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RESEARCH OF DYNAMICS OF TIRE WEAR OF TRUCKS AND PROGNOSTICATION OF THEIR SERVICE LIFE

Summary. The dependences of tire wear on the tire life are determined on the basis of the system measurements of residual tread depth in the actual operating conditions; the factors which influence the critical tire wear are analyzed. The prediction technique of the operation life and the tire changing is devised.

ИССЛЕДОВАНИЕ ДИНАМИКИ ИЗНОСА ШИН ГРУЗОВЫХ АВТОМОБИЛЕЙ И ПРОГНОЗИРОВАНИЕ ИХ СРОКА ЭКСПЛУАТАЦИИ

Аннотация. На основе системных измерений остаточной высоты рисунка протектора шин в реальных условиях эксплуатации определены зависимости износа автомобильных шин от пробега, проанализированы факторы, которые влияют на критический износ шин. Разработана методика прогнозирования срока эксплуатации и замены шин.

1. INTRODUCTION

Trucking volume rising continuously happens under the present-day conditions. Development of carrying system leads to enhancement of the role of tires during the vehicle and especially truck operation. Distribution of the traffic handling cost according to the principal articles of expenditure is as follows: direct maintenance costs – up to 25 percent; trucker wage costs – up to 20 percent; fuel costs – up to 20 percent; tire costs – up to 10 percent. Observations for the trucking development in Ukraine showed the essential increase in use of the heavy-duty trucks made by the main world's top manufacturers. At the same time the production schedules, total running, quantity and utilized tire kits are increasing. Maintenance running has increased simultaneously; the quality of utilized trucks has improved; the specific consumption of fuel and wage costs are reduced as the cargo volume increases; quantity of tires in the tire kits raises. All this leads to decrease of the first three cost prices specified above and to increase in the item connected with tire costs. General tire costs make up 60 – 80 percent of the cost of the car for all the operating life. The organization of modern accounting of the actual tire life at the motor transportation and that of dynamics of wear process of tire tread with the use of computer engineering in the conditions of the particular enterprises with taking into account their production specifics allows specifying of the established standards and the actual operation life of tires. It is topical in the conditions of industrial regions where trucks are used in difficult conditions of big cities, anthropogenic influence, chemical pollution, difficult operation assignments.

2. THE ANALYSIS OF PUBLICATIONS AND RESEARCH OBJECTIVE

The problem of checking over the technical state of tires of truck is topical. It is proved in research works [1, 2, 3] that the measurement of residual tread depth of the tire of trucks, its documenting and comparison with the previous values is the most expedient method of monitoring of the dynamics of the wear under the operating conditions. The method does not demand complicated equipment, the previous influence on the tire, destroying influence on it and tire dismantling.

Besides, the method of direct measurement of tread depth allows finding of unevenness of the tire wear, both on the width of the tread cap and on the length of its circle that is almost impossible under the application of the volume and weight valuation methods.

Research objective is the research of laws of intensity and character of the tread wear of truck tires and the development of prediction technique of their actual life.

3. EXPERIMENTAL RESEARCH OF TREAD WEAR OF TIRES

Materials and results of the research. The research was done at the enterprises of the Donetsk region. The models of the trucks, the tires which were researched and axes of their installation are given in table 1. The special device [4] to control the residual height of the tread pattern of the tires was used.

The results of the research have shown that the tire has a difficult, nonlinear dependence of the wear on run (fig. 1) which can be observed on the example of many technical objects [5, 6, 7]. The wear rate of the tire h_{tr} is measured in percentage ratio (y-axis) and it depends on run of the trucks L_T - it is measured in thousand kilometer of run (x-axis). In terms of the variable intensity of wear the tire life can be divided into three stages: a wearing-in zone, a well-established (stable) wear zone, and a zone of critical wear which is necessary to be researched separately.

Consequently, the phases of the running-in and critical wear are the sedate functional dependences of the residual height of the tread pattern on the tire life; it means that they allow changing of the wear intensity with accumulation of the tire life. At the same time the wear has the linear dependence in the constant phase, and the tangent of inclination of line ψ is the average wear intensity:

$$I_h = \frac{\Delta h_{tr}}{\Delta L_T} = \frac{\Delta h_{tr_1} - \Delta h_{tr_2}}{\Delta L_{T2} - \Delta L_{T1}}, \frac{mm}{1{,}000\ km}, \tag{1}$$

where: h_{tr_i} – the height of the tread pattern in i-point, mm; L_{Ti} – the tire life in i-point, thousand km.

The running-in period present at the beginning of the tire operation is extensively conditioned by the tire accommodation to the running-in to specific features of the geometry of the truck chassis and the work of the units of the truck suspension [3, 8, 9, 10, 11]. It is obvious that the truck chassis which were in operation in different and not always favorable conditions have a number of imperfections, such as frame twisting, flexure or misalignment of axles, their one or versatile shift, deformation of the wheel disk and many other things. The dependence of the tire wear for Goodyear RHD, the dimension-type 315/80 R22.5 (fig. 2) established on the driving axles of the transit-mix truck Volvo FM 6x4 in their running-in period was obtained during the experiment.

According to the dependence it is possible to draw a conclusion that the running-in period makes up about 8,000 km. According to reports of measurements, the value of I_h made up 0.377 mm/1,000 km at that period and at the first 1,500 km reached the value of 1.04 mm/1,000 km, and at the first 4,000 km of the tire life it had the average value of 0.504 mm/1,000 km. In the interval of the tire life from 4,000 to 8,500 km the value I_h gradually decreased to the size which is normal for the tires which operate in the operation conditions of building areas, having reached the value of 0.147 mm/1,000 km.

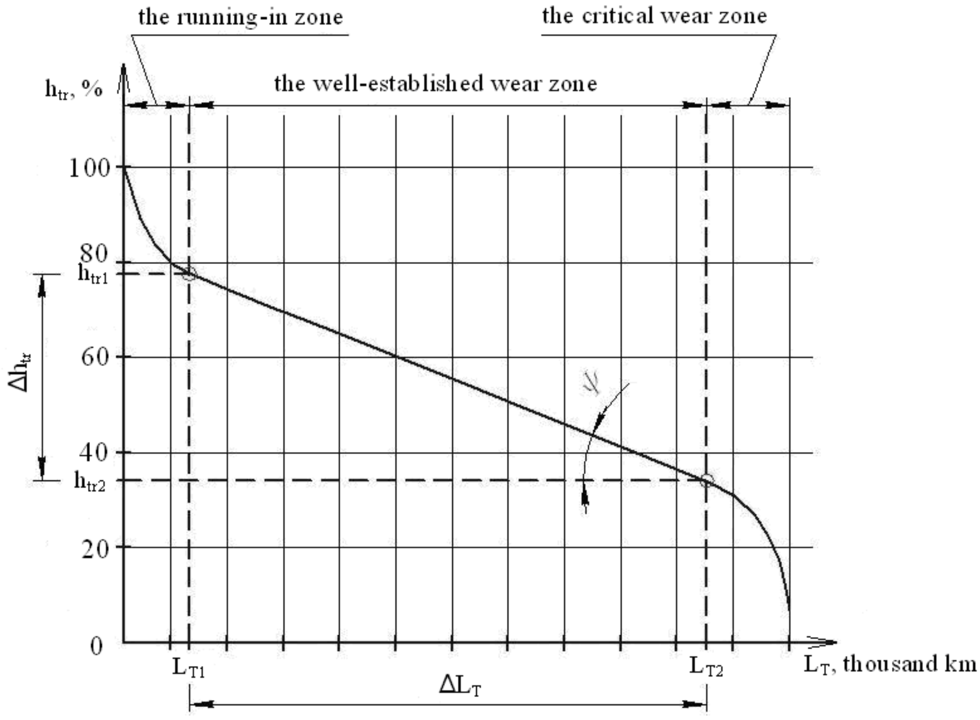

Fig. 1. Dependence of the residual height of the tread pattern on the tire life
Рис. 1. Зависимость остаточной высоты протектора шины от ее пробега

The fact of existence the running-in of tires has also been proved during the supervision over the dynamics of the wear of drive wheels of dump trucks. It is established that if tires with the tire life of about 216,000 km wore out with the intensity of 0.066 ... 0.079 mm/1,000 km at the moment of their reducing from the operation, the tires established instead of them having the tire life of 41,100 km showed the wear-rate of about 0.14 ... 0.2 mm/1,000 km. Thus, the moderate wear for the stage of the running-in of the tires makes up about 2.5 mm of the initial height of the tread and in exceptional cases is up to 3 mm (10 … 15 percent of the full height of the tread).

The stage of the well-established wear is the longest stage concerning the tire life which makes up about 85 percent of the tire life of large-tonnage trucks. This stage is characterized by the uniform I_h supported due to rather stationary conditions of tire operation and the end of the running-in process. The constant wear is investigated in the full cycle of operation of the tires Michelin XZY-2, the dimension-type 315/80R22.5 which are established on the operated axes of the dump truck Volvo (fig. 3).

On the basis of the positions [12] the up limit of the well-established wear corresponds to the value of the tire life at which the establishment of the stable average wear rate I_h *of* the tire tread has taken place. Data-based research makes it possible to speak about the beginning of the well-established wear for 16,000 km of the tire life.

The transitive zone to the critical wear for the tires (fig. 3) is at 100,000 km of the tire life. At this point the swift increase of the divergence between the average remaining-tread depths which smoothly increased to 100,000 km is observed. As a whole the tire life of the driving wheels of trucks exceeds the tire life of steering wheels almost twice as much which can be explained by a number of factors (variable load, presence of the twin wheels, presence of the steering angle and etc.).

Thereby in the conditions of the well-established wear the tire of the steering wheel of tetra-axial dump truck Volvo FM 8x4 overcomes about 70 percent of the tire life. The value I_h for this period makes up 0.112 mm/1,000 km at the minimum value of the intensity equal to 0.088 mm/1,000 km. The average tread depth of the tire for the beginning of the phase of the well-established wear made up

14.75 mm, and in the end of the phase was equal to 4.64 mm. Thereby the own average value of the wear made up 10.11 mm which exceeds 60 percent of the general tread depth which can be reached by the time of the tire retirement.

Table 1

General characteristic of the tires of the trucks

Truck model	Arrangement of axes			
	1-st controllable	2-nd controllable	1-st driving	2-nd driving
VOLVO FM 400 8x4 	Michelin XZY-2 315/80 R22.5 		- Michelin XDY-3 315/80 R22.5; - Michelin XZY-2 315/80 R22.5; - Continental HDC-1 315/80 R22.5 	
VOLVO FM 400 6x4 	Michelin XZY-3 385/65 R22.5  	–	- Goodyear RHD 315/80R22.5;  - Bridgestone R297; - Michelin XDY-3 315/80R22.5 	
KAMAZ 6520-61 6x4 	- KAMA ID-304 Y-4 12.00R20; - Belshina ID-304 Y-4 12.00R20; - Omsktire ID-304	–	- KAMA ID-304 Y-4 12.00R20; - Belshina ID-304 Y-4 12.00R20; - Omsktire ID-304	- KAMA ID-304 Y-4 12.00R20; - Belshina ID-304 Y-4 12.00R20; - Omsktire ID-304

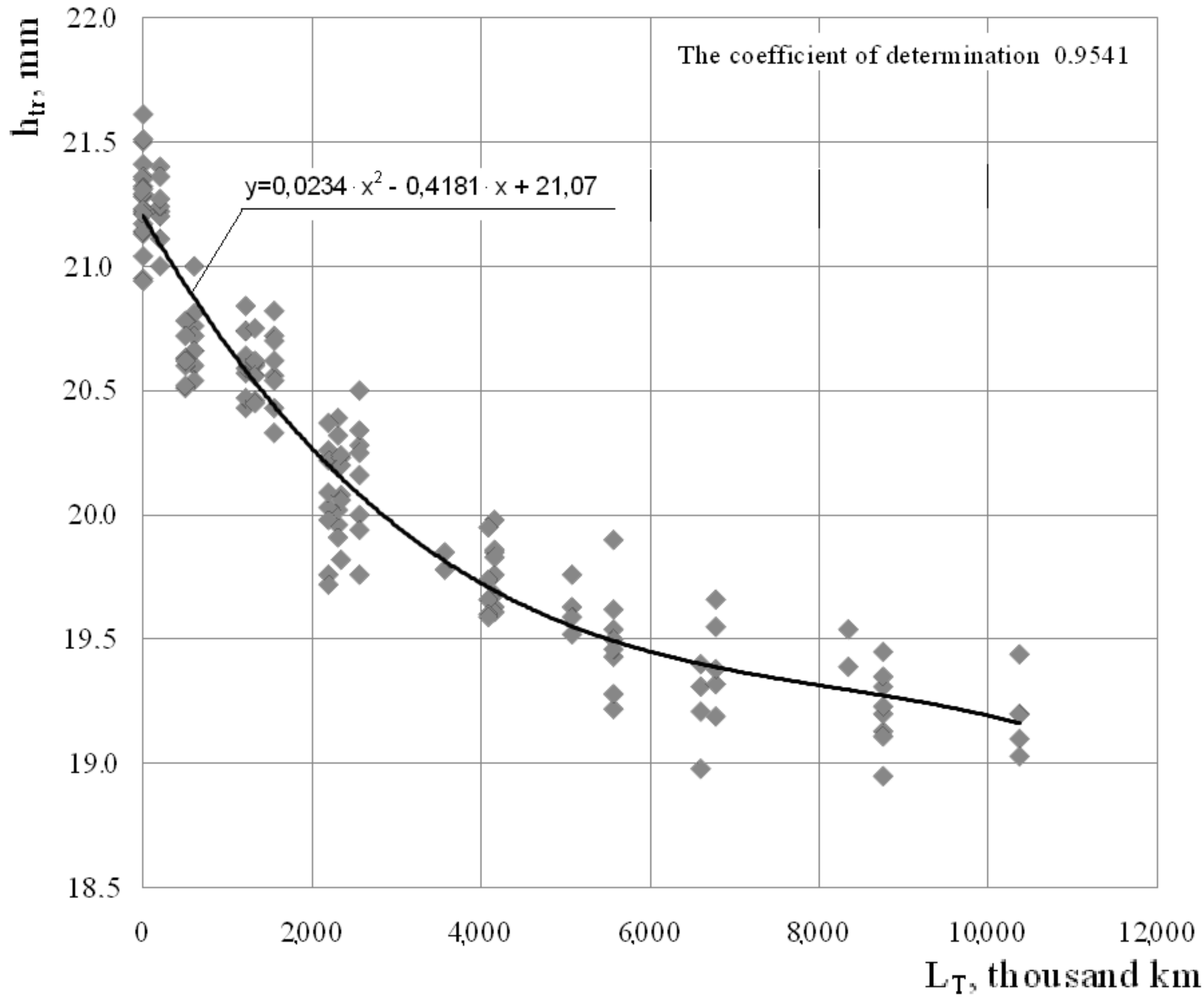

Fig. 2. Wear during the running-in period of tires of make Goodyear RHD
Рис. 2. Износ в период приработки шин марки Goodyear RHD

The stage of critical wear is characterized by the raised average wear intensity and instability of the value. The dispersion of the remaining-tread depths (fig. 3) increases with the tire life that testifies to the variability of the wear intensity which reaches the variation limits at the tire life 120,000 km – 0.08 ... 0.2 mm/1,000 km for the tires of the steering wheels of the dump trucks and 0.04 … 0.25 mm/1,000 km for the driven wheels.

The wear process in the period of the tire critical wear is over-specified, more sensitive to the environmental effect and internal factors and it approximates to the boundary zone (fig. 4).

In terms of economic expediency of the operation the stage of entry of the tire to the phase of the critical wear is the most adverse. Practice shows that more than 80 percent of cases of damages of the tire tread and the carcass of tires which are not subject to repair are exactly connected with the exhaustion of the tire life.

As at the motor transportation enterprise is economically interested in the constant operation of the trucks, it is necessary to take tires which have the average remaining-tread depths of about 2 mm. out the operation beforehand.

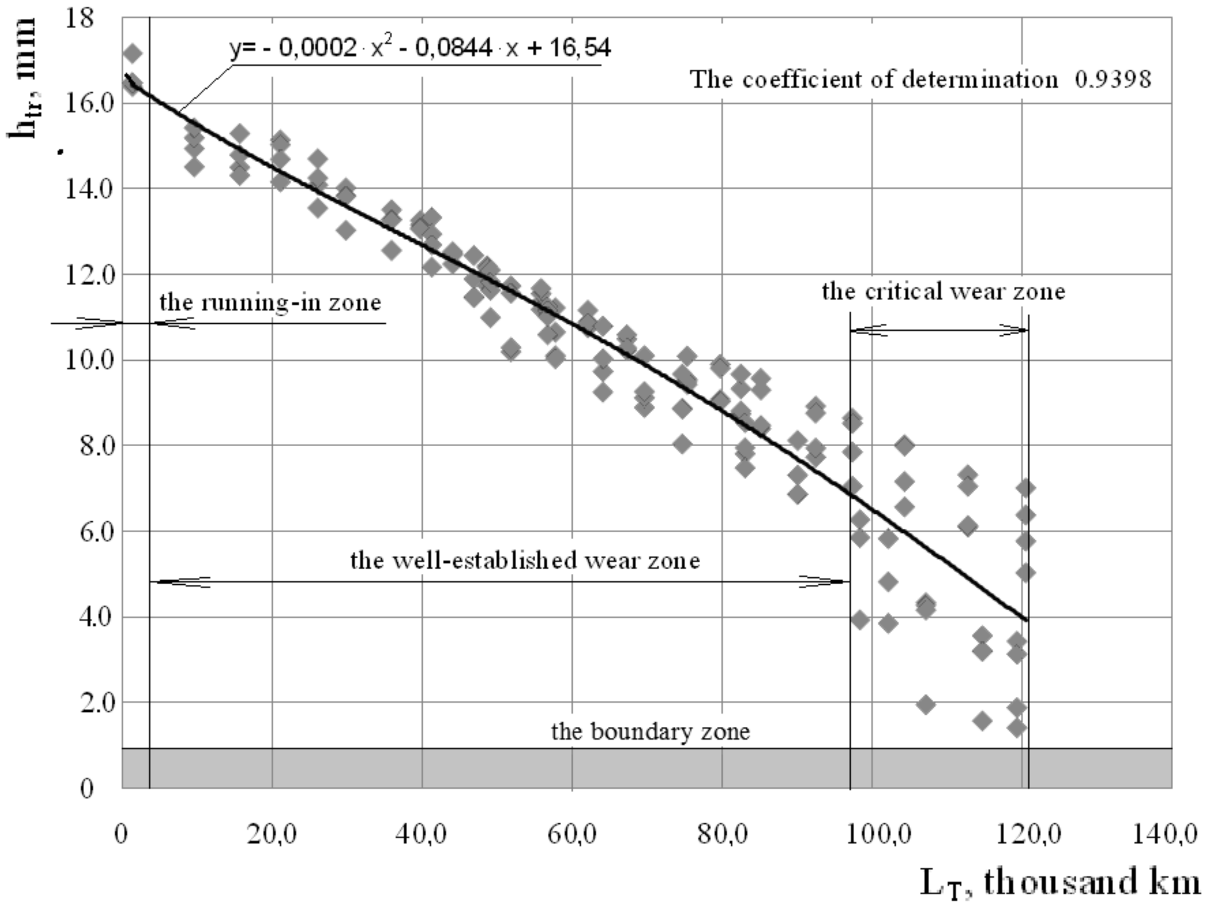

Fig. 3. Tire wear of the make Michelin XZY-2
Рис. 3. Износ шин марки Michelin XZY-2

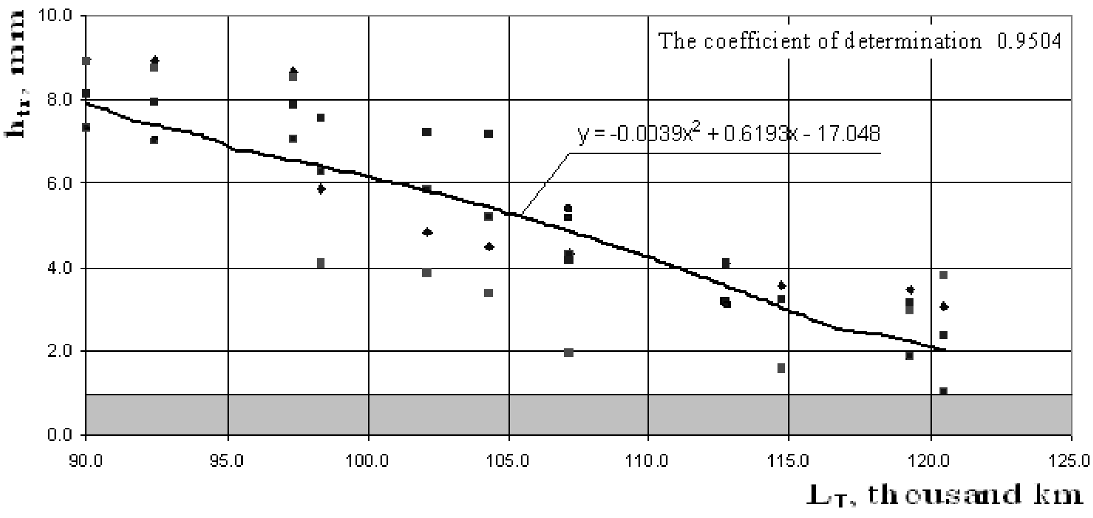

Fig. 4. The tire wear of the make Michelin XZY-2 in the approximation to dismantling from the operation
Рис. 4. Износ шин марки Michelin XZY-2 при приближении к снятию из эксплуатации

It is established that the main factors which predetermine the critical deterioration are as follows:

1. Accumulation of fatigue stress and destructions in the array of the tread rubbers.
2. Increase of non-uniformity of the wear on the length of the tread which results in change of the rolling radius. In view of the constancy of the speed of the truck and inconsistancy of the rolling radius of the wheel, the strengthened tire scrubbing in the contact zone appears and the amplitude of tangents of the longitudinal stress increases. Depending on the correlation of the wheel rolling with the changeable radius the influence of the abrasive or fatigue wear is increased. In case of the double spikes the non-uniformity of the tire wear can lead to the fact that the coupled tire in some central section will behave as the truncated cone fixed by a lateral surface on the plane. The points of the basis of the truncated cone at rolling of its lateral surface on the plane overcome different distances. If the similar phenomenon happens at the contact markings of the coupled tires, it can lead to the circulation of the shear stress caused by the moment of friction with a shoulder which equals to half of the distance between the planes of symmetry of the tires.
3. Increase of the tire rate in the tangent direction. Increase of the tangent of the tire rate causes decrease in ability of the tire of elastic deformation, hence, its earlier transition to the tire scrubbing. Thus, with other things being equal the worn tire will pass to the condition of full lateral tire scrubbing before that one which has a heavy stock of the tire life.
4. Increase of the tire rate in the normal direction. With increase of the tire rate in the normal direction its counteraction to getting influences, such as blowouts, cuts, shears and others that are capable to intensify detrition is decreased.
5. Reduction of the tire diameter. The geometrical precondition of the greater cyclic load of the tire has reduction of the length of its reamer. In the long term, more operating cycles for the unit of the tire life take place, so the wear rate of the tread has grown.

The experimental research allowed establishing of distribution of kinds of wear of the tires (fig. 5) that allows finding out the nonconformity of the ideal technical state of the major units of the truck during the operation.

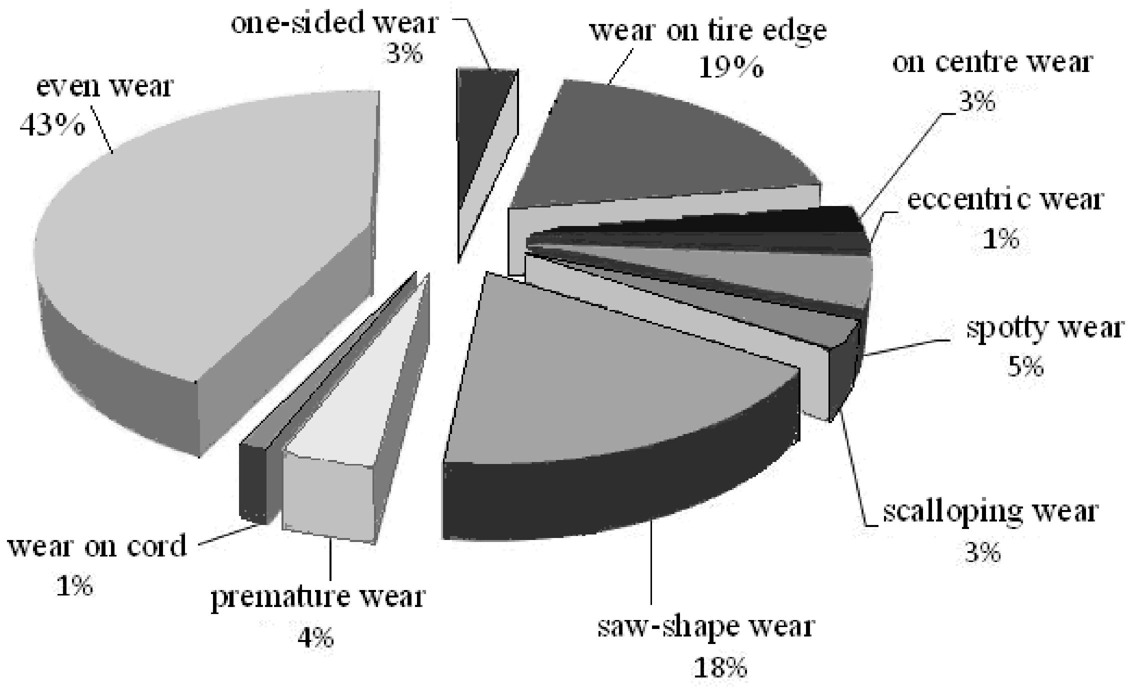

Fig. 5. Distribution of kinds of the tire wear of trucks
Рис. 5. Распределение видов износа шин грузовых автомобилей

4. PROGNOSTICATION OF THE ACTUAL TIRE LIFE

One of the main priorities at the motor transport enterprise is reduction of operating costs and increase of technical preparedness of vehicles. The methods for definition of the tire life of trucks according to the individual statistical data concerning the actual tire life and for prognostication of the actual operation of the life of tires on the basis of the constant control of the remaining-tread depths is devised to the effect.

The most accurate method of prognostication of the tire life is calculation on the actual wear rate which is defined at systematic measurement of the remaining-tread depths. The method is expedient to use for the truck transport enterprises with well developed technical service, large quantity of trucks, sufficiently stable conditions of their utilization, routes and the big daily run of the trucks. The method of implementation of the measurements of the remaining-tread depth is shown in [13]. The comparison of different rated methods [14, 15, 16, 17] proves that it is the compulsory checking of the remaining-tread depths that will allow the most accurate prognosticating of the operation life. It also is proof in the process of the experimental research.

Measurement of the remaining-tread depths is proposed to carry out under the technical influences. Thereby the information array which can be used in several directions is stored. One of these directions is the calculation of the separate tire life, pair of the tyres, driving and controllable tires, tire set in tote and the accurate planning of the time of replacement of the kit of tires in total or the most worn tire substitution made by the tires which are in the replacement stock.

The minimum necessary number of measurements for each tire is nine. The average remaining-tread depths are calculated for each tire, pair of tires at the use of the doubled for the operated and driving tires:

$$\bar{h}_i = \frac{\sum h_i}{9};\quad \bar{h}_{iop} = \frac{\sum \bar{h}_i}{m};\quad \bar{h}_{idr} = \frac{\sum \bar{h}_i}{n}, \tag{2}$$

where: h_i – the value of the i-measurement of the remaining-tread depths, mm; $\bar{h}_i$, $\bar{h}_{iop}$, $\bar{h}_{idr}$ – the average remaining-tread depths of each tire, the operated tires of the trucks, the driving tires of the trucks, mm; *m, n* – the quantity of the operated and driving tires of the trucks, unit.

The forecast of the tire life of each kind is estimated as follows:

$$L_{i(o,d)} = 10^3 \cdot \left[(0.85...0.90) \cdot H_{in} - H_{lim}\right] \Big/ \left[\frac{\bar{h}_1 - \bar{h}_i}{L_{act,i} - L_1}\right], \tag{3}$$

where: H_{in} – the initial height of a new track, mm; 0.85...0.90 – the coefficient, which considers the heightened wear rate in the process of wearing-in; H_{lim} – the limiting value of the remaining-tread depths (it is defined by road regulations), mm; $\bar{h}_1$, L_1 – the height of the tread and tire life at the first measurement which is carried out in 8,000…10,000 km after the process of wearing-in ends, mm, thousand km respectively; $L_{act,i}$ – the actual tire life at the moment of the measurement, thousand km.

Considering that process wearing-in as a rule is finished by the moment of the first measurement of the remaining-tread depths of the tire and also the fact that new tires have fluctuations of depth of the thread (5 … 10 percent), it is possible to exclude the first stage of the wear (the wearing-in) from the calculation and carry on the calculation of the wear rate only for the linear part of the dependence of the wear, specifying the average wear rate after each measurement.

Then the wear rate of each tire can be estimated by the formula, mm/1,000 km:

$$I_{i(o,d)} = \frac{\bar{h}_1 - \bar{h}_i}{L_{act,i} - L_1}. \tag{4}$$

Prognostication of each tire life:

$$L_{i(o,d)} = \frac{\bar{h}_1 - H_{lim}}{I_{i(o,d)}} + L_1. \tag{5}$$

Thus the life of the truck tire set (separately operated and driving) is defined by the tire life which is most intensively worn out. If the wear rate of one of the tires essentially exceeds the average one of the truck (more than 15 - 20 percent) it is necessary to consider the organizational question on replacement of this tire, pair of tires by the tires from the replacement stock.

The measurement data is recorded on the information cards of the tire recording, and the prognosis of a tire life of the truck is specified after each measurement as the wear rate is changed in the truck operational process depending on the operation and road climatic factors [18, 19]. The time of carrying out works concerning the tire set replacement is defined on the basis of the quantity of the possible working days which is based on the remaining life after current measurement with taking into account the daily production schedules which are planned as follows:

$$n_{work} = \frac{L_{i(o,d)} - L_{act,i}}{L_{daily}}, \tag{6}$$

where: L_{daily} – the daily run of the tire, thousand km.

On the basis of this prognosis it is necessary to make the decision on acquisition of the new tire set. Besides, after the replacement of the tire set the decision on its subsequent use is made. The tires from the complete set which have the greatest remaining-tread depths can be used as the replaceable complete sets at the repair of the basic tires, replacement of the tires which are most intensively worn out, during the waiting period of getting the new tire set; tires with the intact carcass can be sent to tread restoring which is an economically expedient decision; tires with a bad condition of the carcass and having had retreading are sent to utilization.

5. CONCLUSIONS

The topical problem of reduction of operational costs and increase of technical readiness of the trucks is solved by the calculation of the actual standards of the tire life of the trucks and the term of their operation. Thereto the methods, which on base of the individual approach and with taking into account the production of the tires by different producers with the technologies, models and materials:

- increase the standard life. The analysis of statistics indices allows correcting the standard life in rather wide limits. It occurs with taking into account the actual operating conditions of the tires at the particular enterprise, and allows prompt correcting of the appointed standards;
- give the possibility of the individual prognostication of the operation life of each particular tire and the tire set that will allow making the optimal decisions as to the tire replacement.

Measuring of the remaining-tread depths and the analysis of the running conditions of trucks can give the information on the share of each factor which influences the tire wear; find out principal reasons of the raised wear rate and failure of the tires and units of the trucks. The information about the character and the wear rate of the tire allows developing recommendations for the reduction of the tire wear of the trucks in actual service and it improves the control of the technical state of the vehicle fleet of the enterprise.

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