

## REAL-TIME TENSION CONTROL IN A MULTI-STAND ROLLING SYSTEM

by

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### ABSTRACT

The problem of real-time tension control in a metal-strip processing line is addressed. The tension in a metal strip changes due to not only the speed difference but also thickness changes at the ends of a span. The mathematical dynamic model which describe relationship between the tension change and the roll-speed change is improved to include the effect of the strip thickness change on tension variation.

Through the computer simulation of this model, the parameter sensitivity analysis and the static and dynamic characteristic study are carried out. The tension variation in a metal strip turned out to be very sensitive to the thickness variation as well as to the speed difference at the ends of the metal strip.

In the rolling process, the master speed drive is usually located at the last stand. The speeds of rollers in upstream stands are adjusted with respect to the speed of the last stand to compensate the speed change for the tension regulation. A new tension control strategy in a multi-stand rolling process is suggested. The tension transfer phenomena is used in the design of the suggested controller. The developed mathematical model is used to design a controller for the real-time control system. A real-time software for the tension control in a multi-stand system is designed by using the VxWorks real-time scheduler and the Force Target board.

The suggested control strategy needs less control efforts and shows better performance than those of the existing control method in a rolling process.

### NOMENCLATURE

- A Cross-sectional area of strip
- E Modulus of elasticity
- L Length of strip span
- $h_{i0}$  Steady-state value of strip thickness
- $H_i$  Change in strip thickness from a steady-state operating value
- $h_i$  Strip thickness =  $h_{i0} + H_i$

- K<sub>s</sub> Equivalent stand spring constant
- p Rolling force
- P<sub>i</sub> Change in rolling force from a steady-state operating value
- R Radius of roll or roller
- S Change in roll gap from a steady-state operating value
- t<sub>i0</sub> Steady-state value of strip tension
- T<sub>i</sub> Change in strip tension from a steady-state operating value
- t<sub>i</sub> Strip tension = t<sub>i0</sub> + T<sub>i</sub>
- U Control value
- v<sub>i0</sub> Steady-state operating value of strip speed
- V<sub>i</sub> Change in strip speed from a steady-state operating value
- v<sub>i</sub> Strip speed = v<sub>i0</sub> + V<sub>i</sub>
  
- ε Strain of metal strip

Subscripts:

- 0 Steady-state operating condition
- i 1,2,3,4 . . .

## INTRODUCTION

The automatic gauge control (AGC) system in a metal strip rolling process generally consists of the three major control systems: a roll gap control, a roll speed control, and a strip tension control system. These control systems severely interact each other(1). The thickness of the strip can be changed by using the roll gap, but can not be controlled precisely without controlling the tension of the strip. The tension in a strip can be again changed by speeds and thickness at the ends of a strip. It is also reported that the effect of roll gap control can be cancelled out due to the interaction between the strip tension and roll gap. But, authors did not found literature on the mathematical model that fully describes interactions among the roll gap, the roll speed, and the strip tension. In order to design a highly accurate AGC system, a better mathematical model is necessary.

Grimble(2) derived a mathematical model which describes the relationship between the strip tension and the roll speed. He studied the effects of the parameter changes and the undriven rolls on tension variation using his mathematical model. But, his model can be used to calculate tension variation only in a single span. Moreover, from his mathematical model, it is impossible to predict the tension transfer and the tension variation due to the thickness change at the ends of a strip.

The minimum tension control(MTC) method was developed by Siemens in Germany(3). In MTC method, the strip tension is calculated from the change in rolling torque in a stand before and after the strip enters the following stand. And, the method of successive set point coordination of speeds is used to control the strip tension with the MTC loop superimposed. But, with this method, it is not easy to determine the strip tension since the change in rolling torque due to tension variation is very small in value compared with the operating torque value. Moreover, there is no way to determine the tension variation after the strip is already nipped at both ends of the strip.

In this paper, a new mathematical model which describes the relationship among the roll gap, the roll speed, and the strip tension is developed. Through the computer simulation of this model, characteristics of tension variation due to the change in roll gap and speed are studied. The tension variation in a metal strip turned out to be very sensitive

to the thickness variation as well as to the speed difference at the ends of the metal strip. The cancellation mechanism of roll gap control due to the tension interaction is also shown by using this model.

In the industrial rolling process, the master speed drive(MSD) is usually located at the last stand. The speeds of rolls in upstream stands are adjusted with respect to the speed of the last stand to compensate the speed change for the tension regulation. A tension control strategy in a multi-stand rolling process is suggested. In the suggested control strategy, the MSD is located in the first stand(or upstream stand) and the tension transfer phenomena is used. The suggested control strategy needs less control efforts and shows better performance than those of the existing control method in a rolling process.

The developed mathematical model is used to design a controller for the real-time control system. A real-time software for the tension control in a multi-stand system is designed by using the VxWorks real-time scheduler and the Force Target board.

### STRIP TENSION, ROLL SPEED, STRIP THICKNESS RELATIONSHIP

Consider a metal strip with tension between two stands as shown in Fig. 1. In the Fig. 1, the strip is transported from left to right and rolled to change its thickness from  $h_0$  to  $h_1, h_2$ . The machine-direction strain of the metal strip is  $\epsilon_0$  in the entrance side of stand #1,  $\epsilon_1$  between stand #1 and stand #2, and  $\epsilon_2$  in the exit side of the stand #2. In order to facilitate the derivation of the mathematical model for tension, the rolling process is divided into the plastic (01 - 1, 12 - 2 region) and the elastic region(1 - 12 region) as shown in Fig.1. It is assumed that the strip thickness at the neutral point (where the strip speed and the tangential speed of the roll are same: 1 and 2 in Fig.1) is same as the thickness at the exit side of the stand.

For the plastic and the elastic regions in Fig. 1, the law of conservation of mass, stress-strain relationship, and Hooke's law are used to derive a mathematical model as follows(4) which describes a dynamic relationship among the strip tension, the roll speed, and the strip thickness.

$$\frac{d[T_1(t)]}{dt} = -\frac{v_{20}}{L}T_1(t) + \frac{v_{10}}{L} \frac{A_1E_1}{A_0E_0} T_0(t) + \frac{A_1E_1}{L} \left[ \frac{V_2h_{20} + v_{20}H_2 - v_{120}H_1}{h_{10}} - V_1(t) \right] \quad (1)$$

Equation (1) shows that the tension in a strip between two stands is very sensitive to not only the speed changes but also the thickness changes of strip at the ends of the strip.

The tension variations due to changes in speed and thickness are calculated using the mathematical model and the parameters. The results are shown in the Table 1. Note that more variations in speed or thickness than 7 % of the steady-state values may cause a plastic elongation for the material used, which may induce a necking in the strip.

### CANCELLATION OF ROLL GAP CONTROL DUE TO TENSION INTERACTION

When the strip at the exit side is thicker than desired, the AGC will reduce the roll gap resulting in lower entry strip tension. Consequently, when the entry strip tension reduces, the exit strip thickness increases, canceling the effect of AGC(1). Literature which can be used to demonstrate this cancellation mechanism was not available. This cancellation mechanism can be shown by using the mathematical model developed together with equations for the rolling process and the rolling force.

The rolling process can be represented as follows by using the gauge meter principle(5).

$$H_2 = S_2 + \frac{P_2}{K_{S_2}} \quad (2)$$

The change in the rolling force can be calculated by using a linearized version of the Bland and Ford equation for the rolling force as follows(6).

$$P_2 = \frac{\partial p_2}{\partial T_1} T_1 + \frac{\partial p_2}{\partial T_2} T_2 + \frac{\partial p_2}{\partial h_1} H_1 + \frac{\partial p_2}{\partial h_2} H_2 \quad (3)$$

Equations (1) - (3) can be solved simultaneously to calculate the strip thickness and the strip tension for the given roll gap and roll speeds. The roll gap and the roll speed were assumed to be controlled perfectly. The simulation results are shown in Fig. 2 - 3. The parameters used for the simulation are shown in Table 2. The roll gap is reduced by 1 % of the operating roll gap( $S_2=1.1189$  mm) to obtain a desired thickness reduction(about  $9.5 \mu\text{m}$ ) in the strip at the exit side of the last stand. But, the reduction in the roll gap( $S_2$ ) introduces the reduction in tension(see equations (1), (2), and Fig. 2), and again the reduction in the tension( $T_1$ ) causes increase in the rolling force (see equation (3)). The increase in the rolling force turned out as the increase in the thickness(see equation (2)), reducing the effect of roll gap control. As shown in Fig. 3, the strip thickness is not controlled as desired (about 60 % error).

## TENSION CONTROL STRATEGY IN MULTI-STAND SYSTEMS

In many industrial multi-stand rolling systems, the MSD is usually located at the last stand. And, upstream roll speeds are correspondingly adjusted to keep the strip tension unchanged in upstream spans even with the roll gap changed in the last stand(MSD) to avoid the cancelling effect of AGC. But, the strip tensions in upstream spans may not be kept unchanged due to the tension transfer phenomena even though the speeds are adjusted(7). Thus, the proper selection of the location of the MSD is important for the precise control of the tension and the thickness of the strip.

Consider a multi-stand rolling system shown in Fig. 4 as an example. When the MSD is in location (B) of Fig. 4,  $V_3$  should be changed to control  $T_3$ . And  $V_2$  and  $V_1$  are changed accordingly to compensate the tension variation due to change in  $V_3$ . This approach is called as the successive control (or progressive set-point coordination control). The MSD might be located in the last stand since the control of final thickness of the strip at the exit side of the last stand is very important. But, as pointed out in the previous section, the control of strip tension is very important for the precise control of the strip thickness. And it is not desirable to locate the MSD in the downstream for the good control of tension since tension is transferred from an upstream span to downstream spans.

In this section, the successive control which is commonly used in industry will also be examined. And, the cases of tension control with different locations of the MSD will be studied. Finally, a tension control strategy for multi-stand rolling system will be suggested which utilizes the tension transfer mechanism.

### Successive Control

The mathematical model for tension  $T_i$  ( $i = 1, 2, 3$ ) in the system shown in Fig. 4 is as follows(8). The effect of thickness change on tension variation will be dropped from this point to simplify the demonstration of a tension control idea to be suggested.

$$\frac{dT_1}{dt} = -\frac{v_{30}}{L_1}T_1 + \frac{v_{10}}{L_1} \frac{A_1 E_1}{A_0 E_0} T_0 + \frac{A_1 E_1}{L_1} (V_2 - V_1) \quad (4)$$

$$\frac{dT_2}{dt} = -\frac{v_{30}}{L_2}T_2 + \frac{v_{20}}{L_2} \frac{A_2 E_2}{A_3 E_3} T_1 + \frac{A_2 E_2}{L_2} (V_3 - V_2) \quad (5)$$

$$\frac{dT_3}{dt} = -\frac{v_{30}}{L_3}T_3 + \frac{v_{30}}{L_3} \frac{A_3 E_3}{A_2 E_2} T_2 + \frac{A_3 E_3}{L_3} (V_4 - V_3) \quad (6)$$

Observing equations (4), (5), and (6), the strip tension  $T_i$  can be controlled by the speed difference at the ends of a metal strip ( i.e.,  $V_{i+1} - V_i$  ). But, as can be seen in equations (4) and (5), the change in  $V_2$  will vary both  $T_1$  and  $T_2$ . The idea of successive control is as follows. Assume that the MSD is in the location (A) of Fig. 4. When  $V_2$  is changed to control  $T_1$ ,  $V_3$  and  $V_4$  are changed to compensate the tension variations due to change in  $V_2$ . For the change in  $V_2$ ,  $T_2(\infty)$  can be calculated by using equations (4) and (5) in steady state. But,  $T_2(\infty)$  will be the same as  $T_2(0)$  in steady state. That is, tension variation  $T_1$  due to change in  $V_2$  is transferred to  $T_2$  (7).

In other words, the successive control is based on the following mathematical model instead of the model described by equations (4), (5), and (6).

$$\frac{dT_1}{dt} = -\frac{v_{30}}{L_1}T_1 + \frac{A_1 E_1}{L_1} (V_2 - V_1) \quad (7)$$

$$\frac{dT_2}{dt} = -\frac{v_{30}}{L_2}T_2 + \frac{A_2 E_2}{L_2} (V_3 - V_2) \quad (8)$$

$$\frac{dT_3}{dt} = -\frac{v_{30}}{L_3}T_3 + \frac{A_3 E_3}{L_3} (V_4 - V_3) \quad (9)$$

If the mathematical model of the systems is represented by equations (7) - (9), which does not fully describe the system, the successive control strategy is very effective.

### **Multi-Stand Tension Control Strategy Using Tension Transfer**

From the mathematical model described by equations (4) - (6), it is clearly shown that strip tension  $T_i$  depends not only the speed difference at the ends of a strip but also the tension  $T_{i-1}$  in an upstream strip. Thus, when  $V_2$  is changed to control  $T_1$  with the MSD in the location (A) of Fig. 4,  $T_2$  and  $T_3$  does not actually vary much even though  $V_3$  and  $V_4$  are not changed successively. If  $V_3$  and  $V_4$  are changed successively, they will become rather disturbances on  $T_2$  and  $T_3$ .

An idea to be suggested is to use the tension transfer mechanism and not to change the speeds successively for the tension control in multi-stand systems.

### **Tension Control and MSD Location**

When the MSD is located in a downstream stand, the tension transfer mechanism can not be used in the tension control since tension is transferred from upstream to downstream. And it is helpless to use successive coordination of speed to compensate the effect of disturbance ( speed or thickness ). This approach ( MSD in downstream stand and successive control ) needs extra control effort compared with the suggested idea and will

generate undesirable transient performance. Considering the tension transfer and MSD location, a simple and effective tension control strategy is to locate the MSD in the upstream of the strip and use the tension transfer mechanism together with speed adjustment.

### **Tension Control Strategy Suggested**

An idea that authors want to suggest is to locate the MSD in an upstream stand rather than in downstream stand(or last stand) and to use the phenomenon of tension transfer for the control of tension in the multi-stand rolling systems. Then, speeds of rolls in downstream stands need not adjusted with respect to the speed of the master drive to compensate the speed change for the tension regulation. Examples will be solved later in this paper to demonstrate the advantages of the suggested strategy compared with the method that is commonly used in the industries today(progressive set point coordination control with MSD in the last stand). Before the comparison of the methods, a real-time tension control system will be designed in the following section.

## **DESIGN OF REAL-TIME SOFTWARE FOR TENSION CONTROL**

A real-time software for tension control in a multi-stand rolling system is designed in this section. Consider a real-time tension control system shown in Fig. 5. It is assumed that there is no slip between the strip and the roll. The strip tension is controlled by using the speed difference between the stands at the ends of a metal strip. The mathematical model was used for the simulation instead of a real system. It was assumed that the tension could be measured exactly.

### **Specifications and Requirements for Real-Time Software**

Important specifications and requirements include followings. The mathematical model of the system should be activated periodically according to the sampling period( $T$ ). The mathematical model and the control task should be synchronized. While a task uses a global data, the data should be mutually excluded so that other tasks can not use the data. The periods of the periodic tasks should be kept consistently. The values of the state variables should be logged in the file periodically.

### **Tasking**

In order to satisfy the specifications and the requirements, tasking was carried out as follows.

```
speedModel()
speedControl()
tensionModel()
dataLogger()
finish()
```

The tasks are listed in the order of priority(higher priority task first). The behavioral requirements between tasks are shown in Fig. 6. The program begins with the execution of the start() function which initializes real time functions and timers, creates tasks and semaphores, opens files to be used, obtains parameter values from user, sets the system clock.

### **Time Scheduling for Periodic Tasks**

In order to guarantee the timing of the periodic tasks, the execution time of tasks were measured by using the tickSet() and tickGet() functions. And the watchDog timer

was used to give the semaphore periodically such that execution activation periods of the periodic tasks can be met as planned.

## REAL-TIME SIMULATION

For the real-time simulation, the following tension control system and the mathematical model were used. To demonstrate the advantages of the suggested control strategy, two cases of the tension control system were simulated and the results were compared.

- (A) When the MSD is located in the first stand of the system shown in Fig. 4.
- (B) When the MSD is located in the last stand.

### Tension Control System

A block diagram of the tension control system is shown in Fig. 7. The speed of the roll is controlled in a closed loop. But, the strip tension is controlled in an open loop in order to simply show advantages of the suggested control strategy. The mathematical model developed was discretized with sampling period 0.01 second as follows.

Tension model:

$$\begin{aligned}
 T_1(k+1) &= 0.9704 T_1(k) + 48.2723 V_2(k) \\
 T_2(k+1) &= 0.0232 T_1(k) + 0.9608 T_2(k) - 47.1845 V_2(k) + 36.0247 V_3(k) \\
 T_3(k+1) &= 0.0003 T_1(k) + 0.0285 T_2(k) + 0.9418 T_3(k) \\
 &\quad - 0.7052 V_2(k) - 35.1360 V_3(k) + 23.7795 V_4(k)
 \end{aligned} \tag{10}$$

Speed model:

$$\begin{aligned}
 V_2(k+1) &= 1.000 V_2(k) - 0.9810 T_1(k) + 0.9810 T_2(k) + 74.48 U_2(k) \\
 V_3(k+1) &= 1.000 V_3(k) - 0.9810 T_2(k) + 0.9810 T_3(k) + 74.48 U_3(k) \\
 V_4(k+1) &= 1.000 V_4(k) - 0.9810 T_3(k) + 74.48 U_4(k)
 \end{aligned} \tag{11}$$

The control for the speed was designed as follows such that the desired poles are located at 0.35(10).

$$\begin{aligned}
 U_2(k) &= -0.0083 (V_{2ref} - V_2(k)) \\
 U_3(k) &= -0.0083 (V_{3ref} - V_3(k)) \\
 U_4(k) &= -0.0083 (V_{4ref} - V_4(k))
 \end{aligned} \tag{12}$$

The parameter values for the real-time system simulation is shown in Table 3.

### Computer Simulations and Results

Tension variations at the entrance of the first stand and the exit side of the last stand are assumed to be zero. The reference step input to the speed model was selected as 1 % of the operating speed.

(A) With MSD in the first stand: the control objective is to keep  $T_1(\infty) = 48$ ,  $T_2(\infty) = T_3(\infty) = 0$ .

- (1) A speed change only in the  $V_2$  is given to achieve the tension control objective

without successive coordination of speed in downstream stand. The tension variation for given change in speed,  $V_2$ , is shown in the Fig. 8. Tensions  $T_1$ ,  $T_2$ , and  $T_3$  were controlled as desired even though there is small steady state and transient error.

(2) A speed change in the  $V_2$  is given to achieve the tension control objective. And the speed of the downstream roll is adjusted accordingly to compensate the speed change in the  $V_2$  : progressive set-point coordination control. The simulation results are shown in Fig. 9. Tension  $T_1$  was controlled with small steady state error, but the  $T_2$ , and  $T_3$  showed big steady-state error.

As seen in Fig. 8 and 9, when the MSD is located in the first stand, the successive coordination of the roll speed aggravates the performance to the tension control system since the tension transfer was not considered in the control.

(B) With MSD in the last stand: the control objective is to keep  $T_3(\infty) = -25$ ,  $T_1(\infty) = T_2(\infty) = 0$ .

(1) A speed change only in the  $V_3$  is given to achieve the tension control objective without successive control. The tension variation for given change in speed,  $V_3$ , is shown in the Fig. 10. Tension  $T_1$ ,  $T_2$ ,  $T_3$  were controlled as desired even though there is small error. The tension variation in the upstream span is transferred to the following spans.

(2) A speed change in the  $V_3$  is given to achieve the tension control objective. And the speed of the upstream roll is adjusted accordingly to compensate the speed change in the  $V_3$  : progressive set-point coordination control. The simulation results are shown in Fig. 11. Tension  $T_3$  was controlled as desired in this case. But, note that the tension in the entrance side of the first stand was assumed constant.

(3) When the entrance tension is not kept constant:  $V_1 = 0$ ,  $V_2$  and  $V_3$  are changed with step. The simulation results are shown in Fig. 12. The change in tensions  $T_1$ ,  $T_2$ , are bigger than those of Fig. 9. And  $T_3$  were not controlled as desired.

As can be seen from the results, when the successive control method is used with MSD located in the last stand(or downstream stand), the tension in the entrance side of the first stand should be kept constant to properly control the tension in multi-stand rolling systems. Otherwise the performance of the tension control system is degraded significantly as shown in Fig. 12.

## CONCLUSIONS

A new mathematical model which describes the relationship among the roll gap, the roll speed, and the strip tension is developed. The tension variation in a metal strip turned out to be very sensitive to the thickness variation as well as to the speed difference at the ends of the metal strip. And, by using the mathematical model developed, the cancellation mechanism of roll gap control due to the tension interaction could be demonstrated.

A tension control strategy in a multi-stand rolling process is suggested. That is, the MSD should be located in the first stand(or upstream stand) and the tension transfer phenomena is used. The suggested control strategy needs less control efforts and shows better performance than those of an existing control method in a rolling process.

The developed mathematical model is used to design a controller for the real-time control system. A real-time software for the tension control in a multi-stand rolling system is designed by using the VxWorks real-time scheduler and the Force Target board.



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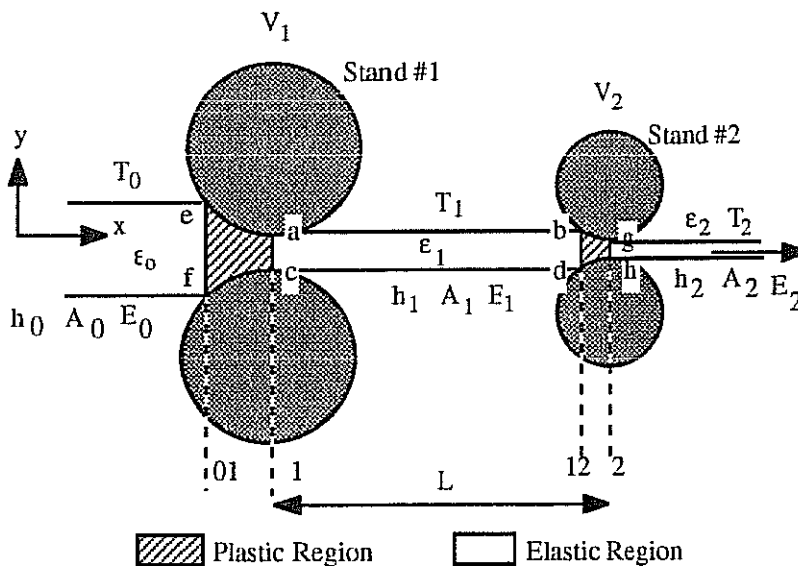


Fig. 1 Rolling of a Strip with Tension between Two Stands

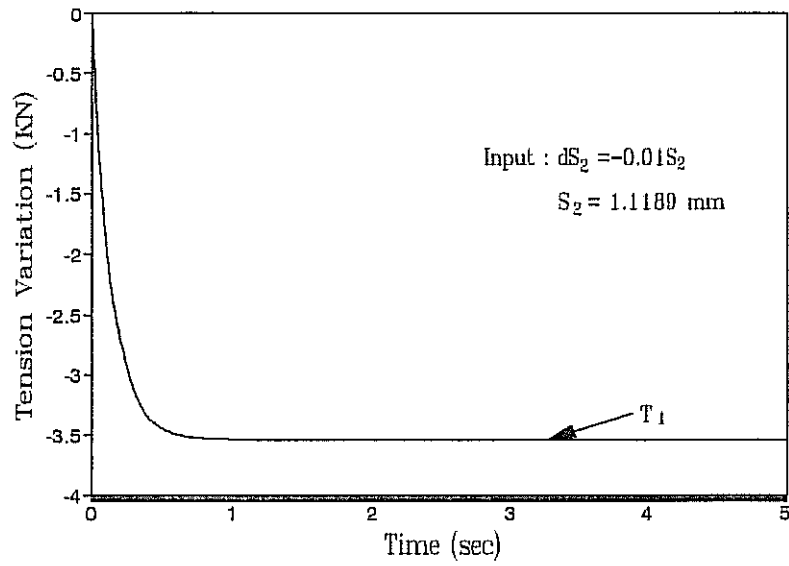


Fig. 2 Tension Variation for Roll Gap Change

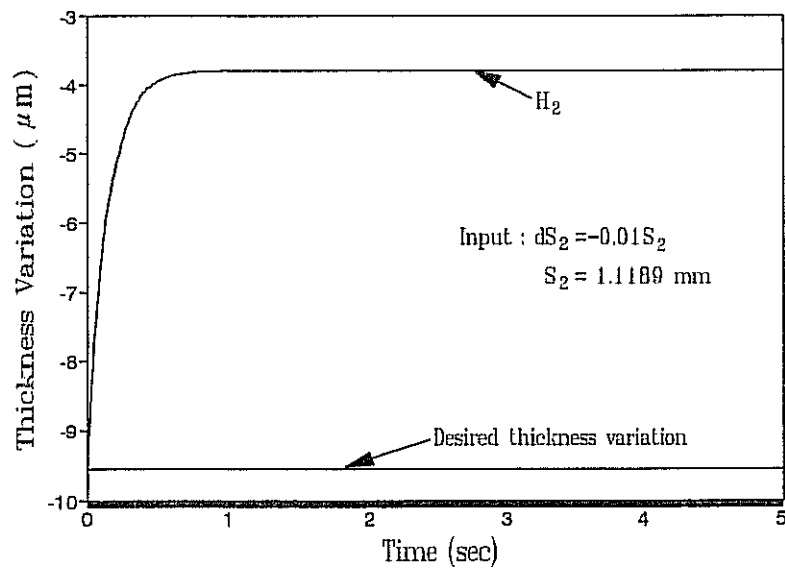


Fig. 3 Strip Thickness Variation for Roll Gap Change

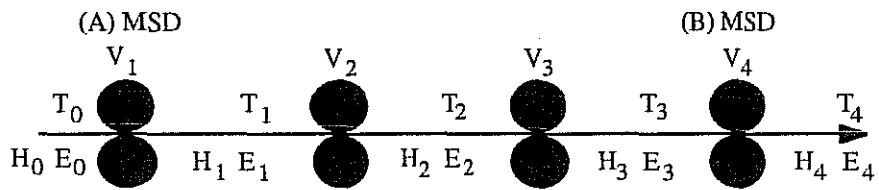


Fig. 4 A Multi-Stand Rolling System

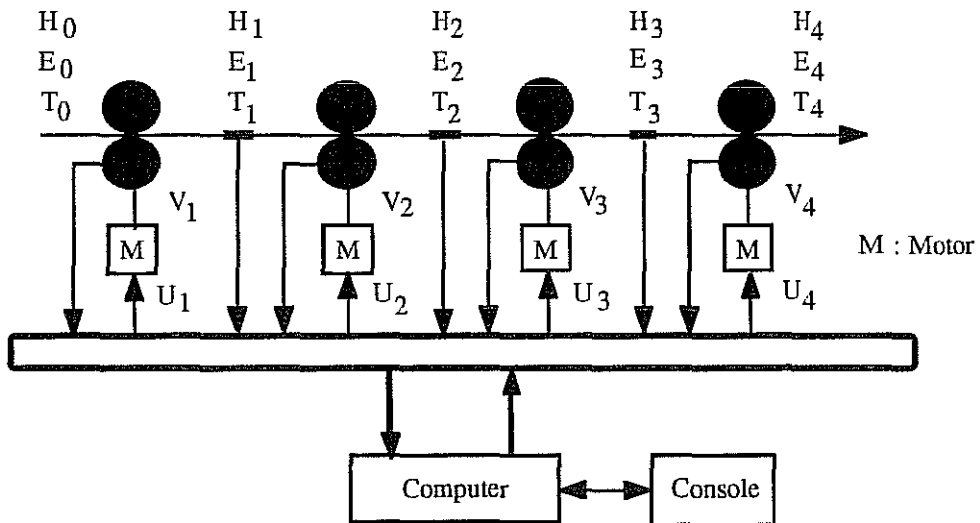


Fig. 5 Real-Time System for Strip Tension Control

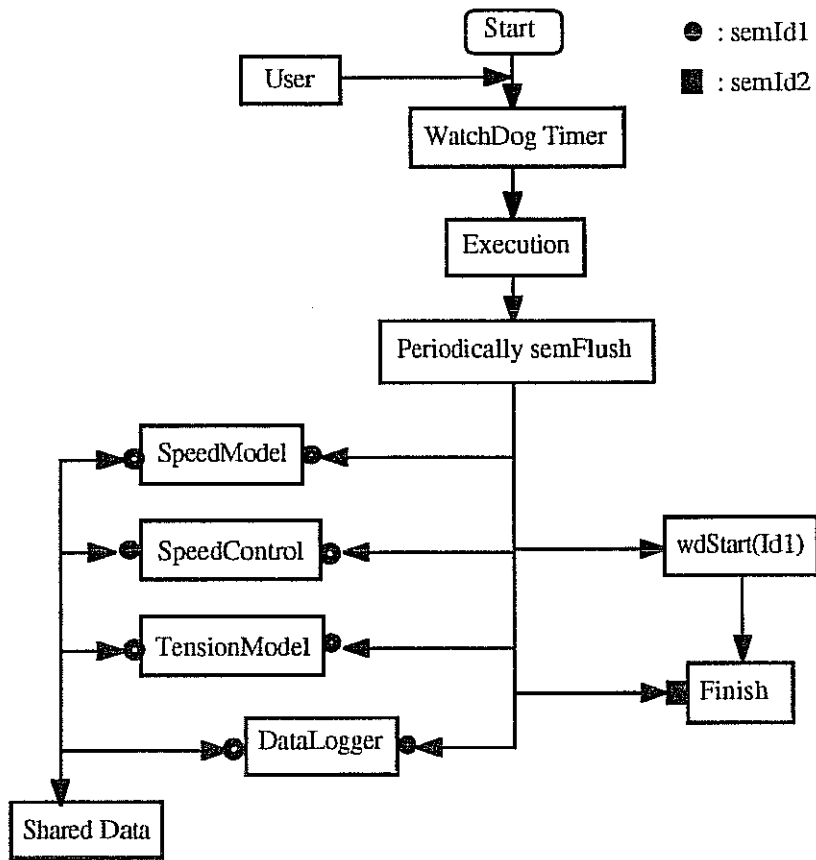


Fig. 6 Behavioral Requirements of Tasks

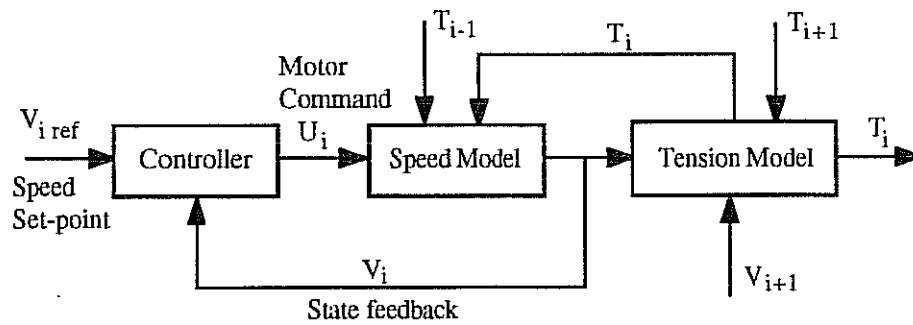


Fig. 7 A Block Diagram of the Tension Control System

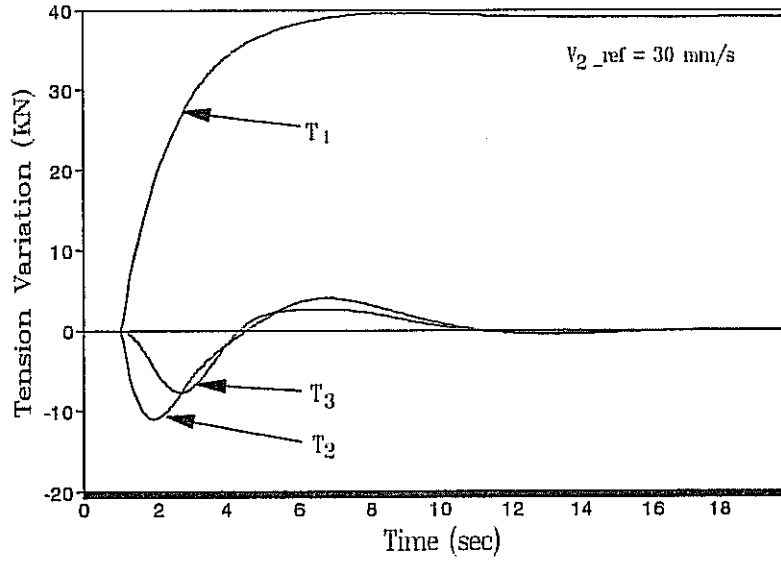


Fig. 8 Tension Control without Successive Control: MSD at First Stand

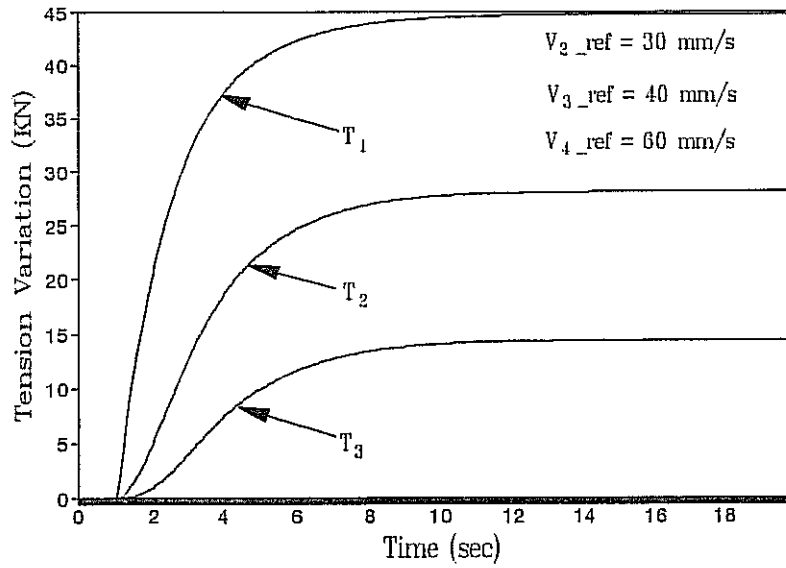


Fig. 9 Tension Control with Successive Control: MSD at First Stand

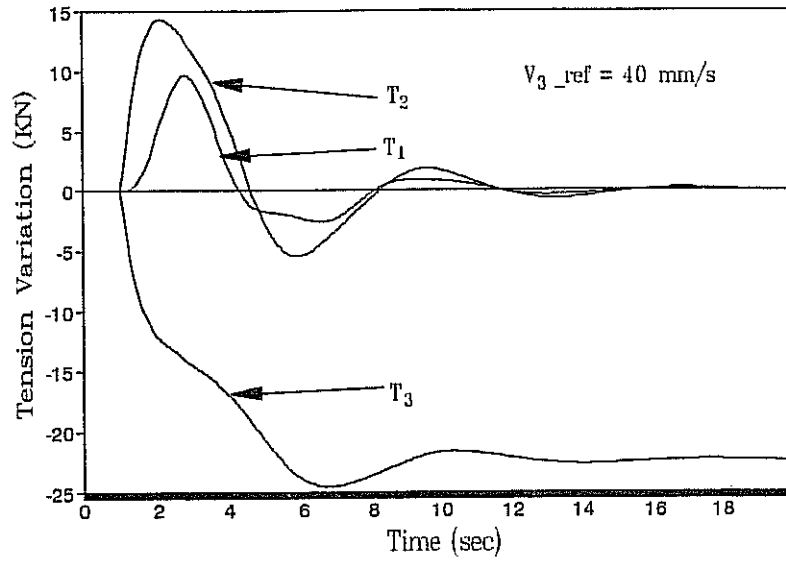


Fig. 10 Tension Control without Successive Control: MSD at Last Stand

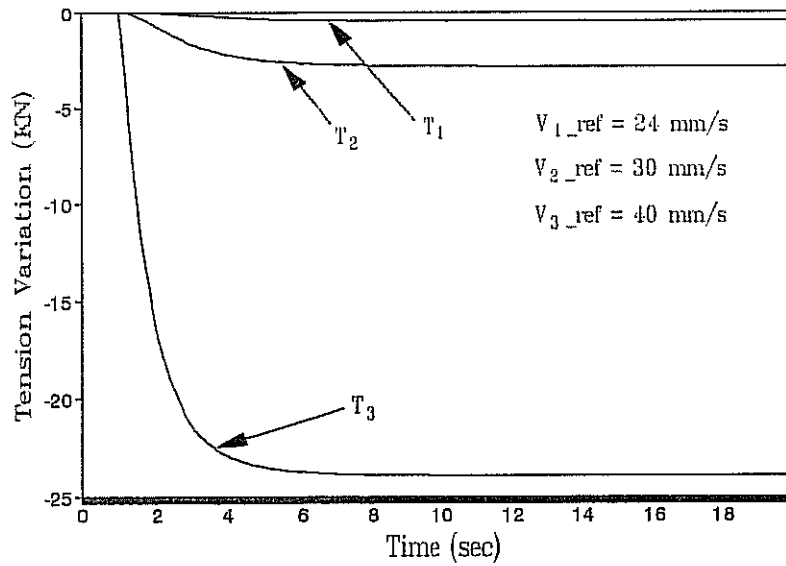


Fig. 11 Tension Control with Successive Control: MSD at Last Stand

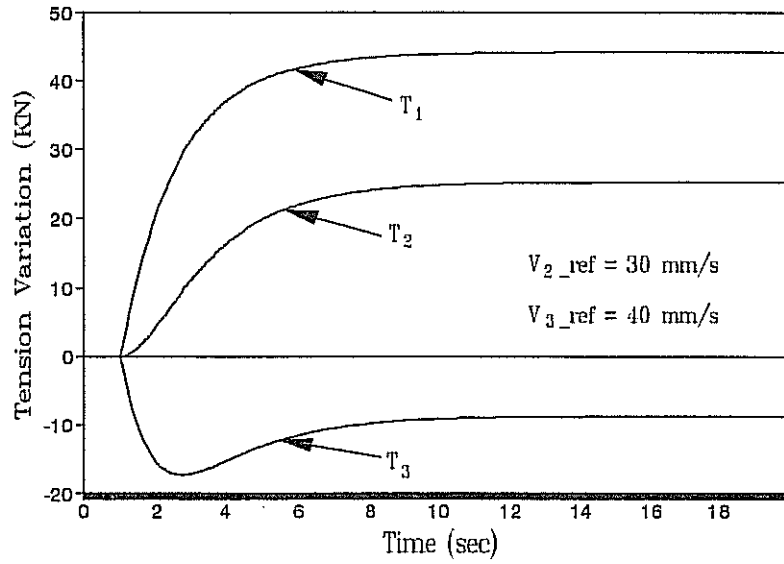


Fig. 12 Tension Control with Successive Control: MSD at Last Stand, (Entrance Tension is not Constant)

Table 1. Tension Variations due to Change in Speed and Thickness

	$T_1$ (MN)	$T_2$ (MN)
$H_1$ (-5 %)	1.104	0.581
$H_2$ (-5 %)	-1.102	0.212
$H_3$ (-5 %)	0.000	-0.375
$V_1$ (5 %)	-1.102	-0.551
$V_2$ (5 %)	1.102	-0.184
$V_3$ (5 %)	0.000	0.775

(The values of operating condition:  $h_{10}=2.4$ ,  $h_{20}=1.8$ ,  $h_{30}=1.2$  mm  
 $v_{10}=3000$ ,  $v_{20}=4000$ ,  $v_{30}=6000$  mm/s)

Table 2. Parameter Values for Roll Gap Control Simulation

parameter	value
$h_{10}$	1.626 mm
$h_{20}$	1.245 mm
$S_2$	1.1189 mm
$t_{10}$	6972 N
$t_{20}$	7493 N

Table 3. Parameter Values for Real-Time Simulation

parameter		value
$E_0$ $E_1$ $E_2$ $E_3$	Young's modulus	2,450 N/mm <sup>2</sup>
$L_1$ $L_2$ $L_3$	Span Length	1,000 mm
$R_1$ $R_2$ $R_3$ $R_4$	Roll Radius	150 mm
$J_1$ $J_2$ $J_3$ $J_4$	Mass moment of inertia	237x103 kgmm <sup>2</sup>
$Bf_1$ $Bf_2$ $Bf_3$ $Bf_4$	Friction Coefficient	0.2
$C_1$ $C_2$ $C_3$ $C_4$	Motor Torque/Speed constant	0.01
$K_1$ $K_2$ $K_3$ $K_4$	Motor torque constant	12x10 <sup>6</sup>
$A_0$	Cross sectional area	3,000mm <sup>2</sup>
$A_1$	Cross sectional area	2,500 mm <sup>2</sup>
$A_2$	Cross sectional area	2,000 mm <sup>2</sup>
$A_3$	Cross sectional area	1,500 mm <sup>2</sup>
$A_4$	Cross sectional area	1,000 mm <sup>2</sup>
$V_{10}$	Strip exit speed	2,400 mm/s
$V_{20}$	Strip exit speed	3,000 mm/s
$V_{30}$	Strip exit speed	4,000 mm/s
$V_{40}$	Strip exit speed	6,000 mm/s
$h_0$	Strip thickness	3.0 mm
$h_{10}$	Strip thickness	2.5 mm
$h_{20}$	Strip thickness	2.0 mm
$h_{30}$	Strip thickness	1.5 mm
$h_{40}$	Strip thickness	1.0 mm



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Real Time Tension Control in a Multi-Stand Rolling System

6/20/95 Session 4 10:45 - 11:10 a.m.

Question - What was the purpose of your investigations. Was it to get a good tension control, or it to get control of viscosity of matter?

Answer - The thickness, yes, the final purpose is to control the thickness. But in the meantime I need to control the thickness and the tension. I have some pictures here which includes the thickness control. This is from another project I'm doing. By using my method you can improve performance of the thickness control very much. Sometimes it works because in the hot business they cut a strip in the middle so you can have a free hand in finishing mill so you can keep the tension constant from entering span. In this case it works. But it isn't easy to keep it constant in normal case.

Thank you.