Modeling the stressed-deformed state of a technological tank with a mechanical defect of type "dent"

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Abstract. In the process of transporting the tank to the place of operation, as well as during installation and repair work, the formation of mechanical defects on the body, such as a “dent”, of various sizes, shapes and locations relative to structural elements and technological fittings is possible. Defects of this type are stress concentrators, which may be the key to premature equipment failure due to its failure. The current regulatory documentation in the field of assessing the technical condition and strength analysis of capacitive equipment has established the necessary set of work to assess the negative impact of defects such as a “dent” on the normal operation of the vessel. However, in most cases, normative documents presuppose types of work aimed directly at identifying the geometrical dimensions of the dent and conducting non-destructive testing of the areas closest to it in order to identify unacceptable defects and unacceptable thinning zones, as well as strength calculation with a defect. According to these parameters, the so-called “admissibility” or “inadmissibility” of the detected dent is evaluated. In this paper, we study the relationship between the impact of a dent with certain geometric dimensions on the body of the technological tank on its stress-deformed state, considering the location of the technological fittings, and constructive solutions are developed to reduce the numerical values of maximum stresses.

1. Introduction

Oil refining and petrochemical plants operate a large quantity of steel technological tanks with various individual features, specially designed for the necessary operating conditions in many technological processes [1-4]. Technological tanks are used for storage and processing of hydrocarbon combustible and flammable liquids and gases, which serves as a prerequisite for increasing operational reliability during operation and tightening industrial safety rules during operation. Operational reliability depends on many factors, such as, for example: operating conditions, material, operating loads, periodic monitoring of the technical condition, the presence of defects, etc [5-6]. Particular attention is paid to identifying equipment defects, determining the size of defects, location, causes and “admissibility” or “inadmissibility”, since defects adversely affect the safe operation resource and operational reliability, significantly reducing them [7-8]. Of particular interest is the assessment of the technical condition of vessels and apparatuses of a capacitive type with mechanical defects of the “dent” type, which can form during transportation, installation and repair, and the possibility of operation with defects of this type.

The current regulatory documentation regulates the scope of work when bulges, dents, corrugations along the length of each deformed section are detected on the vessel’s body.
For dents or bulges, the largest size of which on the surface of the element does not exceed 20S (where S is the wall thickness of the vessel element), but not more than 200 mm, the maximum relative deflection should not exceed 5%, and the absolute value of the deflection should not exceed half the thickness of the element wall. If these requirements are not met, the question of the possibility of admission to further operation of the vessel with a dent (bulge) is decided on the basis of a special strength calculation.

Therefore, it is advisable to simulate the stress-strain state (SDS) of technological tanks with a “dent” type defect on the case with dimensions as large as or exceeding the “allowable”, in order to determine the effect of a dent on the SDS of the equipment as a whole, to identify areas of increased stress and to develop constructive solutions to reduce these stresses and increase operational reliability [9-14].

2. The research method

In order to investigate the effect of a “dent” type mechanical defect with certain geometric dimensions on the technological body of the tanks on the stress-deformed state of the body, considering the location of the technological fittings, the technological tank of one of the oil refineries with a dent of 200 mm and a deflection of 30 mm was visualized and measuring control. A dent is located on the body on the left side of the vessel between the DN 400 hatch and the saddle support at a distance of 450 mm from the edge of the cylindrical shell. The material of the body and technological fittings of the tank is 09G2S low alloy steel.

The technical parameters of the tank are as follows:

- design pressure \( P_{\text{calc}} = 1.6 \text{ MPa} \);
- design temperature \( t_{\text{calc}} = 100 \degree \text{C} \);
- working environment - liquid petroleum product;
- inner diameter \( D = 1200 \text{ mm} \);
- wall thickness of the body \( S = 20 \text{ mm} \);
- the length of the container body - 5790 mm.

The tank is a horizontal welded vessel, consisting of a cylindrical shell of the body, elliptical bottoms, technological fittings with patch rings on fittings of larger diameter and mounted on saddle supports. The tank is designed to separate liquid and gas and plays the role of a separator.

In the research process, the licensed SolidWorks software package was used with the Simulation system integrated in it for solving engineering and research problems.

This system is built into the software product and allows modeling to solve strength and thermal problems. The procedure is performed 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. At the first stage, a dent model was built in the SolidWorks software package.

The constructed capacity model is shown in figure 1.

![Figure 1. The model of the tank with the dent.](image-url)
Then, using the Simulation Strength Analysis module, which is part of the SolidWorks Premium basic configuration, internal pressure was applied; fastenings are installed on the supports. After this, a finite element mesh was created and a stress-deformed state (SDS) calculation was performed.

The results of calculating the SDS of the tank with a dent are shown in Figure 2.

![Figure 2. The results of SDS calculation of the tank with a dent.](image1)

Analyzing the result, it can be seen that the maximum stresses arise in the insertion area of the hatches and amount to 301.7 MPa, which is significantly higher than the yield strength of 09G2S steel at a design temperature of 100 °C, equal to 235 MPa.

In order to assess the impact of a dent on the result, it was decided to remove the dent from the model and calculate the SDS without it. The result of calculating SDS without a dent is shown in Figure 3.

As can be seen from Figure 3, the maximum stresses arise in the insertion zone of the DN 25 fitting and amount to 223.5 MPa, which is slightly less than the yield strength for 09G2S steel at a design temperature of 100 °C. Consequently, the dent itself, as well as its location, have a significant impact on the SDS of the technological capacity as a whole.

The next step was an attempt to study the influence of the location of the largest diameter of the hatch fittings of size DN 400 on the SDS of the tank body. The hatch was transferred, based on design considerations, to the most favorable area for its free location relative to other technological fittings at a distance of 3000 mm from the left edge of the cylindrical shell of the body. The results of calculating the SDS of tank with the transferred hatch are shown in Figure 4.

![Figure 3. The result of calculating the SDS of tank without a dent.](image2)
Figure 4. Results of calculating the SDS of a tank with the transferred hatch at 3000 mm relatively to the left edge of the cylindrical body.

The maximum stresses are 375.2 MPa and significantly exceed the yield strength of the steel used at the design temperature. Consequently, the initial location of the hatch, established by the design and construction documentation, is more optimal from the point of view of the occurrence of maximum stresses.

In order to reduce the maximum occurring stresses, an attempt was made to change the design of the technological tank by welding a ring of stiffness with a size of 140 × 140 × 10 mm from 09G2S steel on the body in order to give additional rigidity and strength in the dent area and insert of the DN 400 hatch. The initial distance of the welding of the stiffening ring was set to a distance equal to 920 mm relative to the left edge of the cylindrical body of the tank, corresponding to the nearest free space for its installation relative to the technological fittings. The distance from the stiffening ring to the nearby fittings is at least 100 mm, which corresponds to the current regulatory documents in the field of designing vessels and apparatuses. The results of calculating the SDS of a tank with a stiffening ring at a distance of 920 mm from the left edge of the cylindrical shell of the tank are shown in Figure 5.

As can be seen from the figure, the maximum stresses are 272.2 MPa in the insertion area of the hatch, which is less than the maximum stresses that were obtained when calculating the SDS of a tank without a stiffening ring equal to 301.7 MPa, but still more than the yield strength of steel at the design temperature, equal to 235 MPa.

Figure 5. The results of calculating the SDS of tank with a stiffening ring at a distance of 920 mm from the left edge of the cylindrical body of the tank.
As an experimental study, a SDS was also calculated with the hatch moved to a distance of 3000 mm relative to the left edge of the cylindrical shell of the body with a stiffening ring at a distance of 920 mm from the left edge of the cylindrical shell of the tank. The calculation results are shown in Figure 6.

![Figure 6](image)

**Figure 6.** SDS calculation results with the hatch moved to a distance of 3000 mm and the stiffening ring at a distance of 920 mm from the left edge of the cylindrical shell of the tank.

As can be seen from Figure 6, when welding the stiffening ring, the maximum stresses moved from the insertion area of the hatch (compared to Figure 4) to the area of the edges of the indentation and began to be 485.7 MPa, which led to the formation of a crack.

In this regard, it was suggested that the key aspect of changing the maximum stress values is the location of the stiffening ring relative to the hatch and dent. To test this hypothesis, the stiffening ring was moved from a distance of 920 mm relative to the left edge of the cylindrical shell of the tank to a distance of 1600 mm, which satisfies the condition of free installation of the stiffening ring relative to location of technological fittings. The results of calculating the SDS of a tank with a stiffening ring at a distance of 1600 mm from the left edge of the cylindrical shell of the tank are shown in Figure 7.

![Figure 7](image)

**Figure 7.** The results of calculating the SDS of a tank with a stiffening ring at a distance of 1600 mm from the left edge of the cylindrical shell of the tank.
As can be seen from the obtained results, the maximum stresses from the insertion zone of the fitting moved to the area of the edges of the dent (compared to Figure 5) and make up only 189.7 MPa in the area of the edges of the dent, which is less than the yield strength for steel 09G2S at a design temperature of 235 MPa. Therefore, the use of stiffening rings to solve problems of strength with mechanical defects of the “dent” type and the influence of the location of technological fittings is permissible and advisable.

3. Conclusion
Based on the results of modeling the SDS of a technological tank with a mechanical defect of the “dent” type and considering the influence of the location of technological fittings on the tank body, the following conclusions can be made:
- it was established that the occurrence of maximum stresses in the body of capacitive equipment is significantly affected by the presence and location of a mechanical defect of the “dent” type, as well as the location of technological fittings on the vessel’s body relative to the dent, with hatches with a maximum nominal diameter being decisive;
- it was revealed that in order to change the places of occurrence of maximum stresses in the case of technological tanks and reduce their numerical values, it is advisable to use stiffening rings, the sizes of which and the welding spots should be determined experimentally when modeling the SDS of the object under consideration, considering its design and operational features.

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