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# ESTIMATION OF THE STRESS-STRAIN STATE OF PORT HANDLING MACHINES

***Abstract.*** *The state of metal structures of port handling machines in Ukrainian ports is alarming due to several problems, such as corrosion, mechanical wear, lack of modernizations, limited resources for maintenance and insufficient application of modern control methods. Over time, structures that have been in operation for several decades are subject to significant wear and tear, which reduces their load-bearing capacity and increases the risk of accidents. The humid marine environment contributes to corrosion, while the stresses of transhipment machinery cause material fatigue and cracking. Lack of modernisation and limited funding for maintenance often lead to accidents. Irregular use of modern non-destructive testing methods makes it difficult to detect hidden defects on time. This paper examines the problems and potential solutions regarding the condition of metal structures of port handling machines in Ukrainian ports. Several major problems are identified, such as corrosion, mechanical wear, lack of modernisation and limited maintenance funding. In particular, methods are used to assess the stress-strain state of metal structures of portal cranes, a combination of the analytical finite element method (FEM) and the experimental method of strain measurement. As a result, the integration of FEM and strain gauging has made it possible to obtain accurate data on the condition of structures, which is critical to ensuring their safety and efficiency in operation.*
***Keywords:*** *Port handling machines, corrosion, mechanical wear, fatigue and cracking, finite element method, stress-strain state, strain gauging, modernization, maintenance, non-destructive testing.*

## Introduction

The state of metal structures of port transhipment machines in the ports of Ukraine today causes concern due to a number of factors. Many of these machines have been in operation for several decades, which leads to significant wear and tear of metal structures. The main problems are: corrosion, mechanical wear, lack of modernisation, limited resources for maintenance, and insufficient implementation of modern control methods. Constant exposure to the wet marine environment contributes to corrosion damage to metal structures, which reduces their load-bearing capacity [1,2]. The load during the operation of handling machines leads to fatigue of the material, and the appearance of cracks and deformations, which requires careful control and timely repair. Many machines have not undergone significant modernisation, which reduces their efficiency and safety. Due to economic difficulties, not enough attention is often paid to regular maintenance and repair of machines, which can lead to emergency situations. Modern methods of non-destructive testing are limited, making it difficult to detect hidden defects in a timely manner. To ensure the safety and efficient operation of port handling machines in Ukraine, it is necessary to strengthen the monitoring of the technical condition of metal structures, introduce modern diagnostic technologies and increase investments in modernisation and repair of equipment.

**Setting the problem.**

One of the promising methods for determining the stress-strain state of metal structures of port machines is the combination of the analytical method of finite elements and the experimental strain gauge method. This combination is suitable for assessing the condition of structures, allowing to obtain detailed information about the distribution of stresses and deformations in various elements of metal structures. The combination of the analytical method of finite elements (FEM) and the experimental strain gauge method is indeed one of the promising approaches for determining the stress-strain state of metal structures of port machines. The finite element method allows you to create a detailed mathematical model of the structure, taking into account all possible variants of loads and material properties. This makes it possible to predict the behaviour of the structure in various conditions and to identify potential zones of increased stresses and deformations, which can be critical for safe operation. The strain gauge method complements this analysis with experimental data obtained directly during the actual operation of the equipment. It allows you to measure the actual stresses at individual points of the structure, confirming or correcting the results obtained using FEM [3-5].

The advantages of this combination are the possibility of obtaining both theoretical and practical data on the state of the structure, which provides a more accurate and reliable analysis. This is especially important for complex metal structures, where the influence of various factors can be difficult to predict using only one method. Thus, the integration of analytical and experimental approaches not only increases the accuracy of assessing the state of metal structures but also reduces the risks of emergency situations, which contributes to increasing the overall safety of port handling machines.

In this paper the results of research on the stress-strain state of the metal structure of the portal crane ‘Condor’ are presented as an example. The application of the Finite Element Method (FEM) to the entire metal structure of the gantry crane is very important and has several key advantages:

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**1. Complex analysis of the stress-strain state:**

• FEM allows for a detailed analysis of the distribution of stresses and deformations in all elements of the metal structure of the crane, including the column, jib system, support beams, frame and other components.

• it provides a comprehensive understanding of how various loads (cargo weight, wind, inertial forces, dead weight) affect the overall strength and reliability of the crane.

**2. Detection of zones of increased stress concentration:**

• FEM allows you to identify critical zones where increased stresses or deformations may occur, which helps to identify potential structural weaknesses.

• is important to prevent accidents and cracks in key elements of the crane, such as welds or joints.

**3. Evaluation of stability and stability:**

• with the help of FEM, it is possible to evaluate the resistance of the cargo crane to external loads, such as wind or dynamic loads during movement or lifting of loads.

• this method helps to determine the risk of loss of balance or overturning of the crane, which is critically important for ensuring the safety of its operation.

**4. Design optimization:**

• is used to optimize the design of the metal structure of the crane in order to reduce its weight, increase strength and reduce material costs.

• optimization may include changing the shape of elements, choosing optimal materials, or modifying connections to improve the overall performance of the faucet.

**5. Analysis of dynamic processes:**

• the finite element method allows us to analyse the influence of dynamic loads, such as vibrations, accelerations, and shocks that occur during the operation of the crane.

• makes it possible to predict the behaviour of the crane in different operating modes and ensure its stable and safe operation.

**6. Consideration of various operating conditions:**

• simulation of the influence of various external factors on the metal structure of the crane, such as corrosion, temperature changes, and the influence of an aggressive environment, which affects the durability and reliability of the structure.

• it is important to estimate the service life of the crane and to plan maintenance and repairs.

**7. Simulation of emergency situations:**

• can be used to simulate emergency situations such as loss of load, failure of elements or exposure to extreme loads. It helps to prepare for potential dangers and develop measures to prevent them.

The application of the finite element method to the entire metal structure of a cargo crane is an extremely effective tool for ensuring reliability, safety and optimization of the structure. FEM allows you to comprehensively analyse the behaviour of the crane under various loads, identify potential problems and develop design solutions that increase the durability and efficiency of the crane. This helps to reduce the risks of accidents and ensures stable operation of the crane in various operating conditions [6].

The ANSYS APDL program, which is based on the finite element method, was used to check the strength of the crane's metal structure. In the process of analysis, five calculated cases of the crane design were considered, differing among themselves in the direction of the forces caused by the slope and wind.

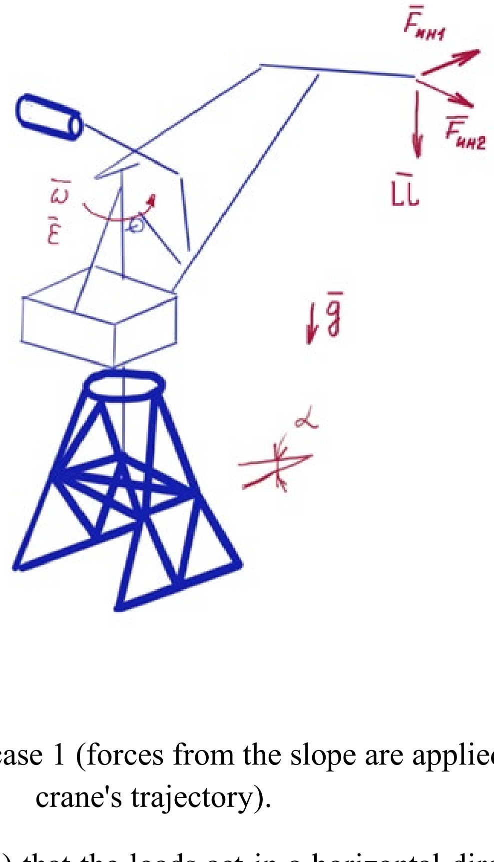

Fig. 1. Load scheme for case 1 (forces from the slope are applied along the crane's trajectory).

This means (Fig. 1) that the loads act in a horizontal direction along the moving path or rails along which the crane moves. The influence of tilting forces can lead to additional stresses in the structural elements of the crane, such as columns, booms and rails, which can increase the load on certain areas of the structure and require careful analysis to ensure its strength.

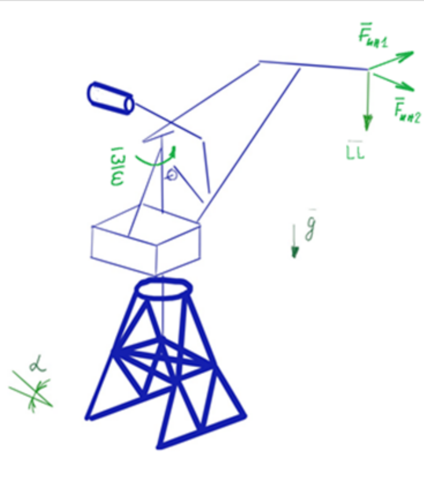

Fig. 2. Load diagram for case 2

In Fig. 2, the forces from the slope act perpendicular to the direction of movement of the crane. This can create lateral loads on the structure. affecting the stability and balance of the structure. Such forces can cause additional stresses in the horizontal and vertical elements of the crane structure, such as columns, crossbars, booms and rails. Lateral forces can lead to deformations of the structure, such as bends or shifts, which can affect the accuracy of positioning and operation of the crane.

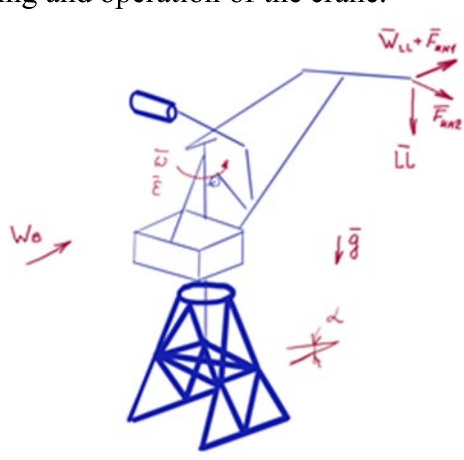

Fig. 3. Load diagram for case 3 (forces acting along the crane path).

Forces along the path create longitudinal loads on the structure, which can affect the columns, cross members and booms of the crane, leading to stretching or compression of the structural elements. The occurrence of longitudinal stresses can create additional forces in horizontal and vertical elements. Longitudinal forces can cause deformations (bending, twisting).

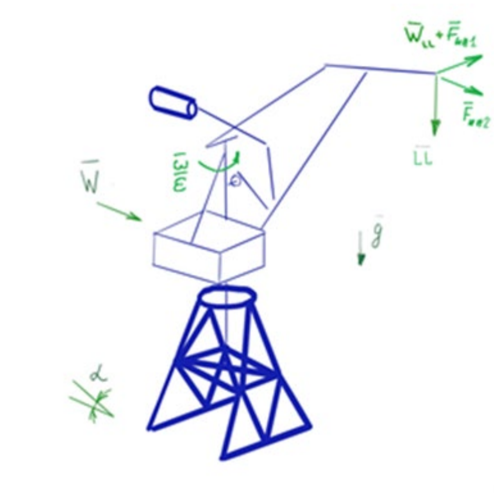

Fig. 4. Load diagram for case 4

For Case 4, forces acting across the crane path create lateral loads that can cause structural members to bend or shift. This can be especially important for booms, wheel blocks and brackets. Lateral forces can reduce the stability of the structure, which can lead to unwanted deformations or even damage to the integrity of the structure.

For case 5, the scheme of Fig. 1 is used, in which the forces from the slope are applied along the trajectory of the crane and the weight of the cargo increases from 32 t to 40 t.

On the example of case 1, we will consider the results obtained with the help of this program.

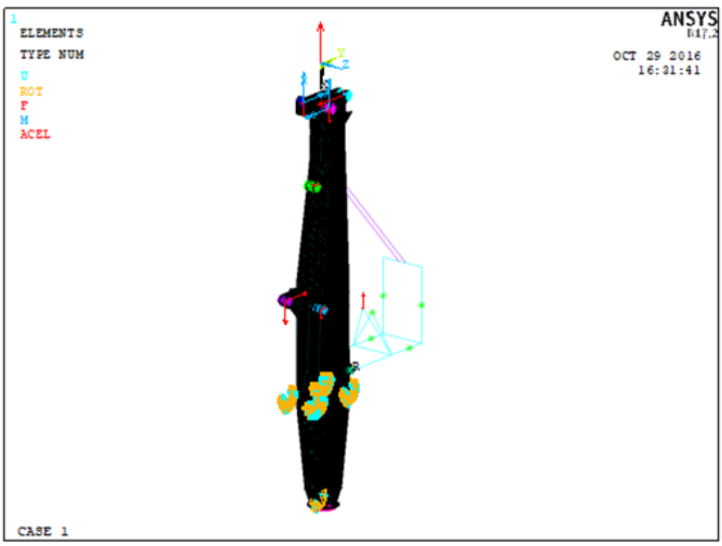


Fig. 5. Boundary conditions for case 1

Shell end elements SHELL 181 (four nodal elements) were used to model the metal structure of the column. This type of element allows you to accurately take into account the bends and deformations of thin-walled structures. The machine room was modelled using rigid beam elements MPC 184. It was modelled with an end element working only in tension/compression (MPC 184, LINK), which allows you to take into account only vertical forces. Concentrated masses (MASS 21) [5] were used to model the weights of the engine room, fixed counterweights on the rear wall and the floor of the engine room.

The lower part of the frame was attached to the column using a pivot joint (MPC184, rev). This provides the ability to rotate the frame and transfer the load through the hinge. It is forbidden to move the "leading" node in all directions and rotate around the vertical axis of the column. The support rollers are limited in the horizontal direction by means of contact with the head of the portal. The column is loaded by the forces obtained from the calculation of the jib system. In addition to the loads from the jib system, the column is subject to inertial loads from the rotation and acceleration of the rotation of the column. For certain cases (3,4), the load is taken into account from the wind. A force acting at a point that models the drum of the lifting mechanism is added to the model.

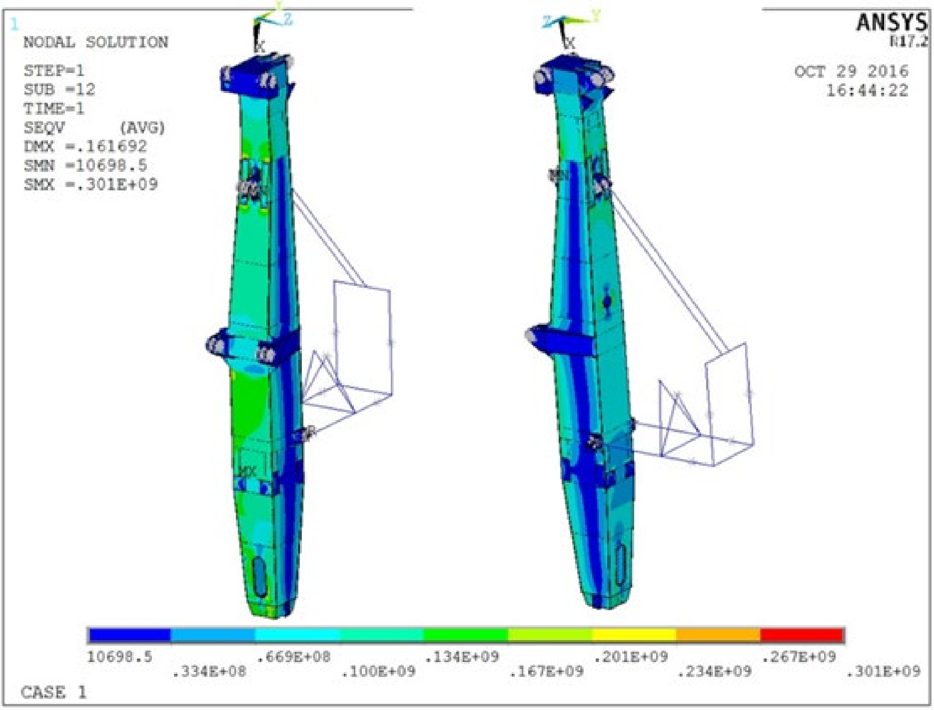


Fig. 6. Equivalent stresses according to Mises in the column

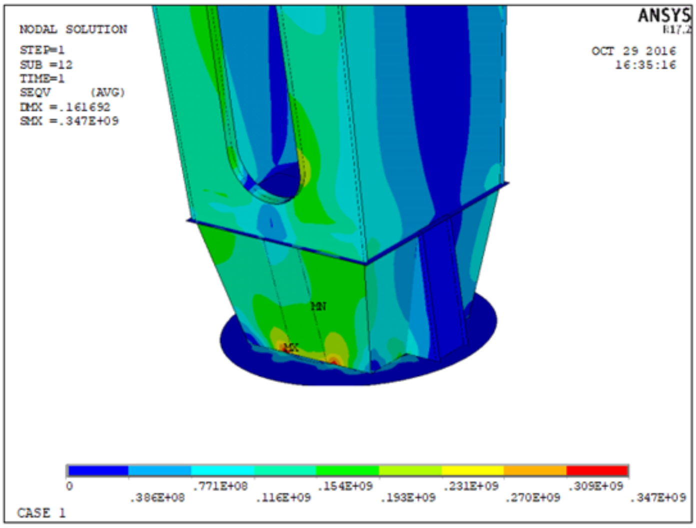


Fig. 7. Equivalent stresses according to Mises in the support of the column

After building the model and applying all efforts, it became clear that the stresses in the front and rear shelves of the column in some places exceeded the allowable for the given thickness and type of steel. Local strengthening of the front and rear shelves of the column is required.

The calculation of cyclic strength must be carried out for a specific scheme of column reinforcement after the calculation of static strength. At the same time, the criterion of static strength must be satisfied. Analysing the data obtained by the ANSYS program, they concluded that the strength of the side sheet of the column according to the criterion of loss of stability meets the requirements. The static strength of the front sheet according to the criterion of loss of stability does not meet the requirements. The sheet must be reinforced with a corner L300x100x10.5x15, material 17GS or 17G1C, located in the centre, along the axis of the column.

**2. Methodology of strain gauge studies of pressures on the supports of the crane «Kondor».**

Determination of the pressure in the horizontal rollers of the portal crane column is carried out in order to assess the adequacy of the crane model used in the calculations. Information about the centers of gravity of additional elements (electrical cabinets, crane operator's cabin, stationary counterweights, etc.) was taken from the technical documentation of Dialab LLC.

The Power Graph 3.3 program was used to register and process the information obtained from the primary deformation transducers.

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Fig. 8. Tension station with 32 information channels.

Strain gauges were glued to the unloaded part of the roller. When the tap is turned, the tension resistor falls into the tension zone in the roller, caused by its contact with the support-rotary circle. After calibration using the calibration curve obtained as a result of calculations, on the basis of the known values of the deformation of the point of the wheel where the tensor is glued, the horizontal force on the roller was determined [7,8].

On each front roller there is one tensor resistor, the axis of which is welded radially. The skating rink has a cover on one side, so the sticker should be applied from the side opposite to the cover. The place of strain gauge sticker was pre-cleaned to a smooth state (the last skin is the finishing one), the surface was cleaned of dirt and abrasives with the help of acetone, and moisture was removed from the surface with alcohol. After the sticker was left for some time, the glue hardened.Measurements were made for a nominal load of 32 tons.

1. The jib system of the crane was placed in a position corresponding to the departure of 32 meters with a test load. First, the tensors on the rollers must be unloaded.

2. Started recording the signal.

3. We made a corner turn, achieving the fact that the part of the roller with tensor resistors, rotating, received the load from contact with the portal head. The rotation was continued until the load completely subsided.

4. Turned the tap in the opposite direction to the initial position of the tensor (until it is fully unloaded).

5. Repeated once more.

The procedure was repeated for a departure of 24 and 15 meters, respectively.

The strain gauge results confirmed the adequacy of calculation models and load distribution on the side sheet. That is, the side sheet is strong enough and does not need additional reinforcements to ensure the stability of the structure. High levels of stresses and deformations occurred in the front sheets, exceeding the permissible limits. This may indicate the presence of risks of destruction or instability of the front sheet under load.

The results of the strain measurement confirm the previously obtained data by the ANSYS program.

**Conclusions.**

Analysis of the technical condition of metal structures of port handling machines in Ukraine shows the presence of significant problems related to corrosion, mechanical wear, limited resources for maintenance and insufficient implementation of modern control methods. Port handling machines, which have been in operation for several decades, require increased attention to ensure their safety and reliability.

One of the promising methods for assessing the stress-strain state of metal structures is a combination of the analytical method of finite elements and the experimental strain measurement method. FEM allows you to create detailed mathematical models of structures, evaluate their strength and stability under various loads, and the strain measurement method provides accurate measurements of actual stresses in real operating conditions. In the case of the 'Condor' portal crane, the use of FEM demonstrated the possibility of detailed analysis of stress distribution, detection of areas of increased loads and design optimization. In particular, calculations using the ANSYS APDL program confirmed the need to strengthen certain structural elements, such as the front and rear pillars of the column, which are critical for preventing accidents. Strain measurement studies confirmed the adequacy of the model obtained using FEM and indicated the need to strengthen the front sheets of the column. The data of the strain gauges, which were carried out on the rollers of the crane, confirmed that the side sheet of the structure is strong enough, but the front sheets need additional strengthening.

In general, the combination of analytical and experimental methods makes it possible to increase the accuracy of assessing the technical condition of port transhipment machines, reduce the risks of emergency situations and ensure their stable and safe operation. In order to improve the situation of national ports in Ukraine, it is necessary to introduce modern diagnostic technologies and invest in the modernization and maintenance of equipment.

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## ОЦІНКА НАПРУЖЕНО-ДЕФОРМОВАНОГО СТАНУ ПОРТОВИХ ПЕРЕВАНТАЖУВАЛЬНИХ МАШИН

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***Анотація.*** *Стан металоконструкцій портових перевантажувальних машин в українських портах викликає тривогу через ряд проблем, таких як корозія, механічне зношування, відсутність модернізації, обмеженість ресурсів для технічного обслуговування та недостатнє застосування сучасних методів контролю. З часом конструкції, що експлуатуються вже кілька десятиліть, підлягають суттєвому зносу, що призводить до зменшення їхньої несучої здатності та збільшує ризик аварій. Вологе морське середовище сприяє корозії, а навантаження під час роботи перевантажувальних машин — втомі матеріалу і появі тріщин. Часто відсутність модернізації та обмежене фінансування технічного обслуговування призводять до аварійних ситуацій. Нерегулярне використання сучасних методів неруйнівного контролю ускладнює своєчасне виявлення прихованих* *дефектів. У даній роботі розглянуто проблеми та потенційні рішення щодо стану металоконструкцій портових перевантажувальних машин в українських портах. Виявлено кілька основних проблем, таких як корозія, механічне зношування, відсутність модернізації та обмежене фінансування технічного обслуговування. Зокрема, використовуються методи для оцінки напружено-деформованого стану металоконструкцій портальних кранів, зокрема поєднання аналітичного методу кінцевих елементів (МКЕ) та експериментального методу тензометрії. У підсумку, інтеграція МКЕ і тензометрії дозволила отримати точні дані про стан конструкцій, що є критично важливим для забезпечення їх безпеки і ефективності в експлуатації.*

***Ключові слова:*** *машини для перевантаження вантажів у портах, корозія, механічний знос, втома матеріалу та тріщини, метод скінченних елементів, напружено-деформований стан, тензометрія, модернізація, технічне обслуговування, неруйнівний контроль.*