

Conventional Control of Loop-Height in Steel Rolling Mill.



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Abstract

This paper describes the loop height formation in steel rolling mill, and how to control the height of the loop. Loops are useful in steel rolling processes. They improve the quality of the steel production and reduce the chances of tension and/or bending in the production between the successive rolling stands. The driver of the rolling stand is of DC-motor type in which its speed can be controlled. A conventional controller is used to control the height of the loop and to keep the synchronization of the rolling stands. Simulation results reveal how the synchronization is maintained and the height of the loop can be kept constant when any disturbances occur.

Keywords: Loop height, Steel Rolling Mill, Control.

Introduction

Steel rolling mill emerged in the beginning of the twentieth century in industrial systems such as textile and paper mills. Steel mills consist of several stands operated in tandem. Number of the stands depends on the type and the shape of the production those are produced [1]. Fig. (1) shows such a system of 5 stands.

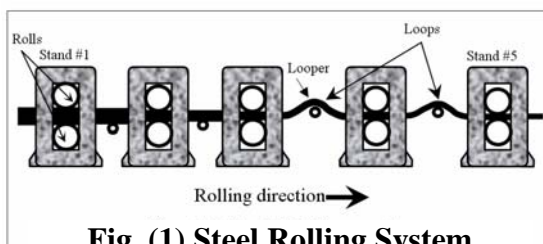


Fig. (1) Steel Rolling System

Loopers installed between the rolling stands. These loopers allow for speed differences between the stands and enable to control the integrated strip tension; therefore they improve quality of the steel production [2]. In past, Speed control of the rolling drivers was employed magnetic amplifiers then they developed to analog computers. These drivers suffer from several drawbacks like drift due to voltage and temperature variations [3].

After the progress of the microelectronics and the LSI devices, they have been available at low prices. Therefore, fully digital speed control system has become practical [3].

Modern control systems have been involved in steel rolling mills. Neural networks were used for accurate prediction of the separating force of the roll to get the best quality in final product dimension and flatness [4]. Then a new hybrid phenomenological inductive model is utilized to improve prediction of the separating force of roll [5].

For optimal control, a new approach was used in Cold Tandem mill for nonlinear systems [6]. Loopers are of variable position to damp the changes in speed of the rolls. Loopers are required to raise the line production. These tensions and longitudes affect the production quality [2].

In this paper, heights of the loops are maintained constant to reduce the effects of the tensions on the production. This is done by changing speed of the roll stands, hence by keeping the line flow-rate constant.

Steel Rolling Mill

Rolling is the process of shaping the steel into a linear element with constant cross-section. Many shapes can be constructed from simple shapes, like round rods, flat bars, strips and plates. The complex shapes have different types as, I, H, T, C, Z and many other shapes [7]. Designations, dimensions and properties of these structural shapes are declared by the American Institute of Steel Construction [8]. Two methods are used to produce steel: the ore based, or the integrated process, and the scrap based, or electric arc furnace process [9].

The line production consists of a specific number of rolling stands depending on type of the product and/or size of its cross-section. Each stand in the rolling system consists of two rolls arranged vertically to shape the production. These rolls are driven by DC-motors.

The production starts rolling from first stand, which is the metal source with a constant cross-section. The metal is passed through all the stands by changing its cross-section and shape till it reaches the last stand. The last stand is the speed governor of the train and the output product will have the desired shape. After shaping, the production is put on large cooling beds of about 40m to 80m long then they cut to the desired lengths by shears.

Rolls Drivers

Rolling stands are driven by separately excited DC-motors, due to their precise control. This form of control has separate sources on the armature and the field windings. This kind of combined control can drive the DC-motors over their rated speed [1].

The nonlinear equations of the DC-motor are:

$$\dot{N}(t) = \frac{N(t)}{\tau_m} + \frac{k \cdot \varphi(t) \cdot I_a(t)}{J} - \frac{T_L(t)}{J} \dots (1)$$

$$\dot{I}_a(t) = \frac{I_a(t)}{\tau_a} - \frac{k \cdot \varphi(t) \cdot I_a(t)}{L_a} + \frac{V_t(t)}{L_a} \dots (2)$$

$$\dot{I}_f(t) = \frac{I_f(t)}{\tau_f} + \frac{V_f(t)}{L_f} \dots (3)$$

Where $N(t)$ is the angular velocity of the motor, $V_t(t)$, $I_a(t)$, τ_a , L_a and $V_f(t)$, $I_f(t)$, τ_f , L_f are the terminal voltage, the current, the time constant and the inductance of the armature and the field, respectively. τ_m is the mechanical time constant, J is the rotational inertia, $T_L(t)$ is the load torque, and $\varphi(t)$ is the flux density.

It is required to regulate speed of the motor to a constant reference value. This can be achieved by changing values of the input voltage $V_t(t)$ and $V_f(t)$. Therefore, two controllers are utilized which are the armature voltage and the field voltage controllers. The former used when the angular speed is below the rated value. The latter enters controlling when the speed exceeds the rated.

The controller parameters are chosen so:

- ❖ Plant speed tracks reference value,
- ❖ Back emf voltage not exceed its rated,
- ❖ Armature current not exceeds its maximum.

The armature controller is of cascade type. It have inner loop to control the armature current and reduces the effect of the starting current [10]. The outer loop is used to control the angular speed to track the speed reference which is of PI controller (Proportional and Integral) type. Output of the PI-controller is used as a reference of the inner loop.

There is a reverse relation between the speed and the field current. Therefore, to increase the speed of the motor, it is required to weaken the field by decreasing the field voltage. Weakening is limited to a minimum value depending on the mechanical design of the motor. The field controller is of cascade type. The outer

loop consists of a PI-controller to control the field voltage, and its output is used as a reference value to the inner loop which controls the field current. The inner loop is only of a proportional controller. The field current is limited to a minimum value so that not to fall below that. A block diagram of the plant and its controller are shown in Fig. (2).

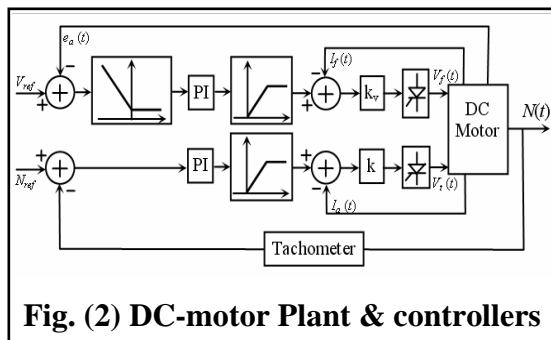


Fig. (2) DC-motor Plant & controllers

Loop Control and Synchronization

Quality of the steel production can be improved by including loops between subsequent rolling stands. The reason of this is to reduce the effect of tightness when tension is not required [2].

Loops are formed by a roll, raised by a piston into a specific height, which is varied when tightness or lengthiness take effect [1]. In rolling system, speed synchronization between the stands is very important to avoid system breakdown, which is a serious matter in industrial systems.

Synchronization can be achieved by ensuring the flow rate of the metal from the first stand (metal source) to the last stand (speed governor), be constant. This can be shown by the relation [11],

$$v_1 \cdot S_1 = v_2 \cdot S_2 = \dots = v_i \cdot S_i \quad \dots (4)$$

where i is the stand number, S_i is the output cross section, and v_i is the linear velocity of stand i .

Previously, any change happens in speed of any stand, heights of the loops were changed to bypass the speed change [2].

More changes can not overcome, thus they lead to breakdown the system.

In this paper, height of the loop is kept constant, and in reverse, speed of the tandem is changed to overcome the drawback that took place.

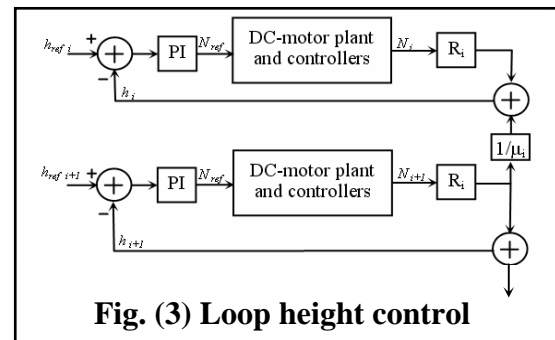


Fig. (3) Loop height control

Height of the loop can be obtained by the relation:

$$h_i(t) = 0.5\sqrt{l_i^2(t) - L^2} \quad \dots (5)$$

where, L_i is the distance between the successive stands, and $l_i(t)$ is the length of the production between two successive stands from stand i .

The aim is to keep this height constant. A PI-controller is sufficient to ensure the loop height tracks a constant value. The block diagram below shows the loop height control for two successive stands.

Simulation Results

All simulations are done by employing C++ language. The parameters used for simulation are listed in the appendix. The DC-motor is first tested to reveal tracking of the speed of the motor to its reference value if any disturbance or loading affects the rolling system.

Loading the DC-motor affects its speed, as obvious in Fig. (4-a). However, due to the speed regulation in the system, the speed tracks the reference value. Fig. (4-b) shows the voltage and the current of the armature and the field. It is obvious how the armature current is increased due to loading, while the field voltage remains

unchanged because the motor runs under the rated value.

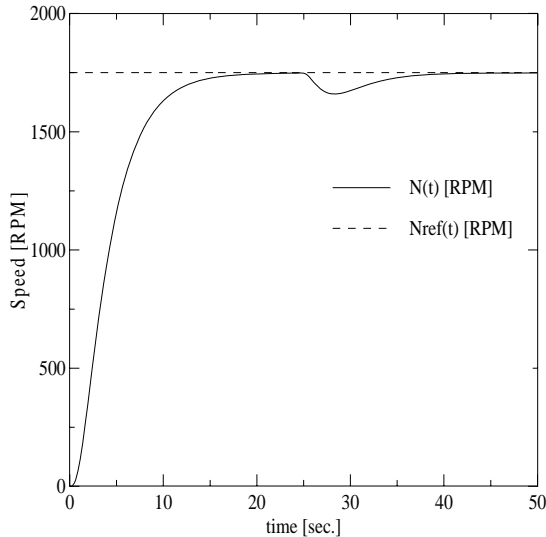


Fig. (4-a) Speed response at TL=30 N.m.

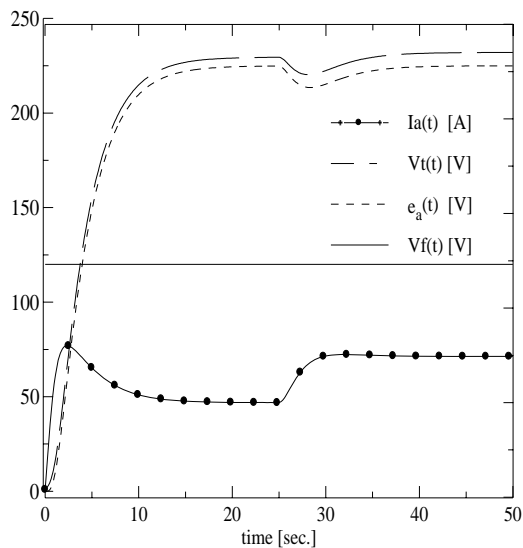


Fig. (4-b) Armature & field characteristics at load TL=30 N.m.

The other effect tested is the step change in the reference value to a higher value than the rated value. Where Fig. (5-a) describes how the tracking is done successfully. As the speed is in the excess of its rated, then it is required to decrease the field as it is obvious in Fig. (5-b). In this figure, the field voltage is decreased due to entering the field controller in the regulation. Also, the back emf of the

motor was not exceeded its rated value as required and it is shown below.

Data of the steel rolling system is given in the table below, which is of practical data of Khor al Zubir/Basrah-Iraq steel rolling mill. The data is termed as its delivery size, which is L50 scheme. The L50 scheme requires 10 stands in the tandem. The rolling system was tested on two different disturbances which are the step reference value change and the load torque change.

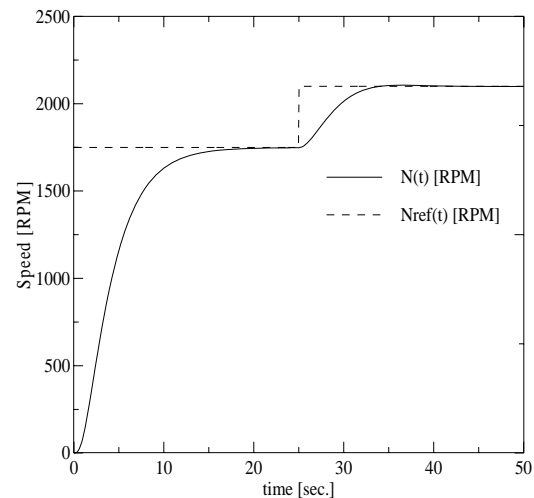


Fig. (5-a) Speed response at Ref. change

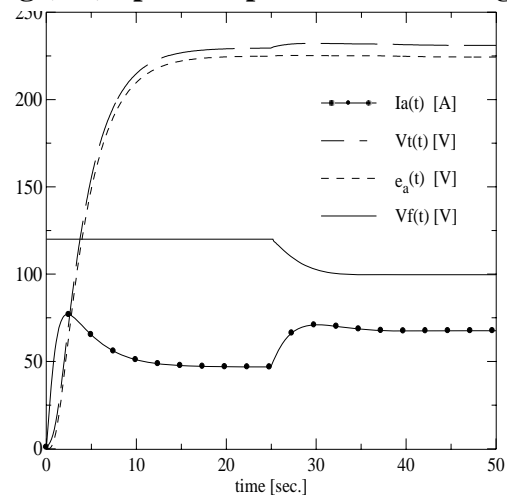


Fig. (5-b) Armature & field characteristics at reference step change

Fig. (6-a) shows the rotational speed of all the stands. It is shown when the metal enters any stand its speed will changes but is regulated to its reference value that sets to it. A speed reference change is forced on stand #7 to a value over its rated value.

As obvious, the change is damped and its effect is lesser for former stands in the downstream. Heights of the loops are changed as shown in Fig. (6-b) but the changes are bypassed and the heights return to their reference values. These are done by changing speed of the former stands.

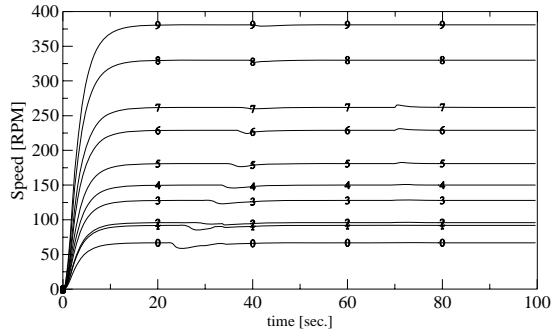


Fig. (6-a) Speed responses

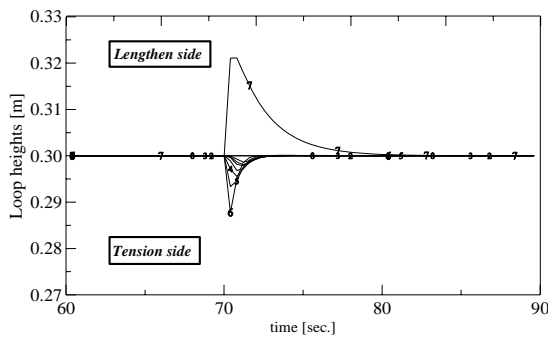


Fig. (6-b) Loop heights response at reference step change

Fig. (7-a) and Fig. (7-b) show responses for the load change of L50 scheme production. A load change on stand #8 is taken place to test the system regulation. Again, the speeds of the stands controlled and returned to their reference values, also the loop heights are overcome their changes by returning to their fixed value.

Conclusions

In this paper a constant loop height was obtained instead of using dynamic height loopers. These loopers were employed to predominate the changes in speed of the stands. The changes in the motor speed which affected by the disturbances were absorbed through varying speed of the former stands. This is accomplished by using a PI-controller in the loop-height controller.

It is suggested to employ Artificial Intelligence techniques to control these loop heights to remove the existed changes after controlling to obtain a robust control.

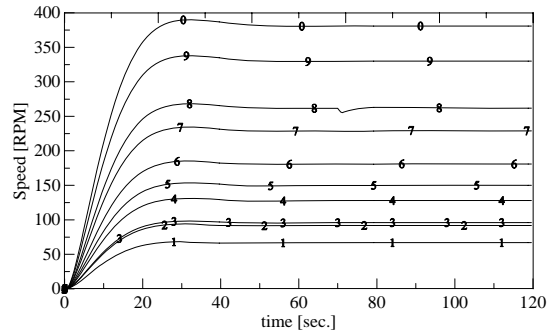


Fig. (7-a) Speed responses

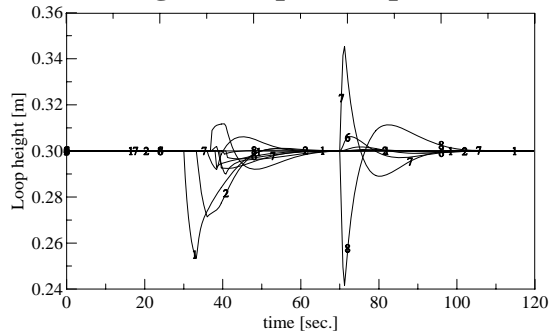


Fig. (7-b) Loop heights responses for load change

Appendix

The following parameters are chosen from a typical nameplate sheet and the frame is Frame 505 as given in Table 1, [11].

$J=2.2 \text{ kg.m}^2, \tau_m=7 \text{ sec}, L=8 \text{ mH}, \tau_a=0.08 \text{ s}, L_f=60 \text{ H}, \tau_f=0.8 \text{ s}, \varphi_{max}=10 \text{ mWb}, N_{rate}=1750 \text{ rpm}, N_{max}=2250 \text{ rpm}, I_{arate}=46.8 \text{ A}, e_a=220 \text{ V}, \text{Tacho}=0.0546 \text{ V/rad}, V_{f \text{ min}}=93.14 \text{ V}, L=5 \text{ m}, h_r=0.3 \text{ m}.$
 Armature controller, inner loop: $K=1.5$, outer loop: $K=15, T_i=0.7 \text{ s}.$
 Field controller, inner loop: $K=400$, outer loop: $K=5, T_i=0.5 \text{ s}.$
 Loop controller, $K=2$ and $T_i=0.5 \text{ s}.$

Table 1 Scheme L50 data

Stand No.	Speed N(t) [RPM]	Linear velocity v [m/s]	Load torque T_t [N.m.]	Rolls Diameter R [mm]	Cross-section S [mm ²]	Reduction factor % μ
# 1	67	1.54	2.46	438	2590	35.9
# 2	92	1.86	1.97	385	2146	17.1
# 3	97	1.98	0.64	390	2020	5.9
# 4	128	2.35	1.46	350	1700	15.8
# 5	150	2.75	1.24	350	1450	14.7
# 6	181	3.32	1.32	350	1200	17.2
# 7	229	4.20	1.38	350	950	20.8
# 8	262	4.81	0.71	350	830	12.6
# 9	330	6.05	1.00	350	660	20.5
# 10	382	7.00	0.58	350	570	13.6

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