Identification of zone of increased stresses of the apparatus with a shirt under conditions of corrosion wear by modeling

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Abstract. Apparatuses with a shirt have two working cavities with independent pressures and temperatures, as well as independent working environments. When operating two cavities, a certain difference in pressure and temperature is simultaneously created, leading to the appearance of unfavorable zones, which can negatively affect the life of the apparatus. For the timely identification of the most unfavorable zones, a wide range of non-destructive testing methods are used, which make it possible to assess the actual technical condition and level of metal defectiveness. However, due to the design features of the apparatus with the shirt, it is quite difficult to conduct a full visual control of the inner surface. Therefore, the actual work is to assess the stress-deformed state of equipment with an original design using modeling in modern software systems in order to identify potentially dangerous sections in terms of maximum operating stresses.

1. Introduction
Diagnosis of apparatuses with several working cavities is almost always associated with inconveniences in terms of a qualitative and complete examination of all surfaces in contact with corrosive working environments. Under conditions of elevated pressures and temperatures, working fluids can be even more aggressive towards the material of equipment [1], [5]. The design of the apparatus and harsh operating conditions and conditions can serve as a prerequisite for the occurrence of various stagnant zones and the occurrence of corrosion wear in these places with the greatest activity. One of these apparatuses are apparatuses with a shirt. Different temperatures and pressures in each of the working spaces make it possible to develop areas with a predisposition to more intensive corrosion wear due to the difference in temperatures and pressures acting on the same section of the apparatus from different sides. Also in the development of these areas the decisive role is played by the name and composition of the working environment. An effective tool for solving problems of this type is the use of specialized programs for the development of a 3D model of the apparatus, taking into account design features and modeling of the stress-deformed state (SDS), taking into account all the influencing determining factors. Therefore, the actual work is the modeling of the SDS apparatus with a shirt under various conditions of corrosion wear in order to identify possible adverse areas with high operating stresses.

2. The research method
To conduct studies on the assessment of the SDS of an apparatus with a shirt from the effects of workloads and corrosion, an identical apparatus of one of the manufactures was chosen [6-10]. The shell
The material of the main apparatus is cast iron of the SCH 15-32 type, the bottom and the detachable cover of the main apparatus is cast iron of the SCH 18-36 type. The material of the shell and elliptical bottom of the shirt is carbon steel of ordinary quality St3.

The technical parameters of the apparatus with a shirt are as follows:

- design pressure in the body $P_{\text{calc}} = 0.6$ MPa;
- design pressure in the shirt $P_{\text{calc}} = 0.4$ MPa;
- design temperature of the outer wall of the body under the shirt $t_{\text{calc}} = 95^\circ$C;
- design temperature of the shirt body wall $t_{\text{calc}} = 100^\circ$C;
- design temperature of the inner wall of the body = $90^\circ$C;
- medium in the body - petrochemical product;
- medium in the shirt - steam;
- diameter of the cast iron body = 900 mm;
- length of the cast iron body = 750 mm;
- wall thickness of the apparatus body = 23÷24 mm;
- wall thickness of the body's bonnet = 24 mm;
- diameter of the shirt body = 1000 mm;
- shirt body thickness = 6 mm;
- length of steel shirt body = 605 mm.

The apparatus with a shirt is a vertical apparatus consisting of a solid cast-iron body of the main apparatus, including a cylindrical shell and a bottom, a removable bonnet of the body, a steel cylindrical shell of a shirt, a welded steel elliptical bottom of a shirt, technological fittings and is mounted on support legs at a height. The apparatus is intended for heating a petrochemical product to the required process temperature.

In the process of research, the KOMPAS-3D licensed software package was used with the APM FEM system integrated in it, which allows for static calculation for the preparation and subsequent finite element analysis of a three-dimensional solid-state model.

The preparation of the geometric 3D model and the task of the material is carried out by means of the KOMPAS-3D system. Using APM FEM, you can apply loads of various types, specify boundary conditions, create a finite element mesh and perform the calculation. In this case, the finite element generation procedure is carried out automatically.

Initially, an apparatus with a shirt was modeled in the KOMPAS-3D program. Then, using the APM FEM strength analysis system, working pressure and temperature were applied; fixed fixtures. After that, a finite element mesh was created using the CE-mesh generation command, and SDS calculation was performed. A 3D model of the apparatus with a shirt is shown in figure 1.

![Figure 1. Built model of the apparatus with a shirt.](image-url)
The first task of the research was to evaluate the stress-deformed apparatus with the shirt, taking into account the action of working pressures and temperatures without taking into account corrosion on the executive wall thicknesses specified during design. The SDS of an apparatus with a shirt without corrosion is shown in figure 2 [11-14].

Figure 2. SDS of an apparatus with a shirt excluding corrosion wear.

As can be seen from the figure 2, the maximum stresses of the apparatus with the shirt appear in the upper place of welding of the support legs on the body of the steel shirt. Also places of increased stress are the zones near the welding of support legs on the steel shirt body and the zone at the insertion point of the technological fittings.

Further, the SDS modeling of the apparatus with a shirt was carried out with the following development scenarios and the places of corrosion wear:

- corrosion of 0.1 mm of the inner surface of the upper belt of the shirt with a width of 100 mm, starting from the upper edge of the shell of the shirt along the entire circumference;
- corrosion of 0.1 mm of the inner surface of the middle zone of the shirt with a width of 100 mm along the entire circumference;
- corrosion of 0.1 mm of the inner surface of the lower belt of the shirt with a width of 100 mm, starting from the lower edge of the shell of the shirt along the entire circumference;
- corrosion of 0.1 mm of the outer surface of the upper belt of the case with a width of 100 mm, starting from the upper edge of the shell of the case under the shirt along the entire circumference;
- corrosion of 0.1 mm of the outer surface of the middle belt of the body under a shirt with a width of 100 mm along the entire circumference;
- corrosion of 0.1 mm of the outer surface of the lower case belt 100 mm wide, starting from the lower edge of the shell body under the shirt along the entire circumference;
- general uniform corrosion of 0.1 mm of the entire inner surface of the shirt;
- pitting corrosion of 0.1 mm of the inner surface of the shirt on four generators in three sections (top, middle, bottom).

Figure 3 shows the SDS of the apparatus for the corrosion wear of 0.1 mm of the shirt for individual belts of the inner surface of the shirt with a width of 100 mm each (top, middle, bottom) along the entire circumference.

As can be seen from the figure 3, even with corrosion wear of 0.1 mm in individual belts of the inner surface of the shirt with a width of 100 mm, the bottom of the shirt deforms and the maximum stresses in the areas of welding the bottom of the shirt and supporting legs to the shirt of the apparatus increase.
Figure 4 shows the SDS of the apparatus for corrosion wear of 0.1 mm for individual belts of the outer surface of the body 100 mm wide each (top, middle, bottom) along the entire circumference.

As can be seen from the figure 4, with corrosion wear of 0.1 mm in individual zones of the outer surface of the apparatus body 100 mm wide, deformation of the bottom of the shirt and a significant increase in maximum stresses in various areas of the body and bottom of the shirt, as well as the zones of welding of the supporting legs to the shirt, occur apparatus.

Figure 5 shows the SDS of the apparatus with a general uniform corrosion of 0.1 mm of the entire inner surface of the shirt, as well as pitting corrosion of 0.1 mm of the inner surface of the shirt along four generators in three sections (top, middle, bottom).

**Figure 3.** SDS of an apparatus with corrosion wear of 0.1 mm for individual belts of the inner surface of the shirt 100 mm wide each (top, middle, bottom) along the entire circumference. a) SDS of the apparatus with corrosion of 0.1 mm of the upper belt of the inner surface of the shirt 100 mm wide along the entire circumference; b) SDS of the apparatus for corrosion of 0.1 mm of the middle belt of the inner surface of the shirt with a width of 100 mm along the entire circumference; c) - SDS of the apparatus for corrosion of 0.1 mm of the lower zone of the inner surface of the shirt with a width of 100 mm along the entire circumference.

**Figure 4.** SDS of an apparatus with corrosion wear of 0.1 mm for individual belts of the outer surface of the body with a width of 100 mm each (top, middle, bottom) along the entire circumference. a) SDS of the apparatus with corrosion of 0.1 mm of the upper zone of the outer surface of the apparatus body 100 mm wide; b) SDS of the apparatus for corrosion of 0.1 mm of the middle belt of the outer surface of the body with a width of 100 mm; c) - SDS of the apparatus for corrosion of 0.1 mm of the lower belt of the outer surface of the body with a width of 100 mm.
Figure 5. SDS of the apparatus with a general uniform corrosion of 0.1 mm of the entire inner surface of the shirt, as well as pitting corrosion of 0.1 mm of the inner surface of the shirt in four generators in three sections (top, middle, bottom). a) SDS of the apparatus with a general uniform corrosion of 0.1 mm of the entire inner surface of the shirt; b) SDS of the apparatus with pitting corrosion of 0.1 mm of the inner surface of the shirt in four generators in three sections (top, middle, bottom).

As can be seen from the figure 5, the most favorable of the above results when the bottom is deformed is observed with uniform corrosion wear of 0.1 mm of the entire inner surface of the shirt. In this case, the deformations are insignificant and the maximum stresses are less than 100 MPa. To protect the apparatus shirt from possible deformations, a constructive decision was made to use a stiffening ring. A variant of welding the stiffening ring to the shirt body from the inside at a distance of 100 mm from the top edge of the shirt was simulated in order to give additional rigidity. The stiffening ring is a 15 × 15 × 4 mm corner made of St3 steel. The results of calculating the SDS of a apparatus with a stiffening ring on the inside of a shirt are presented in figure 6.

Figure 6. The results of calculating the SDS of the apparatus with a stiffening ring on the inside of the shirt.

As can be seen from the figure 6, when using the ring of stiffness, deformation of the bottom from the effects of corrosion wear and operating loads does not occur, and a significant decrease in the values of maximum stresses is noted. The final stage of modeling using a stiffening ring was the task of estimating the SDS of the apparatus with the shirt as a result of changing the distance of welding the stiffening ring on the inner surface of the shirt relative to its upper edge, as well as increasing the number of stiffening rings welded at a possible distance from one to two. The sizes and material of the rings were taken to be the same as in the previous problem when assessing SDS, taking into account the welding of the stiffening ring to the inside of the shirt at a distance of 100 mm from the top edge of the shirt. The results of calculating the SDS of a apparatus with a welded stiffening ring on the inner side of the shirt at a distance of 200 mm from its upper edge, two welded stiffening rings on the inner side of
the shirt at a distance of 100 and 200 mm, as well as 200 and 300 mm from its upper edge, respectively, are presented in the figure. 7.

Figure 7. SDS of the apparatus with stiffening rings. a) SDS of the apparatus with a welded ring of rigidity on the inner side of the shirt at a distance of 200 mm from its upper edge; b) SDS of the apparatus with two welded stiffening rings on the inside of the shirt at a distance of 100 and 200 mm from the top edge of the shirt; c) SDS of the apparatus with two welded stiffening rings on the inside of the shirt at a distance of 200 and 300 mm from the top edge of the shirt.

As can be seen from figure 7, with an increase in the welding distance of the stiffening ring on the inner side of the shirt up to 200 mm from its upper edge, the maximum stresses increase from 58.98 MPa to 70.1 MPa, and a noticeable deformation of the bottom of the shirt. When using two welded rings on the inner side of the shirt at a distance of 100 and 200 mm from its upper edge, the values of maximum stresses increase from 58.98 MPa to 62.06 MPa. With the use of two stiffening rings welded on the inside of the shirt at a distance of 200 and 300 mm from its upper edge, there is a general loss of stability in the shape of the bottom of the shirt.

3. Conclusion
Based on the simulation results of the SDS of the apparatus with a shirt under various conditions of corrosion wear, we can make the following conclusions:

- it was found that the maximum stresses and deformations for the apparatus with the shirt become significantly higher with corrosion wear of 0.1 mm in individual belts, both the outer surface of the case and the inner surface of the shirt, than with general uniform or pitting corrosion of the surfaces. This condition must be taken into account when drawing up a diagnostic program for the object in question and ensure the most careful monitoring of these places by various non-destructive testing methods;
- it was revealed that in order to protect the apparatus with the shirt from loss of shape stability and lowering the values of the existing stresses, it seems possible to use stiffening rings, the optimal sizes and location of which must be determined in the process of modeling the SDS of the apparatus depending on its design features, operational parameters, lo-cations and degree corrosive wear;
- it is shown that in order to prevent loss of stability of the bottom shape and reduce the values of the existing stresses, the most optimal option for welding the stiffening ring from the inside of the shirt is the area of the/ upper part of the shirt body at a distance of 100 mm from its upper edge.

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