A CALCULATION OF THE CONTINUOUS COLD ROLLING PARAMETERS TAKING INTO ACCOUNT THE POSSIBILITY OF A VIBRATION IN THE WORKING STANDS

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ABSTRACT

A method of the working stands vibrations elimination when calculating the parameters of a rolling technology in a continuous mill is developed and its application is considered. The second strip volumes effect on the occurrence of sheet rolling process unsteadiness is established and confirmed considering the actual variation of the thickness.

Options of an adjustment of the existing mode and an approach of designing new one ensuring a stability of the continuous sheet rolling process in mill stands in an absence of negative vibrations are advanced.

A method of calculation of the circumferential rotational speeds of the surfaces of the work rolls barrels, taking into account the strip advances, the possible thickness fluctuations along the length of the rolled product, and the need to control the metal specific volumes in the inter-stand gaps is developed. It can improve the existing methodologies of designing effective cold rolling modes. An experimental data is presented.

Keywords: chatter, velocity mode, rolling mode, reduction of the steel strip width, tension of the steel strip, sheet value regulation.

INTRODUCTION

The growth of the industrial rolling equipment productivity has a positive effect on the cost and the competitiveness of the steel products. The rolling speeds in modern rolling mills can reach 20 mps - 25 mps in the last stands, while the annual productivity is more than 1700 thousand tons / year. However, the production of a steel strip at a speed of the order of 25 mps, which is more characteristic for small rolled thicknesses, is rare in practice. In fact, high rolling speeds cannot be attained because of the highly probable strip breaks in the inter-stand gaps resulting from significant fluctuations of the tension and the vibration of the working stands. These effects are determined by the features of the automatic thickness and tension control system of the strip (ATaTCSoS).

Many papers focusing on this issue [1-8] have been published. Later communications [9-10] conclude that the steel tension in the inter-stand gaps behind the stand and in front of it should be constant in sign, i.e. the tension should not be replaced by a support and vice versa.

Statement of the problem and its solution

According to the hypothesis formulated, the following inequalities referring to the inter-stand gap second volumes must be observed to maintain support or tension of the strip during rolling:

$\Delta V_i = v_{i-1}h_{i-1}b - v_i h_i b < 0$ – in case of rolling with strip tension,

$\Delta V_i = v_{i-1}h_{i-1}b - v_i h_i b > 0$ – in case of rolling with strip support, (1)

where $v_i h_i b$ are the speed, the thickness and the width of the strip at the exit from the i^th^ stand, while ΔV_i is the difference in the second volumes prior to and after the i^th^ stand.

Aiming this hypothesis test, the differences between the second volumes of the strip in the 2^nd^ and the 3^rd^ inter-stand gaps, and also between the 3^rd^ and the 4^th^ inter-stand gaps during operation are analyzed in view of the modes where vibrations are recorded in the working stands. The difference between the second volumes of the steel strip of the 2nd inter-stand gap is estimated by the expression V_2-V_3, where V_2 is the second volume of the strip at the exit from the 2nd stand of the rolling mill, while V_3 is the second volume of the strip at the exit from the 3rd stand of the rolling mill. Hence, the difference between the second volumes of the 3rd and the 4th inter-stand gaps is evaluated on the ground of V_3-V_4, where V_3 and V_4 are the second volume of the strip at the exit from the 3rd and the 4th stand, correspondingly.

The typical differences between the second volumes of the 2nd and 3rd inter-stand gaps along the length of the strip operating in the mode mentioned above are shown in Fig. 1. It is seen that alternating oscillations of the second volumes occur along the length of the strip, which verifies the conclusion referring to the cause of the vibrations arising, i.e. the alternating values of the difference between the second volumes of the strip along its length in the stands.

It should be noted that the graphs lay only in the negative section of the diagram in case of modes with a strip tension and a vibrations absence.

The verified hypothesis referring to the causes of vibrations in the working stands is used to improve the methodology of determining the technological regimes of cold rolling of steel strips on continuous mills.

The elimination of vibrations at the stage of setting technological parameters prior to rolling is possible by choosing such thicknesses and speeds of the strip along the stands of the continuous mill, which will ensure the fulfillment of one of Conditions (1).

Moreover, for the prompt elimination of the vibrations arising, in case of their occurrence, it is more expedient to adjust the strip thickness decrease in the stands than to change the rotation speeds of the work rolls. This is due to the fact that the process of adjusting the strip thickness decrease is less inert than that of the rolls rotating speed in view of the operation of the automated hydraulic or the electromechanical systems.

The method of determining the settings of the rolls angular speeds of rotation is considered. The required angular velocity of rotation determined according to the law of the strip second volumes constancy is evaluated considering the advance coefficient. This is done on the ground of:

$$\omega_{vi} = \frac{V_i}{R(S_i+1)}. \quad (2)$$

where S_i is the advancing coefficient in the i-th stand of the rolling mill, which can be calculated by the formulas of ref. [5], V_i is the required metal velocity at the exit of the i^{th} stand, while R is the radius of the roll barrel.

Because the strip has a certain thickness variation along its length, it is obvious that second volume fluctuations can be expected in the inter-stand gap. Besides, conditions providing an alternation of the strip support and the strip tension between the stands may arise, which in turn will lead to undesirable vibrations. To exclude the possibility of such an unstable mode of operation, it is

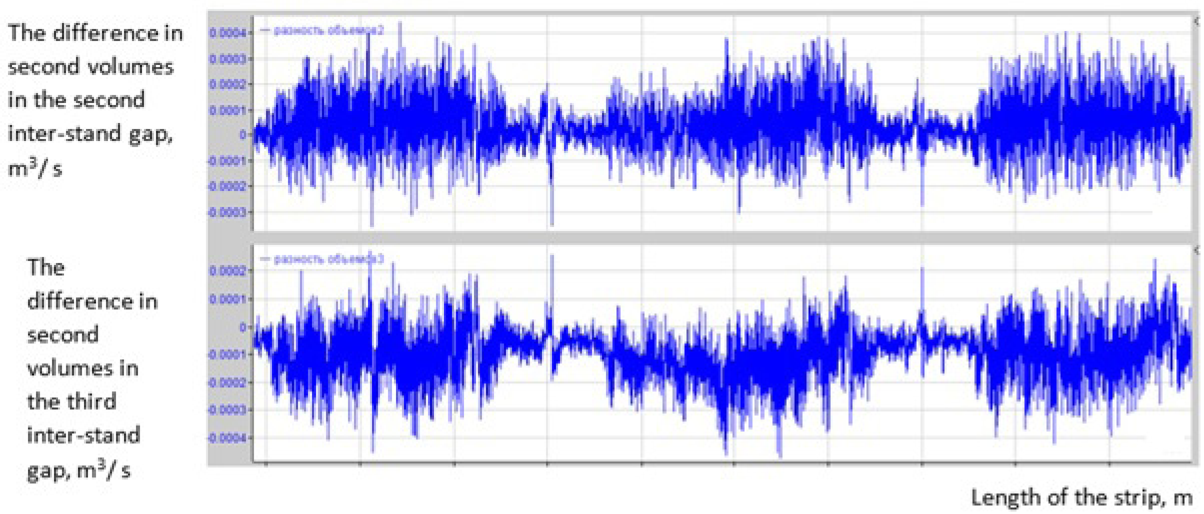

Fig. 1. Difference between second volumes of the 2nd and 3rd inter-stand gaps of 5-stand rolling mill 1700 when operating in accordance with the existing modes of strip rolling.

better to set an angular velocity taking into account the maximum thickness fluctuations, i.e. the speed increase determined by the limiting value of the fraction of the thickness fluctuation. This will ensure the fulfillment of the first condition of a vibrations' exclusion according to Eq. (1) referring to rolling with tension. Thus, taking into account the advance coefficient, the angular speed of the rolls' rotation can be estimated in accordance with the following formula:

$$\omega_{vi} = \frac{(1+\Delta h)V_i}{R(S_i+1)}, \quad (3)$$

where Δh is the maximum possible thickness variation of the strip. It is a share of the nominal thickness.

The requirements referring to the maximum possible thickness variation of the strip are usually specified in the technological documentation of the rolling mill. Thus, for example, the value of the permissible fluctuation of the finished products longitudinal thickness at the 5-stand mill 1700 is 3 %.

Next, the optimal regime of adjusting the steel thickness decrease is determined in case of instability during the rolling process. It can be used in an on-line mode.

The formulation of the conclusions is done on the ground of the conditional process diagram shown in Fig. 2. A part of the strip located in the deformation zone of stand No 1 is considered in the calculation. Using the basic law of dynamics, a formula is obtained that expresses the relationship between the strip speeds and the tensions:

$$V_1 - V_0 = \left(\sqrt{\frac{2(T_0-T_1)}{h_1 b\rho}}\right) \text{ или } V_1 = \left(\sqrt{\frac{2(T_0-T_1)}{h_1 b\rho}} + V_0\right) \quad (4)$$

where V_0 and V_1 are the speeds of the strip in front of and behind the stand, T_0 and T_1 are the strip tension in front of and behind the stand, h_1 and b are the thickness and the width of the strip at the exit of the stand, while ρ is the density of the strip material after rolling.

This expression can be easily converted to:

$$h_1 V_1 = h_1\sqrt{\frac{2(T_0-T_1)}{h_1 b\rho}} + h_0(1-\varepsilon_1)V_0 \quad \text{or}$$

$$h_1 V_1 = h_0(1-\varepsilon_1)(\sqrt{\frac{2(T_0-T_1)}{h_1 b\rho}} + V_0) \quad (5)$$

The obtained expression confirms the previous conclusion that the second volume of the metal behind the stand is determined by the tension of the strip. It demonstrates also the dependence of this volume on the strip thickness decrease in the stand. Thus, Eq. (3) provides to identify the main ways of regulating the second volume behind the stand in case of fluctuations through the differences of these second volumes of the strip in front of and behind the stand.

Since the strip width remains unchanged during cold rolling of thin wide strips, the rolling condition with tension but no vibrations (1) can be written as follows: $h_1 V_1 > h_0 V_0$. According to this expression, the unstable state of the strip found in front of the rolling stand (fluctuations of the support and the tension of the strip) can be eliminated through an increase of $h_1 V_1$ value. Aiming this, it is possible, in accordance with (3), to correct the thickness strip decrease in the stand: it can be decreased and thereby the metal outflow from the inter-stand gap can be increased. It will provide the increase of the strip tension in front of the stand T_0 and will also provide the increase of $h_1 V_1$ value. This variation of the technological regime can be used to eliminate quickly the vibrations in the rolling stand and change the mill pre-setting in case of rolling instability revealed by Eq. (1).

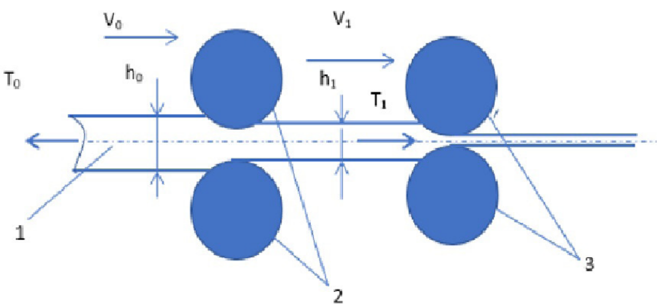

Fig. 2. A scheme for determining the relationship between the speeds of the strip and the tension (1- strip, 2 - work rolls of stand No. 1, 3 - work rolls of stand No. 2).

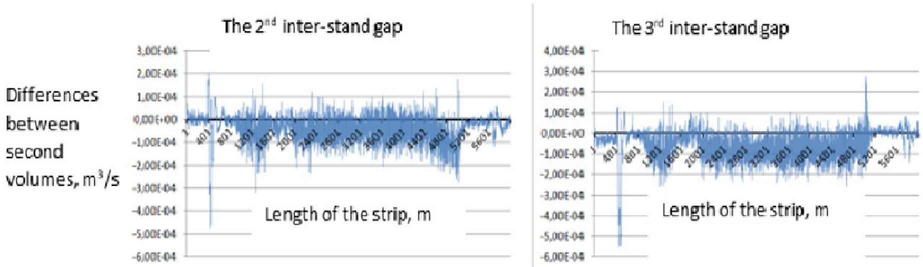

Fig. 3. Fluctuations of the differences of the second volumes of the strip in the 2nd and 3rd inter-stand gap during an operation in accordance with the existing regime.

RESULTS AND DISCUSSION

The effectiveness of the solutions proposed is evaluated. This is done through an industrial testing of the cold continuous rolling regimes calculated on the ground of the solutions presented.

The testing is carried out on a 5-stand continuous cold rolling mill. The production regimes of strips of a thickness ranging from 0.35 mm to 1.2 mm are investigated. The parameters referring to one of the regimes investigated (in this case a strip of a thickness of 0.5 mm) are shown in Table 1.

Table 1 shows that the presented data does not correspond to the law of volumes constancy. This is so because inequalities (1) must be observed to create tension or support of the strip. For example, $\Delta V_i = v_{i-1}h_{i-1}b - v_i h_i b < 0$ in case of tension of the strip behind the stand. If there is support of the strip, then $\Delta V_i = v_{i-1}h_{i-1}b - v_i h_i b > 0$. The data of Table 1 refers to a rolling regime with tension of the strip in all inter-stand gaps, so the difference between the second volumes must correspond to $\Delta V_i = v_{i-1}h_{i-1}b - v_i h_i b < 0$. It shows also that the rolling is carried out with strip tension, because the second volume of the strip after each stand increases.

The differences between the second volumes of the strip along its length in the 2nd and 3rd inter-stand gaps in presence of vibrations are presented in Fig. 3.

The main reason of these vibrations refers to the disadvantages of the technology regimes design and the automatic control of the rolling process, as well as to the fluctuation of the strip thickness or the thickness variation along the strip length. Thus, an alternation of the support and the tension of the strip occurs in the second and third inter-stand gaps according to Eq. (1).

The thicknesses of the strips in the second and third inter-stand gap are adjusted to eliminate the discovered disadvantage of the technology. The second volume in front of the 3rd and 4th stand is decreased in accordance with Eqs. (1) and (5). Moreover, the mentioned value of the second volume in each inter-stand gap is decreased so that the relative difference between the second volumes becomes equal to the share of the longitudinal thickness variation of the strip in respect to its nominal value. This type of a correction will provide the validity of inequalities (5) along the length of the strip.

The maximum thickness variation of the strip along its length leads to the following thickness and second volumes adjustments:

- a thickness of the strip in the 2nd inter-stand gap $h_{2cor} = h_2 \cdot 0{,}94$,

Table 1. Nominal (specified by the technology) parameters of the existing rolling mode of the strip of a 0.5 mm thickness.

Stand number	A peripheral speed of rotation of the surface of the work rolls barrel, m/s	A strip thickness behind the stand, mm	A strip thickness private decrease, %
1	4,35	1,45	30
2	6,44	1,01	30
3	9,25	0,72	29
4	13,6	0,51	30
5	14,2	0,5	2

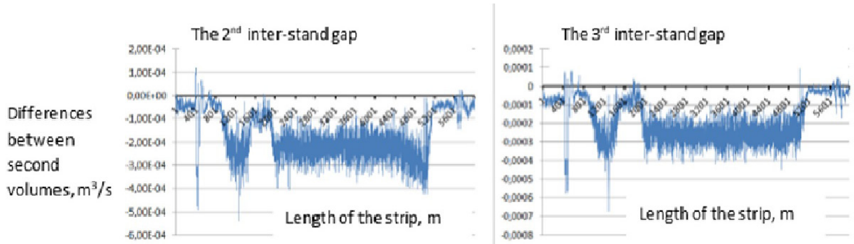

Fig. 4. Fluctuations of the differences of the second volumes of the strip in the 2nd and 3rd inter-stand gaps during operation in accordance with the newly proposed regime assuming only a decrease of the strip thickness.

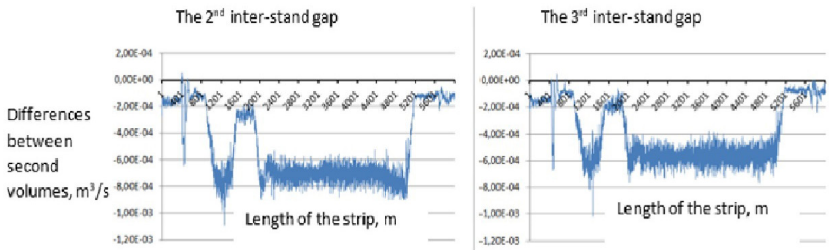

Fig. 5. Fluctuations in the differences of the second volumes of the strip in the 2nd and 3rd inter-stand gap during an operation in accordance with the newly proposed regime providing adjustments of the decrease of the strip thickness and tension.

- a thickness of the strip in the 3rd inter-stand gap $h_{3cor} = h3 \cdot 0{,}97$.

Thus, the second volume of the 2nd inter-stand gap is decreased by 6 %, while that of the 3rd inter-stand gap - by 3 %, i.e. a decrease of 3 % of the difference between the second volumes is achieved. This adjustment ensures the fulfillment of Conditions (1) during rolling with tension for stands No. 3 and No. 4, where vibrations have been previously detected. The diagrams of the second volumes differences are almost completely located in the negative region, which corresponds to rolling with tension along the entire length of the strip (see Fig. 4).

Fig. 4 shows that alternating fluctuations of the second volumes are still observed in small areas at the beginning and at the end of the strip. The elimination of these fluctuations and the solution of the problem of the rolling velocity increase require the increase of the longitude coefficient up to 10% – 15% in relation to its basic value. This can be done using the equation $\lambda = \frac{V_1}{V_0}$, . Then the tangential velocity of the working rolls rotation has to be corrected using Eq. (3). Its value is increased up to maximum share of the second volume fluctuation in correspondence with Eq. (1).

An additional adjustment of the angular velocities of rotation of the work rolls ensures that the entire diagram of the differences of the second volumes of stands No 3 and No 4 is located in the negative region (see Fig. 5). It provides also an increase of the rolling velocity up to 5 %.

The final parameters of the adjusted regime are presented in Table 2.

Table 2. Parameters of the corrected regime of production of a strip of 0,5 mm thickness.

Stand number	A peripheral speed of rotation of the surface of the work rolls barrel, m/s	A strip thickness behind the stand, mm	A strip thickness private reduction, %
1	4,45	1,45	30
2	6,9	1,01	34,5
3	9,7	0,72	26,4
4	14,5	0,51	26,9
5	14,9	0,5	2

CONCLUSIONS

The paper considers an engineering approach applicable to the design of a technology for rolling cold-rolled strips eliminating the occurrence of negative vibration effects (the phenomenon of "chatter"). It is found and verified that the elimination of the "chatter" in the rolling stand requires the preservation of the sign of the difference of the strip volume during rolling. It is necessary to take into account the actual thickness difference along the length of the strip.

An analytical dependence of the effect of the tension of the rolled strip on the value of second volumes of the metal, which can also be used in the design of the technology, is obtained.

The effectiveness of the proposed method for eliminating vibrations and increasing the productivity of continuous mill working stands are demonstrated on the specific example of rolling a steel strip of a thickness of 0.5 mm.

The developed technical solutions can supplement the well-known methodologies for calculation and design of cold rolling modes.

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