***Problems of Tribology**, V. 28, No 4/110-2023, 22-27*

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2023-110-4-22-27

Determination of the dependencies of the wear influence of the cylindrical brush on the operational characteristics of the garbage truck's mounted sweeping equipment

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Received: 23 September 2023: Revised: 20 October 2023: Accept: 21 November 2023

Abstract

The article is dedicated to the establishment of dependencies of the influence of the wear of the cylindrical brush on the operational characteristics of the mounted sweeping equipment of the garbage truck. By using the planning of the second-order experiment with the first-order interaction effects, using the Box-Wilson method, the adequate dependencies of the influence of the wear of the cylindrical brush on the performance characteristics of the mounted sweeping equipment of the garbage truck were determined. It was established that, according to the Student's criterion, among the investigated factors of influence, the wear of the cylindrical brush has the greatest effect on the deformation of the cylindrical brush, and the width of the contact spot has the least influence. The required pressing force of the cylindrical brush is most affected by the width of the contact spot, and the least by the wear of the cylindrical brush. The response surfaces of the target functions are shown – the amount of deformation and the required pressing force of the cylindrical brush and their two-dimensional cross-sections in the planes of influence parameters, which make it possible to visually illustrate the specified dependences of target function data on individual influence parameters. It was established that the wear of the cylindrical brush of 50% of cases leads to an increase in the deformation of the cylindrical brush by 1.3 times, and the necessary force of pressing of the cylindrical brush – by 3.1...3.6 times, depending on the width of the contact spot. It is shown the expediency of conducting further researches of the effect of antifriction materials on the wear of the friction pairs of the mounted sweeping equipment of the garbage truck.

Keywords: wear, operational characteristics, mounted sweeping equipment, cylindrical brush, deformation, clamping force, garbage truck, regularity, experiment planning.

Introduction

Increasing the wear resistance, reliability and service life of machine parts is one of the main problems that are being solved in the field of mechanical engineering in Ukraine, in particular for sweeping and cleaning machines [1, 2]. To clean the road surface from dirt, the utility machines with brush work equipment are generally used. At the same time, brush work equipment with cylindrical brushes with a pile made of polymer material has become the most widespread. During the work process, the pile of a cylindrical brush wears out when it interacts with the working surface, which contains abrasive particles, while its elastic characteristics change, which requires an increase in the necessary pressing force to maintain the most desirable value of the width of the contact spot under the conditions of ensuring high cleaning quality and minimum intensity of pile wear. According to the analysis of statistical data, the fleet of utility companies of the Khmelnytskyi region experienced a slight decrease in the level of wear and tear in the period 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], an important task is to ensure the use of modern and highly efficient garbage trucks in the country's communal economy. This is important for an industry that is key in the collection, transportation and primary processing of municipal solid waste (MSW). In particular, this is facilitated by the expansion of the garbage truck's functionality by equipping it with attached sweeping equipment. This helps to increase the overall reliability of the functioning of communal enterprises,

simultaneously with the solution of various environmental problems. The planning of renewal, maintenance and repair of municipal equipment is facilitated by determining the dependencies of the influence of the wear of the cylindrical brush on the operational characteristics of the mounted sweeping equipment of the garbage truck.

Analysis of recent research and publications

The article [6] sets out measures that allow to significantly increase the efficiency of the technological process of road surface cleaning, reduce the need for cleaning equipment and manual labor costs, and improve the sanitary-hygienic, aesthetic, and transport-operational condition of road surfaces in urban areas. In particular, it is stated that the required modulus of elasticity of road surface of inner-quarter passageways should be at least 125 MPa, sidewalks and pedestrian alleys with a width of more than 3 m – not more than 85 MPa. When the humidity of the garbage is up to 20%, it is advisable to use sweeping machines, additionally moistening the garbage with a humidity of less than 15%, and when the humidity of the garbage is more than 20%, it is advisable to use washing machines.

The work [7] presents the results of a study of a set of partial indicators (operating fuel consumption, performance of work, costs for maintenance and repair of elements of brush work equipment, cost of cleaning a fixed unit of the area of a road or urban area), which can be used to evaluate the effectiveness of the use of communal cleaning machines with a brush working body; the functional scheme of the formation of the generalized efficiency criterion is presented and the mathematical expression for its determination is obtained. An expression for the determination the generalized criterion for the efficiency of the use of utility vehicles is obtained, which is based on the selected aggregation function. Also, for a visual presentation of the interrelationships of factors that affect the partial efficiency indicators of the use of a communal sweeper machine, with a generalized efficiency criterion, a functional scheme of its formation is proposed in the work.

The materials of the article [8] present a study of brush modeling using the finite element method to facilitate the automation of the road sweeping process. Depending on the type of garbage and road conditions, the sweeper machine's driver needs to adjust the vertical pressure, angle of inclination and rotation speed of the curb brush, and also has to frequently monitor the sweeping results. The driver's job becomes more difficult because he has to concentrate on the road and sweep its surface at the same time. Achieving effective road sweeping has been difficult in the past, in part because the basic characteristics of sweeping brushes were unknown. A finite elements model was used to analyze the deformation of metal sweeping brushes when they are compressed and rotated on the road. The following key brush parameters were considered: bristle length, width and thickness, bristle installation radius, bristle installation angle and bristle orientation, number of bristles per cluster, number of clusters per row, and number of rows. The brush bristles were treated as thin cantilever beams and modeled by the commercial FEA software package ANSYS. Using this model, some important brush characteristics such as force-deformation relationship, contact pattern, and torque were obtained. By means of this model, the influence of different geometry of the bristle on the characteristics of the brushes was also analyzed.

In [9], it is stated that brush seals can improve engine performance by reducing losses. Brush seal wear models provide methods for predicting wear and leakage. However, rotor eccentricity, radial deformation, and bristle hysteresis effects are not systematically considered in existing models, which can lead to large errors in some cases. To investigate the effect of rotor-stator eccentricity and radial strain on the wear process and leakage characteristics of a brush seal, a brush seal test was conducted, in which the air leakage rate was measured at different test times and operating conditions, and the eccentricity and radial strain were measured using eddy current sensors. The test results showed that eccentricity and radial deformation significantly affected the wear behavior and leakage efficiency. In the theoretical study, the abrasive wear equation is adopted to describe the loss of material by bristles, and a simplified description is used to express the eccentric movements of the rotor-stator. A wear model of the brush seal was obtained, taking into account the eccentricity of the rotor-stator and radial deformation, in which the hysteresis effect is particularly pronounced. The wear model was validated quantitatively based on brush seal test data, and the results show that there is an error of 20% with the estimated wear loss when rotor eccentricity, radial deformation and hysteresis effect are comprehensively considered.

The idea of the work [10] is to take into account the mutual, force and temperature influence on the friction and wear of the brush pile, as well as to establish quantitative characteristics that determine the resource and efficiency of the sweeping work process in relation to the properties of the removed dirt and the operating modes of the process itself. A simulation model of the functioning of the brush unit of a communal cleaning machine was developed and implemented on a PC, which allows predicting the characteristics of the process and identifying their cause and effect relationships with the parameters of the brush, modes and conditions of the work process itself. The simulation model makes it possible to predict the resource and performance of the brush even at the early stages of designing the brush body of the utility vehicle, and taking into account the model conditions of its subsequent use. Parametric adjustment of the simulation model was carried out by matching the estimated and experimental values of brush pile wear obtained in real conditions. The criteria characterizing the intensity of brush pile wear are also defined. It has been established that the main reason limiting the improvement of the operating modes of utility vehicles is the frequency of rotation of the brush and, to a lesser extent, the speed of the vehicle, the heating of the contact surface of the pile occurs, and, as a result, the intensity of wear increases due to the decrease in the mechanical properties of the material of the pile.

Article [11] is dedicated to the problem of improving the quality of road surface cleaning and increasing the operating life of brush work equipment. Improving the quality of cleaning and the operating life of the brush work equipment will allow to reduce the costs of the utility machine. In the work process, the pile of the cylindrical brush wears out, while its elastic characteristics change, which is reflected in the necessary pressing force to maintain the most favorable value of the width of the contact spot under the condition of ensuring high cleaning quality and minimal intensity of pile wear. The dependence of the degree of pile wear of brush work equipment on the actual radius of the cylindrical brush is given. The effect of the degree of wear on the elastic characteristics of brush work equipment is considered. The dependence of the average stiffness coefficient on the degree of wear of the pile of a cylindrical brush, as well as the value of the required pressing force on the degree of wear for different values of the width of the contact spot of the cylindrical brush, is given. The dependence of the pressure in the hydropneumoaccumulator of the device for controlling the position of the brush working body on the actual free length of the pile wire of the cylindrical brush was obtained.

In the scientific article [12], regression analysis was used to establish dependencies that describe and allow predicting the wear and tear of garbage trucks in Khmelnytskyi region. In addition, the results of this analysis can help develop strategic plans for the infrastructure of utilities, such as the storage and renewal of garbage trucks, the creation of a production base for maintenance and repair. All this is necessary to solve the problem of solid municipal waste management.

The scientific article [13] presents an improved mathematical model of the functioning of the solid waste dehydration mechanism in the garbage truck, which takes into account the wear of the auger. This model made it possible to carry out numerical studies of the dynamics of the mechanism during start-up and to determine the effect of screw wear on the operational characteristics of the device. The results of the study showed that with an increase in the degree of wear of the screw, the pressure of the working fluid at the input of the hydraulic motor of the mechanism increases, and the angular speed and frequency of rotation of the screw decrease significantly with a constant flow of the working fluid. The dependence of these parameters on the degree of wear of the auger was expressed in the form of power functions. In addition, it was established that the wear of the auger by 1000 μm leads to an increase in the energy consumption of the solid waste dehydration process by 11.6%, which, accordingly, increases the costs of this process in the garbage truck and accelerates the process of wear of the auger.

However, as a result of the analysis of known publications, the authors did not find specific mathematical dependencies describing the impact of the wear of the cylindrical brush on the operational characteristics of the mounted sweeping equipment of the garbage truck.

Aims of the article

Study of the effect of wear of the cylindrical brush on the operational characteristics of the mounted sweeping equipment of the garbage truck.

Methods

Determination of the dependencies of the influence of the cylindrical brush wear on the operational characteristics of the mounted sweeping equipment of the garbage truck was carried out by planning a second-order experiment with first-order interaction effects by 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 law for the developed software and is described in the work [15].

Results

Preliminary processing of the results of experimental studies [11] showed that such operational characteristics of the mounted sweeping equipment of the garbage truck, such as the amount of deformation and the necessary pressing force of the cylindrical brush, are functions of the following 2 main parameters:

$$\Delta Y_{CB}, F_{PR} = f(C_w, X_k), \tag{1}$$

where ΔY_{CB} is the amount of deformation of the cylindrical brush, mm; F_{PR} – necessary pressing force of the cylindrical brush, N; C_w – degree of wear of the cylindrical brush , %; X_k – the width of the contact spot, mm.

The study of the influence of the above factors on the amount of deformation and the necessary force of pressing the cylindrical brush when processing the results of one-factor experiments by the method of regression analysis is characterized by the significant difficulties and amount of work. Therefore, in our opinion, it is expedient to conduct a multivariate experiment to obtain regression equations for the response functions – the values of deformation and the necessary pressing force of the cylindrical brush using the planning of a multivariate experiment by the Box-Wilson method [14].

The data about the effect of wear of the cylindrical brush on the value of deformation and the necessary force of pressing the cylindrical brush for different widths of the contact spot are given in table 1 [11].

Table 1

Data on the influence of wear of a cylindrical brush on the amount of deformation and the necessary force of pressing the cylindrical brush for different widths of the contact spot [11]

The degree of wear of the cylindrical brush C_w, %	Width of the contact spot, X_k					
	X_k = 80 mm		X_k = 100 mm		X_k = 120 mm	
	ΔY, mm	F_{PR}, N	ΔY, mm	F_{PR}, N	ΔY, mm	F_{pr}, N
0	2.92	1060	4.58	1426	6.63	1874
10	3.06	1282	4.80	1740	6.94	2312
20	3.21	1572	5.03	2156	7.28	2904
30	3.37	1960	5.29	2722	7.65	3726
40	3.55	2492	5.58	3514	8.07	4907
50	3.75	3242	5.89	4662	8.54	6676
60	3.98	4341	6.25	6399	9.07	9463
70	4.24	6026	6.66	9175	9.67	14157
80	4.53	8767	7,13	13940	10.36	22792
90	4.86	13584	7.66	22953	11,15	40755
100	5.25	23019	8.29	42533	12.08	85554

Based on the data in Table 1, using the planning of the second-order experiment with the first-order interaction effects, by means of the developed software (protected by a copyright law), after rejecting insignificant factors and interaction effects according to the Student's criterion, the dependencies of the influence of the wear of the cylindrical brush on the amount of deformation are determined and the necessary pressing force of the cylindrical brush for different widths of the contact spot:

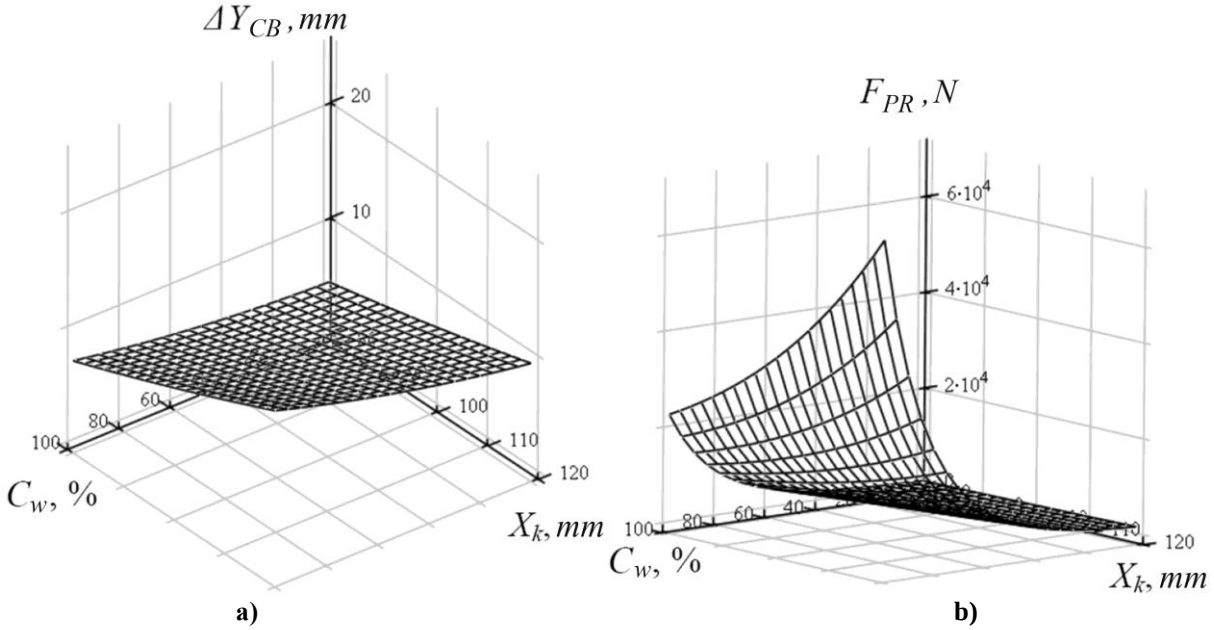
$$\Delta Y_{CB} = 0{,}02832X_k - 0{,}04836C_w + 6{,}822\cdot10^{-4}C_w X_k + 1{,}674\cdot10^{-4}C_w^2 - 4{,}297\cdot10^{-4}X_k^2; \quad (2)$$

$$\ln F_{PR} = 6{,}13 - 0{,}03422C_w + 0{,}01138X_k + 1{,}571\cdot10^{-4}C_w X_k + 2{,}061\cdot10^{-4}C_w^2 + 3{,}497\cdot10^{-6}X_k^2; \quad (3)$$

from where, by potentiating the dependence (3), the following is obtained:

$$F_{PR} = e^{6{,}13-0{,}03422C_w+0{,}01138X_k+1{,}571\cdot10^{-4}C_w X_k+2{,}061\cdot10^{-4}C_w^2+3{,}497\cdot10^{-6}X_k^2}. \quad (4)$$

In Fig. 1 shows the response surfaces of the objective functions – the amount of deformation and the required pressing force of the cylindrical brush and their two-dimensional cross-sections in the planes of influence parameters, built using laws (2) and (4), which allow to visually illustrate the specified dependencies.



a) **b)**

Fig. 1. The response surfaces of the objective functions – the values of deformation (a) and the required pressing force (b) of the cylindrical brush

It was established that, according to Fisher's criterion, the hypothesis about the adequacy of regression models (2) and (4) can be considered correct with 95% confidence. The multiple correlation coefficients were 0.99894 and 0.99315, respectively, which indicates the high accuracy of the obtained results.

According to the Student's criterion, it was established that among the investigated influencing factors, the degree of wear of the cylindrical brush has the greatest effect on the deformation of the cylindrical brush, and the width of the contact spot has the least influence. For the required pressing force of a cylindrical brush is most affected by the width of the contact spot, and the least by the degree of wear of the cylindrical brush.

It was established that the degree of wear of the cylindrical brush of 50% leads to an increase in the deformation of the cylindrical brush by 1.3 times, and the necessary pressing force of a cylindrical brush 3.1...3.6 times depending on the width of the contact spot.

Thus, the determination of the influence on wear and development of recommendations for the selection of anti-friction materials for the friction pairs of the mounted sweeping equipment of the garbage truck require further researches.

Conclusions

The dependencies that describe the wear influence of the cylindrical brush on the operational characteristics of the mounted sweeping equipment of the garbage truck have been determined, which are adequate according to the Fisher criterion. It was established that, according to the Student's criterion, among the investigated factors of influence, the degree of wear of the cylindrical brush has the greatest effect on the deformation of the cylindrical brush, and the width of the contact spot has the least influence. The required pressing force of the cylindrical brush is most affected by the width of the contact spot, and the least by the degree of wear of the cylindrical brush.

The response surfaces of the objective functions are shown – the values of deformation and the required pressing force of the cylindrical brush and their two-dimensional cross-sections in the planes of influence parameters, which make it possible to visually illustrate the specified dependences of given objective functions on individual influence parameters. It was established that the degree of wear of the cylindrical brush in 50% of cases leads to an increase in the deformation of the cylindrical brush by 1.3 times, and the necessary force of pressing the cylindrical brush by 3.1...3.6 times, depending on the width of the contact spot. Determination of the influence on wear and development of recommendations for the selection of anti-friction materials for the friction pairs of the mounted sweeping equipment of the garbage truck require further research.

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Березюк О.В., Савуляк В.І., Харжевський В.О., Гарбуз Є.С. Визначення закономірностей впливу зносу циліндричної щітки на експлуатаційні характеристики навісного підмітального обладнання сміттєвоза

Стаття присвячена встановленню закономірностей впливу зносу циліндричної щітки на експлуатаційні характеристики навісного підмітального обладнання сміттєвоза. За допомогою використання планування експерименту другого порядку з ефектами взаємодії першого порядку методом Бокса-Уілсона визначено адекватні закономірності впливу зносу циліндричної щітки на експлуатаційні характеристики навісного підмітального обладнання сміттєвоза. Встановлено, що за критерієм Стьюдента серед досліджених факторів впливу найбільше на величину деформації циліндричної щітки впливає ступінь зносу циліндричної щітки, а найменше – ширина плями контакту. На необхідне зусилля притискання циліндричної щітки найбільше впливає ширина плями контакту, а найменше – ступінь зносу циліндричної щітки. Показано поверхні відгуків цільових функцій – величини деформації та необхідного зусилля притискання циліндричної щітки та їхні двомірні перерізи в площинах параметрів впливу, які дозволяють наглядно проілюструвати вказані залежності даних цільових функцій від окремих параметрів впливу. Встановлено, що ступінь зносу циліндричної щітки в 50% призводить до зростання величини деформації циліндричної щітки в 1,3 рази, а необхідного зусилля притискання циліндричної щітки в 3,1...3,6 рази в залежності від ширини плями контакту. Показано доцільність проведення подальших досліджень впливу антифрикційних матеріалів на знос вузлів тертя навісного підмітального обладнання сміттєвоза.

Ключові слова: знос, експлуатаційні характеристики, навісне підмітальне обладнання, циліндрична щітка, деформація, зусилля притискання, сміттєвоз, закономірність, планування експерименту.