Modeling of the stress-deformed state of a capacitive apparatus with geometric deviations when mounting on a foundation

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Abstract. The reliable and trouble-free operation of the capacitive equipment of hazardous production facilities is significantly influenced by the quality of the installation performed before commissioning. So, during the installation of capacitive equipment, various geometric inconsistencies and deviations may occur, which are established by the current regulatory and technical documents for the installation of technological equipment. If unacceptable deviations and inconsistencies established by regulatory and technical documents are found, they must be fully eliminated. However, in certain cases, the regulatory and technical documentation allows operation with various insignificant geometric deviations and inconsistencies that do not go beyond the established limits. This may relate to deviations from the design horizontal position of the apparatus when installed on a foundation. It should be noted that during operation, under the influence of increased pressure, temperature and other loads, an apparatus with deviations of this type can undergo a completely different stress-deformed state compared to an apparatus without geometric deviations, which is not taken into account in expert diagnostics, strength analysis and assessment of residual resource. The solution to this issue can be approached using software systems that allow building 3D models of the objects under consideration with the introduction of all the necessary parameters into these models and getting a real picture of the distribution of zones of increased stress. In this work, the stress-deformed state of the process vessel is simulated due to the impact of working loads and different directions of deviation from the horizontal design position of the body when the apparatus is mounted on the foundation.

1. Introduction

One of the most important stages before putting technological devices into operation is installation and installation on a foundation. The quality of installation work has a significant impact on the safe and trouble-free operation of the equipment. Various deviations and inconsistencies that arise during the installation process can make a significant contribution to the redistribution of places where the maximum acting stresses are concentrated [1-5]. Such a redistribution can worsen the forecast of the residual resource of the apparatus. One of such deviations may be a violation of the horizontal position of the apparatus on the foundation, for example, due to non-compliance with the horizontal foundation under the supports. Due to such unevenness, a skew of one end of the apparatus is formed relative to the other. The slightest bias can affect both the values of the arising maximum stresses and the areas where they are concentrated. The current regulatory and technical documents establish the
requirements for the methodology for the installation of devices and its quality control. However, insufficient attention is paid to minor deviations that do not exceed the permissible deviations during diagnosis. However, sometimes even insignificant values of deviations can lead to the fact that the distribution of stresses in the elements of devices will not be uniformly distributed but concentrated at a certain point. This can be a harbinger of premature destruction of the most loaded element. In the question of studying the nature of stress distributions, software systems can help that allow analysis of the stress-deformed state with various existing deviations and defects [6-8]. Therefore, the actual work is the assessment of the stress-deformed state of the capacity with different directions of deviation from the horizontal design position of the body when the apparatus is mounted on the foundation and the simultaneous action of operational loads.

2. Methodology of the research
To carry out studies on the impact on of different directions of deviation from the horizontal design position during installation, the capacity of the process oil refinery was selected. The structural material of the shell of the hull, elliptical bottoms and manhole is steel Fe37B1FN. Material design of connectors - steel 20. The vessel is operated with hydrocarbon gas at an internal overpressure of 0.65 MPa at a temperature of 100 °C. Container has inner diameter equal to 2400 mm and shell thickness equal to 22 mm. The thicknesses of the left and right elliptical bottoms are 24 mm and 28 mm, respectively. Vessel body has length equal to 10 meters.

Vessel is installed horizontally on two saddle supports, left of which is fixed, and right support is movable. Vessel body consists of 6 separate cylindrical shells of different lengths, which are welded to each other by means of annular seams.

To evaluate the change in stress-deformed state, the license software complex "KOMPAS-3D" was used with the APM FEM system integrated into it. Initially, a 3D capacity model was developed in the COMPAS-3D software complex. The 3D capacity model developed is shown in figure 1 [9-11].

Further, using the strength analysis system "APM FEM," operational loads were applied and the necessary fasteners were installed [12-14].

3. Research results and their discussion
In order to compare the obtained research results, at the first stage, the stress-deformed state of the tank at working pressure and temperature was estimated for the design horizontal position on the foundation without any deviations. The results of the stress-deformed state assessment of the tank at operating pressure and temperature for the design horizontal position on the foundation without any deviations are shown in figure 2.

It can be seen from figure 2 that the value of maximum active stresses is 200 MPa and the zone of maximum stress concentration is the tie-in of the lower nozzle into the cylindrical shell No. 1. Stresses, which in their values are close to maximum stresses, are located in areas of annular welds of the vessel. Moreover, the zone of increased stresses in the zone of welding of the right elliptical bottom to the shell of the body is most clearly indicated due to the different thickness of the jointed elements.

At the second stage, the stress-deformed state of the tank was estimated with deviations from the horizontal design position when mounting 5 mm up and down each of the supports relative to the other support.

The results of stress-deformed state assessment of capacity with maximum stresses are given in figures 3-6.
Figure 1. 3D capacity model. A, B, C, D, E – designation of circumferential welds of the container body; 1,2,3,4,5,6 – numbers of welded cylindrical shells of the vessel body. $+\Delta$ - an example of a 5 mm vertical displacement upward of fixing one of the tanks supports on the foundation relative to the other support. $-\Delta$ - example of 5 mm vertical displacement downward of fixing one of the tanks supports on the foundation relative to the other support.

Figure 2. Results of tank stress-deformed state assessment at operating pressure and temperature without deviations from horizontal design position during installation.

Figure 3. Results of tank stress-deformed state assessment at operating pressure and temperature with deviation from the horizontal design position during installation by 5 mm upwards of the left fixed support relative to the right movable support results of calculating the stress-deformed state.
Figure 4 shows that the maximum stresses do not change their location in comparison with figure 2, but are already 238 MPa, which is 38 MPa more than the maximum stresses without deviations from the horizontal. Also, the square of areas of increased stress has decreased.

Figure 4. Results of stress-deformed state assessment of the tank at operating pressure and temperature with deviation from horizontal design position during installation 5 mm down of the left fixed support relative to the right movable support.

Analyzing figure 4, a very interesting fact is seen. The values of the maximum effective stresses fully correspond to the values of the maximum effective stresses for the variant without deviations from the horizontal. However, the area of the areas of increased stresses has increased and the zone of concentration of maximum stresses has changed and is concentrated in the rightmost choke of the case.

Figure 5 shows that the maximum stresses with a deviation of 5 mm upward of the right movable support relative to the left fixed support are 320 MPa. This value is 82 MPa more than with the same deviation from the horizontal of the left fixed support. The zone of concentration of maximum stresses is concentrated in the extreme right nozzle of the body.

Figure 5. Results of tank stress-deformed state assessment at operating pressure and temperature with deviation from horizontal design position during installation by 5 mm upwards of RH movable support relative to LH fixed support.
The results shown in figure 6 show that the maximum stresses are 1040 MPa and have increased by 3.25 times compared to the results in figure 5 and 5.2 times compared to the results in figure 4. The area of increased stresses is predominantly the case.

In order to reduce the values of maximum voltages in the tank for the most unfavorable scenario shown in figure 6 (the presence of a deviation from the horizontal design position during installation by 5 mm down the left movable support relative to the right fixed support; maximum stresses are 1040 MPa), it is proposed to use a stiffening ring. In the 3D model of the container, a ring is installed on the inside to give additional stiffness. The distance from the stiffening ring to the left edge of the cylindrical body of the container is 2400 mm. The profile of the ring is an angle with dimensions of 15 × 15 × 5 mm made of St3 steel. Figure 7 shows the welded stiffness ring on the inside of the cylindrical vessel housing.

The results of the stress-deformed state assessment of the tank with the presence of a stiffness ring on the inside of the housing are shown in figure 8.
Figure 8. Results of stress-deformed state assessment of the tank with stiffness ring on the inner side of the housing.

As shown in figure 8, the value of the maximum stresses resulting from the installation of the stiffening ring on the inner surface of the container body is only 220 MPa, which is 4.7 times less than the values of the maximum stresses without using the ring.

4. Conclusion

Based on the results of modeling the stress-deformed state of a buffer tank with deviations from the horizontal design position during installation by 5 mm up and down each of the supports relative to the other support, the following conclusions can be drawn:

- it was found that the magnitude and zone of concentration of maximum stresses is influenced by the type of support (movable or fixed) and its location, where there is a deviation from the horizontal during installation, relative to other structural elements of the tank;
- it is shown that the maximum stresses arise when the deviation from the horizontal design position of the right movable support relative to the left fixed support is concentrated downward.
- it has been established that in order to reduce the numerical values of maximum voltages in capacitive equipment in the presence of deviations from horizontality during installation, stiffening rings are used, the dimensions and area of their installation of which should be selected depending on the individual features of the process equipment under consideration.

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