Estimation of efficiency of the thermal diagnostic method for detecting corrosion defects of fixed offshore platforms

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Abstract. Currently, the world is actively developing offshore fields. This production is carried out using fixed offshore platforms. During operation, offshore platforms are exposed to various influences, including corrosion. As a result of this effect, caverns are formed on the surface of the structural elements of the platform, which are stress concentrators and capable of causing critical overvoltage of the platform elements. To prevent this situation, it is necessary to identify hazardous corrosion defects in a timely manner. The article describes a comparative analysis of modern non-destructive testing methods, as well as the results of a method developed by the author on the basis of experimental studies for assessing the depth of corrosion defects.

1. Introduction
In the world there are significant reserves of oil and gas located offshore. Oil and gas in these conditions is conducted with the use of offshore platforms of various types, the most common of which is the fixed offshore platform of gravitational type. Nowadays, most of these platforms have been in operation for more than 30 years, which cannot but raise the question about the safety and reliability of operation of the facilities. The solution to this question, according to the author, lies in taking timely measures to identify and eliminate constructive elements of FOPs, to develop their resources and adversely affecting the possibility of further safe operation of offshore platform. During the entire period of operation of FOPs, its constructive elements (CE) are subjected to the influence of various loads and impacts, which leads to the formation and development of various defects, contributing to the destruction of TBE FOPs. Defects of structural elements of offshore stationary platforms have different origins and are also categorized according to its location (weld or base metal) and excellent in the degree of danger. These can be defects industrial production of the base metal, such as sinks, hairline cracks, thermal cracking; the weld defects like pores, lack of fusion, undercuts; the defects obtained in the process of operation such as dings, stress cracks, nicks etc. Of course, all of these defects under the influence of variable loads and impacts, can be further developed and to turn TBE FOPs in a potentially dangerous element. However, the biggest action since the specificity of the marine deposits, have corrosion defects. In figure 1- figure2 presents photographs of various FOPs exposed to the corrosive effect of illustrating their actual condition.
The analysis of operating offshore platforms have shown that the highest corrosion of the structural elements of SMEs, equal to approx 12% of the initial wall thickness is achieved in the zone of variable wetting. In the underwater area, corrosion of the lower and varies in the range of 5-8.8% (depending on the underwater currents). In the atmospheric zone corrosion average is 7%. Assessing the degree of damage of the steel structures supporting the SME units, it should be noted that all elements of the platforms corroded, however for SMEs it can be noted a very important trend: the actual state of the metal surface parts of the production blocks in the zone of alternating wetting is characterized by the highest corrosive wear. The average wear of the elements in this zone is 25 to 40%. The maximum wear of the individual elements reaches 75-85%. These data are confirmed normative and technical documentation in which the rate of corrosion in the zone of alternating wetting is estimated at 0.16 mm/year, and in submarine and surface areas of 0.12 mm/yr and 0.10 mm/year, respectively. Numerous data indicate that the maximum wear is in the zone of periodic wetting. Based on this statement we can conclude that the greatest amount of potentially faulty elements is in the zone of periodic wetting. The identification of such potentially defective items in the opinion of the author, possible only through a comprehensive diagnostic survey of the whole platform of modern methods of nondestructive testing.

2. Methods
Currently there are developed and effectively applied various methods of nondestructive control, but the specific conditions of the marine deposits, the scale of construction FOPs and many other factors create certain requirements for various NDC methods. Let us formulate the requirements for NDC methods with respect to FOPs: 1) High speed of operation of the control; 2) Accuracy of detection of dangerous defects; 3) Corrosion layer SMEs should not impede the inspection; 4) Full control should be 100% of the surface and welded joints of structural elements of FOPs rather than their individual plots; 5) the Possibility of conducting monitoring in remote areas; 6) Low cost of control operations; 7) this method of NDC, it is possible to diagnose large-sized object, like FOPs; 8) A successful application of this method in various industries. It is necessary to note the fact that due to the nature of the environment CE underwater part, almost there is no substitute for a visual diving survey. None of the following NDC techniques cannot be used in submerged conditions, with the exception of maybe ultrasonic thickness measurements. The author is aware of such successful control operations; however, the ultrasonic underwater thickness measurements were accompanied by frequent breakage of the expensive ULTRASONIC thickness gauges, due to the ingress of moisture into the electrical circuit of the device. In addition, it is difficult to find a well-prepared ultrasonic testing inspector and diver at the same time, it is technically difficult to provide the controlled surface sweep from the corrosion layer, etc.
Let us consider the modern methods of NDC. First in popularity among the modern techniques is ultrasonic inspection. This method has shown good results in the detection of defects in aircraft, quality control of welded joints of gas pipelines and other industries, but in reality the whole surface of the FOPs covered with a layer of corrosion thickness 3-4mm, which prevents the spread of ultrasonic vibrations and reliable detection of defects. In addition, the presence of a significant number of corrosion cavities will give a lot of false defects. Remove the same corrosion layer on hard-to-reach and large size elements FOPs are technologically feasible. The second most popular among the NDC methods is the x-ray inspection method (XK), which is not as sensitive to corrosion damage. However, the complexity of equipment location XK control on difficult structural elements of SMEs, a very long time to prepare to conduct operations control and removal of platform personnel to a safe distance in accordance with the safety requirements in the conduct of Kazakhstan makes the method is practically unusable. The next popular application followed by eddy-current (ECC), the magnetic (MK) and capillary (CC) control methods. Just note that these methods can only detect certain defects. For example, the ECC method only detects surface defects located at a depth of no more than 3mm from the surface of the structural element, the CC method may be used only provided that the output of the defect to the surface and the ratio of defect depth to its width not less than 10, etc. In General, all these methods have strict requirements to the quality of Stripping the structural elements of FOPs, roughness of surface, etc., that does not allow effective use of them for complex diagnostics. In addition, the cost of such control operations and supplies will greatly exceed the cost of the FOPs. In recent years, considerable popularity so-called thermal control (TC). This control method is based on the fact that the functioning of many objects connected with the effect of wind, hydrodynamic, etc. loads, so with the action variable and fixed heat (temperature) fields. However, their internal structure has a significant impact on the nature of the emitted thermal field, which allows the analysis of anomalies to judge the change of metal structure as a whole or its individual zones. Thermal field of the surface of the object is a source of information about the features of the process of heat transfer, which in turn depends on the design and shape of the object and the presence of the defect. To date, various industries have successful experience of identifying with the heat of cracks, voids, delaminations, pores, lack of fusion, cavities and other defects are also typical for FOPs. The experience of using the thermal control method in the aircraft industry, shipbuilding, energy and other industries helped to create the methodology and consistency of its implementation. However, for the diagnosis of FOP methodology thermal control is currently lacking. In this regard, the author seeks to develop such a methodology that would require an examination of processes of heating and cooling for SMEs under the action of solar radiation, study of the influence of corrosion layers on the processes of heat transfer, and most importantly, studies of the distortion of the thermal field at different parameters of the defect. From the point of view of thermal control, all defects can be divided into passive ones, i.e. not generating heat, and active, which are a source of heat. The detection of passive defects characteristic of SMEs is best possible with the active method. The active control method involves heating the controlled object. When a controlled object is heated, the defect resists the heat flux, because its thermal conductivity differs from the thermal conductivity of the metal of the structural element of the FOP. Spreading deeper into the spacecraft core, the heat flux flows around the defect along the surrounding layers of the base metal. In this case, there is an accumulation of heat in the layer before the defect and its lack in the layer behind it, which is manifested in a local change in temperature on the surfaces of the controlled object. The described phenomenon is also true for the cooling process. The author proposes to investigate not a one-time thermogram of an FOP, but several thermograms sequentially executed at equal intervals of time, which will allow characterizing the rate of change of the temperature state, which will allow better interpretation of the size of the defect. In addition to this, it is also necessary to establish the effect of the corrosion layer on the heat transfer processes in the CE of the FOP. Currently, such techniques are absent and the author sets the task to develop them. Here is a comparative table of NDC methods as applied to performing diagnostic work on FOPs (table 1).
Table 1. Comparative table of non-destructive testing methods for the implementation of diagnostic work on FOPs

| Parameter                                                                 | USC | XC | ECC | MC | CC | TC |
|---------------------------------------------------------------------------|-----|----|-----|----|----|----|
| Speed of control operations operations                                     | Low | Low| Average | Low| Low| High|
| Defect detection accuracy                                                  | Average | High| Average | Low| Average| Average|
| Sensitivity of the NDC method to the corrosion layer                       | High | High| High | High| High| Low|
| Possibility of 100% control of base metal and welds                       | Flimsy | Flimsy| Flimsy | Flimsy| Flimsy| High|
| The ability to control in inaccessible places                              | Average | Low| Average | Average| Average| High|
| Cost of control                                                            | Average | High| Average | Average| High| Low|
| The ability to control large-scale objects                                 | Flimsy | Flimsy| Flimsy | Flimsy| Flimsy| High|
| Experience in applying the NDC method                                       | Long-life | Long-life| Long-life | Long-life| Long-life| Average|

Thus, according to the author, the identification of dangerous corrosion defects is possible by conducting comprehensive diagnostics using modern non-destructive testing methods, the best of which is thermal monitoring.

3. Result
The author proposes to determine the depth and their equivalent volume based on data on temperature contrasts arising during heating of OOGS elements with defects. In order to implement this proposal, an experiment was performed (Figure 3 and Figure 4).

Figure 3. Preparation of the experimental sample  Figure 4. View of the experimental sample through the thermal imager

In the wall of pipes with different diameters and wall thicknesses (in Figure 3 and Figure 4, a pipe with a diameter of 133 mm and a wall thickness of 8 mm is shown) with a thickness of a uniform corrosion layer of 1 mm, holes of different diameters were drilled, simulating corrosion damage in depth that were filled with Fe2O3. The relationship between the following parameters was studied:
the ratio of wall thickness to the depth of corrosion damage and the effectiveness of the heat flux; the ratio of the temperatures of defect-free and corrosion-modeling areas.

As a result of the experiment, the following was established: 1) The magnitude of the temperature contrast is greater, the deeper the defect and the greater its geometric dimensions in the projection; 2) The temperature contrast is affected not only by the depth of the defect, but also by its size in the projection onto the area. Most often, corrosion cavities have a projection shape that is close to rounded (circle, ellipse, etc.). Because of the projection area of a corrosion defect can be visually estimated using a thermal imager, it becomes possible to calculate its depth. According to the author, the most dangerous from the point of view of stress concentration will be a defect of "V"-shaped form. The volume of such a defect can be described by the formula:

In case of corrosion defects with the shape of its projection onto a plane close to a circle:

\[ l = \frac{3(k_1D^2+k_2D+k_3C^2+k_4C+a)}{\pi r^2}, \]  

where: \( l \) is the depth of the defect [mm]; \( \pi = 3.14 \), \( r \) is the radius of the defect, [mm]; \( D \) is the dynamics of the heat flux, \([W/m^2]\); \( C \) is the temperature contrast, constants [scalar number]; \( k_1=0.00463937; k_2=-8.70561; k_3=132.525; k_4=1432.5; a=3748.46. \)

In case of corrosion defects with the shape of its projection onto a plane close to an ellipse:

\[ l = \frac{3(k_1D^2+k_2D+k_3C^2+k_4C+a)}{\pi hb}, \]  

where: \( l \)-depth of the defect, [mm]; \( h \) and \( b \)-axis of the elliptical base of the defect, [mm] and the remaining values are the same as in the previous formula.

4. Conclusion

1) It was shown that the thermal method has higher efficiency compared to other modern methods of non-destructive testing in the detection of dangerous corrosion defects.

2) According to the conducted experimental studies, the author developed new formulas that allow determining the depth of a corrosion defect during an active heat control procedure.

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