

# The problems of mastering the production of special purpose railway products in the conditions of universal rail-and-structural steel mill

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**Abstract.** The paper contains the analysis results of technological features of asymmetric rail profiles production in the conditions of a universal rail-mill, as well as the stages of the development of intensified rolling mode of switch point rails, the introduction of which allowed the productivity of the rail-and-structural steel mill to be increased and the quality of the finished rails to be improved. On the example of the operating rail-and-structural steel mill of EVRAZ ZSMK JSC the technological difficulties in the production of asymmetric rail profiles with the use of a continuous universal train are illustrated. Ways for optimization of rolling modes for asymmetric rail profiles (switch point rails are taken as an example) are shown using the developed technique for calculating the resistance to deformation of rail steels and modeling the flow of metal using modern software systems. The existing standards regulating the quality parameters of switch point rails is analyzed and the recommendations for its improvement are given.

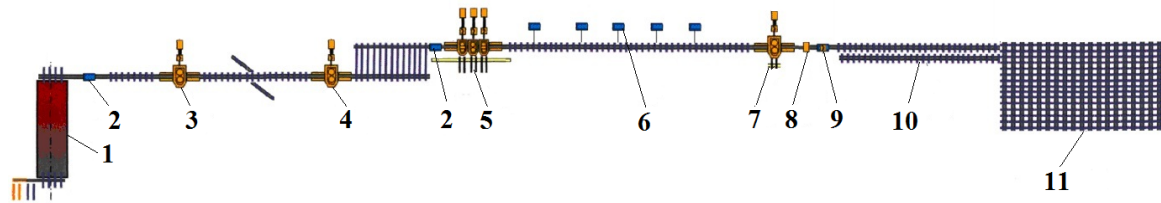
## 1. Introduction

Domestic and foreign practice of metallurgical production testifies that the initial period after commissioning of rolling mills is characterized by the most intensive development of new sizes of produced profiles [1-4]. The completeness of such machines with modern equipment opens up wide opportunities for the production of rolling profiles in accordance with international requirements, which in its turn opens new promising markets for finished products.

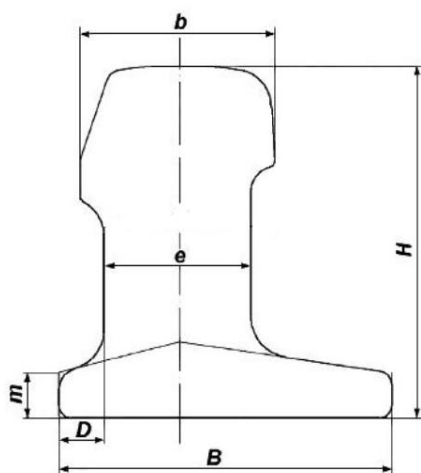
In 2013 at EVRAZ ZSMK JSC the first in the national metallurgy universal rail-and-structural steel mill was launched. The rolling mill consists of two successive two-roll reversing crimping stands (BD1 and BD2) and a universal tandem mill displaced relative to the rolling line, consisting of two universal and one auxiliary two-roll stand, as well as a separately located finishing universal stand (figure 1).

The main assortment of the universal rail-and-structural steel mill of EVRAZ ZSMK JSC is the railway rails of wide track (including long ones up to 100 m in length) of rails of types R65 and R50 supplied in heat-strengthened and non-heat-strengthened condition. However, the production of rails for industrial railways (RP65, RP50), tramway grooved rails (T62), crane rails (KR80, KR120), railway rail counter rail (PK50, PK65), switch point rails (OR43, OR50, OR65). It should be noted that the greatest difficulties arise when mastering the production of profiles that have a pronounced asymmetric shape, including switch point rails (figure 2).





**Figure 1.** The layout of the equipment of the universal rail-and-structural steel mill at JSC EVRAZ ZSMK: 1 – heating furnace; 2 – hydraulic descaling device; 3, 4 – crimping stands BD1 and BD2; 5 – tandem train; 6 – saws of hot cutting; 7 – finishing stand; 8 – laser profiler; 9 – marker; 10 – section of differentiated hardening; 11 – section of the refrigerator.



**Figure 2.** Cross-section profile of switch point rails ( $H$  – rail height;  $b$  – width of the rail head;  $e$  – rail web thickness;  $B$  – width of the rail foot;  $D$  – width of the short arm of rail foot;  $m$  – height of the rail base blade).

The difficulty in developing calibrations of rolling rolls for the production of such profiles is exacerbated by the presence of a continuous train in the universal rail-and-structural steel mill. It also should be noted that the tendency towards the increase in the speed of railway trains [5-7] in recent years has caused a corresponding increase in the requirements for the quality of railway switching, which are the most rapidly wearing part of the track upper structure.

In particular, rails switching requirements for high-speed traffic (speed above 200 km/h) need to meet higher requirements in terms of geometric parameters (unevenness on the rolling surface of rails). Since the initial workpiece for the production of switch points are switch point rails, improvement of the quality of the latter is an urgent task. This thesis is supported by the available data that the main causes of defects in the manufacture of switch point rails are unsatisfactory geometry and the dispersion of the residual stress values in the initial blanks – the switch rails [8].

## 2. Results and discussion

In accordance with the contract calibration of the equipment supplied for the rail-and-structural steel mill (by SMSMeer), the rolling scheme for the switch point rail of OR65 type included the following main steps:

- seven passes in the box gauges of stand BD1 to obtain a rectangular semifinished rolled products;
- seven passes in BD2 stand, including the first pass in the “lying trapezoid” gauge, the second and third passes – in the “standing trapezoid” gauge, the fourth and fifth passes – in the cut rail gauge of the closed type, the sixth and seventh passes – in the preparatory rail gauge of open type;

- rolling in the tandem mill cages in three passes, including the first pass – in the universal stand UR and the auxiliary (edger) stand E, the second pass – in the UR stand; the third pass – successively in all three stands of the tandem mill (UR, E, UF).

Practical experience in the production of switch point rails according to the scheme described above made it possible to identify a number of its significant shortcomings:

- during rolling in stand BD2 there was a twisting of the rolls at the exit from the gauges;
- in the closed groove of the angular wire gauge, intensive adherence of metal along the perimeter of the walls occurred;
- the impossibility of restoring an angular wire gauge of closed type to the width with a regulated metal removal during the reconditioning of roll.

To overcome the above disadvantages, a new rolling method has been developed (figure 3) for switch point rails with intensified crimping mode in stand BD1, reduced number of passes in stand BD2 and the use of an inclined angular wire gauge with diagonal connectors instead of a angular wire gauge of closed type.

The possibility for intensification of the deformation regime is preliminarily justified by calculations of the rolling force, carried out using the technique developed earlier by the authors for calculating the resistance of deformation of rail steels [9, 10]. According to this technique, the deformation resistance is determined from the expression:

$$\sigma = A \cdot e^{m_1 \cdot t} \cdot \varepsilon^{m_2} \cdot e^{\frac{m_3}{\varepsilon}} \cdot (1 + \varepsilon)^{m_4 \cdot t} \cdot e^{m_5 \cdot \varepsilon} \cdot u^{m_6 \cdot t}, \quad (1)$$

where  $A, m_1-m_6$  – the coefficients of the equation, depending on the chemical composition of the steel;

$e$  – the Euler number;

$t$  – the rolling temperature, °C;

$\varepsilon$  – logarithmic degree of deformation;

$u$  – the deformation rate, s<sup>-1</sup>.

$$A = 4365.4 + 69118 \cdot [S], \quad (2)$$

$$m_1 = -0.0033 - 0.0043 \cdot [V], \quad (3)$$

$$m_2 = 0.2607 - 5.7663 \cdot [P], \quad (4)$$

$$m_3 = -0.0025 + 0.00308 \cdot [C] + 0.00025 \cdot [Mn], \quad (5)$$

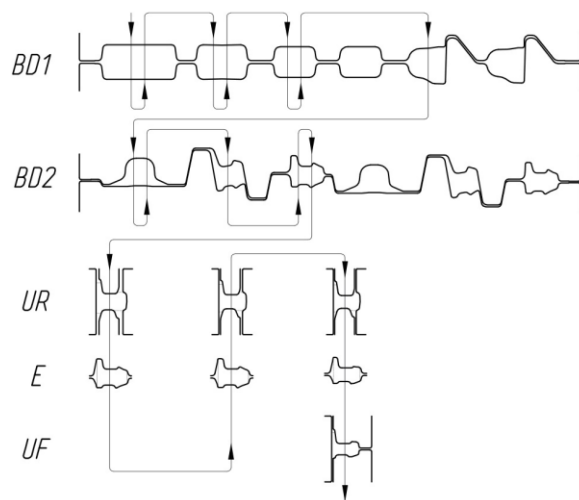
$$m_4 = -0.0015 + 0.0475 \cdot [P], \quad (6)$$

$$m_5 = -0.407 + 0.655 \cdot [Mn], \quad (7)$$

$$m_6 = 0.0002 - 0.0012 \cdot [V], \quad (8)$$

where  $[S], [V], [P], [C], [Mn]$  – the content in the steel of sulfur, vanadium, phosphorus, carbon and manganese, respectively.

Calculations were carried out for steel grade E76KhSF according to GOST R 55820-2013. The actual chemical composition of this steel grade from the current production melts was used for the calculations (table 1), the rolling temperature for the passages was selected based on the temperature of billet preheating at 1170 °C and the temperature drop by 5 °C per each pass.

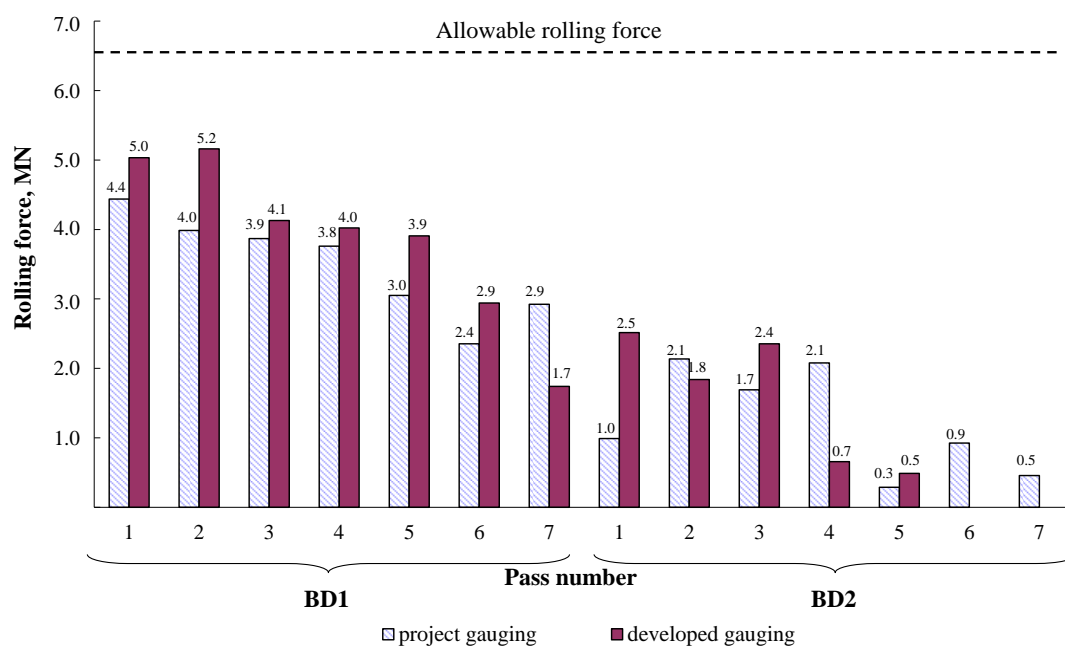


**Figure 3.** Improved rolling scheme of switch point rails of OR65 type at the universal rail-and-structural steel mill of EVRAZ ZSMK JSC.

**Table 1.** Chemical composition of steel E76KhSF for the production of rails OR65.

	Element content, %						
	C	Mn	Si	V	Cr	P	S
Actual average composition	0.76	0.90	0.60	0.07	0.60	0.015	0.015
Requirements of GOST R 55820-2013	0.69-0.80	0.70-1.00	0.3-0.7	0.03-0.15	0.35-0.80	not more than 0.020	not more than 0.020

According to the calculated data, confirmed by the actual experience of rail-and-structural steel mill operation, when using the new rolling mill mode of switch point rails, the rolling force does not exceed 80% of the permissible rolling force (figure 4).



**Figure 4.** Calculated rolling forces during deformation in the break-down mills of the universal rail-and-structural steel mill at EVRAZ ZSMK JSC.

As a result of the introduction of the new mode of rolling RR65 rails, by reducing the number of passes in BD2 stand, a reduction in the rolling cycle was achieved by 22.5 s, which conditioned the increase in the mill's productivity during production of this product by 39.8 tonne/h. The economic effect from increasing the mill's productivity was 29.7 million rubles per year.

The use of the inclined arrangement of the rail gauge in the new rolling scheme made it possible to achieve the following advantages in comparison with the contract calibration:

- to ensure the rolls resharpening without changing the width of the gauges;
- to increase the intensity of breakdown;
- to eliminate the danger of the “shackle” of rolls by rolling due to the diagonal arrangement of closed and open flanges;
- to facilitate the task of rolling into rolls due to the large output of the gauge;
- to abandon the rolling scheme with different diameters of the lower and upper rolls.

According to the actual data, the simplification of the task conditions of rolling into the rolls with the use of a new rolling regime made it possible to reduce the rejection of the finished rails OR65 by the defect of “captivity” by 0.5%.

Analyzing the processes of metal flow and the formation of a final shape of rails using the developed rolling scheme, it should be noted that the control of the width of the sole flanges and the profile head of the processed workpiece after the first and third four-roll gauges is carried out in the auxiliary open two-roll gauges of the edger stand. The final design of the profile of the switch point rail is carried out in a three-roll finishing universal gauge.

Grooves of this gauge forming the rail head are designed according to the same rules as for two-roll finishing gauges with a roll connector in the middle of the rolling surface of the profile head, and the sole is formed in a three-roll section of the gauge where the width of the sole is made by expansion of the metal in the roll connectors (figure 5 a).

Thus, the broadening of the short and long arm of the profile sole ( $\Delta B_f$ ) is made up of natural broadening ( $\Delta B_e$ ), due to the basic breakdown of these elements in the gauge, and the forced broadening that results from additional breakdown of the local metal deposits at the tips of the short and long arm of the sole ( $\Delta B_b$ ), obtained in the result of deformation of these elements in the auxiliary gauges of the horizontal edger stand:

$$\Delta B_f = \Delta B_e + \Delta B_b \quad (9)$$

$$\Delta B_e = \frac{2.54 \cdot \Delta t \cdot (\varepsilon_f - \varepsilon_w)}{\varepsilon_f} \quad (10)$$

$$\Delta B_b = \frac{k \cdot \Delta H \cdot t'}{\lambda \cdot t} \quad (11)$$

where  $\Delta t = t' - t$  – average flange breakdown in thickness;

$\varepsilon_f$  and  $\varepsilon_w$  – relative compression of the flanges and web, respectively;

$$\varepsilon_f = \Delta t; \quad \varepsilon_w = d' - d$$

$\Delta H_f = H'_f - H_f$  – breakdown of flanges in height in the auxiliary stand;

$\lambda$  – drawing coefficient in the universal gauge;

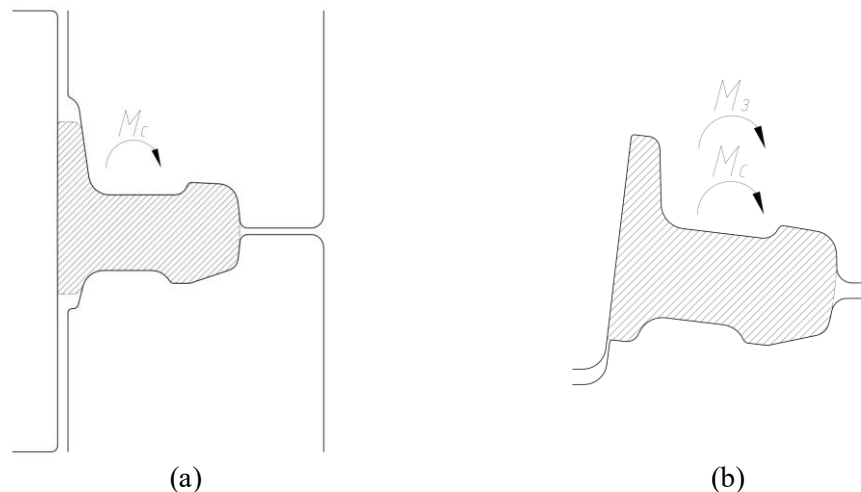
$k$  – coefficient that takes into account the proportion of metal in the flange broadening (it is assumed 0.5 for breakdown mill and 0.7 for finishing stands).

The rail foot formation of the switch rail in the three-roll section of the gauge makes it possible to eliminate the moment typical for rolling in the two-roll gauge (figure 5 b), caused by the pinching of

metal in the closed upper flange of the gauge that forms the long arm of the rail sole ( $M_3$ ), which coincides with the direction of the twisting moment ( $M_c$ ) caused by the difference in speeds along the perimeter of the final pass gauge of the switch point rail (figure 5 a), and reduce the torsionality when leaving the rolls.

At the same time, the attention should be paid to the limitations inherent in the developed rolling mode of switch point rails in the conditions of universal rail-and-structural steel mill. As shown above, the final formation of the rails profile in the finishing universal gauge by the vertical roller and lateral surfaces of grooves of horizontal rolls provides the formation of the width of the profile sole due to free broadening of metal upon deformation of this element (figure 5 a). As a result, the width of the profile sole in the final pass is achieved not by a tool, but by a free metal broadening, which depends on many technological parameters and can not be predicted with a high degree of accuracy. In this regard, there are natural difficulties in meeting the requirements of regulatory documentation on the accuracy of the size of the profile elements. The available production data of domestic and foreign metallurgical enterprises make it possible to speak about the achievable accuracy of the dimensions of the elements of rolling profiles obtained by hot rolling with the presence in the rolling scheme of free metal broadening  $\pm 1.0$  mm.

The value of this parameter is also confirmed by the results of modeling the processes of metal flow in the program complex "DEFORM-3D". At the same time, according to the current Russian GOST R 55820-2013, the maximum tolerance limits for the width of the short arm of rail foot for the accuracy classes of the "high grade" (X) and "first grade" (Y) profiles are set within  $\pm 0.3$  mm and  $\pm 0.5$  mm, respectively. In accordance with the foregoing, the fulfillment of this requirement is impossible, which requires the adjustments in the current regulatory and technical documentation for the production of switch point rails.



**Figure 5.** General view of the universal three-roll (a) and finished two-roll (b) gauges for rolling switch point rails.

### 3. Conclusion

Based on the analysis of the production technology of switch point rails in the conditions of the universal rail-and-structural steel mill at EVRAZ ZSMK JSC, an intensified rolling mode has been developed that ensures the increase in mill productivity and improves the quality of rail products, as well as recommendations on improving the regulatory documentation governing the quality parameters of switch point rails.

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