Korean Nuclear Society Virtual Autumn Meeting 2020
December 16-18, On-line

Mechanical Analysis of Single Load for HCCR TBM-set at Preliminary Design Phase 3

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(P09B13)

ABSTRACT: Korea has designed a helium cooled ceramic reflector (HCCR) test blanket module (TBM) including the TBM-shield, which is called the TBM-set, to be tested in ITER. This design is in progress with the preliminary design phase 3 (PD-3) in which the manufacturability was preferentially considered. This TBM design proceeded from PD-2 to PD-3 at preliminary design phase with some major changes. The engineering analysis were performed to confirm structural integrity of TBM-set with estimated loads in ITER operating conditions. Thermal hydraulic analysis was performed according to TBM operating conditions, and the results were used as input data for thermal load in structural integrity analysis. Gravity, thermal load and electromagnetic load were used for structural integrity for each single load. The structural integrity assessment was performed based on the design criteria of RCC-MRx. The criteria for structural integrity of the TBM-set is satisfied.

Introduction

- The HCCR TBM-set consists of TBM and TBM-shield
  - The TBM is composed of four sub-modules and a common Back Manifold (BM).
  - The associated shield (TBM-shield) is a water-cooled 316L(N)-IG block with internal cooling channels, cooled by ITER FW/BLK-PHTS as the main ITER FW and Blanket.
- Main design parameters and materials were as follows
  - Each sub-module consists of FW, BZ, and SW
  - BZ consists of 7 layers considering efficient tritium breeding and temperature requirement; 3 breeder layers, 3 multiplier layers and one reflector layer
  - HCCR-TBM has an unique concept of graphite reflector to be located at the last layer considering the maximized nuclear efficiency
    - Reduce Be amount
    - Decrease of cost
    - Comparable nuclear performance

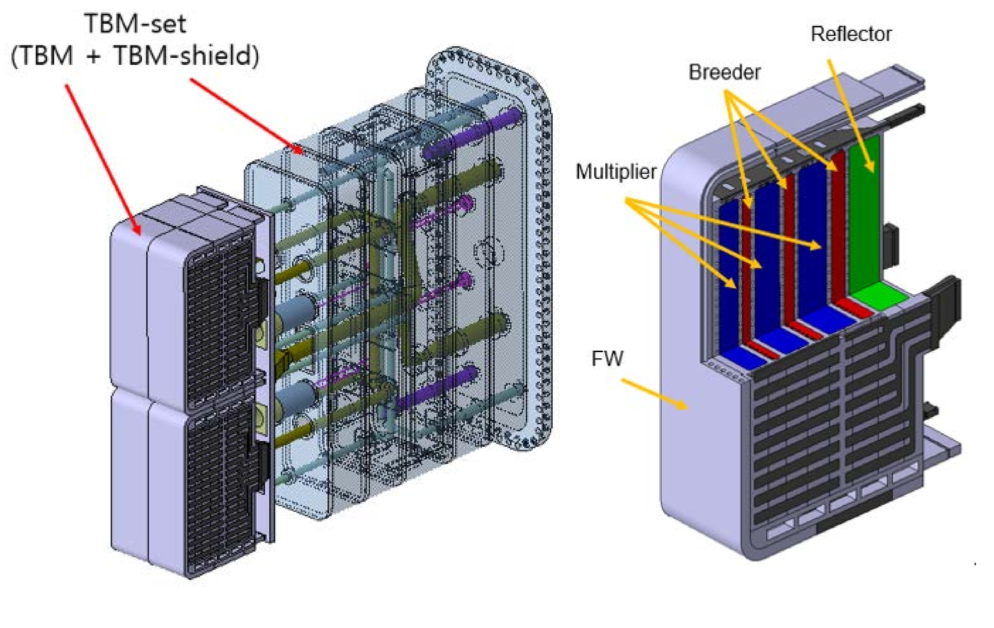
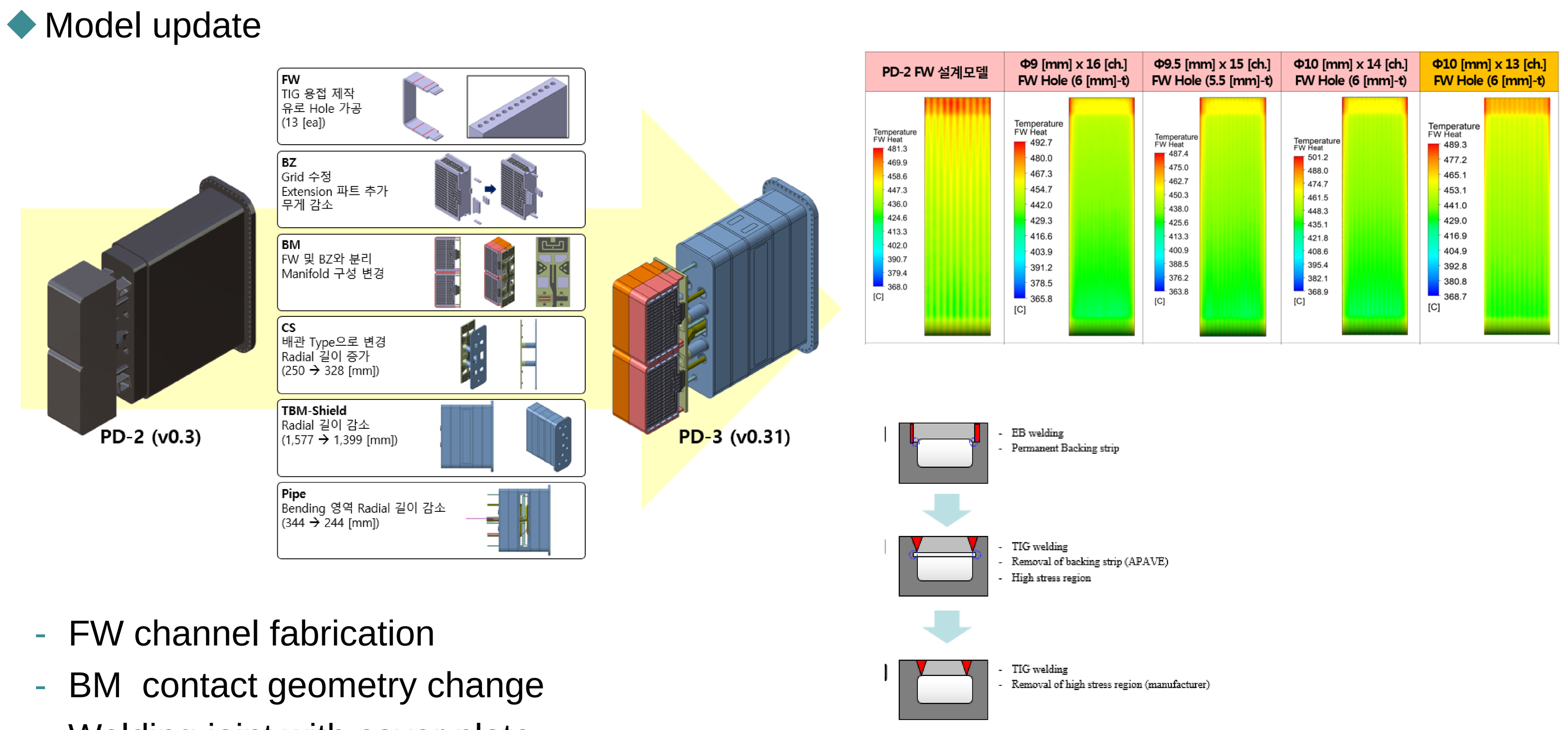


Fig.1 HCCR TBM-set configuration at PD-3 phase

Parameters	Values
FW heat flux	0.3 MW/m^2
Neutron wall loading	0.78 MW/m^2
Thermal power	0.98 MW
Structural material	KO-RAFM steel (ARAA)
Breeder	Li_2TiO_3
Multiplier	Be
Reflector	Graphite
Size	1670mm(P) x 462mm(T) x 549mm(R)
Coolant	8 MPa He, 1.14 kg/sec (300°C inlet, 466°C outlet)
Purge gas	0.1 MPa He with 0.1 % H_2 (20°C inlet, 450°C outlet)

PD-3 model

- Model update



- FW channel fabrication
- BM contact geometry change
- Welding joint with cover plate

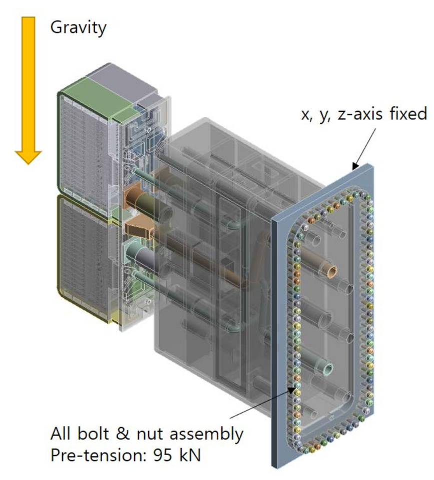
Load combinations (LCs)

Cat	LC No.	States	Load conditions	Initiating event	# of events
I	2	Operation, Plasma-on	DW, PresO, THO, MXW, Pre-tension	-	30,000
II	7	Operation, Plasma-on + MD-II	DW, PresO, THO, MXW, Pre-tension	MD-II	700
II	18	Seismic (SL-1) + Outgassing	DW, PresOTG, THOTG, Pre-tension, MXW	SL-1	5

- DW: gravity acceleration (9.81m/s²).
- PresO: design pressures of TBM and TBM-shield are 10 MPa and 5 MPa
- THO: normal operation thermal load (surface heat flux of 0.3 MW/m^2 (INT-TBM) and nuclear heating)
- MXW: Maxwell force in the steady state of normal operation
- MD-II: Lorentz force in the downward exponential 16 milliseconds (Cat. III scenario)
- THOTG: Outgassing thermal load (TBM and TBM-shield are 500 °C and 70 °C)
- PresOTG: Outgassing pressure load (TBM and TBM-shield are 1 MPa and 4 MPa)

FEM analysis

- Modeling & constrain condition



- FEM tool: ANSYS & ICEM-CFD
- Mesh element: tetra & hexa type
- No. of elements: ~33 million
- Min. element quality: 0.101
- Avg. element quality: 0.807
- Constrain: frame fixed, bolt & nut pretension

- Material
  - ARAA material for TBM body
  - 316L(N)-IG for TBM-shield

* ARAA(Advanced Reduced Activation Alloy) : KO-RAFM steel, (Reduced Activation Ferritic / Martensitic)

Table. Physical properties of ARAA

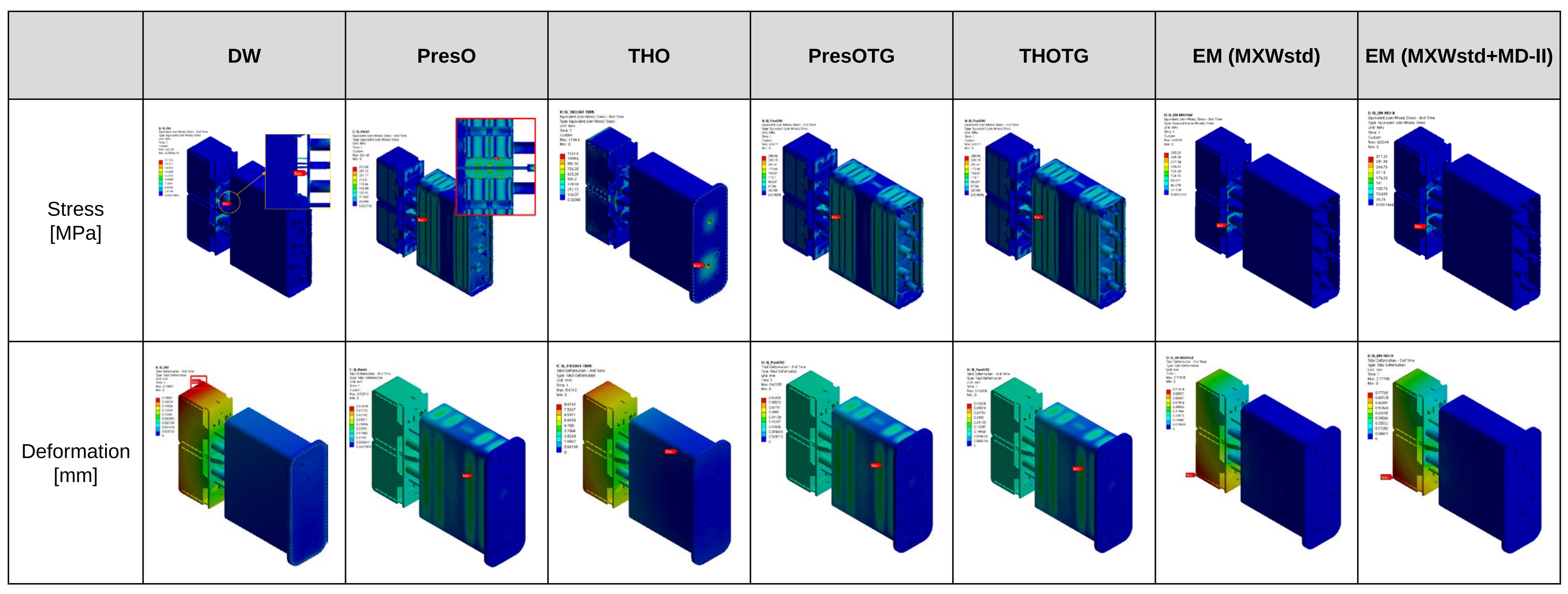
Temperature (°C)	Density ρ (kg/m³)	Thermal expansion α (10^{-6}/K)	Specific heat C_p (J/kg·K)	Thermal conductivity λ (W/m•K)	*E* (GPa)	$(R^t_{p0.2})_{min}$ (MPa)
20	7730	8.59	357	25.7	209	501
100	7708	10.10	456	27.1	201	476
200	7679	11.14	492	27.5	197	444
300	7650	11.55	527	27.4	194	432
400	7620	11.93	570	27.3	187	398
500	7589	12.30	631	27.2	167	381
600	7558	12.60	714	26.8	151	315

Table. Physical properties of 316L(N)-IG

Temperature (°C)	Density ρ (kg/m³)	Thermal expansion α (10^{-6}/K)	Specific heat Cp (J/kg·K)	Thermal conductivity λ (W/m•K)	*E* (GPa)	$(R^t_{p0.2})_{min}$ (MPa)
100	7899	15.9	501	15.48	193	172
200	7858	16.6	522	16.98	185	144
300	7815	17.2	538	18.49	176	128
400	7770	17.8	556	19.99	168	116
500	7724	18.3	578	21.49	159	109
600	7677	18.7	601	22.99	151	105

- Results
  - Maximum stress for each case is not exceed the allowable stress. Structural integrity meets for all single load case.
  - The maximum deformation is lower than the allocated gap requirement for all case.

Event Cat.	Single loads	Max. von Mises stress [unit : MPa]	Max. stress location	Deformation [mm]
I	DW	21.7 < $1.5S_m$	Back manifold	0.15 [mm]
I	PresO	220.5 < $1.5S_m$	Back manifold	0.54 [mm]
I	THO (INT)	562.4 < $3S_m$	BZ side	3.81 [mm]
I	PresOTG	259.0 < $1.5S_m$	TBM-Shield	0.21 [mm]
I	THOTG	527 < $3S_m$	BZ side	0.21 [mm]
I	EM (MXWstd)	280.2 < $1.5S_m$	Back manifold	0.21 [mm]
II	EM (MXWstd + MD-II)	317.2 < $1.5S_m$	Back manifold	0.62 [mm]



* Gap requirement between the TBM-set and TBM frame: The designed gaps are 9 mm gap for TBM and 7 mm gap for TBM-shield from TBM frame
* Allowable stress is calculated based on the RCC-MRx.

Conclusions

- The mechanical analysis for the single load were performed with only single load acting on the HCCR TBM-set model of the PD-3 phase. Gravity, thermal load and electromagnetic load were used for structural integrity for each single load.
- The structural integrity assessment is performed based on the design criteria of RCC-MRx. Structural integrity meets all single load case.
- The maximum deformation is lower than the gap between the TBM-set and the port frame. There is no contact of TBM-set to the port frame.

ACKNOWLEDGMENTS: 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-IN2003)

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