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Higham et al.
[11] 3,869,892
[45] Mar. 11, 1975

[54] FEED FORWARD GAUGE CONTROL SYSTEM FOR A ROLLING MILL

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[52] **U.S. Cl.** **72/9**, 72/16, 72/34, 250/358
[51] **Int. Cl.** **B21b 37/02**, B21b 37/14
[58] **Field of Search** 72/10, 16, 8, 9, 11, 12

[56] **References Cited**

UNITED STATES PATENTS

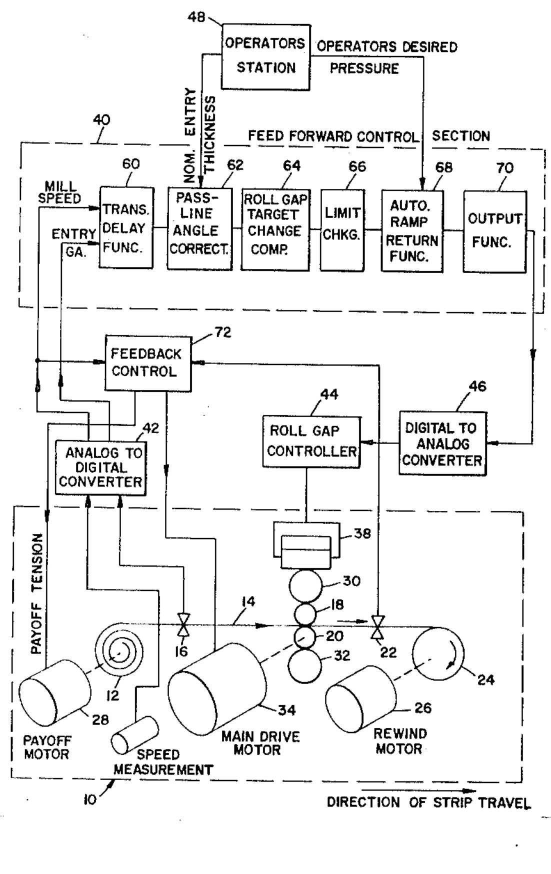
3,194,036 7/1965 Canfor et al. 72/11
3,553,991 1/1971 Chope 72/8

Primary Examiner—Milton S. Mehr
Attorney, Agent, or Firm—Owen, Wickersham & Erickson

[57] **ABSTRACT**

A control method and apparatus for maintaining a uniform predetermined thickness of rolled sheet metal in a metal rolling mill where variations in sheet thickness are measured prior to its entry into the mill rolls. As a basic function, signals corresponding to the measured variations are fed forward to control pressure actuator means for the rolls, to provide corrections that eliminate the variations. The actuator means are also controlled by a secondary function that operates independently to slowly return the pressure value of the actuator means toward its original pre-set value as corrections are applied in response to measured variations. These two control functions are added together to form a composite change to the roll pressure actuactor means which controls the roll pressure and prevents it from exceeding its original pre-set value by an amount that would disturb the strip "shape." The variations of the unrolled sheet thickness are measured accurately even though the pass angle seen by the entry gauge is constantly varying.

12 Claims, 3 Drawing Figures



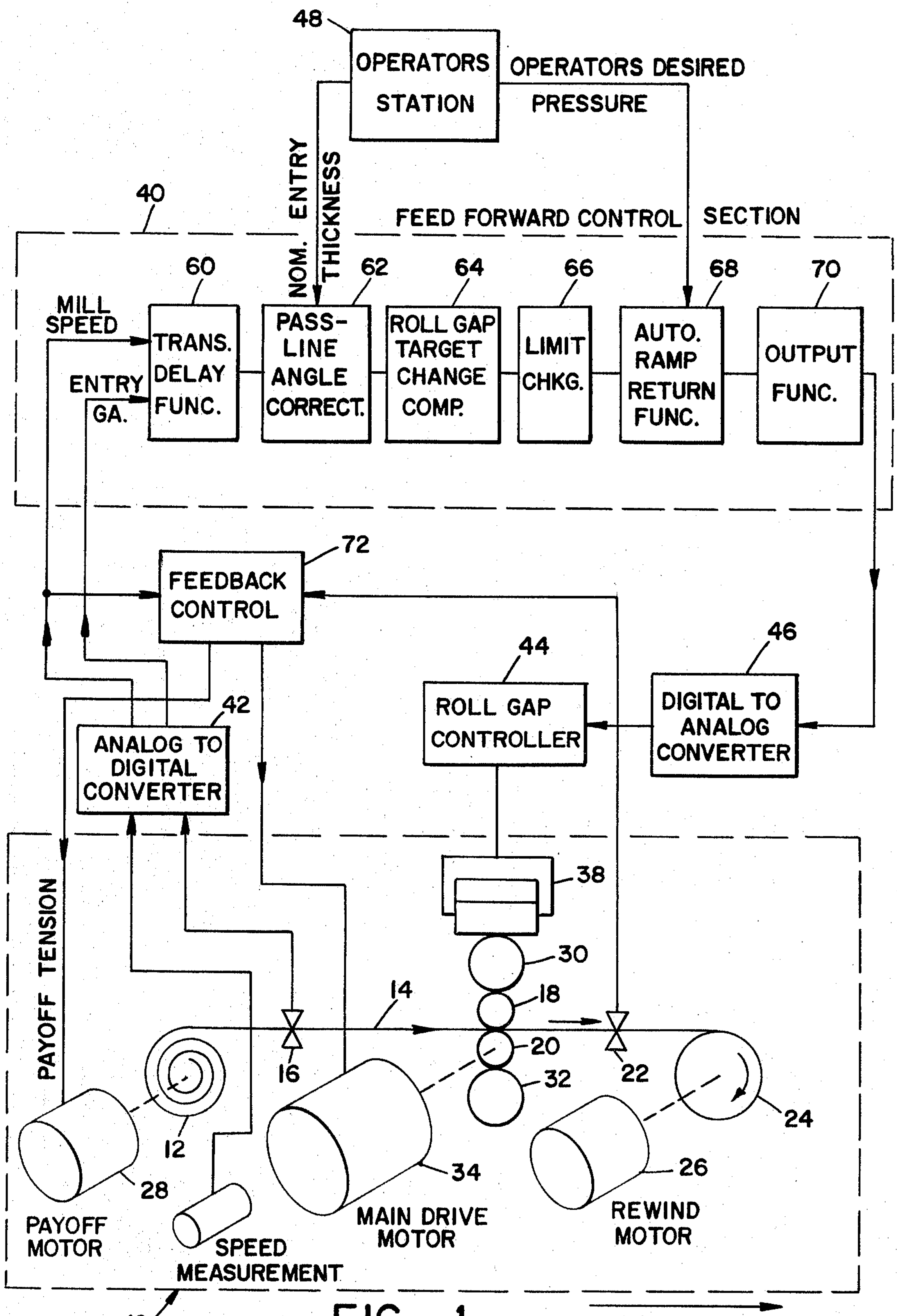

48
OPERATORS STATION
OPERATORS DESIRED PRESSURE
NOM. ENTRY THICKNESS
40
FEED FORWARD CONTROL SECTION
60
62
64
66
68
70
MILL SPEED
ENTRY GA.
TRANS. DELAY FUNC.
PASS-LINE ANGLE CORRECT.
ROLL GAP TARGET CHANGE COMP.
LIMIT CHKG.
AUTO. RAMP RETURN FUNC.
OUTPUT FUNC.
72
FEEDBACK CONTROL
44
46
42
ROLL GAP CONTROLLER
DIGITAL TO ANALOG CONVERTER
ANALOG TO DIGITAL CONVERTER
38
30
14
18
20
32
16
22
24
12
26
28
34
PAYOFF TENSION
PAYOFF MOTOR
SPEED MEASUREMENT
MAIN DRIVE MOTOR
REWIND MOTOR
10
DIRECTION OF STRIP TRAVEL

FIG_1

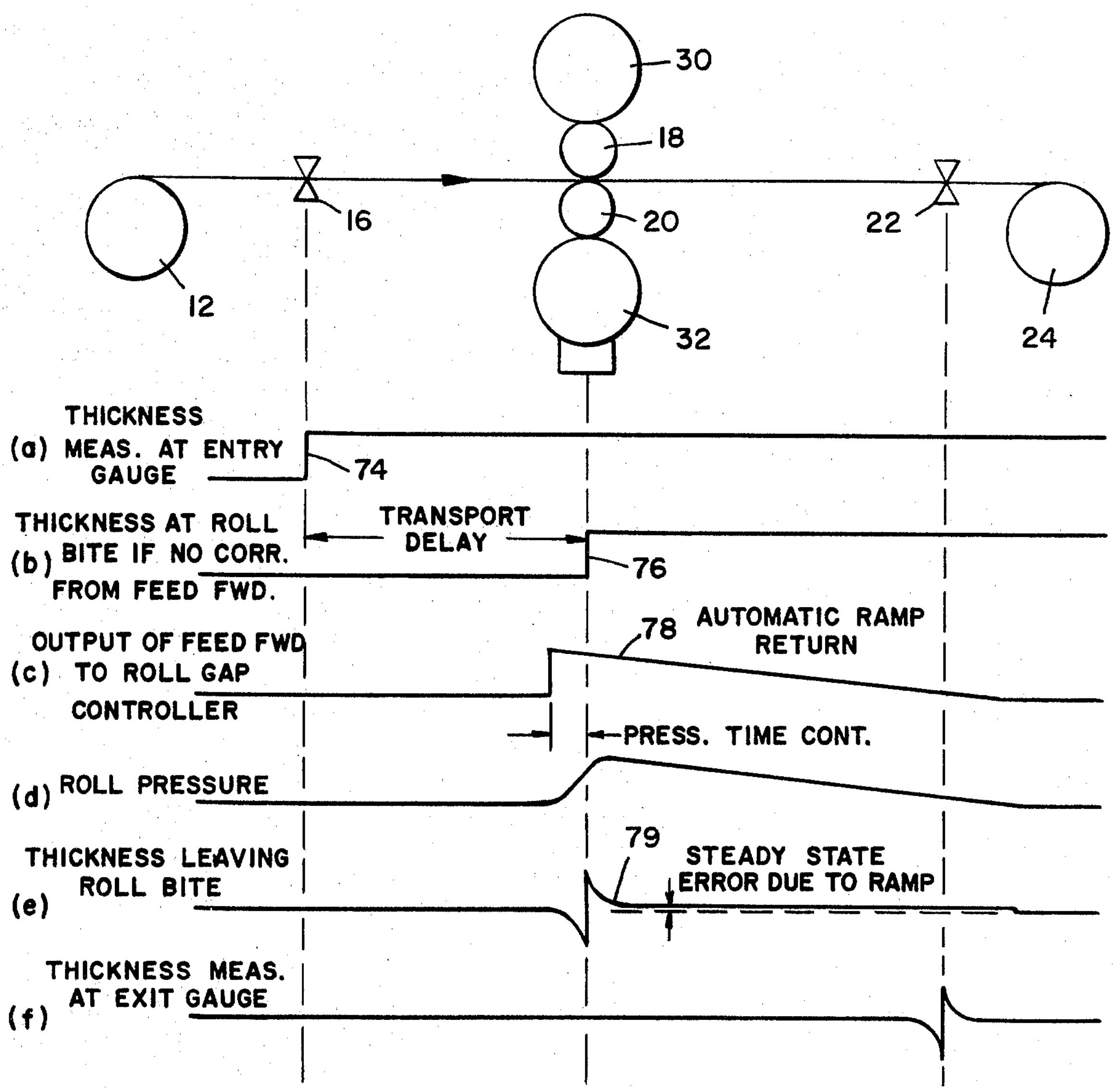

30
18
16
20
22
12
32
24
THICKNESS
(a) MEAS. AT ENTRY
GAUGE
74
THICKNESS AT ROLL
(b) BITE IF NO CORR.
FROM FEED FWD.
TRANSPORT
DELAY
76
OUTPUT OF FEED FWD
(c) TO ROLL GAP
CONTROLLER
78
AUTOMATIC RAMP
RETURN
PRESS. TIME CONT.
(d) ROLL PRESSURE
THICKNESS LEAVING
ROLL BITE
(e)
79
STEADY STATE
ERROR DUE TO RAMP
THICKNESS MEAS.
AT EXIT GAUGE
(f)

FIG_2

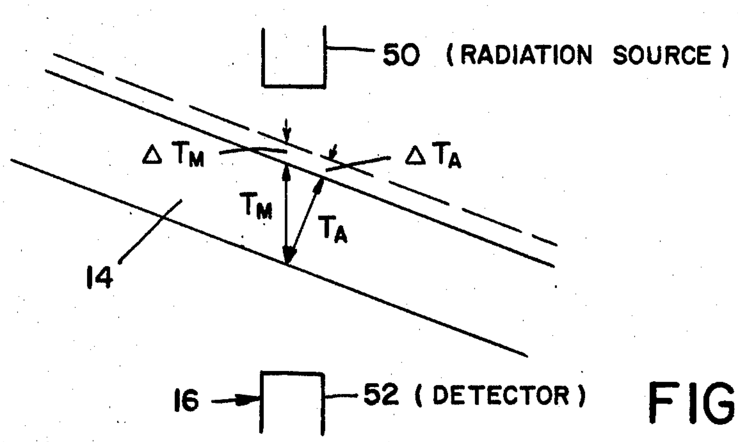

50 (RADIATION SOURCE)
Δ TM
Δ TA
TM
TA
14
16
52 (DETECTOR)

FIG_3

FEED FORWARD GAUGE CONTROL SYSTEM FOR A ROLLING MILL

In the rolling of sheet metal to a predetermined thickness the major reduction in thickness is accomplished by the mill rolls which are forced together by some controllable pressure means. Variations in thickness of the sheet metal stock to be rolled must be accounted for during the rolling process in order to obtain a rolled end product of uniform thickness. Measurement of such variations prior to entry of sheet material into the pressure rolls is essential so that feed forward corrections can be made.

One problem heretofore encountered by certain rolling mill control systems related to maintaining the proper cross-sectional shape and thickness of the sheet material. In such mills the rolls are tapered so that the proper cross-sectional shape of material is maintained only when the pressure of the rolls is held within certain limits. Where thickness variations in the supply material required increased roll pressure to control the output sheet thickness, a distortion of the rolls sometimes occurred where the pressure required was excessive. This caused the rolls to bend, thereby resulting in a cross-sectional variation in sheet thickness. Yet, if the pressure of the rolls was excessively diminished, a distortion in the cross-sectional shape in the opposite direction occurred. The present invention solved this problem.

Another problem with prior feed forward control systems was that they did not provide any correction for a varying passline angle through the input gauge. In most rolling mills the material removed from supply rolls passes through a varying passline angle with the horizontal before it enters the rolls and does not pass through either a constant angle or a horizontal path for any appreciable distance before entering the pressure rolls. Thus, in such mills it is impossible or impractical to locate a gauge where the material passline is not varying as the supply roll diameter constantly decreases. The present invention eliminates this problem so that the gauge reading used for the feed forward control is essentially not affected by a varying passline angle.

OBJECTS AND SUMMARY OF THE INVENTION

It is, therefore, a general object of the present invention to provide an improved method for controlling the gauge of metal material being rolled to a predetermined thickness from rolled stock of a greater thickness and having random thickness variations.

Another more specific object of the invention is to provide a method as above which measures the sheet thickness of material prior to its entry between pressure rolls even where a varying passline is seen by the entry gauge.

Yet another object of the present invention is to provide a method for controlling the uniform thickness of metal being rolled in a rolling mill wherein the measured entry thickness is utilized to control the pressure of the rolls so as to provide the desired material thickness despite thickness variations, and more specifically wherein when sudden variations in incoming thickness occur, the roll pressure is abruptly increased when the variation reaches the roll bite to rapidly eliminate the variation in thickness and immediately thereafter the pressure is automatically returned at a relatively slow

rate toward the operator's set point, thereby generating a small error in thickness at the output gauge of the mill to cause the feedback controller to compensate by changing payoff tension and/or mill speed.

The apparatus for accomplishing the aforesaid method steps generally comprises a fixed noncontacting radiation gauge of the X-ray or nuclear isotope kind that is mounted near the payoff reel. The strip material being rolled has an angular, varying passline through the entry gauge which generates measurement signals as a result of absorption of nuclear particles in the strip. The measurement signals are generated intermittently at a constant rate (e.g. 20 times per second), and are converted into a measure of the variations in strip thickness.

These signals from the entry gauge are supplied to a high speed feed forward section of a computer system having a series of function blocks with inputs controllable from an operator's station having video monitoring facilities. The computer system provides output control signals to a pressure controller which is connected to a pressure actuating system on the mill rolls and it also provides signals to the speed and tension control means on the mills.

The angle of the strip passing through the X-ray gauge at entry affects both the absolute thickness seen by the gauge and also the difference between one reading and the next. The differential of the gauge reading is calculated assuming nominal entry gauge thickness and this value is all that is required for feedforward. The differential entry gauge reading is delayed by a time delay, representing the transport delay of the mill less the time constant of the pressure controller. Delayed changes in entry gauge are used to modify the set point of the pressure controller. The transport delay is modified with mill speed. The gain is modified by strip width and thickness, and also by the alloy being rolled.

Further objects, advantages and features of the present invention will become apparent from the following detailed description taken in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic and block diagram of a feed forward control system embodying the principles of the present invention;

FIG. 2 is a diagram of my feed forward system showing the action of various parameters during typical operation;

FIG. 3 is a diagrammatic view of the entry gauge for providing measurement signals of strip material with a varying angular passline.

DETAILED DESCRIPTION OF EMBODIMENT

General

With reference to the drawing, FIG. 1 shows in block diagram form a control system for a metal cold-rolling mill **10** which in broad terms comprises a payoff reel **12** of the metal strip material **14**, such as aluminum or copper which is to be rolled to a smaller uniform thickness. The strip is threaded through an entry guage **16** and thence between the bite of a pair of work rolls **18** and **20** and an exit gauge **22** to a rewind reel **24**. The latter has a suitable power drive **26** and means to increase tension of the strip between the rewind reel and the work rolls. The payoff reel **12** has a similar drive **28** including means to increase tension between it and the work rolls. The strip engaging work rolls **18** and **20** are pressed together by a pair of back-up rolls **30** and **32** in the conventional manner. The back-up rolls are supported in chocks (not shown) and they are mechanically controllable to vary the gap between the work rolls. One of the work rolls **20** is mechanically connected to a main drive motor **34** having a connected speed measurement device **36** that provides an output equivalent to actual mill speed. A system is provided for moving one work roll toward the other and against the metal strip **14** with the particular pressure necessary to maintain the preselected roller gap. This system, though not shown in detail, is well known to those skilled in the metal rolling art and typically includes a hydraulically powered actuator (not shown) with a preload cylinder **38.**

The mill **10** is connected to a feed forward control section **40** of a computer via a computer/mill interface including an analog to digital converter **42** connected to the entry gauge **16.** This interface also includes a roll gap controller **44** that controls the actual pressure which the rolls apply to the strip material and hence the thickness of the metal coming out of the roll bite. This controller receives input control signals from a computer system through a digital to analog converter **46** which is part of the computer/mill interface.

As shown in FIG. **1,** the computer feed forward control section **40** receives input data from the entry gauge **16** located near the payoff reel **12.** This section comprises a series of calculating or functional elements of the computer which process data received from the computer/mill interface and an operator's station **48.** These functional computer elements compute a new target change for the roll gap controller **44** via the computer/mill interface.

A more detailed description of the elements at the operator's station **48** as well as those comprising the feedforward control section **40** will now be presented.

The Entry Gauge 16

An important aspect of the present feed forward system is that thickness measurements of the strip metal **14** are made as it leaves the payoff reel **12** and are fed forward through the computer system **40** to control small, short term variations of pressure on the mill work rolls **18** and **20** by the roll group control **44.** The thickness measurements between the payoff reel **12** and the work rolls are made by the gauge **16** which may, of necessity, be located closely adjacent to the payoff reel where the metal strip being measured passes through the gauge at a varying passline angle. The signal from the entry gauge is read at a high frequency synchronized to the execution rate of the functions in the section **40** of FIG. **1,** which is typically 20 times per second.

The gauge itself is preferably of the non-contacting radiation type utilizing either an X-ray or nuclear isotope radiation source. One form of such a gauge is shown in U.S. Pat. No. 3,757,122.

As shown in FIG. **3,** a correction to the thickness measurement for the pass angle of metal through the entry gauge **16** is accomplished by combining the actual measurement of the gauge with an assumption that the actual thickness of the strip is near to target thickness, in the following manner:

For a radiation measuring device such as shown in FIG. **3,** the equation relating thickness of material between a radiation source **50** and a detector **52** to the radiation received by the detector is generally known to those familiar with the art as the "gauge equation" and is expressed as follows:

$$T = -(1/\mu)\log_e R \tag{1}$$

where

T = measured thickness

R = measured ratio between the voltage provided by the detector with material present, and the voltage with only air present, subsequently referred to as "the ratio."

μ is a constant depending on the absorption characteristics of the material being measured.

Referring to FIG. **3,** which shows material at an angle other than 90° to the source detector time:

T_M = thickness of material which the radiation must penetrate.

T_A = actual thickness of material.

By considering a small change in actual thickness ΔT_A, which results in a small change ΔT_M in thickness for the radiation to penetrate, the gauge equation (1) can be differentiated to produce the relationship.

$$\Delta T_M = -(1/\mu R_M)\,\Delta R_M \tag{2}$$

Where R_M is the measured ratio for thickness T_M, and ΔR_M is a small change in that measured ratio. From basic geometry (FIG. **3**)

$$T_A/T_M = \Delta T_A/\Delta T_M \tag{3}$$

Combining equations (2) and (3) by basic algebra

$$\Delta T_A = T_A/T_M\,(-1/\mu R_M)\,\Delta R_M \tag{4}$$

But, from the basic gauge equation (1),

$$T_A/T_M = {}_{loge} R_A/\log_e R_M \tag{5}$$

Now, combining equations (4) and (5):

$$\Delta T_A = -1/\mu R_M\,(\log_e R_A/\log_e R_M)\,\Delta R_M \tag{6}$$

Where R_A is the ratio R as previously defined if the metal is presented to the gauge perpendicular to the radiation beam; and

R_M is the ratio R actually measured with the strip at some angle to the radiation beam.

This equation relates a change in actual thickness of the material to a change in measured ratio taken at an angle other than 90° to the gauge.

It it is assumed that R_A is approximately equal to the ratio corresponding to the nominal thickness of metal entering the mill, which may be entered by the operator, then the magnitude of thickness changes of the metal strip entering the mill can be obtained by measuring the ratio R_M. Thus, in the method of the present invention, the input gauge measures the actual thickness (T_M) to obtain the ratio R_M even though the angle of the strip through the gauge (the passline angle) may be varying.

The Operator's Station 48

The operator's station 48 normally located within an enclosure near the mill includes suitable apparatus comprising:

a. means for selecting feedforward control on or off;

b. means for entering the nominal entry thickness of the metal being rolled into the mill into the computer system;

c. means for entering the roll pressure target, which the operator desires for good strip shape, into the computer system; and

d. a means for displaying all selected inputs for checking purposes.

These functions are preferably implemented with a video display and keyboard entry station. Since all of the aforesaid apparatus and arrangement of same is well known to those skilled in the art, it is not shown in detail.

The Computer Feed Forward Control Section 40

The feed forward control section 40 of the computer system comprises:

a. Transport Delay Function **60.**

The instant speed of the mill, measured via the speed measurement device **36** and furnished to the analog to digital converter **42** is supplied to the transport delay function block **60.**

Using this speed, the block **60** computes the transport time of the strip from the measurement point to the roll bite. This may be expressed by the following equation:

$$t = d/v \tag{7}$$

where d is the distance from the measurement point **16** to the roll bite **18** and v is the strip velocity. In order to make a compensatory adjustment to the roll gap to eliminate the gauge disturbance it takes a finite time for the roll gap controller **38** to move. This time is referred to as the roll gap time constant t_c. To allow for this, the time delay t_d calculated by block **60** is reduced by this amount and using equation (7) the computation in block **60** is

$$t_d = (d/v) - t \tag{8}$$

The voltage received from the entry gauge for the initial correction is delayed by the amount t_d computed by this transport delay function by setting up a shift register in the computer software in the conventional manner. This shift register is shifted at a fixed execution frequency which is the same as that of the other functions of section **40** in FIG. **1**, typically 20 times per second. Various values of the t_d are represented by taking a value out of the shift register at a point down the register proportional to t_d. For example, if $t_d = 735$ milliseconds and the execution time is once every 50 milliseconds the time delay is represented by a value N items down the shift register where

$$N = 735/\mathbf{50} = 14.7$$

The fractional part of N is handled by linear interpolation of the 14th and 15th values in the shift register in the conventional manner.

b. Pass Angle Correction Function **62.**

The nominal entry thickness is entered into a pass angle function block **62** of the computer by the operator at the operator's station **48.** Here, this input data is used in conjunction with calibration constant held within the computer to convert the delayed change in entry gauge measurement from the block **62** into a thickness change as described in equation (6) in the previous section on the entry gauge.

For example, if $\Delta R_M = 0.01$, $R_A = 0.6$, $R_M = 0.5$ and $\mu = 0.4$ then

$$\Delta T_A = -(1/0.4 \times 0.5)(\log_e \mathbf{0.6}/\log_e \mathbf{0.5})\ 0.01$$

$= -0.0368$ which is the amount of thickness change that will be entering the roll gap, the units being thousandths of an inch if the units of μ are (thousandths of an inch) $^{-1}$.

c. Roll Gap Target Change Computation **64.**

From the thickness change input, provided by the pass angle function block **62,** a change in roll gap is computed in order to eliminate this thickness change. This is a straightforward computation using previously determined values and calculations relating thickness out of the mill to roll gap target, strip width, strip hardness, and strip thickness.

d. Limit Checking **66.**

For operational safety of the mill and to maintain strip quality, it is important that the roll pressure does not depart too far from the value P_o originally set in by the operator. An excessive change in pressure will cause work roll bending and will alter the "shape" of the strip. On the other hand the feedforward control section needs to make some pressure change in order to effect a gauge connection. Block **66** therefore checks the absolute value of the difference between the demanded roll gap pressure P and the operator's value P_o and prevents this value from exceeding a preset limit P_L by restricting the value of P.

Expressed as equations this process is as follows: At control period n, block **64** generates a required change in pressure ΔP^n. The calculation in block **66** is first to calculate the new requested pressure P'^n from the previous pressure P^{n-1} as:

$$P'^n = P^{n-1} + \Delta P^n$$

The value of P'^n is then limit checked as follows:

9f 1 $P'^n - P_o$1 $< P_L$ then $P^n = P'^n$

9f 1 $P'^{n\,i} - P_o$ 1 $> P_L$

then $P^n = P_o + P_L$ if $P'^n > P_o$

or $P^n = P_o - P_L$ if $P'^n < P_o$

The value of P_L is different for different metal thicknesses and alloys and so the computer selects the appropriate value from a table based on the actual alloy and thickness being rolled.

e. Automatic Ramp Return Function **68.**

Up to this point the feedforward control function has calculated a change to the roll gap controller target to completely eliminate changes in entry gauge thickness as the metal is rolled. Now, an automatic ramp return function block **68** compares the roll pressure P_o desired by the operator (for reasons of good strip shape) with the computed roll gap pressure P^n and superimposes upon this computed pressure a change which causes the roll pressure to slowly return or ramp back to the operator's desired roll pressure.

This would result in a slowly increasing error in exit gauge of the strip since we are slowly removing the corrective pressure change requested by the feedforward control section **40.** However, this gauge error is seen by a standard feedback controller **72** conventionally present in rolling mills, which corrects for the error by adjusting other mill variables such as speed or tension. The effect of the auto ramp return function **68** is to slowly transfer any long term changes in roll pressure required by changing incoming strip thickness to other variables that also control thickness such as speed or tension. Because the feedback controller **72** does not have an instantaneous response, the effect of the slow ramp return **78** of pressure by block **68,** is to cause a small steady state gauge error **79** during the ramp return (See FIG. **2**). The ramp is slow enough that this error **79** is negligibly small. To completely eliminate this error it would be possible to send a signal directly from block **68** to the payoff tension or speed used by the feedback controller **72.** However, in practice, the size of this gauge error does not require this additional complexity.

f. Output Function **70**

The output function takes the resultant composite change in roll gap target and outputs it through the digital to analog converter **40** to the roll gap controller **44.**

The computation described and embodied by the elements of section **40** of FIG. **1** are typically made 20 times per second. This frequency may vary and is chosen so that a reasonable number of executions are made in the time taken for the strip to travel from the entry gauge to the roll bite.

The aforesaid thickness error caused by the ramping back action is measured by the exit gauge **22** which is connected to the feedback controller **72.** This controller receives an input from the analog to digital converter **42** equivalent to actual mill speed, and it supplies feedback outputs to the main drive motor **34** and to the pay-off drive motor **28** which also controls tension of the strip material. Thus, control action taken by the feedback controller **72** substantially removes the thickness error introduced by block **68** described above by changing other mill control values which affect thickness (e.g., pay-off, tension and mill speed control).

The overall combined effect of the feedforward and feedback control systems is illustrated graphically in FIG. **2.**

Assume that a sudden change in incoming thickness occurs at the entry gauge **16,** as indicated at **74** on the upper trace (a) of the diagram. When this change reaches the roll bite the pressure of the work rolls **18** and **20** is increased abruptly as indicated at **76** of next lower trace (b) to eliminate the change in thickness. Simultaneously, the automatic ramp return function is automatically set up to commence the steady return of roll pressure toward the operator's setpoint, as indicated by the ramp **78** of the trace (c). The actual roll pressure change is shown in trace (d) of FIG. **2.** This ramping along line **78** generates a small error in thickness out of the mill which causes the feedback controller **72** to compensate in its normal manner by changing the pay-off tension at the control **28** and/or mill speed by the main drive motor **34.** Thus, in accordance with the present invention, the initial control action is taken by first changing the roll pressure which is capable of changing at a fast rate. Then, this initial change of roll pressure is slowly transferred to the pay-off tension and mill speed. The resulting variation in strip thickness are shown at the roll bite and at the exit gauge in traces (e) and (f) of FIG. **2.** The unique combination of feed forward and feedback control serves to keep the roll pressure of a mill within limits consistent with good strip shape while maintaining a high degree of accuracy on the rolled output thickness of the metal strip material.

To those skilled in the art to which this invention relates, many changes in construction and widely differing embodiments and applications of the invention will suggest themselves without departing from the spirit and scope of the invention. The disclosures and the description herein are purely illustrative and are not intended to be in any sense limiting.

We claim:

1. A method for controlling the gauge without changing the shape of strip material issuing from a rolling mill that includes a payoff reel, a pair of pressure rolls to produce a desired roll force, pressure control means for varying the pressure of said rolls on the strip material and the gap between them, a takeup reel, an input gauge between said payoff reel and said rolls, tension control means for the strip material, an output gauge and feedback means connected to said output gauge, said method comprising the steps of:

generating a signal at the input gauge for determining a variation in the gauge of material from the payoff reel from a nominal thickness;

producing a primary control function causing said pressure control means to operate in response to the variation in gauge detected by said input gauge when the actual gauge variation reaches said pressure rolls, said primary control function operating on said pressure rolls to change their force on the strip at a relatively rapid rate to substantially eliminate the thickness variation;

superimposing a secondary function on said pressure control means immediately after the activation of said primary function, said secondary function causing the changed force of the pressure rolls on the strip material by said primary control function to commence returning at a relatively slow steady rate toward the original preset level and thereby causing a relatively small variation in target gauge of the material passing from said rolls;

generating an error signal proportional to said small variation at the exit gauge; and

utilizing said error signal to activate a mill control means for eliminating said small variation in gauge.

2. The method as described in claim **1** wherein said error signal is utilized to operate the tension control means to counteract said small variation in gauge.

3. The method as described in claim **1** wherein said error signal is utilized to vary the speed of strip material in the mill to counteract said small variation in gauge.

4. The method as described in claim **1** wherein the signal is generated at the input gauge by measuring the actual thickness of the strip as it passes at a varying angle between the radiation source and detector elements of the entry gauge and using said signal from the input gauge in conjunction with the assumed nominal thickness value of the strip material to compute the actual variation in incoming strip thickness.

5. The method as described in claim 4 wherein said actual variation in incoming strip thickness is determined by the equation

$$T_A = -1/\mu R_M (\log_e R_A/\log_e R_M) \Delta R_M$$

where: μ = a constant depending on the absorption characteristics of the material being measured; R_A is the ratio between the voltage provided by the detector with material present and the voltage with only air present when the metal is perpendicular to the detector's radiation beam; R_M is the ratio between the voltage provided by the detector with material present and the voltage with only air present which is actually measured with the strip at an angle to the radiation beam; ΔR_M is the current R_M minus the previous R_M.

6. In a rolling mill including a payoff reel for a strip of sheet material connected to a takeup reel, a pair of pressure rolls for applying a forming force on said strip material and a pressure control means for controlling said pressure rolls, an entry gauge between said payoff reel and said rolls and an exit gauge between said rolls and said takeup reel, a feed forward thickness control system for said mill comprising:

means for utilizing signals from said entry gauge and comparing them with an input proportional to the assumed nominal thickness of the strip material from said payoff reel to produce signals proportional to variations in thickness of the strip material;

primary control means for utilizing said signals proportional to said strip thickness variations for operating said pressure rolls control means to cause a relatively rapid increase in pressure by said rolls;

means responsive to activation of said pressure control means for commencing a steady reduction of roll pressure;

feedback control means responsive to signals generated by said exit gauge compared with a preselected target gauge for producing an error signal;

and means responsive to said error signals for activating another gauge control means on the mill.

7. The method as described in claim 6 wherein said primary control function is produced by:

computing the transport time of a gauge variation from the measurement point to the roll bite and subtracting from this time a roll gap time constant;

providing a pass angle correction to the nominal entry thickness and using it in conjunction with a calibration constant to convert the delayed change in entry gauge measurement into a thickness change;

computing a change in the roll gap based on the previously computed thickness change modified by characteristics of the strip material; and

checking the computed roll pressure for compliance with operational limits.

8. An apparatus for controlling the gauge and shape of strip material issuing from a rolling mill that includes a payoff reel, a pair of pressure rolls adjustable to a preselected gap to produce a desired target thickness, pressure control means for varying the pressure of said rolls on the strip material and the gap between them, a takeup reel, an input gauge between said payoff reel and said rolls, tension control means for the strip material, an output gauge and feedback means connected to said output gauge, said apparatus comprising:

means for generating a signal at the input gauge for determining a variation in the gauge of material from the payoff reel from a nominal thickness;

means responsive to said signal from said input gauge for producing a primary control function causing said pressure control means to operate when the actual gauge variation reaches said pressure rolls to change their force on the strip at a relatively rapid rate to substantially eliminate the thickness variation;

means for superimposing a secondary function on said pressure control means immediately after the activation of said primary function, said secondary function causing the changed force of the pressure rolls on the strip material by said primary control function to commence returning at a relatively slow steady rate toward the original preset level and thereby causing a relatively small variation in target gauge of the material passing from said rolls;

means for generating an error signal proportional to said small variation at the exit gauge; and

means for utilizing said error signal to activate a mill control means for eliminating said small variation in gauge.

9. The apparatus as described in claim 8 including means for utilizing said error signal to operate the tension control means to counteract said small variation in gauge.

10. The apparatus as described in claim 8 including means for utilizing said error signal to vary the speed of strip material in the mill to counteract said small variation in gauge.

11. The apparatus as described in claim 8 wherein said means for generating a signal at the input gauge includes means for measuring the actual thickness of the strip as it passes at a varying angle between the radiation source and detector elements of the entry gauge and means for using said signal from the input gauge in conjunction with the assumed nominal thickness value of the strip material to compute the actual variation in incoming strip thickness.

12. The apparatus as described in claim 8 wherein said means for superimposing a secondary function comprises an automatic ramp return means for generating a signal which moves the pressure control means at a preselected constant rate towards an original preset level until that preset level has been reached.

* * * * *