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Simulation Model of Cold Rolling Mill

Waleed I. Breesam *[1], Khearia A. Mohamad[2], Mofeed T. Rashid[2]
[1]Electrical Department, Basra Oil Training Institute, Basra, Iraq
[2]Department of Electrical Engineering, University of Basrah, Basrah, Iraq

Correspondence
* Waleed I. Breesam
Electrical Department,
Basra Oil Training Institute, Basra, Iraq
Email: waleedbreesam@gmail.com

Abstract
This work deals with the simulation model of multi-machines system as cold rolling mill is considered as application. Drivers of rolling system are a set of DC motors, which have extend applications in factories as aluminum rolling. Interconnection of multi DC motors in such a way that they are synchronized in their rotational speed. In cold rolling, the accuracy of the strip exit thickness is a very important factors. To realize accuracy in the strip exit thickness, Automatic Gauge Control system is used. In this paper MATLAB/SIMULINK models are proposed and implemented for the entire structures. Simulation results were presented to verify proposed model of cold rolling mill.

KEYWORDS: Automatic gauge control, Cold rolling mill, DC motors, PID control, Simulation.

I. Introduction

Rolling strip is commonly used for auto manufacturing, food packaging, home, machinery, industry, devices, communications and other fields [1]. Rolling is the process of changing the cross section of a work piece or reducing the thickness by applied compressive forces through a set of two rolls that rotate in opposite directions, the distance between the rolls being less than the thickness of the incoming material [2]. Cold rolling mills work over a wide range of speeds, tensions, thicknesses and their dynamics are nonlinear and fluctuate with time. In the tandem cold rolling mill process, there are number of possible inputs and outputs [3]. The cold rolling of strip is individual process in a sequence of processes made to convert raw materials into a completed product. The cold rolling process happens after the hot rolling process in which metal slabs are heated in a furnace, and then rolled into loops of reduced thickness suitable for advance processing [4]. The thickness of the strip is reduced by two or four-high arrangement of rolled products. The rotate of rolls are shown in Fig.1 to pull and simultaneously squeeze the strip between them [5]. In a usual stand-alone four stand cold mill that shown in Fig.2, the strip is passed through four driven rolls, with every work roll supported by a backup roll of bigger diameter. Fig.3 show illustrates a typical four mill stand arrangement.

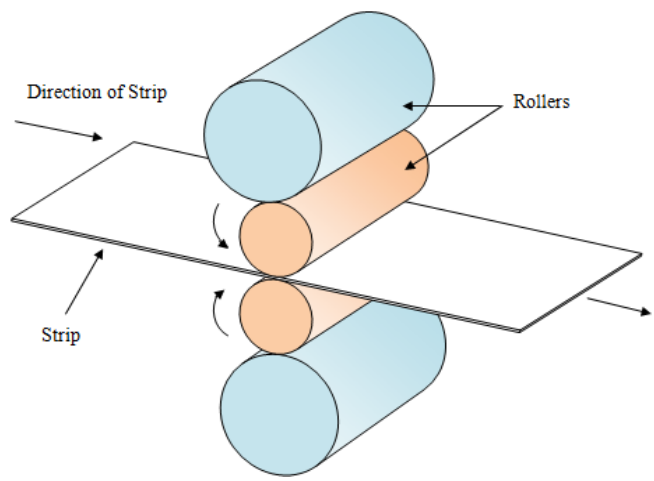

Fig.1: The rolling process.

As the strip passes through the individual of driven work rolls, the thickness is continuously reduced. This reduction in thickness is produced by high compression stress in a small region denoted as the roll bite or the roll gap between the work rolls. The strip metal is plastically deformed in this region, and there is sliding between the strip and the work roll surface. The hydraulic rams are necessary to apply the compression force, or in many older mills by an electric motor through a screw arrangement driven. The drive required to complete the reduction in strip metal thickness causes a rise in temperature at the gap which is decreased considerably by the cooling special effects of air and rolling lubricant as the strip movements between the stands. Mill instrumentation commonly consists of sensors to measure force of the roll at each stand, metal thickness at the exit of the first and last stands, inter-stand tension force, the speed of work rolls, roll gap actuator positions and in some cases the actual speed of strip. Earlier to rolling, the references of roll gap actuator position and the speed of work roll are considered based on expected steady state behavior of the mill [4].

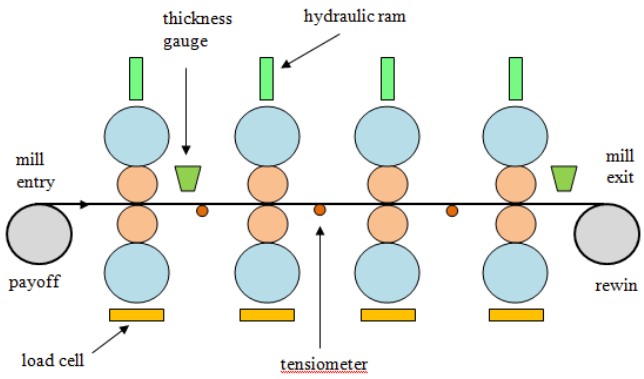

Fig.2: Stand-alone configuration of four stand cold rolling mill.

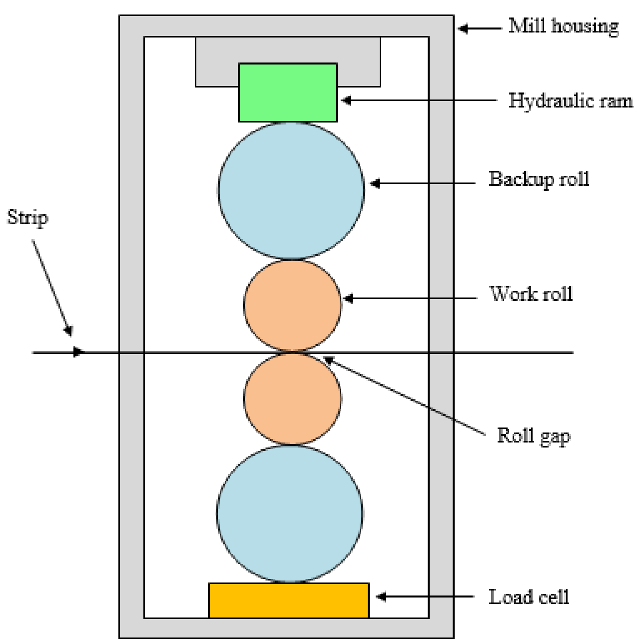

Fig.3: Typical arrangement of mill stand.

The paper is organized as follows: in Section 2, a mathematical model has been driven for single-stand cold rolling mill. In Section 3, SIMULATION of Cold Rolling System based on MATLAB Simulink have been presented. In Section 4, the results of the system model have been presented. Finally, section 7 presents the conclusions.

II. Mathematical Model of Cold Rolling Mill

A mathematical model of the cold rolling process is a collection of expressions which relate parameters of the rolling to each other. The expressions are given and apply to each mill stand. The subscripts (i) is used, where i represents the number of mill stand [4].

Denoting to Fig.4, which approximately shows the strip in the roll gap or bite region, the entering strip is thickness h_{in} at its centerline and is moving toward the roll gap with speedv_{in}. The strip exits of the roll gap with thickness h_{out} at its centerline with speed v_{out} [4,5]. In uniform rolling, the strip is squeezed between two rolls so that its thickness is reduced by a quantity called the draft [5]:

$$d = h_{in} - h_{out} \tag{1}$$

Where d = the draft in mm.

The rolling strip contact length (L) can be approached by [6]:

$$L = \sqrt{R(h_{in} - h_{out})} \tag{2}$$

The strain ε qualified by the strip in rolling is established on before and after standard thickness. In equation form [5]:

$$\varepsilon = ln \frac{h_{in}}{h_{out}} \tag{3}$$

The true strain can be used to conclude the average flow stress *Yavg* that applied to the material in flat rolling [5]:

$$Y_{avg} = \frac{k_s \varepsilon^n}{1+n} \tag{4}$$

Where *ks* = the coefficient of strength in MPa, and *n* is the strain hardening exponent.

The force F required to keep up separation between the two rolls and can be estimated based on the average flow stress practiced by the strip material in the roll gap [5, 6]. That is:

$$F = Y_{avg} wL \tag{5}$$

Where w = the strip width.
L = contact length.

The torque (T) in rolling can be calculated by supposing that the roll force is positioned on the work as it passes between the rolls, and that it performances with a moment arm of one half the contact length L. Therefore, torque for each roll is [5]:

$$T = 0.5\ F\ L \tag{6}$$

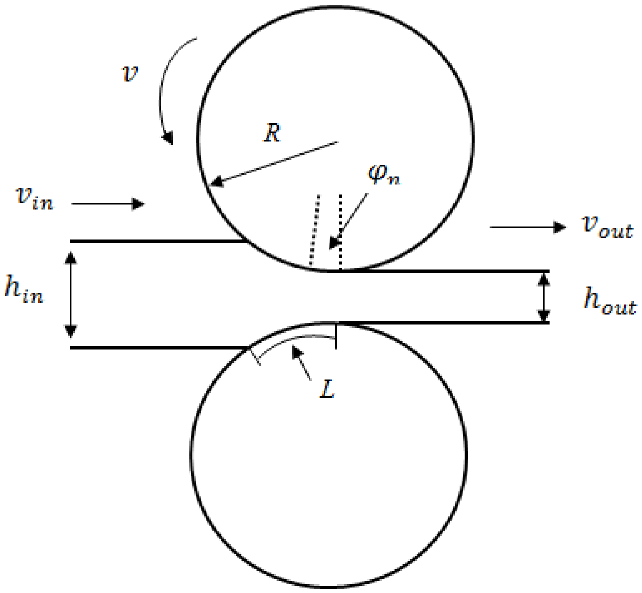

Fig.4: Roll gap or bite area

The forward slip *f* is given by:

$$f = \frac{v_{out} - v_r}{v_r} \tag{7}$$

Where v_{out} the speed of strip at the exit of the roll and v is the peripheral speed of the work roll. A formula for the forward slip that is suitable for control expansion [4]:

$$f = \frac{h_{in} - h_{out}}{h_{out}} \left(\frac{\varphi_n}{\varphi_1}\right)^2 \tag{8}$$

Where

φ_1 is the angle of contact

φ_n is the angle at the neutral plane

The angle of contact is given by

$$\varphi_1 = \sqrt{\frac{(h_{in} - h_{out})}{R}} \tag{9}$$

The angle φ_n is given as [7]:

$$\varphi_n = \frac{\tan(a+b)}{\sqrt{\frac{R}{h_{out}}}} \tag{10}$$

Where:

$$a = \frac{\pi}{8} \frac{log_e(1+r)}{\sqrt{\frac{R}{h_{out}}}} \tag{11}$$

$$b = \frac{1}{2}\ tan^{-1}\sqrt{\frac{1-r}{r}} \tag{12}$$

$$r = \frac{h_{in} - h_{out}}{h_{in}} \tag{13}$$

The relationship between the work roll gap *S*, the exit thickness h_{out}, and the roll force *F* generated at the roll stand is given as [8, 9]:

$$h_{out} = S + \frac{F}{M} \tag{14}$$

Where M is the mill modulus

The block diagram of exit thickness control is shown in Fig.5. In the inner loop of hydraulic Automatic gauge control (AGC) system, the difference between desired position of roll gap and the real position measured by distance sensor of hydraulic cylinder is the input of automatic position controller (APC) system. APC can affect the exit strip thickness by controlling the position of hydraulic cylinder [1].

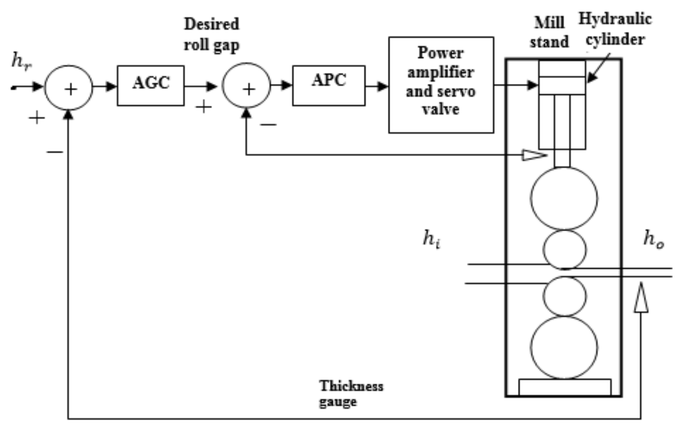

Fig.5: Exit strip thickness control block diagram.

The speed synchronization between different stands is very significant in rolling systems to avoid system breakdown, which is actual serious matter in rolling systems [10]. Commonly, the mass flow model is applied assuming that the strip width is constant during the mill, it can be expressed anywhere as following:

$$MF = v_s\, h \tag{15}$$

Where v_s the strip speed and h is the thickness at exacting point of interest, which is typically at the input or output of the stand. Mass flow conservation across the roll bite is given by [4]:

$$v_{in,i}\, h_{in,i} = v_{out,i}\, h_{out,i} \tag{16}$$

The relation between the peripheral speed of the work roll v_r and rotational speed ω_r is:

$$\omega_r = \frac{v_r}{R} \quad rad/s$$

Thus, the speed of the work roll in r.p.m is:

$$N_r = \frac{\omega_r \times 60}{2\pi}$$

Rolling mill process has been provided with the assistance of the roll driver, which is separately excited DC motor type as shown in Fig.6.

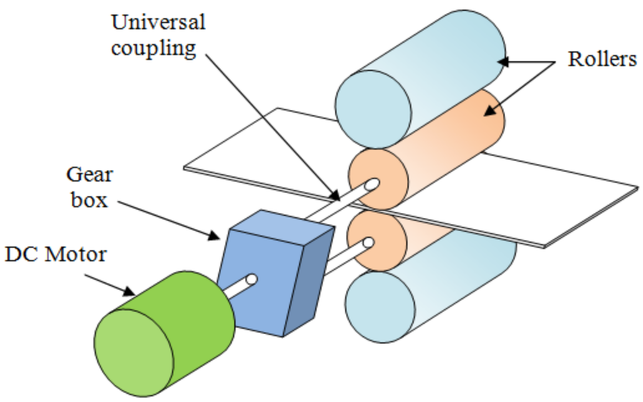

Fig.6: The main drive system of rolling mill.

III. SIMULATION OF COLD ROLLING SYSTEM

Four stand cold rolling mill system have been implemented in MATLAB software. The strip and mill parameters are given in the table 1. The implemented Simulink model of force equation is shown in Fig.7. The Simulink model used to obtain the forward slip is shown in Fig.8. The strip thickness control Simulink model for single stand is shown in Fig.9. PD controller is used as APC while PI controller is used as AGC. Also the Simulink model of hydraulic servo system is shown in Fig.10.

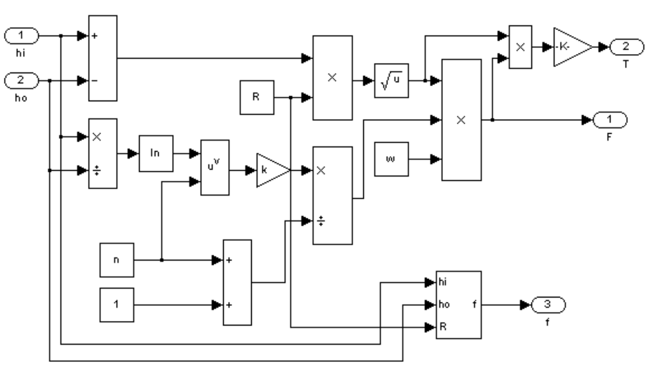

Fig.7: Implemented Simulink model of force equation.

TABLE 1. The mill and strip properties

Parameters	Dimension
Work roll radius (R)	250 mm
Mill modulus (M)	3,921 kN/mm
Strip width (w)	600 mm
Strength coefficient (*ks*)	240 MPa
Strain hardening exponent	0.15

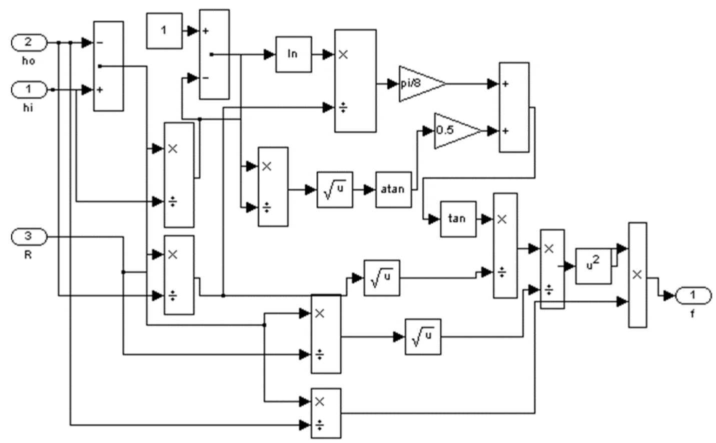

Fig.8: Simulink model of forward slip.

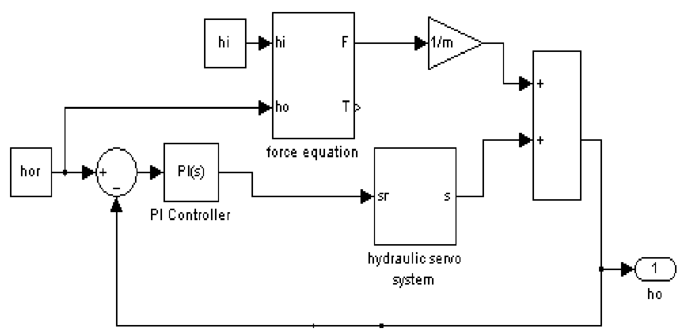

Fig.9: Simulink model of the strip thickness control.

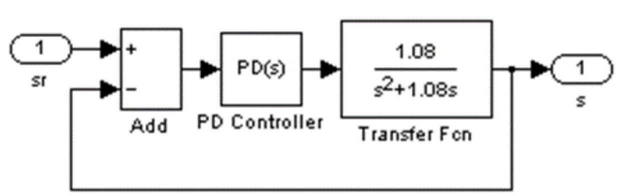

Fig.10: Simulink model of hydraulic servo system.

IV. Simulation Results

Referring to Fig. 6, the speed responses of the DC motors are shown in Fig.11 while the work roll speed for each stand are shown in Fig.12. To maintain the synchronization between the stands set-point, coordinated motion control method to drive the motors has been used. Also the output thickness responses are shown in Fig.13. The responses of output thickness and motor speed for a +10 % step change in the input thickness to stand 1 at t = 1 second are shown in Fig.14 and Fig.15 respectively. It is notice that the speed of the motor at stand 2 that colored green have been changed to keep the synchronization when this disturbance occurred. Fig.16 show the output thickness at stand four which represent the final stage of material product at the desired thickness equal to 0.38 mm.

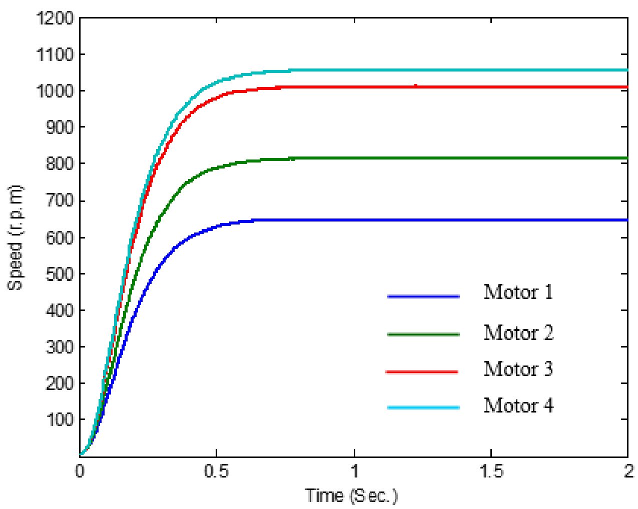

Fig.11: Speed response of the motors.

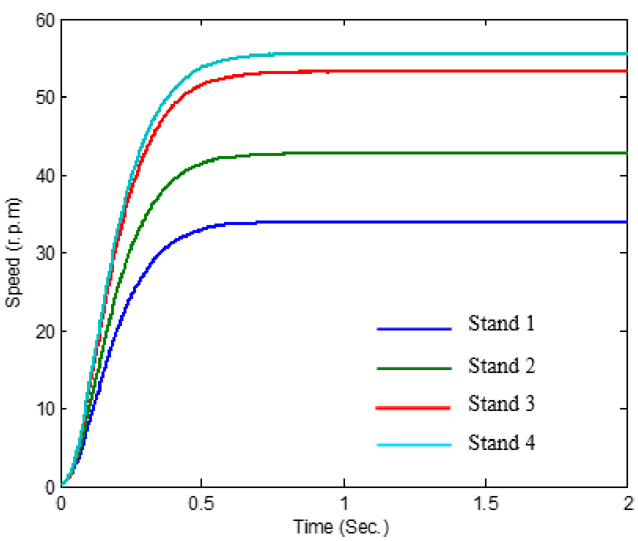

Fig.12: speed response of the work roll for each stand.

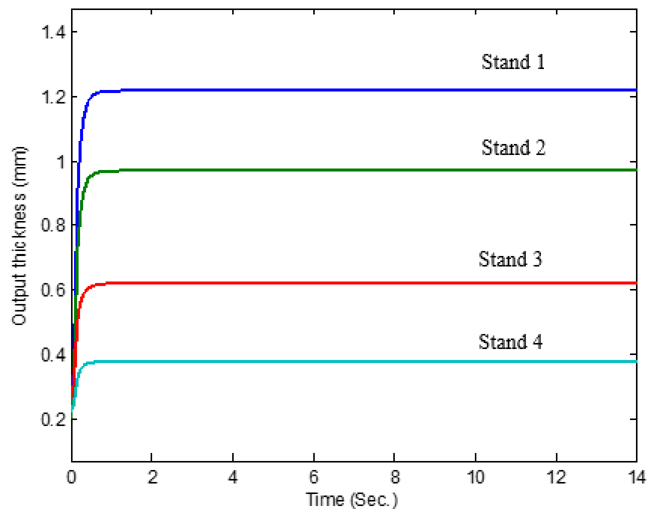

Fig.13: Output thickness responses.

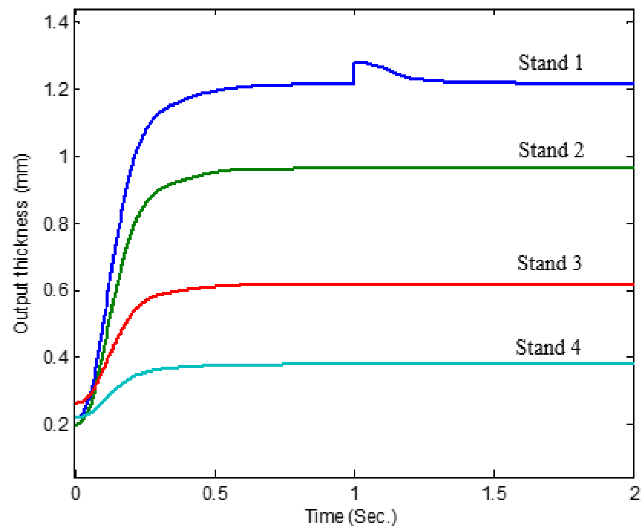

Fig.14: Output thickness responses to +10% step change in stand 1 input thickness.

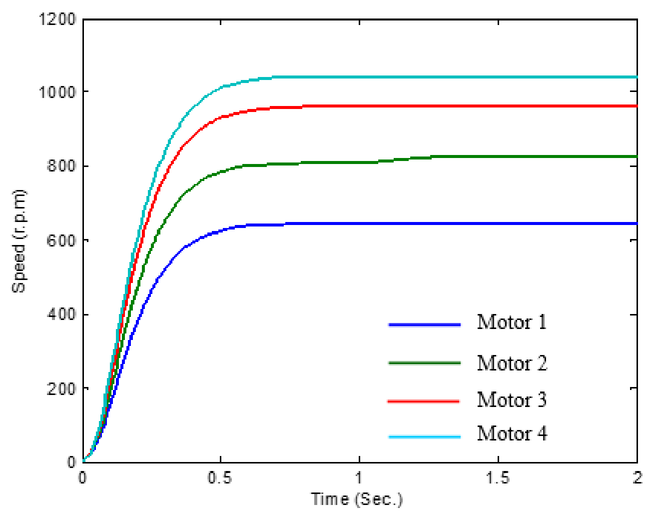

Fig.15: Motor speed responses.

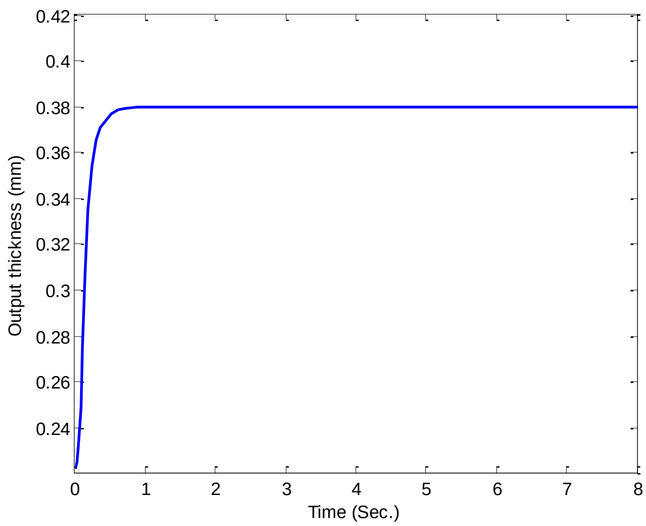

Fig.16: Output thickness of stand four.

V. Conclusions

In rolling mill, the accuracy of the strip metal output thickness is a very significant factors. To get high accuracy in the output thickness of the strip, the automatic gauge control system is used. In this paper, mathematical model of four stand cold rolling mill is established. PI controller in outer loop has been designed for the output thickness of strip whilst PD controller in inner loop for the work roll actuator position. The simulation results show the responses of the modeling system.

Conflict of Interest

The authors have no conflict of relevant interest to this article.

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