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Dependence of wear of friction pairs of the mechanism for loading solid household waste into a garbage truck on the characteristics of antifriction materials

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Abstract

The article is dedicated to the establishment a regression dependence of wear of friction units of the mechanism of loading a garbage truck on the properties of antifriction materials. By using a first-order planning of experiment with first-order interaction effects using the Box-Wilson method, an appropriate regularity of wear of friction units of the garbage truck loading mechanism on the properties of antifriction materials has been determined. It is established that, according to the Student's criterion, among the studied factors of influence, the wear of friction units of the garbage truck loading mechanism is most influenced by the pressure in the friction zone, and the least – by the Brinell hardness of the antifriction material. The response surfaces of the objective function – wear of friction units of the garbage truck loading mechanism and their two-dimensional cross-sections in the planes of the influence parameters are shown, which allow to clearly illustrate the specified dependence of this objective function on individual influence parameters. It has been established that an increase in the pressure in the friction zone and sliding speed by 60% leads to an increase in the wear of friction units of the garbage truck loading mechanism during reverse motion by 6.3...34%, depending on the properties of antifriction materials. The expediency of conducting further research to determine ways to further improve the wear resistance of friction units of the mechanism for loading solid household waste into a garbage truck has been shown.

Keywords: wear, friction units, loading mechanism, garbage truck, solid household waste, dependence, experiment planning.

Introduction

Among the actual tasks of the municipal engineering industry of Ukraine, in particular for mobile equipment of the manipulator type, which include garbage trucks, the problems of increasing the wear resistance, reliability and durability of machine parts have a prominent place [1, 2]. In Ukraine, collection and transportation of municipal solid waste (MSW) is carried out mainly by body garbage trucks with manipulators as loading bodies. There are almost 3,700 garbage trucks in use in Ukraine that are capable of compacting solid waste, reducing transportation costs and the required landfill space. At the time of the technological operation of loading MSW into a garbage truck, the friction units in the form of hinge joints of its manipulator are subject to intensive wear. This is due to the considerable weight of the container with solid waste (up to 500 kg) that is lifted, operation in reverse mode (reverse rotation), a significant number of work cycles per route, as well as operation in a wide range of relative humidity, temperature, and environmental dust. Deterioration of material quality or insufficient lubrication leads to increased friction forces in hinge joints and increased vibrations in the system, which in turn can affect the dynamic stability of the manipulator and its ability to withstand high loads in reverse friction conditions. Wear and tear on friction components can affect the efficiency and safety of a refuse garbage truck's manipulator, which can have negative consequences for both operators and the environment. According to statistics, the wear and tear of the fleet of garbage trucks owned by municipal enterprises in Khmelnytskyi region

over the 2015-2020 years, despite the measures taken, has decreased only from 63 % to 59 % [3]. According to the Resolution of the Cabinet of Ministers of Ukraine No. 265 [4], the problem of ensuring of the usage of modern, highly efficient garbage trucks in the domestic municipal sector as the main link in the structure of machines for the collection, transportation and primary processing of solid waste is a key task. This allows to solve a number of environmental problems and improve the overall reliability of the country's utilities. Planning for the renewal, maintenance and repair of garbage trucks is facilitated by determining the regression dependence of wear of the friction units of the garbage truck loading mechanism on the properties of antifriction materials.

Analysis of the recent research and publications

In the work [5] a method for optimizing a robotic cell by changing the placement of the robot manipulator in the cell in applications with a fixed endpoint trajectory is described. The aim of the study was to reduce the overall wear of the robot's joints and prevent uneven wear of the joints when one or more joints are under more load than others. Joint wear was approximated by calculating the integral of the mechanical work of each joint along the entire trajectory, which depends on angular velocity and torque. The method is based on the usage of dynamic modelling to estimate the torques and velocities in the robot's joints for its certain positions. It is established that, provided the robot base is correctly positioned, the total wear of the joints of the robotic arm of the robot manipulator can be reduced by 22...53%, depending on the trajectory.

The scientific article [6] investigates the performance of reversible friction joints in the control systems of transport machines under various operating conditions. It is noted that hinge assemblies and joints are among the most critical and highly loaded connections of industrial transport machines, and are also the most metal-intensive and heavily loaded machine elements that connect the main structural elements and functional units. As a result of the analysis of the wear of parts of reversible joints of transport machines in a corrosive and abrasive environment, their increased wear and unreliability in operation were observed. The study of the operating loads of the hinge parts of coupling devices has made it possible to establish that plastic contact occurs in the friction pair, which leads to increased wear of the friction surfaces. Improvements to the design of the joints are proposed, which provide auto-compensation for wear of the friction surfaces of mating parts and improve their operation by constantly supplying lubricant to the friction zone.

The authors of the paper [7] determine a dependence of maximum impact dynamic stresses in the most loaded section of the garbage truck boom depending on the wear of the manipulator joint and the level of its load, according to the Fisher criterion. It is established that, according to the Student's criterion, among the considered factors of influence, the wear of the manipulator joint has the greatest impact on the maximum impact dynamic stresses in the most loaded section of the manipulator boom, and the level of its load has the least impact. The response surface of the target function – 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 are shown, which allow to clearly illustrate the specified dependence of this target function on individual impact parameters. It is established that the wear of the joint by 1000 μm leads to an increase in the maximum impact dynamic stresses in the most loaded section of the garbage truck manipulator boom by 2.6...4 times, depending on the level of its load. The expediency of further studies of the influence of antifriction materials on the wear of friction units of the mechanism for loading solid household waste into a garbage truck has been shown.

Article [8] analyses the types of wear of hinge joints of forestry manipulators, which made it possible to identify possible ways to increase their wear resistance, which will help design engineers to increase the working life of hinge joints depending on the requirements for them in the process of work. It is noted that manipulator-type machines often operate in conditions of ambient temperature differences, which negatively affects the properties of lubricants and joint materials. At low temperatures, the materials of friction pairs become more brittle, the yield strength decreases and the stiffness of working surfaces increases. This complicates the processes of dislocation movement and annihilation, the occurrence of exoelectronic emission and, in turn, intensifies the wear process. At low ambient temperatures, the lubricant hardens or its viscosity increases, significantly reducing its lubricating properties. In the summer time, at high temperatures, the lubricant heats up and can leak out of the friction zone, which negatively affects the lubrication and cooling of working surfaces. To prevent this, it is proposed to protect the hinge joints of manipulators from the polluting and corrosive effects of the environment, as well as from leakage of lubricant, with special sealing devices. The expediency of introducing contact and labyrinth sealing into the design of hinges has been established.

In the work [9], a mathematical model is proposed to determine the geometric parameters of the manipulator's structural elements depending on the maximum outreach, load capacity, and other kinematic parameters of the machine. Given the frequency of operation of the manipulator's hinge joints, it is noted that there is no hydrodynamic friction process there, since the process proceeds under conditions of semi-dry and boundary friction. In contrast to the established hydrodynamic friction process, the operation of sliding bearings under semi-dry and boundary friction increases the wear of friction surfaces. This, in turn, causes a violation of kinematic accuracy, additional dynamic loads, impacts, vibrations, which lead to fretting corrosion and destruction. It is proposed to reduce the friction force by applying lead, phosphate, indium coatings to the mating parts of manipulator joints. It is established that contact wear can be reduced by introducing oil and fat-based lubricants or

grease lubricants, which at a temperature of 25 °C take on a thick ointment-like consistency. The expediency of using phosphate and anodic metal coatings for better lubricant retention on the surface has been determined.

The work [10] describes a method for synthesizing the trajectory of a manipulation robot by degrees of mobility. It was found that the bending of the rod causes support reactions in the contact zone, as in a beam on two supports. After determining the contact pressure, it is possible to determine the possibility of wear of the surfaces of the hydraulic cylinder, rod and groundbox. It was found that the contact stress, reaching one third of the tensile strength, with complete safety of the rod from bending, can cause a significant acceleration of wear of friction surfaces. This makes it possible to clarify the cause of the identified wear patterns and the specifics of their identification.

In the paper [11] it is found that when creating new promising designs of hinge joints, it is necessary to apply an integrated approach to scientific and technical solutions to take into account a significant number of parameters that affect their performance. As a result, it is possible to create new design solutions that provide increased performance of hinge joints of logging machine manipulators. They can significantly improve the mechanical and tribotechnical characteristics, as well as optimize the thermal operation of the assembly.

The authors of [12] specified that the usage of plastics as an antifriction material eliminates the need for periodic supply of lubricant to the gap of a hinge joint. As a result, the need for oil channels disappears. In addition, the metals used to make the shaft and the enclosing lug are mated to a softer sliding material, so that wear on the surface layers of the mating parts due to elastic and plastic deformation will occur primarily in the sliding sleeve and be transmitted to the pin and enclosing lug to a lesser extent. Antifriction materials can significantly increase the service life of hinge joints.

The research paper [3], by means of the regression analysis usage, identified a dependence that describes and allows predicting the dynamics of garbage trucks' wear and tear in the Khmelnytskyi region as a whole, as well as planning the infrastructure (composition and renewal of garbage trucks, production facilities for maintenance and repair) of municipal enterprises, which is necessary to solve the problem of solid waste management.

The paper [13] presents the results of the analysis of the designs of the grippers of body manipulators of garbage trucks. The results of a study of the reliability of garbage trucks are shown. A calculation scheme of a garbage truck as an oscillating system is developed. The type of oscillations of the garbage truck frame in the operating mode is determined. The regularities of force formation in the grab-tank-grab system are determined. It is established that the maximum loads occur on the traction rod and rod of the hydraulic cylinder, which increase with the increase in the mass of the container. Changes in the mass of the garbage truck do not affect the magnitude and amplitude of the loads, but only their frequency response changes. Observations of garbage trucks can determine that the largest number of failures occurs due to wear and corrosion of the working surfaces of the working equipment parts. 32% of all failures of hydraulic drive parts are caused by hydraulic cylinder failures caused by wear of the working surfaces of the mating surfaces, deformation of the rod and cylinder during operation, which is caused by uneven loading of the body, as well as abrasive wear of the working surfaces in hard conditions of the garbage truck. The main reason is the wear of the working surfaces of the main parts in the hydraulic drive structure, in particular – spools and hydraulic distributor housings, hydraulic cylinder rods, etc., as well as water-abrasive damage due to untimely replacement of the working hydraulic fluid and the use of poor-quality or worn sealing parts such as hydraulic cylinder seals, which causes dust particles and wear products to enter the sliding zone, accelerating the wear process of the working surfaces of the parts. In order to produce chrome coatings with high deposition quality and performance, cold self-regulating electrolyte chrome plating is proposed as one of the most promising methods of restoring worn parts.

However, the authors did not find any specific mathematical regularities describing the wear of friction units of the garbage truck loading mechanism depending on the properties of antifriction materials as a result of the analysis of known publications.

Aims of the article

Determination of the regression dependence of wear of friction units of the garbage truck loading mechanism on the properties of antifriction materials.

Methods

The regression dependence of wear of friction units of the garbage truck loading mechanism on the properties of antifriction materials was determined by planning a first-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 [15].

Results

Preliminary processing of the results of experimental research [12] showed that the wear of friction units of the garbage truck loading mechanism is a function of the following 4 main parameters:

$$u = f(f, HB, v, p), \tag{1}$$

where f – the friction coefficient of a pair of steel - antifriction material; HB – the Brinell hardness of the antifriction material; v – the sliding velocity, m/s; p – the pressure in the friction zone, MPa.

Investigating the influence of the above factors on the wear of friction units of the garbage truck loading mechanism when processing the results of single-factor experiments by regression analysis is associated with significant difficulties and amount of work. Therefore, in our opinion, it is advisable to conduct a multifactorial experiment to obtain a regression equation for the response functions – wear of friction units of the garbage truck loading mechanism by planning a multifactorial experiment using the Box-Wilson method [14].

The wear values of the friction units of the garbage truck loading mechanism during reverse motion for different values of the properties of antifriction materials are given in Table 1 [12].

Table 1

Values of wear of the friction units of the garbage truck loading mechanism for different values of the properties of antifriction materials [12]

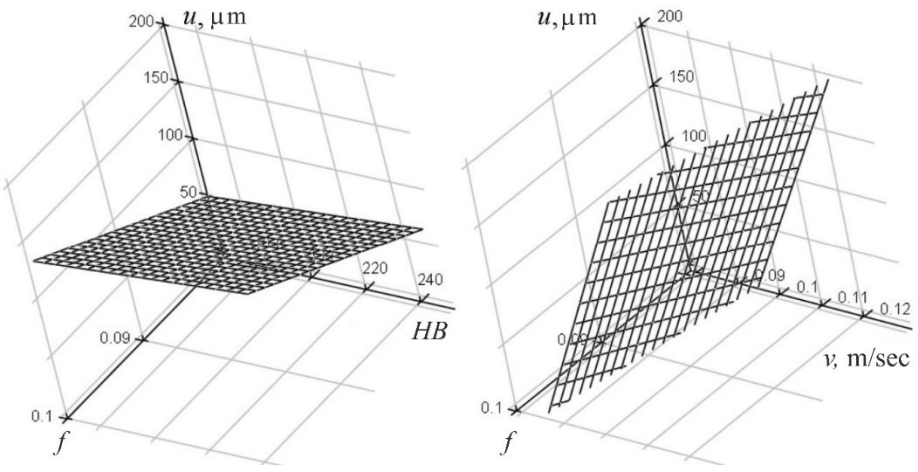
Friction coefficient of a pair of steel - antifriction material f	Hardness HB of the antifriction material according to Brinell	Sliding velocity v, m/sec	Pressure in the friction zone p, MPa	Wear amount in reverse motion u, μm
0.1	250	0.08	1.06	127
0.1	250	0.13	1.7	170
0.08	235	0.08	1.06	63
0.08	235	0.13	1.7	67
0.1	170	0.08	1.06	117
0.1	170	0.13	1.7	150

Based on the data in the Table 1, using the planning of a first-order experiment with first-order interaction effects, using the developed software, which is protected by a certificate of copyright law, after rejecting insignificant factors and interaction effects by the Student's criterion, the regularity of wear of friction units of the mechanism for loading a garbage truck on the properties of antifriction materials was determined:

$$u = 458.2f + 0.1696HB + 4366v - 546.2p + 33782fv \text{ [μm]}. \tag{2}$$

Fig. 1 shows the response surfaces of the target function – wear of the friction units of the garbage truck loading mechanism u and their two-dimensional sections in the planes of the influence parameters, plotted using the regularity (2), which allows us to clearly illustrate this dependence.

It was found that according to the Fisher's criterion, the hypothesis about the adequacy of the regression model (2) can be considered correct with 95% confidence. The coefficient of multiple correlation was $R = 0.99857$, which indicates the high accuracy of the obtained results.



a) **b)**

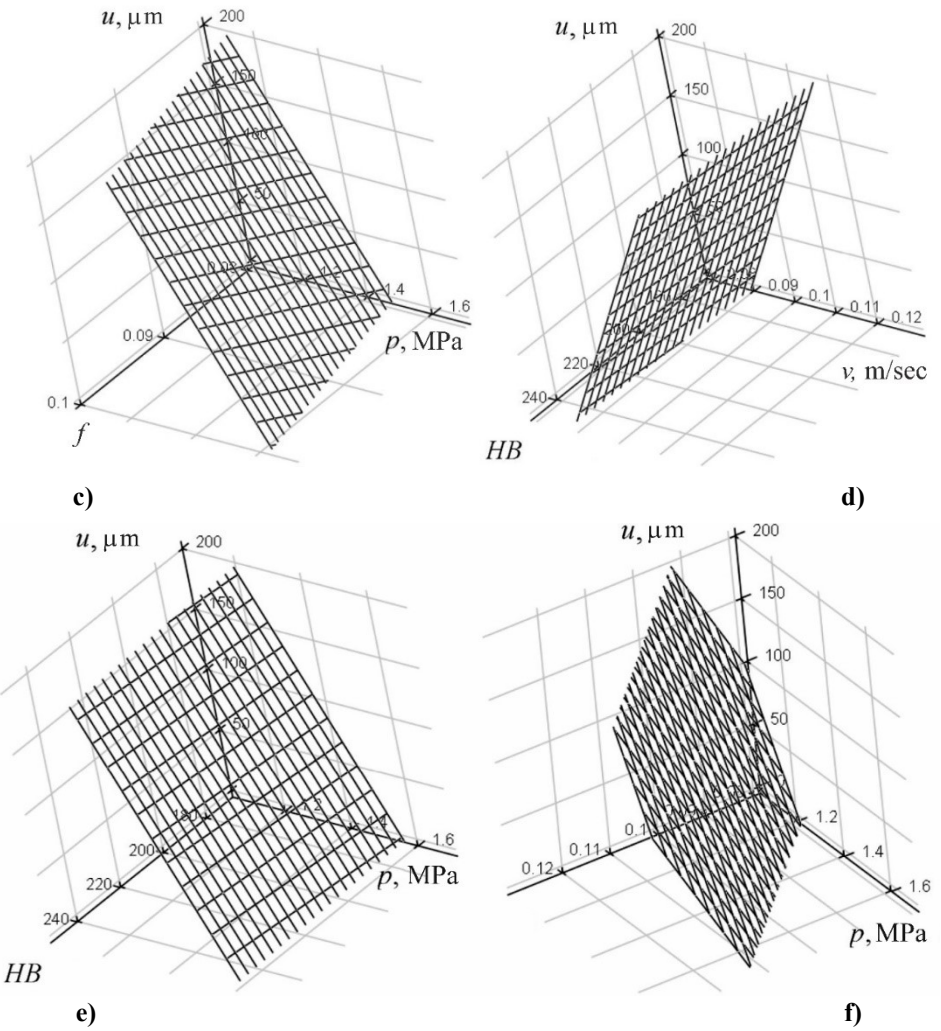


Fig. 1. Response surfaces of the objective function - wear of the friction units of the garbage truck loading mechanism *u* in the planes of influence parameters: a) $u = f(f, HB)$; **b)** $u = f(f, v)$; **c)** $u = f(f, p)$; **d)** $u = f(HB, v)$; **e)** $u = f(HB, p)$; **f)** $u = f(v, p)$

According to the Student's criterion, it was found that among the studied factors of influence, the pressure in the friction zone has the greatest impact on the wear of the friction units of the garbage truck loading mechanism, and the Brinell hardness of the antifriction material has the least.

It has been established that an increase in the pressure in the friction zone and sliding speed by 60% leads to an increase in the wear of friction units of the garbage truck loading mechanism during reverse motion by 6.3...34%, depending on the properties of antifriction materials.

The determination of the ways to further improve the wear resistance of the friction units of the mechanism for loading solid household waste into a garbage truck requires further research.

Conclusions

An adequate dependence of the wear of friction units of the mechanism for loading garbage trucks on the properties of antifriction materials has been determined according to the Fisher criterion. It is established that, according to the Student's criterion, among the studied factors of influence, the wear of friction units of the garbage truck loading mechanism is most affected by the pressure in the friction zone, and the hardness of the antifriction material is the least. The response surfaces of the objective function – wear of friction units of the garbage truck loading mechanism and their two-dimensional sections in the planes of the influence parameters are shown, which allow to clearly illustrate the specified dependence of this objective function on individual influence parameters. It has been established that an increase in the pressure in the friction zone and sliding speed by 60% leads to an increase in the wear of friction units of the garbage truck loading mechanism during reverse motion by 6.3...34%, depending on the properties of antifriction materials. To determine the ways to further increase the wear resistance of friction units of the mechanism for loading municipal solid waste into a garbage truck, further research is required.

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Березюк О.В., Савуляк В.І., Харжевський В.О., Сердюк О.В., Яворський В.Є. Залежність зносу пар тертя механізму завантаження твердих побутових відходів у сміттєвоз від характеристик антифрикційних матеріалів

Стаття присвячена встановленню регресійної закономірності зносу вузлів тертя механізму завантаження сміттєвоза від властивостей антифрикційних матеріалів. За допомогою використання планування експерименту першого порядку з ефектами взаємодії першого порядку методом Бокса-Уілсона визначено адекватну закономірність зносу вузлів тертя механізму завантаження сміттєвоза від властивостей антифрикційних матеріалів. Встановлено, що за критерієм Стьюдента серед досліджених факторів впливу найбільше на знос вузлів тертя механізму завантаження сміттєвоза впливає тиск в зоні тертя, а найменше – твердість антифрикційного матеріалу за Бринелем. Показано поверхні відгуку цільової функції – зносу вузлів тертя механізму завантаження сміттєвоза та їхні двомірні перерізи в площинах параметрів впливу, які дозволяють наглядно проілюструвати вказану залежність даної цільової функції від окремих параметрів впливу. Встановлено, що підвищення тиску в зоні тертя та швидкості ковзання на 60% призводить до зростання зносу вузлів тертя механізму завантаження сміттєвоза при реверсивному русі на 6,3...34% в залежності від властивостей антифрикційних матеріалів. Показано доцільність проведення наступних досліджень з визначення шляхів подальшого підвищення зносостійкості вузлів тертя механізму завантаження твердих побутових відходів у сміттєвоз.

Ключові слова: знос, вузли тертя, механізм завантаження, сміттєвоз, тверді побутові відходи, закономірність, планування експерименту.