The influence of hinges wear on the dynamic load of the articulated boom of a garbage truck's manipulator

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Abstract

The article is dedicated to establishing the relationship between the maximum impact dynamic stresses in the most loaded section of the garbage truck manipulator boom and the wear of the manipulator's hinge and its load level. By utilizing a first-order experimental design with first-order interaction effects using the Box-Wilson method, an adequate dependence of maximum impact dynamic stresses in the most loaded section of the manipulator boom on the wear of the manipulator's hinge and its load level was determined. It has been found that, according to the Student's criterion, among the investigated influencing factors, hinge wear has the most significant impact on the maximum impact dynamic stresses in the most loaded section of the manipulator boom, while its load level has the least impact. The response surface of the objective function is shown – the maximum impact dynamic stresses in the most loaded section of the manipulator boom and their two-dimensional sections in the planes of the impact parameters, which allows to visually illustrate the specified dependence of this objective function on individual impact parameters. It was established that the wear of the hinge by 1000 μm leads to an increase in the maximum impact dynamic stresses in the most loaded cross-section of the boom of the garbage truck manipulator by 2.6...4 times, depending on the level of its load. The expediency of conducting further studies of the effect of antifriction materials on the wear of the friction pairs of the mechanism for loading municipal solid waste into the garbage truck is shown.

Keywords: wear, dynamic load, hinge, boom, manipulator, garbage truck, municipal solid waste, dependence, experimental planning.

Introduction

The problem of increasing wear resistance, reliability, and durability of machine parts holds a leading position among the top priorities in the field of municipal engineering in Ukraine, particularly for manipulator-type machines [1, 2]. The collection and transportation of municipal solid waste (MSW) to further disposal sites in Ukraine are primarily carried out by body garbage trucks, equipped with loading mechanisms in the form of manipulators. Nearly 3700 body garbage trucks are capable of compacting MSW, reducing transportation costs and the required landfill areas. During the technological operation of loading MSW into the body garbage truck, the hinges of its manipulator are subjected to intensive wear. This is due to the substantial weight of the MSW container (up to 500 kg) being lifted, operation in reverse mode (reversing and rotating movement), a high number of work cycles per one route, and operation under conditions of a wide range of temperature fluctuations, relative humidity, and environmental dustiness. Insufficient lubrication or a deterioration in material quality leads to increased friction in the hinges and an increase in vibrations within the system. This, it can affect the dynamic stability of the manipulator and its ability to withstand high loads. Hinge wear can impact the efficiency and safety of the garbage truck manipulator's operation, which can have negative consequences for operators and the environment. According to statistical data, the wear and tear of the municipal waste collection fleet in the Khmelnytskyi region from 2015 to 2020, despite measures taken, decreased only marginally from 63% to 59% [3, 4]. According to the text of the Resolution of the Cabinet of Ministers of Ukraine No. 265 [5], among the important

tasks, a prominent place is to ensure the use of modern highly efficient garbage trucks in the country's communal economy, as the main link in the structure of machines for collection, transportation and primary processing of solid waste. This not only helps address various environmental issues but also enhances the overall reliability of municipal services. Planning for the renewal, maintenance, and repair of garbage trucks is facilitated by determining the regression relationship between hinge wear and the dynamic load on the articulated boom of the garbage truck manipulator.

Analysis of recent research and publications

In the work [6], an improved mathematical model of the operation of the solid waste dehydrating drive in a garbage truck, taking into account the wear of the auger, was published, which made it possible to numerically study the dynamics of this drive during start-up and determine the effect of auger wear on the operating characteristics of the drive: with increasing wear of the auger, the pressure of the working fluid at the inlet increases of the drive hydraulic motor, and the angular speed and rotation frequency of the auger are significantly reduced with a constant supply of working fluid. Dependencies in the form of power-law functions of changes in the nominal values of pressures at the hydraulic motor inlet, angular velocity and rotation frequency of the auger depending on the amount of its wear have been determined. At the same time, the dependence of the rotation frequency of the auger on the amount of its wear describes the adjustment from the optimal rotation frequency of the auger in the process of its wear and is used to determine the energy intensity of MSW dehydration taking into account the wear of the auger. In particular, it was found that the wear of the auger by $1000~\mu m$ leads to an increase in the energy consumption of solid waste dehydration by 11.6%, and, therefore, to an increase in the cost of the process of their dehydration in the garbage truck and acceleration of the wear process.

The article [7] examines the performance of reversible friction hinges in the control systems of transport vehicles operating in various operating conditions. It is noted that hinged assemblies and connections are among the most responsible and highly loaded power connections of industrial transport machines, and are also the most metal-intensive and most loaded elements of machines that connect the main structural elements and functional units. As a result of the analysis of the wear of the parts of the reversible hinges of transport vehicles operating in a corrosive environment, their increased wear and unreliability in operation was noted. The active loads of the parts of the hinges of coupling devices were studied, as a result of which it was established that there is plastic contact in the friction pair, which causes increased wear of the friction surfaces. As a result of the research, it is proposed to improve the design of the hinges, which allow self-compensation for the wear of the friction surfaces of the coupled parts and improve their operation due to the constant supply of lubricant to the friction zone.

In work [8], an analysis of the types of wear of hinged joints of forest manipulators was carried out, which made it possible to outline possible ways of increasing their wear resistance, which will help design engineers to increase the working life of hinged joints depending on the requirements placed on them in the process of work. It is noted that manipulator-type machines often work under conditions of environmental temperature drops, which negatively affects the properties of lubricants and hinge materials. At a low temperature, the materials of the rubbing pairs become more brittle, the yield strength decreases and the hardness of the working surfaces increases. This complicates the processes of movement and annihilation of dislocations, the occurrence of exoelectron emission, and thus intensifies the wear process. At low ambient temperature, the lubricant hardens or its viscosity increases, which significantly reduces its lubricating properties. In the summer, at high temperatures, the lubricant heats up and it randomly flows out of the friction zone, which negatively affects the process of lubrication and cooling of working surfaces. Therefore, it is proposed to protect the hinge joints of the manipulators from the polluting and corrosive effects of the environment, as well as from the leakage of the lubricant, with special sealing devices. It was established that it is most expedient to introduce contact and labyrinth sealing devices into the design of hinges.

In the article [9], a mathematical model was developed that allows to determine the geometric parameters of the design elements of the manipulator depending on the load capacity, maximum displacement and other kinematic parameters of the machine. It is noted that, taking into account the periodicity of the operation of the hinge joints of the manipulators, there is no hydrodynamic process of friction in them, since the process takes place under conditions of semi-dry and marginal friction. Unlike the established hydrodynamic friction process, the operation of sliding bearings with semi-dry and extreme friction increases the wear of the friction surfaces, which leads to a violation of kinematic accuracy, causes additional dynamic loads, shocks, vibrations, which lead to fretting corrosion and, as a result, to destruction. It is proposed to reduce the force of friction by applying lead, phosphate, and indium coatings to the joint parts of manipulator hinges.

It has been established that contact wear can be reduced by introducing oil and fat-based lubricants or by using consistent lubricants, which at a temperature of 25 °C acquire a thick, ointment-like consistency. For better maintenance of the lubricant on the surface, it is advisable to use phosphate and anodic metal coatings.

The work [10] presents the method of synthesis of the motion trajectory of a manipulative robot by degrees of mobility. It was established that the bending of the rod leads to the occurrence of support reactions in the contact zone, as in a beam on two supports. Having obtained the contact pressure, it is possible to establish the wear of the

surfaces of the rod, hydraulic cylinder and ground box. Contact stress reaching a third of the strength limit, with complete safety of the rod from bending, can cause a significant acceleration of the wear of the rubbing surfaces, which makes it possible to specify the causes of the detected wear patterns and the features of their identification.

In the article [11], it was established that when creating new promising designs of hinged joints, it is necessary to apply a complex approach to scientific and technical solutions that take into account a significant number of parameters affecting their performance. At the same time, taking into account the above possibilities and principles of increasing the efficiency of tribotechnical units, it is possible to create new constructive solutions that ensure the increased efficiency of hinged joints of manipulators of logging machines, which allow to significantly ensure the achievement of increased mechanical and tribotechnical characteristics, as well as to optimize the thermal mode of operation node

The authors of the work [12] carried out computer modeling of the process of forming additional dynamic load of metal structures of manipulator cranes with increased clearances in cylindrical joints. A significant drawback of cylindrical hinges is indicated: in the process of operation, over time, the gaps between the hinge fingers and the surfaces of the holes of the eyelets increase monotonously as a result of frictional wear and impact crumpling of their contact surfaces. It is shown that the time-progressive wear of hinges leads to a significant increase in short-term shock stresses in the connections of hinged-jointed booms, an increase in their load level even under stable operating conditions and an increase in the risk of developing permanent destruction, as well as the maximum dynamic shock stresses in the most loaded cross-sections of the manipulator boom for different wear values of the manipulator hinge and its load level.

In the materials of the article [13], using regression analysis, a dependence is determined that describes and allows forecasting the dynamics of wear and tear of garbage trucks in general in the Khmelnytskyi region, as well as planning the infrastructure of communal enterprises (warehouse and renewal of garbage trucks, production base for maintenance and repair), which necessary to solve the problem of solid household waste management.

However, as a result of the analysis of known publications, the authors did not find specific mathematical dependencies describing the effect of wear of hinges on the dynamic load of the articulated boom of the garbage truck manipulator.

Aims of the article

Study of the effect of hinge wear on the dynamic load of the articulated boom of the manipulator of the garbage truck.

Methods

Determining the dependence of the impact of hinge wear on the dynamic load of the hinged boom of the garbage truck manipulator was carried out by planning a second-order experiment with first-order interaction effects using the Box-Wilson method [14]. The coefficients of the regression equations were determined using the developed computer program "PlanExp", which is protected by a certificate of copyright registration for the work and is described in the work [15].

Results

Preliminary processing of the results of experimental studies [12] showed that the maximum impact dynamic stresses in the most loaded section of the manipulator boom are a function of the following 2 main parameters:

$$\sigma_{max} = f\left(u, \frac{G}{G_n}\right), \tag{1}$$

where σ_{max} – maximum impact dynamic stresses in the most loaded section of the manipulator boom, MPa; u –manipulator hinge wear, μm; G/G_n – load level of the manipulator; G – weight of a solid waste container, N; G_n – nominal load capacity of the manipulator, N.

The study of the influence of the above factors on the maximum impact dynamic stresses in the most loaded section of the boom of the garbage truck manipulator when processing the results of one-factor experiments by the regression analysis method is associated with significant difficulties and amount of work. Therefore, in our opinion, it is advisable to conduct a multivariate experiment to obtain a regression equation for the response functions – maximum impact dynamic stresses in the most loaded section of the manipulator boom using the planning of a multivariate experiment using the Box-Wilson method [14].

The maximum impact dynamic stresses in the most loaded section of the manipulator boom for different wear values of the manipulator hinge and its load level are given in the Table 1 [12].

Table 1

Maximum impact dynamic stresses in the most loaded cross-section of the manipulator boom for different wear values of the manipulator hinge and its load level [12]

#	Maximum impact dynamic stresses in the most loaded section of the manipulator boom σ_{max}, MPa	Wear of the manipulator hinge u, μm	The ratio of the weight of the container with municipal solid waste to the nominal load capacity of the manipulator G/G_n
1	21.9	0	0.25
2	65.6	500	0.25
3	87.5	1000	0.25
4	100	1500	0.25
5	109.4	2000	0.25
6	40.6	0	0.5
7	100	500	0.5
8	134.4	1000	0.5
9	153.1	1500	0.5
10	162.5	2000	0.5
11	62.5	0	0.75
12	121.9	500	0.75
13	162.5	1000	0.75
14	187.5	1500	0.75
15	203.1	2000	0.75
16	78.1	0	1
17	153.1	500	1
18	200	1000	1
19	231.3	1500	1
20	246.9	2000	1

Based on the data in Table 1, using the planning of the second-order experiment with first-order interaction effects, using the developed software protected by a certificate, after discarding insignificant factors and interaction effects according to the Student's criterion, the regularity of the maximum impact dynamic stresses in the most loaded section of the boom is determined of the manipulator from the wear of the manipulator hinge and the level of its load:

$$\sigma_{max} = 0,08552\, u + 89,58\, \frac{G}{G_n} + 0,06243\, u\, \frac{G}{G_n} - 2,99 \cdot 10^{-5} u^2 - 10,02 \left(\frac{G}{G_n} \right)^2. \qquad (2)$$

In Fig. 1 shows the response surface of the objective function – the maximum impact dynamic stresses in the most loaded section of the manipulator boom σ_{ma} and their two-dimensional sections in the planes of the impact parameters, built using the dependence (2), which allows to visually illustrate it.

It was established that, according to the Fisher criterium, the hypothesis about the adequacy of the regression model (2) can be considered correct with 95% confidence. The coefficient of multiple correlation: $R = 0.99748$, which indicates the high accuracy of the obtained results.

According to the Student's criterion, it was found that among the investigated influencing factors, the maximum impact dynamic stresses in the most loaded section of the manipulator boom are most affected by the wear of the manipulator hinge, and the least by its load level.

It was established that the wear of the hinge by 1000 μm leads to an increase in the maximum impact dynamic stresses in the most loaded cross-section of the boom of the garbage truck manipulator by 2.6...4 times, depending on the level of its load.
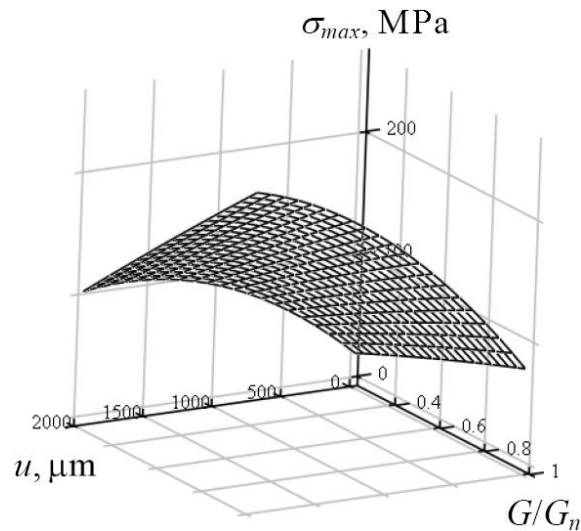
Fig. 1. The response surface of the objective function – the maximum impact dynamic stresses in the most loaded section of the manipulator boom σ_{max}

Determination of the influence on wear and development of recommendations for the selection of anti-friction materials for the friction nodes of the solid waste loading mechanism in the garbage truck require further research.

Conclusions

The dependence of the maximum impact dynamic stresses in the most loaded section of the manipulator boom of the garbage truck due to the wear of the manipulator hinge and the level of its load was determined to be adequate according to Fisher's criterion. It was established that, according to the Student's criterion, among the investigated factors of influence, the maximum impact dynamic stresses in the most loaded section of the manipulator boom are most affected by the wear of the manipulator hinge, and the least by its load level.

The response surface of the objective function is shown – the maximum impact dynamic stresses in the most loaded section of the manipulator boom and their two-dimensional sections in the planes of the impact parameters, which allow you to visually illustrate the specified dependence of this target function on individual impact parameters. It was established that the wear of the hinge by 1000 μm leads to an increase in the maximum impact dynamic stresses in the most loaded cross-section of the boom of the garbage truck manipulator by 2.6...4 times, depending on the level of its load. Determining the effect of antifriction materials on the wear of the friction nodes of the solid waste loading mechanism in the garbage truck requires further research.

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Березюк О.В., Савуляк В.І., Харжевський В.О., Яворський В.Є. Вплив зносу шарнірів на динамічну навантаженість шарнірно-сполученої стріли маніпулятора сміттєвоза

Стаття присвячена встановленню залежності максимальних ударних динамічних напружень в найбільш навантаженому перерізі стріли маніпулятора сміттєвоза від зносу шарніра маніпулятора та рівня його навантаженості. За допомогою використання планування експерименту першого порядку з ефектами взаємодії першого порядку методом Бокса-Уілсона визначено адекватну закономірність максимальних ударних динамічних напружень в найбільш навантаженому перерізі стріли маніпулятора сміттєвоза від зносу шарніра маніпулятора та рівня його навантаженості. Встановлено, що за критерієм Стьюдента серед досліджених факторів впливу найбільше на максимальні ударні динамічні напруження в найбільш навантаженому перерізі стріли маніпулятора впливає знос шарніра маніпулятора, а найменше – рівень його навантаженості. Показано поверхню відгуку цільової функції – максимальних ударних динамічних напружень в найбільш навантаженому перерізі стріли маніпулятора та їхні двомірні перерізи в площинах параметрів впливу, які дозволяють наглядно проілюструвати вказану залежність даної цільової функції від окремих параметрів впливу. Встановлено, що знос шарніра на 1000 мкм призводить до зростання максимальних ударних динамічних напружень в найбільш навантаженому перерізі стріли маніпулятора сміттєвоза в 2,6...4 рази в залежності від рівня його навантаженості. Показано доцільність проведення подальших досліджень впливу антифрикційних матеріалів на знос вузлів тертя механізму завантаження твердих побутових відходів у сміттєвоз.

Ключові слова: знос, динамічна навантаженість, шарнір, стріла, маніпулятор, сміттєвоз, тверді побутові відходи, закономірність, планування експерименту.