Comparison of Required Thrusts between Static Diagnostic Test and Performance Prediction for Air-Operated Valves in NPPs

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1. Introduction

Design basis performance evaluation has been performed to ensure the design-basis operability of safety-related Air-Operated Valves (AOVs) in Nuclear Power Plants (NPPs) and meet the requirements of In-Service Testing regulation specified in Nuclear Safety Security Commission notification 2016-14.

Design basis performance evaluation consists of 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 includes 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.

For some AOVs which are not applicable to diagnostic tests under dynamic conditions, an analytical method called performance prediction is used as an alternative. For performance prediction, a type of analysis program, Kalsi Valve & Actuator Program (KVAP), is used.

This study describes required thrust calculation method and comparison of required thrust between the performance prediction software (KVAP) calculation results and static diagnostic test results of gate valves.

2. Methods and Results

2.1 Required thrust calculation method

2.1.1 Total required thrust ($F_{R,open}$, $F_{R,close}$)

Total required thrust to open or close the valve disc ($F_{R,open}$, $F_{R,close}$) can be defined by packing thrust (F_{pack}), piston effect or stem rejection load (F_P) and differential pressure thrust (F_{DP}), and can be calculated as follows.

$$F_{R,open} = F_{pack} - F_P + F_{DP} \quad \text{(lbf)} \qquad (1)$$

$$F_{R,close} = F_{pack} + F_P + F_{DP} \quad \text{(lbf)} \qquad (2)$$

$$F_{pack} = \pi \times S \times D_S \times L_{pack} \times fY \quad \text{(lbf)} \qquad (3)$$

$$F_P = P_B \times A_S \quad \text{(lbf)} \qquad (4)$$

$$F_{DP} = VF \times \Delta P \times A_0 \quad \text{(lbf)} \qquad (5)$$

where,
S : diameter direction packing thrust (psi)
D_S : stem dimeter (in)
L_{pack} : packing height (in)
fY : packing friction factor (dimensionless)
P_B : bonnet pressure (psig)
A_S : stem sectional area (in^2)
VF : valve factor (dimensionless)
ΔP : differential pressure across the valve (psid)
A_0 : cross section area for differential pressure (in^2)

2.1.2 Total required thrust using static diagnostic test results

Total static thrust required to operate the valve can be defined by running thrust (F_{run}), piston effect thrust ($F_{P,DB}$) and differential pressure thrust ($F_{DP,DB}$) , and can be calculated as follows.

$$F_{R,open,static} = F_{run} - F_{P,DB} + F_{DP,DB} \quad \text{(lbf)} \qquad (6)$$

$$F_{R,close,static} = F_{run} + F_{P,DB} + F_{DP,DB} \quad \text{(lbf)} \qquad (7)$$

where,
$F_{R,open,static}$: total required thrust at opening stroke using static diagnostic test results (lbf)
$F_{R,close,static}$: total required thrust at closing stroke using static diagnostic test results (lbf)
F_{run} : running thrust (lbf)
$F_{P,DB}$: design basis piston effect thrust (lbf)
$F_{DP,DB}$: design basis differential pressure thrust (lbf)

2.1.3 Operational margin calculation

Equations for operational margins at opening stroke (M_{open}) and closing stroke (M_{close}) are as below.

$$M_{open} = \frac{F_{A,air} - F_{R,open,min}}{F_{R,open,min}} \times 100\% \qquad (8)$$

$$M_{close} = \frac{F_{A,spr} - F_{R,close,min}}{F_{R,close,min}} \times 100\% \qquad (9)$$

where,
$F_{A,air}$: Maximum available thrust limit at opening stroke (lbf)
$F_{A,spr}$: Maximum available thrust limit at closing stroke (lbf)
$F_{R,open,min}$: Minimum required thrust limit at opening stroke (lbf)
$F_{R,close,min}$: Minimum required thrust limit at closing stroke (lbf)

2.2 Performance prediction

As part of the EPRI Air-Operated Valve (AOV) Performance Prediction Program (PPP), state-of-the-art engineering software (Kalsi Valve & Actuator Program, KVAP) was developed to predict the thrust or torque required to operate gate, globe and butterfly valves installed in NPPs. To run a thrust prediction, the information is needed in basic categories. The used information is specified below.

Table 1. Design basis information

Item	Valve A, B, C and D
Valve type	Gate
Disk overall	Solid wedge
Fluid medium	Water

2.3 Required thrust comparison of the static diagnostic test results and the performance prediction results

2.3.1 Static diagnostic test results

Static diagnostic tests of air-operated gate valves were performed in NPPs. Using the results of static diagnostic tests, performance prediction for each valve was implemented. Among those results, Table 2 shows the static diagnostic test results. (The test result values are normalized based on $F_{R.close}$ and M_{close} of Table 2.)

Table 2. Static diagnostic test results (normalized values)

Item	Valve A	Valve B	Valve C	Valve D
F_{run}(lbf)	52.31	44.03	33.11	41.32
$F_{P,DB}$(lbf)	39.93	39.93	51.13	51.13
$F_{DP,DB}$(lbf)	7.76	7.76	14.99	14.99
$F_{R,close}$(lbf)	100.00	91.72	99.23	107.44
M_{close}(%)	100.00	137.63	242.37	222.37

2.3.2 Performance prediction results

Performance prediction of the air-operated gate valves was also performed. Performance prediction was carried out as an alternative to the dynamic diagnostic test. Performance prediction methodologies can eliminate unnecessary valve modification and provide an alternative to expensive dynamic diagnostic test as a means of demonstrating air-operated valve's operability.

Table 3 shows the performance prediction results using KVAP. (The test result values are normalized based on $F_{R.close}$ and M_{close} of Table 2.) Comparison of the required trusts ($F_{R.close}$) of Tables 2 and 3 shows that required trust of performance prediction results using KVAP is larger than static diagnostic test results. Generally, as the required thrust increases, the operational margin decreases.

Table 3. Evaluation results (using KVAP) (normalized values)

Item	Valve A	Valve B	Valve C	Valve D
F_{pack}(lbf)	52.31	44.03	33.11	41.27
F_P(lbf)	40.12	40.12	51.74	51.74
F_{DP}(lbf)	10.00	10.00	18.85	18.85
$F_{R,close}$(lbf)	102.44	94.16	103.70	111.86
M_{close}(%)	89.83	104.07	218.31	201.02

The difference in required trust between performance prediction and static diagnostic tests is mainly due to the differential pressure thrust difference. And the differential pressure thrust is calculated by the equation 5. The differential pressure thrust results using KVAP is larger than design basis differential pressure thrust in Tables 2 and 3. This is because valve factor applied to KVAP is larger than valve factor applied on design basis differential pressure thrust and the valve factor applied to KVAP is calculated in the software itself.

Table 4. Valve factor comparison

Item	Design basis	KVAP	
Valve No.	Valve A~D	Valve A,B	Valve C,D
Valve factor	0.5	0.634	0.635

According to NRC Generic Letter 96-05, periodic verification of design basis capability of safety-related valves should be performed. Periodic verification is verifying safety-related valves can function properly during the life of plant considering age-related valve degradations.

"Threshold Coefficients of Friction (COF)" applied at periodic verification is 0.57 for gate valves and COF can be converted to valve factor. The conversion equation is as follows.

$$Valve\ factor \cong \frac{\mu_S}{\cos\theta \pm \mu_S \times \sin\theta} \qquad (10)$$

where,
μ_S : coefficient of friction between seat and disc (dimensionless)
θ : one-half of total included wedge angle (deg)
+ sign in the denominator applies to valve opening
− sign in the denominator applies to valve closing

The Threshold COF converted to valve factor is 0.599 at valve closing stroke. Comparison of the applied valve factor between KVAP and periodic verification, the valve factor applied at KVAP is larger than the valve factor applied at periodic verification.

The larger valve factor, the larger differential pressure thrust. (Refer to the equation (5).) That is the required thrust becomes larger and the operational margin becomes smaller under the same conditions of ΔP and A_0. Therefore the performance prediction using KVAP predicts required thrust greater than static diagnostic test.

3. Conclusions

This study describes the comparison between performance prediction results and static diagnostic test results of the air-operated gate valves. The results of KVAP have been compared with static diagnostic test results for air-operated gate valves in NPPs. With the review of static diagnostic test data and KVAP results, it is concluded that the KVAP predicts required thrust of the air-operated gate valves greater than static diagnostic test.

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