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Dependence of wear intensity on the coating material of the hydraulic cylinder of the garbage truck's sealing plate

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Abstract

The article is dedicated to the study of the influence of the coating material on the wear rate of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate. By means of a first-order planning of experiment with first-order interaction effects using the Box-Wilson method, an adequate dependence of the wear rate of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate on the coating material was determined. It is established that according to the Student's criterion, among the studied factors of influence, the intensity of wear of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate is most affected by the iron content in the coating, the least – by the chromium content, and the nickel content affects only indirectly in interaction with the iron content. The response surfaces of the goal function – the intensity of wear of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate and their two-dimensional sections in the planes of the influence parameters are shown, which allow to clearly illustrate the specified dependence of this goal function on individual influence factors. The expediency of conducting further research to determine ways to further improve the wear resistance of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate is shown.

Keywords: wear, wear resistance, wear rate, hydraulic cylinder, mechanism, sealing plate, garbage truck, coating material, municipal solid waste, dependence, experiment planning.

Introduction

One of the important tasks of mechanical engineering is to increase the wear resistance and reliability of actuators of machines' mechanisms [1, 2], especially municipal ones, which mainly use hydraulic drive of working bodies. One of the main technologies for the primary processing of municipal solid waste (MSW) aimed at reducing transportation costs and reducing the negative impact on the environment is its compaction during the loading process into a garbage truck. Solid waste is compacted in a garbage truck using a compaction plate, the hydraulic cylinder of which is subject to intense wear due to the large number of operating cycles and significant pressing forces. This is due to the nonlinear compression characteristic of solid waste. Hydraulic cylinders are usually made of alloy steel, and wear-resistant coatings are widely used to increase their wear resistance. Therefore, it is an important task to determine the dependence of the wear rate of the hydraulic cylinder of the garbage truck's sealing plate mechanism depending on the coating material.

Analysis of recent research and publications

The scientific article [1] analyzes the disadvantages of using fluoropolymers in the friction unit "piston seal – car air conditioner compressor cylinder". Promising methods of modifying polytetrafluoroethylene and requirements for its fillers are considered. There was experimentally confirmed the advantages of antifriction composite fluoroplastic materials that were modified with combined fillers: carbon and glass fiber, carbon fiber and copper or lead oxide powder for the friction unit "piston seal – car air conditioner compressor cylinder"

In the paper [2] the effect of laser pretreatment on the nitriding intensity, structure, and wear characteristics of nitrided coatings on VT6 titanium alloy is considered. It is shown that pretreatment reduces the nitriding time, while increasing the thickness of the nitrided layer. It is established that the wear intensity is determined by the tribological structures of dissipative type arbitrarily formed in contact, which are formed from ultra-dispersed products of interaction of the components of the solid bodies of the friction pair and lubricants. The wear resistance of coatings obtained with pretreatment is 1.5-2 times higher than the wear resistance of coatings that are obtained by the traditional method.

In the scientific article [3], by means of the regression analysis it was established the power law that describes the dynamics of wear and tear of garbage trucks in the Khmelnytskyi region that allows its forecasting. This helps to plan the infrastructure of utility companies, including the composition and renewal of the garbage truck fleet, as well as the development of the base for their maintenance and repair, which is important for effective solid waste management. According to the forecast, the level of depreciation of garbage trucks in Khmelnytskyi region by 2030 will decrease to 51.9% if the current rate of renewal is maintained.

Among the main components of garbage trucks with side loading of MSW, the hydraulic system has the lowest mileage before failure, which, according to the research [4], significantly affects the increase in overall wear and tear of garbage trucks. In the paper [5] is shown that the structure and main causes of hydraulic equipment failures are: hydraulic cylinders – 34.92% (wear of seals, rod; rupture of the piston to rod fastening nut; rod bending; mechanical damage), hydraulic pumps – 16.40% (wear of the housing, gears, seals, cracks), pipelines and hoses – 15.34% (hose ruptures, pipeline wear), hydraulic distributors – 13.23% (wear of seals and spools; cracks in the housing).

An analysis of the causes of technical failures of garbage truck units [6] showed that a significant proportion of failures (about 45%) are associated with hydraulic drive failures. These failures are mostly caused by manufacturing defects arising from the use of low-quality components, as well as large fluctuations in the loads on the working mechanisms. The study of the causes of failures of working bodies showed that breakdowns are caused by defects in heat treatment and deviations from the design dimensions during machining (35%), as well as defects in the assembly, adjustment and tightening of threaded connectors (30%) and poor-quality welding (30%). It has been found that the vast majority of failures (80-90%) are caused by wear and corrosion of the working surfaces of machine parts. At the same time, failure does not occur immediately, but only when wear or corrosion reaches a certain critical level. It was also found that hydraulic cylinder failures caused by wear of the mating surfaces, deformation of the rod and cylinder during operation – up to 28% of all hydraulic drive component failures. Analysis of the durability results shows that the average operating time before failure of hydraulic actuator components, in particular the hydraulic cylinder, is approximately 1/3 of the maximum. That is, the manufacturer does not implement the planned service life by 45-55%. Most of the failures of hydraulic cylinder parts after the start of operation or repair are related to rods (31%) and sealing cuffs (42%). The analysis of failures of hydraulic system elements showed that the main faults are associated with the loss of external and internal tightness due to contamination of the working fluid, which leads to malfunctioning of the units.

These data are consistent with the results published in [7], which also indicates the main causes of failures of the hydraulic system of garbage trucks caused by wear: for a hydraulic pump – wear of gears; for hydraulic cylinders – wear of seals and rod; for a hydraulic distributor – wear of seals and spools; for hoses – wear of pipelines. Adequate dependencies of wear of garbage truck tires on the front and rear axles were determined according to the Fisher's criterion, which depend on the transported mass of MSW and the mileage of the garbage truck. According to the Student's criterion, it was found that the transported mass of MSW has the greatest impact on tire wear on both the front and rear axles, while the mileage of the garbage truck has the least impact. The dependencies of the number of garbage truck trips before the maximum permissible wear of tires on the front and rear axles were obtained.

The scientific paper [8] provides the causes of garbage truck failures, according to which the main causes of failures are external and internal leaks in hydraulic systems. External leakage was in 48% of all failures in the hydraulic system and occurs due to the destruction of hoses and pipelines, as well as due to the depressurization of seals in hydraulic cylinders and other units. Another significant cause of failure is internal leaks, which was in 36% of cases. Most of the failures caused by internal leaks are observed in such units as spool valves, safety and check valves, hydraulic cylinders and hydraulic pumps.

A study that was caried out in [9] showed that "tapered" wear of the hydraulic cylinder rod from 0.2 to 0.4 mm in length during the operation of the hydraulic cylinder before the first overhaul leads to a 7.2% decrease in pressure, an 11.4% increase in specific fuel consumption, and a 26% increase in the carbon monoxide content in exhaust gases. Increasing the wear of the rods in their working area by 0.6-0.7 mm causes a drop in pressure in the hydraulic system by 13.4%, an increase in specific fuel consumption by 21.3%, and a sharp increase in the toxicity of exhaust gases from 25% to 59%, which exceeds the maximum permissible standards. It is proposed to consider the wear of the geometric parameters of the hydraulic cylinder rod of the hydraulic drive of construction and road machines as the maximum permissible wear if its value does not exceed 0.4 mm. It was also found that rod wear worsens the physical and chemical properties of the working fluid, doubling the content of iron and impurities. This leads to the need for more frequent fluid changes and cost overruns, which significantly

reduces efficiency and durability, as well as shortens the service life of the hydraulic drive of construction and road machines.

The article [10] showed that the wear of sealing elements in hydraulic systems causes the gradual penetration of hydraulic fluid into non-working cavities of hydraulic machines. Although this process is not always visible, it leads to unproductive power losses of the hydraulic drive, which, in turn, increases fuel and lubricant consumption and reduces the power of the working bodies. The power loss due to the wear of sealing elements can cause non-optimal operating modes of the hydraulic motor, which negatively affects the efficiency of the hydraulic drive in general. The mechanical system "hydraulic cylinder – sealed piston – compressed hydraulic fluid" was researched. Thus, it was established the dependence of the efficiency of the hydraulic cylinder on the size of the leakage, and the results of the piston subsidence for the working fluid of the VMGZ type and the mechanism of fluid flow through the hydraulic cylinder seal are determined.

In the paper [11], the authors analyzed data from observations of garbage trucks and found that most failures are caused by wear and corrosion of the working surfaces of the equipment parts. Failures of hydraulic cylinders caused by wear of working surfaces, deformations of the rod and cylinder during operation account for 32% of all breakdowns of hydraulic drive parts. This is due to uneven loading of the body and abrasive wear of the working surfaces under conditions of intensive operation of the garbage truck. Studies of the cases of failures have shown that the main reason is the wear of the working surfaces of the main elements of the hydraulic drive, in particular spools and hydraulic distributor housings, hydraulic cylinder rods and other components. The main reason of the wear was found to be water-abrasive damage caused by untimely replacement of the hydraulic fluid and the use of low-quality or worn sealing elements, such as hydraulic cylinder seals. This causes that dust particles and wear products got into the sliding zone, which accelerates the wear of the working surfaces of the parts. One of the most promising methods for restoring worn parts is chromium plating in a cold self-regulating electrolyte, which produces chrome coatings with high quality deposits and ensures high performance of the process.

In the paper [12], the wear-resistant coatings alternative to galvanic chromium plating for the protection of hydraulic cylinders was analyzed and the optimal operating conditions under which each of them will be most effective were determined. It was also performed comparative studies of wear resistance in different working environments of protective multilayer vacuum-plasma coatings obtained by applying alternately thin layers of chromium and complex nitride (TiCr)N, α-Ti layers, titanium nitride - TiN and magnetron coating based on TiN, oxide ceramic coatings on aluminum electric arc coatings sprayed on a base of magnesium alloy MA-5, titanium alloy PTZV.

Paper [13] presents the results of studies on the effect of the pressing force on the wear rate of hydraulic press mechanism parts, in particular, on the hydraulic cylinder. Studies have shown that with an increase in the force applied during pressing, there is a decrease in the acceleration coefficient of the wear of the working cylinder. This indicates that higher forces do not always lead to faster wear, but rather that wear can slow down due to the peculiarities of the mechanism's operation under high loads. This result may be important for further optimization of hydraulic presses, as it allows to predict the service life of components depending on the operating conditions. In addition, the work showed the importance of developing effective measures for continuous automatic control of press operation parameters. This includes monitoring of the pressing force, hydraulic fluid temperature, and other critical indicators that may affect press operation. Preventing the hydraulic press from approaching emergency limits is a key factor for ensuring reliable and faultless operation of all its major components. The successful implementation of such control systems avoids situations where the system operates under conditions that can lead to breakdowns or premature wear. This is possible if the press is designed rationally, using high-quality materials and ensuring that all performance characteristics meet the specified requirements, which in turn can significantly increase the efficiency and durability of the equipment.

Paper [14] deals with the effect of the pressing force on the wear resistance of the working hydraulic cylinder of the garbage truck's sealing plate mechanism. An exponential dependence of changes in the rate of wear of the working hydraulic cylinder of the mechanism of the garbage truck's sealing plate depending on the pressing force was determined. It was established that for a Ukrainian-made garbage truck of the model KO-436, the wear rate of the working hydraulic cylinder of the mechanism of the garbage truck's sealing plate, according to the obtained dependence, will be 0.257 μm/h.

In the paper [15], it was researched the structure, hardness, and wear resistance of plasma coatings made of metals of the fourth row of the periodic table's fourth period: iron, nickel, and chromium, made from the mixtures of the corresponding powders to replace wear-resistant galvanic chromium coatings. Based on the determination of the intensity of molecular-mechanical and abrasive wear, the optimal composition of the plasma coating, which has advantages of galvanic chromium and free from its disadvantages, was proposed.

However, as a result of the analysis of known publications, it should be noticed that the authors did not find any specific mathematical dependencies in the intensity of wear of the hydraulic cylinder of the garbage truck's sealing plate mechanism on the coating material.

Aims of the article

Determination of the dependence of the wear intensity of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate on the coating material.

Methods

The determination the dependence of changes in the intensity of wear of the hydraulic cylinder of the garbage truck's sealing plate mechanism from the coating material was carried out by planning a first-order experiment with first-order interaction effects using the Box-Wilson method. The coefficients of the regression equations were determined using the developed computer program "PlanExp", which is protected by a certificate of copyright law's registration.

Results

Preliminary processing of the results of experimental studies [15] showed that the wear rate of the hydraulic cylinder of the garbage truck's sealing plate mechanism is a function of the following three main parameters:

$$I_h = f(C_{Fe}, C_{Ni}, C_{Cr}), \tag{1}$$

where I_h – the intensity of abrasive wear, $\times 10^{10}$; C_{Fe} – the iron content in the coating of Fe-Cr-Ni composition, %; C_{Ni} – the nickel content in the coating of Fe-Cr-Ni composition, %, C_{Cr} – the chromium content in the coating of Fe-Cr-Ni composition, %.

The research of the influence of the above factors on the wear rate of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate 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 function – the wear rate of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate by planning a multifactorial experiment using the Box-Wilson method.

The values of the wear intensity of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate for different composition of the coating material are given in the Table 1 [15].

Table 1

Values of the intensity of wear of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate for different composition of the coating material [15]

Abrasive wear intensity I_h, $\times 10^{10}$	Iron content in the coating C_{Fe}, %.	Nickel content in the coating C_{Ni}, %.	Chromium content in the coating C_{Cr}, %.
1.979	75	25	0
0.947	50	25	25
0.547	25	25	50
1.789	0	0	100

Based on the data in the Table 1, using a first-order experiment planning with first-order interaction effects, using the developed software protected by a copyright law's certificate, after rejecting insignificant factors and interaction effects by the Student's criterion, the dependence of the intensity of wear of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate from the coating material was determined as follows:

$$I_h = 0{,}07343\,C_{Cr} - 0{,}6671\,C_{Fe} + 0{,}03053\,C_{Fe}C_{Ni} - 5{,}554 \ [\times 10^{10}]. \tag{2}$$

Fig. 1 shows the response surfaces of the goal function – the wear intensity of the hydraulic cylinder of the mechanism of the sealing plate of the garbage truck I_h and their two-dimensional sections in the planes of the influence parameters, drawn using the equation (2), which allows to clearly illustrate this dependence.

It was found that according to 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 determined as R = 0.96513, which indicates quite sufficient accuracy of the results.

According to the Student's criterion, it was established that among the studied factors of influence, the intensity of wear of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate is most affected by the iron content in the coating, the least – by the chromium content, and the nickel content has an indirect effect only in interaction with the iron content.

The determination of the ways to further improve the wear resistance of the hydraulic cylinder of the garbage truck's sealing plate mechanism requires further research.

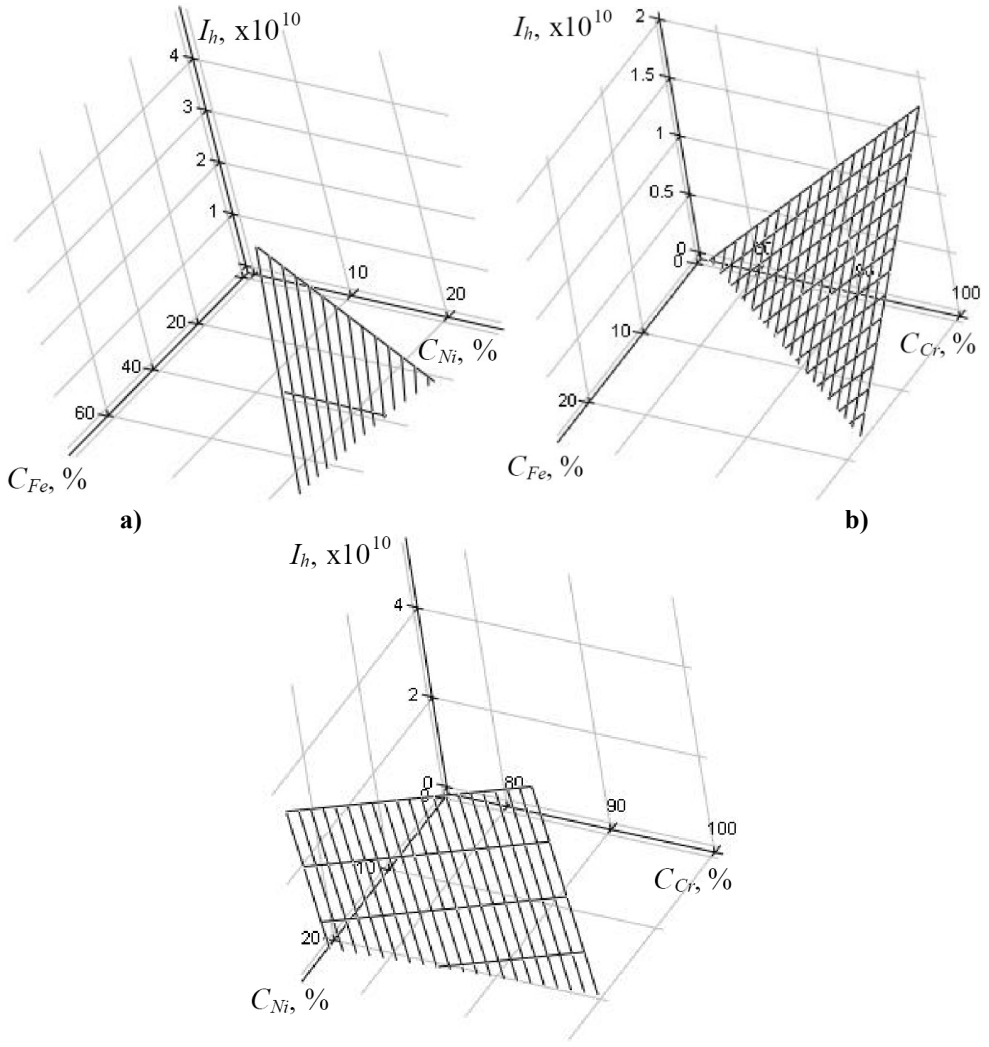

Fig. 1. Response surfaces of the goal function - wear intensity of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate I_h in the planes of influence parameters: a) $I_h = f(C_{Fe}, C_{Ni})$; b) $I_h = f(C_{Fe}, C_{Cr})$; c) $I_h = f(C_{Ni}, C_{Cr})$

Conclusion

The adequate dependence of the intensity of wear of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate on the coating material was determined according to the Fisher criterion. It is established that, according to the Student's criterion, among the studied factors of influence, the intensity of wear of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate is most affected by the iron content in the coating, the least – by the chromium content, and the nickel content affects only indirectly in interaction with the iron content. The response surfaces of the goal function – the intensity of wear of the hydraulic cylinder of the mechanism of the garbage truck's sealing plate and their two-dimensional sections in the planes of the influence parameters are shown, which allow to clearly illustrate the specified dependence of this goal function on individual influence factors. The determination of the ways of improvement of the wear resistance of the hydraulic cylinder of the garbage truck's sealing plate mechanism requires further research.

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Березюк О.В., Савуляк В.І., Харжевський В.О., Алексеєв А.Є. Залежність інтенсивності зносу від матеріалу покриття гідроциліндра ущільнюючої плити сміттєвоза

Стаття присвячена дослідженню впливу матеріалу покриття на інтенсивність зносу гідроциліндра механізму ущільнюючої плити сміттєвоза. За допомогою використання планування експерименту першого порядку з ефектами взаємодії першого порядку методом Бокса-Уілсона визначено адекватну закономірність інтенсивності зносу гідроциліндра механізму ущільнюючої плити сміттєвоза від матеріалу покриття. Встановлено, що за критерієм Стьюдента серед досліджених факторів впливу найбільше на інтенсивність зносу гідроциліндра механізму ущільнюючої плити сміттєвоза впливає вміст заліза у покритті, найменше – вміст хрому, а вміст нікелю впливає лише опосередковано у взаємодії із вмістом заліза. Показано поверхні відгуку цільової функції – інтенсивності зносу гідроциліндра механізму ущільнюючої плити сміттєвоза та їхні двомірні перерізи в площинах параметрів впливу, які дозволяють наглядно проілюструвати вказану залежність даної цільової функції від окремих факторів впливу. Показано доцільність проведення наступних досліджень з визначення шляхів подальшого підвищення зносостійкості гідроциліндра механізму ущільнюючої плити сміттєвоза.

Ключові слова: знос, зносостійкість, інтенсивність зносу, гідроциліндр, механізм, ущільнююча плита, сміттєвоз, матеріал покриття, тверді побутові відходи, закономірність, планування експерименту.