United States Patent

Murtland, Jr.

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[54] **ROLLING MILL CONTROL SYSTEM**

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[52] **U.S. Cl.** 72/9, 72/12, 72/16
[51] **Int. Cl.** **B21b 37/12**
[58] **Field of Search** 72/6–12, 16

[56] **References Cited**

UNITED STATES PATENTS

3,015,974	1/1962	Orbom et al.	72/9
3,444,713	5/1969	Barnikel	72/8
3,564,882	2/1971	Harbaugh et al.	72/8

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[57] **ABSTRACT**

A rolling mill control system based upon the constant volume principle and wherein strip length or velocity at the entrance or exit side of the mill is compared with calculated strip length or velocity, to derive an error signal for the rolling mill screwdown and/or a tension regulating device to maintain output gage at a desired value.

9 Claims, 4 Drawing Figures

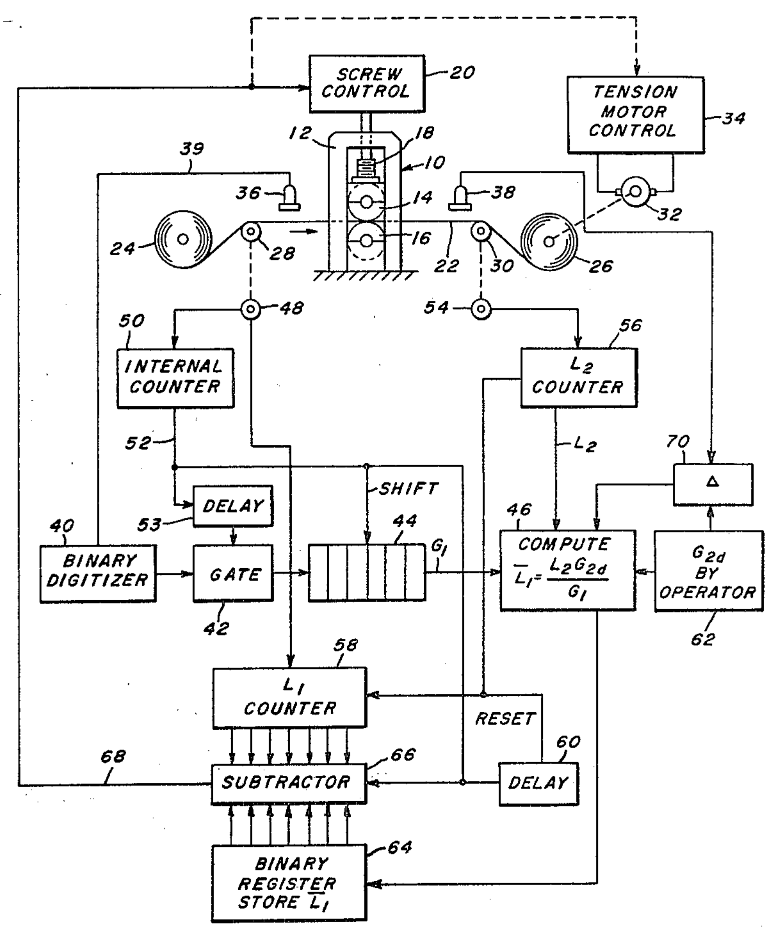

FIG. 1.

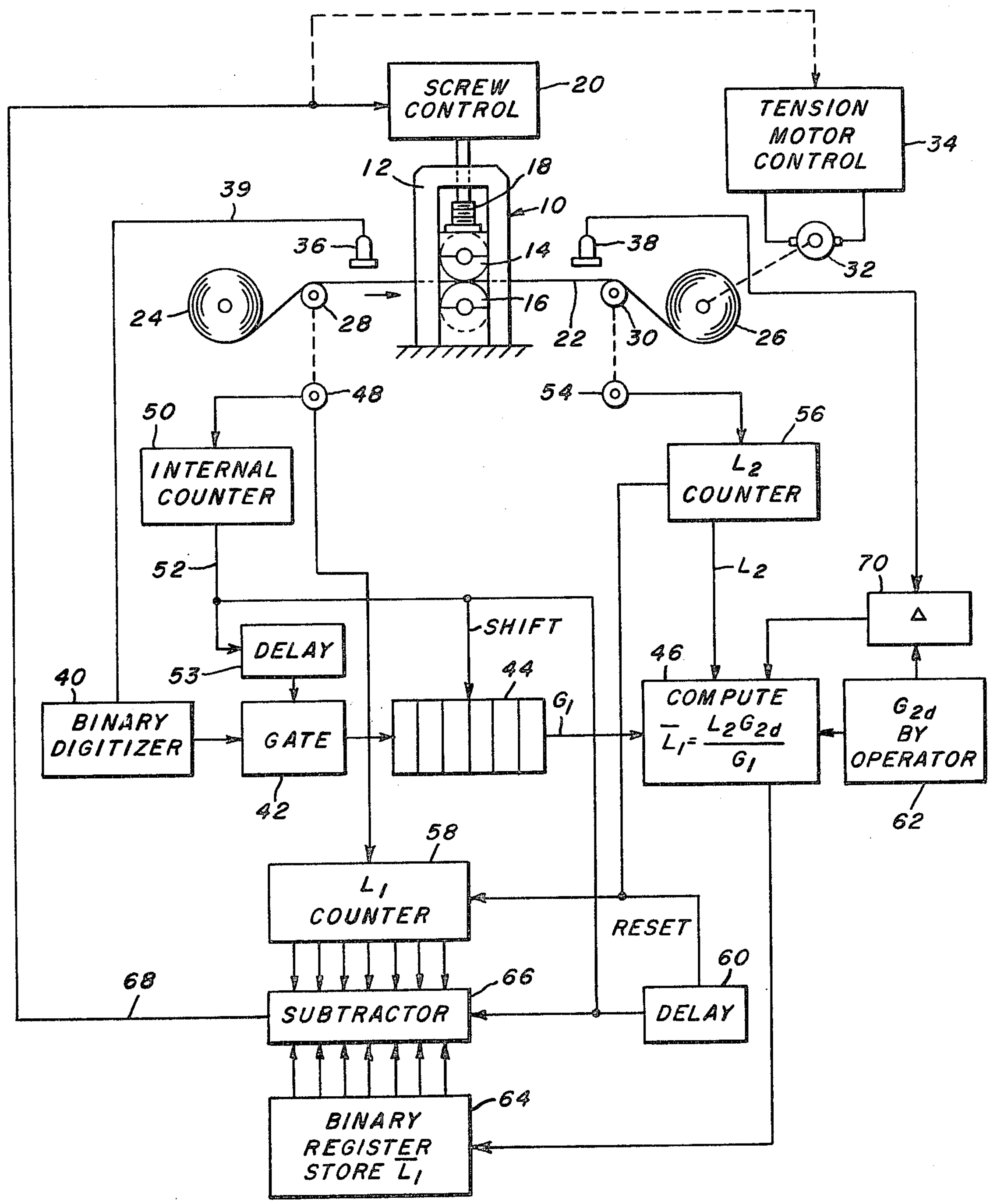

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FIG. 2.

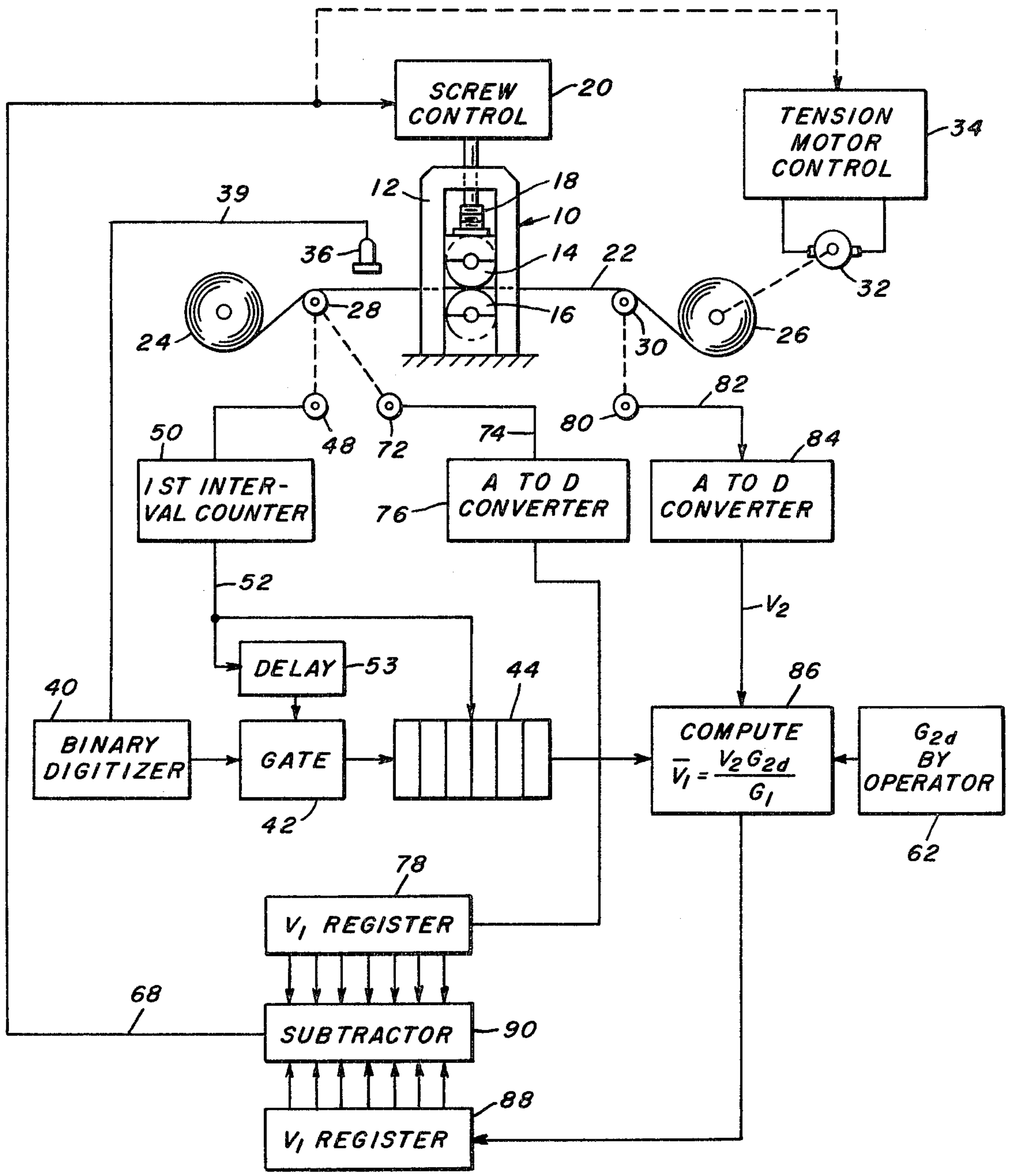

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FIG. 3.

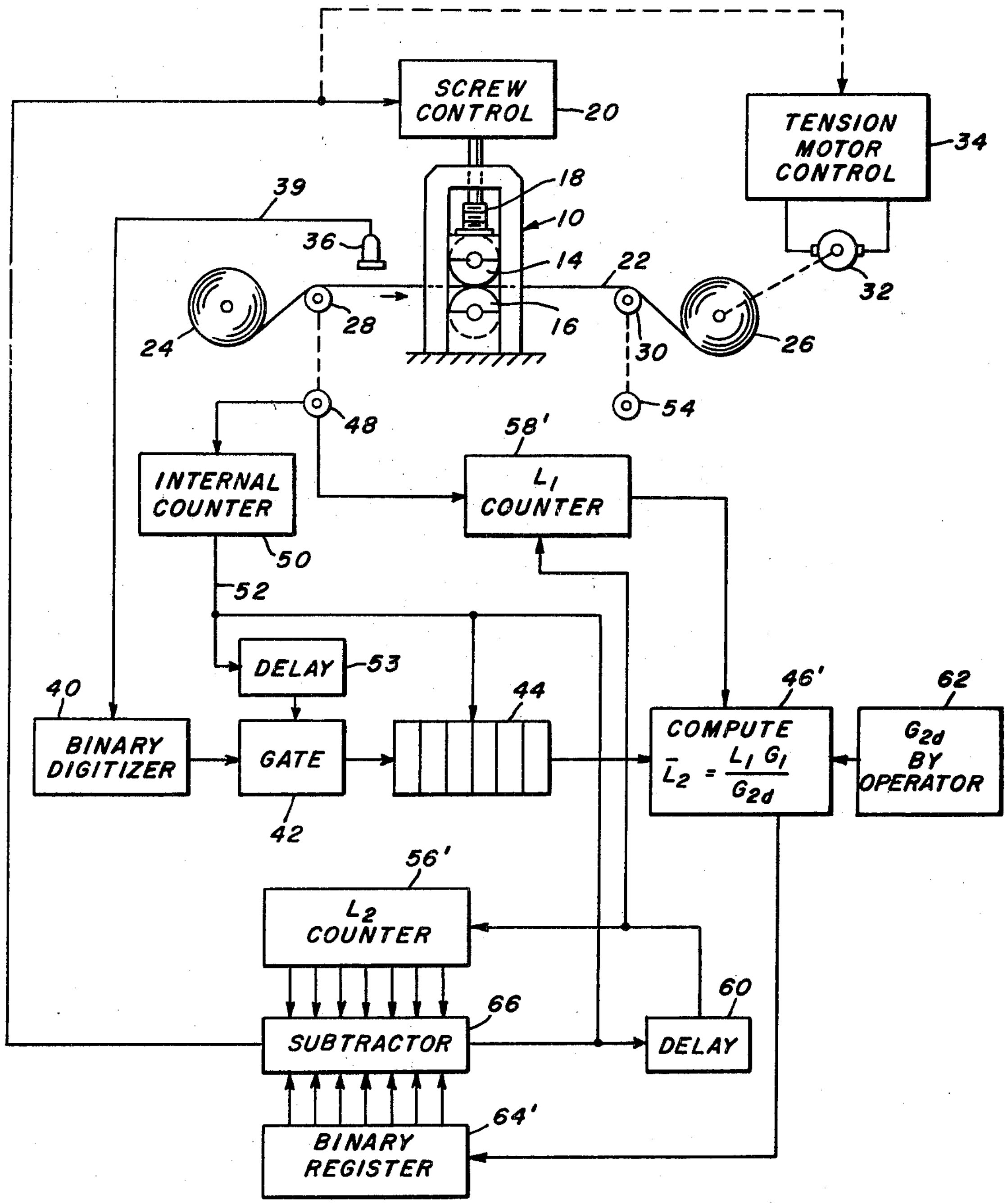

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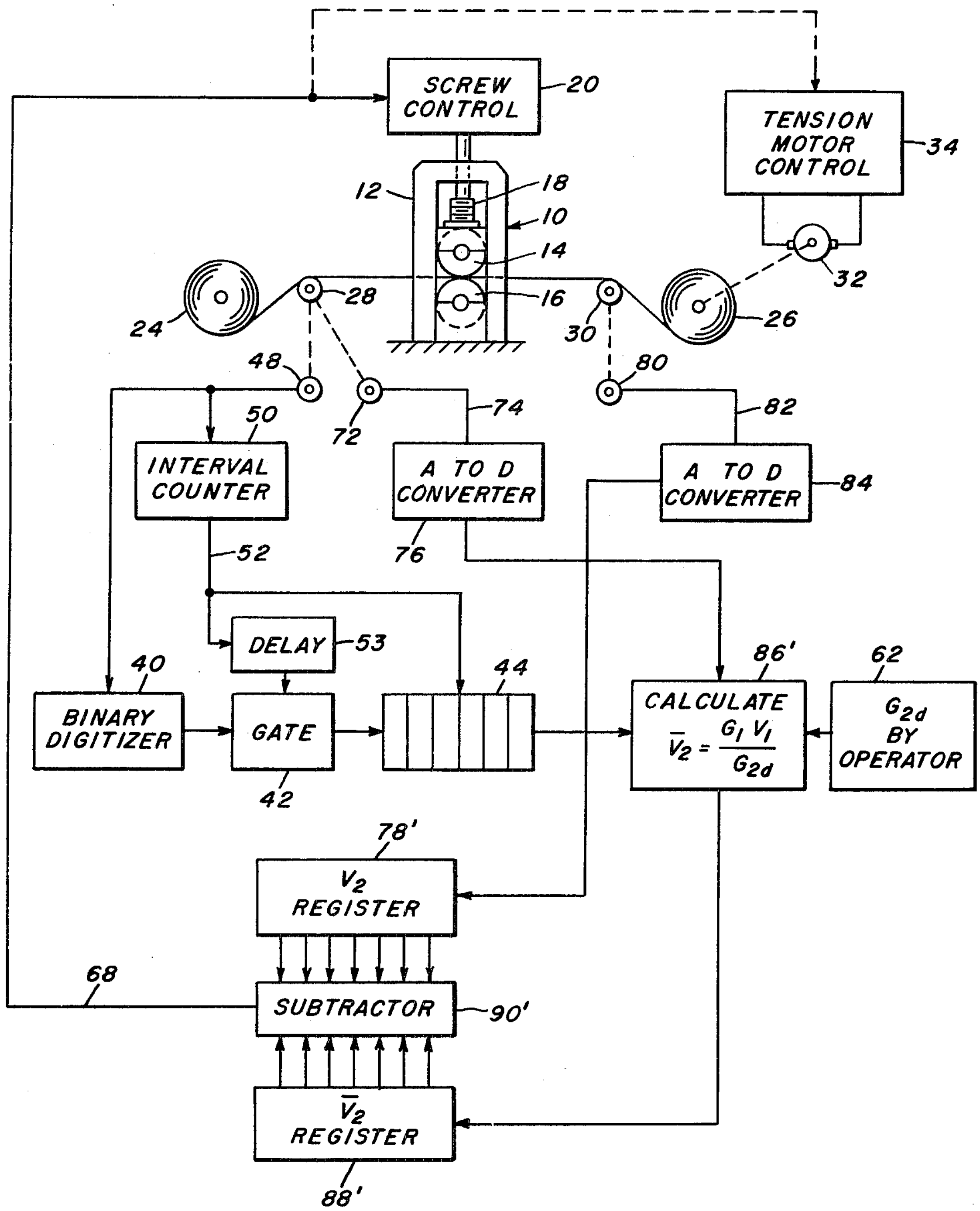
FIG. 4.



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ROLLING MILL CONTROL SYSTEM

BACKGROUND OF THE INVENTION

As is known, many prior art control systems for rolling mills and the like are such that a mill screwdown is controlled from a gage measurement taken several feet beyond the exit side of the mill. In a system of this type, the material, after reduction, progresses to the gage which may be several feet beyond the bite of the mill rolls before any error present in the material thickness can be detected. This distance from the bite of the rolls to the gage is commonly referred to as "transport distance." The time required for the material to reach the exit gage is denoted as "transport time"; while the time required to measure the strip exit gage is referred to as "sensing time." Transport time and sensing time are major elements in developing error commands. Transport distances of 5 feet or more are common in many prior art rolling mill control systems, meaning that such systems are not capable of detecting an error until 5 feet of material has passed from the bite of the mill rolls. The corrective signal is then transmitted to the mill screwdown; but the measuring gage does not detect the result of this action until 5 feet more of the material has passed through the mill. With a high gain system of this type, a natural frequency of oscillation results; and if this oscillation is left to exist without any attempt to control it, the results are undesirable. That is, for material entering the mill with fairly noticeable changes in gage, the system described would cause wide variations in output gage and in all probability would eventually result in tearing of the strip.

The undesirable transport time and sensing time inherent in conventional feedback gage control systems can be eliminated by a gage control system based on the constant volume principle wherein the gage of the strip material is, in effect, measured directly at the bite of the rolls. Such a system is shown, for example, in U.S. Pat. No. 3,015,974 and copending application Ser. No. 723,121, filed Apr. 22, 1968, now U.S. Pat. No. 3,564,882, both being assigned to the Assignee of the present application. Control systems of this type are based on the concept that the volume, V_1, of material coming out of the mill must be equal to the volume, V_2, entering the mill. Thus:

$V_1=V_2$

and

$L_1W_1G_1=L_2W_2G_2$

where:

L_1 = length of material entering the mill;
L_2 = length of material leaving the mill;
G_1 = gage of material entering the mill;
G_2 = gage of material leaving the mill;
W_1 = width of material entering the mill; and
W_2 = width of material leaving the mill.

In actual practice, it has been found that the ratio of the width of the material at the input to the mill to the output remains essentially constant. Accordingly, the factors W_1 and W_2 can be eliminated from the foregoing equation resulting in:

$L_1G_1=L_2G_2$

In rolling mill control systems of this type based upon the constant volume principle, the input gage, G_1, is measured at a point ahead of the roll bite each time the strip passes through an interval, such as one inch or less. These gage measurements, then, are advanced through a memory unit such as a shift register and are used to derive an error signal for the rolling mill screwdown when the gage fed into the computing circuitry is that of the strip which is then at the bite of the rolls. In this manner, the undesirable transport time and sensing time mentioned above are eliminated.

In any rolling mill control system, the output gage, G_2, is the ultimate parameter to be controlled. Accordingly, an electrical signal proportional to G_{2d} (desired output gage) is fed into the circuitry for computing an error signal. In U.S. Pat. No. 3,015,974, two control systems are disclosed. In the first of these, an electrical quantity proportional to L_1G_1 is generated and subtracted from a second electrical quantity proportional to L_2G_{2d} to derive an error signal. In another control system shown in the aforesaid U.S. Pat. No. 3,015,974, an error signal for the rolling mill screwdown is derived by subtracting calculated desired input gage from actual input gage.

Thus:

$$\text{Error}=G_1-\overline{G}_1$$

or

$$\text{Error}=G_1-\frac{L_2G_{2d}}{L_1}$$

where

G_1 = actual input gage;
$\overline{G}_1$ = calculated desired input gage;
L_1 = actual measured input length; and
L_2 = actual measured output length.

In copending U.S. Pat. No. 3,564,882, on the other hand, an error signal for the screwdown is derived from a consideration of predicted or calculated exit gage, $\overline{G}_2$, and desired exit gage, G_{2d}, as determined by the operator of the mill. Thus:

$$\text{Error}=\overline{G}_2-G_{2d}$$

or

$$\text{Error}=\frac{G_1L_1}{L_2}-G_{2d}$$

Hence, in the aforesaid copending application, the error signal for the screwdowns is derived from a consideration of exit gage parameters rather than input gage parameters.

All of the systems above, while workable, are based upon a comparison of input or output desired gage measurements with a calculated gage measurement, or upon subtraction of the product of input gage times input length from the product of output length times desired output gage.

SUMMARY OF THE INVENTION

In accordance with the present invention, it has now been found that instead of comparing actual or desired gages with calculated gages, a rolling mill control system based upon the constant volume principle can be devised wherein actual input length or velocity is compared with calculated input length or velocity. Alternatively, an error signal for the rolling mill control system can be derived by comparing actual exit length or velocity with calculated exit length or velocity. Velocity measurements can be used equally as well as length measurements since the time factor cancels out from both sides of the constant volume formula. Thus, the present invention provides a means whereby an error signal is derived from either:

$$\text{Error}=L_1-\frac{L_2G_{2d}}{G_1}$$

or

$$\text{Error}=V_1-\frac{V_2G_{2d}}{G_1}$$

or

$$\text{Error}=L_2-\frac{L_1G_1}{G_{2d}}$$

or

$$\text{Error}=V_2-\frac{L_1G_1}{G_{2d}}$$

where:

V_1 and V_2 are the entering and exit velocities of the strip material, respectively.

In all of the foregoing cases, either the entrance gage or velocity or the exit gage or velocity is actually measured and compared with a calculated value for the same parameter based upon a consideration of the three remaining parameters in the equation:

$L_1G_1=L_2G_{2d}$

or the equation:

$V_1G_1=V_2G_{2d}$.

The error signal may be applied to either a rolling mill screwdown, a tension controlling device for the strip material passing through the mill, or both, depending upon requirements. In either case, the gage of the mill is varied as the error signal varies.

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:

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a schematic diagram of one embodiment of the invention wherein actual input length is compared with calculated input length to derive an error signal;

FIG. 2 is a schematic illustration of another embodiment of the invention wherein actual input velocity of the strip material is compared with calculated input strip velocity to derive an error signal;

FIG. 3 is a schematic diagram of a further embodiment of the invention wherein actual output length of material leaving the rolling mill is compared with calculated output length of material leaving the rolling mill; and

FIG. 4 is a schematic illustration of still another embodiment of the invention wherein actual output velocity of strip material leaving the rolling mill is compared with calculated exit velocity to derive an error signal.

With reference now to the drawings, and particularly to FIG. 1, a single stand rolling mill 10 is shown including an outer housing 12 which supports upper and lower rolls 14 and 16, the spacing or gap between the rolls being controlled by means of a screwdown mechanism generally indicated by the reference numeral 18. The screwdown mechanism 18, in turn, is controlled by means of a screwdown control 20 which conventionally includes a drive motor mechanically connected to the screwdown mechanism itself, together with electrical controls for the drive motor. Alternatively, the gap between the rolls can be controlled by a wedge or other similar device for varying the spacing between the rolls 14 and 16.

The material being reduced in the mill is identified by the reference numeral 22 and ordinarily comprises strip material which is unwound from coil 24 and rewound on coil 26. The strip material on coil 24 passes over idler roll 28, thence through the roll bite defined between rolls 14 and 16, and then over idler roll 30 to the coil 26. The takeup reel for coil 26 is driven by means of motor 32 controlled by motor control circuit 34 for the purpose of keeping the strip under tension as it is being rolled. As will be appreciated by those skilled in the art, the gage of the strip material can be varied by either varying the spacing between the rolls 14 and 16, by varying the tension on the strip provided by means of motor 32, or by both.

The mill shown in FIG. 1 is of the reversing single stand type, meaning that during one pass the strip moves from right to left while during the succeeding pass the mill is reversed and the strip moves from left to right. As the mill is reversed, the function of the reels for the two coils 24 and 26 is reversed with the reel for coil 24 acting as the tension reel and the reel for coil 26 acting as a payoff reel. As will be understood, the reel for coil 24 is also provided with a drive motor, not shown. In the following description, it will be assumed that the strip is moving from left to right and that the coil 26 maintains tension on the strip.

At the input to the mill, and usually spaced about 5 or 6 feet from the bite of the rolls 14 and 16, is a thickness gage 36 which measures the actual input gage of the strip material entering the mill. On the other side of the mill is a second thickness gage 38 which is used to measure the input gage of the strip material when the mill is reversed. However, when the material is passing from left to right as shown in FIG. 1, the gage 38 may be used to monitor the desired gage as selected by an operator as will hereinafter be explained in detail.

The two gages 36 and 38 are typically of the X-ray type; however in certain cases contact gages may be employed. In either case, the output of the gage is an analog signal on lead 41, for example, proportional to the gage, G_1, of the entering strip material. This analog signal is applied to a binary digitizer or analog-to-digital converter 40 wherein the gage signal is converted to a plurality of ON or OFF signals representing bits in a binary number. These signals are then applied through gate 42 to the input of a shift register 44 which advances gage measurements taken, for example, at 1-inch intervals along the strip 22 to computation circuitry, generally indicated by the reference numeral 46 in FIG. 1.

The idler roll 28 is connected to a tachometer pulse generator 48 which will produce an output pulse each time the strip travels through a predetermined distance. Normally, the generator 48 will produce a pulse each time the strip passes through a small fraction of an inch such that during 1 foot of travel of the strip 22, a large number of pulses is generated by the generator 48. These pulses are applied to an interval counter 50 which will produce an output pulse on lead 52 each time the strip passes through a predetermined distance, say 1 foot. The output pulses from the interval counter 50, in turn, are used as shift pulses for the shift register 44 and are also applied through a delay circuit 53 to the gate 42. In this manner, each time the strip 22 moves through 1 foot, a pulse on lead 52 will initially be applied to the shift register 44 to advance the gage measurements stored therein to the next succeeding storage cores in the shift register while advancing the oldest gage measurement stored in the register 44 to the computing circuitry 46. After the information is advanced in this manner, the delay circuit 53 opens the gate 42 to enter a new gage reading into the first core of the shift register. Thus, the cores of the shift register 44 are first shifted to advance information to the computing circuitry 46, followed by the introduction of new information into the unit from gage 36.

It will be appreciated that the shift register 44 serves to store and advance successive entry gage measurements from gage 36 in synchronous correlation with the movement of the strip 22. That is, each time the gate 42 is enabled by the interval counter 50, it feeds the instantaneous entry gage measurement to the first core of the shift register 44 which progressively advances these instantaneous measurements from one end of the shift register to the other. The time required to advance from one end of the shift register 44 to the other is equal to the time required for the strip 22 to travel from the gage 36 to the bite of the rolls 14 and 16.

Let us assume, for example, that the gage 36 is spaced 6 feet in front of the bite of the rolls 14 and 16. After the strip 22 has moved 1 foot, the gate 42 opens and the instantaneous gage measurement, in binary form, is fed into the first storage core of the shift register 44. After the strip has traveled another foot, this first gage measurement is shifted to the second storage core and the gate 42 will then open to feed the second instantaneous gage measurement into the shift register. This process continues until 6 feet of material has passed from the gage 36 to the bite of the rolls, at which time the gage measurement at the output of shift register 44 is that taken from a point on the strip which is directly at the bite of the rolls 14 and 16. Thus, length of velocity calculations are made in accordance with the constant volume principle given above, not after the fact, but directly at the bite of the rolls.

Connected to the idler roll 30 is a second pulse generator 54 which, like generator 48, will produce a pulse each time the strip 22 travels through a predetermined distance. For a given length of material, both generators will produce the same number of pulses. The pulses from generator 54, in turn, are applied to an L_2 counter 56 which has stored therein a number of pulses proportional to the length of the strip material 22 passing out of the mill. The pulses generated by generator 48 will be less in number than those generated by generator 54 since the strip material, in passing between the rolls 14 and 16, is elongated or increased in length.

The pulses from pulse generator 48 are also applied to an L_1 counter 58. The counters 56 and 58 are reset to again begin counting from zero by a reset pulse derived from lead 52 but delayed in delay circuit **60**. The counters **58** and **56**, while being shown herein as reset each time a new gage measurement is taken, need not necessarily be reset over the same time interval. If they are not reset over the same time interval, a second interval counter will be required.

The output of the L_2 counter, in digital form, is applied to the computing circuitry **46** along with the binary signal, G_1, from shift register **44** representing the gage of the material directly at the bite of the rolls **14** and **16**. Also applied to the computing circuitry **46** is a signal, G_{2d}, from circuit **62** which is proportional to the desired exit gage of the strip material **22** as determined by the mill operator. The computing circuitry **46** may, for example, comprise part of a general purpose computer or may comprise a separate hardware component for computing the equation:

$$\overline{L}_1=\frac{L_2G_{2d}}{G_1}$$

Since V_1G_1 must always be equal to V_2G_2 as described above, the input length can be computed in circuitry **46** in accordance with the equation:

$$\overline{L}_1=\frac{L_2G_{2d}}{G_1}$$

where

$\overline{L}_1$ = calculated input length;
L_2 = actual output length;
G_1 = actual input gage; and
G_{2d} = desired output gage as determined by the operator.

The electrical signal proportional to $\overline{L}_1$, therefore, may be applied to a binary register **64** and compared or subtracted in subtractor **66** from the stored value of L_1 in counter **58** to derive an error signal on lead **68**. This error signal, in turn, is applied back to the screwdown control **20** or, alternatively, to the tension motor control circuit **34** to vary the gage of the strip material **22**.

After the mill has been running for a period of time, the actual output gage as measured by gage **38** can be compared with the gage, G_{2d}, selected by the operator in comparison circuit **70** to derive a correction signal for the computing circuitry **46**. That is, if the actual output gage is not equal to the desired gage selected by the operator, it is known that the product at the output of the computation circuitry **46** is incorrect or that possibly the L_1 counter is not registering correctly. This can be corrected by the error signal from comparator **70**.

With reference to FIG. **2**, a control system is shown which is similar to that of FIG. **1** except that input and output velocity measurements are taken rather than length measurements. Accordingly, elements corresponding to those shown in FIG. **1** are identified by like reference numerals. Again, entry gage measurements, after being converted into binary form in digitizer **40**, are passed through gate **42** and entered into shift register **44** where they are advanced in synchronous correlation with the movement of the strip **22** from the gage **36** to the bite of the rolls **14** and **16**. In this case, however, a tachometer **72** is connected to idler roll **28** along with pulse generator **48**. The tachometer generator **72** will produce an analog signal on lead **74** proportional to the velocity of the entering strip material. This is converted to binary form in analog-to-digital converter **76** and applied to a V_1 register **78**. Similarly, the idler **30** is connected to a tachometer generator **80** which produces an analog signal on lead **82** proportional to the exit velocity of the strip material. This is converted to digital form in analog-to-digital converter **84** and applied to computing circuitry **86** where the equation:

$$\overline{V}_1=\frac{V_2G_{2d}}{G_1}$$

is calculated from a consideration of the quantity G_1 from the shift register **44**, V_2 from the analog digital converter **84** and G_{2d} from circuit **62** as determined by the operator. The quantity $\overline{V}_1$, comprising calculated input strip velocity, is applied to a second register **88** and subtracted in subtractor **90** to provide an error signal on lead **68** which is fed back to the screwdown control **20** or tension motor control circuit **34**.

As was explained above, velocity measurements can be used equally as well as length measurements since velocity appears on either side of the constant volume formula and, consequently, the time element cancels out.

In FIG. **3**, another embodiment of the invention is shown which again is similar to that of FIG. **1** except that in this case actual output length, L_2, is compared with computed exit length, $\overline{L}_2$. Thus, the L_2 counter **56'** is now connected to subtractor **66** while the output of L_1 counter is connected to the computing circuitry **46'** which computes:

$$\overline{L}_2=\frac{L_1G_1}{G_{2d}}$$

$\overline{L}_2$, of course, is computed from a consideration of the entry gage measurement, G_1, from shift register **44**, the desired output gage, G_{2d}, from circuit **62** and the input length measurement, L_1, from counter **58**. The output of the computation circuitry **46**, in turn, is applied to binary register **64'** and compared with the count of L_2 counter **56'** to derive an error signal on lead **68** which is fed back to the screwdown control **20** or tension motor control circuit **34**. Again, since the calculated value of exit length must be equal to

$$\overline{L}_2=\frac{L_1G_1}{G_{2d}}$$

comparison of the quantity $\overline{L}_2$ with the actual value of L_2 derives an error signal for gage corrections.

In FIG. **4**, still another embodiment of the invention is shown which is similar to that of FIG. **2** and wherein elements corresponding to those of FIG. **4** are identified by like reference numerals. In this case, however, the output of the analog-to-digital converter **76** is connected to the computation circuitry **86'**; whereas the output of the analog-to-digital converter **84**, comprising a signal proportional to the exit velocity, V_2, is applied to register **78'**. Computation circuit **86'**, in this case, computes:

$$\overline{V}_2=\frac{V_1G_1}{G_{2d}}$$

where the various quantities are the same as those identified above. The output of the computation circuitry **86'**, comprising a signal proportional to $\overline{V}_2$ is applied to register **88'** and compared with the actual value of V_2 in register **78'** to produce an error signal on lead **68**.

Although the invention has been shown in connection with certain specific embodiments, 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. In a system for controlling a rolling mill based on the principle of constant volume of material entering and leaving the mill, the combination of means for producing a first electrical signal proportional in magnitude to the desired output gage of strip material leaving the rolling mill, means for producing a second electrical signal which varies as a function of the actual gage of strip material entering the rolling mill, means for producing a third electrical signal which varies as a function of the length of strip material entering the mill over a predetermined period of time, means for producing a fourth electrical signal which varies as a function of the length of strip material leaving the mill over said predetermined period of time, means responsive to said first, second and one of said third and fourth

signals for deriving a fifth electrical signal proportional to a calculated value of a quantity which varies as the length of material on one side of the mill varies over said predetermined time interval, and means for comparing said fifth electrical signal with one of said third and fourth electrical signals to derive an error signal for controlling said rolling mill.

2. The system of claim 1 wherein said third and fourth electrical signals vary as a function of the length of strip material entering and leaving said rolling mill over said predetermined period of time.

3. The system of claim 1 wherein said third and fourth electrical signals vary as a function of the speeds of the strip material entering and leaving said rolling mill.

4. The system of claim 1 wherein said first signal is proportional to G_{2d}, the desired output gage of said material leaving the rolling mill; said second signal is proportional to G_1, the actual gage of the material entering the rolling mill; said third and fourth signals are proportional to L_1 and L_2, the actual lengths of material entering and leaving the rolling mill, respectively, over said predetermined period of time; and said fifth signal is proportional to

$$\frac{L_2 G_{2d}}{G_1}$$

and is compared with said third signal L_1 to derive an error signal.

5. The system of claim 1 wherein said first signal is proportional to G_{2d}, the desired output gage of strip material leaving the rolling mill; said second signal is proportional to G_1, the actual gage of material entering the rolling mill; said third and fourth signals are proportional to V_1 and V_2, the actual velocities of the strip material entering and leaving the rolling mill, respectively; and said fifth electrical signal is proportional to

$$\frac{V_2 G_{2d}}{G_1}$$

and is compared with said third electrical signal to derive an error signal.

6. The system of claim 1 wherein said first electrical signal is proportional to G_{2d}, the desired output gage of material leaving said rolling mill; said second electrical signal is proportional to G_1, the actual gage of material entering the rolling mill; said third and fourth signals are proportional to L_1 and L_2, the actual lengths of material entering and leaving the rolling mill, respectively, over said predetermined period of time; and said fifth electrical signal is proportional to

$$\frac{L_1 G_1}{G_{2d}}$$

and is compared with said fourth electrical signal to produce an error signal.

7. The system of claim 1 wherein said first signal is proportional to G_{2d}, the desired output gage of strip material leaving the rolling mill; said second electrical signal is proportional to G_1, the actual gage of material entering the rolling mill; said third and fourth signals are proportional to V_1 and V_2, the actual velocities of strip material entering and leaving the rolling mill, respectively; and said fifth electrical signal is proportional to

$$\frac{V_1 G_1}{G_{2d}}$$

and is compared with said fourth electrical signal to derive an error signal.

8. The system of claim 1 wherein said error signal is applied to a screwdown control mechanism for said rolling mill.

9. The system of claim 1 wherein said error signal is applied to a tension regulating device for said rolling mill.

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