Continuous multiple-stand hot-rolling mill speed rate investigation

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Abstract
The results of continuous hot-rolling mill mathematical model investigation in software environment Simulink are introduced. This software environment allows quantitative assessment of influence of each stand speed change on the mill operation in free rolling mode.
Key words: CONTINUOUS HOT-ROLLING MILL, FREE ROLLING MODE, ELECTRIC MOTOR, SECOND VOLUME, MODELING

The hot-rolling mills high rate of productivity to cold-rolling mills imposes high production requirements to the rolling speed rate control ensuring the section accuracy and the stable operation of the mill.

Statement of the problem

The conditions of constant second volume must be observed in order to ensure a stable process of continuous rolling in the hot-rolling mill [1]. The strict adherence of these conditions will allow ensuring of the mill operation in free rolling mode. This mode allows ensuring the production of more accurate required section by improving of the gauges filling [2].

The rolling process on this mills often progress with back pressure or tension, which rate is visually (by amperemeter reading) controlled by process team (system operator) by mill stands speed change in order to avoid emergency situations (hot-rolling mill cobbling).

It is possible to achieve the mode of free rolling in the short run by system operator actions due to speed ratio “fine” regulation. But manual mill setting, the problems, which affect significantly the hot-rolling mill operation quality, are not solved:

- the setting of free rolling mode is practically impossible in three or more stands simultaneously;
- the mill resetting for each ingot (because of differences in cross section, different heating t^0C etc.);
- the human error during manual setting is not excluded.

The researches conducting of speed rate of multiple-stand mill connected by hot metal considering its electromechanical and technological working features [3,4], will allow the considering of the question of stands electric drive automatic control system building. This system ensures the mill operation in free rolling mode.

The problem and its relation to scientific and practical skills

So far, indirect method of back pressure and tension measurement (currents consumed by electric motors, their speed, etc.) under hot-rolling is caused by the lack of direct method of these parameters measuring. The error in back pressure and tension current intensity measurement by indirect method is commensurable to current change value (back pressure and tension).

The mathematical model [4] of continuous multiple-stand hot-rolling mill speed rate investigation allows performing of quantitative analysis of electric drive control system operation by hot-rolling mill stands in order to ensure the mill stable operation in the free rolling mode.

Analysis of research and publications

The analysis of most publications showed that earlier the experts in electric drive worked on control and rolling processes studies under dynamic conditions because the technologists are more interested in system behavior under static conditions. And the experts of electric drive generally considered the drive dynamics without the process properties.

The rolling processes considering the dynamic properties of both metal stands systems and electric drive, where the interstand connection is described as elastic linkage, which is satisfied for cold-rolling mills, but is not applicable for hot rolling mills, where there is plastic deformation, are considered in papers [6, 7].

Some systems building approaches, which ensure the mill operation in the free rolling mode, are described in papers [8, 9, 10]. Their principle consists in storing of the motor current value and comparing it with the actual speed value. In the case of inequality, the system synchronizes the current values (actual value with the stored value) changing the adjacent stands speed values, which causes the measurements error (current sensor, speed, etc.) that is commensurable to back pressure and tension current value.

The mathematical model of continuous hot rolling mill as an object of automatic control system is presented in papers [3, 4]. It allows qualitative assessment of influence of each stand speed change on the mill operation in free rolling mode and also investigating of the control system work in order to maintain the mill stable operation in the free rolling mode considering both the object technological properties and the drive dynamic properties.

The material presentation

On the basis of the results of paper [3], the free rolling mode with the rolling stand drive control system may be presented in the form of structural diagram shown in Figure 1.

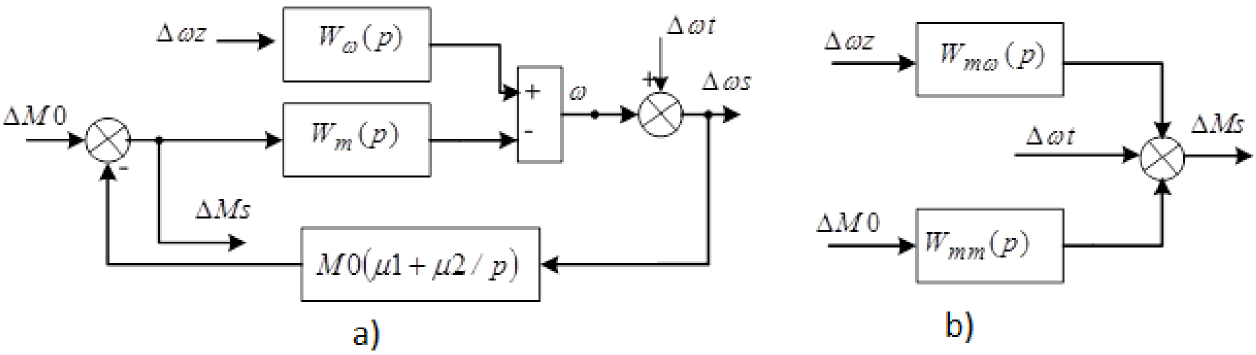

Figure 1. The structural diagram of speed stabilization system in free-rolling mode
a – initial system; b – reduced system

The control system coordinates deviations are considered in the Figure with these coordinates values in free rolling mode:

$\Delta\omega z$ - the speed demand change;

$\Delta M0$ - the change of load torque associated with the metal deformation in the mill rolls;

$\Delta\omega s$ - the motor armature rotation speed change;

$\Delta\omega t$ - the roll speed change caused by mechanical tolerance and converted to motor shaft;

ΔMs - the total load torque change;

Transfer functions:

$W_{\omega}(p)$ – linking of the speed demand change and the electric motor shaft rotation;

$W_m(p)$ - linking of the load torque on the motor shaft changes and the electric motor shaft rotational speed change (initial);

$W_{mm}(p)$ - as above but after structural diagram reduction;

M0 - calculated load torque on the motor shaft in free rolling mode;

$\mu1, \mu2$ - coefficients linking the additional torque change on the motor shaft when the speed deviation from the free-rolling speed.

It is obvious that

$$W_{m\omega}(p)=\frac{\Delta Ms(p)}{\Delta\omega s(p)}=\frac{(\mu 1p+\mu 2)}{p+W_m(p)\cdot(\mu 1p+\mu 2)},\quad (1)$$

Using the limit theorems [5], it is possible to evaluate the nature of steady-state process for various types of systems speed regulation. Let us consider the two main types of control systems: static and astatic of the first order. Let the transfer functions of the systems under consideration respectively are $WS_m = Kw\cdot\frac{NS_m(p)}{MS_m(p)}$ and $WA_m = Kw\cdot p\frac{NA_m(p)}{MA_m(p)}$, at that $\lim\limits_{p\to 0}\frac{NS_m(p)}{MS_m(p)}$ and $\lim\limits_{p\to 0}\frac{NA_m(p)}{MA_m(p)}=1$. Then for single jump of ingot move speed deviation from the free rolling mode speed, we obtain:

for static system;

$$\Delta Ms(\infty)=\lim_{p\to 0}W_{mm}(p)=\frac{1}{Kw}$$

for astatic system;

$$\Delta Ms(\infty)=\lim_{p\to 0}W_{mm}(p)\to\infty$$

Therefore, it is necessary to use a static speed control system in order to limit the load torque change when roll motion speed deviation from required speed for the free rolling mode. But the astatic system is more effective for speed stabilization when the ingot capture. Considering the fact that transition processes in the control system carry by one or two orders of magnitude faster than the processes of interstand space, the combined system, where the astatic system is worked under the ingot capture mode until the speed setting, can be implemented. And then, the static system operates when rolling ingot.

This raises the question how the suggested system will behave when load torture changing in the rolling process. For example, when ingot temperature changing, the load torture changing can reach 15-30% due to the temperature difference during the heating. Moreover, the speed control transfer ratio is reduced significantly.

From the Fig. 1 we obtain

$$W_{mm}(p)=\frac{\Delta Ms(p)}{\Delta M0(p)}=\frac{p}{p+W_m(p)\cdot(\mu 1p+\mu 2)}$$

Using the passage to the limit, we obtain that additional torque will be zero under steady-state conditions; h.e. the system exhibits self-adjusting properties.

As an example, the slave control system speed controller with varying structure is shown in Figure 2.

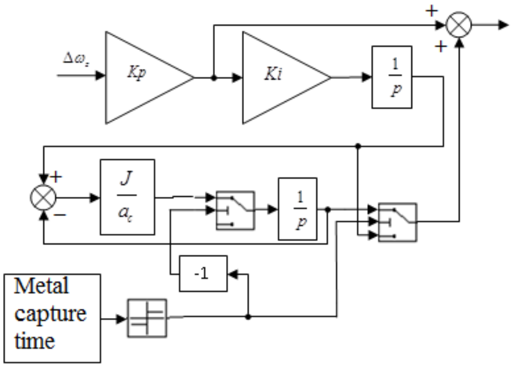

Figure 2. The speed controller with varying structure

In the slave control static system with speed P-regulator $Kw=\frac{a_c T_T\cdot StF}{Js}$

The speed error when load rise is directly proportional to the value Kw.

The natural self-adjusting mills speed difference may be one of the variants of control systems construction. The motor rotation speed is reduced with the increasing of shaft load torture at proportional speed control of mill electric drive control system. And a speed change depends on gain ratio (*k*gain) and speed controller (SC). But it also leads to a significant drive speed change when the roll entering into stand rolls. At that, a combined SC is considered; when metal capture the controller operates by the Pi-law; then the task is stored and the speed controller is switched to P-law of current demand increment control. Therefore, if there is an additional moment caused by the inconformity of currant and preceding mills speeds, then the speed controller causes the speed increasing (decreasing) directed to reduction of mills speed deviation. Currently, the controllers configuration settings calculation problem is solved analytically when changing from Pi-law to P-law.

The speed controller with the changing structure, which belongs to the electric drive control system (EDCS) of each stand, is shown in Figure 2. This system is built on the well-known principle of the slave control analog systems of direct current motor separate excitation [12].

In the Figure 3 (a, b, c) we can see the researches results oscillograms of speed control system behavior using P, PI and P + PI speed controllers with the speed of stand No2 increase on the 7th second by 10% (0.1) and the torture of stand No3 increase by 30% (caused by the variation in thickness over the entire length of the roll) on the 30th second:

Figure 3 (a) shows that when using P controller, there is a slight speed self-adjusting, which does not allow the system to ensure the mill

operation in the free rolling mode (the speed change value of each stand tends to zero);
on a system with the use of P + PI controller (Figure 3 (b)), there is rapid change in the speed value (the speed values of all the stand tends to zero) of the stand No2 and adjacent stands (speed self-adjusting effect); this allow ensuring of the mill operation in free-rolling mode, which can be seen when the stand No3 torture increasing by 30% (caused by the variation in thickness over the entire length of the roll);
when using the PI-regulator (Figure 3 (c)), the speed change by the value 0.1 on the stand No2 and the absence of adjacent stands speed change are established; it gives evidence of inability of the system to ensure the mill operation in the free rolling mode.

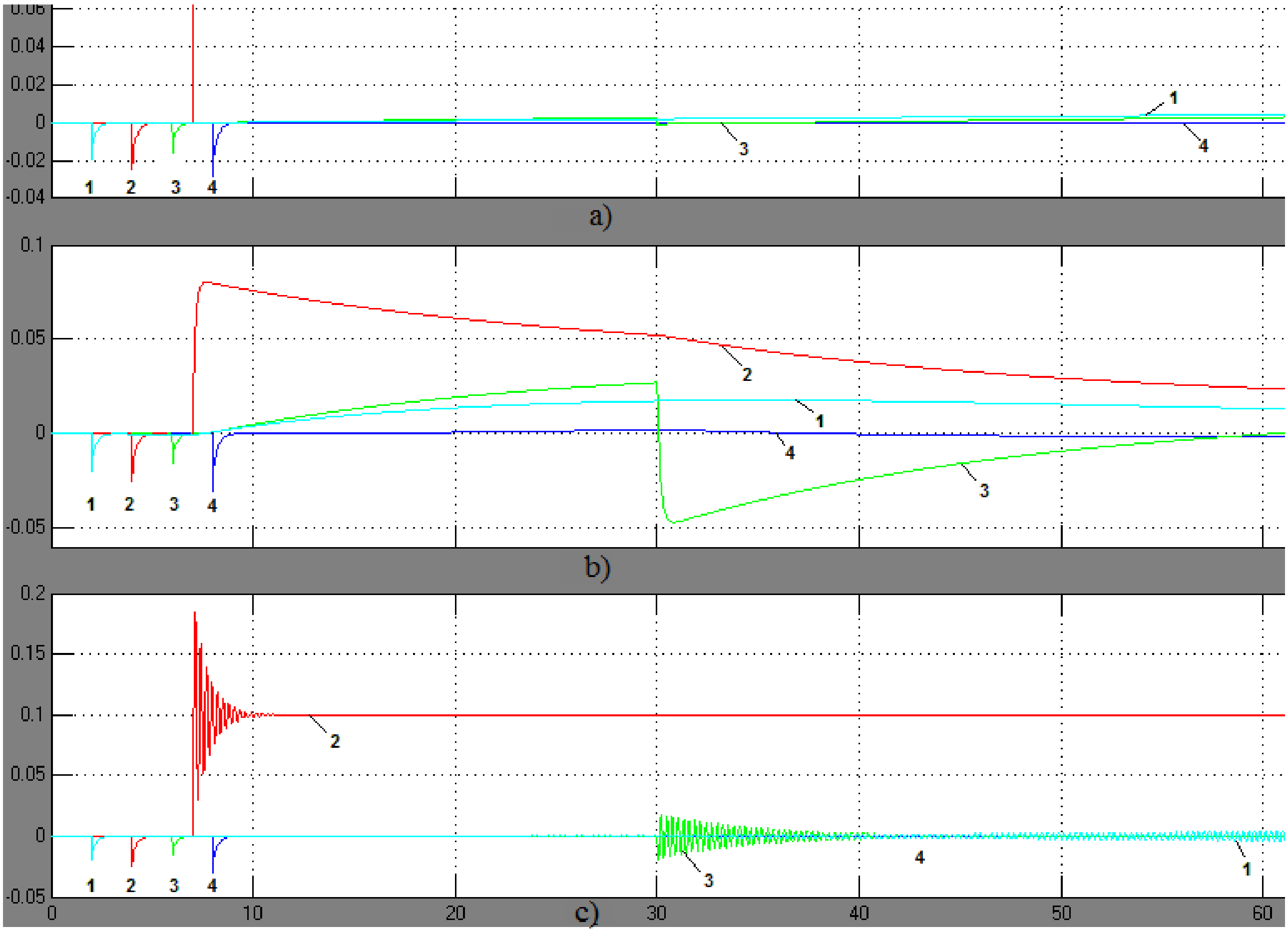

Figure 3. The oscillogram of speed change of the stans No1-4
Where:
1 – the speed of stand No1;
2 – the speed of stand No2;
3 – the speed of stand No3;
4 – the speed of stand No4.

Ensuring self-adjusting effect is caused by a significant decrease in the P-regulator transfer ratio, so if there are perturbations in rolling process (the roll variation in thickness along the length), the P-regulator operation must be investigated in order to achieve self-adjusting effect.

The research results of the motor torque change when using P, Pi and P + Pi-regulators of speed are shown in Figure 4 (a, b, c). These results show that if the speed increases on the 7th second by 10% and the static torque by 30% (30^{th} second), then in the system with P + Pi-regulators of speed, we can observe the torture stabilization on the value, which is 2-2.5 times less than in the systems where P or Pi-regulators are used. After Pi-component citing off from P + Pi-regulator (Fig. 4 b and Fig. 3 b), the torture of the stand No3 is increased abruptly by 30% on the 30^{th} second (due to the belt dimensions and its mechanical properties, the friction conditions on the contact surface and in the tension belt). It caused the rolling speed change (Fig. 3, b) of the stand No3 by 50% lasting about 10 seconds, which at first glance may seem to have a negative impact on the stand operation. But it should be noted that the load torque of current and adjacent stands (stand No2, 3, 4) have been slightly changed.

Practical operational experience of hot rolling mills shows that the abrupt increase in the load torque by 30% from the nominal one may occur in practice extremely rarely.

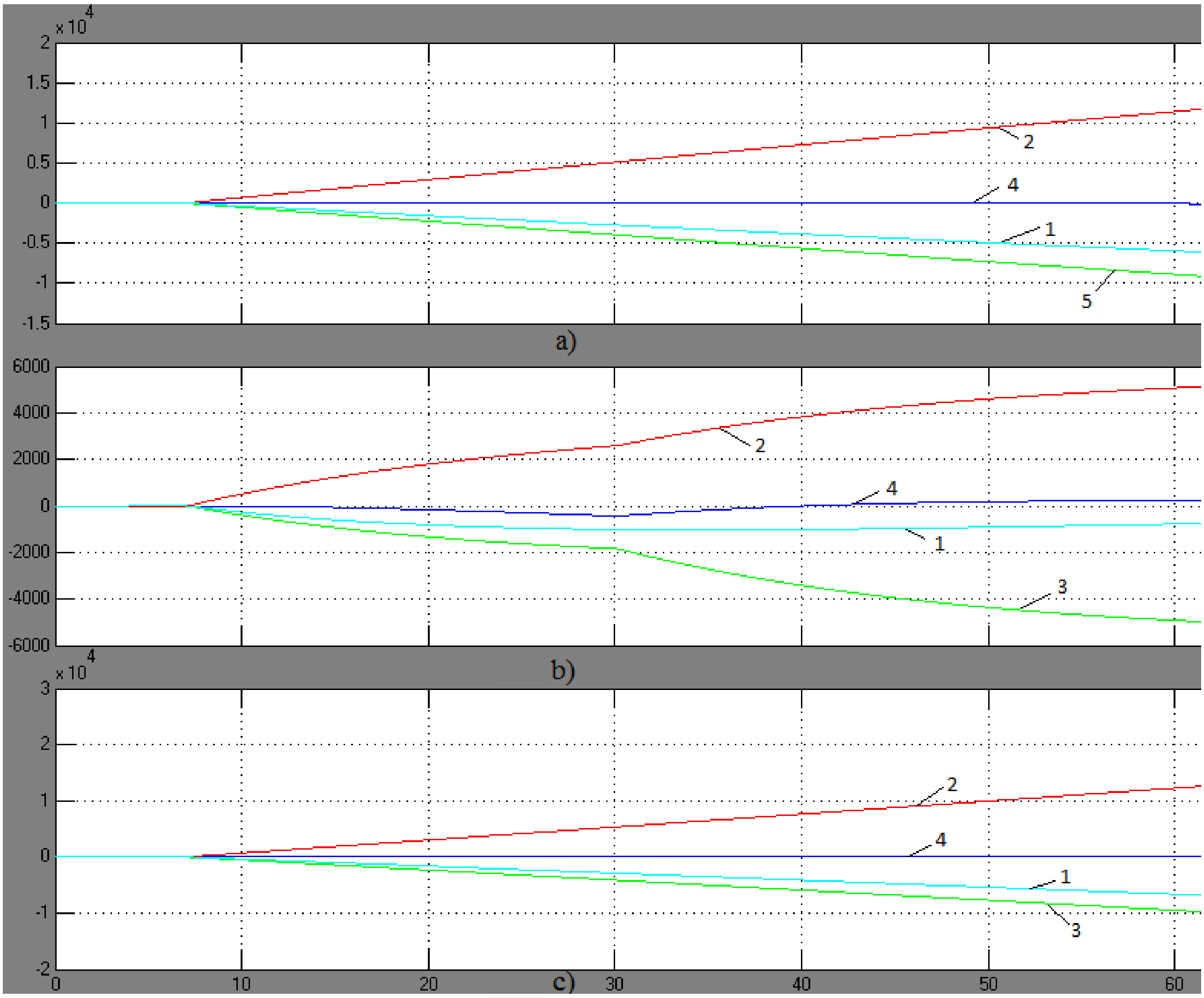

Figure 4. The oscillogram of current change of the stands No1-4
Where:
1 – the speed of stand No1;
2 – the speed of stand No2;
3 – the speed of stand No3;
4 – the speed of stand No4.

Conclusions

The conducted researches of continuous multiple-stand hot-rolling mill speed rate allowed quantitative analysis performing of the electric drive control system of hot-rolling mill stands. These researches showed that when the combined using of P + Pi-regulators, there is self-adjusting effect, which allows compensating of additional torque, which is caused by the inconformity of currant and preceding mills speeds, by the adjacent stands speed increase (decrease). This will allow the mill to operate in the free rolling mode.

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