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Establishing the peculiarities of tire wear of garbage trucks during the transportation of municipal solid waste

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Abstract

The article is dedicated to the establishment of peculiarities of tire wear of garbage trucks during the transportation of solid waste. Using the planning of the first-order experiment with the first-order interaction effects using the Box-Wilson method, adequate dependencies of wear of garbage truck tires on the front and rear axles due to the transported mass of municipal solid waste and the mileage 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 garbage truck tires on both the front and rear axles is most affected by the transported mass of municipal solid waste, and the least – by the mileage of the garbage truck. The response surfaces of the objective functions – tire wear of the garbage truck on the front and rear axles and their two-dimensional sections in the planes of the impact parameters are shown, which allow to visually illustrate the indicated dependences of the objective function data on individual impact parameters. The dependencies of the number of routes of the garbage truck to the maximum allowable tire wear on the front and rear axles were obtained. The response surfaces of the target functions – the number of routes of the garbage truck to the maximum permissible wear of the tires on the front and rear axles and its two-dimensional sections in the planes of the influence parameters, which allow to visually illustrate the specified dependencies, are obtained. The expediency of conducting further research on the influence of speed, unevenness of the road surface, weather conditions and other factors on the wear of garbage truck tires has been revealed.

Key words: wear, tire, garbage truck, municipal solid waste, dependence, experiment planning.

Introduction

The increase of the wear resistance, reliability and durability of machine parts occupies a prominent place among the important tasks of utility engineering [1, 2]. The collection and transportation of municipal solid waste (MSW) to landfills, processing and disposal sites in Ukraine is mainly carried out by body garbage trucks in the amount of more than 3,800 units, which are able to compact solid waste, reducing transportation costs and the required area of landfills. At the same time, during the technological operation of solid waste transportation by garbage trucks, their tires are subjected to intensive wear. This is due to the significant carrying capacity and length of garbage trucks' routes, since the placement of solid waste landfills takes place outside the sanitary zone, which in Ukraine is 30 km from populated areas. The wear and tear of the fleet of garbage trucks of municipal enterprises of Khmelnytskyi region during 2015-2020, despite the measures taken, almost did not change: it decreased only from 63% to 59% [3, 4]. According to the text of Resolution of the Cabinet of Ministers of Ukraine No. 265 [5], it is particularly important to ensure the use of modern highly efficient garbage trucks in the country's communal economy, as the main link in the structure of machines for collection, transportation and primary processing of solid waste. This allows not only to solve a number of environmental problems, but also to increase the reliability of the work of utility companies as a whole. The planning of renewal, maintenance and repair of garbage trucks is facilitated by the determination of the regression dependencies of wear of garbage truck tires on the front and rear axles from the transported mass of municipal solid waste and the mileage of the garbage truck.

Analysis of recent research and publications

In the materials of the work [6], an improved mathematical model of the operation of the solid waste dehydration drive in the garbage truck was proposed, which takes into account the wear of the auger, made it possible to numerically study the dynamics of this drive during start-up and determine that with an increase in the wear of the auger, the pressure of the working fluid at the inlet of the hydraulic motor of the drive increases, and the angular the speed and frequency of rotation of the auger are significantly reduced with a constant supply of working fluid.

The power-law regularities of changes in the nominal values of the pressures at the hydraulic motor inlet, angular velocity and rotation frequency of the auger depending on the amount of its wear were determined, the last of which describes the deviation from the optimal rotation frequency of the auger during its wear and was used to determine the energy intensity of solid waste dehydration taking into account the wear of the auger. It was found that the wear of the auger by 1000 μm leads to an increase in the energy intensity of solid waste dehydration by 11.6%, and, therefore, to an increase in the cost of their dehydration in the garbage truck and acceleration of the wear process.

In the article [7] it was established that the resource of large-sized tires depends on many factors of the operating conditions, which lead to their premature scrap due to an excess of the thermal state and, as a result, peeling of the tread. Management of the thermal state of the large-sized tire, taking into account the rational loading of the dump truck during operation, allows you to achieve its maximum productivity. To determine the productivity in various conditions of operation of quarry dump trucks, the computer program "Optimal degree of loading" has been developed.

The paper [8] provides an analysis and assessment of factors affecting the wear of large-size tires of quarry dump trucks, and recommendations for increasing their service life.

In the materials of the article [9], the problem of increasing the accuracy of determining the resource of pneumatic tires of trucks is considered. Tire resource calculations were carried out using 5 methods, the results of which were compared with the results of an experimental study, which showed the need to refine the calculation methods to solve the specified problem. It is noted that the more accurately the tire resource is determined, the more qualitative the management of the technological processes of tire maintenance, their replacement, and scrapping will be, which will significantly affect traffic safety and the economic indicators of the operation of the motor vehicle enterprise.

In work [10], a mathematical model of wear of a highly elastic wheel during its rolling on a rigid base was developed. In the proposed model, it is assumed that wear occurs in the sliding region, and the intensity of wear is a power-law function of pressure. A distinctive feature of the model is accounting for changes in contact pressures on the contact area, the size of the contact area, and the extent of the sliding sub-region during wear. An analytical dependence was obtained for calculating the length of the slip zone. The kinetics of the change in the radius of a highly elastic wheel during wear was studied. A theoretical-experimental method of calculating the wear life of a massive highly elastic wheel when rolling on a rigid base is proposed. An analysis of the influence of the relative slip on the durability of a massive highly elastic tire was carried out. The nature of the influence of the parameters of the wear law on the evolution of contact characteristics and the service life of the wheel was studied.

In the article [11], on the basis of measurements of the height of the tire tread pattern in operating conditions, one-factor linear and quadratic models of the dependence of car tire wear on mileage were determined. Factors affecting critical wear of tires were analyzed: accumulation of fatigue stresses and destruction in the tread rubber array; increasing unevenness of wear along the length of the treadmill, which results in variability of the rolling radius; increasing the stiffness of the tire in the tangential and normal directions; reducing the diameter of the tire. Recommendations for reducing the wear of truck tires for the enterprise in real conditions have been developed. Recommendations for improving control over the technical condition of the company’s vehicle fleet based on information on the nature and intensity of tire wear are proposed.

The authors of the paper [12] describe the specifics of the work of vehicles for collecting and transporting municipal solid waste to the places of their further handling, show the method of measuring the height of the tire tread pattern, and also give the average arithmetic values of the wear of garbage truck tires installed on the front and rear axles depending on from the transported mass of solid household waste and the mileage of the garbage truck.

In the article [13], a regression analysis was used to determine a regularity that describes the dynamics of wear and tear of garbage trucks in general in the Khmelnytskyi region and allows it to be predicted and planned for the infrastructure of municipal enterprises (warehouse and renewal of garbage trucks, production base for maintenance and repair), which is necessary for solving problems of municipal solid waste management.

However, as a result of the analysis of known publications, the authors did not find specific mathematical dependences describing the tire wear of the garbage truck on the front and rear axles on the transported mass of solid household waste and the mileage of the garbage truck.

Aims of the article

The aims is to study the influence of the transported mass of municipal solid waste and mileage on the wear of garbage truck tires.

Methods

The determination of the dependencies of garbage truck tire wear on the front and rear axles from the transported mass of municipal solid waste and garbage truck mileage was carried out 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 and is described in the work [15].

Results

Preliminary processing of the results of experimental studies [12] showed that the wear of garbage truck tires on different axles is a function of the following 2 main parameters:

$$u_{FA}, u_{RA} = f(m, L), \tag{1}$$

where u_{FA}, u_{RA} –tire wear of the garbage truck on the front and rear axles, respectively, μm; m – transported mass of solid household waste, tons; L – mileage of the garbage truck, km.

The study of the influence of the above factors on the wear of garbage truck tires when processing the results of one-factor experiments by the method of regression analysis is associated with significant difficulties. Therefore, in our opinion, it is advisable to conduct a multivariate experiment to obtain a regression equation for the response functions – wear of garbage truck tires on different axles using the planning of a multivariate experiment using the Box-Wilson method [14].

The average arithmetic values of wear of garbage truck tires installed on one axle depending on the transported mass of solid household waste and the mileage of the garbage truck are given in the table 1 [12].

Table 1

Average arithmetic values of wear of garbage truck tires installed on one axle [12]

№	Transported mass m, tons	Mileage L, km	Wear, μm	
			Front axle	Rear axle
1	41,16	1304,63	98,715	136,8
2	46,9	1021,63	114,55	157,5
3	76,72	1597,33	191,5	245,8

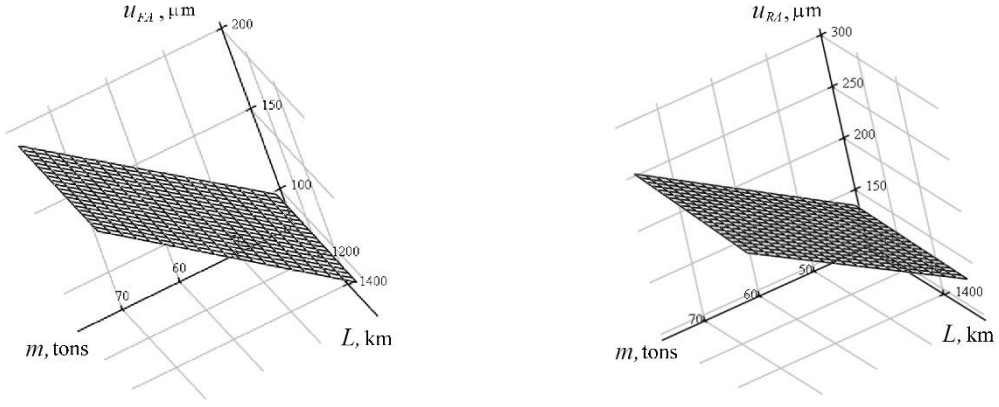
Based on the data in table 1, using the planning of the first-order experiment with first-order interaction effects, applying the developed software, which is protected by a certificate, after rejecting insignificant factors and interaction effects according to the Student's criterion, the dependencies of wear of garbage truck tires on different axes depending on the transported mass of solid household waste and garbage truck mileage:

$$u_{FA} = 2,507m - 0,006786L + 8,186 \cdot 10^{-5} mL; \tag{2}$$

$$u_{RA} = 3,539m + 0,003974L - 2,615 \cdot 10^{-4} mL. \tag{3}$$

In the fig. 1 are shown the response surfaces of the target functions – tire wear of the garbage truck on the front u_{FA} and rear u_{RA} axles and their two-dimensional cross-sections in the planes of the influence parameters, constructed with the help of dependencies (2, 3), which allow you to visually illustrate the specified dependencies.

It was established that according to Fisher's test, the hypothesis about the adequacy of regression models (2, 3) can be considered correct with 95% reliability. The coefficient of multiple correlation was R = 0.99999, which indicates the high accuracy of the obtained results.



a) b)

Fig. 1. Response surfaces of the target functions - the wear of the tires of the garbage truck on the front u_{FA} and rear u_{RA} axes and its two-dimensional sections in the planes of influence parameters: (а) – $u_{FA} = f(m, L)$, (б) – $u_{RA} = f(m, L)$

According to the Student's criterion, it was established that among the investigated factors of influence, the weight of municipal solid waste transported has the greatest influence on the wear of garbage truck tires on both the front and rear axles, and the least – the mileage of the garbage truck.

To determine the number of routes of the garbage truck before the maximum allowable tire wear, we will use the following formulas:

$$m = m_1 n; \tag{4}$$

$$L = L_1 n; \tag{5}$$

$$u = h - h_{\min}, \tag{6}$$

where m_1 – the carrying capacity of the garbage truck, tons; L_1 – length of route of the garbage truck, km; n –the number of garbage truck routes; h – tread depth of a new tire, μm; h_{min} –minimum allowable tire tread depth, μm (for trucks h_{min} = 1 mm).

After substituting formulas (4-5) into dependencies (2, 3), we will obtain dependencies of the number of routes of the garbage truck to the maximum allowable tire wear on the front and rear axles:

$$n_{FA} = \frac{\sqrt{\left(2{,}507m_1 - 0{,}006786L_1\right)^2 + 3{,}274\cdot 10^{-4} m_1 L_1 \left(h - h_{\min}\right)} - 2{,}507m_1 + 0{,}006786L_1}{1{,}637\cdot 10^{-4} m_1 L_1}; \tag{7}$$

$$n_{RA} = \frac{\sqrt{\left|\left(3{,}539m_1 + 0{,}003974L_1\right)^2 - 1{,}046\cdot 10^{-3} m_1 L_1 \left(h - h_{\min}\right)\right|} + 3{,}539m_1 + 0{,}003974L_1}{5{,}23\cdot 10^{-4} m_1 L_1}. \tag{8}$$

In the fig. 2 are shown the response surfaces of the objective functions – the number of routes of the garbage truck to the maximum allowable wear of tires on the front n_{FA} and rear n_{RA} axles and its two-dimensional sections in the planes of the influence parameters, which are constructed with the help of dependencies (7, 8) and allow to visually illustrate the specified dependencies.

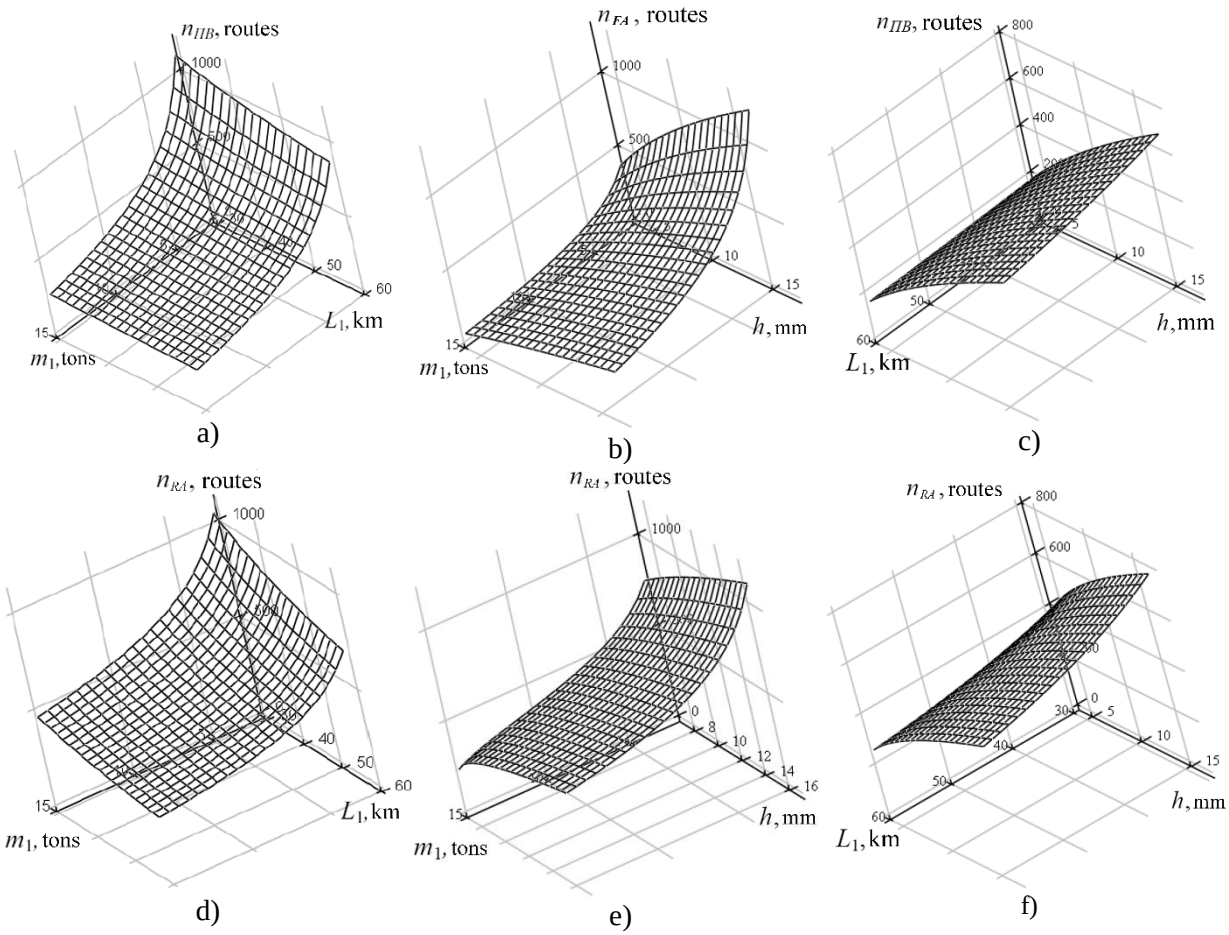


Fig. 2. The response surfaces of the objective functions – the number of trips of the garbage truck to the maximum allowable wear of the tires on the front n_{FA} and rear n_{RF} axes and their two-dimensional sections in the planes of the impact parameters: (a) – $n_{FA} = f(m_1, L_1)$, (b) – $n_{FA} = f(m_1, h)$, (c) – $n_{FA} = f(L_1, h)$, (d) – $n_{RA} = f(m_1, L_1)$, (e) – $n_{RA} = f(m_1, h)$, (f) – $n_{RA} = f(L_1, h)$

The determination the impact of speed, road surface irregularities, weather conditions and other factors on garbage truck tire wear requires further research.

Conclusions

According to Fisher's criterion the adequate dependencies of tire wear of the garbage truck on the front and rear axles due to the transported mass of municipal solid waste and mileage 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 garbage truck tires on both the front and rear axles is most affected by the transported mass of municipal solid waste, and the least – by the mileage of the garbage truck. The response surfaces of the objective functions – tire wear of the garbage truck on the front and rear axles and their two-dimensional sections in the planes of the impact parameters are shown, which allow you to visually illustrate the indicated dependences of the objective function data on individual impact parameters. The dependencies of the number of routes of the garbage truck to the maximum allowable tire wear on the front and rear axles were obtained. The response surfaces of the target functions – the number of routes of the garbage truck to the maximum permissible wear of the tires on the front and rear axles and its two-dimensional sections in the planes of the influence parameters, which allow to visually illustrate the specified dependencies, are constructed. The determination of the impact of speed, road surface irregularities, weather conditions and other factors on garbage truck tire wear requires further research.

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Березюк О.В., Савуляк В.І., Харжевський В.О. Встановлення закономірностей зносу шин сміттєвозів під час транспортування твердих побутових відходів

Стаття присвячена встановленню закономірностей зносу шин сміттєвозів під час транспортування твердих побутових відходів. За допомогою використання планування експерименту першого порядку з ефектами взаємодії першого порядку методом Бокса-Уілсона визначено адекватні закономірності зносу шин сміттєвоза на передній та задній осях від перевезеної маси твердих побутових відходів та пробігу сміттєвоза. Встановлено, що за критерієм Стьюдента серед досліджених факторів впливу найбільше на знос шин сміттєвоза як на передній, так і на задній осях впливає перевезена маса твердих побутових відходів, а найменше – пробіг сміттєвоза. Показано поверхні відгуків цільових функцій – зносу шин сміттєвоза на передній та задній осях та їхні двомірні перерізи в площинах параметрів впливу, які дозволяють наглядно проілюструвати вказані залежності даних цільових функції від окремих параметрів впливу. Отримано закономірності кількості рейсів сміттєвоза до граничнодопустимого зносу шин на передній та задній осях. Побудовано поверхні відгуків цільових функцій – кількості рейсів сміттєвоза до граничнодопустимого зносу шин на передній та задній осях та її двомірні перерізи в площинах параметрів впливу, які дозволяють наглядно проілюструвати вказані залежності. Виявлено доцільність проведення подальших досліджень впливу швидкості руху, нерівностей дорожнього покриття, погодних умов та інших факторів на знос шин сміттєвоза.

Ключові слова: знос, шина, сміттєвоз, тверді побутові відходи, закономірність, планування експерименту.