, respectively. Only one set without selected area consists of 9 tests as shown in Table I. And the total number of test is 297 and it will take about 11 weeks including mockup installation and heat flux calibration. It is required to reduce the test matrix to show the similarity between the proposed test by the simulation.

Table I IO proposed test conditions for NBDLM.

		heat flux [MW/m2]				
	heating time [sec]	0.5	1	2.2	Subtotal	remarks
Test 1	1	1	1	1	3	entire heating
	10	1	1	1	3	
	60	1	1	1	3	
Test 2	1	20	20	20	60	selected area
	10	20	20	20	60	heating
	60	20	20	20	60	
Test 3	1	4	4	4	12	selected area
	10	4	4	4	12	heating
	60	4	4	4	12	
Test 4	1	4	4	4	12	selected area
	10	4	4	4	12	heating
	60	4	4	4	12	
Test 5	1	1	1	1	3	entire heating
	10	1	1	1	3	
	60	1	1	1	3	
Test 6	1	1	1	1	3	entire heating
	10	1	1	1	3	
	60	1	1	1	3	
Test 7	1	1	1	1	3	entire heating
	10	1	1	1	3	
	60	1	1	1	3	
Test 8	1	1	1	1	3	entire heating
	10	1	1	1	3	
	60	1	1	1	3	
	Subtotal	99	99	99	297	

3. Simulation results for the proposed test conditions

To simulate the test conditions, a preliminary analysis with ANSYS-CFX was performed. The mockup has 6 holes for cooling with a 23 mm diameter and 40 mm pitch. The U-shaped mockup has a bending angle of 170 mm in the center and 270 mm in width. The heated length is 220 mm. These dimensions were used for redrawing the CATIA model and draft. Since there is one inlet and one outlet for the coolant, the coolant was also modeled in CATIA for thermal-hydraulic analysis with ANSYS-CFX. Using the developed CATIA model, hexa meshes were produced with ICEM-CFD as shown in Fig. 1, in which the numbers of elements were 215,265 and 306,198 for a solid and fluid, respectively. In Fig.2, the CFX-pre was also shown including monitoring point considering the thermocouples location.

Since the temperature measurement and cooling is important in this simulation, the KAERI coolant system (0.5 kg/sec flow rate, 0.2 MPa pressure, and 100 ^oC temperature of water) was considered. And IO proposed test conditions for heat flux and heating time were changed as shown in Table II.

Table II Simulation conditions for ITER NBDLM.

Test matrix		Surface heat flux [MW/m²]							Remark
		0.5	1.0	1.2	1.3	1.4	1.5	2.2	
Duration time [sec]	20 sec duration 1 sec heating / 19 sec cooling								Time step 0.1 sec Data interval 0.2 sec
	60 sec duration 10 sec heating / 50 sec cooling								Time step 0.5 sec Data interval 1 sec
	120 sec duration 60 sec heating / 60 sec cooling								Time step 1 sec Data interval 5 sec

In order to find the proper heat flux conditions for wall temperature of 250 °C, additional heat fluxes from 1.2 to 1.5 MW/m^2 were simulated.

From the analysis with the uniform profile heat flux cases, the wall temperature was about 400 °C and it is too higher than the ITER operation conditions. Therefore, the heat flux should be reduced. From the analysis with 1.5 MW/m^2 heat flux, the temperate distribution became similar to the target value as shown in Fig. 2.

A similar result was obtained with Gaussian profile heat flux cases. And the reduced heat flux was also 1.5 MW/m^2, as shown in Fig. 3. Morever, if we consider the selected area heating like test sets 2 to 4, the temperatures were below target value as shown in Fig. 4, the heat flux should be increased. However, the entire heating can produce the proper temperature and reduce the testing time.

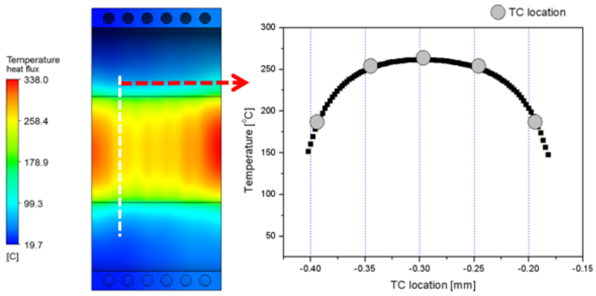

Fig. 2 Temperature distribution with uniform heat flux of 1.5 MW/m^2.

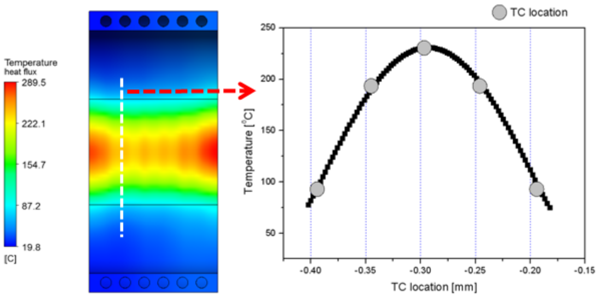

Fig. 3 Temperature distribution with Gaussian heat flux of 1.5 MW/m^2.

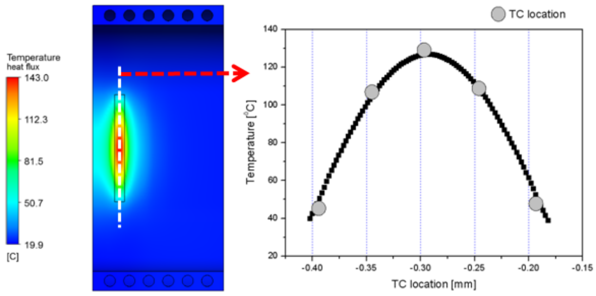

Fig. 4 Temperature distribution with Gaussian heat flux of 1.5 MW/m^2 in selected area.

3. Conclusion

In order to determine the ITER NBDL mockup test conditions, the proposed conditions by IO were simulated using ANSYS-CFX. The proposed heat flux of 2.2 MW/m^2 seems to be too high considering the actual ITER operation conditions and 1.5 MW/m^2 heat flux shows a similar wall temperature in both uniform and Gaussian profiles. Moreover, the simulation for the selected area heating shows that the temperatures were below target value. It can be concluded that the entire heating can produce the proper temperature and reduce the testing time.

In KAERI, a new electron beam facility will be installed by the end of June 2012, including a trial operation, which can produce about a 10 MW/m^2 heat flux. In addition, an NBDL mockup will be tested in the late 2012.

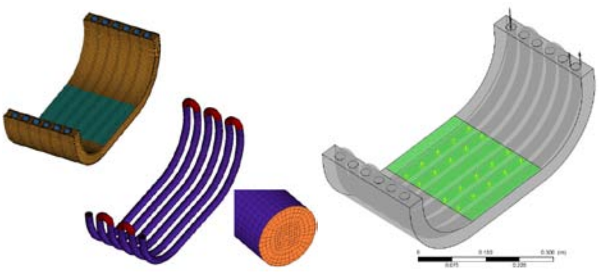

Fig. 1 Hexa meshes for simulation (solid and fluid) and CFX-pre.

References

[1] ITER Vacuum Vessel Design Description Document (DDD15), G 15 DDD 4 R0.2, 2004.
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