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DEVELOPMENT OF A COMPUTER PROGRAM FOR DROP TIME AND IMPACT VELOCITY OF THE ROD CLUSTER CONTROL ASSEMBLY

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ABSTRACT

In PWR the rod cluster control assembly(RCCA) for shutdown is released upon the action of the control drive mechanism and falls down through the guide thimble by its weight. Drop time and impact velocity of the RCCA are two key parameters with respect to reactivity insertion time and the mechanical integrity of fuel assembly. Therefore, the precise control of the drop time and impact velocity is prerequisite to modifying the existing design features of the RCCA and guide thimble or newly designing them.

During its falling down into the core, the RCCA is retarded by various forces acting on it such as flow resistance and friction caused by the RCCA movement, buoyance mechanical friction caused by contacting inner surface of the guide thimble, etc. However, complicated coupling of the various forces makes it difficult to derive an analytical dynamic equation for the drop time and impact velocity.

This paper deals with the development of a computer program containing an analytical dynamic equation applicable to the Korean Fuel Assembly (KOFA) loaded in the Korean nuclear power plants. The computer program is benchmarked with an available single control rod drop tests. Since the predicted values are in good agreements with the test results, the computer program developed in this paper can be employed to modify the existing design features of the RCCA and guide thimble and to develope their new design features for advanced nuclear reactors.

I. Introduction

Rod Cluster Control Assembly (RCCA), which controls the power of fuel assembly (FA) by means of control rod drive mechanism, falls down into the guide thimble of FA by its own weight to shutdown the reactor. At this moment the drop time and the final impact velocity of RCCA on the top of FA must be strictly controlled in views of reactor safety shutdown and mechanical integity. For the safe shutdown point of view, it is desirable that the RCCA drop as fast as possible, which results in high impact on the FA that may deteriorate the mechanical integrity of FA. Thus the drop time and the impact velocity should be compromised within a certain limits.

Very often the change of parameters which are affecting the drop time and impact velocity might occurr in consequence of the change of RCCA or dimensions of guide thimble. In this case the drop time and the impact velocity must be evaluated carefully by test or analyticcal method whether these values fall within the specified limit. Thus this paper deals with the modelling of drop of the RCCA and the program which predicts the drop time and impact velocity of it on the fuel assembly, especially for the Korean fuel assembly. Most of the data herein used are quoted from 17 x 17 KOFA because this type of FAs is widely prevalent in Korea and the potential of change in geometries is highly expected.

The comparison of the calculated results with the test results shows that this program can be used for the prediction of rod drop and impact velocity for Korean fuel assembly.

2. Equation for the Modelling of RCCA

When the control rod drop by its own weight it is exerted various kinds of retarding forces which deter its drop velocity, consequently it will increase the drop time. Those retarding forces are fluid drag forces, friction between control rod and guide thimble and buoyance force as in Fig.1. The fluid drag forces comprises fluid drag on the control rod tip, pressure force in the guide thimble and fluid friction.

Considering those resultant forces the equation of motion of control rod can be formulated as :

$$\sum F = mx'' = W - F_{BUOY} - F_{FRIC} - F_P - F_{SPRING}. \quad \text{-------- -- (1)}$$

where W : Weight of RCCA

F_{BUOY} : Buoyance of RCCA

F_{FRIC} : Mechanical friction force between control rod and guide thimble

F_P : Pressure on the control rod tip

F_{SPRING} : Force exerted by retainer spring after contact.

The pressure is the product of the pressure on the control rod tip in the guide thimble and the cross sectional area of the control rod.

The other two equations are pressure and continuity equations. The pressure relation between the top of guide thimble and cooling hole is

$$P_3 - P_{EX} = K_A * \rho/2 *(V_{GT/CR} + dX/dt)V_{GT/CR} + dX/dt, \quad \text{----- (2)}$$

and for cooling hole to transition of dashpot;

$$P_5 - P_3 = K_B * \rho/2 * (V_{DT} + dX/dt)V_{DT} + dX/dt, \quad \text{- - - - - - - - -} \ (3)$$

for transition of dashpot to control rod tip;

$$P - P_5 = K_C * \rho/2 * (V_{DT} + dX/dt)V_{DT} + dX/dt, \quad \text{- - - - - - - - -} \ (4)$$

where P, P_3, P_5 are the pressures at the rod tip, flow hole, dashpot locations, respectively, K_A, K_B, K_C are loss coefficients, V means flow velocity, and the subscripts GT, DT are the guide thimble and dashpot tube. The other equation is the continuity equation as

$$A_{CR} * x'_{CR} = A_{CR/GT} * V_{CR/GT} - A_{CH} * V_{CH} - A_{DH} * V_{DH}. \quad \text{- - - - -} \ (5)$$

Here, A and V represent area and velocity of the flow and the subscripts CR, CH, DH mean control rod, cooling hole, drain hole, respectively.

Because the pressure in the guide thimble at each position also depends on the external pressure of guide thimble, the pressure distribution of fuel assembly should be considered.

The equation of motion is to be solved in iterative manner due to its coupling of the motion dependent parameters such as pressure in the guide thimble and fluid friction. Thus it was solved separately in the region of guide thimble which is divided in accordance with the flow hole and dashpot positions.

3. Solution of the Equation

The mathematical drop model is programmed in FORTRAN. In the calculational procedure of the equation of motion it must be solved by numerically due to its non-linear coupling of the pressure force and fluid friction.

First of all, the pressure in the guide thimble is evaluated using the predicted linear interpolation method, and then this value is used in the next solution of the equation of motion to calculate the drop distance and velocity of the control rod.

4. Result and Discussions

Table 1 shows the comparison of the total drop time from this calcuation with that of inspection report[1]. Fig. 2 shows the comparison of impact velocity with the test results[2] which was performed to determine the dashpot effects as a function of dashpot entry velocity of control rod. This figure represents that the final impact velocity of control rod is insensitive to the dashpot entry velocity rather the gap between control rod, and dashpot is more sensitive to the impact velocity. It also shows that the predicted impact velocity well agrees with the test results. Fig. 3 shows the impact velocity as a function of dashpot entry velocity with various drain bore diameters,i.e., 1.0, 0.8, 0.0 mm. From this figure the calculation predicts well in coincidence with the test results as the dashpot length increase.

Fig. 4 shows the drop velocity of the control rod as a function of drop distance with the dimension of KOFA and Westinghouse OFA, and Fig. 5 shows the drop distance as a function of drop time. Due to the smaller diameter of guide thimble, Westinghouse OFA results in lower drop velocity than that of KOFA. Fig. 6 shows internal pressure in the guide thimble as a function of drop distance.

5. Conclusion

To predict the drop time and drop velocity of control rod during the RCCA scram, a program was developed based on the dynamic equation of motion and some fluid equations. The computer program is benchmarked with an available single control rod drop tests. Since the predicted values are in good agreement with the test results, the computer program developed in this paper can be employed to modify the existing design features of the RCCA and guide thimble and to develope their new design features for advanced nuclear reactors.

6. References

1. KORI Nuclear Unit 3 Inspection Report, KINS/AR-011, Jan.,1990
2. Schiffer, "Analysis of Control Rod Drop Test with Drainage Hole-Dashpot Effectness", U6 312/88/e86, Siemens KWU Apr.,1988

Table 1. Comparison of Drop Time at Dashpot with KORI-3 Inspection Report[2]

	Report*	This Program		Relative Deviation
	Hf/B_4C,Ag/In/Cd	Hf/B_4C	Ag/In/Cd	
Time (sec)	1.65 - 1.49	1.74	1.60	0.05 - 0.07

* Report : Values of Ref.[1]

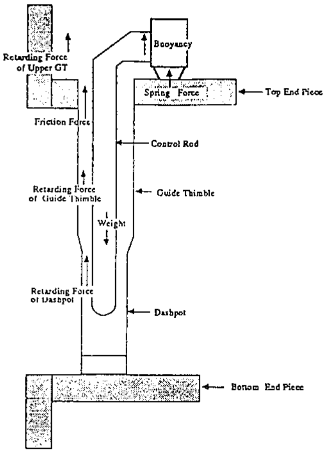

Fig. 1 Force Components of RCCA Drop

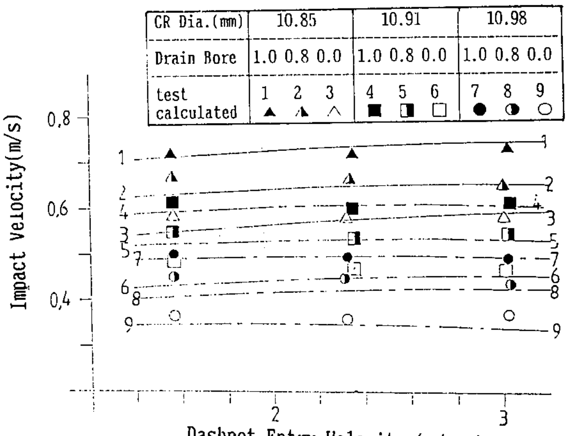

Fig.2. Impact Velocity as a Function of DT Entry Velocity

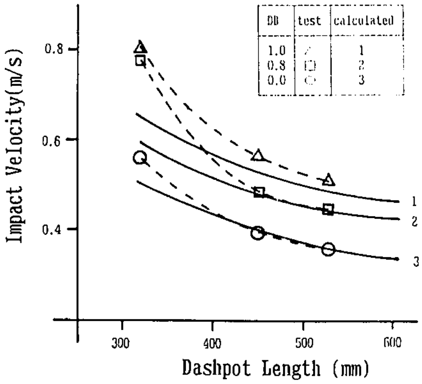

Fig.3 Impact Velocity as a Function of DT length

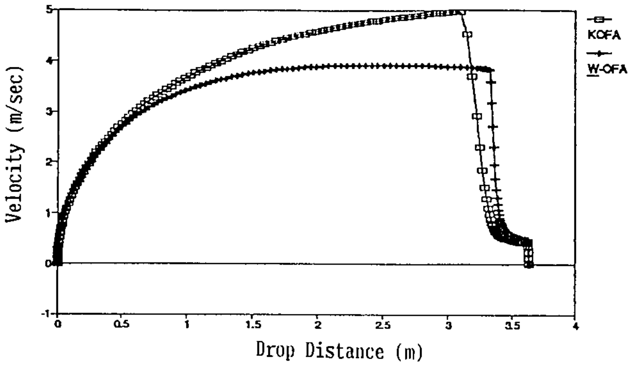

Fig. 4 Drop Velocity as a Function of Drop Distance

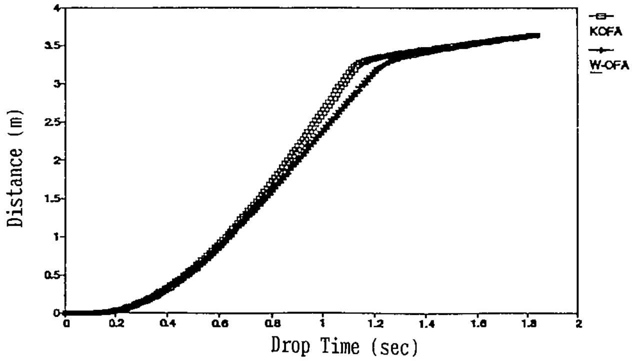

Fig. 5 Drop Distance as a Function of Time

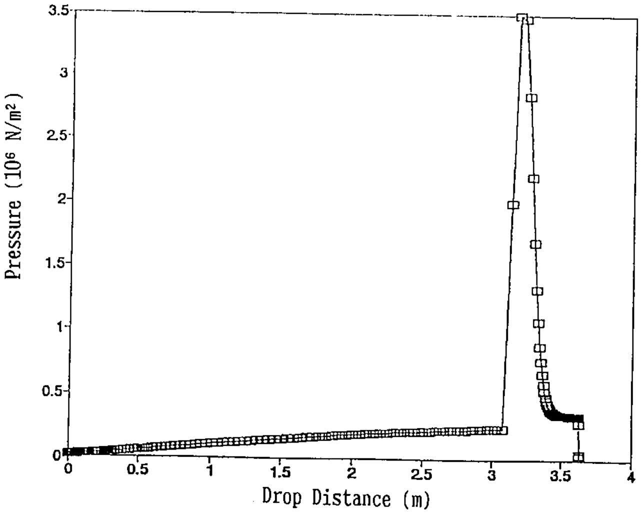

Fig. 6 Internal Pressure in Guide Thimble