Co simulation of multi-body dynamics and fluid flow for valve design in Nuclear Power Plant

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1. Introduction

Currently, pressure relief valve, check valve, air operated valve, and motor operated valve are used in nuclear power plant where the water is used as the coolant. And pressure relief valve and check valve may be used in the small modular reactor in which the sodium liquid metal is used. Pressure relief valve may be used in the small modular reactor in which the lead-bismuth eutectic is used.

But there was no serial process consisted of design, manufacturing, and functional test for the nuclear valve.

Especially, no facility about functional test reduces the research will for the nuclear power plant valve. For this problem, the test facility for the functional test of the valve and pump in nuclear power plant has been made until 2012. With the test facility, the research project related the valve were initiated in KIMM(Korea Institute of Machinery & Materials). And the joint project to SNU(Seoul National University) has been going on the numerical analysis for the valve in nuclear power plant.

The target valves are POSRV(Piolot Operated Safety Relief Valve) and CCCV(Controlled Closure Check Valve). These valves have various operation characteristics according to the clearance in which the fluid flow is occurred. But there was no active study how to change the characteristics of flow as the clearance is needed.

Especially, there was no will to the research and development because the related company is poor condition in finance. The manufacturing company used the shape and material of the valve whose intellectual property rights have been already expired. But the fast response to the change of design specification in nuclear power plant is impossible for the lack of original design technology. This difficult situation weakens the international competitiveness for the valve in nuclear power plant.

And the commercial software cannot solve this problem because the valve design problem is related to the big scale different problem between the clearance and the flow region and the moving grid. In addition to the characteristics of the problem, the co-simulation with multi-body dynamic and fluid flow makes the analysis more difficulty.

This study is on the numerical analysis in which the co-simulation of multi-body dynamics and fluid flow was performed for the valve in nuclear power plant. From the result of this study, the design technology of the valve will be given whether or not the coolant is water or liquid metal such as sodium and lead bismuth eutectic.

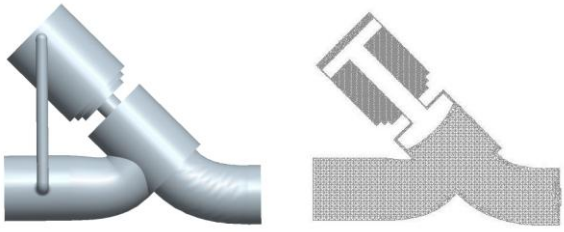
2. Methods and Results

This section shows the analytical method in which the multi-body dynamic and fluid flow are co-simulated.

Generally, the dynamic motion of the valve is expressed by the simultaneous differential equations. So the partial differential equations which express the fluid flow motion must be solved simultaneously with the simultaneous differential equations which express dynamic motion.

There is another method in which the force by the fluid flow is calculated by fluid flow analysis and applied the dynamic equations. This case is effective where the force has small change. This study uses co-simulation method where the multi-dynamic analysis and fluid flow are considered simultaneously.

The CCCV was selected for the target valve in this study. But the result may be used in the general valve design in which the flow makes effect on the motion of valve. Used shape of CCCV was showed in Fig. 1, that is the shape of the expired patent.



Source : Lift check valve with dashpot
(US05622007(1975.10.14)
Fig. 1 Shape of CCCV

Fluid flow analysis was performed by the commercial soft ware Fluent in this study. The simultaneous differential equations of the multi-body dynamics are coded in user subroutine, UDF. The result of the multi-body dynamics is used in the fluid flow analysis, computational fluid dynamics. During the fluid flow analysis, the force by the flow was calculated pressure and shear stress of the fluid. The fluid region is changed

to the motion of valve body, which makes the movement of the mesh. General moving mesh problem is possible using commercial software. But the fluid flow problem in valve has a difficulty in the region of the clearance which is very small size compared to the size of inner fluid region. So this study uses alternative method for this difficulty. The mathematic equations for the fluid flow in the clearance were applied in the user subroutine, UDF. The calculated pressure and velocity is connected to the fluid flow analysis.

The possible issues about co-simulation with the multi-dynamic and fluid flow analysis and the alternative method for the fluid flow in the clearance are that the dynamic model is accurate and that the alternative method brings to the accurate and tendentious results.

Firstly, if the multi-body dynamic model is complex, has many degree of freedoms, and has various contacts and impact model, it will be very difficult and impossible to model the valve by the hand without using the computer. But the commercial software related the multi-body dynamics has good function with which the simultaneous equations can be extracted. Using these extracted simultaneous equations, there will be no problem in modeling the complex and accurate valve.

Secondly, there will be the issue about accurate and tendentious in the alternative method to the fluid flow in the clearance. This study made effort to verify the issue of the fluid flow in the clearance. For the verification, the fluid flow analysis was performed using the general computational fluid dynamic without using the alternative mathematical method, Ant the result is compared to one which was come from the alternative method using mathematical model and user subroutine. The difference of the valve operability is compared and come to a conclusion that the alternative method is feasible method.

The problem description and boundary condition was showed in Table 1.

Table I: Problem Description and Boundary Condition

Mesh size	880,000
Material	Water
Time Step	10^{-6}sec
Viscous model	k-epsilon model
Inlet pressure	2,000,000 pa
Outlet pressure	1,000,000 pa
User Define Function	Dynamic mesh
Piston Displacement	3.685cm

The result in which co-simulation and alternative method was applied was showed in Fig 2 and Table 2. Fig 2 shows that the co-simulation leads to consistent result and that the alternative method in fluid flow in clearance has good accurate and tendency to the general continuum method, computational fluid dynamics.

If the valve was designed by co-simulation and alternative method in fluid flow in clearance and the some experiment was performed for the functional test and compensation, the development process of the valve in nuclear power plant make feasible consequence.

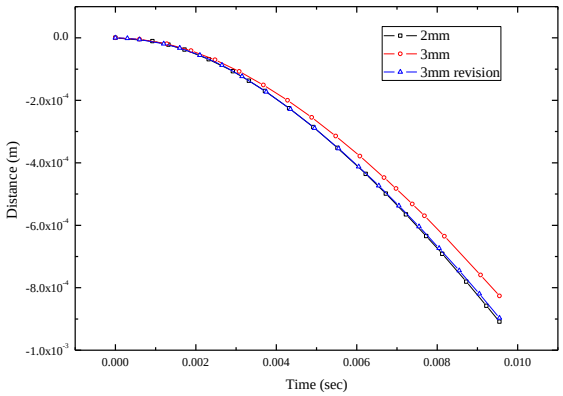


Fig. 2 Result of Co-simulation and Alternative Method in Fluid Flow in Clearance.

Table 2: Result of Co-simulation and Alternative Method in Fluid Flow in Clearance

	2mm	3mm	3mm Revision
Time(sec)	0.235	0.255	0.238
Distance(cm)	3.685	3.685	3.685
Accuracy	1	0	0.85

3. Conclusions

Co-simulation with the multi-body dynamic and fluid flow analysis was performed for the valve design in nuclear power valve. And the alternative method to the fluid flow in clearance was applied to the valve design and verified for the feasibility of the new method. The proposed method for the valve design in nuclear power plant will be feasible.

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