

Causes of POSRV Leakage and Prevention Measures

Sujun Kim, Eric Yee
Kepco International Nuclear Graduate School
wowsjsj@naver.com

***Keywords : Pilot Operated Safety Relief Valve(POSRV), Leakage, Reactor Coolant System**

1. Introduction

Nuclear power plants are equipped with various safety devices to prevent overpressure in their systems. One such device is the Pilot Operated Safety and Relief Valve (POSRV), which is installed to provide overpressure protection in reactor designs such as the APR1400 and APR1000. However, frequent leakage occurrences during plant startup operations have led to regulatory concerns and significant challenges in ensuring the normal operation of nuclear power plants. Existing studies have examined the transient flow generated downstream of the valve when it opens and the detection of leakage after it has occurred, but the thermal condition imposed on the valve during startup pressurization has not been related quantitatively to the onset of seat leakage, and the pressurization process itself has not been treated as a controllable variable for leakage prevention. To address this gap, this study analyzes the causes of POSRV leakage on the basis of instrumented tests at an empirical testing facility and measurements obtained during actual plant startup, and proposes measures to prevent and minimize leakage. Ultimately, this research aims to establish an effective response to the persistent issue of POSRV leakage, contributing to regulatory compliance and the safe operation of nuclear power plants. Additionally, by managing the POSRV leakage issue proactively, this study seeks to prevent recurrence in future exports of Korean-designed nuclear power plants, thereby supporting the international deployment of these reactors.

2. Literature Review

Extensive research has been conducted on overpressure protection system in pressurized water reactors(PWRs), particularly focusing on pressure relief systems designed to prevent overpressure accidents. among these, Pilot Operated Safety and Relief Valves (POSRVs) are essential components in PWRs, tasked with maintaining reactor pressure integrity by releasing excess pressure. Their design includes a main valve (MV), spring-loaded pilot valves (SLPVs), and motor-operated pilot valves (MOPVs). To function properly, these components must ensure a tight seal during normal operation, a condition that can be difficult to maintain due to thermal and mechanical transients.

An early domestic study numerically examined the unsteady flow field generated downstream of the

POSRV at valve opening [1]. Using a shock-tube analogy and two-dimensional compressible Navier–Stokes computations, that work compared instantaneous opening with stepwise gradual opening and showed that a longer opening time attenuates the pressure rise transmitted through the moving shock and produces a milder pressure gradient downstream, thereby reducing the load imposed on the discharge piping. Its concern was therefore the structural integrity of the downstream piping during valve actuation.

A more recent study applied computational fluid dynamics to the detection of leakage once it has occurred [2]. Steady-state heat transfer analyses of the POSRV discharge lines were carried out for leakage and no-leakage cases over a range of containment temperatures, with the leak rate fixed at 0.1 gpm from a single valve. The analyses showed that such a leak raises the discharge line temperature by at least about 28 °C above the containment temperature, whereas the no-leakage discharge line temperature remains within a few degrees of it, and that temperature detectors located downstream of the first bend of each discharge line, close to the discharge nozzle, are suitable for detecting a leak of this magnitude. The study concluded that the calculated temperatures can be used to establish the leak detection alarm setpoint.

Together, these two studies [1][2] show that the POSRV has so far been examined at two distinct moments: during actuation, where the concern is the transient load imposed on the discharge piping [1], and after leakage has developed, where the concern is detecting it [2]. Neither addresses the condition of the valve during the slow thermal transient of plant heat-up, nor treats the startup pressurization process as a variable that can be controlled so that leakage does not arise. The present study therefore examines the thermal condition of the valve during pressurization, with the aim of preventing leakage rather than detecting it, and thereby complements the actuation-load and detection perspectives established by the earlier work.

3. Methods

This study employed a combination of instrumented empirical testing, field measurement, and analytical evaluation to investigate POSRV leakage. Empirical tests were conducted at a dedicated test facility in which a single POSRV was mounted on a pressurizer mock-up capable of reproducing startup conditions under

controlled temperature and pressure. The valve assembly used in the tests, consisting of main valves (MV), spring-loaded pilot valves (SLPV), and motor-operated pilot valves (MOPV), is shown in Fig. 1.

3.1. Instrumentation

Surface temperature sensors were installed upstream and downstream of the valve, at the upper and lower parts of the valve body, and at internal and external positions, so that the temperature distribution across the valve could be tracked continuously throughout pressurization. The upper–lower temperature differential and the internal–external temperature differential used in the following sections were derived from these measurements.

3.2. Leakage criteria

At the test facility, an instrument installed downstream of the valve allowed the leakage rate to be measured directly, so that the onset and the magnitude of leakage could be identified quantitatively. In the field, where direct measurement of the leakage rate is not practicable, leakage is judged from the temperature of the discharge line: the temperature instrument downstream of the valve raises an alarm when the measured temperature exceeds 60 °C, and this alarm is taken as an indication that the valve is leaking. Both criteria were applied consistently throughout this study.

3.3. Test scenarios

Four pressurization scenarios were applied, each reaching an identical target temperature and pressure corresponding to normal operating conditions but differing in pressurization duration and in the shape of the pressurization profile. Field measurements were subsequently obtained during the startup of an actual nuclear power plant in order to confirm, under plant conditions, the behavior observed at the test facility. In the field application, the selected pressurization profile was combined with vacuum venting of the upper region of the pressurizer to remove non-condensable gases.

3.4. Structural evaluation

The deformation behavior of the main valve disc under the measured thermal gradients was examined separately by structural assessment. The detailed results of that assessment are proprietary and are not reproduced here; only the qualitative conclusion relevant to the leakage mechanism is used in the discussion that follows.

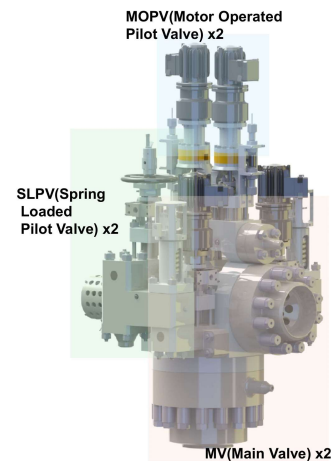


Fig. 1. Configuration of the POSRV assembly.

4. Results and Discussion

Continuous temperature measurement during the empirical tests showed a consistent relationship between the temperature distribution across the valve body and the occurrence of leakage. In the cases in which leakage was measured at the downstream instrument, the temperature differential between the upper and lower parts of the valve was large, whereas the cases in which this differential was kept low were not accompanied by measurable leakage. The internal–external differential, by contrast, remained at a similar level in all scenarios (Fig. 2) and did not distinguish leaking from non-leaking cases. The upper–lower temperature differential was therefore identified as the parameter governing leakage.

This relationship is consistent with a thermally driven deformation mechanism. A temperature difference between the upper and lower parts of the valve produces differential thermal expansion across the main valve disc, distorting the disc and its seating surface (Fig. 3). Once the seating surface is no longer uniform, the contact seal between the disc and the seat is degraded and leakage develops under operating pressure. A structural assessment performed separately for this study supports this interpretation; as noted above, its detailed results are proprietary and are not presented, and the mechanism is therefore reported on the basis of the measured temperature distribution together with that assessment.

The pressurization profile was identified as a second contributing factor. Rapid or unstable pressurization increased the likelihood of leakage where the disc had already been distorted, since the pressure load is imposed before the temperature distribution across the valve has had time to equalize. Keeping the upper–lower temperature differential low during pressurization is therefore favorable for leakage prevention, and the pressurization rate is the practical means of achieving this. The rate cannot, however, be reduced without limit. An excessively slow pressurization prolongs the startup process and results in lost generation and the associated economic penalty, while an excessively rapid pressurization increases the probability of leakage.

Selection of an optimal pressurization rate—slow enough to limit the thermal differential across the valve, yet fast enough to avoid unnecessary startup delay—is thus the practical objective.

The four scenarios were compared on this basis, as summarized in Table I. The EPRI guideline-based profile [3] produced the lowest upper–lower temperature differential, 0.58–0.79 in normalized terms, at a relative duration of 0.70; that is, it achieved a smaller thermal differential than the Plant B case in approximately 70 % of its duration, and it was selected for field application on this basis.

The advantage of the EPRI guideline-based profile lies in the shape of the pressurization curve rather than in its total duration. Instead of raising the pressure at a single uniform rate, the profile holds the pressure at several intermediate levels and reduces the ramp rate in stages as the pressure increases, so that the later and thermally more sensitive part of the heat-up proceeds far more slowly than the early part (Table 6-12 of [3]). The hold periods allow the temperature distribution across the valve to equalize before the next increment of pressure is applied, and the progressively lower ramp rate limits the differential that develops within each increment. This explains why the profile achieved a lower upper–lower temperature differential than the Plant B case despite a shorter total duration: the parameter governing the differential is the distribution of the pressurization over the heat-up, not the elapsed time alone.

In the field, this profile was applied together with vacuum venting of the pressurizer upper region. Two rounds of venting were carried out using a temporary vacuum pump connected to the exhaust line upstream of the POSRV in order to remove non-condensable gases. Non-condensable gas accumulated in the upper region impedes steam condensation and heat transfer at the upper part of the valve and therefore tends to sustain the upper–lower temperature differential identified above as the governing parameter; its removal is consistent with the same mechanism and was expected to act in the same direction as the pressurization profile. With both measures applied, no leakage was indicated by the downstream temperature criterion during setpoint verification or main valve actuation testing, and the valve remained leak-free throughout the approach to normal operating temperature and pressure.

These findings also relate to the detection approach evaluated in [2]. The alarm setpoint of 60 °C used in the field is consistent with the temperatures calculated there: it lies above the no-leakage discharge line temperatures obtained even for the highest containment temperature considered, and well below the temperatures obtained on the main valve discharge line for the leakage cases. The field criterion applied in this study is therefore supported by an independent analysis, and preventive control of the pressurization profile and temperature-based leak detection can be regarded as complementary rather than alternative measures.

Table I: Normalized comparison of the four pressurization scenarios. Linear-1 and Linear-2 in Fig. 2 are two runs of the non-stabilized scenario; as the results did not differ appreciably, a single representative value is given.

Scenario	Relative Duration	Relative Temp. Differential (Upper/Lower)	Result
Plant A	0.76	0.83–1.00	—
Plant B	1.00	0.83–1.00	—
Non-stabilized (Linear-1/2)	0.47	0.58–0.92	—
EPRI Guideline	0.70	0.58–0.79	Most Stable

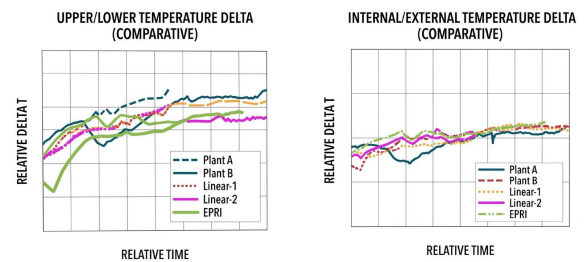


Fig. 2. Comparative relative temperature differentials (upper/lower and internal/external).

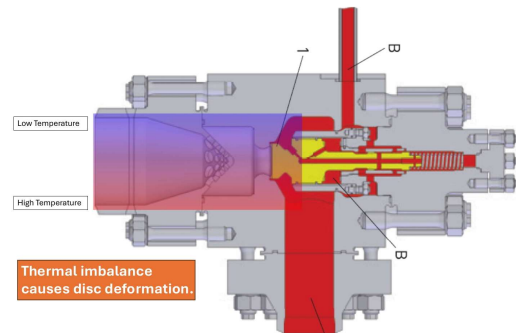


Fig. 3. Thermal imbalance across the main valve leading to disc deformation.

Several limitations should be noted. The empirical testing was conducted on a mock-up model that does not perfectly replicate the actual pressurizer used in APR1400 nuclear power plants. The field measurement was obtained during the hot functional test of a single domestic APR1400 plant, and long-term operational data are not yet available. Because the pressurization profile and the vacuum venting were applied together in that test, their individual contributions to the leak-free result cannot be separated from the present data. In addition, the disc deformation is inferred from the measured temperature distribution together with a structural assessment whose detailed results cannot be disclosed, rather than from direct observation of the deformed geometry. Finally, the EPRI guideline-based profile is the most favorable of the four scenarios examined rather than a demonstrated optimum; the pressurization rate that best balances leakage risk against startup duration has not yet been quantified.

5. Conclusion

This study identified the temperature differential between the upper and lower parts of the valve during startup as the principal factor governing POSRV leakage. The cases accompanied by measurable leakage were consistently those in which this differential was large, and the relationship is consistent with distortion of the main valve disc caused by differential thermal expansion. Rapid or unstable pressurization was identified as a further contributing factor, increasing the likelihood of leakage once the disc has been distorted.

Of the four pressurization scenarios examined, the EPRI guideline-based profile maintained the lowest temperature differential across the valve, achieved through intermediate hold periods and a stepwise reduction of the ramp rate rather than through a longer overall duration. When this profile was applied during the startup of an actual plant, together with vacuum venting of the pressurizer upper region to remove non-condensable gases, no leakage was observed under the applied criterion. These results provide a basis for reviewing the startup pressurization process of Korean-designed nuclear power plants and may be used as supporting material in regulatory briefings concerning POSRV leakage. Verification over additional startups would be required before the combined process could be adopted as a standard startup guideline for exported Korean reactors.

Future work should focus on separating the individual contributions of the pressurization profile and the vacuum venting through single-variable testing, on quantifying the pressurization rate that balances leakage risk against the generation loss caused by an extended startup, on improving the structural design of the POSRV to reduce its sensitivity to thermal gradients, and on developing real-time, temperature-based leak detection systems.

ACKNOWLEDGEMENT

This research was supported by the 2026 Research Fund of the KEPSCO International Nuclear Graduate School (KINGS), the Republic of Korea.

REFERENCES

- [1] S. B. Kwon, I. G. Kim, H. J. Ahn, D. W. Lee, S. C. Baek, and K. H. Kim, A Study on the Flow of POSRV in Reactor Coolant System, Fall Conference of the Korean Society of Mechanical Engineers, pp. 568-573, 2003.
- [2] Y. S. Ko, S. J. Baik, Y. J. Choe, S. J. Yune, and E. K. Kim, Numerical Study on POSRV Leak Detection, Transactions of the Korean Nuclear Society Autumn Meeting, 2015.
- [3] Safety and Relief Valve Testing and Maintenance Guide, EPRI, Palo Alto, CA, TR-105872, 1996.