Increasing service life of chuck unit of tank during cyclic loading

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Abstract. Performance of the tanks depends on the tightness of all their components and joints, quality thereof formed during the construction phase. Analysis of the results of the VST (vertical steel tank) examination shows that a greater number of defects are concentrated in the chuck unit of the tank - the place where wall and bottom meet. The main issue that arises in the installation of vertical steel tanks is technological lack of penetration of the chuck unit, as well as excess of the clearance in the joint of the welded joint directly prior to welding, due to high threshold deviations in the foundation base dimensions and imperfect assembly operations. Additional tensile stresses resulting from elastic deformation of the bottom to ensure the required clearance in the welding lead to premature failure of the tank. It has been experimentally shown that with increasing clearance in the joint (with subsequent reduction to the rated value), the fatigue life of the chuck unit decreases. Various types of additional treatment allowing one to prolongservice life of the chuck unit.

1. Introduction
During construction of the tank during welding, problems such as edge misalignment, increased clearance, and their elimination leads to an increase in internal stresses in the joint and occurrence of structural deformations, which adversely affects service life of the tank.

2. Results and discussion
Analysis of the results of defects detected during technical surveys shows that the greatest number of failures is associated with defects of the chuck unit - the place of the interface between the wall and the bottom. This is due to the fact that this unit is experiencing a difficulty - stress state, caused by annular tensile and meridional stresses of bending from the edge moments. [1-3]
1 – defects located on the wall; 2 - defects located in the chuck connections; 3 - defects located in the assembly joints; 4 - defects located in the branch pipe; 5 - defects located in the bottom; 6 - defects located in the pipeline.

**Figure 1.** A function of the number of tank failures versus their location [1].

To determine internal stresses in the joint produced when violating the technology, namely, during elastic deformation of the bottom corner, mathematical models of the chuck unit in ANSYS software package have been calculated.

2° sector of VST 5000 m3 has been taken as a calculation pattern according to GOST 31385-2016 “Vertical cylindrical steel tanks for oil and oil products” [4]. Precise dimensions of the pattern are:

- width - 510 mm;
- length - 597 mm (sector 2°);
- height - 1200 mm;
- metal thickness - 10 mm.

Geometric dimensions of the defect:
- width - 4 mm;
- height - 2 mm.

When calculating the first pattern (without deformation), the joint was heated to 1600°C followed by cooling at 20°C for 66 minutes. Firmfastening was ensured in the bottom and edges of the pattern.

Calculation of the internal equivalent stress fields is shown in Figures 2, 3.
Figure 2. Distribution of internal equivalent stresses in the chuck unit of VST 5000: a - after welding, b - after welding with elastic deformation of the bottom (bringing clearance to the rated value from 6 mm to 0 ± 2 mm)

Figure 3. Distribution of internal equivalent stresses after welding with elastic deformation of the bottom in the zone of maximum deformation

Based on mathematical models (Fig. 3), one can see occurrence of local zones with maximum voltage of 296 MPa, which is close to the yield point of the given steel 09G2S - 345 MPa. Operational loads and permissible defects after welding in these sections will inevitably result in premature failure of the unit, and hence, the entire tank.

Experimental studies have been performed to determine the degree of influence of the clearance between the wall and margin on the service life of the chuck unit. For that purpose, samples were prepared for fatigue test from sheets of 10 mm in thickness made of steel 09G2S (Figure 4). The width of the samples was 40 mm. Sheets were welded in laboratory conditions using semiautomatic welding in carbon dioxide medium with a wire of 1.2 mm in diameter, Sv-08G2S.

Studies on low-cycle fatigue have been performed in accordance with GOST 25.502-79 for three assembled units: welded by technology, simulating increase in the clearance of 2 and 4 mm above the rated value, equal to 2 mm, i.e. the samples had clearances of 2, 4 and 6 mm, respectively.
The samples being considered were divided into groups. One group of samples was not exposed to thermal and vibration treatment, the remaining samples were divided into groups that were exposed to appropriate treatments:
- heat treatment (tempering) after welding;
- ultrasonic treatment after welding;
- vibration treatment during welding;

For heat treatment of samples, high tempering was selected: heating to 500°C, holding for 3 hours followed by cooling in the air. The use of heat treatment in this work was done only for comparison with other methods of post-welding treatment, since in practice it is associated with technical difficulties and requires a lot of labor.

Ultrasonic processing was performed using technological complex “Shmel” IL100-16 at a frequency of 25-27 kHz and amplitude of 35 microns; time treatment made 15-20 minutes. With the ultrasonic method, plastic deformation of the surface of the treated metal occurs, which leads to slight hardening at shallow depth. During treatment of the welded joints from carbon and low-alloy steels, this method allows tensile stresses to be transferred to compressive surfaces due to deformation [5-12].

Welding of samples with concomitant vibration treatment was performed on a vibrating bench developed by Ufa State Oil University with an amplitude of oscillations equal to 1 mm and a frequency of 50 Hz.

Tests for cyclic durability have been performed with soft axisymmetric loading, when the amplitude of stresses is constant, and strain amplitude varies with the number of cycles.

The experiment was performed on tensile machine INSTRON 8801. This servo-hydraulic test system, model 8801, meets requirements for both dynamic and static testing. Model 8801 enables making various kinds of mechanical tests (static, low and multicyclic fatigue tests).

The experiments were performed under the following conditions: temperature - 20°C, load - 10 kN, frequency - 0.3 Hz. In the course of the test, it was established that cracks in the welded joint of the chuck unit formed in the zone of thermal influence of the wall.

**Figure 4.** Trial sample of the chuck unit made with thermal treatment after welding: a - sample drawing, b - picture of the produced sample
3. Conclusion

1) Increasing clearance at the joint of the chuck unit prior to welding reduces its cyclic durability by 9.9% and 23.2%, respectively, and increasing clearance of 4 and 6 mm, due to elastic deformation of the bottom corner to bring the clearance to regulatory requirements (clearance of 2 mm).

2) Additional treatment of the chuck unit allows increasing its cyclic durability depending on the type of treatment. The most effective treatment, significantly increasing cyclic strength (almost 3 times), is heat treatment, but this treatment method is given as a comparison, as it is the most expensive and difficult to implement in the process of construction. Vibration treatment during welding allowed one to increase durability of the samples almost 2 times in all cases of increased clearance, and ultrasonic treatment gave an increase in the range of 38-45%.

3) Based on the studies performed, it is recommended to use ultrasonic treatment in the areas exceeding regulatory clearance in the joint or performing welding operations with concomitant vibration treatment, which will prevent occurrence of defects in the chuck unit leading to the failure of the tank.

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