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Research of frogs point wear resistance in various conditions for transportation systems: main-line railway and subway

The experience of operating switches shows that load-bearing elements fail for two main reasons: defects and wear. The percentage failure of elements due to one reason or another depends on the operating conditions in which they operate. In this case, the most worn elements of switches are pointers and point frogs and their service life is determined by the amount of tonnage passed through them before reaching the standard values of wear or the appearance defects. The article is devoted to the study of wear resistance of switches operated in various transport systems, namely, mainline transport and subways. The article considers the issues of predicting the standard service life cross elements of typical angles using operational studies for subway conditions and a new theoretical methodology based on the analysis of switches withdrawn from operation after they reach the standard wear values for mainline transport. For analytical calculations, the method of modeling the interaction process and graph-analytical methods were used. As a result of the study, the analytical equations predictive curves for the formation vertical wear as a function of the passed tonnage for the switches point frogs operated on lines of mainline railway transport and the Kyiv subway were established.

Keywords: switch, intensity of traffic, passed tonnage, wear, defects, service life.

Introduction. Switches are complex and special track structures that operate under more difficult and challenging operating conditions than conventional railroad track. At the same time, switches entail technical, economic and operational costs, both in terms of capital expenditures and current maintenance. Therefore, there is a need to properly utilize the service life of switches and rationally predict their service life to plan their replacement.

Analysis of recent research and problem statement. A number of scientific schools have been studying the impact of operational factors and the differences in switch designs that affect the formation of wear and defects in metal elements, and, accordingly, the prediction of their "life cycle". Well-known scientific schools in Soviet Union include the St. Petersburg University of Railways under the leadership of Professors S. Amelin and V. Yakovlev and the VNIIZT (Moscow) scientific school under the leadership of B. E. Gluzberg and M. Putri.

In Ukraine, we can distinguish the scientific school DIIT, whose representatives include such well-known scientists as: M. Frishman, Y. Voloshko, O. Orlovsky and others. Since the late 1990s, the Kyiv Institute of Railway Transport has had a scientific school headed by Professor E. Danilenko, many of whose developments were directly related to the study of the operational characteristics of switches [1].

Different scientific schools have their own approaches to assessing the performance of structures and the impact of operating conditions on the service life of switches.

In particular, scientific developments under the leadership of Professor E. Danilenko take into account the operating conditions for a specific type and angle of switches through a generalized characterization of the track power load [1, 2].

As for foreign studies, they are mainly aimed at studying the life cycle of switches structures to reduce the cost of their design and maintenance; using artificial intelligence to develop an effective

system for early detection of wear of structural elements and prevent the development of switches defects at early stages [3-6].

The purpose and tasks of the study. The aim of the study is to predict the operation of switches under different operating conditions for different transport systems (e.g., mainline railways and subways), as well as to determine the standard service life of switch elements using experimental and theoretical methods.

To achieve this goal, the following was done. For mainline transport, the data set on switches of different types and angles withdrawn from service depending on the operating conditions was analyzed; a methodology was developed to determine the dependence of vertical wear of point frogs based on the data on their withdrawal according to the parameter of acquiring the maximum allowable wear limits and analytical dependencies of predicted wear for areas with different load stresses were established. For subway conditions was analyzed experimental studies of the operation of cross elements (wing rail, crossing wing rail) of typical switches.

Materials and methods of the study. The study of the elements of switches removed from the tracks on mainline railways (stock rail, point tongue, point frog) or switches in general was based on the data of the railways of "Ukrainian Railways" (UZ). We considered the switches (or their elements) of R65 and R50 types of 1/6, 1/9, 1/11, 1/18 angles removed from the tracks, which were operated on main, receiving and sending and other categories of tracks. In just three years (2016-2018), 12879 switches were withdrawn from service, including 9727 due to reaching the maximum wear limit and 3152 due to defects. The distribution of switches elements withdrawn from service (stock rail, point tongue, point frog) by wear and defectiveness is shown in Table 1 and Fig. 1.

Table 1. Quantitative distribution of switches withdrawn from service

Extraction parameter	Deleted item	Quantity of seized items, pcs.	Total number of items removed due to wear and defects	Total seized items
Wear	Stock rail	1412	9727	12879
	Point tongue	5677		
	Point frog	2638		
Defects	Stock rail	390	3152	
	Point tongue	619		
	Point frog	2143		

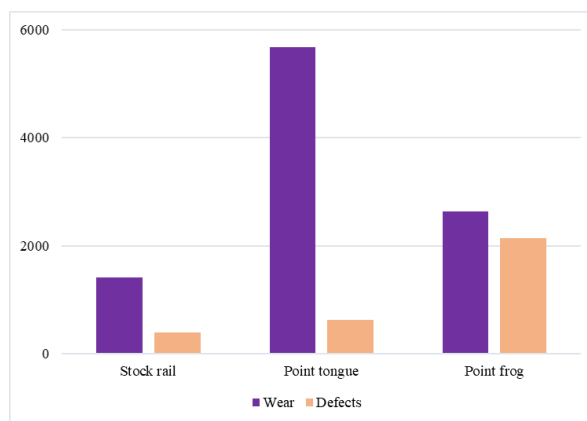


Fig. 1. Distribution of switch elements yield by wear and defects

From the analysis of the yield of switch elements by wear and defects, it can be concluded that the largest yield by wear for switch elements is made up of points - 58%, while crossbars accounted for 27% and frame rails 15% of the total. As for the withdrawn switch elements due to defects, most of them were withdrawn - 68%, while the number of points was 20% and the number of frame rails was 12%. In general, 76% of all switch elements were removed due to wear, and 24% due to defects.

To establish the main regularities of wear formation of switch elements for the Kyiv subway tracks, experimental studies were conducted to determine the vertical wear of switch elements under operating conditions (factors such as speed, load stress, and tonnage passed were taken into account). The study involved switches operated in underground and above-ground sections of the main subway tracks.

Out of the total number of switches operated on the main tracks, 37 switches (73% of the total number) were used for wear resistance studies.

Of these, 22 switches of the project 2497 type P50 of angle 1/9 (73%): Sviatoshyno-Brovarska line - 14 switches (88%); Kurenivsko-Chervonoarmiyska line - 8 switches (50%); Syretsko-Pecherska line - 15 switches of Project 2433 type P65 angle 1/9 (83%).

The selection of switches was performed in such a way that the studied structures differed in terms of the characteristics of the tonnage passed during operation, as well as had different operating conditions (the predominant direction of train movement, different speeds, etc.) The initial data for determining the operating conditions were the operational characteristics of the sections provided by the Service of Track, Tunnel Facilities and Buildings of the Kyiv Metro.

The maximum established speed V , km/h, on the transfers in the forward direction is up to $V_{max} = 80$ km/h, in the lateral direction up to $V_{max} = 40$ km/h.

At the time of the study, the load capacity, million tons per year, of the subway sections was as follows: on the Sviatoshynsko-Brovarska line - 25.23 million tons per year; on the Kurenivsko-Chervonoarmiyska line - 21 million tons per year; on the Syretsko-Pecherska line - 17.1 million tons per year.

The passed tonnage T from the moment of installation to the time of field surveys for P50 crossovers ranged from 13.1 to 133.4 million tons, and for P65 crossovers from 24.6 to 106.2 million tons.

There were 13 and 10 switches with the predominant direction of movement of the P50 and P65 types, respectively, and 9 and 5 switches with the predominant direction of movement were studied, respectively [7].

Service life of switches. The service life of pointers and point frogs is determined by the amount of tonnage passed through the switch until the vertical wear value regulated by [8] is reached or until defects or damage appear regulated by [9] that do not allow further operation of these structures in the track.

There are warranty and standard service lives of switches and crossovers.

The standard service life of pointers and point frogs is determined by the amount of tonnage passed through them - the standard operating time T_n until the value of the regulated vertical wear h_n of the structure the pointer elements (stock rail and point tongue) and the structure of the point frog elements (wing rail and crossing wing rail) for different operating conditions (axial loads, train speeds, load stress, etc.), and they also differ for different types and angles of switches.

The warranty service life of switches and crossovers is determined by the quality of manufacturing of structures at factories (under conditions of technically correct operation) and is set by agreement between the customer and the manufacturer. The warranty periods are measured by the guaranteed minimum tonnage passed through the pointers and point frogs or the guaranteed minimum service life (in years) of these elements in a trouble-free mode and mean that during the warranty period of a pointer or point frog (when operated in the track in accordance with the requirements of [10]) all structural elements must operate without breaks and other defects that disrupt their normal operation, while the dimensions of their vertical wear before the guaranteed minimum tonnage is passed must not exceed the maximum tolerances established by the same instruction.

The standard service life of pointers and point frogs is established by the criterion of reaching the value of their regulated vertical wear.

The warranty service life pointers and point frogs is established by the criterion of accumulation of defects on their structural elements: frame rails and tips (for switches) and crossing wing rails and wing rails (for point frogs).

Defects or damages are considered to be any inconsistencies of structural elements with the available regulatory and technical documentation for them. In particular, elements of switches with wear exceeding the permissible wear specified by the standards are considered defective [8, 10].

The processes and regularities of the formation of vertical wear of the rolling surface of switches' structural elements are well studied and repeatedly described in scientific papers [1, 2, 11, 13, 15]. It has been established that for rigid point frogs made of high manganese steel, the loss of element height during operation (total vertical wear) occurs as a result of several simultaneous processes: due to metal crushing as a result of high contact pressures, due to metal abrasion as a result of impact interaction between the wheels and the rolling surface, and due to structural settling during the period of track stabilization. Fig. 2 shows the graphical dependence of wear (h) on the value of the passed tonnage (T), which sufficiently reliably characterizes the physical nature of the wear phenomenon.

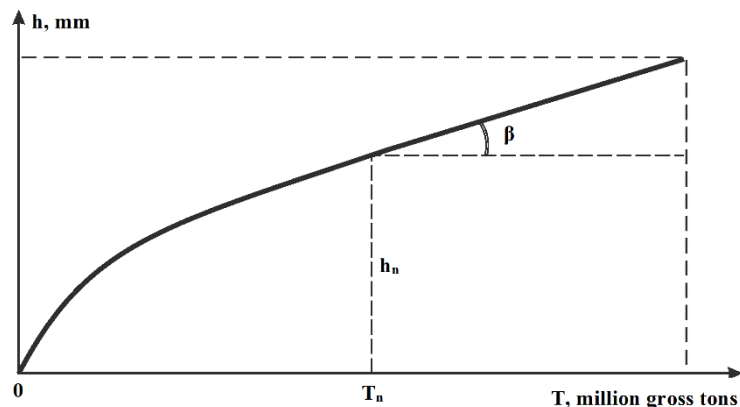


Fig. 2. Dependence of wear on passed tonnage

The formation of vertical wear (Fig. 2) is most closely described by the analytical dependence:

$$h = a \cdot \sqrt{T} + \epsilon \cdot T. \quad (1)$$

In expression (1), denoted:

T - is the tonnage passed through the switch structure element;

a i ϵ – are numerical coefficients that have specific values for each structure, location of the cross section on the cross elements, and operational factors.

Predicting the service life of switches depending on operational factors. In accordance with the methodology [1, 2], the formula for the dependence of wear on the passed tonnage (1) is adopted as the basic one, which allows predicting the standard service life of crossovers T_n depending on the standard wear value h_n and the type of curve from Fig. 2. The specific type of curve $h=f(T)$ (1) is determined by the coefficients "a" and "ε" of equation (1), which are responsible for the crushing and abrasion of metal in the total wear accumulation.

The methodology is based, firstly, on the general laws of the wear kinetics (h) of point frog depending on the passed tonnage (T) of equation (1); secondly, on determining the impact on wear of other operational factors, such as wheel loads P_i (and their spectrum), wheel diameters of rolling stock d_i , train speeds V_i (and their spectrum) and intensity of train traffic.

Using the basic formula (1) and solving it with respect to the value of the passed tonnage T , when substituting a specific value of the wear value h_n , Prof. E. Danilenko obtained a formula that allows predicting the standard service life of point frogs T_n depending on the standard wear value h_n .

$$T_n = \left(\frac{-a + \sqrt{a^2 + 4 \cdot \epsilon \cdot h_n}}{2 \cdot \epsilon} \right)^2, \quad (2)$$

where h_n – is the standard value of vertical wear for the structures under consideration, taken in accordance with [8].

Predicting the wear resistance of point frogs in subways. During the operational observations, when measuring the vertical wear of the rolling surface on the point frogs, we used standard measuring instruments used at the railroad for the current maintenance and inspection of the state of switches, namely "Puteyets" caliper (0.1 mm division price) - for measuring the vertical wear of the rolling surface of the whiskers and crossing wing rails; metal tape measure and metal ruler (1 mm division price) - for breaking down the sections in which wear measurements were performed. Measurements of the vertical wear of the whiskers and crossing wing rails were carried out in the cross-sections defined in [8].

Fig. 3 shows the field marking of cross-sections on the point frogs, which was carried out during the research in the subway tracks, in accordance with the scheme of Fig. 4 of measurements of vertical wear of switch's point frogs of types R50 and R65 of angle 1/9.

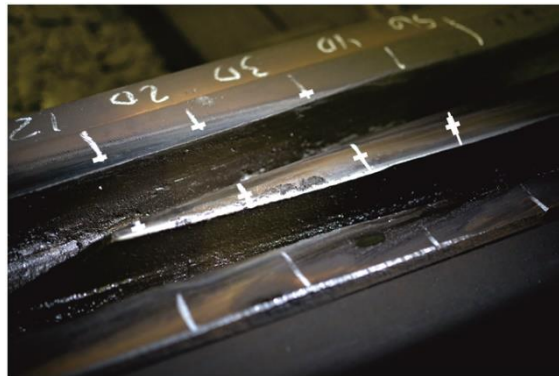


Fig. 3. Marking of cross-sections on point frogs in subway tracks in accordance with the measurement scheme on point frog of types R50 and R65 angle 1/9

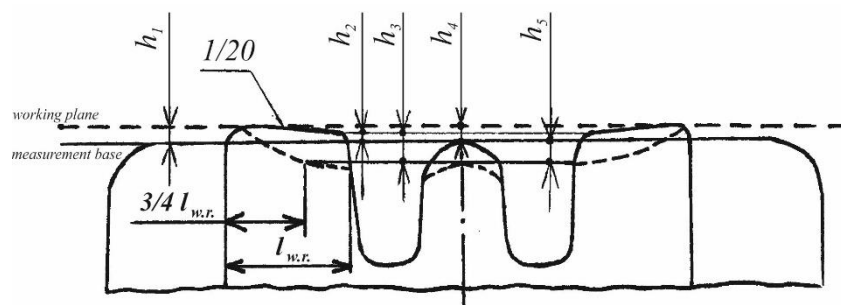


Fig. 4. Scheme for measuring the vertical wear of cross elements

In Fig. 4, we denote:

- h_1 – the design elevation of the wing rail above the design surface along the insertion line, mm;
- h_2 – design elevation at the point of wear measurement on the wing rail relative to the design surface, mm;
- h_3 – the amount of wear on the wing rail, mm;
- h_4 – design lowering of the crossing wing rail relative to the design elevation of the wing rail, mm;
- h_5 – design elevation of the wing rail, mm;
- $l_{w.r.}$ – width of the wing rail in the measured section, mm;
- 1/20 – slope of the wing rail.

According to this methodology, vertical wear was measured on all selected point frogs of switches laid on the tracks of the Kyiv subway for three branches.

The results of the actual values of wear of the wing rails and crossing wing rails at different values of the passed tonnage were processed by mathematical statistics in order to establish an analytical

dependence $h=f(T)$ according to expression (1) and determine the specific coefficients of this dependence. Based on the measurement results, graphical dependence curves were constructed $h=f(T)$ for each group of similar point frogs operating under the same operating conditions.

The approximation of wear curves allows using each specific curve on the projected service life of the cross elements in terms of wear, close to the acquisition of the permissible wear value (h_{permis}), and this allows, in turn, to determine the current value of cross elements wear in any period of operation, characterized by the passed tonnage T_i , as well as to determine or predict the service life of the structure (T_{norm}), both during the initial period of its operation in the track or during the design period of laying the switch, and at any stage of operation before reaching the limit parameters of wear.

Analytical curves of wear of point frogs were determined separately: for point frogs of R50 and R65 types; for whiskers and crossing wing rails; for all standard cross-sections.

The curves in the form (1) were approximated using the Maple software package. As a result, the equations characterizing the formation of vertical wear from $T=0$ to $T=140$ million gross tons for each selected group were obtained.

Taking into account that the wear rates of point frogs in accordance with the Instruction [8] are set by the wear of the crossing wing rails in a cross section of 40 mm, or wear on the wing rails in a cross section against 20 mm of the crossing wing rails, the article presents dependencies $h=f(T)$ for translations of types R50, R65 of 1/9 angles for wing rails and crossing wing rails in these cross sections at the predominant directions of movement (Figs. 5, 6).

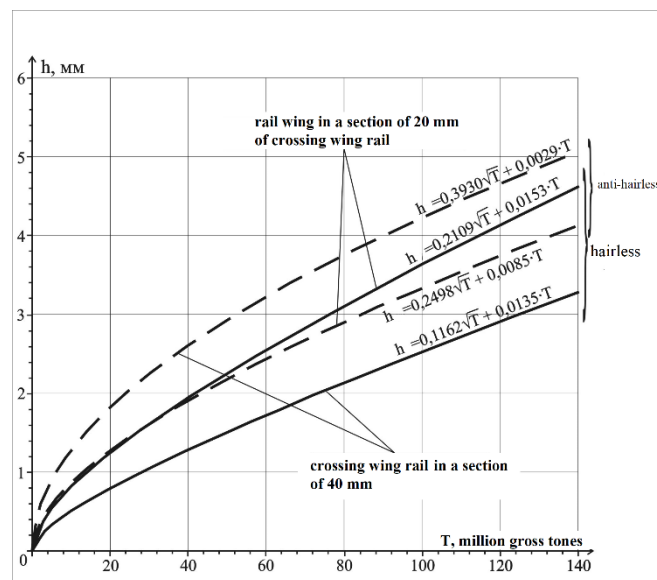


Fig. 5. Analytical dependences of wear crossing wing rails and wing rails of point frogs type R50 angle 1/9 in the main sections

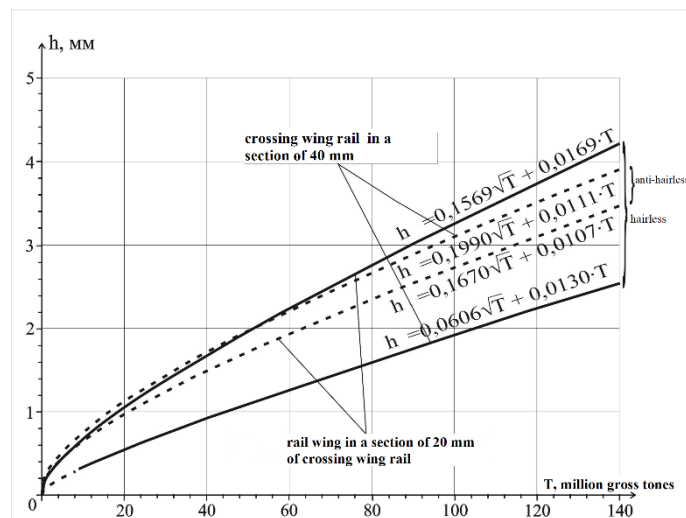


Fig. 6. Analytical dependences of wear crossing wing rails and wing rails of point frogs type R65 angle 1/9 in the main sections

A methodology for determining the service life of switch elements for mainline railroad conditions based on statistical data. In order to obtain objective information about the reliability of a product (in this case, a switch cross elements), statistical data on failures obtained during operation can be used. Having information on failures, it is possible to determine reliability indicators, identify deficiencies in the design of switches and their maintenance, determine the impact of operating conditions on reliability, predict the service life of the structure and, on this basis, take measures to improve track reliability.

Based on the fact that the service life of point frogs is the shortest among the elements of switches, the issue of predicting the service life of point frogs of conventional switches was considered. In this case, for each case of a withdrawn switch or its element, the data on withdrawn from service point frogs of different types and angles in terms of the permissible amount of wear and the presence of defects and for different categories of tracks, which are shown in Table 2, were considered.

Table 2. Quantity of crossing removed due to wear/defects

Elements of point frog	Type of point frog							
	R50				R65			
	1/18	1/11	1/9	1/6	1/18	1/11	1/9	1/6
MAIN TRACK								
Wing rail	-/-	14/8	4/6	-/-	18/10	87/543	63/73	-/-
Crossing wing rail	-/-	32/6	28/24	-/-	18/14	1086/822	327/104	-/-
ARRESTOR TRACK								
Wing rail	-/-	1/4	12/10	-/-	-/-	20/78	60/64	2/1
Crossing wing rail	-/-	20/16	54/36	1/3	-/-	258/137	384/106	15/2
OTHER TRACK								
Wing rail	-/-	-/2	17/3	-/3	-/-	2/4	-/6	-/3
Crossing wing rail	-/-	13/3	10/6	1/3	-/-	13/10	28/4	43/3

The quantitative distribution of extracted switch elements by wear and defects for different categories of tracks is shown in Fig. 7.

The most common types and angles of switches used on the main lines of Ukrainian railways are R65 type 1/11 and 1/9, which account for 94.7% of the total number of switches. Therefore, we consider these types and angles of switches.

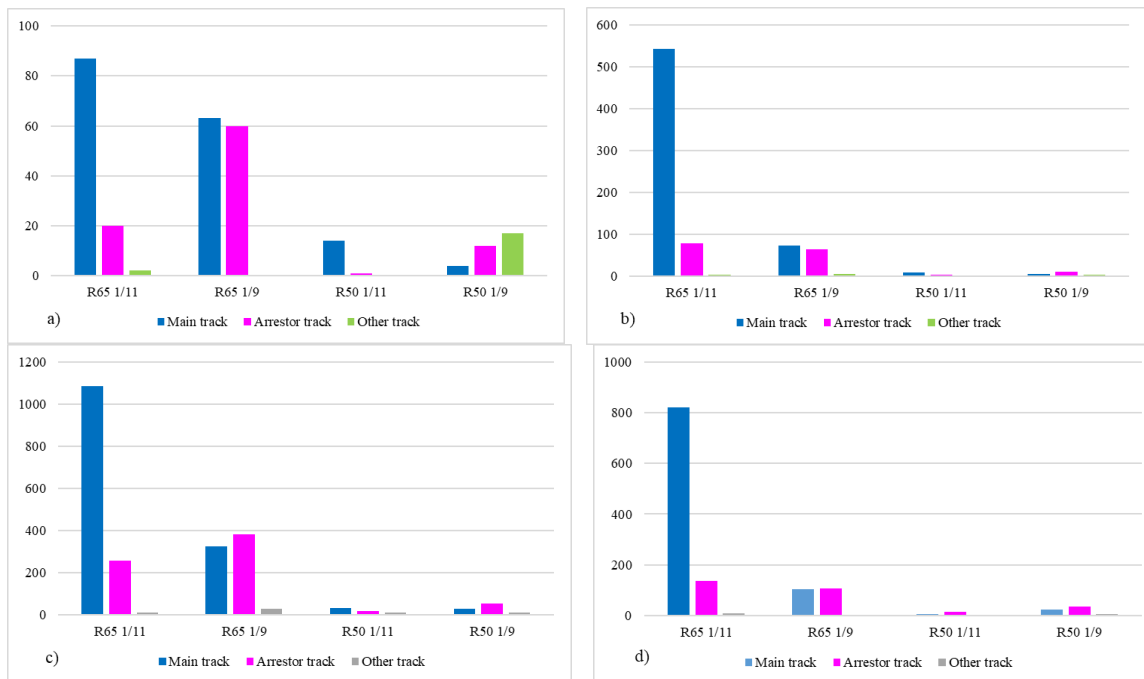


Fig. 7. Extracted point frogs according to wear and defects: a) – wing rail due to wear, b) – wing rail due to defects, c) crossing wing rail due to wear, d) – crossing wing rail due to defects

The distribution of switches within the established categories of tracks according to [13, 14] (by the indicator of load stress) is shown in Table 3 and Fig. 8, with the determined average values of load stress for each of the analyzed groups and the average values of the tonnage passed through the structure before their decommissioning.

Table 3. Distribution of switches within the established categories of tracks by load and tonnage throughput

Type and angles of switches	Gross-load intensity, mln gross ton-kilometers per km per year	Average gross-load intensity, mln gross ton-kilometers per km per year	Passed tonnage, mln gross tones			Quantity of switches, pcs.
			T_{min}	T_{max}	T_{mid}	
R65 1/11	> 80	97,8	51,1	421,4	167,9	11
	50,1-80	57,9	48,0	440,0	193,5	96
	30,1-50	38,7	20,7	482,0	231,1	303
	15,1-30	21,9	30,0	465,3	176,1	426
	5,1-15	10,4	11,5	445,4	159,1	215
	<5	2,7	3,1	209,7	92,0	93
	Total					1144

At the first stage, we analyze the entire data set in each group (in accordance with the established limits of load stress of the sections according to [13, 14]) of the removed cross elements by the vertical wear parameter (h) and determine the average value of the tonnage $T_{mid}^{(n)}$ before removal in each data set for the normalized wear value $h_{mid}^{(n)}$ according to [8], as shown in Fig. 9.

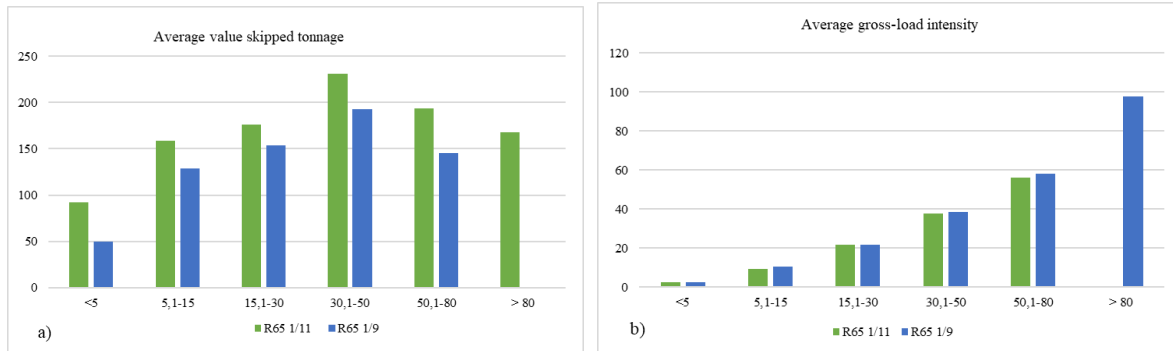


Fig. 8. Average values on switches of type R65 angle 1/11: a) passed tonnage b) gross-load intensity

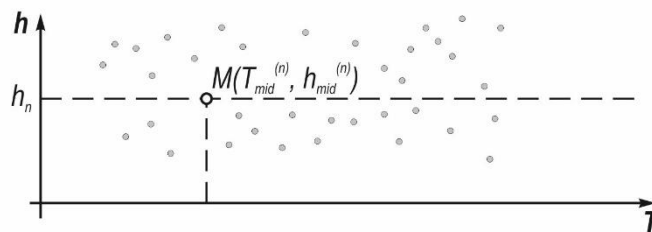


Fig. 9. Determination of average passed tonnage and average wear

The resulting (M) of the average standard tonnage in Fig. 10 is the point through which the analytical curve of the form (1) should pass. This point is different for each specific case, since areas with different load stresses are affected by different operating conditions.

From the analysis of equation (1) and Fig. 2, it follows that the 1st term of the equation ($a\sqrt{T}$) prevails to a greater extent in the area from the initial passed tonnage $T=0$ to the tonnage T_n^{mid} . We determine the forecast curve in the first approximation on the first (curved) section by expression (3), from where we find the coefficient "a₁":

$$h_n = a_1 \cdot \sqrt{T_{mid}^{(n)}} \tag{3}$$

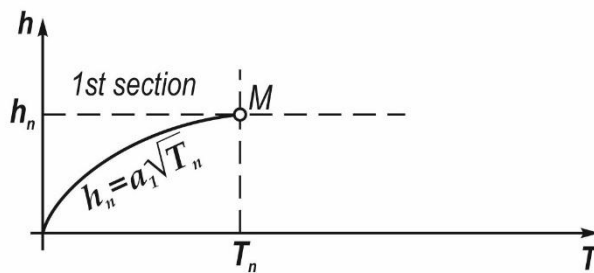


Fig. 10. Initial section of the wear curve

The greater the value of the average tonnage T_n^{mid} , the greater the influence of the second term of equation ($b \cdot T$), so in order to determine the slope of the straight section of the wear curve, we divide the data on the removal of point frogs into three sections: the first section from $T=0$ to T_n^{mid} , the second section from T_n^{mid} to T_2 , the third section from T_2 to $T_2=T_{max}$.

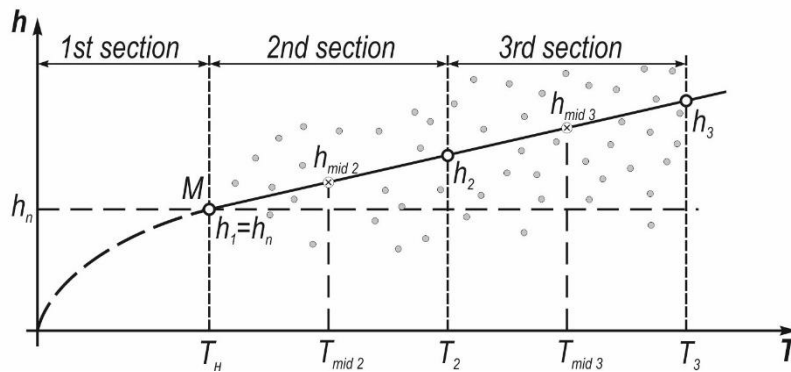


Fig. 11. Determining the slope of the straight section of the wear curve

At the next stage, we consider the area from $T_n = T_n^{mid}$ to $T_3 = T_{max}$. For this section, we determine the average value of the passed tonnage and the corresponding wear value h_2 , at which the point frogs were removed. On Fig. 11, we determine the average wear value h_{mid2} for the second section with coordinates T_{mid2} (Fig. 12); then we similarly determine h_{mid3} the average wear value for the middle of the third section with coordinates T_{mid3} and then connect the points M , h_{mid2} , h_{mid3} and get a straight line.

Next, using the diagram in Fig. 12, we determine the parameters of the line in the range from T_n to T_2 and transform equation (1) to obtain the equation of the straight branch of the wear curve:

$$h = k \cdot T_i + h_0, \quad (4)$$

where h_0 – initial ordinate of the line at tonnage $T=0$;

k – tangent of the slope of the line $k=tg\alpha$, which is determined from the following equation:

$$k = tg\alpha = \epsilon_1 = \frac{h_{mid3} - h_n}{l_2 + l_3 / 2}. \quad (5)$$

The same angle tangent is the coefficient "e" from the original equation (1), i.e. $k=tg\alpha=\epsilon_1$.

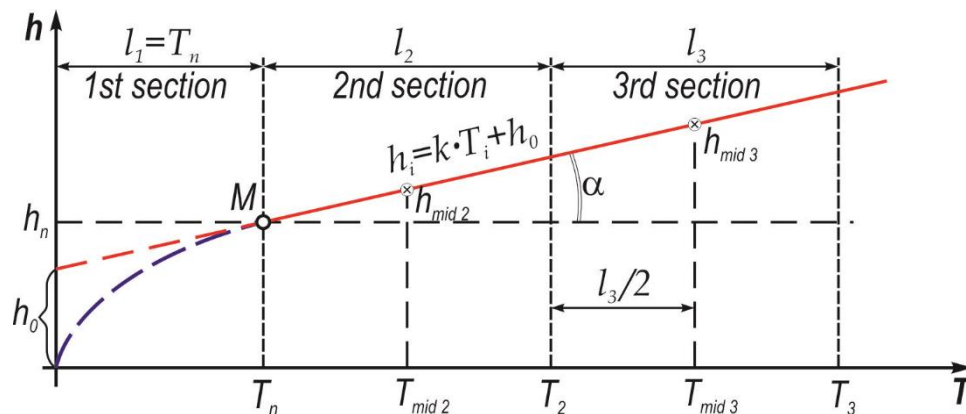


Fig. 12. Scheme for determining the equation of the straight section of the wear curve

Thus, the initial values of the coefficients "a₁" and "e₁" from the original equation (1) are determined, which further need to be specified according to the following algorithm.

In the first approximation, the ordinate h'_0 is found by the equation:

$$h'_0 = h_n - \epsilon_1 \cdot T_n, \quad (6)$$

where ϵ_1 – is the coefficient of the right-hand side of equation (1), which is determined by equation (5).
The value h_0 is ultimately refined after determining the coefficient " ϵ_2 " by the expression:

$$h_0 = h_0'' = h_n - \epsilon_2 \cdot T_n, \quad (7)$$

where ϵ_2 – is the refined value of the coefficient of the right-hand side of equation (1), which is determined further by expression (14).

Let's move on to clarify the coefficients " a_1 " i " ϵ_1 ".

In the first approximation, the first term $h_n = a_1 \cdot \sqrt{T_n}$ of the general equation (3) is taken into account on the curved section of the wear curve, but in reality, the influence of the second term of the equation must also be taken into account in this section $\epsilon_1 \cdot T_n$. Therefore, it is necessary to determine the coefficient " a " in the second approximation, i.e., " a_2 ", which is determined as follows:

$$a_1 \cdot \sqrt{T_n} = a_2 \cdot \sqrt{T_n} + \epsilon_1 \cdot T_n. \quad (8)$$

From here we find the coefficient " a_2 ":

$$a_2 \cdot \sqrt{T_n} = a_1 \cdot \sqrt{T_n} - \epsilon_1 \cdot T_n, \quad (9)$$

$$a_2 = \frac{a_1 \cdot \sqrt{T_n} - \epsilon_1 \cdot T_n}{\sqrt{T_n}}. \quad (10)$$

On the other straight section of the wear curve, it is also necessary to take into account the influence of the first term of Equation (1). Therefore, first, according to the scheme of Fig. 12, we determine the ordinate h_{mid2} :

$$h_{mid2} = h_n + \epsilon_1 \cdot (T_{mid2} - T_n) \quad (11)$$

and taking into account the first term of equation (1), we rewrite equation (11) for the ordinate h_{mid2} as:

$$h_{mid2} = a_2 \cdot \sqrt{T_{mid2}} + \epsilon_2 \cdot T_{mid2}. \quad (12)$$

By equating expressions (11) and (12), we obtain the following:

$$h_n + \epsilon_1 \cdot (T_{mid2} - T_n) = a_2 \cdot \sqrt{T_{mid2}} + \epsilon_2 \cdot T_{mid2}. \quad (13)$$

Finally, by performing mathematical operations, we get a new refined value of the coefficient ϵ_2 , which is calculated by the equation:

$$\epsilon_2 = \frac{h_n + \epsilon_1 \cdot (T_{mid2} - T_n) - a_2 \cdot \sqrt{T_{mid2}}}{T_{mid2}}. \quad (14)$$

This will be the new refined value of the coefficient ϵ_2 , which should be used for the original equation of the wear curve (1). Next, it is necessary to consider the third section in the range from T_2 to $T_3=T_{max}$ and finally refine the coefficients " a_3 " and " ϵ_3 " using the same algorithm as above.

Using this algorithm, we analyzed the entire data set for the removed switches elements and established analytical equations for the predictive curves of vertical wear formation as a function of the passed tonnage for point frogs elements of R65 1/11 switches at different parameters of the load stress of sections (different categories of tracks), which are given in Table 4.

Table 4 – Equations of wear curves for switches point frogs of type R65 of angle 1/11 on reinforced concrete bars under different operating conditions

№ π/ π	Gross-load intensity, mln gross ton-kilometers per km per year	Average gross-load intensity, mln gross ton-kilometers per km per year	Average value of passed tonnage, T mln gross tones for $h_n=6\text{ mm}$	Wear curve equation $h=f(T)$
1	More than 80	96,9	168,0	$h = 0,322498 \cdot \sqrt{T} + 0.010833 \cdot T$
2	More than 50 up to 80 inclusive	57,9	194,0	$h = 0,28568 \cdot \sqrt{T} + 0.010417 \cdot T$
3	More than 30 up to 50 inclusive	38,7	231,0	$h = 0,22107 \cdot \sqrt{T} + 0.011429 \cdot T$
4	More than 15 up to 30 inclusive	21,9	176,0	$h = 0,398113 \cdot \sqrt{T} + 0.004082 \cdot T$
5	More than 5 up to 15 inclusive	7,7	159,0	$h = 0,421787 \cdot \sqrt{T} + 0.004286 \cdot T$
6	Up to 5 inclusive	2,7	92,0	$h = 0,56244 \cdot \sqrt{T} + 0.006579 \cdot T$

Conclusions. To conduct the study, we analyzed previous scientific works on the study of the formation of switches wear in various transport systems, namely in the conditions of main-line railways and subways. For the conditions of main-line railways, a new theoretical methodology was developed to establish the dependence of vertical wear for point frogs on the basis of statistical data on their removal obtained during operational observations of the parameter of reaching the maximum permissible wear limits. As a result, analytical dependencies of the predicted wear were established for sections with different load stresses, i.e., for different categories of tracks.

For subway operating conditions, the difference in the operation of switches is mainly in traffic intensity, load stress, and tonnage passed. It was found that the use of previous studies performed for mainline transport is incorrect for subway conditions. Therefore, the operational studies carried out in real conditions made it possible to obtain specific equations characterizing the formation of vertical wear depending on the passed tonnage in the range from $T=0$ to $T=40$ million gross tons for each selected group.

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Дослідження зносостійкості хрестовин в різних умовах експлуатації для транспортних систем: магістральних залізниць та метрополітену

Досвід експлуатації стрілочних переводів показує, що несучі елементи виходять з ладу з двох основних причин: дефекти та знос. Відсоткове співвідношення виходу елементів по тим чи іншим причинам відбувається залежно від умов експлуатації, в яких вони працюють. При цьому найбільше зношуються з елементів стрілочних переводів стрілки та хрестовини, а строк їх служби визначається за кількістю пропущеного по ним тоннажу до досягнення нормативних значень зносу або появи дефектів. Стаття присвячена дослідженню зносостійкості стрілочних переводів, які експлуатуються в різних транспортних системах, а саме: магістрального транспорту та метрополітенів. Розглядаються питання щодо прогнозування нормативних строків служби елементів хрестовин типових марок за допомогою експлуатаційних досліджень для умов метрополітенів та нової теоретичної методики, яка основана на аналізі вилучених з експлуатації стрілочних переводів по досягненню ними нормативних значень зносу для умов магістрального транспорту. Для аналітичних розрахунків використовувався метод

модельовання процесу взаємодії та графоаналітичні методи. В результаті дослідження були встановлені аналітичні рівняння прогнозних кривих формування вертикального зносу, як функції пропущеного тоннажу для хрестовин стрілочних переводів, які експлуатуються в головних коліях магістрального транспорту залізниць та Київського метрополітену.

Ключові слова: стрілочний перевід, вантажонапруженість, пропущений тоннаж, знос, дефекти, строки служби