The Research of the Stress-Strain State of the Pipeline System, Taking into Account the Change in Spatial Location

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Abstract. In the work, the influence of changes in the geometry of the technological pipeline on the stress-strain state is studied, taking into account the complexity of the strapping of technological equipment and the parameters affecting the deformation. The authors analysed the stress-strain state of technological pipeline systems with a change in their spatial location, simulated 3 options for the spatial location of the pipeline system. The best option was selected to ensure its reliable operation, depending on the design parameters. In conclusion, the effect of hydraulic load on the VAT of the pipeline was investigated. The calculations were carried out according to the standard method in the PC program "Start" and using the finite element method in the PC SolidWorks. It is established that a change in the geometry of the pipeline system significantly affects its stress-strain state. On the example of changing the geometric arrangement of equipment piping shown the possibility of reducing VAT in the pipe bends by 19%. It is shown that when assessing the strength of technological pipelines with complex geometry and a significant number of elements, it is necessary to take into account hydraulic loads, which can increase the VAT in pipeline elements up to 21.7%.

1. Introduction
All pipelines, when the temperature of the transported product and the environment change, are subject to temperature deformations, as a result of which considerable longitudinal forces arise in the pipeline, which exert pressure on the final fixed points (supports), trying to move them out of place. These efforts are so significant that they can destroy the supports, cause longitudinal bending of the pipeline or lead to disruption of flange and welded joints. In pipelines tying tubing equipment, in addition, the high speed of these processes is due to the presence of a significant influence of vibration parameters. At the same time, pipelines are fundamentally different from any conventional structures subject to vibration. They have a specific source of vibration in the form of a stream of gas or liquid in the pipes. In addition, with the installation of elastic supports, vibration of pipelines can even increase. This is due to the complexity of determining the location of the elastic supports and the method of fastening the pipeline to the supports [1-7].

To protect the pipeline from additional loads arising from changes in temperature, it is designed and constructed so that it can elongate freely when heated and shortened when cooled without overstressing the material and connecting pipes. The ability of a pipeline to deform under the influence of thermal elongations within the permissible stresses in the pipe material is called compensation of thermal elongations.
The optimization of complex technical systems is carried out by modeling both the object itself and the processes taking place in it [8-10]. A qualitative model is more accessible for research than a real object, and allows you to achieve the following results:

- to study the device of a particular object, its structure, basic properties and patterns of interaction between elements;
- manage the facility and determine the best management methods for given goals and criteria;
- predict the direct and indirect consequences of the implementation of the given methods and forms of impact on the object.

The model always meets a specific goal and is limited by the scope of the task. It reproduces the most characteristic features of the studied object, the choice of which is determined by the purpose of the study. At the same time, both “overcomplication” and “underestimation” of the model are unacceptable, since this can lead to either an overestimation of the complexity and complexity of creating the model, or to its inadequacy. Therefore, the most important part of building the model is a clear representation of the sequence of stages of formation that ensure that the most essential (for the task posed) attributes of the original object and their hierarchy are taken into account. The latter is used to achieve the necessary accuracy of the description of the model by taking into account the most significant features of the object and when solving the problem of multicriteria in optimization problems [11-14].

2. Analysis of the stress-strain state of the pipeline system using the standard calculation method

Determination of the stress-strain state of the pipeline system was carried out in accordance with the regulatory document for assessing the strength of GOST32569-2013 “Steel technological pipelines. Requirements for the device and operation in explosive and fire hazardous and chemically hazardous industries”.

The design schemes with various geometries of the pipeline system with the numbers of nodes and sections are shown in Figures 1 - 3. The nodes are the details of the pipeline, branches, fasteners, diameter transitions, etc. The section is a part of the pipeline system between nodes.

The wall thickness calculations taking into account the complexity of the geometry were carried out using the START software package.

With the given parameters of the nominal wall thickness 2, 3, 4, 6 mm. Technological thinning and an increase in corrosion are taken equal to 0.

The calculation took into account the fixing conditions, weight and overall dimensions of the reinforcement, weight, design dimensions of the bends, such as diameter, angle of rotation, radius of curvature, wall thickness of the branch, etc.

As a result of the calculation, the following characteristics of the stress-strain state of the pipeline system were obtained:
Figure 3. Calculation scheme 3 of the pipeline indicating the nodes and sections.

- loads transferred by the pipeline to the equipment - fittings of the associated equipment and building structures - supporting structures of the pipeline system;
- deformation of the pipeline system;
- stresses in the pipeline system and its resistance to cyclic influences;
- movement along the axes in all nodes of the pipeline.

Table 1. The results of the calculation of stresses in the pipe branch depending on the wall thickness.

| Circuit number | Pressure, temperature | Wall thickness |
|----------------|-----------------------|----------------|
|                |                       | 2 mm | 3 mm | 4 mm | 6 mm |
| Scheme 1       | P=2, T=230            | 148  | 145  | 135  | 116  |
|                | P=3, T=300            | 178  | 175  | 171  | 150  |
|                | P=4, T=300            | 248  | 194  | 179  | 160  |
| Scheme 2       | P=2, T=230            | 149  | 145  | 135  | 116  |
|                | P=3, T=300            | 200  | 175  | 169  | 150  |
|                | P=4, T=300            | 261  | 196  | 179  | 151  |
| Scheme 3       | P=2, T=230            | 147,7| 144  | 135  | 116  |
|                | P=3, T=300            | 187,9| 173  | 169  | 150  |
|                | P=4, T=300            | 254  | 193  | 178  | 160  |

An analysis of the results presented in Table 2 made it possible to establish critical threshold values for the complexity of the geometry, exceeding which it is necessary to take into account spatial geometry when designating the rejection of the wall thickness [15-20].

In the course of the calculation, it became known that within the subgroup the product density slightly affects the value of the maximum stresses when determining the wall thickness, taking into account the complexity index of the geometry.

Next, graphs of the dependence of stresses at the nodes of the piping schemes with the material of the wall made of steel 20 at the design parameters (Figures 4-6) are constructed. Based on the study, the criteria for the necessity of taking into account the complexity index of spatial geometry when calculating the strength of pipelines are determined.

3. Researches of the stress-strain state of the pipeline system in the SolidWorks program

The three-dimensional solid-state model of the object of study was built in the SOLIDWORKS program. To assess the state of the object, finite element analysis, implemented in the SolidWorksSimulation software package, was selected. The construction and calculation of piping arrangement in the software package allows you to take into account the heterogeneity of the stress-
deformed state (SDS) both in the straight section of the pipeline, and in the turning points (bends) and the locations of the fittings.

Table 2. Comparative analysis of the VAT of geometric patterns of the pipeline from different wall thicknesses with the same design parameters.

| Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 1 | Scheme 2 | Scheme 3 | S, mm |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|-------|
| P=2 MPa/T=230°C | P=3 MPa/T=300°C | P=4 MPa/T=300°C | Wall thickness |
| 86.9 | 85.6 | 84.8 | 97.1 | 97.1 | 97.1 | 126 | 114.6 | 115.3 | 2 |
| 68 | 67.5 | 65.6 | 84.8 | 84.8 | 71.6 | 94.5 | 83.1 | 82 | 3 |
| 63.4 | 63.4 | 56.6 | 79.2 | 83 | 67.4 | 89 | 69.6 | 68.7 | 4 |
| 52.2 | 50.2 | 48.3 | 69.8 | 69.8 | 53.3 | 72.5 | 58.1 | 56.8 | 6 |

Figure 4. Graphs of voltage dependencies in the nodes of pipeline schemes from wall thickness at design parameters P=2 MPa and T=230°C.

Figure 5. Graphs of voltage dependencies in the nodes of pipeline schemes from wall thickness at design parameters at P=3 MPa and T=300°C.

Figure 6. Graphs of stress dependencies in the nodes of the piping diagrams of the wall thickness at the design parameters at P=4 MPa and T=300°C.

At the first stage, a sketch of the pipeline was made in the form of the midline of the entire contour, in a perpendicular plane the cross section of the pipe with the required geometric dimensions is depicted and a shell made using the “surface along the path” command is constructed.

Next, ten nodal tetrahedra are selected as mesh elements, which provides a higher level of approximation compared to four nodal tetrahedra. After splitting into a finite element grid, the model material, boundary conditions, and type of loading are specified (Figure 7).
Then, in Simulation, various systems of equations are generated and solved. The result of solving the equations is a picture of the SDS and the safety factor for equivalent stresses of the pipeline under the influence of static load.

![Figure 7. Model with boundary conditions and acting loads.](image)

During the calculation, the stress-strain state of the pipeline of scheme 2 was obtained depending on the nominal wall thickness with the specified design parameters (Table 3).

**Table 3.** The results of the calculation of stresses in the nodes of the piping scheme 2 depending on the wall thickness at the design parameters.

| Pressure, temperature | Wall thickness |
|-----------------------|----------------|
|                       | 2 mm | 3 mm | 4 mm | 6 mm |
| P=2, T=230            | 361.6| 222.1| 166.5| 128.6|
| P=4, T=300            | 389.8| 238.3| 186.7| 149.4|

According to the data obtained in Table 3, a graph of stresses versus nominal thickness is plotted for different design parameters (Figure 8).

For verification obtained using the SolidWorks PC model, a comparative analysis of the results of calculations of its stress-strain state in the SolidWorks PC and the stress-strain state of the model obtained using the standard method of strength and stiffness calculations in the START PC was performed (Figure 9).

**4. Conclusion**

The analysis of the stress-strain state of the schemes of pipeline systems of various geometry complexity and the analysis of the results of the calculation of the rejection wall thickness for technological pipelines are carried out. The criteria for the need to take into account the spatial complexity index of the geometry are determined.

It is shown that when assessing the technical condition of technological pipelines with complex geometry, a significant number of various elements, straight sections on which have a length of the order of the step of geodetic survey, it is recommended to use numerical methods of strength calculation.

The obtained dependence shows that the voltages obtained in the START PC and the SolidWorks PC are different. When calculating the strength and rigidity of the pipeline system in START, the
minimum allowable wall thickness was 3 mm, and when considering the spatial location in the SolidWorks PC, the minimum allowable wall thickness was 4 mm.

**Figure 8.** Graph of stresses in the nodes of the piping scheme 3 depending on the wall thickness at the calculated parameters.

**Figure 9.** Graph of the verification model of the pipeline scheme 3.

The constructed calculation model of the pipeline scheme in SolidWorks PCs taking into account the spatial arrangement shows voltages up to 21.7% more than without taking into account the spatial arrangement of the START PCs. Presumably, the absence of SolidWorks PC material “Steel 20” contributes to the discrepancy in results.

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