The Development and Application of Methodologies for the Design of Technological Modes of Cold Rolling

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Abstract. The article describes the methodology of designing technological modes of cold rolling of thin steel strips on continuous mills, according to which the design process is presented in the form of seven interconnected modules that perform certain functions. As a result of the implementation of the principles, effective deformation modes are obtained, which provide a reduction in total energy costs by 5-8% in compliance with the requirements for the quality indicators of the strip.

The general tendency to improve the quality of products affects all industries and is expressed in the desire of consumers of rolled metal to receive cold rolled steel sheet with high technological and service properties. In turn, this requires metal manufacturers to constantly introduce technologies that will improve the efficiency of existing plants and the competitiveness of cold rolled products. At the same time, there is a need to accelerate the implementation of developments, which necessitates the creation and improvement of on-line design methods for effective rolling technologies in order to improve product quality, resource and energy saving.

An analysis of the current state of production of cold-rolled steel indicates that in addition to energy saving, a key problem is ensuring the stability of consumer properties of sheet metal, which is achieved only by strictly regulating the deformation modes of rolling and controlling the technological process at the mill in specified ranges of changes in its parameters. The implementation of the above mentioned presents certain difficulties due to the inconstancy and heterogeneity of the chemical composition and structure of the steel, causing fluctuations in the value of the initial yield strength, instability of the strip thickness at the input of the mill and rolling conditions in a continuous mill, when, at the same time, the thickness and tension of the strip are adjusted, the speed and reductions values are not stable and, accordingly, power parameters of the rolling process, as well as indicators of accuracy, flatness and mechanical properties of the strips being rolled. Therefore, when designing the technological mode, it is necessary to take into account existing fluctuations in the technological and power parameters, which will allow us to develop a reliable energy-efficient cold rolling technology that provides products with a given level and stability of its quality indicators, with predicted final properties.

In the majority of works devoted to the study and design of technological modes of cold rolling, a point estimation of the parameters of the process and rolled metal without stochasticity is performed [1-6]. In [7], a methodology was proposed for calculating the instability of the parameters of the cold rolling process, taking into account the influence of random factors according to the criterion of equal forces across all mill stands, however, as practice shows, it is extremely difficult to implement. In [8-12], the application and advantages of modeling the cold rolling process taking into account the unsteadiness...
and stochasticity of its parameters are shown, it is concluded that it is advisable to use a dynamic model of the cold rolling process when creating new and improving existing technologies for the production of thin wide cold-rolled strips. This article is aimed at further development of modeling methods for energy-efficient rolling technologies taking into account stochastic parameters.

When developing the methodology for the design of cold rolling modes, a modular approach was applied (Figure 1). Each module implements a specific function or several interrelated functions.

**Module 1. Initial data**
- Parameters of the initial condition of the strip and equipment
- Limitations of the rolling process parameters
- Quality characteristics of finished strip
- Process efficiency criteria

**Module 2. Strip condition simulation**
- Specifying a selection of strip points
- Simulation of yield strength values for each point
- Simulation of chemical composition and structure for strip points
- Thickness simulation for strip points according to tolerance

**Module 3. Variation of technological parameters**
- Variation of interstand tensions
- Variation of reductions

**Module 4. Calculation of the parameters of the rolling process**
- Calculation of rolling speed taking into account the law of constancy of second volumes
- Calculation of power parameters

**Module 5. Calculation and prediction of strip parameters**
- The calculation of non-uniform thickness of the strip
- Prediction of mechanical properties

**Module 6. Analysis of rolling parameters**
- Corrective measures
- Valid parameters
- Processed data with evaluation of parameters' variation
- Evaluation of process performance in accordance with efficiency criteria

**Module 7. Display and analysis of the results**
- Display of results with evaluation of parameters' variation
- Evaluation of process performance in accordance with efficiency criteria

**Figure 1.** Methodology for the design of technological modes of cold rolling with variation of process and strip parameters.

Module 1 includes a description of the initial data for the rolled strip and allows you to set the characteristics and profile sizes of the semi-rolled and finished strip, the parameters of the mill equipment, the ranges of technological parameters such as interstand tension, reduction, rolling speeds, ranges of strip condition parameters, as well as power and quality parameters of the finished products. At the same time, the existing experience of formalized recommendations on choosing the initial values of the parameters characterizing the rolling mode can be implemented. Module 2 simulates the condition of the strip, taking into account the non-uniformity of the yield strength, chemical composition and structure, thickness along the length of the strip based on the use of the random number generation procedure according to the law of normal distribution. In module 3, it is possible to sort through all possible variations of the reduction distribution over the stands of the continuous mill and the interstand...
tension according to the restrictions specified in module 1. In modules 4 and 5, for each point of the strip, the interaction parameters of the stand and strip are calculated and the condition of constancy of the second volumes of metal is checked. As a result, arrays of values are formed, which are random numbers in connection with the simulation of perturbations implemented in modules 2 and 3. After calculating the process and strip parameters in module 6, the energy and kinematic characteristics of the rolling process are checked and the quality indicators of the finished strip are evaluated. In the case of a positive check, in module 7, the processing of arrays of values characterizing the condition of the strip and process parameters is performed to select a process mode option that meets the efficiency criteria specified in module 1. If for some parameter non-compliance with the established requirements is observed, then in accordance with the design methodology, appropriate corrective measures are taken in module 1, and the calculation is repeated.

The implementation of the methodology for the design of technological modes that provide energy savings for the engines of the main drive of the mill was implemented by rolling strips 1250 mm wide and 0.5, 0.7 and 1 mm thick made of CHES30 steel at the 5-stand mill 1700 of PAO Severstal. The results obtained were evaluated and compared with the modes of strip rolling recorded at the production site. The strip condition was simulated with a standard deviation of 10% for yield strength, 0.012% for carbon content, 0.05% for manganese, 0.001 mm for grain diameter and 2% for thickness.

Table 1 shows the reduction and tension modes when rolling strips of different thicknesses. Each mode is presented in two variants: Variant 1 - actual values taken from an automatic system for measuring and controlling data during rolling; Variant 2 - calculated values in accordance with the design methodology. In all cases, the initial yield strength was 260 MPa, the rolling speed was 21 m/s, the specific tension before the first stand was 28 MPa, after the 5th stand it was 37 MPa. The thickness of the semi-finished rolled stock was 2.1 mm for strips with a thickness of 0.5 mm; 0.7 mm and 2.7 mm for strips with a thickness of 1 mm.

| Variant No. | Percentage reduction in stands, % | Specific tensions in the interstand gaps, MPa |
|------------|----------------------------------|---------------------------------------------|
|            | №1  | №2  | №3  | №4  | №5  | №1  | №2  | №3  | №4  |
| Mode No.1 Strip thickness h = 0.5 mm |
| 1          | 30  | 30  | 30  | 30  | 5   | 145 | 160 | 150 | 165 |
| 2          | 37  | 26  | 26  | 32  | 2   | 132 | 148 | 186 | 201 |
| Mode No.2 Strip thickness h = 0.7 mm |
| 1          | 24  | 25  | 24  | 22  | 3   | 138 | 152 | 153 | 154 |
| 2          | 32  | 20  | 20  | 22  | 5   | 140 | 165 | 189 | 200 |
| Mode No.3 Strip thickness h = 1 mm |
| 1          | 22  | 23  | 22  | 21  | 4   | 136 | 144 | 155 | 169 |
| 2          | 28  | 19  | 21  | 21  | 4   | 150 | 164 | 190 | 200 |

It can be seen from the table that in the second variant, the redistribution of the reductions between the stands with the maximum load of the first stand and the unloading of the second and third stands of the mill with a sequential increase in the specific tension from the first interstand gap to the fourth one is performed. Comparison of the values of the specific energy consumption for the mill stands (Figure 2) showed that the developed modes provide 5-8% energy savings.

Experimental industrial testing of the developed modes for rolling strips of CHES30 steel at the 5-stand mill 1700 of PAO Severstal showed that:
- the average actual power saving during rolling according to the designed modes was 6.5%;
- the distribution of the strip thickness was characterized by an average value $\bar{X} = 0.698$ mm and a standard deviation of $S = 0.011$ mm, for the distribution of the yield strength, these parameters were...
\[ \bar{X} = 668 \text{ MPa}, \ S = 2,17 \text{ MPa}, \text{ i.e. parameters of finished strips satisfy the requirements of rolled products for cold stamping.} \]

Conclusions

1. The methodology of developing technological modes for cold rolling of light strips in continuous mills is presented, according to which the developing process is presented in the form of seven interconnected modules that perform certain functions.

2. The implementation of these principles allows us to solve various problems in the field of the development of effective technologies for the production of thin steel strips, including the development of deformation modes that ensure a reduction in total energy costs while meeting the requirements of rolling quality indicators.

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