On Issue of Strip’s Break during Cold Rolling

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Abstract. The strip breaks during the cold rolling lead to significant losses in a continuous mill: downtime, associated with the elimination of consequences, and additional consumption of metal. Strip break occurs at a specific strip location, which further complicates the identification and analysis of its root causes, since a critical deviation of the parameters in only one small section of the strip may already be the cause of the subsequent break during cold rolling. In this work, the methods for checking hypotheses and regression modeling are used to identify the key parameters of hot-rolled strips that affect the strip break. Then, on the basis of the developed mathematical models, threshold values for key parameters are determined, exceeding which increases the probability of strip break.

1. Introduction
The cold rolling of steel strips on a continuous wideband mill is often accompanied by incidents such as the strip’s shifting along the work rolls’ barrel, tension throws and flatness’s violations, which can lead to the emergency conditions or break of the strip. The elimination of the consequences of break is associated with an additional production’s costs in the form of unplanned downtime, increased of consumption coefficient and breakdowns of rolling rolls [1–30].

The defects in the cross-section profile of hot-rolled rolling are the main cause of the violation of strips’ flatness during the cold rolling, at that the internal stresses, arising during the rolling process and distributed over the strip width, can exceed the strength limit, which inevitably leads to the strip’s break. But even if the strips aren’t breaked, the resulting non-flatness of cold-rolled strips leads to rolls’ defects [1–6] and the need for additional technological correction operations [7–22], which increase the cost price and thereby reduce the competitiveness of the finished product [23–30].

2. Binary logistic regression of cold rolled strip’s break forecast
The parameters of hot-rolled strip, such as the flatness and cross-section profile, are usually described through the integral estimates within the entire length of the strip. The integral estimates of parameters show the overall quality level of the strips, produced in the hot rolling mill, but don’t provide information about its variation. In this case, the cold rolled strip’s break occurs at a specific coordinate along the length, so in the cause-and-effect analysis it is better to use distributed parameter estimates, rather than integral parameters.

The distribution of breaks of the transformer steel grade E3A during the first cold rolling was analyzed in relation to the coordinate along the length of the hot-rolled strip. In figure 1 it can be seen that the largest number of breaks occurs on the head section of the hot-rolled strip.
On the first 5% of the length, the probability of break is 6–7% and gradually falls to almost zero by 24% of the strip length. In the central part of the strip (from 25% to 83% of the length), there are almost no breaks. On the tail section of the strip (starting from 84% of the length) there is an increase in the part of breaks from 0% to 2.5%. Taking into account the above, the analysis of the influence of profile parameters on the strip breakage during the first cold rolling should be conducted in three zones separately: the head section (from 0% to 24%), the central section (from 25% to 83%) and the tail section (from 84% to 100%).

**Figure 1.** Distribution of breaks in the E3A assortment along the hot-rolled strips’ length with an indication of the 95% confidence interval.

For the subsequent regression analysis potentially significant factors were selected by based on a statistical hypothesis checking method similar to the work [23]. The parameter was selecting as potentially affecting on the breaks of strips during the cold rolling, if there was a statistically significant difference between medians or dispersions on strips with and without breaks.

Taking into account that for all the analyzed parameters of the flatness and cross-section profile the observed distribution does not correspond to the normal distribution, the $P$-criterion for the medians was calculated using the Kruskel – Wallis test, and for the dispersions – according to the Levene test [24, 25].

Let $F_a$ be an asymmetric component of flatness, I-Unit (1 I-Unit = 10 mkm/m = $10^{-5}$); $F_s$ be a symmetrical component of flatness, I-Unit; $C$ be a cross-section profile’s convexity, mkm; $TV$ be a cross-section profile thickness, mkm; $D$ be a cross-section profile’s convexity displacement from the center of strip, mkm; $W$ be a cross-section profile’s wedge, mkm; $W_{co}$ be a strip edge wedge from operator-side, mkm; $W_{cd}$ be a strip edge wedge from drive-side, mkm; $R_{sq}$ be a determination coefficient of cross-section profile.

Let’s build a mathematical model of the probability of breaks during the cold rolling on the head section of the hot-rolled strip (within the framework of this article, the mathematical models for the central and end sections are not given). To do this, we use a sampling for one steel grade (E3A) and one
standard size \((2.5 \times 1055 \text{ mm})\) for the period from May 2018 to February 2019. The total number of rolled strips, used in the analysis, is 4546, 485 strips of them were with breaks.

Based on the results of calculations, we obtain the following binary logistic regression [26] for the forecast of the strip break:

\[
P_{\text{break}} = \frac{e^Y}{1 + e^Y},
\]

where 
\[
Y = a_0 + a_1 F_a + a_2 F_s + a_3 C + a_4 D + a_5 W_{co} + a_6 W_{cd} + a_7 W + a_8 R_{sq} + a_9 F_a^2 + a_{10} F_s^2 + a_{11} C^2 + a_{12} D^2 + a_{13} W^2 + a_{14} CD + a_{15} CW_{co} + a_{16} CR_{sq} + a_{17} DR_{sq} + a_{18} W_{cd} R_{sq} + a_{19} W_{co} R_{sq} + a_{20} C W_{co} R_{sq} + a_{21} C W_{cd} R_{sq},
\]

where \(P_{\text{break}}\) is the probability of strip’s break.

The presented mathematical model is adequate. First, the model explains more than a half of all breaks in the cold rolling mill (the determination coefficient of the resulting regression model is 0.6304). Second, the acceptable accuracy of the regression model is provided by a small number of significant factors, because the value of the adjusted determination coefficient (equal to 0.6292) is comparable to the value of the determination coefficient (equal to 0.6304) [27]. All factors used in this model are statistically significant, because the \(P\)-criterion for them is less than 0.001. These properties allow us to use the developed regression model in the technological process for predicting breaks during the cold rolling on the head section of the strip.

3. Influence of parameters of hot-rolled rolling on breaks of cold-rolled strips

We’ll study the influence of the hot-rolled rolling flatness and cross-section profile parameters on the breaks during the cold rolling using the developed binary regression model. For the convenience of displaying the analysis results, we’ll plot the graphs of the strip break probability dependence during cold rolling on of related factors’ pairs.

An increase of the edge’s wedge values on both sides of the strip leads to an increase in the probability of breaks.

Exceeding by the symmetrical and asymmetric components of flatness the optimal diapason’s boundaries also leads to a sharp increase of the breaks during the cold rolling. The determination coefficient’s decrease of the cross-section profile below 0.92 increases the probability of breaks during the cold rolling on the head section of the strip. At the same time, the cross-section profile convexity’s increasing reduces the impact of the determination coefficient on the strips’ breaks. Thus, increasing of the strip cross-section profile’s convexity from 30 microns to 40 microns shifts the lower boundary of the region with a low probability of breakage for the determination coefficient from 0.92 to 0.86. Increasing of the cross-section profile’s wedge leads to increasing of the breaks’ probability, while increasing of the strip cross-section profile’s convexity above 35 microns radically reduces the influence degree of wedge on the breaks. The deflection of the strip cross-section profile’s convexity on the drive-side is more critical than on the operator-side, which may be due to the asymmetry of the temperature field along the width of the hot-rolled strip. On the basis of the developed regression model, the recommendations for the flatness parameters and cross-section profile parameters of the hot-rolled strips which provides minimum number of breaks during the cold rolling were worked out. The optimal values of the strip cross-section profile’s convexity couldn’t be determined unambiguously. This is due to the fact that: firstly, the system for regulating of the strip cross-section profile’s convexity works out a single setting value 30 mkm; secondly, if the other factors are maintained in the optimal diapasons, the influence of the strip cross-section profile’s convexity on the strips’ breaks disappears. However, the modelling shows that increasing of the strip cross-section profile’s convexity extends the optimal diapasons for other parameters.

Using the regression modeling, we also obtained the share estimate of a specific factor influence on the breaks probability, when the factor leaves the optimal diapason.
As a result, we became able to classify sections of the hot-rolled strip according to the degree of criticality in terms of breaks during the cold rolling (figure 2) and “highlight” the most problematic areas for the operator of the cold rolling mill. 80 % of breaks falls on the most critical zones (5 or more considered parameters are out of the optimal diapasons), despite the fact that only 11 % of measurements are analyzed.

**Figure 2.** Influence of the flatness and cross-sectional profile parameters exceeding the optimal boundaries on strip breaks during cold rolling.

**4. Conclusions**

The flatness and cross-section profile parameters of a hot-rolled strip have a significant effect on the breaks during the first cold rolling. When we analyze the influence of the flatness and cross-section profile on the breaks of strips, it is best to use parameters, distributed along the length of the strip, rather than their average value for the entire roll. The developed binary regression model of the strip breaks’ probability during cold rolling of hot-rolled strips can be used for a visualization of the most critical zones for the operator of a cold rolling mill. The optimal values of the flatness and cross-section profile parameters were determined using a regression analysis, which ensuring a breaks minimal number during cold rolling of hot-rolled strips.

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