Modeling a stressed-deformed state of a technological pipeline with a displacement of edges

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Abstract. During installation or repair of pipeline routes, a deviation such as a displacement of the edges of the docking elements, which is formed due to a certain mistake in preparation for welding and welding of the section, is possible. The permissible values of the displacing edges are regulated by the state standard and other regulatory and technical documentation in the field of design, installation, operation and repair of process pipelines. When identifying displacement sizes not exceeding the permissible limits, the pipeline is allowed further operation. In the future, to ensure reliable operation of the pipeline, a periodic assessment of its technical condition is carried out according to current standards. However, even the allowable displacement of the edges is a kind of stress concentrator and can be a source of crack nucleation and further destruction, which will lead to an emergency. Current methods for diagnosing and extending the life of pipelines do not include measures to assess the maximum stresses of welded joints with offsets. There is no analysis of how the displacement of the edges in certain areas affects the stress-deformed state of the entire pipeline as a whole, and what impact do co-locate technical devices have with possible geometric deviations during installation, for example, deviations from verticality. In this paper, we study the interconnection between the effects of technologically neighboring apparatuses and deviations from verticality formed during installation, as well as areas of displacement of the edges of the processing pipeline to the stress-deformed state of the pipeline as a whole.

1. Introduction
The purpose of pipeline systems is the transportation of feedstock, intermediate and commercial products in a technological system designed for a specific technological process of obtaining the necessary high-quality products and the required quantity. The working medium of technological pipelines, as a rule, can be combustible gases, flammable and combustible liquids, toxic products. In this regard, regulatory documents on industrial safety regulate the necessary measures and actions for timely and high-quality technical supervision during operation. During the installation, repair, and operation of process pipelines, various types of defects and deviations inevitably accumulate. These defects can adversely affect the life cycle of pipeline systems and lead to premature decommissioning. One of the most common defects encountered during installation and repair work using welding is the displacement of the edges of the docking elements. Standards for the rejection of displacement values are established by regulatory documents. Usually, the permissible value of the displacement of the edges of the docking elements depends on the thickness of their wall. For detection the presence of edge displacements and determine the displacement values, a measuring control method is used by
using specialized tools, such as a universal welder template. After carrying out the necessary measurements, a conclusion is made about the suitability or unsuitability of the welded joint, and the pipeline is subject to either operation or repair work to eliminate the rejection. With further operation, a fairly narrow set of works is carried out to assess the technical condition, including:
- study and analysis of technical documentation;
- visual inspection and measuring control;
- full-scale examination of the object, including non-destructive testing;
- measurements of wall thicknesses of pipeline elements;
- non-destructive testing of the base metal and welds;
- carrying out verification calculations for strength;
- load test;
- prediction of residual life.

In some cases, additional work may be carried out to determine the mechanical properties, chemical composition of the metal and structural analysis. However, the above methods do not provide a qualitative assessment of the technical condition of the pipeline in the field of stress-deformed state (SDS) of the entire pipeline as a whole, taking into account its geometry, technologically attached apparatuses, edge displacement sections, and other factors. Therefore, it is advisable to simulate the SDS of a technological pipeline with various sections of edge displacement and technologically connected apparatus with geometric deviations as well as to identify sections with the maximum arising stresses from operational loads [1-5].

2. Method of Study

For modeling the SDS of the pipeline, the technological unit of one of the production facilities with an individual geometry, due to the peculiarity of the technological process, was selected. The pipeline technologically connects two apparatuses, one of which is located vertically. The other device has a horizontal arrangement. The pipe material is carbon steel of ordinary quality.

The technical parameters of the technological system under consideration are as follows:
- system operating pressure $P_{\text{calc.}} = 2.0 \text{ MPa}$;
- working temperature $t_{\text{calc.}} = 80 ^\circ \text{C}$;
- working medium - hydrocarbon gas.

The technological pipeline in its composition has the following elements:
- pipeline $168 \times 6 \text{ mm}$ with the length $4300 \text{ mm}$;
- tap $168 \times 6 \text{ mm}$ – 2 pieces.

The pipeline has vertical and horizontal sections with a length of $2000 \text{ mm}$ each, interconnected by taps to change the direction of flow. There is also one horizontal straight section $300 \text{ mm}$ long. The pipeline is connected to the technological fittings of the apparatus using flange connections.

Visual and measuring control of the welded joints of the pipeline revealed a displacement of the edges at all welds equal to $0.9 \text{ mm}$. This value is the boundary value for rejecting butt joints of elements with a thickness of $6 \text{ mm}$.

For modeling SDS, we used the SolidWorks licensed software package into which the Simulation system was integrated to solve engineering and research problems. The above system is built into the software product and makes it possible to simulate the necessary conditions in the process of solving strength and thermal problems.

Modeling and calculation of SDS is carried out in three stages:
- adoption of a method of fixing and application of existing loads;
- creating a finite element mesh, its optimization according to various criteria;
- execution of the calculation.

As a result of the study, a diagram of stresses, displacements, deformations, and others is displayed.
3. Results and Discussion

The first step was the construction of a technological unit, which includes apparatuses and a technological pipeline in the SolidWorks software package [6-11].

The constructed model of the technological unit is presented in Figure 1.

![Figure 1. Model of technological unit.](image)

Figure 2 shows the displacement sections of the welded butt joints of the process pipeline and the direction of displacement.

![Figure 2. Displacement areas of welded docking joints of the process pipeline and direction of displacement](image)

Then, using the “Simulation” strength analysis module, which is part of the SolidWorks Premium basic configuration, internal pressure was applied; fastenings were established on all support. After that, a finite element mesh was created and SDS calculation was performed. The first step was the calculation of the SDS of the pipeline with the sections of the displacement of the edges and the magnitude of the displacement indicated above, without taking into account the impact of adjacent devices. Figure 3a shows the result of calculating the SDS of the process pipeline with edge displacement sections without reference to the devices. The next step was the calculation of the SDS of the pipeline with sections of the displacement edges taking into account the joint binding of the pipeline to the vertical and horizontal apparatus. Modeling was carried out taking into account that the vertical apparatus has no deviation from verticality. The results of calculating the SDS of a pipeline with edge displacement sections and technologically connected devices without geometric deviations are presented in Figure 3b.
Analyzing Figure 3a, it can be seen that the maximum stresses arise in the tap connecting the vertical and horizontal sections of straight pipeline pipes with a length of 2000 mm each, and amount to 39.53 MPa. Analyzing Figure 3b, it can be seen that the maximum stresses moved to another tap connecting the vertical and horizontal sections of the straight pipe with a length of 2000 mm and 200 mm, increasing 1.36 times to 52.01 MPa compared to the maximum stresses of 39.53 MPa, received when calculating the SDS of the pipeline without taking into account binding to the apparatus.

Figure 3. The results of calculating the SDS of the pipeline, excluding and taking into account devices from the common technological system (devices are not shown conditionally): a) - the result of calculating the SDS of the technological pipeline with sections of the displacement of the edges without reference to the apparatus; b) - the result of calculating the SDS of the pipeline with the sections of the displacement of the edges and technologically connected devices without geometric deviations

Therefore, we can conclude that the influence of technologically related equipment and its design features, as well as its location on the SDS as a whole. The next step was the modeling of the SDS of the technological pipeline, taking into account the displacement of the edges, taking into account the joint binding of the pipeline to the vertical and horizontal apparatus. Modeling was carried out taking into account the fact that the vertical apparatus has deviations from verticality of 1, 2, 3 and 4 mm, respectively. The results of calculating the SDS of a pipeline with edge displacement sections and technologically connected apparatuses with a deviation of a vertically located apparatus from verticality by 1, 2, 3, and 4 mm are shown in Figures 4a-d.

Analyzing Figure 4, we can conclude that when a vertically located apparatus deviates by 1 mm from the vertical, the maximum stresses at the pipeline arise in the tap connecting the vertical and horizontal sections of straight pipeline pipes with a length of 2000 mm each and amount to 53.81 MPa. With a further deviation of 2, 3 and 4 mm from the verticality of the vertically located apparatus, the maximum stresses at the pipeline arise in another tap connecting the vertical and horizontal sections of the straight pipe with a length of 2000 mm and 200 mm and are 70.04 MPa, 98.83 MPa and 128.50 MPa, respectively.

The results obtained make it possible to develop nomograms of the dependence of the maximum stresses in the technological pipeline with a displacement of the edges of the abutting elements equal
to 0.9 mm, of abutting elements from deviations from the verticality of a vertically located apparatus (Figure 5).

Figure 4. The results of calculating the SDS of a pipeline with edge displacement sections and technologically connected apparatuses with a deviation of a vertically located apparatus from verticality by 1-4 mm (the apparatuses are not shown conditionally). a) - the result of calculating the SDS of the pipeline with a deviation of the vertically located apparatus from verticality by 1 mm; b) - the result of calculating the SDS of the pipeline with a deviation of the vertically located apparatus from verticality by 2 mm; c) - the result of calculating the SDS of the pipeline with a deviation of the vertically located apparatus from verticality by 3 mm; d) - the result of calculating the SDS of the pipeline with a deviation of the vertically located apparatus from verticality by 4 mm

4. Conclusion

According to the results of modeling the SDS of the technological pipeline with the presence of sections of the displacement of the edges of the docking elements equal to 0.9 mm, in order to assess the impact on it of technologically interconnected equipment, as well as the effect of deviations from the verticality of a vertically located apparatus by 1, 2.3 and 4 mm the following conclusions are drawn:

- it was found that the maximum stresses for the process pipeline increase when modeling its SDS in conjunction with neighboring devices;
- it was revealed that the SDS of the pipeline with the presence of displacement sections of the edges of the joined elements equal to 0.9 mm is greatly influenced by the deviation from the verticality
of a vertically located apparatus in a common technological system. Moreover, the maximum stresses are concentrated in the taps and increase by at least 16 MPa when deviating from the verticality of a vertically located apparatus with a range of 1 to 4 mm;

- it was found that the maximum stresses are concentrated not only in one particular element of the process pipeline, but can change their location depending on the amount of deviation from the verticality of a vertically located apparatus, as well as taking into account the interference of the apparatus from a common technological system;

- It is proposed to use the nomogram to determine the possible maximum stresses in the technological pipeline with the presence of displacement sections of the edges of the joined elements equal to 0.9 mm, taking into account the deviation from the verticality of a vertically located adjacent apparatus in the range from 0 to 4 mm.

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