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Silva

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[54] **SYSTEM TO COMPENSATE FOR ROLL ECCENTRICITY EFFECTS AND/OR TO SIMULATE A MILL WITH VARIABLE STRETCH CHARACTERISTICS**

[76] Inventor: **Antonio V. Silva,** c/o Westinghouse Electric S.A. Caixe Postal 5156, San Paulo, Brazil

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[52] **U.S. Cl.** **72/11**
[51] **Int. Cl.** **B21b 37/12**
[58] **Field of Search** 72/8–11, 16, 21, 72/19

[56] **References Cited**

UNITED STATES PATENTS

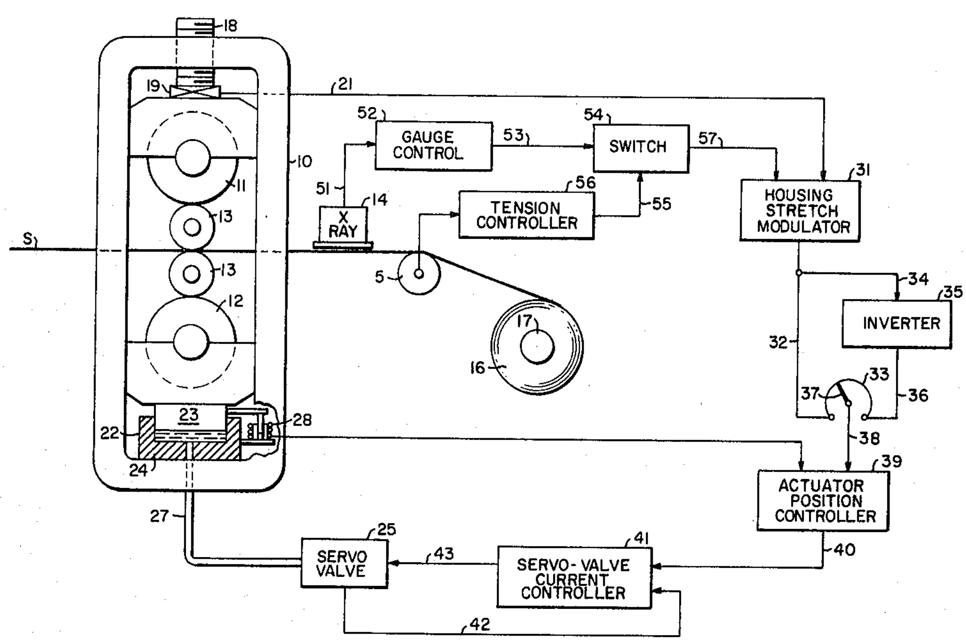
3,478,551	11/1969	Alsop	72/8
3,543,549	12/1970	Howard	72/8

Primary Examiner—Milton S. Mehr
Attorney, Agent, or Firm—R. G. Brodahl

[57] **ABSTRACT**

A rolling mill control system which, in one aspect, compensates for the effects of roll eccentricity during operation of the rolling mill. The control system includes circuitry which produces a control signal for rapid and accurate adjustments to hydraulic roll force actuators in a manner to prevent increases in the roll separating force. This circuitry further includes an outer gage control loop and/or tension control loop for automatic gage control of the rolling mill. According to another aspect of the disclosure, the control system simulates a rolling mill structure having variable spring constants whereby an operator may select a desired mode of rolling mill control. To simulate an infinitely stiff mill construction, the control system provides a control signal for rapid adjustments of the roll force actuators in a direction and by the exact amount to compensate for changes in the housing stretch. The control system simulates infinitely soft mill construction by rapid adjustments to the roll force actuator in a direction and by the exact amount to resist changes in the rolling force.

16 Claims, 2 Drawing Figures



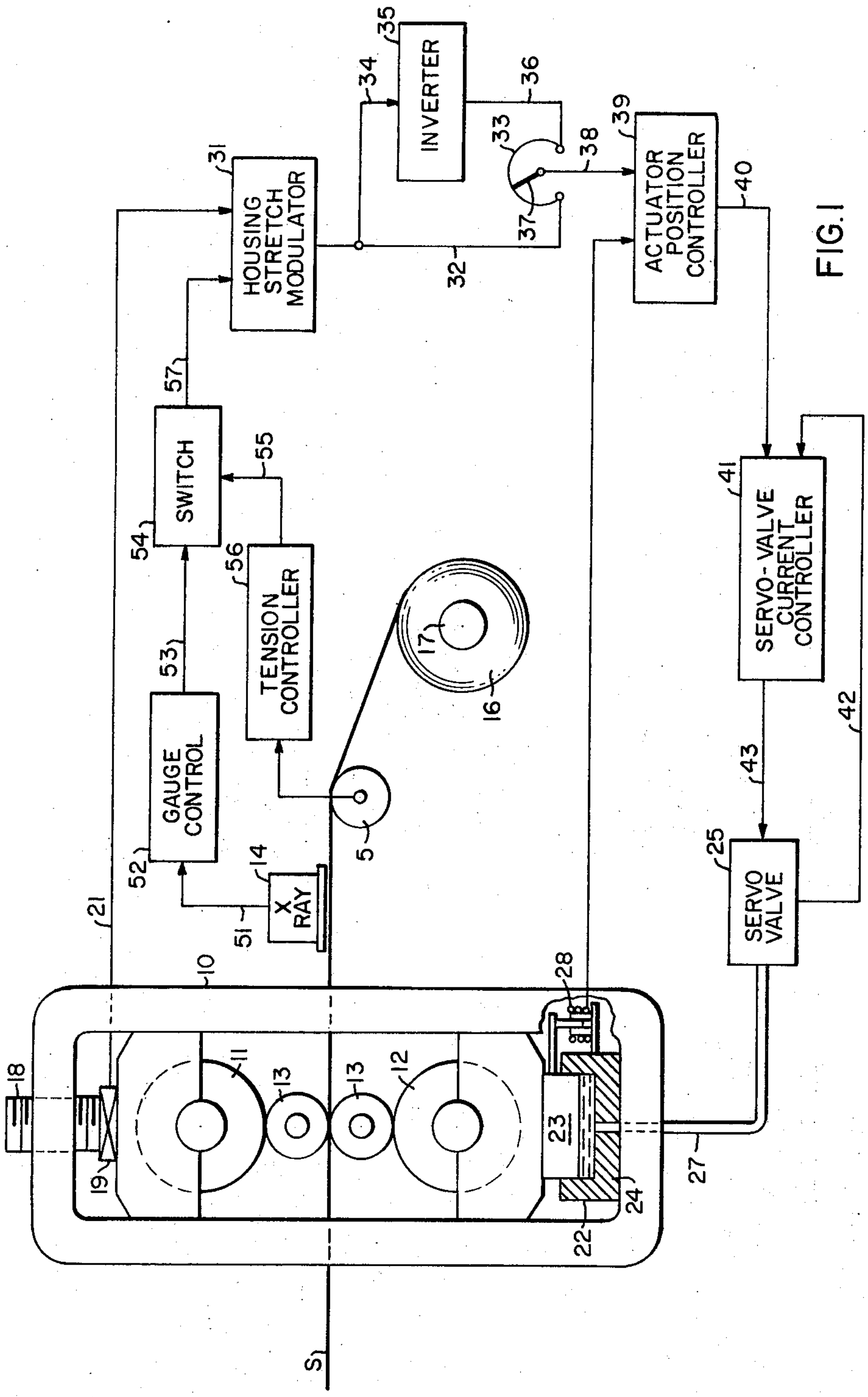

INVERTER
HOUSING STRETCH MODULATOR
ACTUATOR POSITION CONTROLLER
SWITCH
TENSION CONTROLLER
GAUGE CONTROL
X RAY
SERVO-VALVE CURRENT CONTROLLER
SERVO VALVE
S

FIG.1

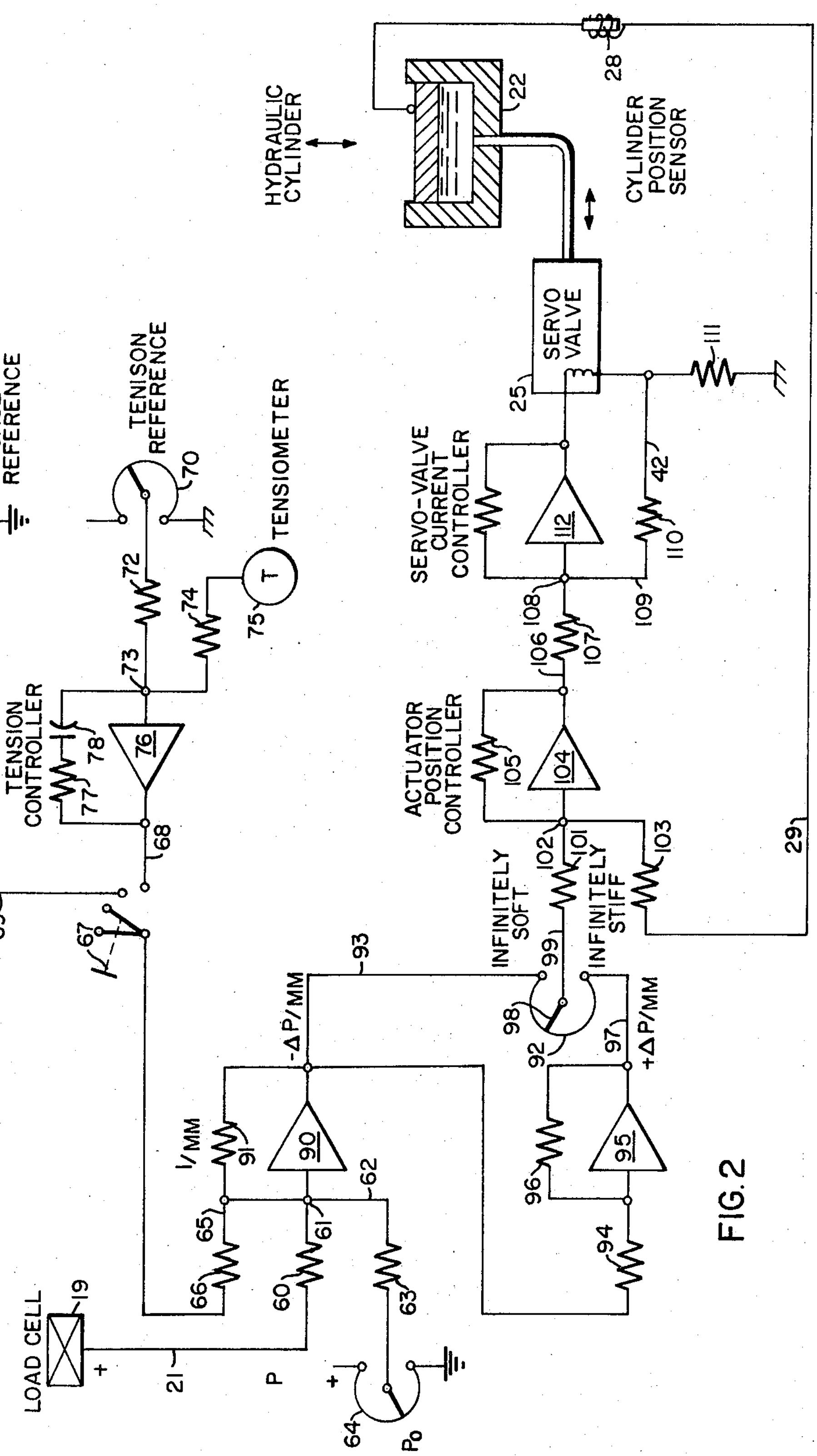

HYDRAULIC CYLINDER
CYLINDER POSITION SENSOR
SERVO VALVE
X RAY
GAGE REFERENCE
TENISON REFERENCE
TENSIOMETER
TENSION CONTROLLER
SERVO-VALVE CURRENT CONTROLLER
ACTUATOR POSITION CONTROLLER
INFINITELY SOFT
INFINITELY STIFF
-ΔP/MM
+ΔP/MM
1/MM
LOAD CELL
P
Po

FIG. 2

SYSTEM TO COMPENSATE FOR ROLL ECCENTRICITY EFFECTS AND/OR TO SIMULATE A MILL WITH VARIABLE STRETCH CHARACTERISTICS

BACKGROUND OF THE INVENTION

The eccentricity characteristics of rolls employed in a rolling mill have the detrimental effect of producing cyclic gage errors during the rolling of metallic strip or the like, as a function of the phase relation between the eccentricities of the rotating rolls. Conventional rolling mill control systems are based on the assumption that absolute concentric rolls are provided in the mill; while in actual practice they are too expensive to produce or impossible to machine and therefore some degree of roll eccentricity is normally present. Moreover, the effect of roll eccentricity constantly changes as the rolls wear and they are replaced with reground rolls, or as a result of bearing and lubrication variations.

Present demands by the industry require a rolling mill control system to provide greater gage control accuracy and increased production levels. In order to meet these demands, such a control must compensate for the effects of roll eccentricity during operation of the rolling mill. Present-day requirements further demand a large degree of versatility in the control system in order to economically utilize the production capacity of a given rolling mill installation. In a cold rolling mill installation, for example, it is desirable to establish a rolling schedule which oftentimes requires different modes of operation for one of more mill stands to process the coils of strip. Certain coils of strip are rolled with the objective of producing uniform gage, thus requiring repeated roll gap adjustments to suit the varying rolling conditions in the mill; while other coils of strip are rolled with the objective of temper or skin pass rolling to improve their metallurgical properties, thus requiring the use of uniform rolling force throughout the rolling operation.

Recent attempts to improve the gage accuracy of rolled strip include the use of hydraulic roll force actuators in the form of piston and cylinder assemblies for adjusting the gap between the processing rolls during rolling. Tests have now established that these actuators are capable of making roll gap changes in response to signals having a frequency as high as 20 cycles per second with no appreciable attenuation. It is a feature of the present invention to control these actuators in a manner to meet the present requirements of the industry.

SUMMARY OF THE INVENTION

In accordance with the invention, an improved automatic gage control system for a rolling mill is provided including control circuitry to compensate for the effects of roll eccentricity during operation of the rolling mill and to simulate a rolling mill structure having variable stretch characteristics.

Specifically, the present invention provides a control system for hydraulic roll force actuators in a rolling mill to respond to the effects of roll eccentricity and compensate for them by actuator adjustments of an exact amount to prevent a rolling force increase. The actuators are controlled in response to deviations in the rolling force to compensate for the effects of roll eccentricity and/or simulate a mill structure with variable stretch characteristics. Load cells arranged in the mill housing provide a signal porportional to the total rolling force P. If M_m is the spring constant of the mill housing, then the housing stretch, h, under the rolling force P, is given by the equation:

$$h = P/M_m \tag{1}$$

The rolling force signal P is received by circuitry to produce a signal Δ P representing a change in the rolling force. Thus, with a given change in the rolling force, there is computed a change in the housing stretch Δh given by the equation:

$$\Delta h = \Delta P/M_m \tag{2}$$

To simulate an infinitely stiff mill, the control system operates on the basis to control the displacement of the force applicator by an amount to exactly correspond to the change in the housing stretch. If the hydraulic actuator is controlled to move by the same amount but in an opposite direction thereby rejecting any incremental changes in the rolling force, the resultant control simulates a mill structure having an infinitely soft stretch characteristic. By selecting the midpoint between these two extremes of stretch characteristics, the control system will simulate the mill stretch characteristic of a conventional rolling mill. By simulating an infinitely soft rolling mill, it was found that any increase in the roll force can be rapidly prevented. This would include roll force increases produced by roll eccentricity and thus they can be completely eliminated by such a control system. Since this control system operates to reject all roll force increases, an outer gage control loop or tension control loop are concurrently employed to provide automatic gage control.

These features and advantages of the present invention as well as others will become more apparent when the following description is read in light of the accompanying drawings, of which:

FIG. 1 is a schematic block diagram of electrical circuitry for controlling a rolling mill in accordance with the teachings of the present invention; and

FIG. 2 is a detailed schematic circuit diagram of the rolling mill control system according to the present invention.

With reference now to the drawings, and particularly to FIG. 1, the rolling mill shown includes a housing **10** having windows which rotatably support upper and lower back-up rolls **11** and **12**, respectively. Each back-up roll supports a work roll **13** which forms a roll gap wherein a strip S is processed. After leaving the gap between the work rolls, the strip passes beneath an X-ray **14** from where it partially wraps about the outer surface of a deflector roll **15** and then continues in the downward direction to a point where it is formed into a coil **16** by a mandrel **17**. At the top of the mill housing **10**, there is provided a screwdown which includes a screw **18** for establishing a desired gap between the work rolls. Between the screw and the roll chocks for the back-up roll **11**, there is arranged a load cell **19** for providing a signal in line **21** proportional to the total roll force P in the mill.

At the bottom of the mill housing between the roll chocks of the lower back-up roll **12** and the housing, there is provided a roll force actuator **22** in the form of a piston **23** and cylinder **24.** Hydraulic fluid is delivered from a source, not shown in the drawings, to a servo valve **25** employed to control the passage of fluid through pipes **27** to the actuator **22.** A position sensor **28** such as an LVDT delivers an electrical signal in line **29** proportional to the relative position of the piston **23** with respect to the cylinder **24.** The rolling force signal P is delivered to a housing stretch modulator **31** having electrical circuitry, to be more fully described hereinafter, which provides a signal in line **32** proportional to the elongation or stretch of the mill housing in response to a change in the rolling force. This signal which is given by the equation:

$$-\Delta h = -\Delta P/M_m \quad (3)$$

has a negative electrical polarity and is connected to one side of a potentiometer or rheostat **33.** The output signal from the housing stretch modulator **31** is also connected by line **34** to a proportional plus derivative circuitry **35.** The circuitry **35** produces a signal representing the same degree of mill housing stretch but having a positive electrical polarity and proportional to the quantity given by the equation:

$$+\Delta h = +\Delta P/M_m \quad (4)$$

Line **36** is connected to the contact of potentiometer **33** at its adjustment extreme opposite from the contact point of line **32.** The potentiometers **33** includes a movable tap **37** constructed for manual positioning by an operator. Depending on the position of the movable tap, a signal lying between or equal to one of the quantities

$$-\Delta P/M_m$$

and

$$+\Delta P/M_m$$

is delivered by line **38** to an actuator position controller **39.** The position sensor signal in line **29** is used as a feedback signal by the controller **39** to generate an actuator position control signal in line **40** connected to a servo valve current controller **41** which also receives a feedback signal in line **42** from the servo valve **25.** A position adjustment signal for the actuator **22** is transmitted by line **43** to the servo valve **25** for accurate and rapid roll gap changes by the actuator. As previously indicated, these actuators are responsive to signals having a frequency as high as 20 cycles per second with no appreciable attenuation.

When an operator positions the movable tap **37** to receive the signal proportional to the quantity

$$+\Delta P/M_m$$

in line **36,** the rolling mill control system simulates an infinitely rigid mill construction whereby the roll gap adjustment made by the roll force actuators **22** is an amount exactly corresponding to and in the direction of the housing stretch. When the movable tap **37** is positioned to receive the signal in line **32** whose value represents the quantity

$$-\Delta P/M_m$$

the control system functions on the basis of simulating a rolling mill having infinitely soft mill stretch characteristic whereby the increase in the housing stretch is immediately responded to by the cylinder position controller **39** in a manner to reject the increase and maintain the rolling force constant. By simulating an infinitely soft rolling mill housing structure, the control system compensates for the effects of roll eccentricity by maintaining a constant rolling force and rejecting any increases to the rolling force. When an infinitely soft mill is simulated, temper rolling or skin pass rolling may be effected whereby a truly constant rolling force is provided at the roll gap.

An outer gage control loop is added when the control system is employed to compensate for the effects of roll eccentricity while processing strip to a uniform thickness. Such a gage control loop includes, for example, the X-ray **14** whose strip thickness deviation signal is transmitted along line **51** to a gage control amplifier **52** whose output signal is transmitted by line **53** to a switch **54.** The switch **54** receives from line **55** an error signal from a tension controller **56** associated with the deflector roll **15** in a manner to provide uniform tension in the strip at the delivery side of the mill. When the switch **54** is actuated, an automatic gage control signal is produced in line **57** representing either the X-ray gage control signal from line **53** or the tension control signal from line **55.** Alternatively, the switch may feed either both or none of these two signals to line **57.** When both signals are transmitted, the gage control function is divided between tension and roll gap adjustments.

Turning now to the schematic circuit diagram of the present invention illustrated in FIG. 2, the load cell **19** provides a signal in line **21** proportional to the rolling force P between the work rolls. The rolling force signal passes through resistor **60** to a summing point **61.** Point **61** is connected by a line **62** through resistor **63** to a potentiometer **64** manually set to a desired rolling force reference signal P_o. Point **61** may also receive an automatic gage control signal in an outer control loop from line **65** connected through a resistor **66** to a switch **67.** This switch is designed to transmit either, both or neither of two input signals consisting of a tension control error signal in line **68** and a thickness error signal in line **69.**

The thickness error circuitry includes a tension reference signal provided by potentiometer **70** in line **71** passing through a resistor **72** to a summing point **73.** Point **73** is connected through a resistor **74** to a tensiometer **75.** The tensiometer **75** when incorporated as part of the deflector roll apparatus **15** produces a signal proportional to the actual strip tension at the delivery side of the mill. Point **73** is also connected to the input of an integrating operational amplifier **76** having a feedback path including resistor **77** in series with capacitor **78.** The output signal from amplifier **76** is transmitted by line **68** to switch **67.**

The circuitry for producing the gage error signal includes an actual strip thickness signal from X-ray gage **14** in line **51** through resistor **79** to a summing point **80.** The point **80** is connected by line **81** through a resistor **82** to a potentiometer **83,** manually set to represent a desired strip thickness reference signal. Point **80** is also connected to the input of a proportional operational amplifier **84** having a feedback path including resistor **85.** The output signal from amplifier **85** is transmitted by line **69** to switch **67.** Returning now to point **61,** it is connected to the input of a proportional operational amplifier **90** having a feedback path including a resistor **91.** The resistor **91** has a resistance proportional to the known mill modulus M_m and represents the quantity.

$$1M_m$$

The signal from amplifier **90** in line **93** is connected to one side of a manually set potentiometer **92** and is proportional to a change in the housing stretch given by the quantity

$$-\Delta P/M_m$$

The output signal from amplifier **90** in line **93** is applied through a resistor **94** to a proportional operational amplifier **95** having a feedback path including a resistor **96.** The output from amplifier **96** is a signal in line **97** connected to the opposed contact point of potentiometer **92** and represents the quantity

$$+\Delta P/M_m$$

The signal in line **97** is produced as an inverted signal such that quantitatively, it is equal to but having an electrical polarity opposite to the signal in line **93.** The potentiometer **92** includes a movable tap **98** for transmitting to line **99** the signal in line **93,** line **97** or proportional parts of the signal quantities lying between the ranges of these signals. Line **99** is connected through resistor **101** to a summing point **102.** Point **102** is connected through resistor **103** to line **29** of the position sensor **28** of the roll force actuator **22.** Point **102** is also connected to the input of a proportional operational amplifier **104** having a feedback path including a resistor **105.** The amlifier **104** is employed as an actuator position controller having an output signal transmitted by line **106** through a resistor **107** to a summing point **108.** Point **108** receives a feedback signal in line **109** through resistor **110** in line **42** from the servo valve **25.** Line **42** is connected to ground through a resistor **111.** Point **108** is also connected to the input of an operational amplifier **112** having a feedback path including a resistor **113.** The amplifier **112** is employed as a servo valve current controller. As previously indicated, the servo valve controls the passage of fluid pressure to the hydraulic force actuator in the pipes **27.**

Let is be assumed that an operator elects to employ the control system according to the present invention to simulate an infinitely stiff mill in which event he will position the movable tap **98** of the potentiometer **92** to receive the signal proportional to the quantity

$$+\Delta P/M_m$$

in line **97.** As the processing of the strip takes place, the load cell **19** at the top of the mill housing continually senses the rolling load P. Let is be assumed that a gage error occurs for any one of a number of well-known reasons in which event the load cell reading will deviate from the rolling load reference P_o. This deviation is computed by the control circuit to provide a housing stretch change signal

$$+\Delta h = +\Delta P/M_m$$

in line **99** which is then fed to the position controller amplifier **104.** Should there at the same time occur a relative displacement between the piston and the cylinder of the roll force applicator, then this actuator position change is represented by a position feedback signal in line **29** to the cylinder position controller amplifier **104.** The amplifier **104** provides an error signal in line **106** for servo valve current controller amplifier **112** to adjust the servo valve to position the hydraulic actuator to reduce the error to zero.

Let is now be assumed that the operator selects a mode of rolling mill control to simulate an infinitely soft rolling mill in which event he will position the movable tap **98** to receive the signal

$$-\Delta P/M_m$$

in line **93.** As rolling proceeds, should the rolling force P increases, for example, due to an increase in the incoming strip thickness or the eccentricity characteristic of the rolls, the electrical signal in line **28** represents a housing stretch change computed by the equation:

$$-\Delta h = -\Delta P/M_m \quad (5)$$

This signal is fed to the cylinder position controller amplifier **104** where it is also combined with the position feedback signal from the cylinder position sensor as previously indicated. The controller then provides an output signal for the servo valve current controller to adjust the servo valve in a manner that will cause the piston to be immediately retracted within the cylinder by an amount equal to

$$-\Delta P/M_m$$

to restore the roll force to its original value and thereby maintain a constant rolling force and eliminate the detrimental effects of roll eccentricity. When the control system simulates an infinitely soft mill modulus, gage corrections are prevented. In the event the mill stand is to provide automatic control gage, the outer gage control loop is added by switch **67** to modify the roll force reference signal P_o. This outer gage control loop may be provided by tension controller error signal, the thickness error signal, or a combination of the signals from lines **68** and **69** as determined the manually-positioned switch **67.**

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. A method of controlling the gap between processing rolls of a rolling mill to simulate a rolling mill structure selected to have a stretch characteristic within a range of infinitely stiff and infinitely soft during operation of rolling mill, said rolling mill including a housing for resisting the rolling force produced between said processing rolls and hydraulic force actuators carried in said housing for adjusting said roll gap, said method of controlling comprising the steps of:

generating a first signal representing a change in the roll gap proportional to a first change in the stretch of said rolling mill structure;

generating a second signal to represent a change in the roll gap proportional to a second change in the housing stretch in a direction opposite to said first change;

selecting a roll gap position control signal within a range defined by said first and second signals; and

controlling said hydraulic roll force actuator in such a way to reduce the said roll gap position control signal to zero.

2. The method of claim 1 including the steps of:

generating an initial electrical signal proportional to said rolling force developed between said processing rolls; and

modifying said initial electrical signal in accordance with the equation

$$h = P/M_m$$

to generate said first electrical signal, where h equals the actual roll gap, P equals rolling force, and M_m equals modulus of said rolling mill structure.

3. The method of claim 2 including the steps of:

generating a position feedback signal from said roll force actuator; and

modifying said roll position control signal with said position feedback signal.

4. The method of claim 3 including the steps of:

generating a gage control error signal; and

modifying said second signal with said gage control error signal.

5. The method of claim 3 including the steps of:

generating a tension controller error signal; and

modifying said second signal with said tension controller error signal.

6. The method of claim 1 wherein said roll gap position control signal produces a frequency of response by said hydraulic roll force actuator of up to 20 cycles per second.

7. A method for controlling a rolling mill wherein eccentric characteristics of the rolls rotating in the mill produce cyclic changes in the rolling force developed between the processing rolls, said rolling mill including a housing for resisting the rolling force produced between said processing rolls and hydraulic roll force actuators carried by said housing for adjusting the gap between said processing rolls, said method comprising the steps of:

computing a change in the housing stretch as a function of a change in the rolling force due to said eccentricity characteristics of the rolls; and

controlling said hydraulic roll force actuator in such a way to compensate for a change in the said housing stretch by preventing rolling force increases between said processing rolls due to said eccentricity characteristics.

8. The method of claim 7 including the steps of:

generating a first electrical signal proportional to said rolling force; and

modifying said first electrical signal in accordance with the equation

$$h = P/M_m$$

for computing an actual change in the housing stretch, where h equals the actual roll gap, P equals rolling force, and M_m equals modulus of the mill housing.

9. The method of claim 8 including the steps of:

generating a second electrical signal proportional to said change in the rolling force;

generating a gage control error signal; and

modifying sid electrical signal by the combination with said gage control error signal.

10. The method of claim 8 including the steps of:

generating a second electrical signal proportional to said change in the rolling load;

generating a tension control error signal; and

modifying said second electrical signal by the combination with said tension control error signal.

11. The method of claim 7 including the step of producing an error signal having a response time by said actuator of up to 20 cycles per second for said step of controlling said hydraulic roll force actuator.

12. A control system for a rolling mill of the type employed to simulate a stretch characteristic of the rolling mill structure selected from a range of stretch characteristics between infinitely stiff and infinitely soft under the rolling forces developed between the processing rolls during the rolling of strip-like material comprising:

means for generating a first signal proportional to the rolling force developed between said processing rolls;

means receiving said first signal for generating a second signal proportional to a change in the housing stretch due to a change in said rolling force;

means receiving said second signal for generating a third signal representing an inverted housing stretch signal having an electrical polarity opposite to said second signal;

control signal selection means receiving said second and third signals for delivering a roll gap adjusting signal selected to simulate a rolling mill structure having a desired stretch characteristic; and

means inlcuding a fluid actuator for adjusting said gap formed between said processing rolls in response to said roll gap adjusting signal.

13. A control system according to claim 12 wherein said control signal selection means including a potentiometer having a movable tap, said potentiometer having a first input contact receiving said second signal, said potentiometer further including a second input contact electrically opposed to said first input contact and receiving said third electrical signal.

14. A control system for a rolling mill of the type employed to compensate for eccentricity characteristics of rolls while rotating in a mill which produce cyclic changes in the gap defined by the processing rolls, said rolling mill including housing means for rotatably supporting said rolls, fluid actuated means carried by said housing means for adjusting said roll gap defined by the processing rolls, the improvement comprising:

means for generating a signal proportional to elastic changes of the housing means as a function of said eccentricity characteristics of the rolls in the mill;

a control circuit receiving said signal for generating a roll eccentricity compensating signal proportional to a roll gap change for eliminating said elastic changes; and

control means receiving said roll eccentricity compensating signal for adjusting said fluid actuated means.

15. A control system according to claim 14, the improvement further comprising:

gage error signal generating means for modifying said signal proportional to elastic changes of the housing means.

16. A control system according to claim 14, the improvement further comprising:

means for generating a tension control error signal to modify said signal proportional to elastic changes of the housing means.

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