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Steel strip quality upgrading through optimization of cold rolling schedules in continuous mills

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Abstract: As a result of research into the cold rolling theory and practice, a complex of mathematical models and model-based process solutions has been elaborated to improve quality of cold rolled steel strips and reduce energy consumption. The use of the above designs made it possible to establish a number of new regularities and employ them for cold rolling practice improvement and cold-rolled strip quality upgrading.

Key words: cold rolling; zone of deformation; neutral cross-section; rolling force; rolling power.

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1 Introduction

Imposition of more stringent requirements upon the quality and accuracy of thin strips and advancement of the relevant rolling practice call for further development of modeling methods and optimization of rolling process schedules.

As a result of research into the cold rolling theory and practice as well as steel strip quality, a complex of the following mathematical models has been devised. (1) Innovative elastic & plastic model of deformation zone which ensures reliable localization of the neutral cross-section and the extent of any elastic and plastic sites. (2) Innovative model of energy-power parameters which takes into account any stressed state of each elastic and plastic site within the deformation zone and makes it possible to calculate the rolling process force and power with errors being 5 to 7 times less than those tolerated by the renowned models. (3) Radically new formulae for forward/backward slip coefficients which are applicable to deformation zones either with a neutral cross-section or without it. (4) Mathematical expressions of forces and momenta relationship within the four-high roll stand which exclude any roll vibration and slipping.

The above designs and techniques have been used to improve the cold rolling practice and upgrade the quality of cold rolled strips. The most significant of them are as follows:

(1) Methods of influence upon the position of a neutral cross section within the deformation zone through redistribution of reduction and tension values which ensure 4% to 8% energy saving, improve strip surface quality and metal structure and exclude any vibration in the work stands. (2) Method of high-speed operating mode adjustment as applied to a continuous strip rolling mill which ensures 30% to 40% diminution of variations in strip thickness and tension due to more thorough account of roll-stand forward slip coeffi-

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cients.

2 Theoretical grounds of the above designs

Theoretical analysis of deformation zone structure in the cold rolling process made it possible to put forward the following hypothesis: cleanliness of rolled steel strip surface and power consumption in the cold rolling process depend on the position of the neutral cross-section in the deformation zone.

The cold rolled strip surface cleanliness dependence of the position of the neutral cross-section is substantiated by the following considerations. The friction stresses in the backward slip zone are directed forward along the direction of rolling. Therefore, the products of metal wear-out and lubricant decomposition are actively evacuated by working rolls from the zone of deformation, thus stipulating continuous process of self-cleaning of the same. The friction stresses in the forward slip zone are directed backward. Therefore, evacuation of the above products from the zone of deformation is hindered; the above products are accumulated in the deformation zone, which results in the increased contaminant deposits on the cold rolled strip surface. Hence, by providing maximum possible shift of the neutral cross-section toward the roll stand exit we can achieve better cleanliness of steel strip surface.

The electric power consumption dependence of the position of the neutral cross-section in the deformation zone is substantiated by the following considerations. The working rolls perform useful work only in the backward slip zone, where their speed is higher than that of strip. In the forward slip zone the strip has higher speed as compared to the speed of rolls, therefore the strip returns a part of the energy obtained in the backward slip zone to the rolls. Hence, shifting neutral section to the side of strip entrance to the rolls it is possible to reduce power consumption due to increase of the forward slip zone length.

Checking of the above hypothesis by means of traditional (classical) methods used for estimation of energy-power parameters was impossible, because such methods are based on plastic model of the deformation zone, which does not take into account any change of contact stresses in its elastic sites. At modern rolling mills the length of elastic sites reaches 40%-50% of the total length of the deformation zone, therefore errors of roll force and rolling power estimated in accordance with classical methods make up 20%-60%. When rolling steel strips less than 0.5 mm in thickness, the discrepancy between estimated and measured values increases up to 70%-90%. This does not permit to determine authentically the positions of the neutral cross-sections in the roll-stands' deformation zones.

We have developed a new method of estimating the contact stresses as well as the roll force and cold rolling power based on elastic & plastic model of the deformation zone. According to this model the deformation zone is to be divided into 4 sites: 1-st site is the site of elastic compression of a strip being entered into the rolls bite; 2-nd site is the plastic site backward slip zone; 3-rd site is the plastic site forward slip zone; 4-th site is the site of elastic recovery of a part of strip at the exit side of rolls.

According to the new method, the energy-power parameters (contact stresses and rolling works) are to be estimated separately at each of the above sites, and then summarized to obtain the roll force and rolling power.

We have made and solved a set of the following three equations in order to estimate the contact stresses at each site: (1) the differential equation of strip balance in the zone of deformation; (2) the elasticity equation (at elastic sites) or plasticity equation (at the backward and forward slip zones); (3) the equation of binding the normal and tangential stresses (the law of friction).

As a result, we have obtained the relationship between the normal contact stresses p_x and strip thickness h_x, having integrated which we came to the formulae for calculation of average values of such stresses.

The results of calculation performed with the use of these formulae showed that there were some rolling schedules under which the zone of deformation could occupy the entire backward slip zone so that neither neutral cross-section nor forward slip zone would be available there. In this case the calculation formulae are changed. There is a formula of strip thickness calculation in the neutral cross-section as well as some formulae for calculation of average contact stress in the zone of deformation.

The new formulae for calculation of rolling power have the following distinguishing features when compared with classical formulae: they take into account the work of the forces arising in the zone of deformation under the influence of both the normal and tangential stresses; they make it possible to separately calculate the work of forces applied in parallel and perpendicular to the axis of rolling; the works of tangential stresses in the backward and forward slip zones are calculated with opposite signs.

To check the new method of estimating the energy-power parameters for its reliability, we have created the database of actual rolling force and power values for as many as 250 real rolling schedules in application to the five-stand cold rolling mill "1700 mm" and have compared the estimated and measured values. The average error of calculation comprised 5%-7%, while the maximum error was 12%-13 %, i. e. 5 to 6 times less than the respective errors of calculation made in accordance with classical methods.

High accuracy of energy-power parameter determination allowed us to predict with assurance the positions of the neutral cross-sections in the roll stand's deformation zone. It enabled us to perform the industrial test of the hypothesis about influence of positions of the neutral cross-sections upon cleanliness of strip surface as well as upon rolling power.

Position of the neutral section in the roll stand i was characterized by indicators: $X_i = \frac{x_{bck}}{x_{plast}}$, where x_{bck} is the length of the backward slip zone, x_{plast} is the full length of the plastic site. The analysis shows that indicator X_i depends on the following parameters of rolling process: interstand tension, partial reduction in a roll stand, and (through the coefficient of friction) the rate of rolling, concentration of emulsion, roughness of semi-finished stock and working rolls. Maximum value attainable by this parameter equals 1; this is the case when the deformation zone occupies the entire backward slip zone and, therefore, the most efficient evacuation of wear-out products from the deformation zone is ensured.

3 The most significant results of our designs and research

At the first stage of this research we studied influence of parameter X_i on strip surface cleanliness. Regression analysis shows that the greatest influence upon cold rolled strip surface cleanliness is made by the following two factors: surface cleanliness of pickled semi-finished stock and positions of neutral cross-sections in the roll stands' deformation zones. On the basis of these results some improved rolling schedules were developed, values of X_i in which were brought as close to 1 as possible.

At the second stage of our research work we studied influence of indicator X_i on electric power consumption in the process of rolling. To reveal the most power-consuming rolling schedules, we have analyzed the database of the five-stand cold rolling mill "1,700 mm" for the first six months of 2003; to do this, the entire variety of rolled products was divided into four groups as to finished strip thickness ranges h_5. A representative product characterized by maximum rolling time consumption was selected from each group. The rolling schedules used to manufacture the representative products were analyzed by using the new method of cold rolling power estimation. Then the rolling schedules were improved through a purposeful variation of relative reduction and interstand tension values.

While doing so, we took into account the fact that any decrease in the backward slip zone length within the deformation zone of each working stand results in electric power saving, but at the same time it increases contamination of steel strip at the exit of roll stand, i. e. the criteria of rolling schedule improvement toward minimization of electric power consumption and maximization of strip surface cleanliness are diametrically opposite. To eliminate this contradiction, we decided to distribute the tasks of rolling process improvement among the working stands. Intermediate stands of the continuous cold rolling mill (stands No. 2 and 3) consume more electric power than the last stands, but exert less influence on strip surface cleanliness. Therefore, the lengths of forward slip zones in the 2-nd and 3-rd roll stands were increased as much as possible. The last roll stands (stands № 4 and 5) consume less electric power than the intermediate ones due to lower reduction in them, but exert twice as much influence on the strip surface cleanliness. Therefore, the lengths of backward slip zones in the 4-th and 5-th roll stands were increased as much as possible. We implemented all the above-mentioned changes through redistribution of interstand tension and reduction values, having executed a series of calculations as applied to energy-power parameters and X_i indicators. As a result, we achieved 4%-8% total electric power saving at the mill without strip surface cleanliness being worsened.

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