Required torque comparison of the performance prediction and the dynamic diagnostic test for motor-operated butterfly valves in nuclear power plants

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1. Introduction

To ensure the design-basis operability of safety-related Motor-Operated Valves(MOVs) in Nuclear Power Plants(NPPs) and meet the requirements of In-Service Testing regulation specified in Nuclear Safety Security Commission issue 2016-14, design basis performance evaluation has been performed. Design basis performance evaluation includes the methods of Design Basis Review(DBR), diagnostic test under both static and dynamic conditions, performance prediction and final operability evaluation considering DBR and test results. DBR consists of evaluation process for system design-basis analysis, required thrust/torque analysis, degraded voltage analysis, weak link analysis, actuator performance analysis and design basis operational margin analysis[1].

The safety-related MOVs consist of gate, globe and butterfly valves. Especially, 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[2]. This study describes the required torque calculation method and the required torque comparison of the performance prediction and dynamic diagnostic test results of butterfly valves.

2. Methods and Results

2.1 Required torque calculation method

2.1.1. Total seating/unseating torque(T_{TS})

The total torque required to seat or unseat the valve disc(T_{TS}) is the sum of four components(seat torque(T_s), bearing torque(T_b), packing torque(T_p), hydrostatic toque(T_h))[3].

$$T_{TS} = T_s + T_b + T_p + T_h \quad \text{(ft-lbf)} \tag{1}$$
$$T_s = \frac{1}{12} \times A \times d_{disk}^2 \tag{2}$$
$$T_b = \frac{1}{12} \times \mu_b \times A_{disk} \times \Delta P \times \frac{D_s}{2} \tag{3}$$
$$T_h = \frac{\pi\rho}{64} \times \left(\frac{d_{disk}}{12}\right)^4 \times sin\varphi \tag{4}$$
$$T_p = \frac{1}{12} \times \mu_p \times \frac{\pi}{4} \times D_s^2 \times P_{pkg} \times l_p \tag{5}$$

where,
A : pressure independent seat torque coefficient(in-lb/in^2)
d_{disk} : maximum disk diameter(in)
μ_b : bearing coefficient of friction(dimensionless)
A_{disk} : disk area(in^2)
ΔP : differential pressure across the valve(psid)
D_s : stem diameter(in)
ρ : fluid density(lb/ft^3)
ϕ : stem angle relative to vertical(degrees)
μ_p : packing friction coefficient(dimensionless)
P_{pkg} : average radial packing pressure(psig)
l_p : packing length(in)

2.1.2. Total dynamic torque(T_{TD})

The total dynamic torque required to operate the valve consists of three components(bearing torque(T_b), packing torque(T_p), hydrodynamic torque(T_{hyd}))[3].

$$Opening\ dynamic\ torque,\ T_{TD} = T_b + T_p + T_{hyd} \tag{6}$$
$$Closing\ dynamic\ torque,\ T_{TD} = T_b + T_p - T_{hyd} \tag{7}$$
$$T_{hyd} = \frac{1}{12} \times C_t \times d_{disk}^3 \times \Delta P \tag{8}$$

where,
C_t : hydrodynamic torque coefficient as a function of disk angle(dimensionless)

2.2 Performance prediction

As part of the EPRI Motor-Operated Valve(MOV) Performance Prediction Program(PPP), state-of-the-art engineering methodologies(Performance Prediction Methodology, PPM) were developed to predict the thrust or torque required to operate gate, globe and butterfly valves installed in safety-related service in NPPs. To run a torque prediction, the information is needed in basic categories. The used information is specified below.

Table 1. Design basis information

Item	Valve A, Valve B	Valve C, Valve D
Safety direction	Close	Open
Valve type	Butterfly	
Valve size(in)	24	30
System method	Equivalent resistance method	
DP(psid)	102	84
Fluid medium	subcooled water	
Flow rate(gpm)	9543	17000

Table 2. Internal design information

Item	Valve A, Valve B	Valve C, Valve D
Disk type	single offset	
Disk orientation	shaft upstream	
Valve inlet diameter(in)	24.37	30.016
Disk diameter(in)	23.031	29.012
Stem diameter(in)	2.52	2.992
Disk thickness(in)	5.32	5.77
Flow coefficient (gpm/psi)	27400	39250
Bearing coefficient of friction	0.25	0.6

2.3 Required torque comparison of the performance prediction results and the diagnostic test results

Static and dynamic diagnostic tests of the butterfly valves were performed in NPPs. Using the result of static diagnostic test, performance prediction was implemented. Figure 1~4 show the comparison of total dynamic torque of the performance prediction results and dynamic diagnostic test results. If performance prediction total dynamic torque is more than the total dynamic torque of test results, the operational margin of the butterfly valve has lower margin. It means that design basis performance evaluation of the butterfly valve is assessed conservatively. It is confirmed that the PPM total dynamic torque results of valve A, B, C and D are more than the dynamic diagnostic test results due to difference of bearing friction coefficients mainly.

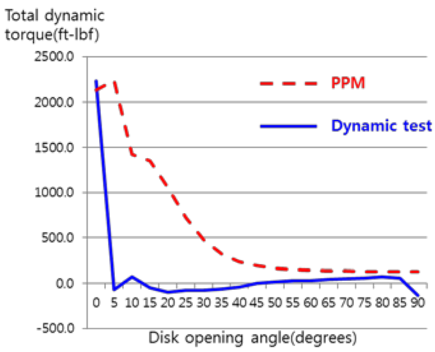

Fig 1. Valve A total dynamic torque

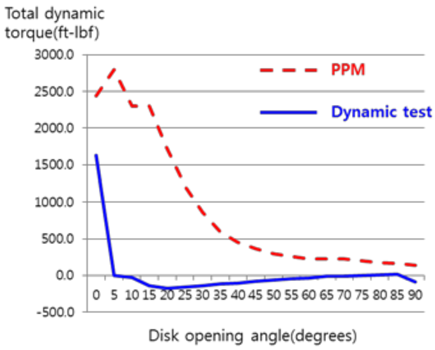

Fig 2. Valve B total dynamic torque

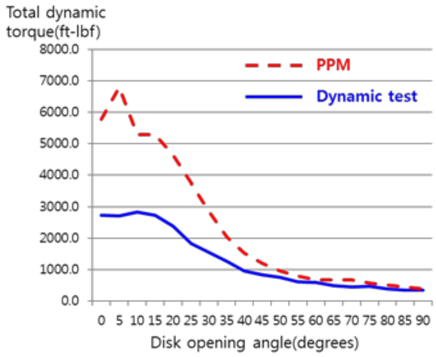

Fig 3. Valve C total dynamic torque

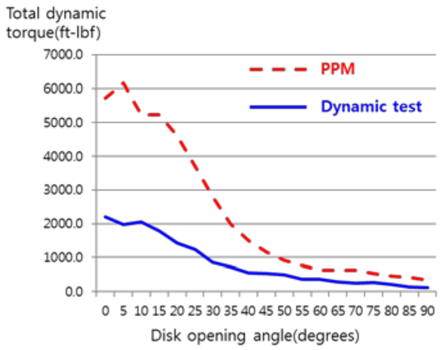

Fig 4. Valve D total dynamic torque

3. Conclusions

This study describes the comparison with performance prediction results and dynamic diagnostic test results of butterfly valves. The results of PPM have been compared with test data for motor-operated butterfly valves in NPPs. With the review of test data and torque prediction results, it is concluded that the prediction methodology is conservative to predict a required torque of motor-operated butterfly valves.

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