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Establishing the regularity of wear of a cylindrical brush of the mounted sweeping equipment of a garbage truck depending on its rotation frequency

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Abstract

The article is dedicated to establishing the regularity of wear of a cylindrical brush of the mounted sweeping equipment of a garbage truck depending on its rotation frequency. Using the mathematical dependencies and corresponding regression analysis programs, it was established a power law of change in the wear of the cylindrical brush of the garbage truck's mounted sweeping equipment on the frequency of its rotation, which can be used to build a mathematical model of the hydraulic drive of the improved mounted sweeping equipment of a garbage truck, taking into account the wear of its working bodies. A graphical dependence of the change in the wear of the cylindrical brush of the garbage truck's mounted sweeping equipment on its rotation frequency was plotted, which confirmed the sufficient convergence of the obtained regularity. The graph of the influence of the rotation frequency of the cylindrical brush of the garbage truck's mounted sweeping equipment on its wear demonstrates the expediency of its reduction. It has been established that for a Ukrainian-made sweeping machine of the serial model KO-713-01, which is equipped with a cylindrical brush with a rotation speed of 3200 rpm, its wear according to the obtained regularity will reach 86.5 mm. It was found that reducing the rotational speed of the cylindrical brush of the garbage truck's mounted sweeping equipment from 62 sec^{-1} (3700 rpm) to 26...38 sec^{-1} (1550...2250 rpm) leads to a decrease in its wear by 2 orders of magnitude. The expediency of conducting additional research to identify further ways to improve the wear resistance of the cylindrical brush of the garbage truck's mounted sweeping equipment has been established.

Key words: wear, rotation frequency, mounted sweeping equipment, cylindrical brush, garbage truck, regularity, regression analysis.

Introduction

Increasing the wear resistance, durability, and reliability of machine parts is one of the main problems in the Ukrainian engineering industry, in particular for municipal sweeping machines [1, 2]. In order to clean the road surface from contaminants, municipal machines with brushing equipment are widely used. The most widespread brushing equipment is cylindrical brushes with a pile of polymeric material. During operation, the bristles of a cylindrical brush undergo intensive wear by interacting with the working surface containing abrasive particles, while its elastic characteristics change, which requires an increase in the required clamping force to maintain the most rational value of the contact patch width in order to ensure high quality cleaning and minimal bristle wear. Based on the analysis of statistical data, the vehicle fleet of municipal enterprises in Khmelnytskyi region experienced a slight decrease in the level of wear and tear from 2015 to 2020, despite the measures taken, from 63% to 59% [3, 4]. According to the Resolution of the Cabinet of Ministers of Ukraine No. 265 [5], one of the main tasks is to ensure the use of modern and highly efficient garbage trucks by the country's municipal enterprises, which are key in the collection, transportation and primary processing of municipal solid waste (MSW). This task, in particular, is facilitated by expanding the functionality of the garbage truck by equipping it with a mounted sweeper. This generally helps to improve the overall reliability of utility companies' operations, while solving

various environmental issues. Planning for the renewal, maintenance and repair of municipal equipment is facilitated by establishing the regularity of wear of the cylindrical brush of the garbage truck's mounted sweeping equipment depending on its rotation frequency.

Analysis of recent research and publications

Paper [6] considers the technology for maintaining the city's street and road network during the period with positive air temperature, outlines methods for planning and determining the volume of cleaning work, provides technical characteristics of cleaning machines and a method for calculating their number. The article describes the characteristics and composition of garbage on the roadway of city streets and roads, its fractional composition, the content of dusty particles by fractions in the air above the road surface, the concentration of the main and most harmful elements of road dust, changes in the composition of garbage during the year, and the estimated annual accumulation of street garbage for Ukrainian cities per 1 m^2 of the road surface. The main factors influencing the performance of sweeping machines for cleaning the city's street and road network are determined. The performance of sweeping machines, factors influencing their performance and its calculation are considered. The modes of road surface cleaning (frequency), the intensity of garbage accumulation on the road surface and its contamination depending on the traffic intensity are also considered.

Measures aimed at significantly improving the efficiency of the technological process of road pavement cleaning are described in the paper [7]. These measures are aimed at reducing the need for cleaning equipment and manual labor, improving the sanitary, hygienic, aesthetic, transport and operational condition of the road surface in urban areas. It is noted that the elastic modulus of road pavement of intra-quarter passages should be at least 125 MPa, and sidewalks and pedestrian alleys over 3 meters wide should be no more than 85 MPa. If the humidity of the garbage is up to 20%, it is recommended to use sweeping machines with additional moisture with a humidity of less than 15%, and if the humidity of the garbage is more than 20%, it is recommended to use water washers.

The results of analyzing a set of partial indicators, such as fuel consumption for operation, work performance, maintenance and repair costs for brush equipment elements, as well as the cost of cleaning a certain area of roads or urban areas, are considered in the study [8]. These indicators allow us to estimate the efficiency of using municipal sweeping machines with brush equipment. The paper shows a functional diagram for the formation of a generalized efficiency criterion and proposes a mathematical expression for its calculation. An expression for determining a generalized criterion for the efficiency of using municipal machines based on the selected aggregation function is also obtained. For a clear presentation of the relationships between the factors that influence the partial indicators of efficiency of the use of municipal sweeping machines, a functional scheme for the formation of a generalized efficiency criterion of the work is proposed.

A study by modeling brushes using the finite element method to create a system for automating the road sweeping process is presented in the paper [9]. Taking into account the type of garbage and road conditions, it is noted that the driver of a sweeping machine needs to adjust the vertical pressure, angle of inclination, and speed of rotation of the curb brush, as well as frequently monitor the results of sweeping. The driver's work becomes more complex as he or she needs to carefully control the machine and perform sweeping operations at the same time. In the past, achieving efficient road sweeping has been problematic, including the reason of the unknown basic characteristics of the sweeping brushes. In this paper, a finite element model is used to analyze the deformation of metal brushes as they are pressed and rotated on the road. The key brush parameters considered include tooth length, width, and thickness, tooth radius, tooth angle and orientation, as well as the number of teeth per cluster, number of clusters per row, and number of rows. The brush teeth were modeled as thin cantilever beams using the commercial software package FE ANSYS. With this model, important brush characteristics such as force-strain ratio, contact pattern, and torque were obtained. The effect of different tooth geometries on the brush characteristics was also analyzed.

In the paper [10], it is noted that the use of brush seals can help improve engine performance by reducing losses. Brush seal wear models provide methods for predicting wear and costs. However, existing models do not systematically account for rotor eccentricity, radial deformation, and the effect of bristle hysteresis, which can lead to significant errors in some situations. Tests were conducted to study the effect of rotor-stator eccentricity and radial deformation on the wear process and flow characteristics of the brush seal. During the tests, the air leakage rate was measured at different times and operating conditions, and the eccentricity and radial deformation were measured using eddy current sensors. The test results showed that eccentricity and radial deformation have a significant impact on wear and flow efficiency. In the theoretical study, the abrasive wear equation was used to describe the loss of pile material, and a simplified description was used to express the eccentric rotor-stator motions. A wear model for the brush seal was developed, taking into account rotor-stator eccentricity and radial deformation, in which the hysteresis effect is observed. This model was validated using brush seal test data, and the results showed that there is an error of 20% compared to the calculated wear loss when rotor eccentricity, radial deformation, and hysteresis effect are fully considered.

The work [11] is dedicated to taking into account the interaction of forces, temperature effects on friction and wear of the brush pile, as well as establishing quantitative characteristics that affect the life and efficiency of the sweeping process, depending on the properties of the removed garbage and operating modes. The developed and implemented computer simulation model of the functioning of the brush unit of a municipal sweeping machine

allows predicting the characteristics of the process and identifying their cause-and-effect relationships with the brush parameters and operating modes. The simulation model makes it possible to predict the service life and performance of the brush at the early stages of designing the brush body of a municipal machine, taking into account the model conditions of the subsequent application. The parametric adjustment of the simulation model was carried out by matching the calculated and experimental values of brush pile wear obtained in the field. The criteria characterizing the intensity of brush pile wear were established. It is found that the main reason that does not allow achieving improved operating modes of municipal machines is the limitation of the brush rotation frequency and heating of the contact surface of the pile, which leads to a decrease in the mechanical properties of the pile material and an increase in the intensity of its wear.

The problem of improving the quality of road surface cleaning and the service life of brushing equipment is discussed in [12]. Improving the quality of cleaning and the service life of brushing equipment will help reduce the cost of municipal equipment. During operation, the pile of a cylindrical brush wears out, which leads to a change in its elastic characteristics. This is reflected in the need to apply the optimal pressing force to ensure the optimal width of the contact patch, which guarantees high quality cleaning and minimal pile wear. The article presents the dependence of the degree of wear of the brush pile of brush working equipment on the actual radius of the cylindrical brush. The influence of the degree of wear on the elastic characteristics of the brush working equipment is also considered. The dependence of the average stiffness coefficient on the degree of wear of the cylindrical brush bristles, as well as the value of the required clamping force on the degree of wear at different values of the width of the contact patch of the cylindrical brush, is given. Also, the dependence of the pressure in the hydropneumatic accumulator of the brush working body position control device on the actual free length of the cylindrical brush pile was obtained.

Regression analysis was used to establish regularities that describe and predict the wear and tear of garbage trucks in Khmelnytskyi region in a scientific article [13]. In addition, the results of this analysis can help to develop a strategy for the infrastructure of municipal enterprises, such as the composition and renewal of garbage trucks, the creation of a production base for maintenance and repair, which is necessary to solve the problem of solid waste management.

An improved mathematical model of the functioning of the mechanism of solid waste dewatering in a garbage truck that takes into account the wear of the auger is presented in a scientific article [14]. This model made it possible to conduct numerical studies of the dynamics of the mechanism during its startup and determine the effect of auger wear on the performance characteristics of the device. The results of the study showed that with an increase in the degree of wear of the auger, the pressure of the working fluid at the inlet of the hydraulic motor of the mechanism increases, while the angular velocity and rotational speed of the auger significantly decrease at a constant flow rate of the working fluid. The dependences of these parameters on the degree of auger wear were expressed as power functions. Additionally, it was found that the wear of the auger by 1000 microns leads to an increase in the energy consumption of the MSW dewatering process by 11.6%, which, accordingly, increases the costs of this process in the garbage truck and accelerates the process of auger wear.

Paper [15] identifies adequate laws, according to the Fisher criterion, that describe the effect of cylindrical brush wear on the performance characteristics of the garbage truck's mounted sweeping equipment. It was found that, according to the Student's criterion, among the studied factors of influence, the degree of wear of the cylindrical brush has the greatest effect on the value of the deformation of the cylindrical brush, and the width of the contact patch has the least effect. The required clamping force of the cylindrical brush is most affected by the width of the contact patch, and the degree of wear of the cylindrical brush is the least. The response surfaces of the target functions - the values of the deformation and the required clamping force of the cylindrical brush and their two-dimensional sections in the planes of the impact parameters - are shown, which allow us to clearly illustrate the specified dependencies of these target functions on individual impact parameters. It is established that the degree of wear of a cylindrical brush of 50% leads to an increase in the deformation of the cylindrical brush by 1.3 times, and the required clamping force of the cylindrical brush by 3.1...3.6 times, depending on the width of the contact patch.

However, the authors did not find any specific mathematical dependencies describing the wear regularity of the cylindrical brush of the garbage truck's mounted sweeping equipment depending on its rotation frequency as a result of the analysis of known publications.

Aims of the article

Investigation of the effect of the rotational speed of a cylindrical brush of a garbage truck's mounted sweeping equipment on its wear.

Methods

The determination of the pairwise regularity of the wear of a cylindrical brush of the garbage truck's mounted sweeping equipment on its rotation frequency was carried out by regression analysis. The regression was determined on the basis of linearization transformations that allow us to reduce the nonlinear dependence to a linear one. The coefficients of the regression equation were determined by the least squares method using the developed computer software program "RegAnaliz", which is protected by a certificate of copyright law.

The results

The values of the two-week period of wear of a cylindrical brush of the mounted sweeping equipment of a garbage truck at different values of its rotation frequency are shown in Table 1 [11]. It was established for a contact area of 2x2.38 mm^2, pressure in the contact of 0.2462 MPa.

Table 1

Wear of the cylindrical brush of the garbage truck's mounted sweeping equipment at different values of its rotation frequency [11].

№	Rotational speed of a cylindrical brush n, sec^{-1}	Cylindrical brush wear, mm
1	25.89	2
2	37.75	1.5
3	43.55	25.3
4	49.77	77.2
5	62.21	200

As a result of the regression analysis of the data in the Table 1, the regularity of wear of the cylindrical brush of the garbage truck's mounted sweeping equipment on the frequency of its rotation was determined

$$u = 0.4593 + 1.834 \cdot 10^{-8} n^{5,6} \text{ [mm]}, \quad (1)$$

where u is the wear of the cylindrical brush, mm; n is the rotational speed of the cylindrical brush, sec^{-1}.

The obtained regularity (1) can be used to create a mathematical model of the operation of the hydraulic drive of the improved mounted sweeping equipment of a garbage truck, taking into account the wear of its working bodies.

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

Table 2

Results of regression analysis of the dependence of wear of the cylindrical brush of the garbage truck's mounted sweeping equipment on its rotation frequency

№	Type of regression	The correlation coefficient R	№	Type of regression	The correlation coefficient R
1	$y = a + bx$	0.90344	9	$y = ax^b$	0.88698
2	$y = 1 / (a + bx)$	0.75548	10	$y = a +$ b-lg x	0.83080
3	$y = a + b / x$	0.74532	11	$y = a +$ b-ln x	0.83080
4	$y = x / (a + bx)$	0.64049	12	$y = a / (b + x)$	0.75548
5	$y = ab^x$	0.91040	13	$y = ax / (b + x)$	0.72063
6	$y = ae^{bx}$	0.91040	14	$y = ae^{b / x}$	0.84135
7	$y = a$ -10^{bx}	0.91040	15	$y = a$ -$10^{b / x}$	0.84135
8	$y = 1 / (a + be)^{-x}$	0.45308	16	$y = a + bx^n$	0.99115

It has been established that the wear of a cylindrical brush of the garbage truck's mounted sweeping equipment increases according to a power law with an increase in its rotation frequency.

For a Ukrainian-made sweeping machine of the serial model KO-713-01, which is equipped with a cylindrical brush with a rotation speed of 3200 rpm, its wear according to the obtained dependence (1) will reach the following value:

$$u = 0.4593 + 1.834 \cdot 10^{-8} \left(\frac{3200}{60} \right)^{5,6} \approx 86.5 \text{ [mm]}.$$

Fig. 1 shows the graphical dependence of the change in wear of the cylindrical brush of the garbage truck's mounted sweeping equipment on its rotation frequency, that was built using the dependence (1), which confirms the sufficient convergence of the obtained dependence at the level of 0.99115 compared to the data given in the Table 1.

From Fig. 1 it can be seen that reducing the rotation frequency of the cylindrical brush of the garbage truck's mounted sweeping equipment from 62 sec^{-1} (3700 rpm) to 26...38 sec^{-1} (1550...2250 rpm) leads to a

decrease in its wear by 2 orders of magnitude, which indicates the importance of identifying further ways to increase its wear resistance.

Consideration of the effect of contact area and pressure in the contact on wear, as well as the development of recommendations for the selection of wear-resistant brush pile materials for the garbage truck's mounted sweeping equipment, require further research.

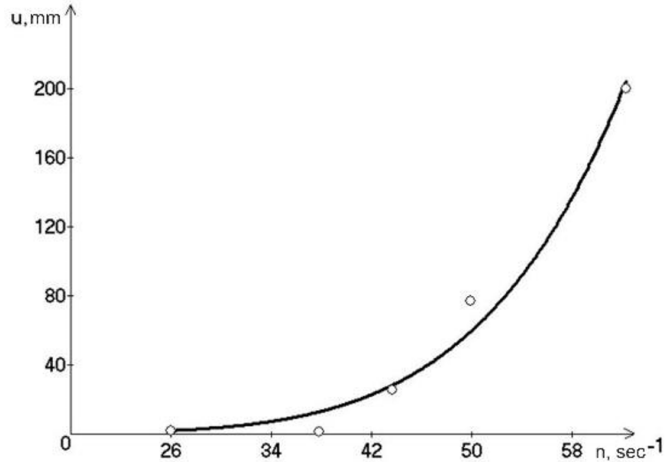

Fig. 1. Dependence of the change in wear of the cylindrical brush of the garbage truck's mounted sweeping equipment on its rotation frequency: actual ○, theoretical –

Conclusions

In the paper it is established a power law of change in the wear of the cylindrical brush of the garbage truck's mounted sweeping equipment with its rotation frequency, which can be used to create a mathematical model of the hydraulic drive of the improved mounted sweeping equipment of a garbage truck, taking into account the wear of its working bodies. It has been determined that for a Ukrainian-made sweeper of the serial model KO-713-01, which is equipped with a cylindrical brush with a rotation speed of 3200 rpm, its wear will reach 86.5 mm according to the obtained dependence. Therefore, taking into account the effect of the contact area and pressure in the contact on wear, as well as identifying further ways to increase the wear resistance of the cylindrical brush of the garbage truck's mounted sweeping equipment, requires further research.

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Березюк О.В., Савуляк В.І., Харжевський В.О., Семічаснова Н.С., Гарбуз Є.С. Встановлення закономірності зносу циліндричної щітки навісного підмітального обладнання сміттєвоза від частоти її обертання.

Стаття присвячена встановленню закономірності зносу циліндричної щітки навісного підмітального обладнання сміттєвоза від частоти її обертання. Використання математичного апарату та відповідних програм регресійного аналізу дозволило визначити степеневу закономірність зміни зносу циліндричної щітки навісного підмітального обладнання сміттєвоза від частоти її обертання, яка може бути використана під час побудови математичної моделі роботи гідроприводу вдосконаленого навісного підмітального обладнання сміттєвоза із урахуванням зносу його виконавчих органів. Побудована графічна залежність зміни зносу циліндричної щітки навісного підмітального обладнання сміттєвоза від частоти її обертання, яка підтвердила достатню збіжність отриманої закономірності. Графік впливу частоти обертання циліндричної щітки навісного підмітального обладнання сміттєвоза на її знос демонструє доцільність її зниження. Встановлено, що для підмітальної машини українського виробництва серійної моделі КО-713-01, яка оснащена циліндричною щіткою з частотою обертання 3200 об/хв, її знос за отриманою закономірністю досягатиме 86,5 мм. Виявлено, що зменшення частоти обертання циліндричної щітки навісного підмітального обладнання сміттєвоза з 62 $с^{-1}$ (3700 об/хв) до 26...38 $с^{-1}$ (1550...2250 об/хв) призводить до зниження її зносу на 2 порядки. Встановлена доцільність проведення додаткових досліджень з виявлення подальших шляхів підвищення зносостійкості циліндричної щітки навісного підмітального обладнання сміттєвоза.

Ключові слова: знос, частота обертання, навісне підмітальне обладнання, циліндрична щітка, сміттєвоз, закономірність, регресійний аналіз.