NONLINEAR NUMERICAL ANALYSIS OF TWO-WAY GLOBE VALVE HOUSING

Ivica Galić, Krešimir Vučković, Zdenko Tonković

Introduction

Two-way globe valve housing DN50 PN160 subjected to internal pressure is investigated. Three-dimensional nonlinear finite element analyses are performed to obtain the plastic yield, collapse and instability pressures. For the determination of the plastic collapse pressure, twice-elastic-slope and the tangent-intersection methods are used. The allowable pressure is obtained according to the limit design method. Unlike the previous investigation of the three-way globe valve housing DN100 PN40, it is shown that allowable pressure for the two-way globe valve housing calculated by the application of the EN 12516-2 standard is highly conservative in comparison with the one derived by the application of finite element results for the plastic collapse pressure, in accordance with the limit design method. Additionally, it is shown that the results for the failure pressure can be obtained by a simpler finite element analysis without taking into consideration the material hardening and geometrical nonlinearity.

Keywords: allowable pressure, finite element analysis, globe valve housing, limit design method, plastic collapse pressure

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instability pressures for the valve housing under internal pressure and to predict the burst pressure obtained by experimental results. A three-port, globe valve housing DN100 PN40 was analyzed (Fig. 2). It was shown that the plastic collapse pressure results obtained by real strain hardening material model agree well with the experimental ones obtained by strain gauges. Slightly better results correspondence was obtained by the application of the TI method than by the TES method. The results also indicated that the allowable pressure determined by the application of the EN 12516-2 standard [2] was close to FE and experimental results obtained by the application of the limit design method.

The aim of this paper is to determine the allowable and failure pressures of the two-way globe valve housing DN50 PN160. The housing subjected to internal pressure is investigated using FE analysis. The allowable pressure of the housing is compared with the solution obtained by the method proposed in [2]. Here, it is necessary to emphasize that the numerical model applied in this paper is similar to the one used in the previous investigation of the three-way globe valve housing DN100 PN40 [16, 17]. The last one was verified experimentally using strain gauges and pressure transducer. In addition, both housings are made of the same cast steel.

2 Problem description

Material

The housing was made by sand casting. Its complex geometry with basic dimensions is shown in Fig. 3. As may be observed, it is a two-way housing consisting of two lateral flanges and one upper flange. In service, a bonnet is connected to the upper flange, while the valve is connected to the pipeline through the lateral ones.

The housing material is cast steel GS-C25. Its chemical composition is shown in Table 1, and basic material parameters at room temperature are summarized in Table 2. It should be noted that specified values are minimum values for this material. The engineering stress-strain diagram (σf, εf) determined experimentally in a standard tensile test [16-18] at room temperature is shown in Fig. 4. As evident from the ratio of the ultimate stress and the yield stress $\sigma_u/\sigma_y$, the given material exhibits considerable strain hardening.
For the large strain FE analysis, the true stress and strain values are determined up to the ultimate tensile stress level (30% of strain). After this specified stress and strain values are determined up to the ultimate shown in Table 3. For the large strain FE analysis, the true stress and strain values are determined by the following relationships:

\[
\sigma_t = \sigma_y \left(1 + \varepsilon_y\right),
\]

\[
\varepsilon_t = \ln \left(1 + \varepsilon_y\right).
\]

The values of engineering terms and true terms are shown in Table 3. For the large strain FE analysis, the true stress and strain values are determined up to the ultimate tensile stress level (30% of strain). After this specified point, the response is assumed to be perfectly plastic.

### Table 3

<table>
<thead>
<tr>
<th>Engineering stress ( \sigma_e / \text{MPa} )</th>
<th>Engineering plastic strain ( \varepsilon_{pl} / % )</th>
<th>True stress ( \sigma_t / \text{MPa} )</th>
<th>True plastic strain ( \varepsilon_{t,pl} / % )</th>
</tr>
</thead>
<tbody>
<tr>
<td>250.0</td>
<td>0.00</td>
<td>250.8</td>
<td>0.00</td>
</tr>
<tr>
<td>250.0</td>
<td>0.21</td>
<td>250.8</td>
<td>0.21</td>
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<td>1.35</td>
<td>290.0</td>
<td>1.34</td>
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<td>322.7</td>
<td>2.13</td>
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<td>2.10</td>
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<td>4.35</td>
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<td>457.0</td>
<td>15.79</td>
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<td>14.59</td>
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<td>467.9</td>
<td>21.58</td>
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<tr>
<td>475.0</td>
<td>29.77</td>
<td>617.5</td>
<td>25.94</td>
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</table>

### Table 1

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
</tr>
</thead>
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<td>0.20</td>
<td>0.33</td>
<td>0.80</td>
<td>0.026</td>
<td>0.026</td>
<td>0.03</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Modulus ( E / \text{GPa} )</th>
<th>Yield stress ( \sigma_y / \text{MPa} )</th>
<th>Ultimate stress ( \sigma_u / \text{MPa} )</th>
<th>Extension strain ( \varepsilon / % )</th>
<th>Area reduction, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>205</td>
<td>250</td>
<td>475</td>
<td>30</td>
<td>55</td>
</tr>
</tbody>
</table>

The investigated housing DN50 PN160 nominal pressure at room temperature is 16 MPa. In Fig. 6a, it is shown that zone of equivalent plastic strain distribution did not appear at the nominal pressure, which means that model housing is completely in the elastic area. The first zone of the equivalent plastic strain appears on the inner surface of the model at the pressure of about 25 MPa, as shown in Fig. 6b. The response of the model housing during an incremental increase of the internal pressure is characterized by the spreading of the plastic region. The equivalent plastic strain distribution at the pressure of 47 MPa, which is close to the allowable pressure determined by limit design method (see section 4), is shown in Fig. 6c. With a further pressure increase, larger elastic-plastic strains occur on the model. At the pressure of 159 MPa, the zone of maximum equivalent plastic strain value of 30% reaches the outer surface of the model housing (Fig. 6d). This value was chosen as it represents the strain at which a fracture of the housing material happens.
Spreading of the zones with maximum equivalent plastic strain throughout the housing wall thickness at the critical location where maximum equivalent plastic strain reaches the outer surface of model housing is shown in Fig. 7. It is evident that critical location determined by the nonlinear FE analysis and represented by the point A in Fig. 7 is away from both points $S_1$ and $S_2$, which represent critical locations at the regions proposed by the EN 12516-2 standard.
Based on the FE results, the plastic collapse pressures for the housing are determined separately for points $S_L$ and $S_R$, as well as for point $A$. Fig. 8 shows the values for critical points $S_L$ and $S_R$, while Fig. 9 shows the values for the point $A$. Herein $p_T^{TIE}$ is the plastic collapse pressure obtained by the TIE method and $p_T^{Ti}$ is the plastic collapse pressure determined by the TES method. The mean value of the plastic collapse pressure determined by TIE and TES method is 95.9 MPa for point $S_L$, 79.3 MPa for point $S_R$ and 71.3 MPa for the point $A$.

Pressure-displacement diagrams for the FE node in the numerical model at the critical point $A$ are shown in Fig. 10. From the pressure-displacement curve, the plastic instability pressure $p_i$ is obtained as the highest point on the curve, i.e. the maximum pressure that could be attained. In the FE analyses it is assumed that the material will fail in a ductile manner so that the plastic instability pressure $p_i$ represents the failure pressure $p_F$ that causes the plastic collapse of the housing. In such a manner, the numerically obtained failure pressure at the point $A$ is 161.2 MPa.

The approximate result for the failure pressure $p_F$ can be obtained by using the reference stress concept [20] without the detailed consideration of the real material hardening and geometrical nonlinearity. The concept can be applied to flawed and unflawed components [21]. In some Failure Assessment Diagram methods [6, 22], the reference stress concept is used to define a parameter $L$, that measures the probability of a ductile failure

$$L_r = \frac{p}{p_Y} = \frac{\sigma_{ref}}{\sigma_Y}.$$ (3)
where $\sigma_p$ denotes the plastic yield pressure. When applied to unflawed components, the reference stress, $\sigma_{ref}$,

$$\sigma_{ref} = \sigma_y \frac{p}{p_y},$$

(4)
can be compared to the material's yield stress, $\sigma_y$, for non-work hardening behaviour, or to some flow stress, $\sigma_f$,

$$\sigma_f = k(\sigma_y + \sigma_u),$$

(5)
when significant work hardening is exhibited, to estimate the onset of plastic collapse

$$P_C = \sigma_y \frac{\sigma_f}{\sigma_{ref}}.$$

(6)

Herein $k$ stands for the flow stress factor ($k = 0.5$, recommended for most assessments [15]). For the analyzed housing the plastic yield pressure amounts to 82.8 MPa (see Fig. 10).

If the term $\sigma_f$ is inserted into the previous expression (6) for the mean value between the yield stress and the ultimate tensile stress ($k = 0.5$), a rather conservative solution for the failure pressure ($P_C = 120.1$ MPa) is obtained. But if the ultimate tensile stress is assumed for the flow stress ($\sigma_f = \sigma_u$), the obtained failure pressure in the amount of 157.3 MPa corresponds well to the numerically determined burst pressure of 161.2 MPa, for real material.

4 Allowable pressure

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In accordance with [4], the allowable pressure $P_{allowable}$ based on the limit designed method is determined from the plastic collapse pressure $P_C$ through the expression

$$P_{allowable} = \frac{2}{3} P_C.$$

(7)
The mean value of the plastic collapse pressures $P_{C}^{TES}$ and $P_{C}^{R}$ at the point A obtained from FE results is $P_C = 71.3$ MPa. If it is inserted into the previous expression, it follows that the globe valve housing allowable pressure is 47.5 MPa.

In common engineering practice, the calculation of the valve housing wall thickness is done in accordance with the EN 12516-2 standard. The calculation needs two steps: the calculation of the housing main section wall thickness and calculation of wall thickness in the crotch area. Since the wall thickness in the crotch area cannot be calculated directly, the initial wall thickness in this area is assumed from the one calculated in the first step and then incrementally increased until the equilibrium of forces is reached. The investigated valve housing DN50 PN160 wall thickness calculation is, therefore, carried out only in the crotch area. The housing dimensions required for the calculation according to EN 12516-2 standard are shown in Fig. 11 and the calculation method is described in the following section.

Based on the dimensions from Fig. 3 and notation from Fig. 11, the following expression is derived:

$$l_0 = \left(\frac{d_0 + e_0}{e_0}\right) = \sqrt{94 + 13} = 37.3 \text{ mm},$$

$$l_1 = 1.25 \cdot \sqrt{(d_i + e_i) / e_i} = 1.25 \cdot \sqrt{(50 + 13)} = 32.0 \text{ mm}.$$

(8)

For the calculated distances $l_0$ and $l_1$, the lined surfaces in Fig. 11 are determined graphically as follows:

$$A_L^L = 1886.76 \text{ mm}^2, A_L^R = 5070.86 \text{ mm}^2,$$

$$A_L^R = 1053.79 \text{ mm}^2, A_L^L = 3511.62 \text{ mm}^2,$$

(9)
where the R and L indices mark the right and left side of the housing, respectively. The maximum allowable pressure for the right and the left side of the housing is determined according to the expression

$$p \leq \frac{f}{k_c \cdot A_f + \frac{1}{2}},$$

(10)

where $f = \sigma_y / 1.9$ and $k_c = 1$ are used for a non-welded structure. If the surfaces determined in expression (9) are inserted into expression (10), the allowable pressures for the left and right side of the housing are derived as: $P_{allowable}^{R} = 41.3$ MPa and $P_{allowable}^{L} = 34.3$ MPa. Since the $p_{allowable}$ is lower than the $p_{allowable}$, the maximum allowable pressure of the housing, calculated according to the EN 12516-2 standard, is 34.3 MPa. If results are compared, it is clear that the maximum allowable pressure value calculated by the application of the EN 12516-2 standard is notably lower than the maximum allowable pressure of 47.5 MPa derived by the application of FE results for the plastic collapse pressure, in accordance with the limit design method [4].

Therefore it can be concluded that for the considered two-way globe valve housing geometry, the standard engineering approach [2] is highly conservative. Economically speaking, this may result in an unsatisfactory housing because the material consumption (thicker walls increase material consumption) has a great influence on the product price. On the other hand, the results shown in [16, 17] for the three-way globe valve housing indicate that the allowable pressure determined by the application of the EN 12516-2 standard compare satisfactorily with the FE based solution. In both cases the allowed pressure is much higher than the nominal pressure of valve housing.
**Discussion and conclusions**

The present paper is a continuation of the authors' previous work published in [16, 17] where a three-port globe valve housing (designation DN100 PN40) was analyzed in details. The results for the mentioned housing indicate that the allowable pressure determined by the application of the EN 12516-2 standard compare satisfactorily with the experimental and FE based solutions.

Two-way globe valve housing DN50 PN160 subjected to internal pressure is investigated in this paper. Three-dimensional nonlinear FE analyses are performed to obtain the plastic yield, collapse and instability pressures. The real material hardening and geometrical nonlinearity were modelled. The numerical model used in this paper is similar to the one experimentally verified in the previous investigation. Based on the numerical results, the housing plastic collapse pressure was determined by means of two methods: the twice-elastic-slope and the tangent-intersection. It is shown that allowable pressure for the globe valve housing calculated by the application of the EN 12516-2 standard is highly conservative compared with the one derived by the application of FE results for the plastic collapse pressure, in accordance with the limit design method.

As presented in this paper, the wall thickness in the crotch areas of the two-way globe valve housing, according to the EN 12516-2 standard, is calculated only in a symmetry plane. Although critical location obtained by the FEM is located in the crotch area, it is located away from the symmetry plane and thus away from both critical locations proposed by the EN 12516-2 standard. Therefore, it can be concluded that EN 12516-2 standard is not precise enough for designing of the two-way globe valve housing details.

In the FE analyses it is assumed that the material will fail in a ductile manner. In accordance with that, from the pressure-displacement diagram obtained by the FE analysis, the failure pressure, i.e. the plastic instability pressure, was determined as the highest point on the curve. The numerically obtained failure pressure has the value of 161.2 MPa. Additionally, it is shown that the results for the failure pressure can be obtained by a simpler FE analysis without taking into consideration the material hardening and geometrical nonlinearity. Thereby, FE results show that the failure pressures obtained by the limit load analyses give conservative results, except those obtained by using the ultimate tensile stress as the flow stress.

Since the EN 12516-2 standard gives too conservative result for the allowable pressure compared to the FE based solution, additional studies are needed to define more precise method for calculation of two-way globe valve housing wall thickness. It is necessary firstly to carry out an experimental investigation to confirm the numerical prediction presented here. These results represent the content of the paper that is in preparation.

**References**


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