Evaluation of the stressed-deformed state of the apparatus taking into account the influence of adjacent equipment and its geometric deviations

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Abstract. For timely field monitoring of equipment, the widest arsenal of non-destructive testing methods is used, which with a sufficient degree of reliability allows determining the degree and admissibility of defects in accordance with established standards. The required list of works and the established values are established by regulatory documents on industrial safety and technical diagnostics. As a rule, each device is subjected to a technical inspection individually with an individual set of tools to predict the residual life of a safe service. Existing methods do not take into account the possible impact on the surveyed apparatus of the loads and effects exerted by operational environment devices of the tested device. In addition, the current regulatory and technical documentation does not take into account the mutual influence of the quality of installation or repair of interconnected equipment. Various geometric deviations appearing during installation, repair, or operation, such as, for example, deviations from verticality, can serve to redistribute the stress-strain state and lead to premature failures and decommissioning. In this paper, we study the relationship between the impact of equipment in a technological connection on the operational parameters, as well as that of the geometric deviations of adjacent equipment on the stress-strain state of the apparatus.

1. Introduction
Technical devices of process facilities of oil refining and petrochemical industries are involved in various processes and in most cases form interconnected technological chains with possible mutual influence in relation to the existing loads during operation [1-5]. The commissioning of process facilities is preceded by installation or repair of the necessary equipment, taking into account all the structural and geometric features of the equipment, location by elevation, etc. Further uptime of technical devices, and, consequently, industrial safety of a hazardous production facility, depend on their quality. The current normative and technical documentation in the field of design and safe operation of the equipment provides for the necessary work, allowing with a certain degree of probability to predict the residual life of the equipment [6-8].

Such mandatory work includes:
- study and analysis of technical documentation;
- study of operational diagnostic data;
- full-scale examination of the object, including non-destructive testing;
- carrying out verification calculations for strength;
The above list of works is carried out for each technical device, as for a separate unit, and in many cases is carried out in the very minimum required amounts. Moreover, for supporting structures of equipment, only a visual inspection is required, and other methods are not regulated. Current methods do not provide for modeling the stress-deformed state (SDS) of equipment, taking into account the impact that interconnected equipment makes, as well as geometric deviations, such as deviations from verticality [9-12]. Therefore, it is advisable to simulate the SDS of each device, taking into account the relationship of the impact of equipment located in a mutual technological connection at operational parameters, the method of its location, as well as the influence of geometric deviations of this equipment from the vertical on the stress-deformed state of the device.

2. The research method

To study the impact of adjoining equipment and its deviations from verticality on the SDS of a device located in a mutual technological connection at operational parameters, two technological devices were selected that are technologically connected by a pipeline and form a single technological system. One of the devices has a vertical arrangement, and the other is horizontal. The material of both the apparatus and the pipeline is St3sp5 carbon steel.

The technical parameters of the technological system under consideration are as follows:
- design pressure Pdesign = 2.0 MPa;
- design temperature tdesign = 80 °C;
- working medium - hydrocarbon gas;
- inner diameter D of the vertical apparatus = 600 mm;
- wall thickness of the casing of the vertical apparatus S = 16 mm;
- the length of the casing of the vertical apparatus = 3130 mm;
- inner diameter D of the horizontal apparatus = 600 mm;
- wall thickness of the casing of the horizontal apparatus S = 16 mm;
- the length of the casing of the horizontal apparatus = 2680 mm;
- a pipe 168×6 mm with length 4300 mm;
- a bend 168×6 mm – 2 pieces.

The vertical apparatus is a vertical welded vessel, consisting of a cylindrical shell, elliptical bottoms, and process fittings, and is mounted on the support legs at a height of about 4 meters. The device is designed to reduce gas ripple.

The horizontal apparatus is a horizontal welded vessel, consisting of a cylindrical shell, elliptical bottoms, and process fittings, and is mounted on saddle supports. The device is designed to purify gas from suspended particles.

The pipeline has one straight vertical and horizontal section with a length of 2000 mm each, interconnected by bends to change the direction of flow. There is also one horizontal straight section 300 mm long. The pipeline is connected to the process fittings of the apparatus using flange connections.

For modeling SDD, 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.
The first step was the construction of a process system that includes apparatuses and a process pipeline in the SolidWorks software package. The constructed model of the system is presented in Figure 1.

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.

![Figure 1. The constructed model of the technological system](image)

For the purpose of practical interest and further analysis of the results, the SDS of the horizontal apparatus was calculated separately without affecting the associated technical devices. The results of calculating the SDS of a horizontal apparatus as a separate facility are shown in Figure 2.

![Figure 2. The results of calculating the SDS of the horizontal apparatus as a separate facility](image)

Analyzing the result, it can be seen that the maximum stresses arise in the welding zone of the stand of the fixed support to the backing sheet and are 204.9 MPa.

The next step was the calculation of the SDS of the entire technological system, which includes apparatuses and a technological pipeline, in order to assess the impact of operational loads on a horizontal apparatus. The result of calculating the SDS of a horizontal apparatus from the mutual influence of technical devices located in a mutual process connection is shown in Figure 3.
As can be seen from Figure 3, the maximum stresses in the zone in the welding zone of the fixed support post to the backing sheet increased by almost 20 MPa to 224.7 MPa compared to the maximum stresses of 204.9 MPa obtained when calculating the SDS of a horizontal apparatus as a separate object. Therefore, we can conclude that the equipment in a mutual process connection affects the SDS of the facility under consideration by increasing the maximum operating load.

The next step was an attempt to study the effect of geometric deviation from verticality, which may appear during the installation of a vertical apparatus, which is interconnected with the horizontal apparatus.

**Figure 3.** The result of calculating the SDS of a horizontal apparatus from the mutual influence of technical devices in a mutual process connection

Figure 4 shows the results of calculating the SDS of a horizontal apparatus for a 1 mm deviation of a vertically oriented apparatus from verticality by.

**Figure 4.** The result of calculating the SDS of the horizontal apparatus with a deviation from verticality
Figure 4 shows that when the vertical position of the apparatus deviates from the vertical by 2 mm, the maximum stresses at the point of welding of the stand of the fixed support of the horizontal apparatus increased to 230.7 MPa.

Further, the deviation from the verticality of the vertically located apparatus was set equal to 2 mm. Figure 5 shows the results of calculating the SDS of a horizontal apparatus with a deviation of a vertically located apparatus from verticality by 2 mm. It can be seen from Figure 5 that the maximum ones increased in the weld zone of the fixed support post and became equal to 236.8 MPa, which is 6.1 MPa more than the result obtained by deflecting the vertically positioned apparatus by 1 mm.

The last step in the research was the calculation of the SDS of the horizontal apparatus with a deviation from the verticality of the vertically located apparatus equal to 4 mm. Figure 6 shows the results of calculating the SDS of a horizontal apparatus with a deviation of a vertically located apparatus from verticality by 4 mm.

The obtained simulation results make it possible to construct a nomogram of the dependence of the maximum stresses in the fixed support of a horizontal apparatus on the deviation from the verticality of a vertically arranged apparatus (Figure 7).

**Figure 5.** The result of calculating the SDS of a horizontal apparatus when the vertically located apparatus deviates from verticality by 2 mm (the vertical apparatus is not conventionally shown)

**Figure 6.** The result of calculating the SDS of the horizontal apparatus with a deviation of the vertically located apparatus from the vertical by 4 mm
3. Conclusion

According to the results of modeling the SDS of a horizontal apparatus in order to assess the effect of interconnected equipment, as well as the effect of deviations from the verticality of a vertically located apparatus by 1, 2 and 4 mm, the following conclusions can be made:

- it was found that the maximum stresses for the apparatus becomes much higher when modeling its SDS in conjunction with process-interconnected technical devices compared to SDS as a stand-alone apparatus;

- it was revealed that deviation from the verticality of a connected vertically-oriented device has a sufficient effect on the SDS of the apparatus. Moreover, the maximum stresses are concentrated in the place of welding of the stand of the fixed support to the backing sheet and increase by 6–6.1 MPa with each deviation from verticality by 1 mm of the adjacent vertically located apparatus. This fact must be taken into account during inspection of a fixed support structure and to increase the amount of control of possible places of increased stresses by non-destructive methods using stress concentration meters based on the use of the metal magnetic memory method;

- It is proposed to use the nomogram to determine the possible maximum stresses in the fixed support of the horizontal apparatus, taking into account the deviation from the verticality of the vertically located adjacent apparatus.

References

[1] Mukhametzyanov Z R 2018 IOP Conference Series: Materials Science and Engineering 451(1) 012077
[2] Kulakov P A, Rubtsov A V, Afanasenko V G, Zubkova O E, Ivanova K K and Sharipova R R 2020 Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering 331(1) 97-105
[3] Tropkin S N, Tlyasheva R R, Bayazitov M I and Kuzeev I R 2018 IOP Conference Series: Materials Science and Engineering 327(4) 042012
[4] Kuzeev I R, Naumkin E A, Pankratiev S A and Tlyasheva R R 2018 Solid State Phenomena 284 SSP 587-592
[5] Balestra P, Henry K, Carlyon C, Epiney A and Strydom G 2020 Nuclear Engineering and Design 362 110526
[6] Chen Y-L, Zhang L-Y, Liu W-K, Wang J-H and Guo J-L 2012 Journal of Shanghai Jiaotong University 46(6) 936-942
[7] Kovshova Y S, Kuzeev I R, Naumkin E A and Fattakhov I G 2016 International Journal of Applied Engineering Research 11(3) 1630-1636
[8] Kovshova Y S, Kuzeev I R, Naumkin E A, Makhutov N A and Gadenin M M 2015 *Inorganic Materials* **51**(15) 1502-1507

[9] Bazhenov V G, Zhegalov D V, Kazakov D A, Nagornykh E V and Samsonova D A 2019 *PNRPU Mechanics Bulletin* **2019**(1) 8-17

[10] Bukleshev D O 2018 *Industrial safety* [in Russian – Bezopasnost’ Truda v Promyshlennosti] **2018**(2) 12-17

[11] Klimau K and Medvedev S 2016 *Procedia Engineering* **136** 21-27

[12] Berezyuk A I, Rovnyi S I, Khusainov M R, Verzakov A V and Sinitshyn E N 2013 *Chemical and Petroleum Engineering* **49**(3-4) 146-155