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Grapho-analytic method of determining the minimum groove at the pivot root of symmetrical switches

Switches are a barrier place in the track for setting the permissible speeds for trains on the main tracks, as they have special structural devices for branching traffic from the main track to the secondary track. Symmetrical switches have a number of advantages compared to conventional ones: with the same brand with conventional switches, symmetric ones allow significantly higher speeds for the train movement with side tracks; symmetrical switches have a shorter length with the same radii of the transfer curves; it is possible to apply crosspieces with a larger angle than in the conventional switches while preserving the length of the curve and the radius. The specified qualities of single, versatile, symmetrical switches determined their use scope. On the main transport tracks, symmetrical switches are used in sorting parks of the stations, as well as in main tracks when it is necessary to achieve increased speeds of movement on both side tracks. Symmetric switches according to the purpose and design have the significant differences from the most conventional switches, and therefore the study of these designs is important and relevant. Moreover, very few scientific works were devoted to such studies of Ukrainian railways.

Keywords: *symmetric switches, design, minimum groove between the pivot and the frame rail.*

Introduction. The design of symmetric directional switches is significantly different from the design of conventional one-way switches. A complete methodology for designing the parameters of a symmetric switch with curvilinear pivots is needed. At the same time, special attention should be paid to the issues of mutual location of the diverted pivots and frame rails, and determining the dimensions of the groove between them, i.e., so that the wheels of rolling stock do not touch the diverted pivots with the inner side face of the rib. The safety of the movement of wheel pairs on these switches depends on a rational solution to this issue.

Analysis of the latest research and problem statement. Technical issues that need to be solved by Ukrainian railway include the issue of improving the structures of switches and their individual elements [1, 2]. The issues of improving the geometric parameters of switches in order to improve the dynamic interaction of rolling stock and switch elements are given considerable attention abroad [3-5]. At the same time, insufficient attention is paid to the design of symmetric switches. The study and analysis of technical literature [6-12] show that the calculations of symmetrical multi-way switches are given very briefly, in some parts only fragmentarily and, as a rule, with references to the calculation method of ordinary switches that are not completely identical. Furthermore, it applies to the methods of designing structural units of symmetrical switches and the features of their design for various operating conditions, including the methods of determining the actual minimum groove between the frame rail and the diverted pivot.

The purpose and objectives of the research. The purpose of the article is to present a new method of calculations and design of symmetrical switches. The task of the research is to introduce the previously missing calculation of the minimum groove according to one of the two possible cases of the mutual location of the frame rail and the diverted pivot (respectively, the root distance is bigger than the stroke of the shutter – $U_n^0 > Sh_p$ and less – $U_n^0 < Sh_p$).

Research materials and methods. One of the two cases of mutual location of the frame rail and the diverted pivot is when the root distance is smaller than the stroke of the shutter at the switch drive ($U_n^0 < Sh_p$, Fig. 1).

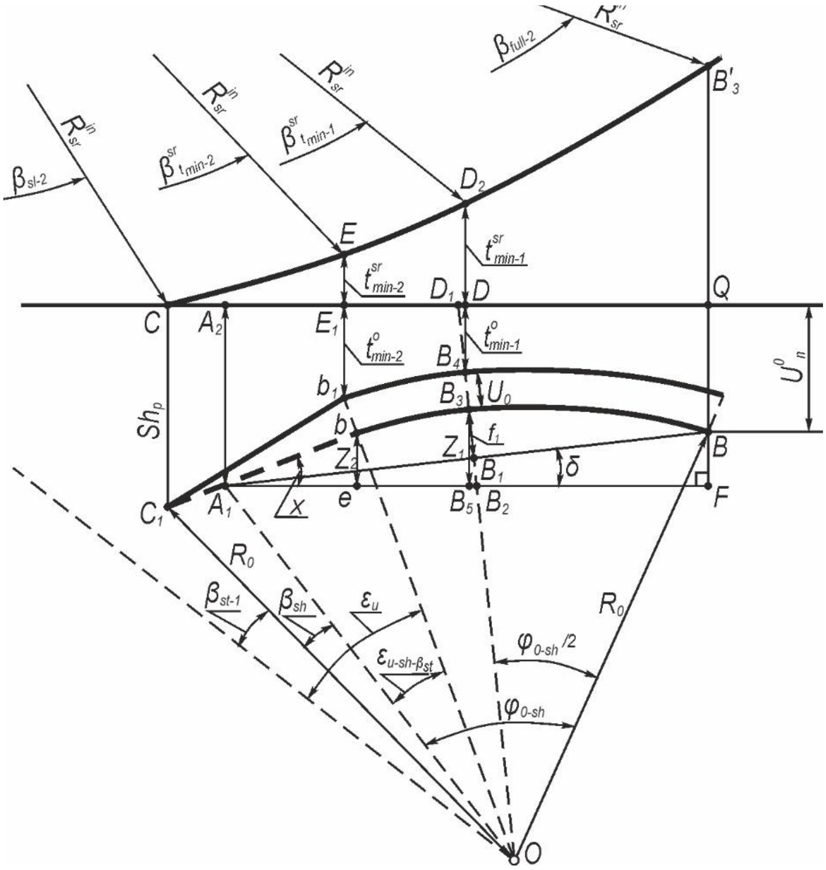

Fig. 1. **Mutual arrangement scheme of the frame rail and the diverted pivot at $U_n^0 < Sh_p$**

For the scheme, the minimum width of the groove between the frame rail and the pivot is determined between 2 competing sections – against the end of the horizontal groove of the pivot (point b$_1$), where the distance from the horizontal CQ to the working face of the frame rail (outside the groove of the pivot) will be the smallest (t_{min-2}^{sr}).

To determine the required values, it will be performed auxiliary construction in the scheme (Fig. 1). A chord A_1B between the root of the pivot (point B) and the attachment point of the switch rod to the pivot (in the point A_1) has been drawn.

The maximum arrow of the segment f_1 from the chord A_1B will be located on the perpendicular radius passing through the middle of the chord – the point B_1. The distance between the points $B_4D_1 = t_1$ has been shown on the continuation of the perpendicular radius against the arrow, but the vertical distance between the points $B_4D = t_{min-1}^0$ will be the minimum vertical distance between the drawn pivot and the calculated horizontal CQ. In this section (against the point B_4), it is need to determine the minimum distance $DD_2 = t^{sr}_{mn-1}$ from the frame rail to the calculated horizontal CQ. And after that, it is need to determine the total minimum groove between the diverted pivot and the frame rail in the first competing section – against the point B_4 – in the place of maximum pivot bending

$$\left(t_{min-1}\right)^{vert} = t^{0}_{min-1} + t^{sr}_{min-1}. \tag{1}$$

The second competing minimum distance between the outer edge of the pivot and the frame rail (Fig. 1) must be determined against the point b_1 (the end of the horizontal groove of the pivot) in the section b_1E_1E

$$\left(t_{min-2}\right)^{vert} = t^{0}_{min-2} + t^{sr}_{min-2}. \tag{2}$$

To calculate the minimum distance $b_1E_1 = t^{0}_{min-2}$ from the diverted pivot to the calculated horizon CQ, it will be performed the following auxiliary constructions in the scheme (Fig. 1):

- draw the radius Obb_1 from the center of the circle to the point b_1 – the end of the sharpener;
- draw also the radii OC_1 and OA_1;
- draw the horizontal A_1F to the intersection be and B_3B_5 with the vertical QBF at the root of the pivot;
- draw a chord A_1B and perpendiculars in the sections under consideration from the points b and B_3 to the horizontal A_1F.

The problem is solved in 4 stages.

1 stage. Definition t^{0}_{min-1} in the section B_4D.

Find the value Sh_p of the distance between the points A_1 i A_2 using the formula [13, 14]

$$Sh_p = Sh + t'_{sh}, \tag{3}$$

where the thickness of the pivot against the arrow thrust t'_{sh} is determined [13, 14] by the formula

$$t'_{ш} = R_0\left(\cos\beta_{st-1} - \cos\left(\beta_{st-1} + \beta_{sh}\right)\right), \tag{4}$$

where the angle $\beta_{sh} = \dfrac{a}{R_0}$, a=360 mm [13, 14].

The value of the ordinate $BQ = U^{0}_{n}$ in the root of the pivot [13, 14] is defined according to the formula

$$U^{0}_{n} = R_0\left(\cos\beta_{st-1} - \cos\beta_{full-1}\right). \tag{5}$$

After that, it is necessary to compare the values of Sh_p and U^{0}_{n}, in order to be sure of the initial condition in the problem solution according to the scheme of Fig. 1 for the case, when $U^{0}_{n} < Sh_p$.

2. Find some auxiliary values for determining t^{0}_{min-1}. Half the length of the chord A_1B marked as $B_1B = A_1B_1$ is determined [13, 14] by the formula

$$B_1B = A_1B_1 = R_0 \cdot \sin\frac{\varphi_{0-sh}}{2}. \tag{6}$$

The whole length of the chord

$$A_1B = B_1B + B_1A_1 = 2R_0 \cdot sin\frac{\varphi_{0-sh}}{2} . \tag{7}$$

The maximum arrow of the segment from the chord A_1B is found [13, 14] according to the formula

$$f_1 = R_0 - B_1O . \tag{8}$$

The length of the perpendicular to the chord is found by

$$B_1O = R_0 \cdot cos\frac{\varphi_{0-sh}}{2} . \tag{9}$$

The value of the segment BF is determined by the formula

$$BF = Sh_p - U_n^0 . \tag{10}$$

The angle BA_1F marked $\angle\delta$ will be determined by

$$\frac{BF}{A_1B} = sin\,\delta . \tag{11}$$

The length of the segment B_1B_2 is determined by

$$B_1B_2 = A_1B_1 \cdot tg\delta . \tag{12}$$

The distance between the points B_2B_3 is found by

$$B_2B_3 = f_1 + B_1B_2 = f_1 + \left(R_0 \cdot sin\frac{\varphi_{0-sh}}{2}\right) \cdot tg\delta . \tag{13}$$

The vertical distance between the points B_3B_5, marked $B_3B_5 = Z_1$ in Fig. 1 is by

$$Z_1 = B_3B_5 = B_2B_3 \cdot cos\,\delta . \tag{14}$$

3. After that, determine the desired $t^0_{min-1} = B_4D$ value in the section B_4D

$$t^0_{min-1} = Sh_p - Z_1 - \frac{U_0}{cos\,\delta} . \tag{15}$$

For further calculations, find the length of the segment B_4D_1

$$B_4D_1 = \frac{t^0_{min-1}}{cos\,\delta} . \tag{16}$$

2 stage. Definition t^{0}_{min-2} in the section b_1E_1.
Find the auxiliary values. The angle OA_1b of the triangle OA_1b (Fig. 1) is defined by

$$\angle OA_1b = \frac{180^{\circ} - \varepsilon_{u-sh-\beta_{st-1}}}{2} = 90^{\circ} - \frac{\varepsilon_{u-sh-\beta_{st-1}}}{2}. \tag{17}$$

The angle $\angle bA_1e$, denoted as the angle x, is found by considering two triangles bA_1e i OA_1F

$$\angle x = \angle OA_1b - FA_1O, \tag{18}$$

where

$$\angle FA_1O = \angle BA_1O - \angle\delta = 90^{\circ} - \frac{\varphi_{0-sh}}{2} - \delta, \tag{19}$$

i.e.

$$\angle x = 90 - \frac{\varepsilon_{u-sh-\beta_{st-1}}}{2} - \left(90 - \frac{\varphi_{0-sh}}{2} - \delta\right) = \frac{\varphi_{0-sh}}{2} + \delta - \frac{\varepsilon_{u-sh-\beta_{st-1}}}{2}. \tag{20}$$

The length of the perpendicular be, lowered from the point b to the horizontal A_1F and marked as $be = Z_2$ in Fig. 1, is determined by

$$Z_2 = A_1b \cdot \sin x. \tag{21}$$

2. After that, determine the desired value t^{0}_{min-2} using the formula

$$t^{0}_{min-2} = Sh_p - Z_2 - U_0 \cdot \cos x. \tag{22}$$

3 stage. Definition t^{sr}_{min-1}, t^{sr}_{min-2} i U_{sr}.

1. Determine all the abscissas along the calculated horizontal, which are necessary for finding the ordinates in the location of the working frame rail face relative to the horizontal CQ.

It is necessary to determine the abscissas: CE_1, CD, CQ.

Determine the value CE_1 by the formula [15]

$$CE_1 = \lambda'_v = \sqrt{R_0^2 - \left(R_0 - B\right)^2} - A = \sqrt{2R_0B - B^2} - A. \tag{23}$$

Length $CD = 360\ mm + A_2D$.

$$A_2D = A_1B_5, \tag{24}$$

where

$$A_1B_5 = A_1B_2 - B_2B_5;$$
$$A_1B_2 = \frac{A_1B_1}{\cos\delta};$$
$$B_2B_5 = Z_1 \cdot tg\delta;$$
$$A_1B_1 = R_0 \cdot \sin\frac{\varphi_{0-sh}}{2}. \tag{25}$$

Thence

$$A_2D = A_1B_5 = \frac{A_1B_1}{\cos\delta} - Z_1 \cdot tg\delta = R_0 \frac{\sin\frac{\varphi_{0-sh}}{2}}{\cos\delta} - Z_1 \cdot tg\delta. \tag{26}$$

The abscissa $CQ = l_0'$ is the projection of the pivot onto the horizontal (Fig. 1) and is determined [15] by the formula

$$l_0' = R_0 \cdot \sin\beta_{full-1} - R_0 \cdot \sin\beta_{st-1}. \tag{27}$$

So, all necessary abscissas are defined.

2. After determining the abscissas, find the necessary ordinates. The procedure for calculating is.

2.1. The ordinate U_{sr} – from the frame rail to the calculated horizontal CQ is determined by the formula

$$U_{sr} = BQ = R_{sr}^{in} \cdot \cos\beta_{st-2} - R_{sr}^{in} \cdot \cos\beta_{full-2}. \tag{28}$$

2.2. The first sought ordinate t_{min-1}^{sr} is determined by considering the equation of projections relative to the central angle $\beta_{t_{min-1}^{sr}}$. The central angle $\beta_{t_{min-1}^{sr}}$ against the desired ordinate t_{min-1}^{sr} at a point D_2 can be determined by

$$R_{sr}^{in} \cdot \sin\beta_{t_{min-1}^{sr}} - R_{sr}^{in} \cdot \sin\beta_{st-2} = CD. \tag{29}$$

From the formula (29), $\sin\beta_{t_{min-1}^{sr}}$ is determined, and then the angle $\beta_{t_{min-1}^{sr}}$. After that, determine the first sought ordinate t_{min-1}^{sr} in the section DD_2

$$t_{min-1}^{sr} = DD_2 = R_{sr}^{in} \cdot \cos\beta_{st-2} - R_{sr}^{in} \cdot \cos\beta_{t_{min-1}^{sr}}. \tag{30}$$

2.3. The second sought ordinate t_{min-2}^{sr} is determined in a similar way to t_{min-1}^{sr}, considering the equation of projections relative to the central angle $\beta_{t_{min-2}^{sr}}$. The central angle $\beta_{t_{min-2}^{sr}}$ against the desired ordinate t_{min-2}^{sr} at the point E is determined by

$$R_{sr}^{in} \cdot \sin\beta_{t_{min-2}^{sr}} - R_{sr}^{in} \cdot \sin\beta_{st-2} = CE_1. \tag{31}$$

Next, $\sin\beta_{t_{min-2}^{sr}}$ is determined firstly, and then the angle $\beta_{t_{min-2}^{sr}}$ itself by the formula (31).

After that, it is possible to determine the second desired ordinate t_{min-2}^{sr} in the section E_1E

$$t^{sr}_{min-2} = EE_1 = R^{in}_{sr} \cdot cos\,\beta_{st-2} - R^{in}_{sr} \cdot cos\,\beta_{t^{sr}_{min-2}} . \tag{32}$$

4 stage. Determination of the required minimum width values of the gutter between the frame rail and the removed pivot in the calculated sections t_{min-1} and t_{min-2} and the absolute minimum gutter $t_{min\,min}$.

Solving the problem of determining the minimum values of the gutter width between the frame rail and the diverted pivot for the calculation scheme of Fig. 1 is performed by methods of analytical geometry. For this, in addition to the main calculation scheme (Fig. 1), it must be analyzed additional calculation schemes in Fig. 2 and Fig. 3, which presents a detailed consideration of the grapho-analytical solution to the problem of finding the minimum dimensions of the gutter in the calculated sections B_4D_2 (against the maximum bend of the pivot) and b_1E (against the end of the pivot groove).

The minimum width of the gutter t_{min-1} (vertically) in the zone of maximum pivot bending (in the section B_4DD_2) is defined as the sum of the smallest distances from the calculated horizontal CQ to the diverted pivot, and to the frame rail in the section B_4DD_2 (Fig. 2)

$$\left(t_{min-1}\right)_{vert} = t^{0}_{min-1} + t^{sr}_{min-1} . \tag{33}$$

The minimum width of the gutter t_{min-2} (vertically) against the end of the horizontal pivot groove (in the section b_1E_1E) is determined by the same method as the sum of the smallest distances from the calculated horizontal CQ to the diverted pivot, and to the frame rail in the section b_1E_1E (Fig. 3)

$$\left(t_{min-2}\right)_{vert} = t^{0}_{min-2} + t^{sr}_{min-2} . \tag{34}$$

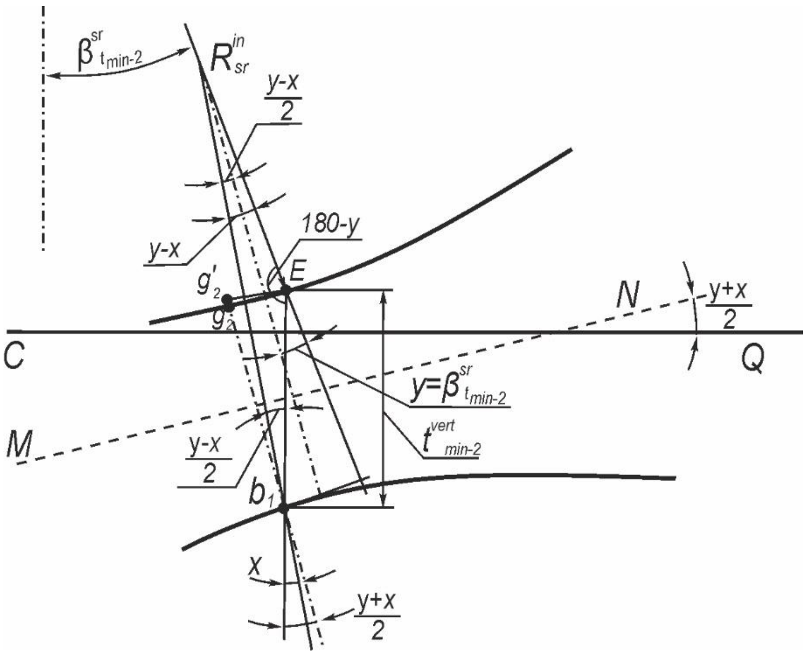

Fig. 2. **Diagram for determining the minimum width of the chute t_{min-1} in the zone of maximum tip bending**

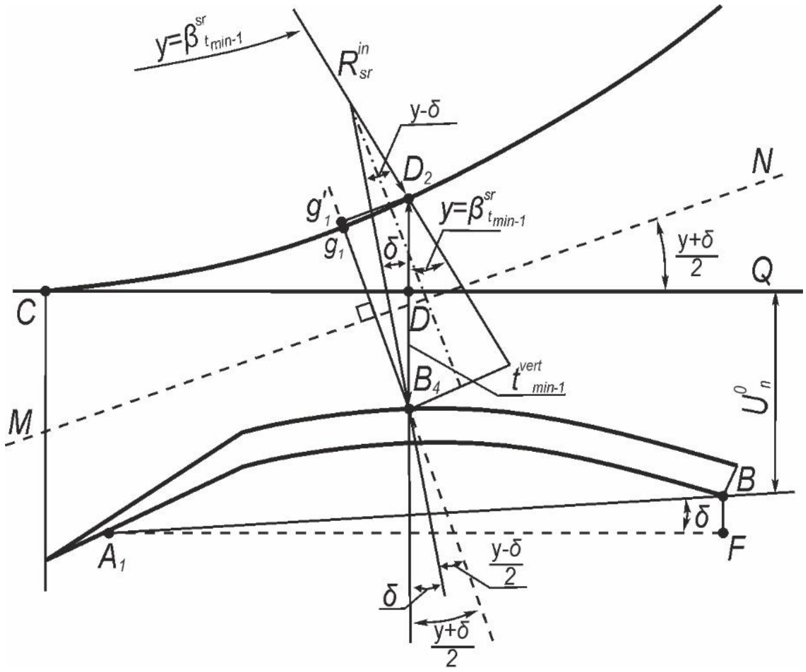

Fig. 3. **Diagram for determining the minimum chute width t_{min-2} against the end of the horizontal gouging**

The absolute minimum gutter t_{minmin} between the frame rail and the removed pivot is determined by comparing the two found values of the minimum gutter $(t_{min-1})_{vert}$ and $(t_{min-2})_{vert}$. Moreover, the ordinate of the absolute minimum gutter is searched for and determined not vertically, but along the shortest distance between the frame rail and the pivot. The shortest distances between these elements are determined along the normal to the conditional middle line of the gutter MN. Calculations show that the generally variable angle of inclination of the middle line of the gutter MN to the calculated horizontal CQ will be equal to the algebraic half-sum of the inclination angles to the horizontal of the working face at the frame rail and the non-working face of the diverted pivot in each calculated section.

Taking into account it, the formula for determining the minimum width of the gutter along the normal in the calculated sections B_4DD_2 and b_1E_1E (Fig. 1) will have the following form:

in the section B_4DD_2 (Fig. 1 and Fig. 2)

$$(t_{min-1})_{norm} = (t_{min-1})_{vert} \cdot cos\left(\frac{\beta_{t_{min-1}}^{sr} + \delta}{2}\right) - (t_{min-1})_{vert} \cdot sin\left(\frac{\beta_{t_{min-1}}^{sr} + \delta}{2}\right) \cdot tg\left(\frac{\beta_{t_{min-1}}^{sr} - \delta}{2}\right), \quad (35)$$

in the section b_1E_1E (Fig. 1 and Fig. 3)

$$(t_{min-2})_{norm} = (t_{min-2})_{vert} \cdot cos\left(\frac{\beta_{t_{min-2}}^{sr} + x}{2}\right) - (t_{min-2})_{vert} \cdot sin\left(\frac{\beta_{t_{min-2}}^{sr} + x}{2}\right) \cdot tg\left(\frac{\beta_{t_{min-2}}^{sr} - x}{2}\right). \quad (36)$$

From the two determined calculated values, it has been choosen the absolutely smallest value, which will determine the absolutely minimum groove between the frame rail and the removed pivot

$$\left.\begin{matrix}\left(t_{min-}\right)_{norm}\\ \left(t_{min-2}\right)_{norm}\end{matrix}\right\} min\left(t_{min\,min}\right)^{des}. \tag{37}$$

At the end, it should be compared the actual minimum design groove $t^{des}_{min\,min}$ with the minimum permissible groove $\left[t_{min}\right]_{accep}$ =71 mm [7], and when the inequality $t^{des}_{min\,min} > \left[t_{min}\right]_{accep}$ is fulfilled, it has been concluded that the safety conditions for the movement of wheel pairs are ensured. But, if the specified inequality is not fulfilled, it is need to choose other geometric parameters, first of all, change the length of the pivot, the radius of curvature or the starting angles of the symmetrical switch.

Conclusions. A refined method of designing a symmetric switch with curvilinear pivots has been proposed, which allows obtaining rational dimensional geometric parameters.

A new approach to the design of symmetric switches with multifactor initial conditions allows reducing such switch parameters as: theoretical and practical length, length of frame rail, length of connecting rails, and length of transfer curve.

Reducing the total length of switches will allow wider use in the compressed conditions of the track stations' development.

Optimum geometric parameters of symmetric switches will make it possible to reduce the cost of the construction in general by reducing its metal capacity while preserving the conditions for the safe movement of trains at the set speeds.

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Графоаналітичний метод визначення мінімального жолобу в корені вістряка симетричного стрілочного переводу

Стрілочні переводи є бар'єрним місцем в колії для призначення допустимих швидкостей руху поїздів по головних коліях, так як вони мають спеціальні конструктивні прилади для відгалуження руху від головної колії на другорядну. Симетричні стрілочні переводи мають ряд переваг порівняно із звичайними: при однаковій марці із звичайними переводами симетричні дозволяють реалізувати суттєво більші швидкості руху поїздів боковими коліями; при однакових радіусах перевідних кривих симетричні переводи мають меншу довжину; при збереженні довжини кривої і радіуса можна застосувати хрестовини з більшим кутом, ніж у звичайному переводі. Указані якості одиночних різносторонніх симетричних стрілочних переводів визначили їх сферу застосування. На коліях магістрального транспорту симетричні стрілочні переводи застосовуються в сортувальних парках станцій, а також в головних коліях коли потрібно досягти підвищених швидкостей руху на обидві бокові колії. Симетричні стрілочні переведи за своїм призначенням і конструкцією мають суттєві відмінності від найбільш розповсюджених звичайних стрілочних переводів, і тому дослідження даних конструкцій є важливими й актуальними. Тим більше, що таким дослідженням на українських залізницях було присвячено зовсім мало наукових праць.

Ключові слова: *симетричні стрілочні переводи, проектування, мінімальний жолоб між вістряком і рамною рейкою.*