Rate of Loading Effect and Sensitivity Analysis of Safety Related Active Motor-operated Gate and Globe Valve under High Differential Pressure Condition

Jin-A Jang [a*], Tae-kyung Oh [a]
[a]*Safety Assessment Department, KEPCO E&C, 269 Hyeoksin-ro, Gimcheon-si, Gyeongsangbuk-do, 39660*
jina@kepco-enc.com

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 2021-27, 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.[1] The operating performance of MOVs which is the final evaluation result is related to the performance of motor and actuator components. The major performance factors are valve factor, stem factor, rate of loading(ROL), etc.[2]

This study describes the rate of loading effect and sensitivity analysis of safety related active motor-operated gate and globe valve under high differential pressure.

2. Methods and Results

2.1 ROL phenomenon

Nuclear power plant experience and laboratory testing have shown that valves with rising stems and motor-driven operators could be susceptible of differences in the relationship between operator output torque and stem thrust as a result of differences in stem load time history. This phenomenon, known as the "rate of loading" effect, can affect MOVs that are set up to shut off the motor using a torque switch.[3] ROL is a phenomenon that arises by the fluid DP (differential pressure) which is generated around the valve disc during the MOV operation. In the event of ROL, the power transmitted from the actuator to the valve stem would be reduced. Since the phenomenon of ROL is not presently considered as a design parameter when designing an actuator, there is a possibility that the valve will not operate properly due to this loss of actuator power.[4]

The ROL is calculated by applying the following formula.

$$\text{ROL} = \frac{Thrust_{trip,static} - Thrust_{trip,Dynamic}}{Thrust_{trip,Dynamic}}$$

Here,
$Thrust_{trip,\ static}$: Thrust at the static condition TST
$Thrust_{trip,\ Dynamic}$: Thrust at the dynamic condition TST
TST : Torque switch trip

2.2 Results of ROL distribution

The static and dynamic tests were conducted using 31 flexible gate valves and globe valves which were installed in the nuclear power plants. The thrust and torque were measured. During the valve operation, test signals were collected from various sensors in real time. The motor current, voltage, spring pack displacement, stem location, and flow pressure were measured using these sensors.

The ROL is calculated by applying the following formula and measured results.

$$ROL_{Applied} = ROL_{i,Smax} \times \frac{\Delta P_{DB}}{\Delta P_{i,Smax}}$$

$ROL_{Applied}$: Applied ROL reflecting design basis differential pressure and ROL with maximum slope
$ROL_{i,Smax}$: i-th ROL with maximum slope
ΔP_{DB} : Design basis differential pressure(psid)
$\Delta P_{i,Smax}$: i-th maximum differential pressure(psid)

Fig.1 shows the distribution of the measured ROL for the test valves. Fig.2 shows the distribution of the applied ROL for the test valves. The Applied ROL is adjusted according the equation. Fig.3 shows the distribution of the ROL according to the differential pressure across each valve. The applied ROL is likely to increase as the differential pressure across the valve increases.

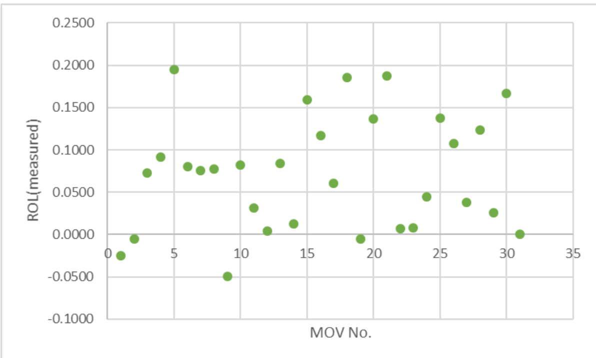

Fig. 1. Measured average ROL distribution of each MOVs.

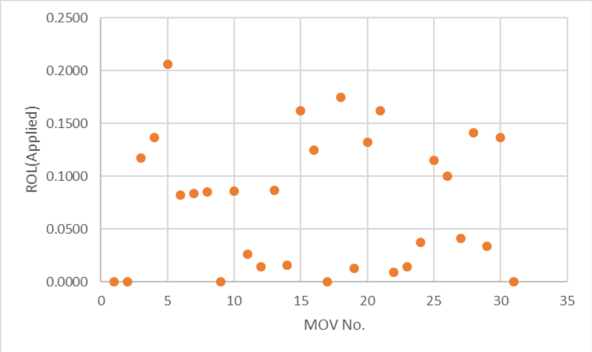

Fig. 2. Applied ROL distribution of each MOVs.

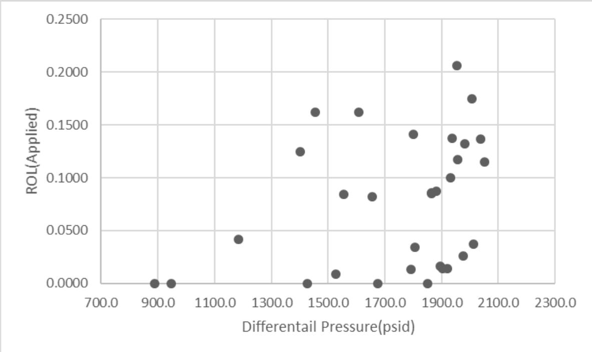

Fig. 3. Applied ROL distribution according to differential pressure across each MOV.

2.3 Sensitivity Analysis reflecting Max. ROL

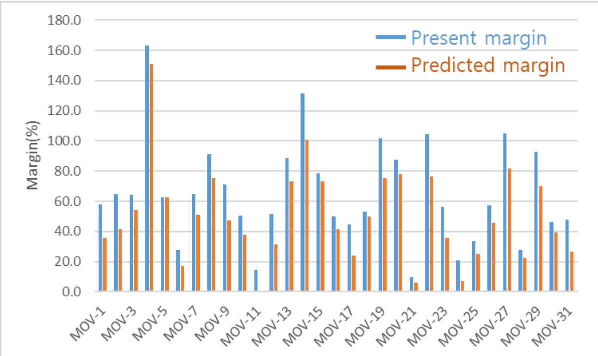

Fig. 4. Margin comparison between the present margin and the predicted margin reflecting maximum applied ROL

The applied ROL of each MOVs vary according to their own characteristic. Fig.4 shows the comparison between the present final evaluation margin and the predicted final evaluation margin. The present final evaluation margin is from actual margin of each valve using dynamic test result including applied ROL. The predicted final evaluation margins are reflected the maximum applied ROL value among 31 MOVs and the valves have positive predicted margin.

3. Conclusions

The results of study have shown that the ROL is likely to be proportional to the differential pressure conditions of the gate and globe valves. The sensitivity analysis shows 31 MOVs have positive margin reflecting the maximum ROL value. Valve manufacturer shall consider various factor including ROL in Shin-hanul 3&4 construction because ASME QME-1 2007 have the contents related to ROL and shall be applied.

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