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Preliminary Drop Time Analysis of a Control Rod Using CFD Code

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1. Introduction

A control rod drive mechanism (CRDM) is a reactor regulating system, which can insert and withdraw a control rod containing a neutron absorbing material to control the reactivity of the reactor core. The latch type CRDM for the SMART (System-integrated Modular Advanced ReacTor) is going to be used. The drop time of the control rod in the design stage is one of important parameters for a safety analysis of the reactor. When the control rod is falling down into the core, it is retarded by various forces acting on it such as fluid resistance, buoyancy and mechanical friction caused by contacting the inner surface of the guide thimble, etc.. However, complicated coupling of the various forces makes it difficult to predict the drop behavior [1]. This paper describes the development of the 3D CFD analysis model using a FLUENT code. The single control rod of the Westinghouse 17x17 type optimized fuel assembly (W-OFA) was considered for the verification of the CFD model. A preliminary drop time analysis for the SMART with the simulated control rod was performed.

2. Analysis

One control rod assembly for SMART consists of twenty-four control rods, which are combined with the grouping plate, and the latter is connected to the CRDM by an extension shaft. Fig. 1 shows the schematic view of the drop time analysis model. A single control rod was considered for a CFD analysis model. The analysis model consisted of the control rod, the guide tube and the fluid between the rod and the tube. The guide tube had four flow holes, one drain hole, two stepped regions of the guide thimble, and the dashpot in the longitudinal direction.

2.*1 Computational Domain*

Fig. 2 shows the computational domain for a control rod time drop analysis and the 3D volume mesh. The analysis model was a single control rod and consisted of hexahedral mesh. The mesh size is 200,000 cells for the W-OFA model and 100,000 cells for the SMART model.

2.2 Analysis Method

The control rod was dropped into a guide tube by gravity. The retarding forces against the gravity of the control rod include the upstream flow of coolant and the hydraulic pressure forces resulting from forcing the coolant out of the guide tube. The analysis methods for the vertical movement of the control rod were dynamic layering method and 1 DOF analysis. These methods included mass and gravitational forces.

2.3 Boundary Condition

The control rod and guide tube were modeled as a rigid body wall condition. The flow holes and the drain hole were modeled as an open condition. When the control rod starts dropping into the guide tube, the coolant flows out through the flow holes and the drain hole. The coolant is supposed to be a compressible fluid. The contact surface between the dynamic layering zone and the stationary zone was modeled with a solution coupled interface boundary condition. Table 1 presents the geometrical dimension and the fluid condition for the analysis model of the control rod drop time.

Table 1: Geometrical dimension of the CFD model

Model	W-OFA	SMART
Rod length (L1′/L1)	1	61/100
Rod diameter (D1′/D1)	1	1
Tube length (L2′/L2)	1	31/50
Guide thimble length (L3′/L3)	1	73/100
Dashpot (I.D.′/I.D.)	1	1
Rod weight (W′/W)	1	3/5
Fluid velocity (V′/V)	1	43/100
Fluid temperature (T′/T)	1	107/100

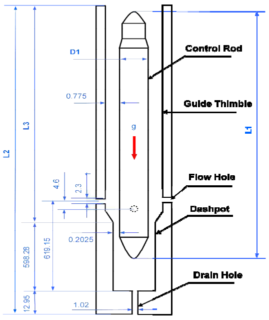

Fig. 1 Shape of the control rod

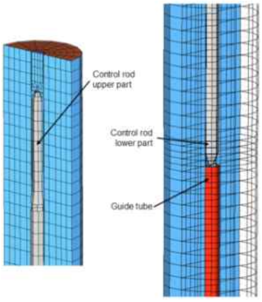

Fig. 2 Computational domain and volume mesh.

3. Results and Discussion

Fig. 3 shows the comparison of results between previously available literature and the present analysis for the W-OFA control rod model. The drop time for the verification model was 1.60s for the present 3D model, and 1.71s for the W-OFA using the 1D model. The time difference of 0.11s may have been caused by the modeling and the analysis technique between two models. However, the trend of the drop behavior was similar, and the drop behavior was greatly changed due to the decrement of the cross-sectional area in the dashpot region.

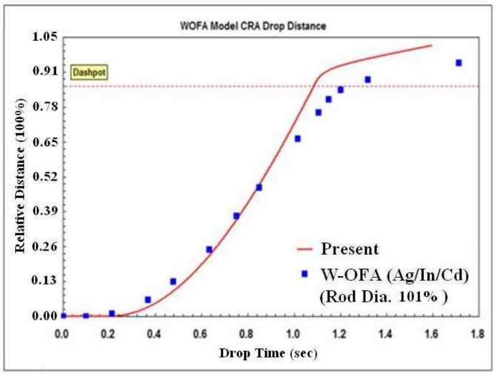

Fig. 3 Comparison of the drop behavior between present 3D and previous work for W-OFA model

The effect of control rod geometry on the drop behavior is shown in Fig 4. Two different diameters of the rod, 100 and 101 percents are considered. The drop in the guide thimble region showed the same behavior regardless of the dimensional change. However, there was a change of the behavior in the dashpot region. That is, the drop time for the 100% rod was 1.35s, and decreased by 0.25s because the pressure was decreased due to the increment of the gap between the rod and the tube.

From the above results, it is thought that the present analysis using a 3D CFD model is valid, and the model can be applicable to a preliminary drop analysis for the SMART control rod with similar geometry to that of the W-OFA model except for the length of the control rod and the dashpot.

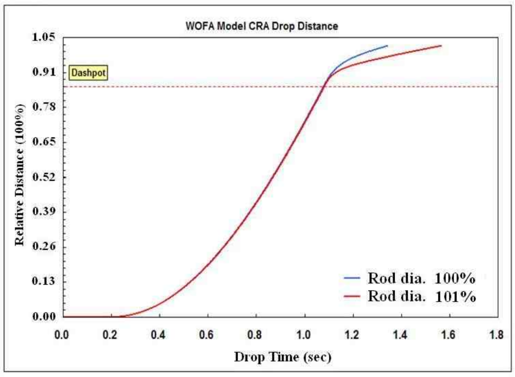

Fig. 4 Effect of the control rod diameter

The detailed design of the control rod and the guide tube for SMART is in progress. Thus, the preliminary drop analysis was performed using a similar dimension based on that of the W-OFA. The major differences between the two models as shown in Table 1 were the length of the rod and the guide thimble, the rod weight and the fluid condition. Fig. 5 shows the results of the 3D CFD analysis for the simulated SMART control rod. The drop time is shortened to 1.25s due to the reduction of the length. However, similar to the trends of the W-OFA, it was found that the velocity of the rod and the internal pressure in the dashpot region were significantly changed.

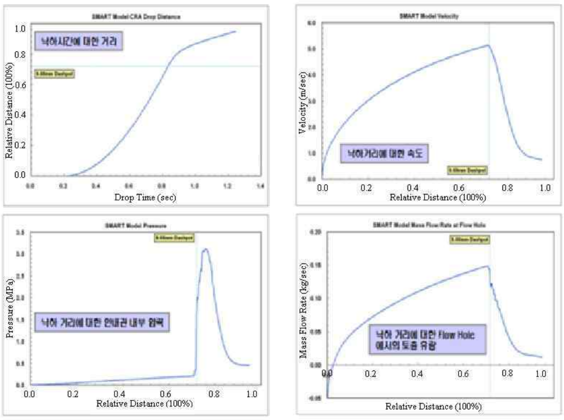

Fig. 5 Drop analysis results for SMART control rod

4. Conclusions

The preliminary drop analysis of the simulated control rod for the SMART was performed using a FLUENT code. A single control rod model of the W-OFA was used to verify the validation of the present 3D CFD model, and it was found that the drop behavior for the two models showed a good agreement with the drop time difference of 0.11s. The flow area between the control rod and the dashpot has significant influence on the drop behavior of the control rod. The drop time and the pressure with the decrement of the flow area in the dashpot region are increased, and the velocity is decreased. For the simulated SMART control rod model, the drop behavior showed the same as that of the W-OFA model except for the shortened drop time due to the decrement of the rod length.

REFERENCES

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