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Simulation of Valve Operation for Flow Interrupt Test in Nuclear Power Plant

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1. Introduction

The valve used in nuclear power plant must be qualified for the function according to the KEPIC MF. The test valve must be selected by shape and size, which is given by KEPIC MF. In the functional test, the mathematical model for the valve operation is needed. The mathematical model must be verified by the test, whose method and procedure is defined in KEPIC MF. The lack of analytical technique has lead to the poor mathematical model, with which the functional test for the big valve is impossible with analytical method. Especially, the tank and rupture disk in the flow test is not considered and the result of the analysis is so different to the real one. In these days, the 3D model for the flow interrupt test makes more accurate analysis.

And 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.

Using the commercial software and user subroutine, UDF, the co-simulation with multi-body dynamic and fluid flow analysis and the addition of tank and rupture disk to the user subroutine make possible to simulate the flow interrupt test numerically. This is not simple and regular analysis, which was introduced in user subroutine. In order to simulate the real situation, the engineering work, related mathematical model, and the programming in the user subroutine are needed.

This study is on the making the mathematical model for the functional test of the valve in nuclear power plan. The functional test is the real test procedure and defined in KEPIC MF.

2. Methods and Results

This section shows the analytical method in which co-simulation with multi-body dynamic and fluid flow analysis and consideration of the tank and rupture disk.

The schematic diagram of the flow interrupt test facility is shown in Fig. 1, whose method and general procedure is defined in KEPIC MF.

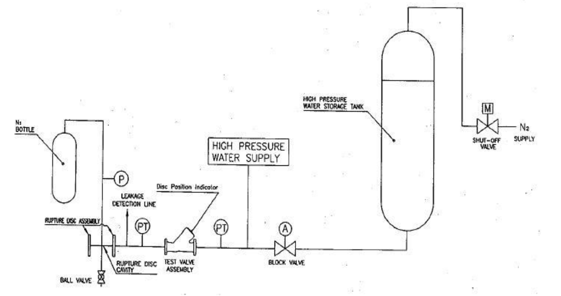
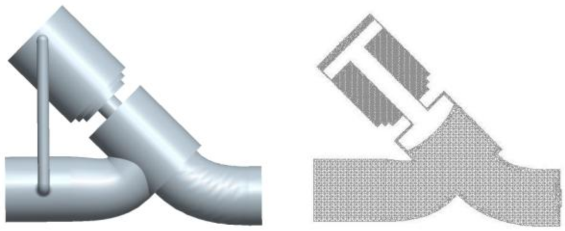


Fig. 1 Schematic diagram for the flow interrupt test.

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. 2, that is the shape of the expired patent.



Source : Lift check valve with dashpot
(US05622007(1975.10.14)
Fig. 2 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.

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.

Until now, the tank was simply modeled as the constant pressure condition. But the real pressure at the tank was changed during the flow interrupt test. So the mathematical model was performed for the tank. The upper part of the tank is nitrogen gas, which gives high pressure and the lower part of the tank was water. During the test, the thermodynamic property of nitrogen gas is changed by the state equation. This equation is programmed in the user subroutine, UDF. The pressure applied to the pipe of the valve is calculated by addition of nitrogen pressure and the pressure by the height of water. This calculation is calculated in the middle of the fluid flow analysis and multi-body dynamics of the valve. From this process, the feasible pressure at the bottom of the tank can be applied to the fluid flow and multi-body dynamics analysis in the valve and pipe.

Additionally, the rupture disk model was applied to the analysis. Until now, the rupture disk was modeled as the exit condition when the test is started. But the real situation is different to that of the analysis. As the rupture disk is destroyed, the shape of the rupture disk is different to the pressure in the tank. The size of hole in the rupture disk is increased to the pressure increase in the tank. So the flow characteristics in the rupture disk must change the valve operation in the flow interrupt test. In this study, the mathematical model for the rupture disk destruction and hole size was programmed in the user subroutine.

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	4,000,000 pa
Outlet pressure	3,000,000 pa
User Define Function	Dynamic mesh
Piston Displacement	3.685cm

The variables which can be used in the modification the mathematical model in order to simulate the real flow interrupt test are as follows.

Shape of the valve and the design specification
Height change of the water level in the tank
Pressure change of the nitrogen in the tank
Length of the pipe in the test
Hole size of the rupture disk

In this study, as the valve's mathematical model is defined, the height of water level, the pressure of nitrogen, and the hole size of the rupture disk were varied and the valve operation is compared. The result, in which the pressure of the tank is simply constant, is compared to the varying pressure from the nitrogen gas pressure. And the result, in which the rupture disk is simply fully open condition when the test is started, is compared to the varying area in rupture disk. The comparison results were summarized in Fig 3 and Fig 4.

From the Fig 3 and Fig 4, the pressure of the tank and hole size of the rupture disk makes big change in valve operation. The mathematical model, which is used in the functional test to KEPIC MF, must include the tank pressure and the hole size of the rupture disk in order to simulate the real flow interrupt test from this study.

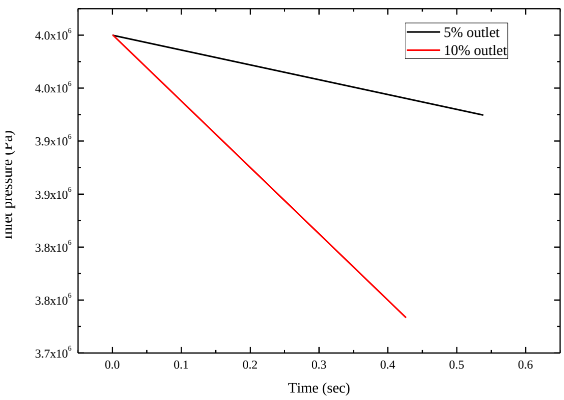


Fig. 3 Comparison of the valve operation with the change of tank pressure

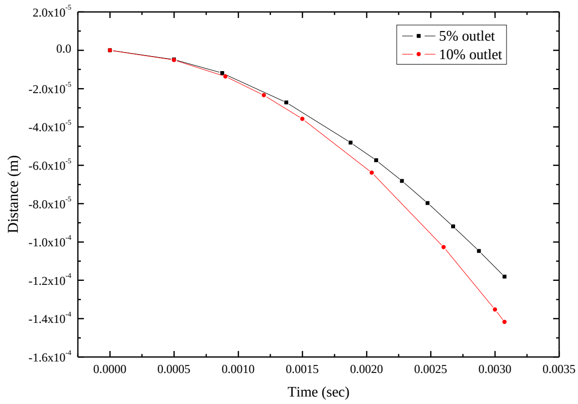


Fig. 4 Comparison of the valve operation with the change of hole size in the rupture disk

3. Conclusions

In this study, the mathematical model used in the functional test for the valve in nuclear power plant was presented. This model includes the pressure of the tank, hole size of the rupture disk, multi-body dynamic model of the valve, and the fluid flow model. The variables can be used to simulate the real flow interrupt test, whose facility and procedure is defined in KEPIC MF and ASME QME-1.

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