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EXPERIMENTAL STUDY OF WEAR OF GEARS OF THE PORTAL CRANE MOVEMENT MECHANISM

Abstract. *Portal cranes play a crucial role in transshipment activities within maritime and riverine environments. As an essential component of the operational chain, the efficiency of port operations is closely tied to their dependable and uninterrupted functioning. Currently, over 88% of cranes in Ukraine's sea and river ports have surpassed their intended service life yet remain in use. The prolonged and intensive operational demands on these metal structures can result in fatigue-related defects, leading to component failures and potential accidents. Thus, prioritizing safe and efficient operations is critical when designing, modernizing, and managing cranes. A review of studies on the reliability of complex technical systems shows that the wear of gears of portal cranes, which have been operated in seaports for more than 35 years, has not been studied enough. The purpose of this study is to analyze the wear of the gears of the movement mechanism of portalcranes operating after their service life. 5 identical gantry cranes were selected for the research. The greatest wear of the working surfaces was recorded on the legs of the teeth, that is in places of maximum sliding, which completely coincides with the work of other researchers. The examination of the findings reveals that as the process continues, the level of wear escalates, nearing its upper limit. This data suggests that wear is affected not only by time elapsed, but also significantly by the operational stresses exerted on the material.*
Keywords: *Port handling machines, portal crane, mechanical wear, gears, experimental testing.*

Introduction. Portal cranes are widely used to perform basic operations in loading and unloading and warehousing operations in open areas in sea and river ports. Their reliable operation is crucial for ensuring the normal technological process at the enterprise [1-6].

The financing situation in Ukraine has led to the fact that ports operate cranes manufactured in the 70s and 80s of the last century, according to the regulatory documents of that time, which have certain design flaws [4,6].. Since their simultaneous replacement would require significant capital that the company could not afford, it is not expected to see any radical changes in the near future.

According to the Law of Ukraine ‘On High Risk Facilities’, cranes are classified as high-risk facilities, so they require increased attention during operation.

As an illustration, in the case of portal cranes, the weight of the lifting crane mechanism components that incorporate gears typically accounts for approximately 15-20% of the overall weight.

Gear systems are fundamental to construction machinery and cranes, allowing for the fluid and effective transfer of energy and movement among various parts.

In order to avoid emergencies, it is necessary to constantly monitor the technical condition and assess the residual life of the crane [1-5].

Setting the problem.

As you know, intensive and overtime operation of port equipment leads to the formation of fatigue defects and subsequent failure of nodes and accidents [2-6].

Research indicates that the movable joints in machinery undergo geometric alterations to their rubbing surfaces as they experience wear.

Over extended periods of wear, these surfaces achieve a stable configuration characterized by a consistent pattern of contact parameters. This implies that the wear process eventually reaches an equilibrium state where the shape and distribution of forces within the joint remain constant [7].

Gear performance is influenced by both external and internal factors. The interplay of these factors can result in various forms of gear damage. Although a gear train maintains a consistent gear ratio during operation, these influencing factors are subject to fluctuation, which can lead to the prominence of specific types of wear or damage.

It should be noted, however these models are simplified and do not take into account the complex interactions between the materials, surface roughness, lubrication, and other factors that can affect wear [8-10].

At the same time, it is known that as wear of the tooth profile exceeds the permissible error, the profile becomes different from the original involute profile. This leads to changes in the load and kinematic parameters of the contact, which in turn changes the wear characteristics and the shape of the tooth profiles [1-5].

As a result, it is important to consider the limitations of these models and use them with caution when making engineering calculations. It may be necessary to conduct experimental testing or use more advanced numerical simulations to accurately determine the wear characteristics of rubbing materials in specific applications.

Additionally, ongoing research and development in the field of tribology aim to improve the accuracy of wear predictions and develop more comprehensive models that take into account a wider range of factors. By continually refining our understanding of wear mechanisms and developing

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more sophisticated analytical tools, engineers can optimize the performance and durability of rubbing materials in various applications.

The failure of a single tooth does not result in the gearbox seizing, thanks to the overlap in the transmission. However, it can induce extra dynamic stresses, which may expedite the deterioration of the drive. At present, the only reliable method to detect these faults involves disassembling the drive and performing a thorough visual examination and measurement of its gears.

The complexity of repairs is compounded by the significant complexity of replacing drives and gears due to wear. The variety of design schemes also complicates repairs.5 identical gantry cranes were selected for the research.

The mechanisms were examined for 3 years.

The studied samples were made of 40X steel.

Visual inspection of all crane structures took place over two years work, every 6 months, after diagnostics of gearboxes by the method of vibration diagnostics.

Defection of gears by measuring the length of the chord at the top of the tooth

The revealed defects of the gear pairs are shown in Fig.1 and Fig.2.

a) b)

Fig.1. Defects of the gear pairs: wear (a) and teeth spalling (b)

The thickness S was assessed using a vernier gear tooth caliper (Fig. 2) equipped with two scales, labeled 1 and 2, along with verniers. Scale 2 is employed to determine the tooth's thickness along its chord, while scale 1 is utilized to calculate the radial distance from this chord to the circumference at the tips of the teeth.

A specialized involute gear measuring device was employed to assess the discrepancies between the real tooth shape and the ideal involute shape.

The initial values of wheel wear were obtained from the gantry crane inspection logs from the results of previous inspections and their corresponding measurements. It should be noted that the wear of the wheels of cranes differed slightly.

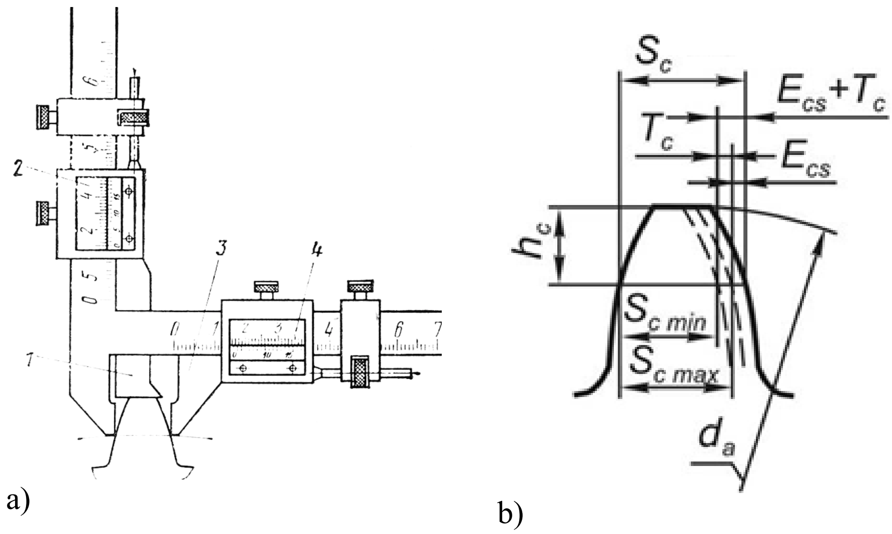

Fig.2 Gear measurement scheme (a) and

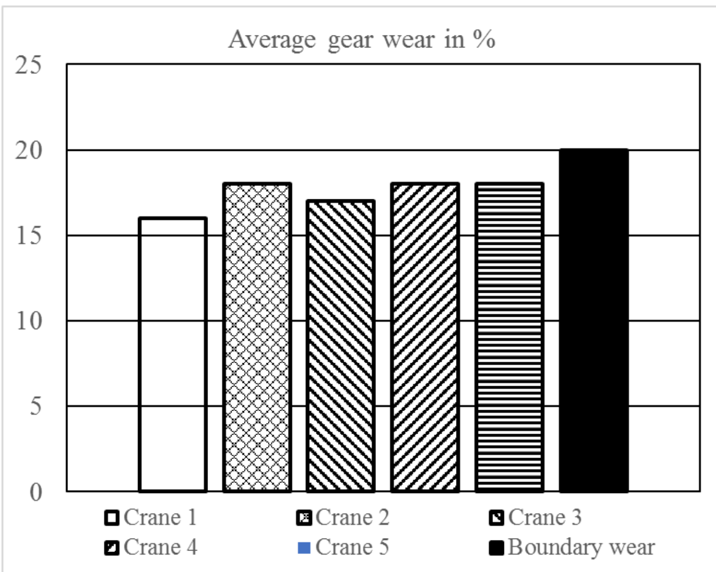

Fig.3 Crane-dependent tooth wear distribution and boundary wear

Tooth thickness was measured by a constant chord. After that, we determined the maximum value of gear tooth wear by thickness as the difference between the actual and the tooth thickness specified by the manufacturer. The results are shown in Fig.4.

The analysis showed that in all toothy Gears of mechanisms, the following types of defects are observed: wear and discoloration of the teeth, cracks near the tooth leg, breakage and crumpling of the teeth (Fig.1 and Fig.3).

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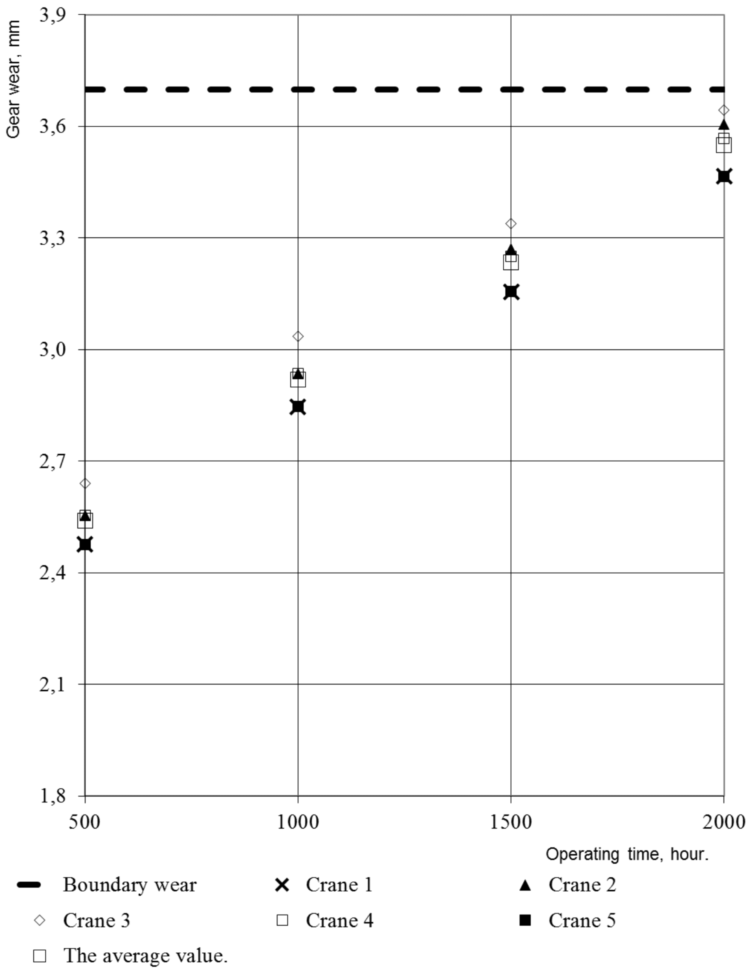

Fig.4 - The dependence of the wear of the teeth of the gears on the time of operation of the crane

Wear occurs both on the gear and on the wheel, which leads to a decrease in the thickness of the teeth.

Analysis of the obtained data showed that:

1) the lubrication level in gearboxes is below normal;
2) on individual teeth suffered small depressions;
3) reducing the thickness of the tooth head (on one of the gearboxes);
4) the appearance of single shallow paint shells;
5) uneven tooth wear;
6) isolated cases of initial dental jamming;
7) uneven location of contact spots;
8) the greatest wear was found on the legs of the teeth

During the investigation, the displacement of the contact spots was established, which is caused by the displacement of the shafts during assembly and wear of the bearings.

Spot painting and single shells did not serve as a basis for the rejection of wheels with hardened surfaces.

The extent of the defect can be assessed by observing the relative rotational angles of the drive gear compared to the follower, while the position of the defect can be determined by the frequency of its recurrence and its relation to the complete rotation step of a wheel situated at a specific point in the kinematic transmission system. Understanding the type of defect that a broken tooth may indicate is crucial, as the gear system is defined by an overlap ratio. [11,12]

This means (Fig. 4) 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 [11,12].

The examination of Figure 4 reveals that as the work progresses, the level of wear also escalates, nearing its limit values. The data suggests that wear is not only a function of time but also significantly connected to the operational stress imposed on the material. As workload intensifies, it becomes evident that the wear characteristics of the component change, highlighting the importance of understanding these dynamics to predict the lifespan and performance of materials under varying conditions.

Moreover, issues with gear components frequently contribute to the distortion of the load-bearing frameworks in port cranes. This can result in metal fatigue, the development of cracks, and a reduction in the stability of various crane parts [11,12].

Fig. 4 shows that the dependence of tooth wear I on the operating time *t* is approaching a linear one. which can be set as:

$$I = a_1 + a_2 t \qquad (1)$$

where a_1 and a_2 – constant.

It is necessary to select the values a_1 and a_2 that minimize the sum of squared differences for the function to have the smallest value:

$$\Phi(a_1, a_2) = \sum_i \varepsilon_i^2 = \sum_i \left(f(t_i, a_1, a_2, \ldots) - I_i \right)^2 \qquad (2)$$

Based on the theory of the local extremum, it is necessary to find partial derivatives of function (2) according to a_1 anв a_2 equate them to zero and obtain a system of equations:

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$$\begin{cases} \Phi'_a(a_1, a_2) = \sum_i 2(a_1 x_i + a_2 - I_i)x_i = 2\left(a_1 \sum_i t_i^2 + a_2 \sum_i t_i - \sum_i t_i I_i\right), \\ \Phi'_b(a_1, a_2) = 2\left(a_1 \sum_i I_i + n a_2 - \sum_i I_i\right), \end{cases} \quad (3)$$

After the transformations, we obtain a system of two linear equations with two unknowns a_1 and a_2:

$$\begin{cases} a_1 n + a_2 \sum_{i=1}^{n} t_i = \sum_{i=1}^{n} I_i, \\ a_1 \sum_{i=1}^{n} t_i + a_2 \sum_{i=1}^{n} t_i^2 = \sum_{i=1}^{n} t_i I_i. \end{cases} \quad (4)$$

The results of calculations according to formulas (1) - (4) are summarized in Table 1.

The analysis indicates that high dynamic loads are the primary cause of gear failure, leading to several forms of damage:

Table 1 - Coefficients of gantry crane gear wear equations

Crane	a_1	a_2
1	0,0007	1,91
2	0,0006	1,92
3	0,0007	1,83
4	0,0006	1,89
5	0,0005	1,92

1) continuous high loads can accelerate the wear process, resulting in the gradual loss of material from the gear teeth. This wear can lead to reduced efficiency, increased noise, and eventual failure;

2) pitting of damage is characterized by the formation of small cavities or pits on the surface of the gear teeth. Pitting often occurs due to the cyclic loading and unloading of the gears, which can initiate fatigue cracks. As these cracks propagate, they lead to significant surface degradation;

3) excessive dynamic loads can exceed the material strength of the gear teeth, causing them to fracture. This failure mode is often sudden and catastrophic, leading to a complete breakdown of the gear system;

4) excessive dynamic loads can exceed the material strength of the gear teeth, causing them to fracture. This failure mode is often sudden and catastrophic, leading to a complete breakdown of the gear system.

Wear is often linked to improper installation and typically does not occur when components are assembled correctly, with precise adherence to radial clearance. Wear in the first case is mainly the result of poor installation, and when assembled correctly (strict adherence to radial clearance), it is usually absent. However, changing the radial clearance may also be a result of wear on the bearing inserts, which can lead to an increase or decrease in the radial clearance (working in interference). If the load on the bearings is transmitted to the sides opposite to the clutch during operation, the radial clearance may increase as the bearings wear out [1-3].

The positioning of contact areas on both operational and non-operational profiles at either the same or opposing edges of the gear teeth during rotation in both directions signifies the misalignment or skewness of the shafts.

The presence of contact spots on both the active and inactive profiles on one or both edges of the teeth during the rotation of the gear pair in both directions respectively indicates misalignment or skew of the shafts [6,10].

The gradual wear due to increased friction depends on several conditions, including the material hardness of the gears, heat treatment, proper lubricant selection, insufficient oil cleanliness, and timeliness of its replacement, transmission overload [6,10].

The initial build-up of different volumetric and structural damages primarily takes place in the outer layers of the teeth. This accumulation leads to significant wear and the emergence of contact fatigue phenomena, which drastically diminishes the overall load-bearing capacity of the entire component.

Conclusions.

An examination of the state of metal frameworks in port handling equipment across Ukraine reveals considerable issues linked to corrosion, mechanical degradation, inadequate maintenance resources, and a lack of updated monitoring techniques. Machines used in port operations in Ukraine that have been service for many years necessitate greater scrutiny to guarantee their dependability and safety.

The proper functioning of gears within a crane's lifting system is crucial for ensuring operational safety.

Changes in radial clearance can also occur due to wear of the bearing shell, leading to variations in both the increase and decrease of radial clearance.

The analysis of the results shows that as the work progresses, the degree of wear increases, approaching the maximum threshold values. This information indicates that wear is not only influenced by the passage of time, but also by the close relationship with the operational stresses to which the material is subjected.

The extent of the defect can be assessed by observing the relative rotational angles of the drive gear compared to the follower, while the position of the defect can be determined by the frequency of its recurrence and its relation to the complete rotation step of a wheel situated at a specific point in

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the kinematic transmission system. Understanding the type of defect that a broken tooth may indicate is crucial, as the gear system is defined by an overlap ratio. Studies indicate that the signal patterns resulting from the interplay of backlash, time-dependent gear mesh stiffness, and errors in the involute profile are intricate and significantly influenced by the design and layout of the gear train.

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ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ЗНОСУ ЗУБЧАСТИХ КОЛІС МЕХАНІЗМУ ПЕРЕМІЩЕННЯ ПОРТАЛЬНОГО КРАНА

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Анотація. *Портальні крани відіграють вирішальну роль у перевантажувальній діяльності в морському та річковому середовищі. Як невід'ємний компонент операційного ланцюга, ефективність портових операцій тісно пов'язана з їх надійним і безперебійним функціонуванням. Наразі понад 88% кранів у морських та річкових портах України відпрацювали свій термін експлуатації, але продовжують використовуватися. Тривалі та інтенсивні експлуатаційні навантаження на ці металоконструкції можуть призвести до виникнення втомних дефектів, що призводять до відмов компонентів і потенційних аварій. Таким чином, пріоритетність безпечної та ефективної експлуатації має вирішальне значення при проектуванні, модернізації та управлінні кранами. Огляд досліджень з надійності складних технічних систем показує, що знос зубчастих передач портальних кранів, які експлуатуються в морських портах понад 35 років, вивчений недостатньо. Метою даної роботи є аналіз зносу зубчастих передач механізму пересування портальних кранів, що експлуатуються після вичерпання терміну служби. Для дослідження було обрано 5 однакових портальних кранів. Найбільший знос робочих поверхонь зафіксовано на лапах зубів, тобто в місцях максимального ковзання, що повністю збігається з роботами інших дослідників. Вивчення отриманих результатів показує, що в міру продовження процесу рівень зносу зростає, наближаючись до своєї верхньої межі.*

Ці дані свідчать про те, що на знос впливає не тільки час, що минув, але й значною мірою експлуатаційні навантаження, що діють на матеріал.

Ключові слова: *Портові перевантажувальні машини, портальний кран, механічне зношування, зубчасті передачі, експериментальні випробування.*