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Peterson et al.

[11] **3,782,151**

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[54] **AUTOMATIC GAUGE CONTROL SYSTEM FOR TANDEM ROLLING MILL**

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(Under Rule 47)

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[52] **U.S. Cl.** **72/9,** 72/16, 72/17

[51] **Int. Cl.** **B21b 37/06**

[58] **Field of Search** 72/6–12, 72/16

[56] **References Cited**

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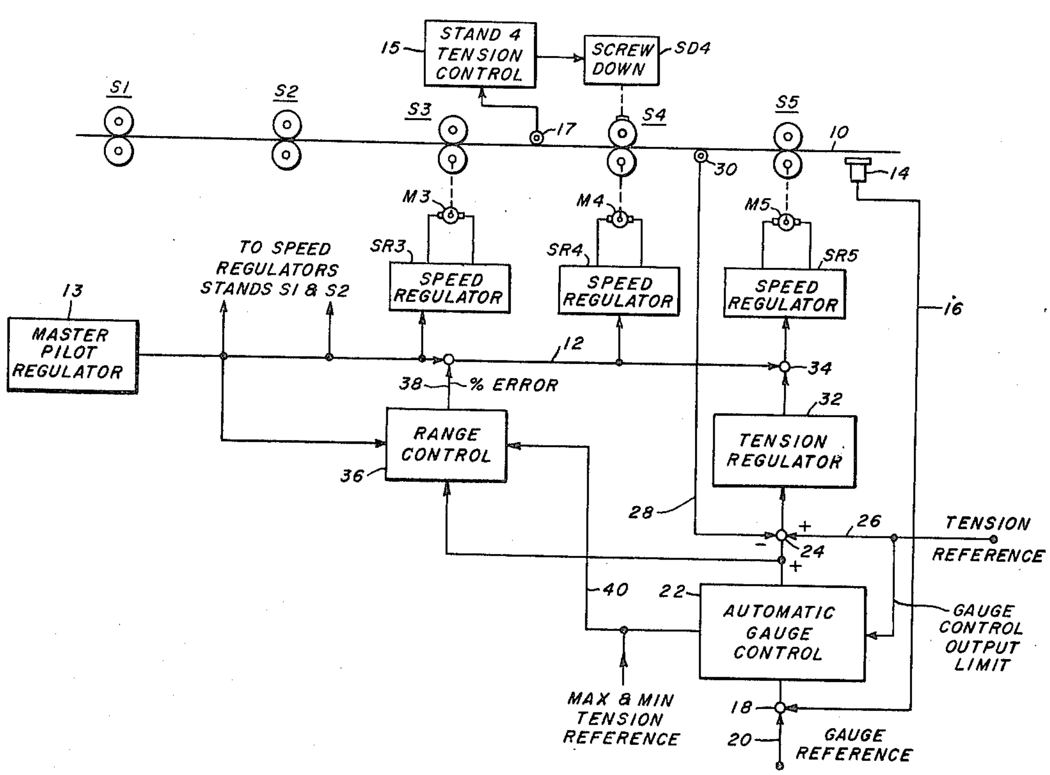
[57] **ABSTRACT**

An automatic gauge control system for a multi-stand rolling mill of the type wherein output guage is normally controlled by varying tension in the rolled strip material between the last two stands in the mill, this tension between the last two stands being limited between upper and lower maximum values. Due to variations in mill set-up and incoming product variations, the allowable tension range between the last two stands is not sufficient to adequately control thickness. Accordingly, when the tension reference is exceeded in either direction, range control means are provided for simultaneously changing by the same percentage the speeds of the fourth and fifth stands in a five-stand mill, for example, permitting tension to remain constant between the fourth and fifth stands while varying tension between the third and fourth stands to effect a correction in output gauge. The range control means is automatically turned ON when the magnitude of a guage error correction signal indicates that the tension between the last two stands is outside its permissible range. When the tension between the last two stands is again within limits, the range control holds its speed correction signal to the last two stands (i.e., does not apply it to the last two stands) until activated again by an out-of-range tension condition.

8 Claims, 3 Drawing Figures



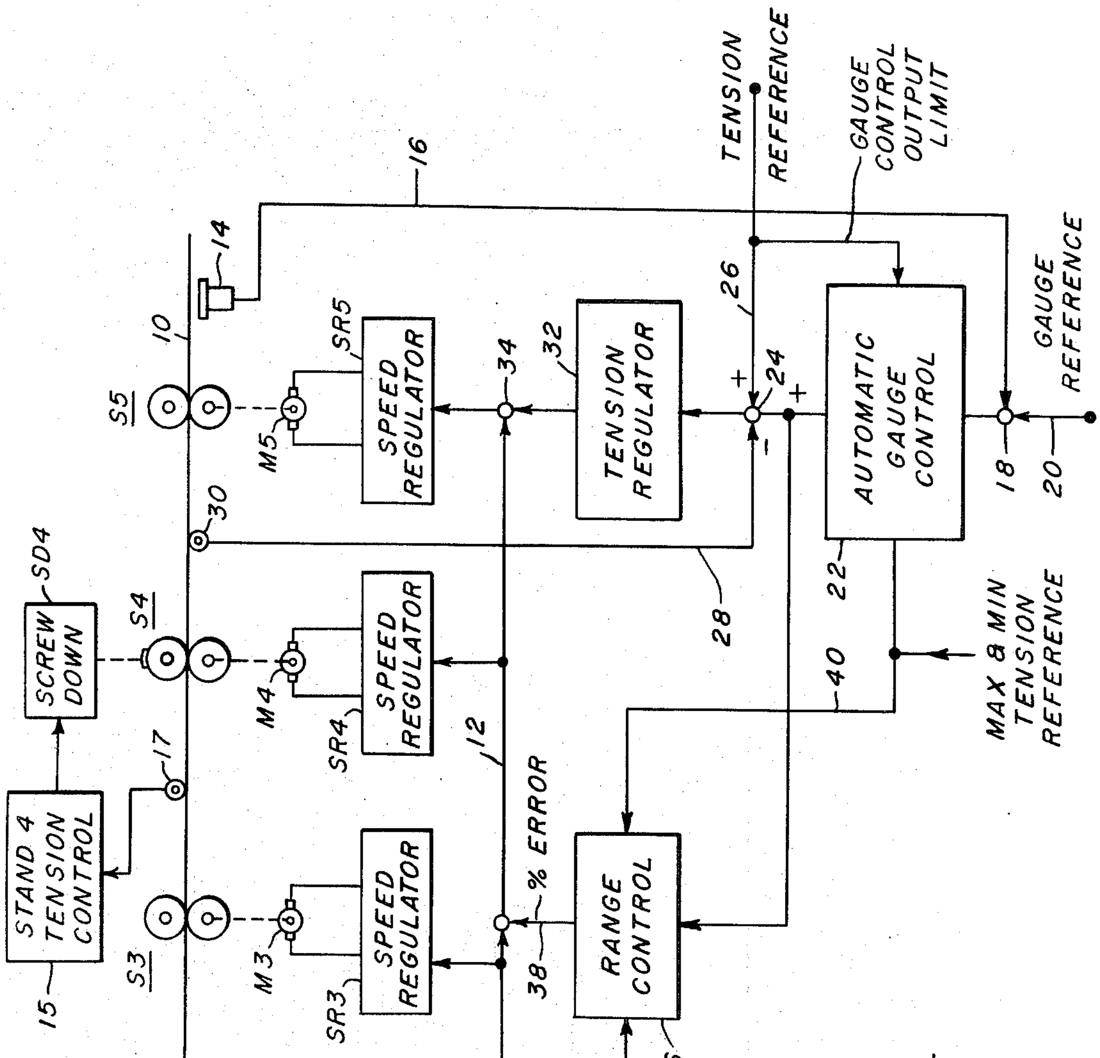

S1
S2
S3
S4
S5
10
14
16
SCREW DOWN
SD4
STAND 4 TENSION CONTROL
15
17
30
M3
M4
M5
SPEED REGULATOR
SR3
SR4
SR5
34
12
% ERROR
38
TENSION REGULATOR
32
RANGE CONTROL
36
TO SPEED REGULATORS STANDS S1 & S2
MASTER PILOT REGULATOR
13
TENSION REFERENCE
26
24
28
GAUGE CONTROL OUTPUT LIMIT
AUTOMATIC GAUGE CONTROL
22
40
18
20
GAUGE REFERENCE
MAX & MIN TENSION REFERENCE

FIG. 1.

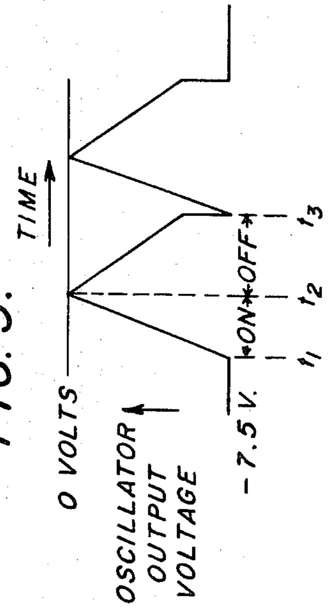

TIME
0 VOLTS
-7.5 V.
OSCILLATOR OUTPUT VOLTAGE
ON
OFF
t_1
t_2
t_3

FIG. 3.

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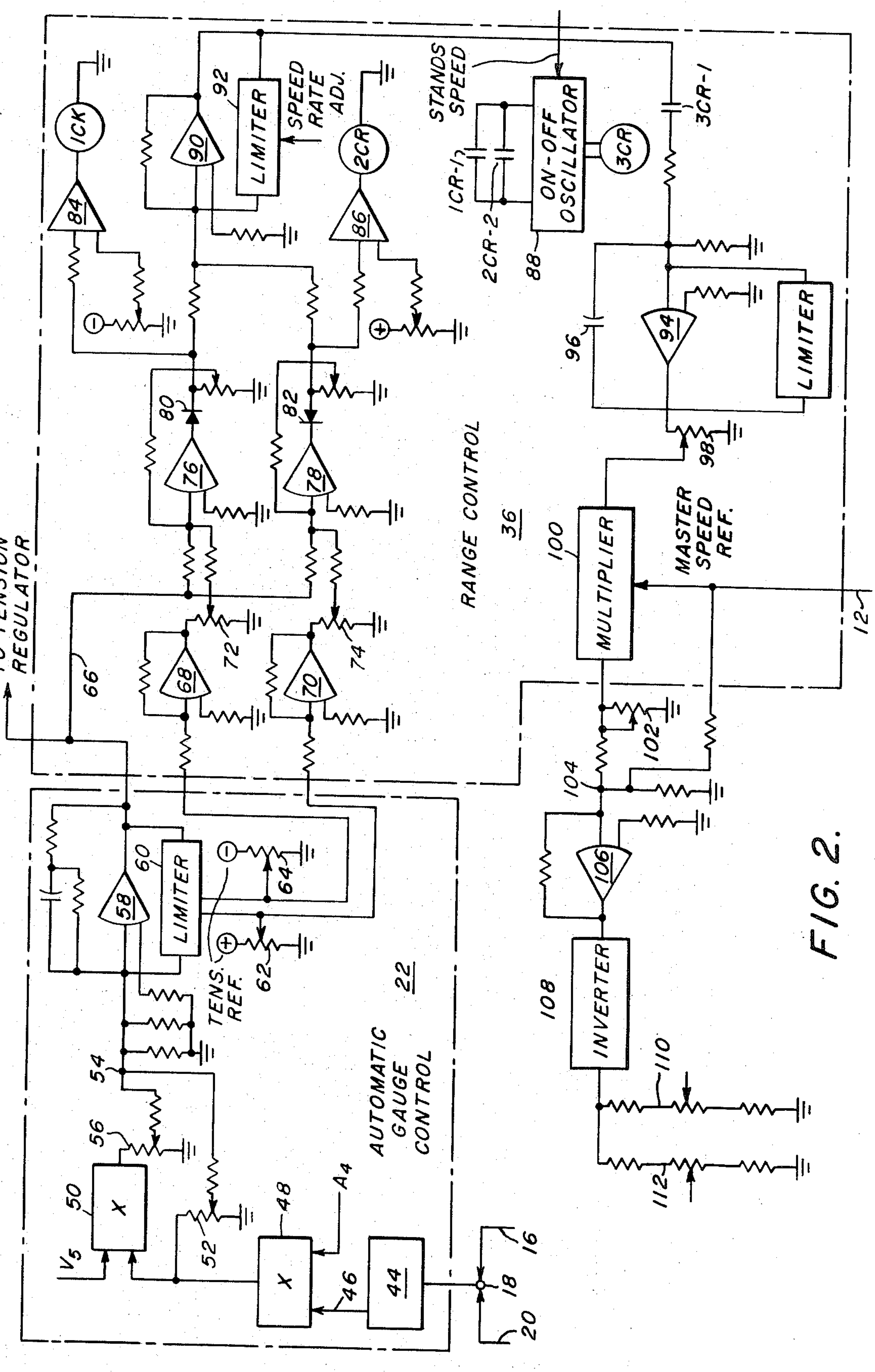

FIG. 2.

AUTOMATIC GAUGE CONTROL SYSTEM FOR TANDEM ROLLING MILL

CROSS REFERENCE TO RELATED APPLICATIONS

Application Ser. Nos. 230,300 and 230,299, filed concurrently herewith.

BACKGROUND OF THE INVENTION

While not necessarily limited thereto, the present invention is particularly adapted for use in an automatic gauge control system for a multistand rolling mill wherein final output gauge is controlled by controlling tension in the strip material being rolled between the last two stands. Normally, the tension is varied by varying the speed of the last stand relative to the next to the last stand. The strip material, after passing through the last stand, progresses to a thickness measuring device which develops an electrical signal proportional to actual gauge. This signal, when compared with a desired gauge signal as determined by the operator of the mill, develops a gauge deviation signal when the actual and desired gauges are not the same. This deviation signal is applied through an automatic gauge control system and a tension regulator to the speed regulator for the last stand. Both minimum and maximum limits are set on tension. Without such limits, strip breakage or difficulty in tracking the strip material through the mill may occur.

Assuming that the tension between the last stands is within the upper and lower limits of the system, it operates satisfactorily. However, due to variations in mill ste-up set-up incoming product variations, the allowable tension range provided for between the last two stands is not sufficient to adequately control thickness. That is, the system performs well when not saturated; but it frequently saturates on either minimum or maximum tension. For that matter, on certain products, it may go from saturation in one direction to saturation in the other direction during the rolling of one coil.

SUMMARY OF THE INVENTION

In accordance with the present invention, there is provided, in a tandem mill automatic gauge control system wherein gauge is controlled by varying tension between the last two stands in the mill, means for raising or lowering the master reference speed signals to both of the last stands by the same percentage simultaneously when a tension error signal, determined by a gauge deviation signal and normally controlling the speed of the last stand, falls outside predetermined maximum and minimum limits. In this manner, and assuming that a five-stand tandem mill is involved, a portion of the necessary gauge corrective action is transferred to the fourth stand whereby part of the gauge correction is effected by changes in tension between the third and fourth stands rather than the fourth and fifth stands.

The deadband range control means of the invention which simultaneously increases the speed of the fourth and fifth stands is actuated periodically, and after each actuation sufficient time is permitted to elapse until the strip material at the bite of the fourth stand progresses to a thickness measuring device. If it is then found that the gauge has been corrected such that the gauge deviation signal falls within permissible limits, no further corrective action is taken via tension variation between the third and fourth stands. However, if the thickness reading indicates that the gauge has not been corrected sufficiently, another cycle of operation is initiated, as well as succeeding cycles, until the output gauge has been corrected and the gauge deviation signal again falls within the permissible upper and lower limits of the tension regulator for the fourth and fifth stands, whereupon gauge is again controlled by varying stand five speed which, in turn, varies tension between the fourth and fifth stands.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification and in which:

FIG. 1 is a schematic block diagram of the automatic gauge control system of the invention;

FIG. 2 is a detailed block and schematic circuit diagram of the range control circuitry of the invention; and

FIG. 3 is a graph illustrating a typical ON and OFF cycle of operation of the gauge error sampling circuitry of FIG. 2.

With reference now to the drawings, and particularly to FIG. 1, a five-stand tandem rolling mill is shown including five stands S1, S2, S3, S4 and S5. Strip material to be rolled passes between the rolls of the successive stands S1–S5 and is progressively reduced in gauge while the speed of the strip material increases at the output of each stand. The rolls for each of the stands are provided with drive motors, only motors M3, M4 and M5 being shown in FIG. 1. Motors M3–M5 are controlled by speed regulators SR3, SR4 and SR5, respectively, which receive a master speed reference signal on lead 12 from master pilot controller 13. Additionally, each of the stands S1 through S5 is provided with a screwdown mechanism and screwdown control, only the screwdown SD4 for stand S4 being shown in FIG. 1. The screwdown SD4 can be controlled by stand S4 tension controller 15 which receives a tension signal from tensiometer 17 in contact with the strip 10 between stands S3 and S4. If the tension between stands S3 and S4 should rise above or fall below predetermined maximum and minimum values, corrective action is taken through the screwdown SD4 to either increase or decrease the roll bite opening of stand S4 until the tension between stands S3 and S4 is again within permissible limits.

The gauge of the strip material issuing from the last stand S5 is measured by an X-ray gauge 14 or the like which produces a signal on lead 16 proportional to actual gauge. The signal from X-ray gauge 14 is compared at summing point 18 with a gauge reference signal on lead 20 determined by the operator of the mill, or possibly by a computer. The gauge reference signal is proportional to desired output gauge. If the desired or reference output gauge signal on lead 20 is not equal to the actual gauge signal on lead 16, a gauge deviation signal is developed which is applied to an automatic gauge control circuit 22, the details of which will be explained hereinafter.

Essentially, the function of the automatic gauge control circuit 22 is to vary the gain of the gauge control loop as a function of transport time between the bite of the rolls of the last stand S5 and the thickness gauge 14. At low mill speeds, the gain of the loop is maintained low by circuit 22 and varied as a function of the cross-sectional area of the strip between the last two stands. At high mill speeds, on the other hand, the gain of the loop is increased and varied as a function of both cross-sectional area and the speed of the last stand.

The output signal from the atuomatic gauge control circuit **22** is summed at summing point **24** with a tension reference signal on lead **26** and with an actual tension signal on lead **28** derived from a tensiometer **30** in engagement with the strip material **10** between the last stands S4 and S5. The signal from the gauge control circuit **22** and the tension reference signal **26** are summed and compared in subtractive relationship at point **24** with the actual tension signal from tensiometer **30.** The resulting signal is then applied as an error signal to a tension regulator **32.**

The details of the tension regulator **32** may be had by reference to copending application Ser. No. 230,300 filed concurrently herewith. However, for purposes of the present application, it will be sufficient to state that the function of the tension regulator is to compensate for the transfer function relating interstand tension between the last two stands to the operating speeds of the last two stands. Specifically, it has been found that the transfer function is dependent upon the cross-section area of the strip between the last two stands, as well as the speed of the next to the last stand. Consequently, the tension regulator **32** compensates for this variation in transfer function as the cross-sectional area of the strip varies, as well as the speed of the next to the last stand varies. The output of the tension regulator **32,** comprising a modified gauge deviation signal, is then summed at summing point **34** with the master speed signal on lead **12** and applied to the speed regulator SR5 for stand S5.

As was explained above, it is necessary to limit the output gauge deviation signal from the automatic gauge control circuit **22** between predetermined upper and lower maximum tension limits. Without such limits, strip breakage may occur if the tension is too great or difficulty may be encountered in tracking the strip material between the fourth and fifth stands if the tension is too low. However, due to variations in mill setup and incoming product variations, the allowable tension range provided for between the last two stands is not sufficient to adequately control thickness.

In accordance with the present invention, range control circuitry, identified by the reference numeral **36** in FIG. **1,** is provided for maintaining the tension between stands S4 and S5 fixed when the tension limits approach the maximum or minimum permissible values. When this occurs, the range control circuit **36** changes the output signal on lead **38** proportional to percent tension error. This is added to the master speed signal on lead **12** for stands M4 and M5, whereby the speeds of these stands are increased simultaneously and in an amount equal to the percent error. As a result, the tension between stands S3 and S4 is varied to effect a gauge correction, notwithstanding the fact that the tension between stands S4 and S5 remains constant. If it should happen that the tension between stands S3 and S4 exceeds the permissible value established by the tension control **15,** the screwdown SD4 will be adjusted to vary the roll gap between the rolls of the stand S4 to bring the tension between stands S3 and S4 back to the desired value.

Maximum and minimum tension reference signals, schematically indicated on lead **40** in FIG. **1,** are applied to the automatic gauge control circuit **22** and to the range control circuit **36.** Range control circuit **36** is activated to maintain tension between stands S4 and S5 constant when the automatic gauge control circuit **22** reaches approximately 60 percent of its full output in either direction.

With reference now to FIG. **2,** the details of the automatic gauge control circuit **22** and the range control circuit **36** are shown, these two circuits being enclosed by a broken lines. The gauge deviation signal from summing point **18** is applied to error compensation amplifier **44** which produces a linear output signal variable above and below the zero axis, depending upon the polarity of the deviation signal, and is limited at values above and below the zero axis. The output signal from amplifier **44,** comprising a signal on lead **46** proportional to deviation from desired gauge, is then multiplied in multiplier **48** with a signal proportional to the cross-sectional area of the strip A_4 between the last stands S4 and S5. The manner in which the signal proportional to A_4 is derived is explained in copending application Ser. No. 230,299, filed concurrently herewith. The signal from multiplier **48** is then applied to a second multiplier **50** where it is multiplied with a signal V_5 proportional to stand S5 speed. This signal may be derived, for example, by means of a tachometer generator or the like coupled to the rolls of the fifth stand.

The signal at the output of the multiplier **48** is applied through potentiometer **52** to a summing point **54.** The signal at the output of multiplier **50** is applied through potentiometer **56** to the same summing point **54.** Summing point **54** is connected to the input of an operational correction amplifier **58** having a feedback path including a variable limiter **60.** The reason for multiplying the gauge deviation signal by cross-sectional area A_4 and fifth stand speed V_5 is to vary the gain of the tension loop as a function of transport time between the bite of the rolls in the last stand and the thickness gauge **14** as is more fully explained in aforesaid copending application Ser. No. 230,299, filed concurrently herewith.

Upper and lower maximum tension levels are derived via potentiometers **62** and **64** and applied to the limiter **60** such that the output signal from amplifier **58** is limited between the upper and lower maximum values determined by the potentiometers **62** and **64.** While the resistive elements of potentiometers **62** and **64** are shown as simply being connected to positive and negative terminals, the voltage across the limiter potentiometers **62** and **64** is actually made to vary as a function of the tension reference on lead **26,** FIG. **1.** The output of the correction amplifier **58** is applied to the summing point **24** (FIG. **1**) via lead **66** shown in FIG. **2.**

The movable taps of potentiometers **62** and **64** are also connected to operational amplifiers **68** and **70** in the deadband range control circuit **36.** Amplifiers **68** and **70** act as inverters, their outputs being connected through potentiometers **72** and **74,** respectively, to the inputs of two deadband operational amplifiers **76** an **78.** Summed with the outputs of amplifiers **68** and **70** and applied to the inputs of deadband amplifiers **76** and **78** is the gauge deviation signal on lead **66.** The arrangement is such that when the deviation signal is of one polarity, and assuming that it exceeds 60 percent of the limit establshed by potentio-meter **72** or **74,** an output will appear from amplifier **76** and will pass through diode **80.** On the other hand, if the gauge deviation signal on lead 66 is of the opposite polarity and reaches 60 percent of the maximum value established by potentiometer 72, an output will appear from amplifier 78 and will pass through diode 82. In other words, if the tension is outside a median band or range (±60 percent) within the maximum and minimum limits, an output will appear at one of the two amplifiers. These two amplifiers 76 and 78 have a very high gain so that their output goes from zero volts to their limit voltage when the automatic gauge control amplifier 58 is out of range. An output, from amplifier 76, after passing through amplifier 84, will trigger or energize relay 1CR. Similarly, an output from amplifier 78, after passing through diode 82, will trigger or energize a relay 2CR through amplifier 86. In either case, regardless of whether a 1CR or 2CR is energized, contacts 1CR-1 or 2CR-2 will be closed to trigger an ON-OFF oscillator 88.

At the same time, the output of amplifier 76 or that from amplifier 78, (depending upon the polarity of the gauge deviation signal) will be applied to the input of a summing operational amplifier 90, having an adjustable limiter 92 in one of its feedback paths. The output of the amplifier 90, in turn, is adapted to be applied through normally open contacts 3CR-1 to the input of a range integrating operational amplifier 94 having a capacitor 96 in one of its feedback paths. Contacts of 3CR-1, in turn, are controlled by relay 3CR of the ON-OFF oscillator 88.

Assuming, for the moment, that the contacts 3CR-1 are closed, the output of amplifier 76 or 78 comprising a fixed voltage is applied to the input of the integrating operational amplifier 94 which integrates it and applies it through potentiometer 98 to the input of a multiplier 100 where it is multiplied by the master speed reference signal on lead 12. Multiplication of the master speed reference signal in multiplier 100 by the gauge error correction signal from amplifier 94 gives at the output of the multiplier a signal proportional to a percentage of the master speed signal, which percentage is proportional to the gauge correction deviation error from circuit 94. This signal is then applied through a potentiometer 102 to summing point 104 where it is summed with the original master speed reference signal on lead 12. This, then, is applied through amplifier 106 and inverter 108 to voltage dividers 110 and 112, divider 110 being for speed regulator SR4 and divider 112 being for regulator SR5. The wiper of the voltage dividers are the speed reference signals going to speed regulators SR4 and SR5 respectively.

Assuming that relay contacts 3CR-1 are open and the automatic gauge control amplifier has not yet gone out of range, the output of multiplier 100 will be zero and the signal applied to the voltage dividers 110 and 112 will be, in essence, the master speed reference signal on lead 12. However, when the contacts 3CR-1 are closed, the voltage across dividers 110 and 112 will be increased in an amount proportional to the gauge error correction signal. Since the signal is applied to both voltage dividers 110 and 112, the speeds of stands S4 and S5 will be increased or decreased simultaneously in the same amount, thereby maintaining the tension between stands S4 and S5 constant. The tension between stands S3 and S4, however, will be varied to effect a gauge correction.

Referring again to the ON-OFF oscillator 88, once relay 1CR or 2CR is energized indicating that the gauge deviation signal has reached 60 percent of its maximum value in either the positive or negative direction, the ON-OFF oscillator will be triggered to initially energize relay 3CR, whereupon contacts of 3CR-1 close and the gauge error correction signal is applied to the input of integrating amplifier 94 where it is stored. At the end of the timed "ON" interval, relay 3CR is de-energized for an "OFF" time which is approximately equivalent to the time required for the strip to move from stand S4 to the X-ray gauge 14. At the expiration of this "OFF" delay, the range control is again allowed to cycle if the automatic gauge control amplifier 58 is still out of range.

The cycling sequence is shown in FIG. 3. The ON-OFF oscillator includes an integrator and the relay 3CR is triggered or energized in response to a negative voltage. The cycle starts at time t_1. Contacts 1CR-1 or 2CR-2 close. Between times t_1 and t_2, while the integrator within the oscillator 88 is building up voltage, contacts 3CR-1 are closed and the constant voltage output of circuit 90 is applied to integrator 94. At time t_2, zero voltage is reached at the output of the oscillator and the relay 3CR is de-energized, opening contacts 3CR-1. Relay 3CR remains de-energized until time t_3 is reached, whereupon the cycle repeats, assuming that contacts 1CR-1 or 2CR-2 are closed. The OFF time between times t_2 and t_3 is, as mentioned above, equal to the time required for the strip material to move from stand S4 to the X-ray gauge 14. If, at time t_3, the thickness detected by X-ray gauge 14 produces a gauge deviation signal which is within plus or minus 60 percent of the minimum or maximum tension reference signals in automatic gauge control circuit 22, either relay 1CR or 2CR will become de-energized again, thereby deactivating the ON-OFF oscillator 88. If, however, the gauge deviation signal is still outside plus or minus 60 percent of the maximum or minimum tension reference signal, the oscillator 88 is again cycled until the gauge is again within permissible limits and both the relays 1CR and 2CR are de-energized. This, then, permits tension control to transfer back to the stand S5 until the gauge deviation signal again falls outside of the permissible band.

During the time that tension between stands S4 and S5 is maintained constant, tension between stands S3 and S4 is controlled by tension control 15 working on the screwdown for stand S4.

Although the invention has been shown and described in connection with a certain specific embodiment, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention.

I claim as my invention:

1. A system for controlling the gauge of strip material issuing from a tandem rolling mill wherein an actual output gauge signal is compared with a desired gauge signal to derive a gauge deviation signal used to vary the speed of the last stand in the mill relative to the next to the last stand, and wherein said gauge deviation signal is effective to vary last stand speed only when it falls within predetermined maximum and minimum values; the combination of:

deadband range control circuit means to which said gauge deviation signal is applied and which will produce a gauge error correction signal at output terminal means thereof only when said gauge deviation signal falls outside a range of values encompassed within said maximum and minimum values,

means for generating a master speed reference signal for controlling the speeds of all stands in said tandem mill,

means for multiplying said master speed reference signal by said gauge error correction signal appearing at the output terminal means of said deadband circuit means, and

means for combining said master speed reference signal with the output of said multiplying means to derive a signal for simultaneously varying the speeds of said last two stands to maintain tension constant between the last two stands while varying tension between the next to the last stand and its preceding stand.

2. The combination of claim **1** including integrating means interposed between said multiplying means and said output terminal means of the deadband range control circuit means.

3. In the method for controlling the gauge of strip material passing through a tandem rolling mill wherein the final output gauge is normally controlled by varying last stand speed to control tension between the last two stands of the mill, the improvement which comprises measuring the gauge of strip material at the output of said tandem mill and comparing it with desired gauge to develop a gauge deviation signal for controlling the speed of the last stand, electrically sensing when the tension between the last two stands is outside a permissible range of tension values by comparison of said gauge deviation signal with tension reference signal means, and when the tension is outside said range of tension values periodically and simultaneously adjusting the speeds of the last two stands to maintain the tension between the last two stands essentially constant while varying tension between the next to the last stand and its preceding stand to effect a gauge correction until comparison of said gauge deviation signal with said reference signal means indicates that tension is again within said range of tension values.

4. The method of claim **3** wherein the speeds of said last two stands are varied by the same percentage value when the tension is outside said permissible range of tension values.

5. The method of claim **4** including the steps of producing an electrical signal proportional to the actual gauge of strip material issuing from said tandem mill, producing an electrical signal proportional to desired output gauge, comparing said signals to derive said gauge deviation signal for controlling the speed of said last stand relative to the next to the last stand, and limiting said gauge deviation signal between predetermined minimum and maximum tension values, said range of tension values being a median range of values between said minimum and maximum values.

6. The method of claim **5** wherein said range of tension values is about ±60 percent of said maximum and minimum values.

7. The method of claim **3** wherein the speeds of the last two stands are increased or decreased simultaneously for a period of time until the strip material from the next to the last stand has traveled to a point of gauge measurement at the output of said tandem mill, whereupon the output gauge is again controlled by controlling the speed of said last stand if the tension between the last two stands is no longer outside said permissible range of tension values.

8. The method of claim **7** wherein the step of adjusting the speeds of said last two stands simultaneously is repeated if the tension between the last two stands is outside said permissible range of values after a gauge measurement is made.

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