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# Determination of the regularity of the rate of wear of the working hydraulic cylinder of the mechanism of the sealing plate of the garbage truck from the pressing force

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**Abstract**

The article is dedicated to the study of the influence of the pressing force on the wear resistance of the working hydraulic cylinder of the mechanism of the sealing plate of the garbage truck. The usage of a mathematical dependencies and appropriate software programs for regression analysis made it possible to determine the exponential regularity of the change in the rate of wear of the working hydraulic cylinder of the mechanism of the sealing plate of the garbage truck depending on the pressing force. A graphical dependence of the change in the rate of wear of the working hydraulic cylinder of the mechanism of the compacting plate of the garbage truck on the pressing force was made up, which confirmed the sufficient convergence of the obtained regularity. Graph of the influence of pressing force on wear rate of working hydraulic cylinder of the mechanism of the compacting plate of the garbage truck demonstrates the expediency of its increase. It was established that for the garbage truck of Ukrainian production of serial model KO-436, the rate of wear of the working hydraulic cylinder of the mechanism of the sealing plate of the garbage truck according to the obtained regularity will be 0.257 μm/h. The expediency of conducting additional studies to determine further ways to increase the wear resistance of the working hydraulic cylinder of the sealing plate mechanism of the garbage truck has been established.

**Key words:** wear, wear resistance, wear rate, hydraulic cylinder, mechanism, sealing plate, garbage truck, pressing force, municipal solid waste, regression analysis.

## Introduction

An important task of mechanical engineering is to increase the wear resistance and reliability of the executive bodies of machines [1, 2], in particular, utility machines equipped mainly with a hydraulic drive of working bodies [3]. One of the main technologies of primary processing of municipal solid waste (MSW) in order to reduce the costs of their transportation, as well as the negative impact on the natural environment, is their compaction during the process of loading into a garbage truck. Compaction of MSW in the garbage truck is performed by a compacting plate, the working hydraulic cylinder of the mechanism of which undergoes from intensive wear, which is caused by a large number of work cycles, as well as significant efforts of pressing solid waste, which have a non-linear compression characteristic. Hydraulic cylinders are usually made of alloy steel. The usage of wear-resistant coatings to increase their wear resistance is explained. Therefore, the urgent task is to determine the regularity of the change in the rate of wear of the working hydraulic cylinder of the mechanism of the sealing plate of the garbage truck due to the pressing force.

## Analysis of recent research and publications

The work [1] gives the research results of the processes of destruction during friction on the example of composite electrolytic coatings. By means of the analysis methods of theoretical and experimental research results within the energy model of the formation of wear particles in the near-surface zones of the friction pair, an

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assessment of the process of destruction of the surface layers was made. The dependence of the size of the wear particles on the mechanical properties of the material was established.

In the article [3], using the results of computer modeling of the hydrodynamic processes of the flow of the working fluid through the hydraulic valve, its pressure losses are determined. In order to reduce pressure losses, it is proposed to make changes to the design of the hydraulic valve without impairing its performance. It made it possible to reduce pressure losses on the working part of the hydraulic distributor, which reduces overall losses in the hydraulic drive.

In the article [4], a study of the peculiarities of the process of pressing wood shavings in screw machines, as well as the processes taking place in different sections of the screw, was carried out also, appropriate regularities were determined. It allows to calculate the loads acting on the turns of the screw, as well as determine the pressing power. The degree of heating of raw materials and specific energy consumption during the pressing process were determined.

In the article [5], a regression analysis was used to determine a power law that describes the dynamics of wear and tear of garbage trucks in the Khmelnytskyi region that allows to forecast and plan the infrastructure of communal enterprises, in particular, the renewal of garbage trucks, the base for maintenance and repair, which is necessary to solve the problem of solid waste management. It has been predicted that by 2030, the wear and tear of garbage trucks in the Khmelnytskyi region will decrease to 51.9% at the current rate of decline.

The logarithmic regularities of screw wear depending on the hardness of its surface for different values of the friction path are defined in the paper [6]. Conducting an additional regression analysis made it possible to obtain the dependence of wear of the auger depending on the hardness of its surface and the friction path. The obtained dependence permitted to establish that during two-week operation and wear of the auger during the dehydration of MSW in the garbage truck, an increase in the surface hardness of the auger from 2.31 GPa to 10.05 GPa leads to a decrease in the rate of growth of the energy intensity of solid waste dehydration from 16.7% to 1. 5%, and, therefore, to the cheaper process of their dehydration in the garbage truck.

Among the main components of garbage trucks with a side-loading method of MSW, the hydraulic system, according to the research [7], has the shortest mileage before failure, which makes the most significant contribution to increasing the wear and tear of garbage trucks. Based on the results of research [8], the structure and most frequent causes of failures of the hydraulic equipment of garbage trucks were determined: hydraulic cylinders – 34.92% (wear of cuffs, seals, rod; rupture of the nut attaching the piston to the rod; bending of the rod; mechanical damage), hydraulic pump – 16.40% (casing failure, wear of gears, extrusion of oil seals, cracks in the casing), pipelines, hoses – 15.34% (breakage of hoses, wear of pipelines), hydraulic distributor – 13.23%, (wear of seals, spools; cracks in the casing).

An analysis of the causes of typical technical failures of garbage truck units [9] also showed that the majority of malfunctions (about 45%) are associated with failures of the hydraulic drive, which mainly are due to manufacturing defects caused by the installation of low-quality components on the hydraulic drive, as well as large fluctuations of loads on working bodies. The study of the causes of failures of working bodies showed that breakdowns occur due to defects in heat treatment and deviations from structural dimensions during mechanical processing (35%), defects in assembly, adjustment, tightening of threaded connections (30%), poor-quality welding (30%), etc. It was established that most failures (80-90%) occur due to wear and corrosion phenomena on the working surfaces of machine parts. At the same time, the failure does not occur immediately, but after the wear or corrosion reaches a certain, critical value, that is, when the limit state of the machine or its units comes. It was also established that failures of hydraulic cylinders due to wear of the working surfaces of couplings, deformation of the rod and cylinder during operation account for up to 28% of all failures of hydraulic drive elements. The analysis of durability results shows that the average working time before failure of the hydraulic drive elements, in particular the hydraulic cylinder, is about 1/3 of the maximum, that is, the resource planned by the manufacturer is not produced by 45-55%. The main share of failures of hydraulic cylinder parts since the start of operation or after previous repair is accounted for by rods - 31% and sealing sleeves - 42%. Analysis of failures of hydraulic system elements showed that the main manifestations of malfunctions are the loss of external and internal tightness due to contamination of the working fluid, which causes a malfunction of the units.

The given data are also correlated with the data published in the article [10], which also states the main reasons for the failure of the hydraulic system of garbage trucks caused by wear: for the hydraulic pump – gear wear; for hydraulic cylinders – wear of cuffs, seals, rod; for the hydraulic distributor – wear of seals, spools; for hoses – wear and tear of pipelines. Adequate dependencies, according to the Fisher criterion, of wear of garbage truck tires on the front and rear axles due to the mass of MSW transported and mileage of the garbage truck are determined. It was established that, according to the Student's criterion, among the investigated factors of influence, the weight of the transported MSW has the greatest influence on the wear of the tires of the garbage truck on both the front and rear axles, and the mileage of the garbage truck has the least influence. The regularities of the number of trips of the garbage truck to the maximum allowable tire wear on the front and rear axles were obtained.

In work [11], the distribution of the reasons for failure of garbage trucks is given, from which it follows that the main causes of malfunctions are external and internal leakage of hydraulic systems. It was established that the external leakage is 48% of all failures in the hydraulic system and occurs as a result of the destruction of hoses and pipelines, as well as depressurization of the seals of hydraulic cylinders and other units. Another common cause of failure is internal leakage, which was observed in 36% of cases. Most of the malfunctions caused by internal leakage have such units as spool distributors, safety and non-return valves, hydraulic cylinders and hydraulic pumps.

In the work [12] it was established that "conical" 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 causes a drop in pressure by 7.2%, an increase in specific fuel consumption by 11, 4% and the content of carbon monoxide in exhaust gases – by 26%; an increase in 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 an increase in the toxicity of exhaust gases from 25% to 59%, which exceeds the permissible norms. It was proposed to consider the value of 0.4 mm as the maximum allowable wear value of the geometric parameters of the rod of the hydraulic cylinder of the hydraulic drive of construction and road machines. It was also established that wear of the rod deteriorates the physical and chemical properties of the working fluid, doubles the content of iron and impurities in the working fluid, which leads to the need for its frequent replacement and overspending, which significantly reduces efficiency and durability, shortens the service life of the hydraulic drive of construction and road machines.

In the work [13] it is stated that the wear of sealing elements in hydraulic systems leads to the gradual ingress of hydraulic fluid into non-working cavities of hydraulic machines. Although this process is not visually apparent, it causes unproductive losses of power of the hydraulic drive, which, in turn, leads to excessive consumption of fuel, lubricants and power losses of working bodies. Loss of power in the elements of the hydraulic system due to the wear of the sealing elements can lead to suboptimal operating modes of the hydraulic motor, which leads to a decrease in the efficiency of the hydraulic drive in a whole. The mechanical system "hydraulic cylinder – compacted piston – compressed hydraulic fluid" is considered. The dependence of the efficiency of the hydraulic cylinder on the size of the leak was established. The piston subsidence results for the working fluid were determined. The mechanism of liquid flow through the hydraulic cylinder seal is also determined.

The authors of the work [14], during the evaluation of the observation results of garbage trucks, found that the largest number of failures occurs due to wear and corrosion of the working surfaces of the working equipment parts. Failures of hydraulic cylinders caused by wear of the working surfaces of couplings, deformations of the rod and cylinder during operation are 32% of all failures of hydraulic drive parts. It happened due to the uneven loading of the body, as well as the abrasive wear of the working surfaces in the hard conditions of the work of garbage truck. The research of the reasons for failures that was carried out, allowed to establish that the main cause is wear of the working surfaces of the main parts in the design of the hydraulic drive, namely spools and housings of hydraulic distributors, hydraulic cylinder rods, etc. The main cause of wear was hydroabrasive damage due to untimely replacement of the working hydraulic fluid and the use of poor-quality or worn sealing parts such as oil seals of hydraulic cylinders, which causes dust particles and wear products to enter the sliding zone, which lead to the acceleration of the process of wear of the working surfaces of the parts. One of the most promising ways to restore worn parts is chrome plating in a cold self-regulating electrolyte in order to obtain chrome coatings with high deposit quality and high productivity.

The paper [15] provides data on the effect of pressing force on the rate of wear of hydraulic press mechanism parts, in particular, the working hydraulic cylinder. It was established that with an increase in the force of the hydraulic press, the acceleration coefficient of the tests of the working cylinder decreases. It is also noticed that the development of measures for permanent automatic control and prevention of the approach of the hydraulic press to the emergency limit is a main factor for ensuring the trouble-free operation of its basic components, at conditions if they are optimally designed and that the performance indicators correspond to the specified operational characteristics.

However, as a result of the analysis of known publications, the authors did not find specific mathematical dependencies of the change in the rate of wear of the working hydraulic cylinder of the mechanism of the sealing plate of the garbage truck due to the pressing force.

**Aims of the article**

Determination of the dependence of the change in the rate of wear of the working hydraulic cylinder of the mechanism of the sealing plate of the garbage truck as a result of the acting of the pressing force.

**Methods**

The determination of the paired regularity of the change in the rate of wear of the working hydraulic cylinder of the mechanism of the compacting plate of the garbage truck from the pressing force was carried out by the method of regression analysis. Regression was determined on the basis of linearization transformations that allow to reduce the non-linear dependence to a linear one. The coefficients of the regression equation were determined by the method of least squares using the developed computer software "RegAnaliz", which is protected by a certificate of copyright law.

**The results**

The values of the rate of wear of the working hydraulic cylinder of the hydraulic press mechanism at different values of the pressing force are given in the Table 1 [15]. The rate of wear decreases with increasing

pressing force. This is explained by the fact that with a constant power of the drive, an increase in the pressing force leads to a decrease in the pressing speed and the amount of work performed.

Table 1

**The influence of pressing force on the rate of wear of the working hydraulic cylinder of the hydraulic press mechanism [15]**

| № | Pressing force $F_{PR}$, MN | Wear rate $v_w$, μm/h |
|---|---|---|
| 1 | 30 | 0.191 |
| 2 | 40 | 0.169 |
| 3 | 50 | 0.151 |
| 4 | 60 | 0.138 |
| 5 | 70 | 0.124 |
| 6 | 80 | 0.111 |
| 7 | 90 | 0.102 |
| 8 | 100 | 0.089 |
| 9 | 110 | 0.080 |
| 10 | 120 | 0.071 |
| 11 | 130 | 0.067 |
| 12 | 140 | 0.062 |
| 13 | 150 | 0.053 |

As a result of the regression analysis of the data in the Table 1, the dependence of the change in the rate of wear of the working hydraulic cylinder of the mechanism of the sealing plate of the garbage truck is determined depending on the pressing force

$$v_w = 0{,}2575\mathrm{e}^{-0{,}01047F_{PR}} \text{ [ μm/h ]}, \quad (1)$$

where $v_w$ is the rate of wear, μm/h; $F_{PR}$ – pressing force, MN.

The results of the regression analysis are shown in Table 2, where cells with the maximum values of the correlation coefficient $R$ for paired regression are marked in gray color.

Table 2

**The results of the regression analysis of the dependence of the change in the rate of wear of the working hydraulic cylinder of the mechanism of the sealing plate of the garbage truck on the pressing force**

| № | Type of regression | Correlation coefficient $R$ | № | Type of regression | Correlation coefficient $R$ |
|---|---|---|---|---|---|
| 1 | $y = a + bx$ | 0.98253 | 9 | $y = ax^{b}$ | 0.97824 |
| 2 | $y = 1 / ( a + ) \_$ | 0.98588 | 10 | $y = a + b \cdot \lg x$ | 0.99858 |
| 3 | $y = a + b / x$ | 0.96354 | 11 | $y = a + b \cdot \ln x$ | 0.99858 |
| 4 | $y = x / ( a + bx )$ | 0.96953 | 12 | $y = a / ( b + x )$ | 0.98588 |
| 5 | $y = ab^{x}$ | 0.99892 | 13 | $y = ax / ( b + x )$ | 0.83269 |
| 6 | $y = ae^{bx}$ | 0.99893 | 14 | $y = ae^{b/x}$ | 0.90835 |
| 7 | $y = a \cdot 10^{bx}$ | 0.99892 | 15 | $y = a \cdot 10^{b/x}$ | 0.90835 |
| 8 | $y = 1 / ( a + be^{-x} )$ | 0.38561 | 16 | $y = a + bx^{n}$ | 0.93336 |

It was established that the rate of wear of the working hydraulic cylinder of the mechanism of the compacting plate of the garbage truck decreases exponentially with increasing pressing force.

In the Fig. 1 is shown the graphical dependence of the change in the rate of wear of the working hydraulic cylinder of the mechanism of the compacting plate of the garbage truck on the pressing force, which is made up using dependence (1), which confirms the sufficient convergence of the obtained dependence compared to the data given in Table 1.

For a garbage truck of serial model KO-436, manufactured in Ukraine, which is equipped with a hydraulic cylinder of a sealing plate with an effective area of $9.5 \cdot 10^{-3}$ m$^2$ at a maximum pressure of the working fluid in the hydraulic system of 10 MPa, the pressing force will be 0.095 MN, and the rate of wear of the working hydraulic cylinder of the sealing mechanism plates of the garbage truck according to the obtained dependence (1) will be

$$v_w = 0.2575\mathrm{e}^{-0.01047 \cdot 0.095} = 0.257 \text{ [ μm/h ]}.$$

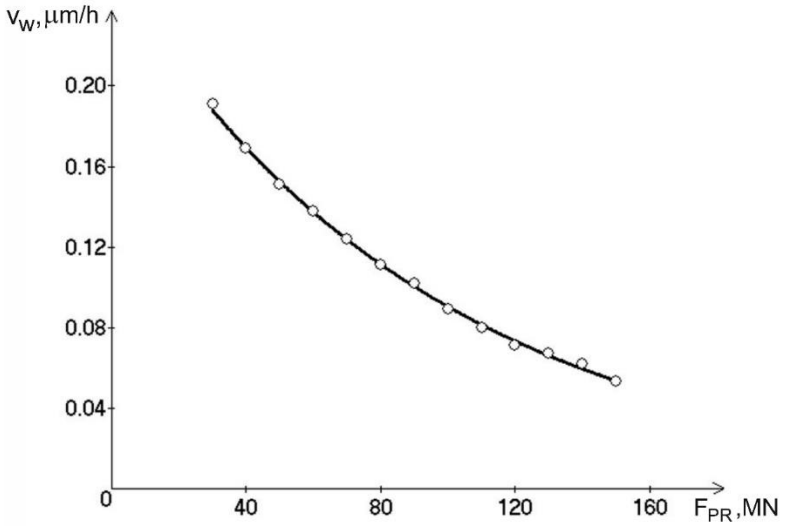


**Fig. 1. Dependence of the change in the rate of wear of the working hydraulic cylinder of the garbage truck sealing plate mechanism, depending on the pressing force: actual ○ , theoretical —**

It can be seen from the Fig. 1 that the increase in pressing force from 30 MN to 150 MN leads to a decrease in the rate of wear of the working hydraulic cylinder of the hydraulic press mechanism by 3.6 times, which indicates the importance of determining further ways to increase its wear resistance.

## Conclusions

The exponential dependence of the change in the rate of wear of the working hydraulic cylinder of the mechanism of the sealing plate of the garbage truck, depending on the pressing force, was determined. It was established that for the garbage truck of Ukrainian production of serial model KO-436, the rate of wear of the working hydraulic cylinder of the mechanism of the sealing plate of the garbage truck, according to the obtained dependence, will be 0.257 μm/h. Therefore, the establishment of further ways to increase the wear resistance of the working hydraulic cylinder of the mechanism of the sealing plate of the garbage truck requires additional research.

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**Березюк О.В., Савуляк В.І., Харжевський В.О., Алексеєв А.Є.** Визначення закономірності швидкості зношення робочого гідроциліндра механізму ущільнюючої плити сміттєвоза від зусилля пресування

Стаття присвячена дослідженню впливу зусилля пресування на зносостійкість робочого гідроциліндра механізму ущільнюючої плити сміттєвоза. Використання математичного апарату та відповідних програм регресійного аналізу дозволило визначити експоненціальну закономірність зміни швидкості зношування робочого гідроциліндра механізму ущільнюючої плити сміттєвоза залежно від зусилля пресування. Побудована графічна залежність зміни швидкості зношування робочого гідроциліндра механізму ущільнюючої плити сміттєвоза від зусилля пресування, яка підтвердила достатню збіжність отриманої закономірності. Графік впливу зусилля пресування на швидкість зношування робочого гідроциліндра механізму ущільнюючої плити сміттєвоза демонструє доцільність його підвищення. Встановлено, що для сміттєвоза українського виробництва серійної моделі КО-436 швидкість зношування робочого гідроциліндра механізму ущільнюючої плити сміттєвоза за отриманою закономірністю складатиме 0,257 мкм/год. Встановлена доцільність проведення додаткових досліджень з визначення подальших шляхів підвищення зносостійкості робочого гідроциліндра механізму ущільнюючої плити сміттєвоза.

**Ключові слова**: знос, зносостійкість, швидкість зношування, гідроциліндр, механізм, ущільнююча плита, сміттєвоз, зусилля пресування, тверді побутові відходи, регресійний аналіз