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A Computational Study on Hydrodynamic Torque Coefficients of a Butterfly Valve

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1. Introduction

Butterfly valves have been widely used for on-off or control purposes in the process industry, since they provide quick opening and closing operation and good flow control characteristics. For the evaluation of the adequacy of valve operability and the actuator sizing, the required torque estimation is necessary. Since the principal contributing component of the require torque in the mid-stroke position is hydrodynamic torque, it is necessary to predict the torque properly under the actual flow conditions.

The research on the prediction of the valve performance was led by EPRI (Electric Power Research Institute) in early 1990s. A performance prediction model was developed based on the experimental results and the free-streamline analysis by Sarpkaya [1]. Recently, Kalsi Engineering carried out extended tests and developed the improved model. Variation of disk geometries and upstream flow conditions were tried to obtain accurate hydrodynamic torque coefficients [2]. However, since the model is only commercially available, a general method to obtain hydrodynamic torque for butterfly valves is called for.

Application of the free-streamline theory to the thin plate valves have been attempted by some researchers [1], [3]. Ogawa and Kimura [3] proposed the prediction equation for hydrodynamic torque coefficients taking into considerations of wall effect and the valve thickness. They verified the adequacy of the equation by comparing the experimental results. One of the problems involving the hydrodynamic torque coefficient models based on the free-streamline theory is that they are applied only to symmetric disk valves. Furthermore, they could not be suited for the accurate prediction of asymmetric disk valves.

When flow tests are not possible, CFD (Computational Fluid Dynamics) methods could be an attractive alternative to estimate the hydrodynamic torque of valves. With the aid of recently developed CFD technology, a 3-D analysis for a flat plate valve was tried by Huang and Kim [4]. Recently, Leutwyler and Dalton predicted the aerodynamic torque and forces on a 2-D model in a compressible flow field [2].

In spite of the industrial interest for the valves, there are few studies related to the prediction of hydrodynamic torque coefficients for butterfly valves by using the computational method. In this study, a 3-D CFD analysis is made to calculate hydrodynamic torque coefficients for butterfly valves. The analysis results are compared with the test data of Ogawa and Kimura [3].

2. Methods and Results

The valve model selected in the present study is shown in Fig. 1. The disk size of the valve is 0.25m (=D) and the aspect ratio which is defined as the ratio of disk thickness to diameter is 0.3. The upstream length and the downstream length of the pipe are 2.0×D and 6.4×D, respectively.

Numerical 3D simulations were performed with the finite volume code Fluent. A realizable k-ε model which is a variant of standard k-ε model was adopted for the turbulent calculation. The model is recommended for flows with boundary layers under separation and recirculation. For the turbulent boundary layer, the standard wall functions were used.

The calculation domain was determined as half of the entire pipe, since the flow field is symmetric with respect to the mid-plane of the pipe. The three-dimensional computational domain was constructed by tetrahedral, pyramid and prism elements. For each calculation, from 140,000 to 220,000 cells were generated. The sensitivity of the computational mesh was tested for the disk angle at 70 degree by increasing the mesh size to 2.8 times. The discrepancy between hydrodynamic torque coefficients was within 1.1%.

As shown in Fig. 2, prismatic meshes were stretched to near wall regions for the turbulent boundary layer treatment. Simulation results revealed that the maximum y^+ values near the wall were less than 280. In order to calculate the moment on the disk, disk wall was separately modeled from other zones.

The fluid passing through the pipe is water at ambient temperature. A second order upwind scheme is used for discretization. The calculations were regarded as converged when all residuals reaches below 10^{-5}.

Velocity-inlet and pressure-outlet boundary conditions were imposed at the inlet and the outlet. The inlet velocities were varied from 2 to 5m/s whish are equivalent to the Reynolds number ranging 5×10^5 to 1.25×10^6. The static pressure of the outlet was set at the atmospheric pressure. The turbulence intensity was fixed to 5%. Steady-state analyses were performed at discrete disk angles in 5-10 degree increments.

Figures 3 and 4 illustrate the pressure contour of the disk front at opening angles of 50 and 60 degrees, respectively. Here, when a disk is placed at a fully open position, the disk opening angle is defined as 90 degree. The inlet pressures of both cases are comparable, i.e., 32,273 Pa for 50 degree and 30,653 Pa for 60 degree. In both figures, the pressure of the upstream side which is shown in the left side of the disk is higher than the downstream side. From this fact, it is presumed that the flow assists the valve closing. Another to be noted is that the higher pressure is acting on the disk at 60 degree than that at 50 degree. Additionally, the pressure difference of the left and right sides is larger for the 60 degree case. This means that hydrodynamic torque of the disk at 60 degree is also larger than that at 50 degree.

The hydrodynamic torque coefficient practically used for valve sizing is defined as

$$C_t = \frac{Tq_{hyd}}{D^3 \times \Delta P}$$

where,

C_t = hydrodynamic torque coefficient, dimensionless

Tq_{hyd} = hydrodynamic torque, N·m

ΔP = differential pressure, Pa

For the estimation of hydrodynamic torque coefficients in the present analysis, the hydrodynamic torque on the disk is calculated first. Using the inlet and outlet pressures, the above coefficients are obtained. In Fig. 5, the experimental data of Ogawa and Kimura [3] and the estimates of hydrodynamic torque coefficients are presented. One of important facts to be found in the figure is that the present predicted result by utilizing 3-D CFD technique is more conservative than the experimental result. It is presumably related to the difference in the pressure prediction and the actual pressure distribution around valves. From the present result, it could be concluded that the CFD analysis a way to assure a margin in the actuator sizing.

3. Conclusion

In the present study, a 3-D CFD analysis is performed to acquire the hydrodynamic torque coefficients for butterfly valves. The pressure distribution around the valve disk at disk angles of 50 and 60 degrees is examined, since the pressure is supposed to be a primary influential factor in the hydrodynamic torque on the valve. Additionally, comparison of the hydrodynamic torque coefficients from the present analysis and the test data is made. It is revealed that the predicted coefficients obtained from the present simulation is more conservative that the experimental data.

REFERENCES

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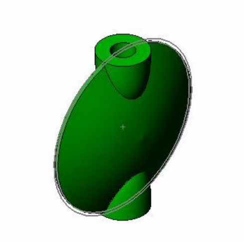

Fig. 1 Shape of the Valve Model

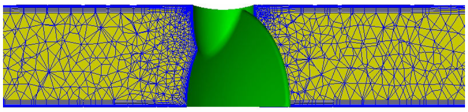

Fig. 2 Computational Mesh

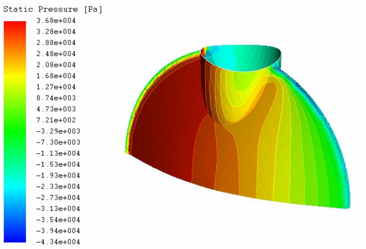

Fig. 3 Pressure Distribution at the 50 Degree Open

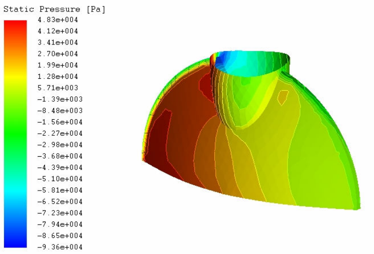

Fig. 4 Pressure Distribution at the 60 Degree Open

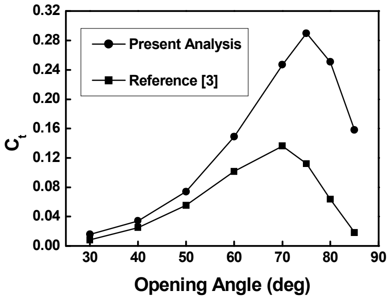

Fig. 5 Hydrodynamic Torque Coefficients