Design of a Class 1 Safety Valve

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1. Introduction

Spring-loaded safety valves are used to protect the over-pressurization of fluid systems or pressure vessels. The valves are required to open for the pressure mitigation and reseat after the system pressure is reduced to a certain value. Due to its critical role in power plants, the structural integrity of the valve is highly demanded. In nuclear power application, the design of the valve is required to comply with the provisions in the codes and standards. In many countries, nuclear service safety valves are designed to the requirements of ASME Section III. In Korea, KEPIC [1](Korea Electric Power Industry Code) as well as ASME Section III [2] is accepted as the standards for the design and manufacturing of nuclear equipment as specified in the Notice No. 2000-17 of the MOST (Ministry of Science and Technology) [3].

To date, the maintenance of safety related valves has been principally relied on by overseas technology, if significant failure was found during the valve operation. This is mainly due to the fact that nuclear service safety valves were not developed domestically until a recent date. In the last two years, KEPRI has developed a MSSV (Main Steam Safety Valve) in cooperation with Jokwang I.L.I. Co. In the design process, the structural adequacy of the valve was assessed as a safety Class 1 valve by principally relying on the FE (Finite Element) technique. Actually, the valve can be designed to the requirement of a Class 2 valve [4].

In spite of the industrial interest, there are few design materials which could be referred to. Therefore, delineation of a design procedure for nuclear equipment is claimed. To this end, the assessment procedure for the safety valve structure is discussed in the present study based on KEPIC MNB (or ASME Section III NB).

2. Methods and Results

The valve consists of a body which houses the nozzle, the lower adjustment ring, the upper adjustment ring, the guide and a disk holder. The yoke surrounds the spring, spring seat and stem. In normal operating conditions, the disk is maintained in the closed position against the seat by the compressive force of a spring. When the upstream pressure exceeds the set pressure, the vertical force on the disk is developed and the valve pop opens. The set pressures of the valves range from 1000 to 1400 psig with rated capacities of over 500,000lbs/hr saturated steam.

The technical requirements for the valves provided by the Owner are specified in the design specification (or technical specification). The loadings, combinations of loadings and design limits are identified in the specification. The service loads provided in the technical specification for Ulchin 5&6 safety/relief valves can be enumerated as follows:

- Operating Pressure and Temperature
- Resultant Force from the Open Discharge at Valve Outlet
- Maximum Bending and Torsional Moments
- Fluid Temperature Ramp Increase or Decrease
- Thermal Transient Load
- Spring Force
- Operating Basis Earthquake
- Safe Shutdown Earthquake

The maximum operating pressure for the primary pressure zone of the valve can be estimated based on the accumulation conditions for the safety valves in KEPIC MNB 7512 (or ASME Section III NB 7512). Then, the maximum operating temperature of the primary pressure zone can be calculated assuming saturation conditions. The maximum operating pressure for the secondary pressure zone can be estimated based on the outlet pressure rating. The steady-state load due to steam discharge at the valve outlet can be computed by using the formula in the KEPIC MGE A2210 (or ASME Section III o-1220). Then, the reaction force which is defined as the twice value of the discharge thrust. Flanged joints subjected to combinations of moment and pressure shall meet the requirements of the KEPIC MNB 3658 (or ASME Section III NB 3658). The thermal transient resulting from continuous fluid temperature ramp increase or decrease at 100°F/hr (56°C/hr) should be considered according to the KEPIC MNB 3545 and 3546 (or ASME Section III NB 3545 and 3546). When the valve opens, the temperature distribution the valve will be increase rapidly, since the steam flows through the secondary pressure zone which is illustrated in the KEPIC Fig. MNB 3591.1 (or ASME Section III NB Fig. NB-3591.1). This transient should be considered as a loading. As shown in the technical specification for Ulchin 5&6 safety/relief valves, the Operating Basis Earthquake, Safe Shutdown Earthquake and pipe break transients are included as loadings.

When the simple stress analysis is not feasible, or Code does not provide analytic equations, the FEM (Finite Element Method) can be applied. At this moment, the stress categorization problem encounters. Specifically, it is difficult to equate the calculated stresses and the code categories unless the analysis is based on thin shells. For the proper categorization of stresses, a recently developed guideline by PVRC (Pressure Vessel Research Council) [5] is applied. Of the recommended guidelines the followings should be noted:

- For the general primary membrane stress, Code-provided equations should be used whenever they are available. On the other hand, the FEA (Finite Element Analysis) is an appropriate tool for calculating the local primary membrane stress (P_L), the local primary membrane stress (P_L) plus the primary bending stress (P_b) and the primary stress (P) plus the secondary stress (Q).
- The global location is expected to be at a discontinuity for all the failure modes except those associated with the general primary membrane stress.
- Use of the SCL (Stress Classification Line) for evaluation of membrane and bending stresses is appropriate for most geometry.

The reference [6] can give complement information for the stress linearization. The procedure in the DBA (Design Basis Analysis) guide is shown below:

- Calculate the elementary stresses in the nodal local coordinates at every node.
- Decompose the elementary stresses calculated above into membrane stress and bending stress. Since the command for the stress linearization is usually provided in commercial FEA tools, the membrane stress, the linearized bending stress and the peak stress along a SCL can be easily obtained. Representatively, ANSIS software has PRSECT command for the linearization.
- Referring to the KEPIC MNB 3213, 3215 and 3217 (or ASME Section III NB 3213, 3215 and 3217), we can classy the decomposed stresses into the different categories: P_m , P_L , P_b , Q_m (secondary membrane stress) and Q_b (secondary bending stress).
- Calculate the sum of the stresses classified in the above way for the set of loads acting simultaneously. Then, evaluate the principle stresses from these stresses.
- Compute the equivalent stresses in accordance with the maximum shear stress theory from the above stresses.

The equivalent stresses should satisfy the relationships shown in the KEPIC MNB 3220 (or ASME Section III NB 3220) for all loading conditions. Note that the stress limits for a Class 1 component are based on the design stress intensity.

For clarity of the forgoing statements, the 3-D finite element model and the locations of SCLs of the valve body are shown in Fig. 2 and 3. Further, the summary of calculated stress for the body under level B service loadings is depicted in Table 1.

3. Conclusion

In nuclear application, the structural reliability of the safety valves should be ensured for the safety of fluid systems and pressure vessels. As a way to confirm the structural integrity, an evaluation procedure for Class 1 valves based on KEPIC MNB (or ASME Section III NB) is introduced in the present paper. The loadings, combinations of loadings and service limits for the valve design are briefly mentioned. Special emphasis is placed on the stress classification and the stress linearization based on the recent study results. In order to facilitate the understanding, the valve body model and the assessment results are presented.

REFERENCES

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[5] J. L. Hechmer, G. L. Hollinger, 3D Stress Criteria Guidelines for Application, WRC Bulletin 429, WRC, 1998.
[6] CEN prEN 13445-3, Design by Analysis Annex C, 2002.

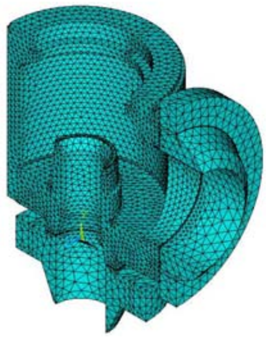

Fig. 2 Finite Element Model of the Valve Body

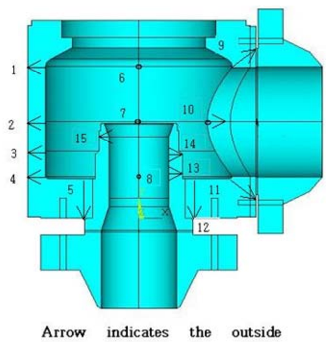

Fig. 3 Locations of Stress Classification Lines

Table 1 Stress of the body for Service Level B

Stress Class	Limiting SCL	Calculation (psi)	Allowance (psi)
P_L	12	8,188	27,000
$P_L + P_b$	5	17,790	27,000
$P_L + P_b + Q$	13	28,466	51,390