Stress-strain condition of flat manhole covers under internal pressure in presence of mechanical defect with different dislocation on surface

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Abstract. One of the most common damage to the structural elements of vessels and apparatus of hydrocarbon processing plants is mechanical damage, which mainly occurs during repair and installation operations. One of the prerequisites for the occurrence of this type of defects is the use of a locksmith tool and other devices, tools and devices, upon contact of which with the surface of the elements to be repaired and mounted, risks, scratches, balls, nicks and other damage are formed. The vast majority in terms of the degree of occurrence on the surface of structural elements of all defects of a mechanical nature occupy scratches. There is practically no technical device operating in a hazardous production facility and does not have at least one of the elements of this type on the external surface. With respect to the surface on which the scratches are arranged, these defects can be both small geometrical dimensions and sufficiently extended. Such defects generally do not limit the life cycle of the object, but can have a significant effect on the redistribution of the stress-strain state in the element. The redistribution of the stress-strain state can serve as an initial stage for the generation of potential fracture sites from the concentration of increased stresses in these zones. Also, not only the presence of a scratch, but also the length, as well as the nature of the location on the surface of the element, can affect the stressed-deformed state of the element. Therefore, the actual work is a study of the change in the stress-deformed state of the flat manhole cover with a scratch, the arrangement of which on the surface has various options. In this work, the stress-strain state of the flat manhole cover is simulated depending on the change in the angle of inclination and the location of the scratch on it relative to the central zone.

1. Introduction
The stress-strain state (SDS) of vessels and apparatus of the oil and gas industry depends on many factors. These include design features, operating conditions, various external factors, etc [1-5]. A special place among these factors is occupied by the presence and level of defects in the material of structural elements, which is a determining parameter in predicting the further service life and assessing the actual technical condition. A permanent tool for detecting defects is non-destructive testing, which allows you to detect defects and evaluate the standards for the admissibility of detected defects in accordance with regulatory and technical documents in this area. These documents define strict criteria for "admissibility" or "inadmissibility" of defects of structural elements of vessels and devices operating under excessive internal pressure. For example, cracks and fistula that occur during welding and during operation are considered unacceptable defects. Such defects unambiguously put the object in an inoperable state, before they are eliminated. However, there are damages, the presence
of which does not imply the transition of the object to the limit state, and there are no risks of the
development of such defects during operation. Such defects include scratches that occur during repair
or installation cycles. The presence of such damage does not endanger the transition of the object to an
inoperable state, but can make significant adjustments to the formation of SDS of the elements on
which this damage is located. The use of various application programs for modeling 3D objects with
existing damage allows you to evaluate SDS and develop certain recommendations for ensuring
reliability [6-8]. Therefore, the actual work is the assessment of SDS of the flat manhole cover
depending on the location of the scratch on it from the impact of loads established by the technological
regulations.

2. Methodology of the research

To examine the SDS of the flat manhole cover of the apparatus, if there is a scratch on it with different
dislocation, the manhole of the apparatus of one of the process units is selected. The device is operated
at operating pressure \( P = 2.0 \) MPa and operating temperature \( t = 20 \) °C. The material of the manhole
and its cover is high-quality carbon steel 10. The hatch has the following technical characteristics: size
of a branch pipe of the union 472×18 mm; flange of connector is flat welded with thickness \( s = 18 \) mm;
thickness of flat cover \( s = 10 \) mm; outer diameter of flat cover \( D = 510 \) mm; cover is equipped
with 20 holes \( \varnothing \) 18 mm for bolted connections. In the process of modeling, the licensed software
complex "KOMPAS-3D" was used with the APM FEM system integrated into it for solving
engineering and research problems [9-11]. At the first stage, a hatch-eye model was built in the
COMPAS-3D program. Then, using the APM FEM strength analysis system, which is part of the
COMPASS-3D program package, loads such as: pressure and temperature were applied; fasteners are
installed [12-15]. Further, a scratch with different dislocation on the surface of the flat cover with
respect to its central zone was simulated. The scratch is an extended linear plane defect with sharp
vertices. The length of the scratch was \( L = 50 \) mm, width \( B = 1 \) mm, depth \( H = 1 \) mm. The shape of
the scratch with the geometric dimensions is shown in figure 1. The angles of inclination were taken as
follows: 15°, 30°, 45°, 60° and 75°. The various options for dislocating the scratch on the flat cover of
the manhole relative to the central part are sketched in the figure 2. V the first of the considered
options, one sharp tip of the scratch comes from the center of the flat cover (figure 2a). In the second
version, the center of the flat cover divides the scratch into two equal halves (figure 2b).

![Figure 1. Scratch shape with geometric dimensions.](image)

3. Research results and discussion

At the first stage of research, a SDS assessment of a flat cover without scratching was carried out.
Results of calculation of SDS of flat manhole cover without scratch are shown in figure 3.

Analyzing the result shown in figure 3, we can conclude that the maximum stresses are 76.59 MPa
and are concentrated in the area close to the bolted circle of the flat manhole cover. Moreover, the
distribution zone of maximum stresses is uneven.

Next, the SDS simulation of the flat cover with different dislocation on the surface of the flat cover
of the manhole-eye with respect to the center of the cover was carried out according to figures 2a-b.
Results of SDS calculation are given in figures 4-8.
Figure 2. Various options for dislocating the scratch on the flat manhole cover relative to the center.

Figure 3. Results of calculation of SDS of flat manhole cover without scratch.

Figure 4. Results of calculation of SDS of flat manhole cover in case of scratch on the surface with inclination angle 15°. a) results of calculation of SDS of flat manhole cover with scratch dislocation relative to the cover center in accordance with figure 2a; b) results of calculation of SDS of flat manhole cover with scratch dislocation in relation to the cover center in accordance with figure 2a.

From figure 4, it can be seen that not only the presence of a scratch, but also its dislocation has an effect on the SDS of the flat manhole cover. Thus, the maximum stresses are concentrated in the scratch area and are 134 MPa in the embodiment where one sharp tip of the scratch comes from the center of the flat cover and the maximum stresses are 114.3 MPa in the embodiment where the center
of the flat cover divides the scratch into two equal halves. In the first version, maximum active voltag-
eses are 1.2 times higher than in the second. Compared to the maximum stresses of the flat cover without scratching, the increase in stresses occurred by 1.7 and 1.5 times, respectively.

Figure 5. Results of calculation of SDS of flat manhole cover in case of scratch on the surface with inclination angle 30°. a) results of calculation of SDS of flat manhole cover with scratch dislocation relative to the cover center in accordance with figure 2a; b) results of calculation of SDS of flat manhole cover with scratch dislocation in relation to the cover center in accordance with figure 2a.

By analyzing figure 5, we can conclude that when the angle of the scratch inclination increases to 30° maximum, the stress is already 157.6 MPa in the case where one sharp tip of the scratch comes from the center of the flat cover. This is 1.2 times higher than with the identical scratch arrangement, but at an angle of 15°. For the variant, when the center of the flat cover divides the scratch into two equal halves, the maximum stresses decreased by about 1.3 times.

Figure 6. Results of calculation of SDS of flat manhole cover in case of scratch on the surface with inclination angle 45°. a) results of calculation of SDS of flat manhole cover with scratch dislocation relative to the cover center in accordance with figure 2a; b) results of calculation of SDS of flat manhole cover with scratch dislocation in relation to the cover center in accordance with figure 2a.

By performing a comparative analysis of the results of figure 6 and the results of figure 5, it can be seen that by increasing the angle of the scratch to 45°, the maximum stresses are reduced to 131.2 MPa
(1.2 times) in the case where one sharp tip of the scratch comes from the center of the flat cover. There
was an increase in maximum stresses to 119.7 MPa (1.3 times) when the center of the flat cover
divides the scratch into two equal halves.

Figure 7. Results of calculation of VAT of flat manhole cover in case of scratch on the
surface with inclination angle 60°. a) results of calculation of SDS of flat manhole cover
with scratch dislocation relative to the cover center in accordance with figure 2a; b) results
of calculation of SDS of flat manhole cover with scratch dislocation in relation to the cover
center in accordance with figure 2a.

Figure 8. Results of calculation of SDS of flat manhole cover in case of scratch on the
surface with inclination angle 75°. a) results of calculation of SDS of flat manhole cover
with scratch dislocation relative to the cover center in accordance with figure 2a; b) results
of calculation of SDS of flat manhole cover with scratch dislocation in relation to the cover
center in accordance with figure 2a.

Results which are given in figures 7-8 show that at increase in a tilt angle of a scratch to 60° and
75° the maximum tension is 128.8 MPa and 98.21 MPa respectively at option when one sharp top of a
scratch comes from the center of a flat cover. The maximum stress values increased to a maximum
value of 156.5 MPa in the case where the center of the flat cover divides the scratch into two equal
halves with the angle of the scratch 60°. As the angle of inclination increased to 75°, the maximum
stresses decreased to 124.3 MPa.
4. Conclusions
Based on the results of the SDS study of the flat manhole cover with scratch length L = 50 mm depth H = 1 mm and width B = 2 mm and with different dislocation relative to the center of the cover when exposed to operating pressure P = 2MPa and operating temperature t = 20 °С, the following conclusions can be drawn:

- it has been established that the SDS of the flat cover is affected by the dislocation of the scratch relative to the central part of the cover. The maximum stress values are significantly influenced by both the angle of the scratch and its location relative to the center of the cover for two versions:
  1) when one sharp tip of the scratch comes from the center of the flat cover;
  2) when the center of the flat cover divides the scratch into two equal halves.

During technical diagnostics, in order to assess the actual technical condition, it is necessary to simulate SDS of flat covers of nozzles with existing scratches to detect maximum active stresses.

- it is shown that with the scratch inclination angle values in question, which are equal to 15°, 30°, 45°, 60° and 75°, the maximum stresses occur in the flat cover when the scratch is arranged at an angle 30° and amount to 157.6 MPa in the embodiment where one sharp tip of the scratch comes from the center of the flat cover. The maximum stresses in the flat cover are 156.5 MPa in the case where the center of the flat cover divides the scratch into two equal halves with the angle of the scratch 60°.

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