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Investigation of mathematical model of continuous multistand hot-rolling mill

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Abstract
Structural scheme of building of mathematical model of continuous multistand hot-rolling mill in Simulink software envelope is presented. It allows to estimate fundamentally the impact of speed change of each of the stand on the mill work in regime of free rolling.
Key words: CONTINUOUS MILL OF HOT ROLLING, REGIME OF FREE ROLLING, ELECTROMOTOR, SECOND VOLUME, MODELING

Continuous billet mill of hot rolling represents complex dynamic multivariable system of stands, including electromechanical and technological characteristics of mill work, rolling stands of which are connected between each other with hot metal.

Problem statement

The process of hot rolling on continuous billet mill commonly occurs with pressure boosting or tension, the size of which, in order to avoid emergency situation, (drilling of hot-rolling mill) is visually (according to ammeter indication) controlled by technical team (operator) by means of change of mill stand velocity. Achievement of rolling regime, where pressure boosting or tension will be absent, so called regime of free rolling [1] will allow to provide more accurate profile of rolled stock, by means of improvement of filling [2]. Short-time run of the mill in regime of free rolling is possible to achieve due to fine adjustment of speed ratio of the mill by operator actions.

To achieve the regime of free rolling on real working hot-rolling mill, it is required to investigate multistand mill connected with each other by hot metal taking into account electromechanical and technological characteristics of its work [3].

Analysis of researches and publications

In the published works [4, 5] there represented mathematical description of rolling mill as multivariable system taking into account dynamic properties both of the system of stands with metal and electric drive, where interstand connection is considered as elastic linkage, which is relevant for mills of cold rolling, but for hot rolling mills, where elastic deformation is present, typical mathematical descriptions are not applied.
Attempts to create the system of electric drive for achieving of regime of free rolling are stated in author's certificates [6, 7, 8], maximum approximate to the real conditions is author’s certificate [6], where the considered way allows more accurately and rapidly to fix deviations from

regime of free rolling, i.e. the output of tension or pressure boosting per allowable ranges, according to the value of motor current. However in the stated source there described the way of process control only in one interstand interval taking into account that disturbance signals, which are caused by oscillations of stand rates while their regulation, are small and are not reflected by significant way on the regime of rolling in all the groups of stands, i.e. in other interstand intervals. Besides, the way does not consider the factor of dynamic loads on stand gearings, arising during metal pickup by rolls and also it does not provide adaptive change of current preset during change of rolling parameters, which are of nonrandom character, for example, during rolling of new betch.

Ideology of abovementioned author's certificates lies in memorizing of value of motor current of the stand with further its comparison with real value of velocity and in case of inequality, the system changing values of speed of related stands synchronizes the values of current with the value that is in the memory). On the working hot rolling mill the value of pressure boosting or tension current (on the basis of operation experience) does not exceed 200 A that makes 0.7% of nominal value (2800 A) and this is comparable with an error of system elements (current, speed sensors etc.). In such conditions it is impossible to provide stable operation of hot rolling mill in regime of free rolling.

Analysis of most published works showed that earlier specialists in the field of electric drive worked with the questions of control and research of rolling processes in dynamic regime, as the technologists were interested in the behavior of the system in static regime, where the specialists in the field of electric drive considered as a rule the dynamics of drive without consideration of properties of technological process.

At the present time there appeared published works [5], which consider in complex the processes of rolling taking into account dynamic properties both the system of stands with metal and electric drive, where interstand connection is considered as elastic linkage, which is satisfactorily for cold rolling mills, but for hot rolling mills, where there present elastic deformation, such mathematical descriptions are not applicable.

Mathematical description of the processes of multistand hot rolling mill, taking into account interstand connection in the form of hot metal (breakdown bar), leads to the building of complex system of equations (probably nonlinear), solution of which in dynamic working regime of the system is impossible. That is why we decided to fulfill mathematical modeling on computer in Simulink software envelope with further comparison of results of modeling with readings of real working hot rolling mill.

Statement of materials

To achieve the regime of free rolling on the hot rolling mill, it is required to follow strictly the conditions of constancy of second volumes [10]

$V_{i-1} = V_i = V_{i+1} = const$

V_i - second volume of the stand of i^{th} stand in sequence of breakdown bar entrance into the stands;

Presence of metal volume change of each of the stands leads to the change of breakdown bar geometry. Supposing that deformation in interstand interval is stable, i.e. there is no deflection of the band and it spreads along the width and height equally, and along the length the deformation is restricted by the rolls of this stand, let us approximately consider that the change of volume leads to the change of breakdown bar height and rise of secondary moment, which is determined according to [3]

$$\Delta Md_i = \frac{M0_i}{\omega 0_i}\mu_i \Delta\omega_i + M0_i \mu_i [\exp(\Theta \cdot t) - 1] \quad (1)$$

where i – is the number of stand in the sequence of breakdown bar movement;

$\omega 0_i, M0_i$ – calculated values of speed and moment on the roll of the i^{th} stand;

$\Delta\omega_i$ - change of velocity of the i^{th} stand;

S_{i-1} – surface of breakdown bar cross section of the previous stand;

R_i – radius of rolls of the i^{th} stand;

Θ – characteristic time of changing of breakdown bar height of the i^{th} stand;

Despite the steel elasticity modulus at the temperature of rolled metal is reduced considerably, it is impossible to neglect the occurrence of secondary moment caused by action of elastic forces. That is why the change of motor moment of i^{th} stand caused by the change of velocities of stands in the line of mill is considered in [3] and there obtained an equation, which connects the change of moment with the change of velocity, depending on the time taking into account elastic forces

$$\Delta Md_i = \frac{M0_i}{\omega 0_i}\mu_i \Delta\omega_i + \left(M0_i \mu_i + Eg \cdot S_{i-1} \cdot R_i\right)[\exp(\Theta \cdot t) - 1] \quad (2)$$

where: *Eg* - modulus of elasticity of rolled steel;

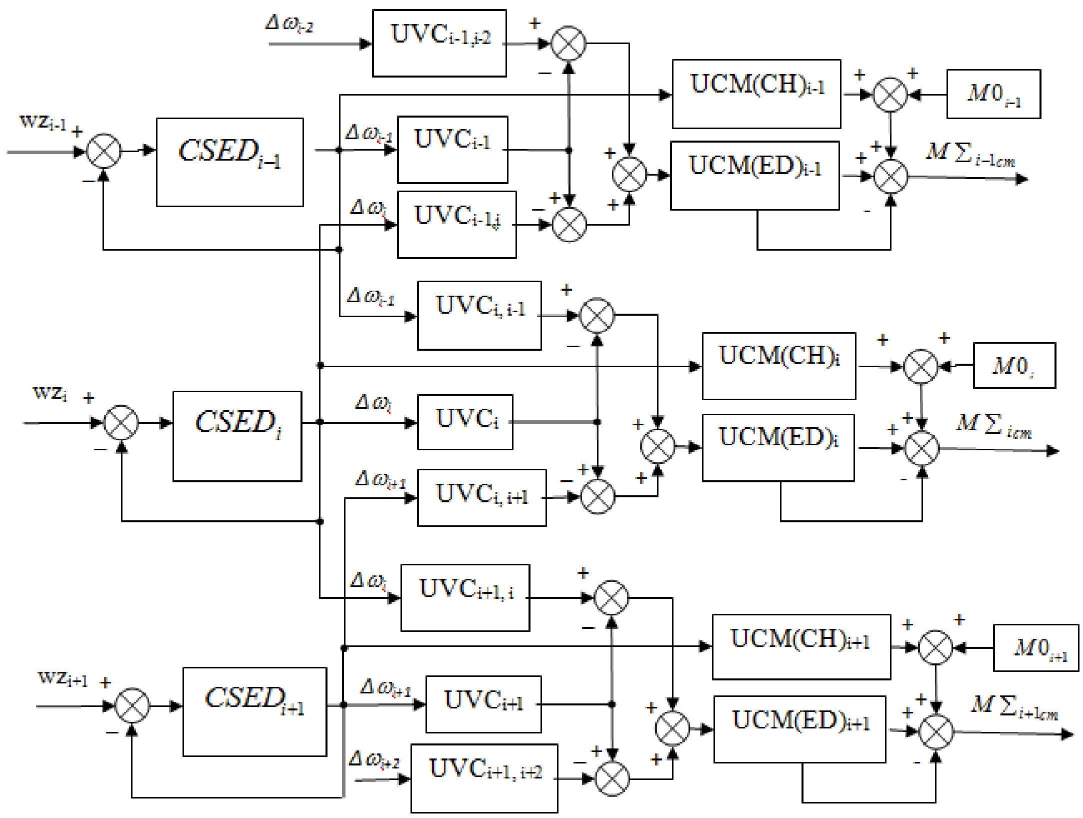

Figure 1. Mathematical model of calculation of secondary moments on the roll of motor caused by the change of velocity of hot rolling mill stands

On the base of above mentioned theory, in the figure 1 there represented structural scheme of mathematical model of 3-stand hot rolling mill, where control system of electric drive (CSED) of each of the stands is designed according to general principle of analog systems of subordinated control of engine of continuous current of independent excitation [9].

The principal of work of mathematical model is built on the change of stand rate (occurrence of errors) - Δw_i, conditioned by the errors of controlling system (speed transducer errors, etc.), difference between height of cross section along all the length of breakdown bar, different heating temperature t^0C along all the cross section of breakdown bar [9].

At the value $\Delta w_i = 0$ of all stands, on the wall there provided mode of free rolling [1].

At the value $\Delta w_i \neq 0$ (presence of velocity variation) involves the occurrence of secondary moment, which consists of:

- moment generated by the change of second volumes of stands;
- moment generated by change of breakdown bar height (1);
- moment generated by elastic deformation (2).

In the figure 1 the value of above mentioned moments are defined by the units: UVC - unit of volume comparison; UCM (CH) - unit of calculation of the moment generated by change of breakdown bar height; UCM (ED) - unit of calculation of moment generated by elastic deformation.

For analysis of system work, let us investigate the change of current intensity and velocity of stand electromotors in Simulink software envelope at different values of Δw_i.

At $\Delta w_i = 0$ (regime of free rolling), we will obtain:

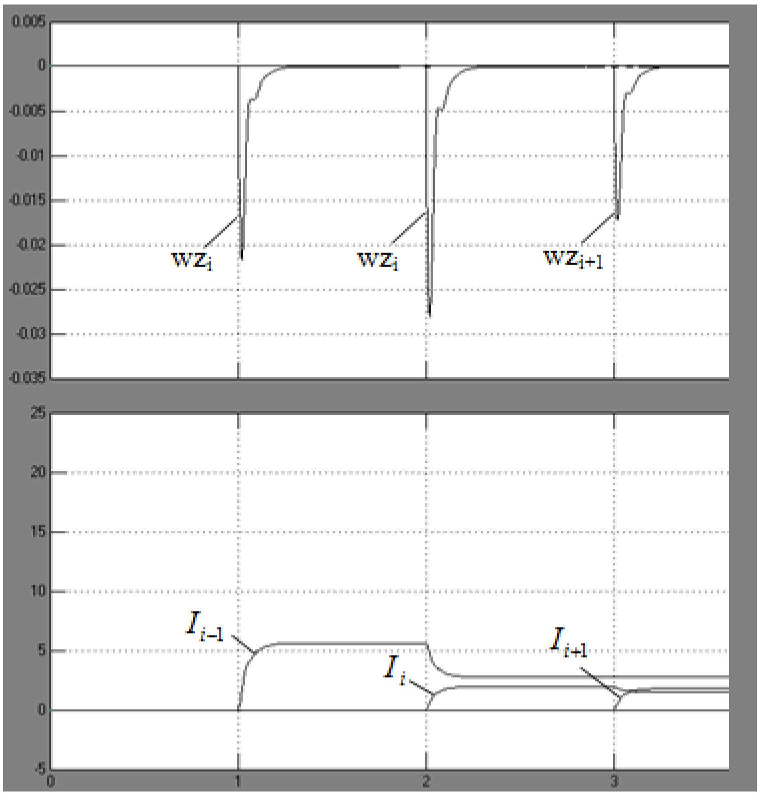

Figure 2. Oscillograph trace for current and velocity at δ=0.

In the figure 2 there shown oscillograph trace for change of current and velocity of hot rolling mill stands, which corresponds to the regime of free rolling, i.e. during metal pickup by the rolls there occur the change of current and velocity values. Reduction of the speed of each stand after metal pickup up to 0, points at the work of stand in regime of free rolling.

At δ_i=0.1 (on the 4th second) on the ith stand, we will obtain the following results:

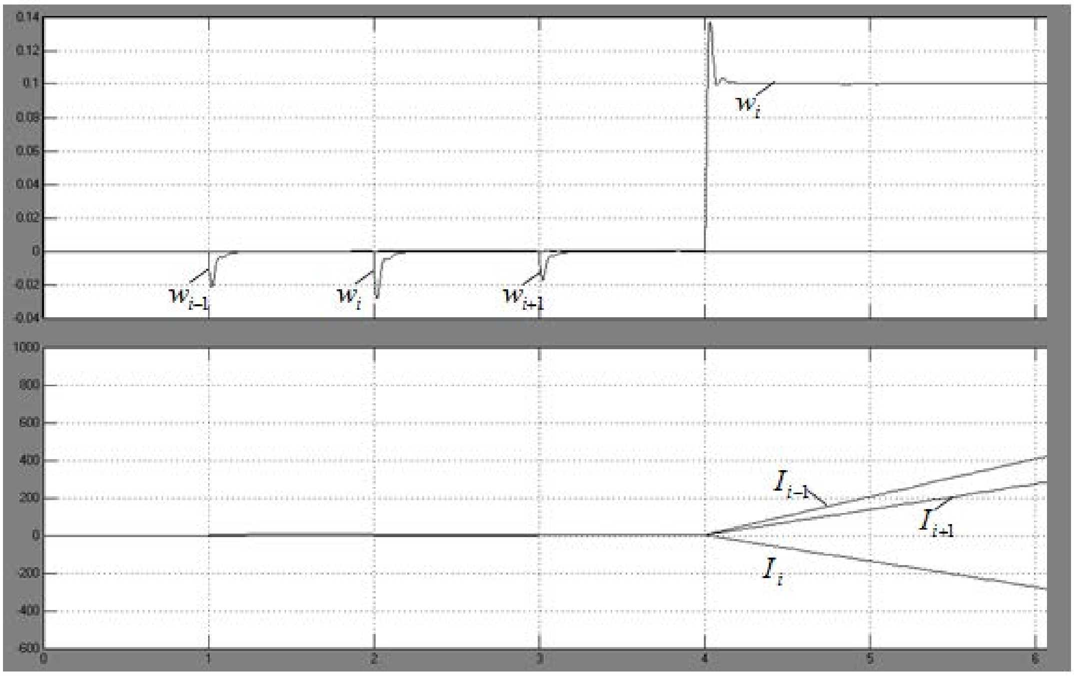

Figure 3. Oscillograph trace for current and velocity at δ_i=0,1.

In the figure 3 there shown oscillograph trace of change of current and speed of stands of hot rolling mill during the change on the 4th second of speed on the value δ_i=0.1, there appear change of value of electromotor current of all mill stands, this leads to mill operating with pressure boosting or tension [1] and impossibility of mill working in regime of free rolling.

Analysis of obtained results shows that the change of speed of one of the mill stands leads to the increase in absolute current value of all mill stands, which does not allow hot rolling mill to work in regime of free rolling.

Conclusions

Mathematical model of continuous hot rolling mill, which allows to estimate fundamentally the influence of change of speed of each stand on the work of mill in the mode of free rolling, and also to investigate the work of controlling system in order to support mill steady operation in regime of free rolling, is built.

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