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A Study on the Effect of Parameters for the Control Rod Drop Time

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1. Introduction

Control rods and corresponding drive rod assemblies are held at fully withdrawn position by Control Element Drive Mechanisms (CEDMs) during power operation of the nuclear power plant. If any operation or accident event necessitates the scram, all CEDMs will release the Control Element Assembly(CEA), allowing them to drop from their fully withdrawn position to their fully inserted position. Therefore, it is essential to show that the reactor can be shut down in specified time limit for appropriate reactor operation. Another important purpose for the control rod drop time evaluation is impact analysis. It is important to show that the stresses caused by the control rod impact are below the allowable stress of PWR fuel and CEA components. The drop time and impact velocity of the control rods are affected by the various parameters in the core. In this study, the effects of the several input parameters on the control rods drop time are investigated.

2. Methods

The basic model for drop time calculation is shown in Figure 1 Control rod drop time is calculated from the acceleration caused by flow induced resistance and CEA weight. There are eight forces which are assumed to act on the CEA, extension shaft and rack. The weight of all components acts downward, the remainder of the forces act upward. Buoyant force and friction are assumed to be constant forces. The mechanism retarding force, shear and form drag in the CEA shroud, and pressure buildup force in the guide tubes and dashpots are velocity and position dependant hydraulic forces. The sum of forces was set equal to the product of the system acceleration and its mass. Using the acceleration, time dependant distance can be calculated by integration [1, 2]. Using the model described above, computer code was written and it is used for this analysis.

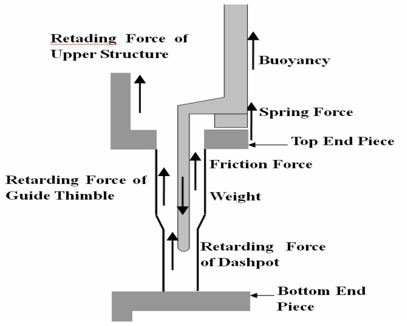


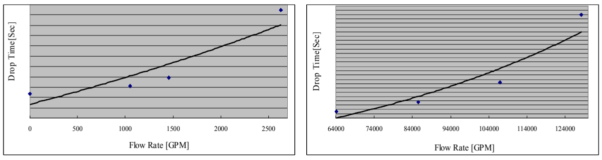
Fig. 1. Drop Time Evaluation Model

3. Results and Discussion

Several main design parameters were selected to be evaluated for the drop time sensitivity. Evaluation was performed using the computer code which was developed to calculate distance dependent control rod position. Each parameters are varied within applicable range to evaluate control rod drop time fixing the other parameters, then the control rod drop time variance are compared each other. In the figures below, one scale of vertical axis is equal to 0.1 second. Some of evaluated drop times for selected condition are compared with the measured drop times for several conditions to show the compliance.

- *Flow vs. Drop Time*

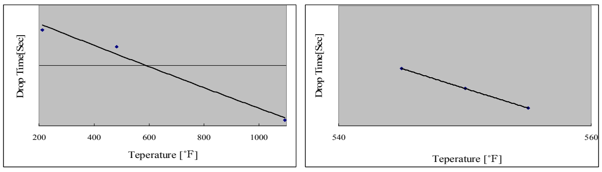
Figure 2 shows that control rod drop time increases as the flow rate increases. The measurement results from the thermal hydraulic test facility show similar tendency. Since the hydraulic flow resistance increases in proportion to the square of flow velocity, drop time become longer as the flow rate increases.



(a) Measured Drop Time (b) Calculated Drop Time
Fig. 2. Drop Time vs. Flow Rate

- *Temperature vs. Drop Time*

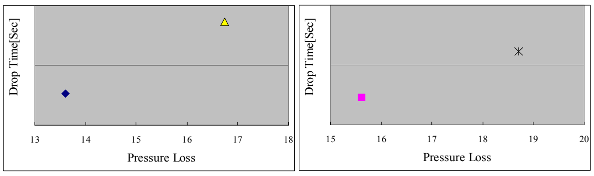
Figure 3 shows that control rod drop time is inversely proportional to the increase of the coolant temperature. The measured results from the thermal hydraulic test loop shows similar tendency. Since the hydraulic flow resistance increases with the fluid density and the fluid density is in inverse proportion to the coolant temperature, the higher coolant temperature induces the lower flow resistance and shorter control rod drop time.



(a) Measured Drop Time (b) Calculated Drop Time
Fig. 3. Drop Time vs. Temperature

- Pressure Loss vs. Drop Time

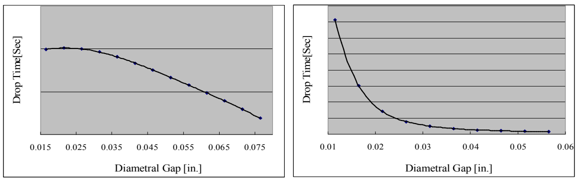
The spacer grid design also has an influence on the control rod drop time. Material of the spacer grid strap was changed from Inconel to Zirconium alloy for neutron economy and the mixing vane shape was complicated for better heat transfer for newly developed PWR fuel. As a result of those changes the projection area of the spacer grid was increased and pressure loss was also increased for the newly developed fuels. The increased pressure loss of spacer grid induces more coolant flow through the control rod guide tube and it causes the bigger flow resistance for control rods in the guide thimbles. Figure 4 shows the increase of the drop time due to the increase of the spacer grid pressure loss.



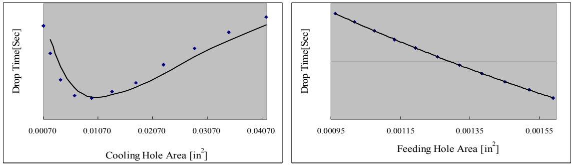
(a) 16Type Fuel (b) 17Type Fuel
Fig. 4. Drop Time vs. Pressure Loss

- Flow Passage area vs. Drop Time

The control rod drop times were calculated as the changes of the parameters defining the flow area such as diametral gap between control rod and guide thimble and flow hole area of the guide thimble. In this evaluation, the variation limits were set to the feasible range of each components. Diametral gap between control rod and guide thimble is divided into two region, the main diameter region and dashpot region. As it can be seen in the figure 5(a) and (b), the drop time change following the change of the diametral gap in the dashpot region is larger than that of the main diameter region diametral gap. The drop time change as to vary the feeding hole at bottom of the dashpot is larger than that of the cooling hole above dashpot region as shown in figure 5(c) and (d).



(a) Upper Region Gap (b) Dashpot Region Gap



(c) Cooling Hole (d) Feeding Hole
Fig. 5. Drop Time vs. Flow passage area

The differences of sensitivity are seemed to come from the fact that the dashpot region flow velocity change is bigger than that of the major diameter region for the same diametral change because of the continuity relation. With the same region, flow through feeding hole at the dashpot bottom has more effect on the control rod drop time.

- Weight vs. Drop Time

The control rod drop times were calculated as the changes of CEA weight. In this evaluation, the variation limits were set to 10 percent of nominal CEA weight. As shown in figure 6, it can be clearly understood that heavier weight results rapid drop.

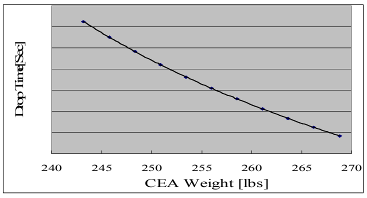


Fig. 6. Drop Time vs. CEA Weight

- Sensitivity Comparison

Figure 7 shows the normalized drop time variation for feasible range of main parameters. It can be seen that the control rod drop time is sensitive to the dashpot diameter and CEA weight change.

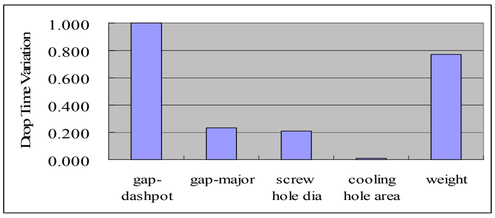


Fig. 7. Drop Variation Comparison

4. Conclusion

(1) It is concluded that among the reactor operating condition, the flow rate is most dominant factor for control rod drop time.

(2) It is evaluated that the control rod drop time is sensitive to the effects of the diametral gap change in dashpot region and CEA weight and accordingly it can be used as the tool for the drop time modification.

Acknowledgement

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REFERENCES

[1] Birkhoff, Garrett, “Hydrodynamics, a study in logic, fact and similitude”, revised edition, Princeton University Press, 1960.
[2] L. E. Idel Chick, “Handbook of Hydraulic Resistance Coefficient of Local Resistance and Friction”, 1966.