Determination of powerful active zones of petrochemical equipment

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Abstract. The paper studies the powerful active state of capacitive equipment. The areas with high values of stresses and deformations that contribute to the formation and development of fatigue and corrosion cracks are identified.

The number of incidents related to depressurization of equipment due to the fault of the operating personnel, disruption of the technological process, failure of instrumentation or safety devices, the occurrence of various defects of the base metal and welded joints of a metallurgical nature or technological origin increases every year [1-4]. Analysis of the causes of accidents and fatal accidents at enterprises shows that most of them (42%) are associated with poor technological and production discipline, inefficient production control over compliance with industrial safety requirements, as well as with a low level of professional training of workers and specialists.

Equipment often fails or is subject to catastrophic destruction not only because of the loss of bearing capacity in the operating mode, but also because of a rapid, uncontrolled increase in pressure above the permissible limit. At the same time, catastrophic destruction for a number of similar equipment originates in the same places and is specific for each type.

The basis of the trouble-free operation of the equipment is its systematic maintenance, inspection and repair, the requirements for which are set out in the Federal norms and rules in the field of industrial safety. According to these rules and regulations, all equipment at the expiration of the service life set by its manufacturer, or at the time of safe operation established by the conclusion of an industrial safety review must be examined to determine the dates for its further safe operation.

The main stages of the equipment examination are as follows [5]:

- analysis of technical and operational documentation related to equipment and equipment operation modes;
- equipment inspection, including visual and measuring control;
- non-destructive or destructive testing of the base metal and welded joints of the equipment;
- evaluation of detected defects based on the results of visual and measurement control, methods of non-destructive or destructive testing;
- calculated and analytical procedures for assessing and predicting the technical state of equipment, including the analysis of operating modes and studies of the powerful active state;
- assessment of service life.

Analysis of the technical and operational documentation of the equipment allows us to get the initial information about the object: to determine compliance with the project used materials and actual design, the actual operating conditions of the project, to select the determining parameters of the technical condition, to pre-set the expected degradation processes, to make a list of elements and areas of the object of examination most prone to damage and defects, to identify the maximum pressure concentration zones.

Examination of equipment, visual and measurement control is carried out in order to identify changes in their shape, surface defects in the base material and welded joints formed during operation (cracks, corrosion damage, deformation, etc.). These measures allow us to assign the best methods of non-destructive and destructive testing of the base metal and welded joints of the equipment for the timely detection of unacceptable defects.

We will single out two main types of tank equipment most widely used at petrochemical complex enterprises: vertical tanks with supports located on the bottom or sidewall, horizontal tanks on saddle supports. At one of the chemical enterprises a serious incident (third level) occurred - the destruction of the technological apparatus-tank with a volume of 34.1 m$^3$, made of stainless steel. It is equipped with automation and process control systems. Technological operations were carried out in the apparatus in preparation for the extraction of a uranium solution that had previously been in contact with organic matter.

Due to non-compliance with the modes of mixing the solutions and blowing the gases out of the apparatus, an increase in the pressure in the apparatus exceeded the permissible due to a chemical reaction between the organic phase and nitric acid. The destruction of the apparatus was accompanied by the explosion of gases, with the destruction of part of the building's building structures and the release of radioactive aerosols into the environment. The explosion of gas caused the ignition of the roof of the building on an area of 3 m$^3$.

The main issue of the investigation of the accident was to determine the place of the beginning of the destruction, namely the state of the structural element with the identification of zones with high pressure and deformations.

For a more accurate control of the current state of the capacitive equipment, one should pay attention to the powerful active state of its elements, select their dangerous zones and monitor them not only after the expiration of the service life, but also during operation. To control the powerful active state of increased danger equipment during the period of operation, it is proposed to install on it a number of sensors that will control the movement of the most dangerous areas in the components of the equipment. This will provide information on the exact number of loading cycles that the object has experienced during the period of operation, as well as the maximum and minimum stresses that occur during this period.

![Figure 1. The scheme of the considered tank.](image-url)
We will analyse the powerful active state of the tank, which is under the influence of internal overpressure, without taking into account the supporting and wind loads using the example of a tank consisting of three shells and two welded bottoms. Let us pay special attention to the areas where the maximum pressure occurs, as well as the maximum relative displacements of the shell points associated with these under pressure. The presented model is axisymmetric, and for information on the powerful active state as a whole, it is enough to consider only its part - the highlighted one (figure 1) [6].

The powerful active state of the tank after the pressure in it is increased by 0.6 MPa is shown in (figure 2), for clarity, the deformations are increased several times. The maximum relative displacements of the shell points fall on the near-shell zone of the shell (0.06 mm) and the central part of the bottom (0.25 mm). Three zones are also distinguished: the bottom welding zone, the bottom top zone, the flared transition zone, in which the maximum pressure occur [7].

![Figure 2](image2.png)

**Figure 2.** The powerful active state of the tank after pressure increase.

![Figure 3](image3.png)

**Figure 3.** Pressure distribution on the outer surface of the bottom wall: on x axis - the distance from the centre of the weld of the shell to the bottom, m; y - pressure, MPa.
Figure 4. Pressure distribution on the inner surface of the bottom wall: along x axis - the distance from the weld centre of the shell welding to the bottom, m; y - pressure, MPa.

Figure 5. Distribution of movements: along x axis - distances from the centre of the weld of the shell to the bottom, m; y-axis - relative displacement, m.

Without taking into account other factors, these zones will always experience the greatest pressure compared to other basic elements of capacitive equipment. Changes in them will be the most dangerous prerequisites for catastrophic destruction. Analysing the obtained results for the bottom as shown in figures 3-5 (KOL are ring pressures, MER are meridional pressures, EQW are equivalent pressures, UX are relative displacements of shell points) it can be concluded that the maximum relative displacements occur at the top of the tank bottom, and the maximum pressures occur in the transition zone bottoms in flanging, where there is a significant bending effect. In this case, the maximum equivalent pressures will be located on the inner surface of the bottom of the tank.

The studies of the container shells allow us to conclude that the values of the maximum pressure and displacements reach maximum in the same areas, namely in the areas of the weld of the bottom welding to the shell. At the same time, the equivalent pressure reaches a maximum on the outer surface of the container shell, at the point of transition to the weld bead and at the bend of the shell caused by the deformation of the bottom.

The analysis carried out above shows that the most probable in terms of fracture nucleation is the zone of transition of the elliptical part of the bottom to the flanging, where maximum pressure occurs compared to other areas. The zone with maximum pressure is located on the inside of the bottom, which makes access to it difficult.

The occurrence of these pressure contributes to the formation and development of fatigue and corrosion cracks, which arise mainly on the surface and are prerequisites for catastrophic damage, which must be taken into account when inspecting equipment in terms of designating control zones by non-destructive or destructive control methods for timely detection of unacceptable defects.
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