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Winchester

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[54] **METHOD AND SYSTEM FOR CONTROLLING A TANDEM ROLLING MILL**

[75] Inventor: **Amos J. Winchester**, Scotia, N.Y.

[73] Assignee: **General Electric Company**, Salem, Va.

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[52] **U.S. Cl.** **72/9**, 72/12

[51] **Int. Cl.** **B21b 37/02**

[58] **Field of Search** 72/8–12, 72/16

[56] **References Cited**

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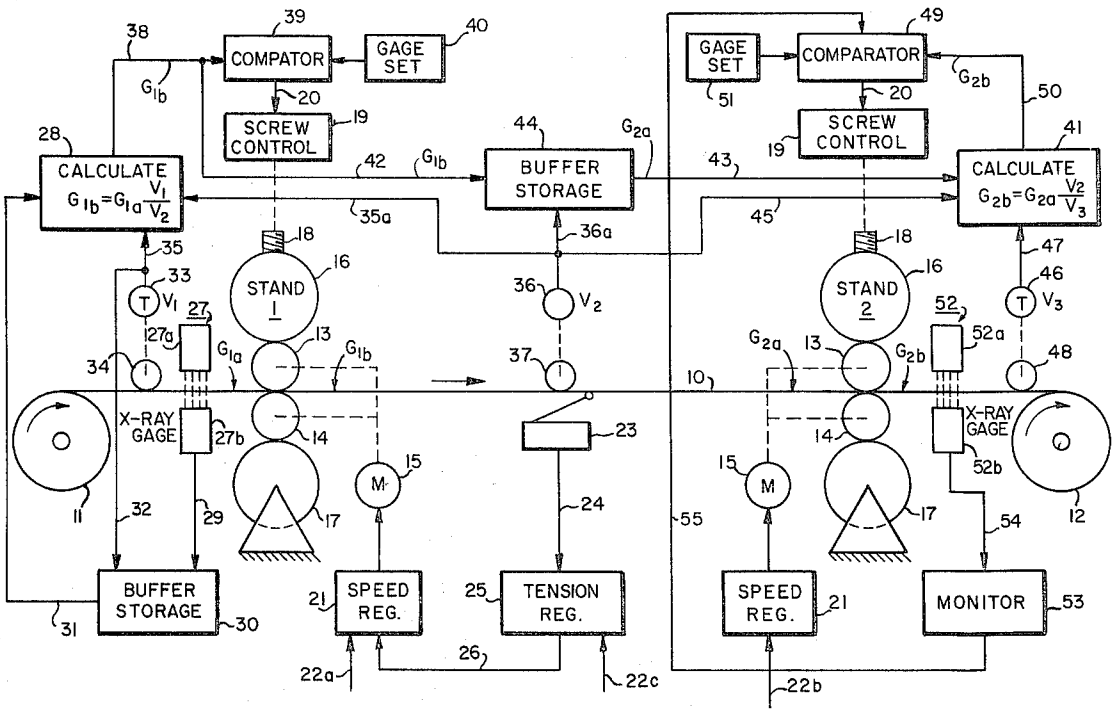
Primary Examiner—Milton S. Mehr

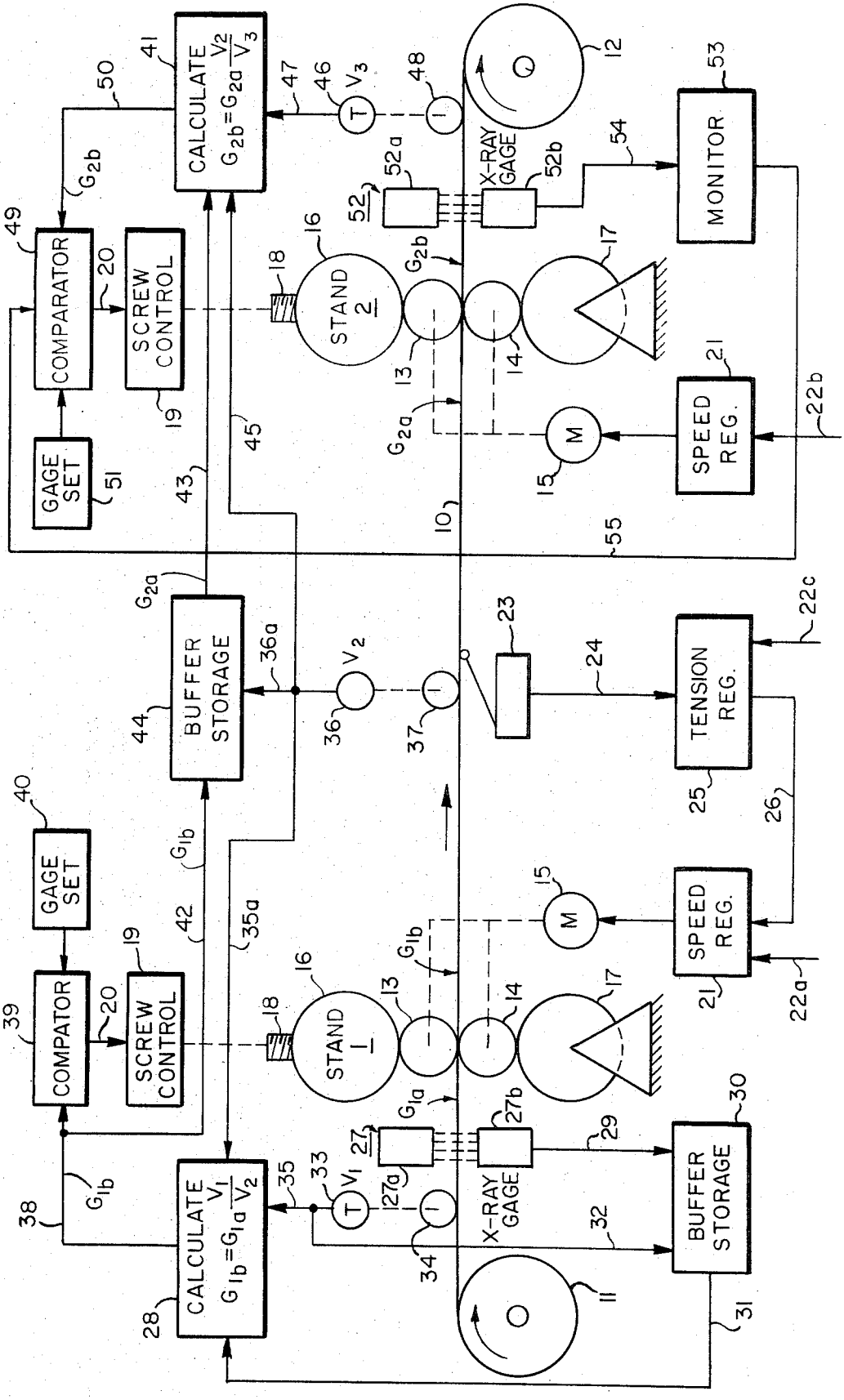
Attorney—John J. Kissane et al.

[57] **ABSTRACT**

An automatic gage control system for a tandem rolling mill wherein separate control loops are provided for the roll opening controls of each stand. Each control loop responds to a feedback signal based on the predicted gage of the rolled strip leaving the associated stand whereby control errors caused by transport lag are eliminated without causing system instability.

6 Claims, 1 Drawing Figure




CALCULATE $G_{2b}=G_{2a}\frac{V_2}{V_3}$
41
50
47
46 V_3
48
12
53
MONITOR
54
X-RAY GAGE
52a
52b
52
16
STAND 2
18
G_{2b}
17
13
14
21
SPEED REG.
22b
G_{2a}
15
M
49
COMPARATOR
20
SCREW CONTROL
19
GAGE SET
51
43
45
10
55
G_{2a}
BUFFER STORAGE
44
36a
V_2
36
37
23
24
TENSION REG.
25
22c
26
40
GAGE SET
42
G_{1b}
35a
39
COMPATOR
20
SCREW CONTROL
19
18
16
STAND 1
13
G_{1b}
14
17
15
M
SPEED REG.
21
22a
38
G_{1b}
CALCULATE $G_{1b}=G_{1a}\frac{V_1}{V_2}$
28
35
33 V_1
27
27a
G_{1a}
34
X-RAY GAGE
27b
29
32
BUFFER STORAGE
30
31
11

METHOD AND SYSTEM FOR CONTROLLING A TANDEM ROLLING MILL

BACKGROUND OF THE INVENTION

The present invention relates to a method and system for controlling a tandem rolling mill for reducing, in successive rolling operations, the thickness of strip material passing through the mill. More particularly, the invention relates to a method and system for minimizing off gage strip caused by time delay, known as transport lag, in the feedback circuits controlling the automatic gag controls of the mill.

Tandem rolling mills have rolling stands provided with screwdown mechansims to vary the roll opening and hence exit gage of rolled strip passing through the mills. The screwdowns are controlled by an automatic gage control system, hereinafter referred to as the AGC system, which senses the gage of the strip passing through the mill and adjusts the screwdown to correct for any departure of the rolled strip gage from a desired value. Typically, the strip thickness is measured by a gage, such as an X-ray gage, which produces a correction feedback signal for the AGC system when the exit gage departs from a desired value. In a system of this type, any error in the thickness of the rolled strip is not sensed unitl a measured section of the strip passes beyond the roll bite of a stand to the measuring gage. This measuring delay in the feedback control of the AGC system is known as "transport lag." The effect of the transport lag is to cause instability or hunting of the control system if the speed of response of the AGC control system is not reduced to compensate for the transport lag or delay time. In actual practice the response time of the AGC system is normally maintained at least three times the transport lag. It is apparent that reduction of response time of the AGC system to prevent instability caused by transport lag increases the amount of off gage strip produced by the mill by slowing down the correction process. Hence, there is more scrap loss due to off gage material. It is desirable, therefore, to eliminate the effect of transport lag in the AGC control system of the mill.

Attempts have been made to reduce the effect of transport lag by using as a feedback signal a predicted gage of the strip leaving the mill. The predicted gage is calculated by use of the constant volume principle; i.e. the volume flow rate of the strip into the mill equals the volume flow rate of the strip out of the mill. Using this principle the exit gage can be calculated by multiplying a measured entry gage by the ratio of the strip speeds entering and leaving the mill. In prior AGC control systems using this predicted exit gage as a feedback sigal the screwdowns of adjacent rolling stands of the mill have been coupled together and adjusted simultaneously in response to the feedback signal. This approach gives rise to complex control problems arising from the coupling together of the adjacent stands. Specifically, it becomes difficult to maintain the interstand tension of the rolled strip when the stands are so coupled and without proper tension regulation the strip is apt to loop or break. Also, the constant volume principle used as a basis for predicting exit gage of the strip is valid for the entire mill, as distinguished from individual rolling stands, only when uniform interstand strip tension is maintained.

Accordingly, it is an object of the present invention to provide an improved method for controlling the

AGC system of a tandem rolling mill to eliminate the effect of transport lag.

Another object of the invention is to provide an improved system for controlling the rolling stands of a tandem rolling mill to maintain a desired strip exit gage which eliminates the effect of transport lag without interconnecting the adjacent rolling stands in such a manner as to cause problems in maintaining or controlling interstand strip tension.

Further objects and advantages of the invention will become apparent as the following description proceeds.

SUMMARY

Briefly, in accordance with the invention, AGC control system for the individual rolling stands of a tandem rolling mill are provided with separate control loops. The control loop of each stand receives, as a feedback signal, a predicted exit gage signal for that particular stand. In this manner, the effect of transport lag is eliminated while avoiding undesired direct intercoupling of the rolling stands. The predicted exit gage signal of the first or upstream stand is calculated by multiplying a measured entry gage signal by the ratio of the strip speeds entering and leaving the first stand. The predicted exit gage signal for the second or downstream stand is calculated by multiplying an entry gage signal by the ratio of the strip speeds entering and leaving the second stand. In this case, the entry gage signal is derived from the exit gage signal of the first stand and is delayed in a buffer storage unit by the amount of time required for measured strip increment to pass between the roll bites of the upstream and downstream stands. The calculation of the predicted strip exit gages from the stands is made by application of the constant volume flow rate principle applied to the individual stands as distinguished from the mill as a whole. To correct for any small gage errors that might result from improper operation of the predicted gage control system, a monitor system is provided which measures strip exit gage leaving the mill and produces an average correction signal which slowly adjusts the set point of downstream stand AGC system in a direction to correct the error.

BRIEF DESCRIPTION OF THE DRAWING

The single FIGURE of the drawing illustrates, in schematic form, a control system applied to a two stand tandem rolling mill which utilizes and embodies the present invention.

DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

In the drawing there is shown schematically a tandem rolling mill comprising upstream and downstream stands **1** and **2** which successively apply pressure to strip material **10** moving from left to right from a payoff reel **11** to a winding reel **12** to reduce the rolled material to a final desired thickness. Each of the stands has a pair of working rolls **13** and **14** driven by a motor **15.** Pressure on strip material between the working rolls **13** and **14** is exerted by backup rolls **16** and **17** and a screwdown device **18** whose position, and hence the opening between the rolls, is adjusted by means of screw controls **19.** It will be understood that the screw control **19** of each stand will act to adjust the roll opening between the working rolls **13** and **14** of each stand in accordance with the magnitude of a reference signal

supplied to input lead **20.** While screw controls have been shown, the roll openings of the stands may also be controlled by hydraulic means responsive to the reference signal.

The speeds of the motors **15** driving the working rolls **13** and **14** of stands **1** and **2** are controlled by speed regulators **21** which typically receive speed signals on leads **22***a* and **22***b* from a process control computer (not shown) as is well understood by those skilled in the art. Also, it is common practice to provide means for regulating the tension of the strip between the stands to prevent looping or breaking of the strip. For this purpose, there is shown a strip tension sensing device **23** bearing against the strip **10** between the stands **1** and **2** which provides a strip tension feedback signal on lead **24** to a tension regulator **25** which receives a tension reference signal from the process control computer on lead **22***c* and provides a speed correction signal on lead **26** to the speed regulator **21** controlling the roll motor speed of upstream stand **1.** The correction signal adjusts the set point of the regulator in a proper direction to maintain the tension of strip **10** within operating limits. The mill control system thus far described is known and for that reason has been illustrated schematically and described in general terms.

According to the invention, the roll openings of the stands **1** and **2** are controlled in a novel manner to maintain the gage of strip **10** leaving the stand **2** at some desired preset value. The manner in which this control system operates will now be described.

Each of the stands **1** and **2** is provided with a separate AGC system having a feedback control responsive to a predicted exit gage from the roll bite of the associated stand. Considering first the control system of stand **1** there is provided a gage measuring device such as an X-ray gage **27** having an upper portion **27***a* producing X-rays and a lower portion **27***b* comprising an X-ray sensor between which the strip **10** passes before entering the rool bite of stand **1.** The X-ray gage **27** produces an entry gage signal G_{1a} proportional to the thickness or gage of a measured increment of strip **10** as it approaches the roll bite of stand **1.** The gage may, for example, be arranged to make measurements at intervals corresponding to the time required for one foot of strip to pass through the gage. These measurement signals are transmitted to a computer component **28** through lead **29,** a buffer storage unit **30** and lead **31,** the computer being used to predict, in a manner to be described, the exit gage of the strip **10** as it leaves the roll bite of stand **1.**

The purpose of the buffer storage unit **30** is to delay the entry gage measurement signal for an interval corresponding to the time required for the measured strip increment to pass from the X-ray gage **27** to the roll bite of stand **1.** This avoids the time delay or transport lag effect in calculating the predicted exit gage used for control purposes. To enable the buffer storage unit **30** to provide the desired time delay function automatically, it is provided with a timing signal on lead **32** from a tachometer generator **33.** The generator is driven by a roller **34** which engages and is rotated by the strip **10** as it moves toward the roll bite of stand **1.** Thus the tachometer generator **33** produces a speed signal V_1 proportional to the strip speed as it approaches stand **1.** Knowing the distance from the X-ray gage **27** to the roll bite of stand **1** and the speed of the strip entering the stand, the time delay introduced in the gage measurement signal is determined by simple calculation of the buffer storage unit in a well known manner.

The computer unit **28** calculates the predicted exit gage of the strip **10** leaving stand **1** by use of the constant volume flow rate principle as applied to stand **1.** According to this principle the volume flow rate of the strip into the stand must equal the volume flow rate of the strip leaving the stand. If the width of the strip is considered to remain constant during the elongation caused by the working rolls of the stand then the product of the strip entry speed V_1 and the strip entry gage G_{1a} must equal the product of the strip exit speed V_2 and the strip exit gate G_{1b}. Expressed mathematically:

$G_{1a}V_1 = G_{1b}V_2$ where:

G_{1a} = strip entry gage for stand **1**

G_{1b} = strip exit gage for stand **1**

V_1 = strip speed entering stand **1**

V_2 = strip speed leaving stand **1** (1)

Thus the exit gage G_{1b} is given by the equation derived from (1):

$$G_{1b} = G_{1a}\, V_1/V_2 \quad (2)$$

The computer unit **28** calculates the predicted exit gage G_{1b} according to equation (2) using three input quantities, namely, the strip entry gage G_{1a}, the strip entry velocity V_1 and the strip exit velocity V_2. The quantity G_{1a} is supplied by the X-ray gage **27** through the buffer storage unit **30** to eliminate transport lag. The strip entry speed quantity is supplied by tachometer generator **33** through lead **35.** The strip exit speed quantity V_2 is supplied via lead **35***a* by a second tachometer generator **36** driven by a roller **37** which engages the strip between the stands **1** and **2.**

The output signal G_{1b} from the computer unit **28** is fed through lead **38** to a comparator unit **39** where it is compared with a desired exit gage signal from a gage set unit **40** which is manually set by an operator. Any difference between the predicted exit gage signal and the desired exit gage signal is fed as an error signal on lead **20** to the screw control unit **19** of stand **1** to cause adjustment of the roll opening in a proper direction to reduce the error signal to zero. Thus it will be seen that the AGC system for stand **1** has a separate control loop into which a feedback signal is introduced which varies in accordance with the predicted gage of the strip **10** as it leaves the roll bite of stand **1.**

Considering now the AGC system for stand **2** there is provided an additional computer unit **41** which calculates the predicted exit gage of the strip leaving stand **2** and generates a signal used as a feedback to control the roll opening of stand **2.** The computer unit **41** uses the constant volume flow rate principle, explained above, as applied to stand **2** according to which:

$G_{2a}V_2 = G_{2b}V_3$ where;

G_{2a} = strip entry gage for stand **2**

G_{2b} = strip exit gage for stand **2**

V_2 = strip speed entering stand **2**

V_3 = strip speed leaving stand **2.** (3)

Thus the exit gage G_{2b} is given by the equation derived from (3):

$$G_{2b} = G_{2a}\, V_2/V_3 \quad (4)$$

According to equation (4) computer unit **41** calcu-

lates the predicted exit gage G_{2b} using three input quantities, namely, the strip entry gage G_{2a}, the strip entry velocity V_2 and the strip exit velocity V_3. The quantity G_{2a} is derived from the quantity G_{1b} calculated by the computer unit **28**, these two quantities being related since the exit speed of the strip leaving stand **1** is approximately equal to the entry speed of the strip into stand **2**. However, to eliminate the transport lag effect the signal G_{1b} is routed to the computer unit **41** by leads **42** and **43** through an additional buffer storage unit **44**. This unit delays the entry gage signal G_{2a} for an interval corresponding to the time required for the strip increment measured by X-ray gage **27** to pass from the roll bite of stand **1** to the roll bite of stand **2** and in this manner eliminates the transport lag which would otherwise occur. To enable the buffer storage unit **44** to provide the desired time delay function automatically it receives a timing signal in lead **36a** from the tachometer generator **36**. The input quantity V_2 is also provided by the tachometer generator **36** via lead **45** and the remaining input quantity V_3 is provided by an additional tachometer generator **46** via lead **47**. To enable the tachometer generator **46** to provide an output signal proportional to the quantity V_3 it is driven by a roller **48** which engages and is rotated by the strip downstream with respect to the roll bite of stand **2**.

The output signal G_{2b} from computer unit **41** is fed to a comparator unit **49** via lead **50** where it is compared with a desired exit gage signal from a gage set **51** which is manually set by an operator. Any difference between the predicted exit gage signal G_{2b} from stand **2** and the desired exit gage signal is fed as an error signal on lead **20** to the screw control unit **19** of stand **2** to cause adjustment of the roll opening of stand **2** in a proper direction to reduce the error signal to zero. Thus, in a manner similar to the control of stand **1**, the AGC system for stand **2** has a separate control loop into which a feedback signal is introduced which varies in accordance with the predicted gage of strip **10** as it leaves the roll bite of stand **2**. In the case of the two stand tandem mill illustrated this is also the predicted exit gage of the strip leaving the mill.

For various reasons, the calculations of the predicted strip exit gages from stands **1** and **2** by the computer units **39** and **41** may not always be 100 percent accurate. For example, the diameters of the rolls **34**, **37** and **48** which drive the speed signal tachometers **33**, **36** and **46** by not be accurately known or they may change due to wear. To correct for small system control errors of this nature there is provided a system for monitoring the actual measured gage of the strip leaving the mill and making any required corrections by a vernier type of adjustment to the roll opening control of stand **2**. For this purpose there is provided a second X-ray gage **52** having an upper portion **52a** producing X-rays and a lower portion **52b** comprising an X-ray sensor between which the strip **10** passes after leaving the roll bite of stand **2**. The X-ray gage **52** produces an exit gage signal proportional to the thickness or gage of a measured increment of the strip as it leaves the roll bite of stand **2**. These measurement signals are transmitted to a monitor unit **53** via lead **54**. By a known process of integration the monitor averages the exit gage thickness signal and transmits it to the comparator unit **49** via lead **55**. If there is any deviation between the actual exit gage and the desired exit gage as determined by the setting of gage set unit **51**, the set point of the screw control unit **19** of stand **2** is automatically adjusted in a direction to correct for the exit gage error. Because of the averaging action of the monitor unit **53** the effect of any transport lag between the roll bite of stand **2** and the X-ray gage **52** is eliminated. Also, it should be understood that because of the relatively slow action of the monitor system the time constant of the feedback signal on lead **55** is long as compared with the time constant of the predicted feedback gage signal on lead **50** so that it does not affect the stability of the AGC system controlling the roll opening of stand **2**.

From the foregoing, it will now be apparent that there is provided, by this invention, a control system for a tandem rolling mill that eliminates the effect of transport lag without direct coupling of the AGC systems controlling the roll openings of adjacent upstream and downstream stands. This is accomplished by providing separate AGC systems for each stand with each system utilizing as its primary feedback control signal the predicted gage of the strip leaving the stand. To implement this concept calculation of the downstream stand exit gage utilizes, as an input, the calculated exit gage of the upstream stand with buffer storage delay to eliminate the effect of transport lag caused by the time required for a measured strip increment to pass between the roll bites of the adjacent stands. Because the adjacent stands are not directly coupled by the AGC controls the tension regulator **25** can function in a normal manner to control interstand strip tension without any instability caused by interaction between the strip tension and gage controls.

While the invention has been illustrated as applied to a tandem rolling mill having two stands, the control principle is applicable to mills having a greater number of stands. Thus, for example, if the mill has three stands there will be provided an additional AGC control system for stand **3** similar to that illustrated for stand **2** and the X-ray gage **52** will be located downstream with respect to stand **3** with the gage correction signal on lead **55** applied to the screw control of stand **3** rather than stand **2**. Also, the system may be used with either analog or digital type of control.

For clarity of illustration the computer units **28** and **41** and the buffer storage units **30** and **44** have been shown as separate components. In actual practice they can be combined with and form a part of the process control computer which is programed to adjust the mill controls automatically.

While there has been shown what is presently considered to be a preferred embodiment of the invention, it will be apparent to those skilled in the art that various changes and modifications may be made therein without departing from the spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. In a control system for a tandem rolling mill comprising upstream and downstream rolling stands, said stands having separate roll opening controls and being operative, successively, to reduce the thickness of a strip of material passing through the mill, the combination comprising:

means for producing strip speed signals V_1, V_2 and V_3 variable, respectively, in accordance with the speed of the strip entering the upstream stand, the speed of the strip between the upstream and down-

stream stands, and the speed of the strip leaving the downstream stand,

means for producing an entry gage signal G_{1a} variable in accordance with the entry gage of the strip entering the upstream stand,

first computer means receiving as input signals said strip speed signals V_1 and V_2 and said entry gage signal G_{1a} for computing a predicted exit gage signal G_{1b} for said upstream stand,

means for controlling the roll opening of the upstream stand in accordance with said predicted exit gage signal G_{1b},

second computer means receiving as inputs said strip speed signals V_2 and V_3 and an entry gage signal G_{2a} for computing a predicted exit gage signal G_{2b} for said downstream stand, said signal G_{2a} being derived from said calculated exit gage signal G_{1b} of said upstream stand, and

means for controlling the roll opening of the downstream stand in accordance with said predicted exit gage signal G_{2b}.

2. The control system of claim **1** wherein the calculation of the signal G_{1b} is in accordance with the equation

$$G_{1b} = G_{1a} V_1/V_2$$

and the calculation of the signal G_{2b} is in accordance with the equation

$$G_{2b} = G_{1b}V_2/V_3$$

3. The control system of claim **1** including delay means for receiving the exit gage signal G_{1b} and providing, as an output signal, the entry gage signal G_{2a} which is proportional, but delayed in time, with respect thereto, said delay means being controlled by the strip speed signal V_2 to determine the amount of time delay.

4. The control system of claim **3** including means for measuring the gage of the strip delivered from the downstream stand and producing an average correction signal variable with deviation of the exit gage from a predetermined value and means controlled by said correction signal for modifying the control of the roll opening of the downstream stand to correct for measured errors in the gage of the strip delivered from the downstream stand.

5. The control system of claim **4** including means for regulating the tension of the strip between the upstream and downstream stands.

6. The method of controlling the roll openings of adjacent upstream and downstream rolling stands used to successively reduce the thickness of strip material passing through a tandem rolling mill, said method comprising:

controlling the roll opening of the upstream stand in accordance with a predicted upstream stand strip exit gage determined by multiplying an incrementally measured upstream stand strip entry gage by the ratio of the speeds of the strip entering and leaving this upstream stand; and,

controlling the roll opening of the downstream stand in accordance with a predicted downstream stand strip exit gage determined by multiplying, after a delay interval related to the transport time for the measured increment to pass between the upstream and the downstream stands, a predicted downstream stand strip entry gage by the ratio of the speeds of the strip entering and leaving the downstream stand, the predicted downstream stand strip entry engage being derived from the predicted upstream stand strip exit gage.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 3,782,153

DATED : January 1, 1974

INVENTOR(S) : Amos J. Winchester

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 26, cancel "unitl" and substitute --until--.
line 52, cancel "sigal" and substitute --signal--.

Column 3, line 39, cancel "rool" and substitute --roll--.

Column 4, line 21, equation (2) should read --$G_{1b}=G_{1a}(V_1/V_2)$--.
line 65, equation (4) should read --$G_{2b}=G_{2a}(V_2/V_3)$--.

Column 5, line 48, cancel "by" and substitute --may--.

Column 7, line 24, equation should read --$G_{1b}=G_{1a}(V_1/V_2)$--.
line 28, equation should read --$G_{2b}=G_{1b}(V_2/V_3)$--.

Column 8, line 33, cancel "engage" and substitute --gage--.

Signed and Sealed this

twenty-seventh Day of *April 1976*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks