MODELING THE INTEGRATION OF FINITE ELEMENT METHOD AND STRAIN GAUGING FOR EVALUATING METAL STRUCTURES IN PORT MACHINERY

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Abstract. The condition of metal structures of port handling machines in Ukrainian ports is alarming due to issues such as corrosion, mechanical wear, lack of modernization, limited maintenance resources, and insufficient application of contemporary control methods. Structures that have been operational for several decades exhibit significant wear, reducing their load-bearing capacity and increasing the risk of accidents. The humid marine environment exacerbates corrosion, while the stresses imposed on transshipment machinery contribute to material fatigue and cracking. This study explores the challenges and potential solutions related to the condition of metal structures of port handling machines in Ukraine. We identify key issues such as corrosion, mechanical wear, inadequate modernization, and limited funding for maintenance. Specifically, we apply a combination of the analytical finite element method (FEM) and experimental strain gauging to assess the stress-strain state of the metal structures of portal cranes. This integrated approach yields accurate data on structural conditions, crucial for ensuring operational safety and efficiency.

Keywords: Port handling machines, corrosion, mechanical wear, fatigue, cracking, finite element method, stress-strain state, strain gauging, modernization, maintenance, non-destructive testing.

Introduction

The condition of metal structures of port transshipment machines in Ukrainian ports raises significant concerns due to various factors. Many of these machines have been in operation for several decades, leading to considerable wear and tear on their metal components. Key issues include corrosion, mechanical wear, a lack of modernization, limited maintenance resources, and inadequate implementation of modern control methods. Prolonged exposure to the humid marine environment promotes corrosion damage, which undermines the load-bearing capacity of these structures [1, 2].

Operational loads on handling machines lead to material fatigue, resulting in cracks and deformations that necessitate careful monitoring and timely repairs. Many machines have not undergone significant upgrades, diminishing their operational efficiency and safety. Economic constraints often hinder regular maintenance and repairs, increasing the likelihood of emergencies.

The sporadic application of modern non-destructive testing techniques complicates the timely detection of hidden defects. To enhance the safety and efficiency of port handling machines in Ukraine, it is essential to strengthen monitoring of the technical condition of metal structures, implement modern diagnostic technologies, and increase investment in the modernization and repair of equipment.

Problem Statement

One promising method for determining the stress-strain state of the metal structures of port machines is the integration of the analytical finite element method (FEM) with the experimental strain gauge method. This hybrid approach facilitates a thorough assessment of structural conditions, yielding detailed insights into stress and deformation distributions across various components. The FEM enables the creation of a comprehensive mathematical model of the structure, accounting for diverse load scenarios and material properties.

Consequently, it allows for the prediction of structural behavior under different conditions and the identification of potential zones of elevated stress and deformation, critical for safe operation. The strain gauge method enhances this analysis by providing empirical data gathered during actual equipment operation, thus validating and refining FEM results [3-5].

The advantages of this combined methodology include the ability to obtain both theoretical and practical data on structural conditions, leading to a more accurate and reliable assessment. This is particularly vital for complex metal structures, where the influence of various factors may be difficult to predict using a single method. By integrating analytical and experimental approaches, we not only enhance the accuracy of structural assessments but also mitigate the risks of emergency situations, thereby contributing to the overall safety of port handling machines.

Research Objectives

This paper presents the results of research focused on the stress-strain state of the metal structure of the ’Condor’ portal crane as a case study. The application of the Finite Element Method (FEM) to the entire metal structure of the gantry crane is critical and offers several key advantages:

1. Complex Analysis of Stress-Strain State:

- FEM enables a detailed analysis of stress and deformation distribution across all components of the crane’s metal structure, including columns, jib systems, support beams, and frames.

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

2. Detection of Stress Concentration Zones:

- FEM identifies critical areas where increased stresses or deformations may occur, assisting in pinpointing potential structural weaknesses.

- This is vital for preventing accidents and cracks in essential elements, such as welds or joints.

3. Evaluation of Stability:

- FEM assesses the crane’s resistance to external loads, such as wind or dynamic forces during load movements.

- It helps evaluate the risk of loss of balance or overturning, critical for operational safety.

4. Design Optimization:

- FEM can be employed to optimize the design of the crane's metal structure, aiming to reduce weight, enhance strength, and minimize material costs.

- This optimization may include altering element shapes, selecting optimal materials, or modifying connections for improved performance.

5. Dynamic Process Analysis:

- FEM allows for analyzing the effects of dynamic loads, such as vibrations and shocks during crane operation.

- This capability enables predictions of the crane's behavior under various operating modes, ensuring stable and safe performance.

6. Consideration of Operating Conditions:

- FEM simulates the impact of various external factors on the crane's metal structure, such as corrosion, temperature fluctuations, and aggressive environments, affecting the structure's durability and reliability.

- This is crucial for estimating the crane's service life and planning maintenance.

7. Emergency Situation Simulation:

- FEM can model emergency scenarios, such as load loss or element failures, aiding in the preparation for potential hazards and developing preventive measures.

The application of the finite element method to the metal structure of a cargo crane proves to be an effective tool for ensuring reliability, safety, and structural optimization. FEM facilitates comprehensive analyses of the crane's behavior under varying loads, identifies potential issues, and fosters design solutions that enhance durability and operational efficiency. This ultimately reduces accident risks and guarantees stable crane operation across diverse conditions [6].

Methodology

The ANSYS APDL program, based on the finite element method, was employed to verify the strength of the crane's metal structure. The analysis involved five calculated scenarios of the crane design, each differing in the direction of forces induced by slope and wind.

1. Load Scenario Analysis:

- Case 1: Forces from the slope are applied along the crane's trajectory (horizontal load direction).

- Case 2 Forces from the slope act perpendicular to the crane's movement, creating lateral loads affecting stability.

- Case 3: Forces act along the crane path, inducing longitudinal loads impacting the columns and booms.

- Case 4: Forces act across the crane path, generating lateral loads leading to potential bending or shifting of structural members.

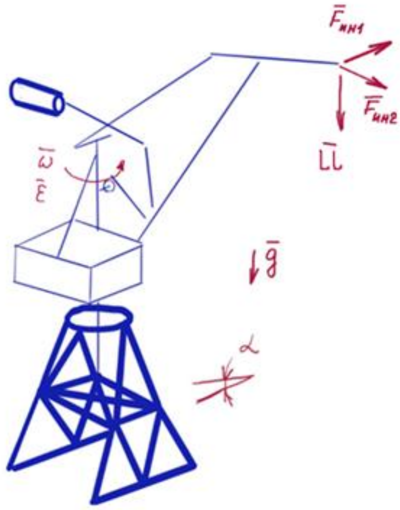

Fig. 1. Load scheme for case 1
(forces from the slope are applied along the crane’s trajectory).

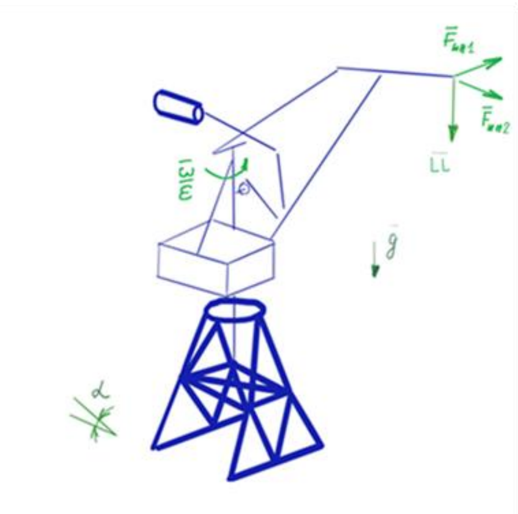

Fig. 2. Load diagram for case 2

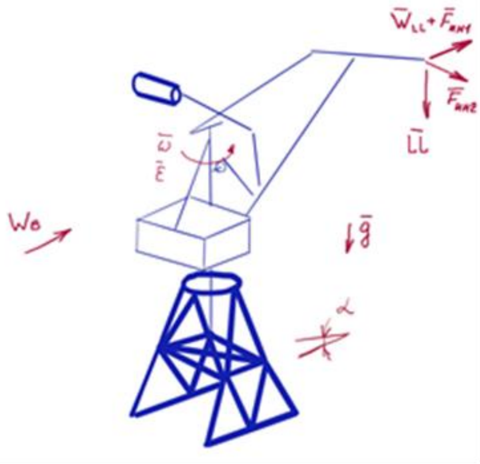

Fig. 3. Load diagram for case 3 (forces acting along the crane path).

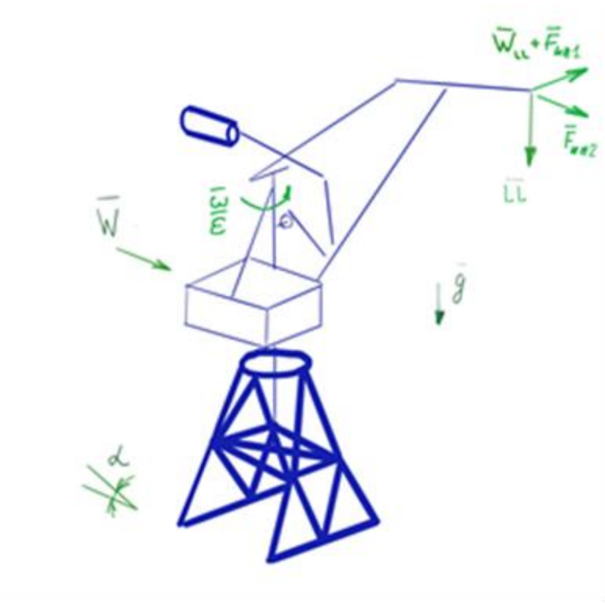

Fig. 4. Load diagram for case 4

- Case 5: Similar to Case 1, with cargo weight increasing from 32 tons to 40 tons.

Example Analysis of Case 1:

- The model utilized SHELL 181 elements (four nodal elements) for the column structure, allowing accurate accounting of thin-walled structures' deformations. The machine room was modeled using MPC 184 rigid beam elements, with a force acting at a point simulating the lifting mechanism's drum.

Following the analysis, it was observed that stresses in certain areas of the column exceeded allowable limits, necessitating local reinforcements for the front and rear shelves. The cyclic strength calculation must follow a specific reinforcement scheme after establishing static strength criteria. Analyses from ANSYS concluded that while the side sheet of the column met stability requirements, the front sheet did not, requiring reinforcement with an L300x100x10.5x15 corner, made of 17GS or 17G1C material.

Strain Gauge Methodology

Determining pressure on the horizontal rollers of the portal crane is essential to assess the adequacy of the crane model used in calculations. Data on the centers of gravity of additional elements were sourced from the technical documentation of Dialab LLC. The Power Graph 3.3 program facilitated the registration and processing of data from primary deformation transducers.

Procedure:

1. Strain Gauge Installation: Strain gauges were affixed to the unloaded part of the roller.
2. Signal Recording: The system began recording signals as the crane's jib system was positioned to correspond with a test load of 32 tons.

3. Measurement and Calibration: The load was adjusted, and the calibration curve facilitated the determination of horizontal force on the roller.

Measurements were repeated for jib system positions of 24 and 15 meters. Results indicated that the strain gauge measurements confirmed the adequacy of calculation models and load distribution on the side sheet. However, high stress levels on the front sheets exceeded permissible limits, indicating potential risks of structural failure.

Conclusions

The analysis of the technical condition of metal structures of port handling machines in Ukraine reveals substantial issues related to corrosion, mechanical wear, limited maintenance resources, and inadequate implementation of modern control methods. Machines that have been operational for decades necessitate increased attention to ensure safety and reliability.

The integration of the finite element method and the strain measurement technique offers a robust approach to assess the stress-strain state of metal structures. The FEM facilitates the creation of detailed models to evaluate strength and stability under various loads, while strain measurements provide precise data on actual stresses in operational conditions. For the ’Condor’ portal crane, FEM applications demonstrated a thorough analysis of stress distribution, revealing critical areas requiring reinforcement. It is imperative to enhance monitoring systems for technical conditions, adopt modern diagnostic technologies, and increase investment in the modernization and repair of port handling machines in Ukraine. These measures are vital to ensure the continued safe and efficient operation of port infrastructure, thereby safeguarding both equipment and personnel.

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СТРУКТУРА ІНТЕЛЕКТУАЛЬНОЇ ТРАНСПОРТНОЇ СИСТЕМИ

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Проєктування та структура інтелектуальної транспортної системи

Інтелектуальні транспортні системи (ІТС) являють собою комплекс рішень, які інтегрують інформаційні та комунікаційні технології для ефективного управління транспортною інфраструктурою та дорожнім рухом. Проєктування ІТС включає розробку структурованої системи, яка дозволяє підвищити безпеку, зменшити затори та покращити загальну ефективність транспортних потоків.

Основними етапами проєктування ІТС є:

1. Аналіз потреб та завдань – на початковому етапі визначаються ключові вимоги до системи, такі як управління рухом, збирання та аналіз даних, забезпечення безпеки та взаємодія з користувачами.

2. Вибір архітектури системи – структура ІТС складається з різних підсистем, таких як системи моніторингу транспорту, управління світлофорами, системи оповіщення про дорожні умови та аварії, навігаційні сервіси тощо. Важливим аспектом є узгодженість цих підсистем для забезпечення безперебійної роботи всієї системи.