Stress-deformed state of a fixed support of the unit with account of influence of near back technical devices with geometric deviations

A V Rubtsov, P A Kulakov, Z R Mukhametzyanov, A R Farshatov, M I Bayazitov, Yu S Kovshova and I K Gimaltdinov

Ufa State Petroleum Technological University, 1, Kosmonavtov street, Ufa, 450062, Russia

E-mail: kulakov.p.a@mail.ru

Abstract. The normative and technical documentation in the field of industrial safety establishes permissible deviation standards at which the equipment can be operated at a given technological mode and regular monitoring of the technical condition. As a rule, the main method for detecting deviations is visual and measuring control, as well as geodetic measurements, allowing fixing the admissibility or inadmissibility of geometric deviations. However, the current methods do not provide the calculation of structures with geometric deviations under current operating loads with the determination and assessment of the places of the occurring maximum stresses, as well as their values. The stress-strain state of the process equipment also does not provide the assessment from the effects of neighboring technical devices that are in a common technological system and have various geometric deviations during installation. In this paper, we study the relation of technical devices that are in a common technological system and have geometric deviations such as deviation from verticality and the displacement of the edges by the stress-strain state of the fixed support of a horizontally located apparatus.

1. Introduction
The technological equipment of the oil and gas-refining complex is usually operated in a connected technological chain and performs a useful function aimed at ensuring the technological process and processing of raw materials in order to obtain marketable products. During the construction of oil and gas refining complexes by the installation companies that have the appropriate license, installation of technological equipment is carried out in the regulated ways and methods. Due to an error in the assembly and installation of technological units during installation technological operation, such as welding, installation of vertical apparatuses, various geometric deviations occur. They represent deviations from verticality when installing the apparatus at elevations, edge displacement when joining elements by welding. Their values are in the range indicated in the design and technical documentation. For identifying such geometric deviations, visual and measuring control is usually used using specialized tools, as well as determining deviations from the verticality of equipment using theodolites. Typically, the field of the above control methods establish the admissibility or inadmissibility of the value and draw conclusions about the possibility or impossibility of further operation. A set of works can also be carried out with non-destructive testing methods for assessing the quality of both the base metal and the welds of the controlled equipment. The main attention is
paid to those units and elements that will directly contact the process fluid at given pressures and
temperatures. However, there are such items of equipment that do not come into contact with the
working environment, but perform an equally important role in the operation of technological devices.
These elements include supporting constructions. Apparatuses during operation heat up and lengthen.
If thermal elongation is not possible, then a lot of stress can occur in the walls. For reducing the
temperature stresses, one support is made stationary, and the other is movable, providing free
movement of the apparatus relative to the supporting structure. The most unfavorable is a fixed
support, since with its help the apparatus is rigidly fixed from possible movements and it is in a fixed
support that maximum stresses can occur during the development of various scenarios. When
examining supporting constructions, the main method is a visual inspection to assess the quality of
fasteners, constructions, identify visible defects. It is possible to use color or magnetic methods to
detect surface cracks in metal structures. However, current methods do not provide for the assessment
of the stress-deformed state (SDS) of a fixed support from the influence of geometric deviations of the
associated equipment. Therefore, it is advisable to simulate the stress-deformed state of the stationary
support of a horizontal apparatus from the impact of equipment located in a common technological
system and having various geometric deviations [1-5].

2. Methods of Study
For modeling the SDS of the fixed support of the technological apparatus, the technological unit was
selected, which includes a vertical buffer tank and a horizontal filter, technologically connected by a
pipeline. The material design of the apparatus and the pipeline is carbon steel of ordinary quality
Ст3сп5.

The parameters of the technological unit are as follows:
- design pressure $P_{\text{design}} = 2.0$ MPa;
- design temperature $t_{\text{design}} = 80^\circ$ C;
- working medium - hydrocarbon gas;
- inner diameter $D$ of a buffer tank = 600 mm;
- wall thickness of the buffer tank body $S=16$ mm;
- buffer tank body length = 3130 mm;
- filter inner diameter $D = 600$ mm;
- the wall thickness of filter body $S=16$ mm;
- The length of filter body = 2680 mm;
- a pipe $168\times6$ mm with the length 4300 mm;
- tap $168\times6$ mm – 2 pieces.

The buffer tank is a vertical welded vessel, consisting of a cylindrical shell of the body, elliptical
bottoms and technological fittings and mounted on the support legs at a height of about 4 meters. The
apparatus is designed to reduce a pulsation of the gas.

The filter is a horizontal welded vessel, consisting of a cylindrical body shell, elliptical bottoms,
and technological fittings and mounted on saddle supports. The apparatus 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 taps to change the direction of flow. There is also one horizontal straight section
300 mm long. The pipeline is connected to the technological fittings of the apparatus using flange
connections.

For model the SDS, we used the licensed SolidWorks 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;
- creation of finite element mesh, its optimization according to various criteria;
calculation. The first step was the construction of a technological unit, which includes apparatuses and a technological pipeline in the SolidWorks software package. The model of the technological unit is shown in the figure 1.

Figure 1. Model of technological unit.

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 [6-11].

3. Results and Discussion

For the purpose of practical interest and further analysis of the results, the SDS filter was calculated separately without affecting the associated technical devices. The results of calculating the SDS filter are shown in Figure 2 [12-13].

Figure 2. Calculation results of SDS of the filter.

Analyzing the result, it can be seen that the maximum stresses arise in a fixed support and amount to 204.9 MPa. The next step was the calculation of the SDS of the entire technological unit, which includes apparatuses and a technological pipeline in order to assess the impact at workloads on a fixed filter support. The result of calculating the SDS filter from the joint influence of equipment located in the common technological system is shown in Figure 3.
As can be seen from Figure 3, the maximum stresses in the zone in the fixed support increased by almost 20 MPa to 224.7 MPa compared to the maximum stresses of 204.9 MPa obtained when calculating the SDS of filter as a separate apparatus. Consequently, we can conclude that the joint equipment affects the SDS of the apparatus by increasing the maximum effective stress.

Next, modeling of the geometric deviation from the vertical of the buffer tank by 1 mm was carried out, as well as the offset when welding the docking edges of the straight horizontal pipe section 168 × 6 mm to the branch 168 × 6 mm 1 mm upward towards tap. Figure 4 shows the results of calculating the SDS of filter when the buffer tank deviates from verticality by 1 mm and the edges of the joined elements are shifted by 1 mm of the process pipeline section.

**Figure 3.** The result of calculating the SDS of the filter from the joint influence of equipment located in a common technological system.

**Figure 4.** The results of calculating the SDS of the filter when the buffer tank deviates from verticality by 1 mm and the edges of the joined elements are shifted by 1 mm of the process pipeline section.
Figure 4 shows that when the buffer tank deviates from verticality by 1 mm and the edges of the joined elements are shifted by 1 mm in the section of the process pipeline, the maximum stresses in the fixed filter support increased to 239.5 MPa.

Further, the deviation from the verticality of the buffer tank was set equal to 2 mm with a constant location and the value of the offset of the edges of the joined elements of the pipeline.

The last step was modeling the SDS of filter with a deviation from the verticality of the buffer tank equal to 4 mm with a constant location and the offset value of the edges of the joined elements of the pipeline.

Figure 5 shows the results of the calculation of the SDS of a horizontal apparatus with a deviation of a vertically located apparatus from verticality by 4 mm.

Figure 5 shows that when the buffer tank deviates from verticality by 4 mm and the edges of the docking elements are shifted by 1 mm in the section of the process pipeline, the maximum stresses in the fixed filter support increased to 261.2 MPa.

In order to reduce the maximum stresses in the fixed filter support from the effects of both operational loads and geometric deviations of technological equipment from the joint technological system, a constructive decision was made to weld a stiffening ring with dimensions 40 × 40 × 4 mm from St3sp5 steel on the inside of the filter body at a distance 200 mm from the edge of the cylindrical part of the body. The filter body in section with a welded stiffening ring is shown in Figure 6.

![Figure 5](image1.png)

**Figure 5.** The results of calculating the SDS of filter when the buffer tank deviates from verticality by 4 mm and the edges of the docking elements are shifted by 1 mm of the pipeline section (buffer tank not conventionally shown)

![Figure 6](image2.png)

**Figure 6.** Section of the filter body with welded stiffening ring
After installing the stiffening ring, the stress-deformed state of filter was modeled for the most unfavorable parameters from the above calculations, namely, when the buffer tank deviates from the verticality of the buffer tank equal to 4 mm with a constant location and offset value of the edges of the joined pipeline elements. The results of calculating the stress-deformed state of the filter when the buffer tank deviates from verticality by 4 mm and the edges of the docking elements are shifted by 1 mm in the section of the process pipeline using a stiffening ring are shown in Figure 7.

**Figure 7.** The results of calculating the stress-deformed state of the filter when the buffer tank deviates from verticality by 4 mm and a displacement of the edges of the elements to be joined by 1 mm of the section of the process pipeline using a stiffening ring (buffer tank not conventionally shown)

As it can be seen from the obtained results, the maximum stresses from the fixed filter support moved to the weld zone of the outlet (compared to Figure 6) and make up only 170 MPa, which is 1.5 times less than the same option, but without using a stiffening ring. Therefore, the use of stiffening rings to make constructive decisions to reduce the maximum acting stresses in the fixed supports of horizontal devices in the presence of geometric deviations from verticality and displacement of the edges of technical apparatuses from a common technological system is advisable.

4. **Conclusion**

According to the results of modeling the stress-deformed state of the technological unit, which includes a vertical buffer tank, a horizontal filter and a pipeline, technologically connected data devices, we can make the following conclusions:

- we found that the maximum stress for the horizontal filter is significantly increased if, when modeling, technical apparatuses from a common technological system are taken into account, and not considered as a separate object;

- we was revealed that the deviation from the verticality of the buffer tank and the displacement of the edges of the joined elements of the process pipeline have a sufficient effect on the stress-deformed state of the filter. Moreover, the maximum stresses are concentrated in a fixed support and increase by a value of at least 6 MPa with each deviation from verticality by 1 mm of buffer capacity. If such geometric deviations are detected, the fixed support should be more thoroughly diagnosed with non-destructive testing methods in the complex;

- it was revealed that in order to change the places of occurrence of maximum stresses in horizontally located apparatuses due to the presence of deviations from verticality and displacement of the edges of the joined elements of technical apparatuses in a common technological system, as well as reduction of their numerical values, it is advisable to use stiffening rings.
5. Acknowledgments
The work was performed within the framework of the Ministry of Science and Higher Education of the Russian Federation state task in the field of scientific activity, publication number FEUR - 2020 - 0004 “Solving urgent problems and researching processes in petrochemical industries accompanied by flows of multiphase media”.

References
[1] Naumkin E A, Shermatov J N and Gaysina A I 2018 Materials Science Forum 945 653-659
[2] Kuzeev I R, Naumkin E A, Pankratiev S A and Tlyasheva R R 2018 Solid State Phenomena 284 587-592
[3] Kuzeev I R, Naumkin E A, Tepsaev A N, Samigullin A V and Gafarova V A 2015 SOCAR Proceedings 4 75-80
[4] Skuridin N N, Tyusenkov A S and Bugay D E 2018 Neftyanoe Khozyaystvo - Oil Industry 8 92-95
[5] Nasibullina O A and Tyusenkov A S 2019 IOP Conference Series: Materials Science and Engineering 537(2),022018
[6] Salha L, Bleyer J, Sab K and Bodgi J 2020 Advanced Modeling and Simulation in Engineering Sciences 7(1) 2
[7] Kulakov P A, Rubtsov A V and Afanasenko V G 2019 International Multi-Conference on Industrial Engineering and Modern Technologies, FarEastCon 2019 8933869
[8] Ma C, Yu T, Van Lich L, Thanh-Tung N and Bui T Q 2020 European Journal of Mechanics, A/Solids 82 103980
[9] Zhang Z and Hesthaven J S 2020 Computer Methods in Applied Mechanics and Engineering 366 113051
[10] Tian F, Tang X, Xu T, Yang J and Li L 2019 International Journal for Numerical Methods in Engineering 120(9) 1108-1125
[11] Ma Y, Wang G, Guo Z, Jiang T and Zhang J 2019 Construction and Building Materials 225 601-610
[12] Bayazitov M I, Berdin V K, Kulakov P A, Afanasenko V G, Bayazitov R M and Tlyasheva R R 2019 Journal of Physics: Conference Series 1399(5) 055064
[13] Tsvetkov A B and Pavlova L D 2018 IOP Conference Series: Earth and Environmental Science 206(1) 012008