Research of geometric parameters of symmetric railroad switches

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Abstract. Turnouts are a barrier in the track for setting the permissible speeds of trains movements on the main tracks, as they have special structural devices for branching traffic from the main track to the side one. Symmetrical switches have a number of advantages over conventional ones: with the same grade as conventional switches, symmetrical switches can provide significantly higher train speeds on the side tracks; with the same radii of transfer curves, symmetrical switches have a shorter length; while maintaining the length of the curve and radius, crosses with a larger angle than in conventional switches can be used. These qualities of single, multilateral symmetrical switches have determined their field of application. On the mainline tracks, symmetrical switches are used in marshalling yards of stations, as well as in main lines when it is necessary to achieve higher speeds on both side lines. Symmetrical switches by their purpose and design have significant differences from the most common conventional switches, and therefore research on these structures is important and relevant. Moreover, very few scientific papers have been devoted to such research, both in our country and abroad. This study reveals the problems of designing the frame rail junction - point, which is the most critical in the operation of a switch and ensuring the safety of trains passing through it.

1. Introduction

The issue of establishing rational parameters of switches has been dealt with by a much smaller number of researchers and scientists, and very few researchers have studied the issues of establishing parameters of symmetrical switches. At the same time, the design of symmetrical switches is significantly different from the design of conventional single-way switches. It is necessary to have a complete methodology for determining the parameters of a symmetrical switches with curved points. When solving this problem, special attention should be paid to the mutual location of the diverted points and frame rails and the size determination of the gutters between them, i.e., so that the wheels of the rolling stock carts do not touch the diverted point with the inner side edge of the rail. The safety of train traffic when wheel sets pass within the switches depends on a rational solution to this issue.

2. Analysis of recent research and problem statement

Technical issues that need to be addressed by track engineers, including the improvement of switches and their individual elements [1-3]. Abroad, considerable attention is paid to the issues of improving the geometric parameters of switches in order to improve the dynamic interaction of rolling stock and switch elements [4-6]. At the same time, insufficient attention is paid to the design of symmetrical switches. The study and analysis of the technical literature [7-13] showed that the calculations of symmetrical switches are given very briefly, in some parts only fragmentary and, as a rule, with references to the methodology for calculating conventional switches, which have important differences. This is even more true for the methods of designing structural units of symmetrical switches and the peculiarities of their design for different operating conditions, including the method of determining the actual minimum gutter between the frame rail and the diverted point. Among the latest works devoted to solving this problem, we can mention works [14-17], which present in detail the methodology for determining the minimum width of the gutter between the frame rail and the withdrawn point in symmetrical switches.

3. Purpose and objectives of the study

The purpose of this publication is to show a modern approach to the design and calculation of symmetrical switches and its implementation by comparing it with typical designs. The objective of the study is to determine the rational design parameters of symmetrical switches, taking into account the mutual location of the frame rail and the diverted point.

4. Materials and methods of the study

Symmetrical switches by their purpose and design have significant differences from conventional switches. In the detailed design of symmetrical switches and

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especially their structural parts and joints within the switch, careful attention should be paid to determining the width of the minimum gutter between the frame rail and the diverted point. This calculation is necessary to determine the actual minimum size of this gutter, which ensures the safety requirements for train traffic due to the safe passage of wheel sets in this area of the switch, i.e. without the wheels of rolling stock carts touching the diverted point with the inner side edge of the rail.

When designing switches, it is necessary to provide the smallest design gutter between the frame rail and the diverted point not less than the permissible gutter of 71 mm [14], i.e. the following condition must be provided:

$$t_{\min}^{calc} \geq t_{\min}^{perm} . \quad (1)$$

To determine the minimum gutter $t_{min\,min}$ between the frame rail and the diverted point [14, 15, 17], two possible cases of the relative position of the frame rail and the diverted point are considered: 1st case - when the root distance is greater U_n^0 than the value of the gate stroke Sh_p of the switch drive ($U_n^0 > Sh_p$, Fig. 1, a); the 2nd case - ($U_n^0 < Sh_p$, Fig. 1, b).

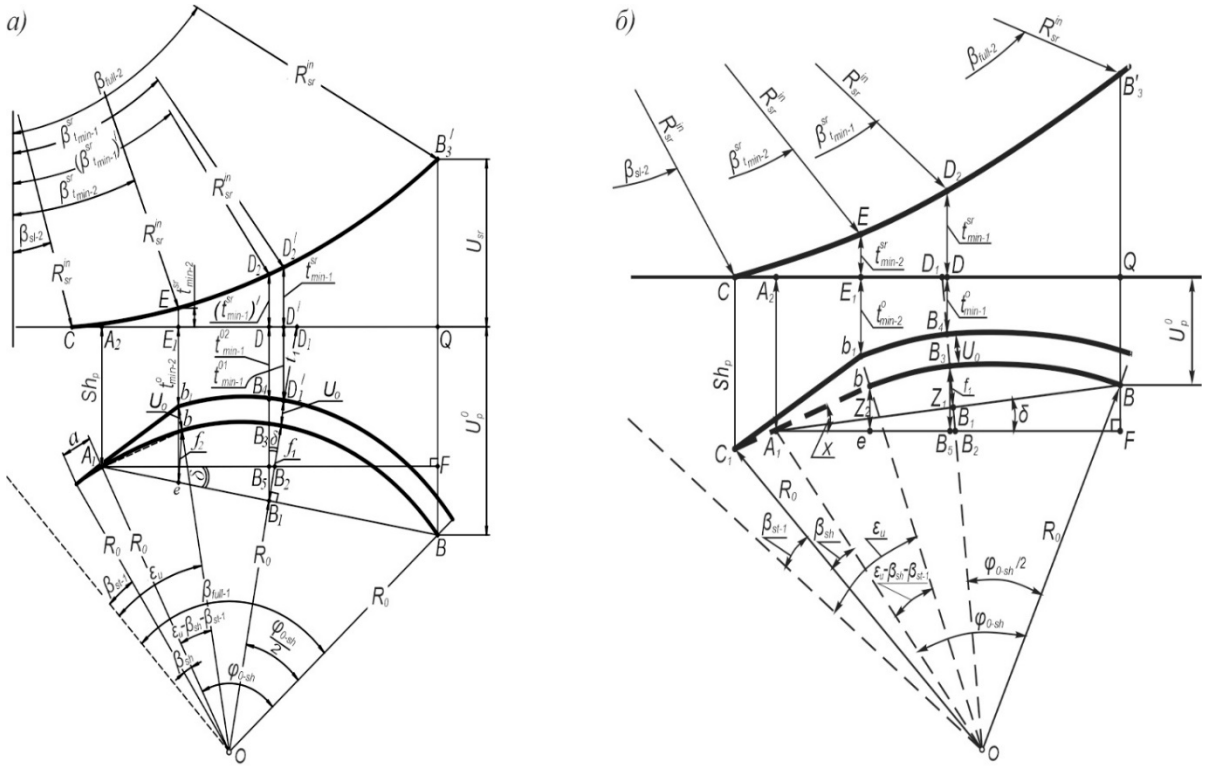

Fig. 1. Diagrams of the relative position of the frame rail and the diverted point

When determining the minimum width of the gutter $t_{\min\,\min}$ between the frame rail and the diverted point, various competing sections ($t_{\min-1}, t_{\min-2}$) must be considered (Fig. 1). According to Fig. 1, the minimum width of the gutter between the frame rail and the point is determined in the following sections: against the boom of the largest bend of the point f_1, where the distance from the diverted point to the calculated horizontal *CQ* will be the smallest ($t_{\min-1}^{01}$ or $t_{\min-1}^{02}$) (Fig. 1, a); against the end of the horizontal gouge of the point (point b_1), where the distance from the horizontal *CQ* to the working face of the frame rail (outside the gouge of the point) will be the smallest ($t_{\min-2}^{sr}$) (Fig. 1, b). In both cases (Fig. 1, a) and (Fig. 1, b), it is convenient to first determine the distances along the vertical ordinates from the calculated horizontal *CQ* to the allocated edge ($t_{\min-1}^{01}$ and $t_{\min-2}^{02}$) and to the working face of the frame rail ($t_{\min-1}^{sr}$ and $t_{\min-2}^{sr}$), and then determine the desired values of the minimum width of the gutter in the sections $(t_{\min-1})^{vert}$ and $(t_{\min-2})^{vert}$.

To determine the sought value, we use a technique based on the methods of analytical geometry, which is presented in detail in [14, 15, 17].

The final expressions for finding the minimum gutters between the diverted point and the curved frame rail [14, 15, 17] are determined by the following formulas:

– For the scheme of Fig. 1, a:

$$\begin{aligned}(t_{\min-1})_{norm} &= (t_{\min-1})_{vert} \cdot \cos\left(\frac{\beta_{t_{\min-1}^{sr}} - \delta}{2}\right) - \\ &- (t_{\min-1})_{vert} \cdot \sin\left(\frac{\beta_{t_{\min-1}^{sr}} - \delta}{2}\right) \cdot tg\left(\frac{\beta_{t_{\min-1}^{sr}} - \delta}{2}\right)\end{aligned} \quad (2)$$

$$(t_{\min-1})'_{norm} = (t_{\min-1})'_{vert} \cdot \cos\frac{(\beta_{t^{sr}_{\min-1}})' - \delta_1}{2} - \\ -(t_{\min-1})'_{vert} \cdot \sin\frac{(\beta_{t^{sr}_{\min-1}})' - \delta_1}{2} \cdot tg\frac{(\beta_{t^{sr}_{\min-1}})' - \delta_1}{2} \quad (3)$$

– For the scheme of Fig. 1, b:

$$\left(t_{\min-1}\right)_{norm} = \left(t_{\min-1}\right)_{vert} \cdot \cos\left(\frac{\beta_{t^{sr}_{\min-1}} + \delta}{2}\right) - \\ -\left(t_{\min-1}\right)_{vert} \cdot \sin\left(\frac{\beta_{t^{sr}_{\min-1}} + \delta}{2}\right) \cdot tg\left(\frac{\beta_{t^{sr}_{\min-1}} - \delta}{2}\right) \quad (4)$$

$$\left(t_{\min-2}\right)_{norm} = \left(t_{\min-2}\right)_{vert} \cdot \cos\left(\frac{\beta_{t^{sr}_{\min-2}} + x}{2}\right) - \\ -\left(t_{\min-2}\right)_{vert} \cdot \sin\left(\frac{\beta_{t^{sr}_{\min-2}} + x}{2}\right) \cdot tg\left(\frac{\beta_{t^{sr}_{\min-2}} - x}{2}\right) \quad (5)$$

The absolute minimum width of the gutter between the frame rail and the diverted point can then be determined as the smallest of the defined values:

$$\left.\begin{matrix}\left(t_{\min-1}\right)_{norm} \\ \left(t_{\min-1}\right)'_{norm} \\ \left(t_{\min-2}\right)_{norm}\end{matrix}\right\} \rightarrow t^{calc}_{\min\,\min} \quad (6)$$

Comparison of the actual minimum design gutter $t^{calc}_{\min\,\min}$ with the minimum permissible gutter $\left[t_{min}\right]$ = 71 mm [14] allows us to conclude that the mandatory condition (1) is met. If condition (1) is not met, it is necessary to select other geometric parameters, first of all, to change the length of the point l_0, consistently increasing it until condition (1) is met. If condition (1) is not fulfilled when increased up to the maximum possible length l_0 determined by the overall distance of the theoretical length L_{Th}, then it is necessary to increase the radius R of the curved part, which will increase the total length of the switch $L_{\Pr}$ or the output angles of the symmetrical switch.

According to the above algorithm, multivariate calculations were performed to verify the standard geometric parameters of symmetrical switches on wooden beams of projects 2063Dn (type P50 grade 1/11) and 2064Dn (type P50 grade 1/9), using both schemes of the arrangement of the frame rail and the diverted point for standard point lengths l_0 = 8700 mm at $U^0_n > Sh_p$ and l_0 = 6515 mm at $U^0_n < Sh_p$.

According to the calculation result of geometrical parameters of symmetrical switch of project 2063Dn [18] with the existing length of the point l_0 = 6515 mm, it was found that the condition $U^0_n > Sh_p$ (at Sh_p = 156 mm) will be met if the length of the point l_0 is not less than 8690 mm.

For the minimum calculated length of the point l_0 = 8700 mm, all other geometric parameters of the switch of the 2063Dn project were also calculated.

In addition, the calculations of the minimum gutter in the root of the point at $U^0_n < Sh_p$ were carried out for symmetrical switches on wooden beams of type P50 grade 1/9 (project 2064Dn [18]) and type P50 grade 1/11 (2063Dn [18]).

For example, the P50 switch of the 1/9 grade does not provide for a straight insert in front of the crosspiece. In the calculations, we considered the possibility of arranging a straight insert with a minimum length of $d_{\min}$ =2485 mm. In this case, the initial geometric parameters of the switch were not changed, and all other parameters were determined by calculations.

The design of the switch type P50 of grade 1/11 provides for a direct insertion in front of the crosspiece with a length of *d* = 4495.5 mm. The initial geometric parameters were also not changed, and all other parameters were determined by calculations.

The results of calculations of the main geometric parameters of the elements of switches of type P50 grade 1/11 and type P50 grade 1/9 are given in Table 1.

Comparison of the geometric characteristics of the switch of the project 2063Dn and the characteristics determined by calculations at l_0 = 8700 mm (for condition $U^0_n > Sh_p$) allowed us to establish the following:

– the following parameters remained unchanged: the initial point angle β_{st-1}, the initial point radius R_0, the radius of the transition curve *R*, the front *h* and rear *p* departures of the crosspiece;

– increased the length of the frame rail l_{sr} and the angle at the root of the point β_{full-1};

– the theoretical length of the switch L_{Th}, the practical length of the switch $L_{\Pr}$, the lengths of the connecting rails $l_1 - l_8$; the length of the transition curve x_k and the length of the straight insert $d_{\min}$ decreased.

Comparison of the geometric parameters of typical switches of projects 2063Dn and 2064Dn and the same calculated parameters according to the above methodology (for condition $U^0_n < Sh_p$) allowed us to establish that

– the initial point angle β_{st-1}, the initial point radius R_0, the radius of the transition curve *R*, the front *h* and rear *p* of the crosspiece remained unchanged;

– the angle at the root of the point β_{full-1} increased,

– the length of the direct insertion $d_{\min}$ (for the 2064 Dn project) was provided;

– the theoretical length of the turnout L_T, the practical length of the switch L_P, the length of the frame rail l_{sr}, the length of the connecting rails $l_1 - l_8$; decreased; the length of the transfer curve x_k; the length of the direct insert $d_{\min}$ (for the project 2063Dn).

Based on the results of calculations of symmetrical switches, comparative diagrams of the geometric parameters of these structures were constructed, which are shown in Fig. 2 for the P50 type switch of grade 1/11 at $U_n^0 > Sh_p$; Fig. 3 for the P50 type switch of grade 1/11 at $U_n^0 < Sh_p$; Fig. 4 for the P50 type switch of grade 1/9 at $U_n^0 < Sh_p$.

Table 1: Comparative characteristics of the existing and design geometric parameters of symmetrical switches.

Parameters	Measure-ment units	Geometric parameters				
		type P50 grade 1/9		type P50 grade 1/11		
		Project 2064Дн	Scheme $U_n^0 < Sh_p$	Project 2063Дн	Scheme $U_n^0 < Sh_p$	Scheme $U_n^0 > Sh_p$
Theoretical lengths of switches L_{Th}	mm	25210	23018	26580	22112	22112
Practical length of the switches $L_{\Pr}$	mm	31410	29390	33201	28 955	26770
Initial point angle, β_{st-1}	degrees	0°34'28,35"				
Point length, l_0	mm	6515	6515	6515	6515	8700
Point radius, R_0	mm	540000	540000	540000	540000	540000
Radius of the transition curve, R	mm	421939	421939	540000	540000	540000
Angle at the root of the point β_{full-1}	degrees	1°00'32"	1°15'56"	1°00'32,81"	1°15'56"	1°29'47,7"
Length of frame rail, l_{sr}	mm	12 500	12 500	12 500	12 500	12 500
Connecting rails	mm	$l_1 = l_7$=6333; $l_3 = l_5$=7994; $l_4 = l_6$=8619; $l_2 = l_8$=12500	$l_1 = l_3 = l_5 = l_7$ =6250; $l_4 = l_6$=8168; $l_2 = l_8$=10641	$l_1 = l_7$=8137; $l_3 = l_5$=9797; $l_4 = l_6$=7619; $l_2 = l_8$=12500	$l_1 = l_3 = l_5 = l_7$ =6250; $l_4 = l_6$=6694; $l_2 = l_8$=10202	$l_1 = l_3 = l_5 = l_7$ =6250; $l_4 = l_6$=5943; $l_2 = l_8$=9427
Length of the transition curve, x_k	mm	17273	14013	15574,5	12542	10356
Length of direct insertion, d	mm	-	2495	4495,5	3060	3060
The length of the front crosspiece departure, h	mm	2085	2085	2650	2650	2650
The length of the rear crosspiece departure, p	mm	1880	1880	2300	2300	2300

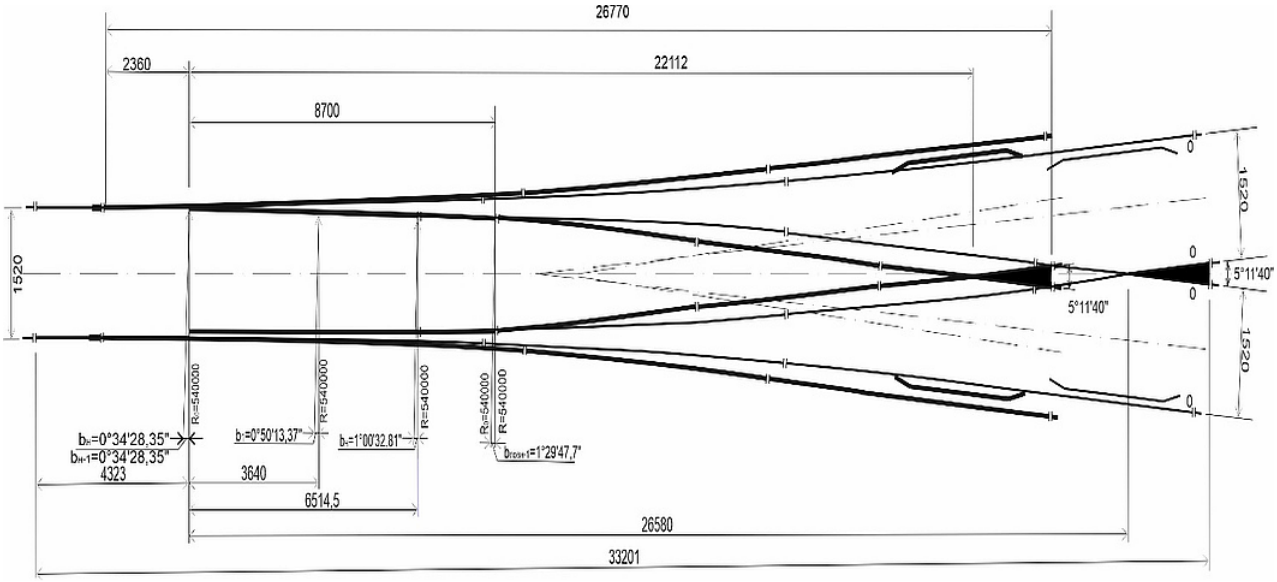

Fig. 2. Geometric dimensions of symmetrical switch type P50 of grade 1/11 are calculated at $U_n^0 > Sh_p$

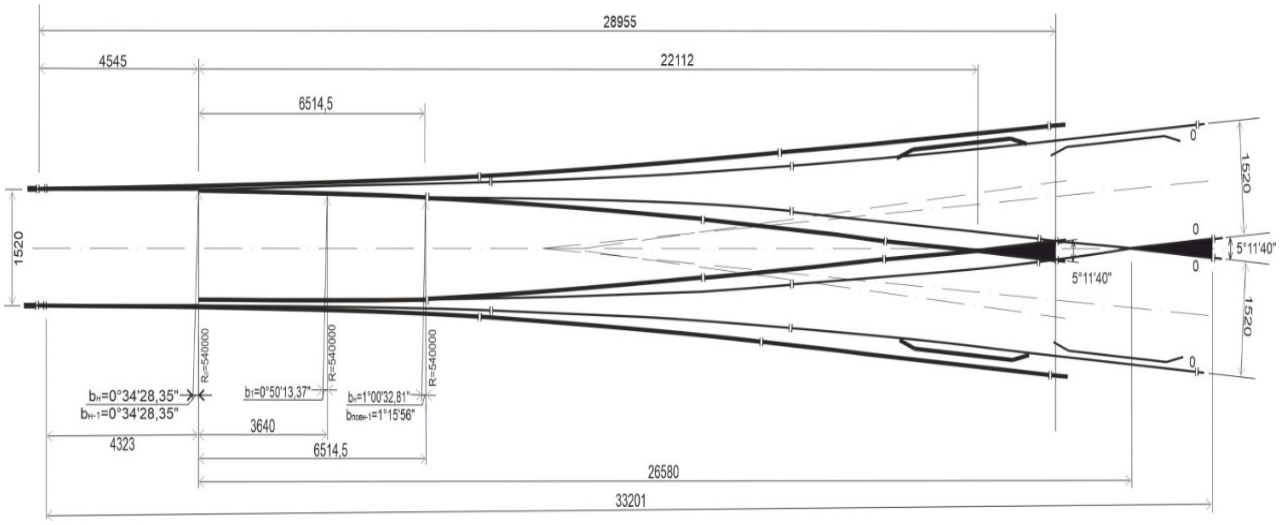

Fig. 3. Geometric dimensions of symmetrical switch type P50 of grade 1/11 are calculated at $U_n^0 < Sh_p$

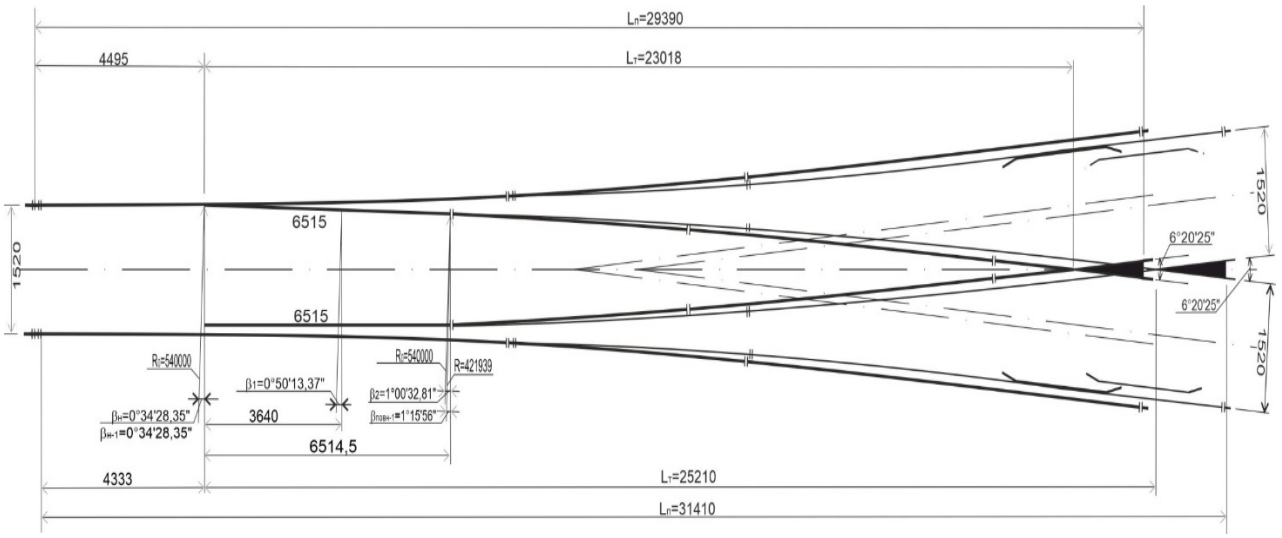

Fig.4. Geometric dimensions of symmetrical switch type P50 of grade 1/9 are calculated at $U_n^0 < Sh_p$

5. Conclusions

When designing symmetrical switches with curved points, it is necessary to ensure the safety of train traffic within the gutters between the frame rail and the curved point. In this case, it is necessary to consider different variants of the design scheme (Fig. 1).

Taking into account that the width of the minimum gutter between the frame rail and the curved point $t_{min\,min}$ is functionally dependent on the length of the point, in the process of designing a switch, it is necessary to select the most rational length of the point by means of multivariate calculations in order to: firstly, to ensure the safety of wheel movement when passing through the gutter, and secondly, to obtain the most rational practical length of the switch based on operational requirements.

It can be argued that the calculations carried out according to the developed methodology make it possible to reduce the total length of all switches while maintaining the conditions for safe movement of trains at the established speeds. At the same time, the reduction in the total length of switches will allow their wider use in the limited conditions of railway stations development.

Calculations of the geometric parameters of curved symmetrical switches determined the possibility of obtaining the expected technical and economic effect from reducing the length of switches of 2063 Dn and 2064 Dn by 6.431 m and 2.020 m, respectively, or by 19.37% and 6.43% (of the existing length), which makes it possible to reduce the metal consumption of the structure as a whole, reduce the number of under-rail bearings, intermediate connectors, which in turn will reduce the cost of these structures.

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