Oct. 13, 1970 R. B. SIMS 3,533,255

ROLLING MILL

Filed Aug. 23, 1966 2 Sheets-Sheet 1

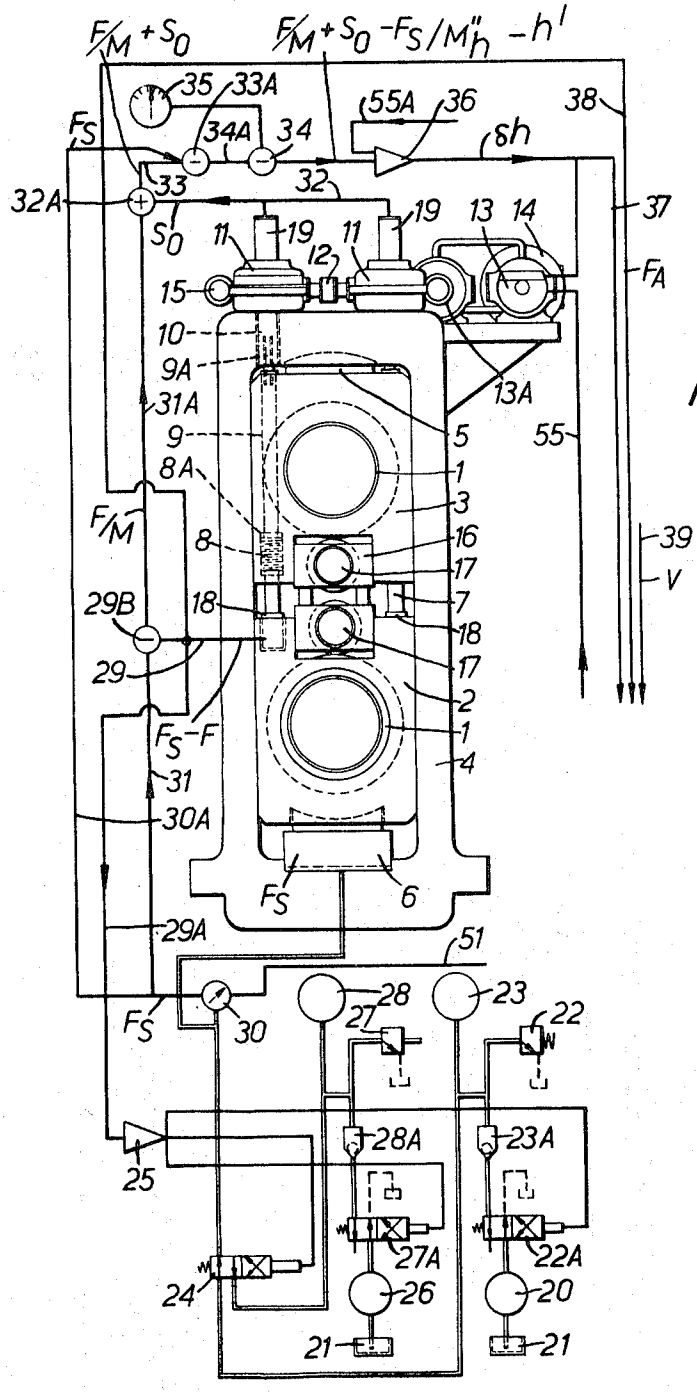


FIG. 1.

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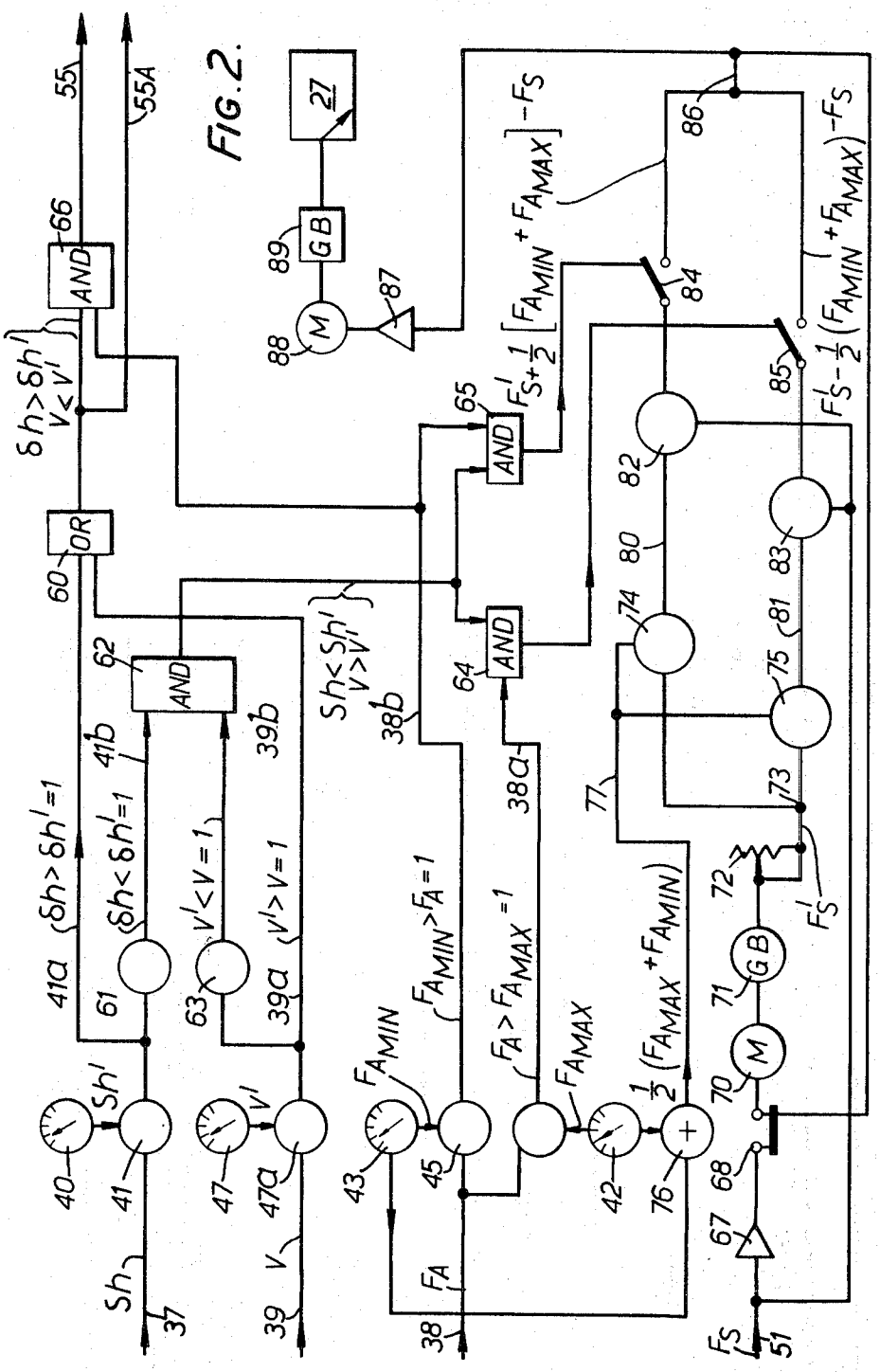
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Filed Aug. 23, 1966 2 Sheets-Sheet 2

FIG. 2.



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United States Patent Office 3,533,255 Patented Oct. 13, 1970

3,533,255

ROLLING MILL

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Filed Aug. 23, 1966, Ser. No. 574,440
Claims priority, application Great Britain, Aug. 24, 1965, 36,190/65; Jan. 13, 1966, 1,592/66
Int. Cl. B21b 37/12
U.S. Cl. 72—8 18 Claims

ABSTRACT OF THE DISCLOSURE

A rolling mill having adjustable screws located between the two roll assemblies and prestressing cylinders which apply a prestressing force greater than the likely rolling load and which urge the roll assemblies against the screws. The mill is controlled by a control system which includes a first signal dependent on the rolling load and a second signal which is dependent on the roll gap under no load conditions. A gauge error signal is derived from the first and second signals and used to control the effective length of the screws, in order to maintain substantially zero gauge error.

This invention relates to rolling mills, particularly to the design of mills to reduce their weight, and cost, and to the control of rolling mills to achieve constant thickness in the material being rolled.

Forces are developed in the area of contact between the rolls when metal is deformed between the rolls of a rolling mill, and these forces (hereinafter referred to as the "rolling load") must be contained by the mill structure. The mill structure including the rolls deforms under the rolling load causing the working faces of the rolls to part. Thus, when the rolling load increases (due for example to the metal becoming harder) the rolls will separate further by an amount proportional to the change in rolling load, and the dimensions of the rolled metal will increase. It has been shown that if F is the rolling load, S_o is the nominal distance between the working faces of the rolls when the mill is unloaded, and h is the roll gap under load, then

$$F=M(h-S_o) \quad (1)$$

where M is the mill modulus and is a constant depending on the elastic properties of the mill structure; during rolling, the roll gap is the same as the thickness of the outgoing material. If F is measured in tons, and h and S_o in inches, then M is in tons per inch, and commonly has a value between 10^3 and 1.3×10^4 tons per inch.

Equation 1 may be written

$$h=S_o+F/M \quad (2)$$

and in the design of conventional mills without automatic gauge control, the mill modulus M is made as large as possible in order to reduce the effect of changes in rolling load on gauge, so that as M becomes larger the strip thickness h departs less from the set value S_o. Hence, mill housings have hitherto been designed to have an average stress of only 0.75 to 0.5 ton per square inch, resulting in housing of over 200 tons in weight which approaches the limit of machining and transportation of these large pieces of metal, and they are also costly.

In a mill fitted with automatic gauge control the accuracy of the dimensions of the rolled product should in prinicple be independent of the mill modulus because the gauge control circuit compensates for departures in the metal from the desired thickness due to changes in mill deformation consequent upon the changes in rolling load.

Unfortunately it has not been possible, hitherto, to make use of this potential advantage because of the time taken for the control circuit to respond to its input error signal proportional to the gauge deviation. In strip rolling the fastest response is obtained by a control system which varies the applied strip tension to change gauge (British Pat. No. 681,373) but this form of control has only limited effectiveness because of the risk of breaking the strip or spoiling the flatness of the finished material.

In mills where tension is not applied to the metal in a controlled manner, all gauge changes are compensated by varying the position of the mill screws (i.e. changing the value of S_o in Equations 1 and 2) and the screws are used to control large changes in mills fitted with the tension type of automatic gauge control. The rolling loads are commonly over 1,000 tons on each of the two screws, so that the screw adjustments against these loads are relatively slow, even where large electric motors of 100 H.P. on each screw are employed for the duty. As a result, when sudden changes of load and gauge occur in mills with a low value for the mill modulus, relatively long lengths of material may be rolled off gauge whilst the automatic control circuits energise the motors to adjust the rolls. Mill designers have, therefore, maintained the practice of designing rolling mills with massive housings to obtain as high a value as possible for the mill modulus to keep these transient gauge changes to a minimum.

In another previous proposal to obtain more rapid and consistent control of gauge, a method of rolling sheet or strip material is proposed in which the material is fed between two roll assemblies subjected to a prestressing force resisting the separating force (rolling load) acting on the roll assemblies. The prestressing force, which is greater at all times than the rolling load, is automatically increased or decreased by an amount approximately equal to any increase or decrease in the rolling load so that the difference between the prestressing force and rolling load is kept substantially constant. This type of control for rolling mills cannot, however, achieve a close control of the thickness of the rolled metal; it will achieve only a constant stress in the abutment means between the bearing chocks, and in parts of the chocks themselves. Other parts of the chocks, together with the rolls and roll-neck bearings, will be distorted by the full effects of the rolling load variations, and this will lead to changes in the strip thickness when the rolling load varies. Measurements which have been made on the elastic distortion of the rolls indicates that they contribute over half of the total mill distortion quantified in the mill modulus M, so that the distortion effecting gauge can be considerable in a mill built according to this previous proposal.

In one aspect the present invention provides a rolling mill and control system therefor comprising a pair of roll assemblies, prestressing means arranged to apply a prestressing force greater than the rolling load to urge the rolls towards one another, abutment means arranged to resist the prestressing force to carry a load equal to the difference between the prestressing force and the rolling load, and automatic control means for adjusting the abutment means to maintain substantially constant gauge.

In another aspect the invention provides a rolling mill and control system therefor comprising a pair of roll assemblies, prestressing means arranged to apply a prestressing force greater than the rolling load to urge the rolls towards one another, abutment means arranged to resist the prestressing force to carry a load equal to the difference between the prestressing force and the roll-

ing load, means for obtaining a first signal dependent on the rolling load, means for obtaining a second signal dependent on the roll gap under no load, means for deriving a gauge error signal from the first and second signals, and control means for using the gauge error signal to control the abutment means to maintain substantially zero gauge error.

In a further aspect the invention provides a rolling mill and control system therefor, comprising a pair of roll assemblies, adjustable spacers between the roll assemblies, normally constant pressure hydraulic prestressing means arranged to prestress the roll assemblies onto the spacers and automatic control means arranged to control the spacers to maintain constant gauge.

Preferably the prestressing means are hydraulic and under normal conditions the hydraulic pressure is kept constant.

Preferably means are provided for automatically maintaining the prestressing pressure at a constant low value when no material is between the rolls and at a relatively high value under rolling conditions, and for switching between the high and low values dependent on whether or not material is between the rolls.

The load on the abutment means which is the difference between the rolling load and the prestressing load may be arranged to be only a small fraction of the rolling load, so that the power of the drive can be reduced and the response time of the control is improved permitting a fast correction for gauge error. The drive may also be made so small in power that an electrohydraulic drive may may be incorporated on even the largest mills, thereby reducing costs and increasing the speed of the response of the control.

The main mill housing is subjected to a normally constant load because only the prestressing force acts on it and the housing stress may be increased from its low value in known arrangements to values commonly found in engineering components generally in the range 1.5 to 7 tons/m.^{2}. This would amount to a substantial increase with corresponding savings in weight and fabrication costs. Moreover, with the sectional dimensions of the stress path in the housings substantially reduced, these larger components may now be welded, taking advantage of the reduced costs afforded by modern welding techniques.

In the design of these mills the dimensions of the abutment means and their drive are restricted by the essential dimensions of the surrounding structure so that an upper limit must be placed on the load on the abutment means to maintain the facility to adjust their dimensions during rolling. Thus, in a mill in which the prestress on each set of chocks may have any value up to 1000 tons (i.e. 2000 tons total prestress on the mill) the maximum permissible load on each of the abutment means might be restricted to 150 tons (i.e. a total of 600 tons with four abutment means). It is also possible for the loads imposed on the abutment means under rolling conditions to fall below a safe working limit; this is particularly likely to happen when the mill is decelerating and the load exerted by the rolls on the strip increases rapidly and approaches the value of the prestress.

In a preferred form of the invention further control means are provided for maintaining the load on the abutment means within a predetermined range. Preferably the further control means are arranged to change the constant value of the prestressing force to bring the load on the abutment means back to the middle of its predetermined range when the load goes out of range. The further control means may be made to operate only when the mill speed exceeds a predetermined value and the gauge error is less than a predetermined value.

The system also may include means for rendering the control means inoperative when the mill speed is less than a predetermined value or when the gauge error is greater than a predetermined value, and means operative under each of these conditions for controlling the abutment means to prevent the load on the abutment means falling below a predetermined minimum value.

Preferably a signal dependent on the prestressing force is also used in deriving the gauge error signal.

One embodiment of rolling mill and control system, in accordance with the invention, will now be described, by way of example only, with reference to the accompanying drawings of which:

FIG. 1 is a side view of a rolling mill, and a control system,

FIG. 2 shows part of the control system of FIG. 1 in detail.

It will be appreciated that only one side of the mill is shown in FIG. 1 and that a similar arrangement exists on the other side of the mill, while the control system is common to both sides.

In the drawings, back-up rolls **1** are rotatably supported in chocks **2** and **3** slidably guided in a main housing **4**. The upper chock **3** carrying the upper back-up roll abuts against a self-aligning pad **5** in the top of the housing. The lower chock **2** is seated on a hydraulic prestressing cylinder **6** also fitted with a self-aligning pad. The two back-up chocks are separated by abutment means in the form of two screws (only one of which is shown in full) with plain shanks **7** and each with a threaded portion **8** engaging in a threaded bore **8A** in the upper back-up chock **3**. The screws are turned by a connecting shaft **9** having a splined section **9A** which engages with an internally splined sleeve **10**. The splined sleeve is in turn driven by worm gearing in casings **11**, the gearing for the two screws being connected together by a clutch **12**.

The two screws are driven via their worm gearing by a self-containing hydraulic pump **13** and motor **13A** which is powered by an A.C. motor **14**. The drive to the two screws is connected to the similar drive to the two screws on the opposite housing by a connecting shaft, indicated at **15**, taken from one of the worm gears **11**. Provision is made to disconnect the two drives connected by the shaft **15** so that the chocks on each side of the mill may be moved independently. The screws **7** thus form spacers, between the back-up roll assemblies (comprising the rolls and their chocks), the dimensions of the spacers being adjustable.

The back-up chocks **2** and **3** cradle chocks **16** carrying work rolls **17**. Each screw **7** bears on a load sensing device **18**, and the position of each screw in its nut is measured by a position transducer, such as a synchro **19**, which produces a signal proportional to S_o, the nominal dimension of the abutment means **7** between the chocks, and so to the roll gap, in the unloaded condition of the mill.

A pump **20**, having an inlet supply from a tank **21**, communicates via a change-over valve **22A**, a non-return valve **23A**, a relief valve **22**, a hydraulic accumulator **23**, and a change-over valve **24**, with the cylinders **6** in the housings **4** to provide a supply of low pressure oil. A pump **26**, with an adjustable relief valve **27** and accumulator **28**, change-over valve **27A** and non- return valve **28A** provides a supply of oil at a high pressure which may be connected to cylinders **6** through valve **24**. Each of the relief valves **22**, **27** is provided with a relief line back to the tank **21**. Changes in load from the load sensing means **18** are used to actuate the change-over valve **24** via the line **29***a* and the switching amplifier **25** so that either lower pressure oil from accumulator **23**, or higher pressure oil from accumulator **28** is connected to the prestressing cylinder **6**.

In this type of mill, if M_r is the elastic modulus of the rolls and those parts of the chocks carrying the rolling load F, F*s* is the prestressing force applied by the cylinders **6** M''_n in the elastic modulus of those parts carrying the difference between the full rolling load and the

prestress load, h is the roll gap under load, and S_o is the nominal roll gap in the unloaded condition of the mill then

$$h=S_o+\frac{F}{M_r}-\frac{(Fs-F)}{M''_h}$$

$$=S_o+F\left[\frac{1}{M_r}+\frac{1}{M''_h}\right]-\frac{Fs}{M''_h}$$

$$h=S_o+\frac{F}{M}-\frac{Fs}{M''_h}$$

where

$$\frac{1}{M}=\left[\frac{1}{M_r}+\frac{1}{M''_h}\right]$$

The gauge error $\delta h=h-h'$, where h' is the predetermined required gauge, is therefore given by

$$\delta h=S_o+\frac{F}{M}-\frac{Fs}{M''_h}-h'$$

The signals from all the load-sensing means **18** are summed and provide a signal in the line **29** proportional to the load F_s-F on the adjustment means; this signal is combined in a unit **29B** with a signal on line **31** from a transducer **30** proportional to the prestress load Fs; unit **29B** subtracts the signal on line **29** from that on line **31** and modifies the difference by the factor $1/M$, to provide a signal in line **31A** proportional to F/M. The signals from each of the screw position sensors **19** provide a signal in the line **32** proportional to the unloaded roll gap S_o. The signals representing these values in lines **31A** and **32** are combined together in a summation unit **32A** to give on line **33**, a signal proportional to $F/M+S_o$. The signal on line **33** is fed to a unit **33A** which also receives a signal proportional to Fs on line **30A**, unit **33A** modifies the signal on line **30A** by a factor $1/M''h$ and subtracts the modified signal from the signal on line **33** to give on line **34A** a signal proportional to

$$\frac{F}{M}+S_o-\frac{Fs}{M''_h}$$

The latter signal is fed to a subtraction unit **34** to which is also fed a signal proportional to the desired gauge h' present in a potentiometer **35**. The gauge error signal issuing from the summation unit **34** proportional to

$$\frac{F}{M}+S_o-\frac{Fs}{M''_h}-h'$$

passes to an amplifier **36** and on to control the hydraulic pump **13** which then adjusts the position of the screws **7** to obtain zero gauge error.

In operation the mill components are first prestressed at a preset low value by the hydraulic cylinders **6**, the pressure in which is controlled by the relief valve **22**, and the motor **14** is switched on. The rolls are set to be separated by an amount a little less than the desired strip thickness, and the relief valve **27** is set so that when effective it provides a pressure in the hydraulic cylinders **6**, sufficiently to give a prestressing force greater than the maximum anticipated rolling load but not so high that the load on the abutment means **7** during rolling exceeds about 20% of maximum rolling load for which the mill is designed. When the strip is entered the sudden reduction in load on the load sensing means **18** automatically operates the switching amplifier **25** and thus valve **24** to disconnect the lower pressure oil in accumulator **23** from cylinders **6** and to connect to the prestressing cylinders **6** the higher pressure oil in accumulator **28**. The control system acts to vary the dimension of the abutment means to maintain constant gauge. When the rolling load is suddenly removed at the end of the strip, or by breakage, the prestress is returned to its lower value automatically via the switching amplifier **25** and solenoid **24** which disconnects the accumulator **28** and connects accumulator **23** to the prestress cylinders **6**.

The amplifier **36** giving the signal h is also connected via line **37** to a comparator switch **41**, to which is also fed a signal $\delta h'$ from a control **40**; this control is also fed a operator to a value which, in his experience for the product being rolled is the limit of gauge error above which no correction of gauge is possible by adjusting the screws, without imparing the shape of the material. The comparator switch **41** compares the two inputs δh and $\delta h'$ and supplies a 0 output for $\delta h'>\delta h$ and a 1 output for $\delta h>\delta h'$ on line **41***a*. Line **41***a* is connected to an OR gate **60** and to an inverter **61** which provides a signal for the condition $\delta h<\delta h'$ on line **41***b* connected to an AND gate **62**.

A signal proportional to the mill speed V is obtained from the mill drive and taken on line **39** to a comparator switch **47***a* into which is also fed a signal V′ proportional to a preset value of mill speed set on control **47**; this control is set by the operator to a value which in his experience is somewhat greater than the limiting rolling speed defined by lubricating conditions in the roll gap, below which adjustment of the screws achieves no control of gauge. The comparator switch compares the two inputs V and V′ emits on line **39***a* a 0 signal for $V>V'$ and a 1 signal for $V'>V$. Line **39***a* is connected to the OR gate **60** and to an inverter **63** arranged to emit a 1 signal for the condition $V>V'$ on line **39***b* connected to AND gate **62**.

A signal proportional to the load $F_A=(F_s-F)$ on the abutment means **7** is taken from line **29** via line **38** to comparator switches **44** and **45**. Comparator switch **44** also receives from a present control **42** a signal F_A max. proportional to the maximum desirable load on the abutment means, and is arranged to emit a 1 signal for the condition $F_A>F_A$ max. on line **38***a* connected to an AND gate **64**. Comparator switch **45** also receives from a preset control **43** a signal F_A min. proportional to the minimum desirable load on the abutment means, and is arranged to emits a 1 signal for the condition $F_A>F_A$ min. on line **38***b* connected to AND gates **65** and **66**. The other inputs of AND gates **64** and **65** are connected to the output of AND gate **62**.

The output of OR gate **60** is connected by line **55A** to amplifier **36** such that a signal on line **55A** disables the amplifier and thus the normal adjustment of the screws for gauge control. The output of OR gate **60** is also connected to the other input of AND gate **66** which thus emits a signal on line **55** for the condition $\delta h>\delta h'$, $V<V'$ and $F_A<F_A$ min.: the signal on line **55** is fed to the pump **13** and arranged to control the abutment means so as to reduce the signal to zero. The effect of this control is that when the mill is not up to a speed at which gauge can be controlled to the required value by adjusting the screw or when the gauge error is so large that the required value of gauge cannot be restored by adjusting the screws, the normal gauge control system is disabled and the screws are adjusted not to maintain the required gauge, but to prevent the load on the abutment means falling below the predetermined lower limit.

A line **51** from the pressure transducer **30**, giving a signal proportional to the prestress pressure F_s, is connected through an amplifier **67**, a normally closed swtich **68**, a motor **70** and gear box **71** to set a potentiometer **72** so that the potential appearing across the potentiometer is equal to the prestress pressure F_s whenever the value **27** is not being adjusted. Calling this potential F'_s, and normally $F'_s=F_s$, a signal proportional to F'_s is emitted on line **73** and fed to adding units **74** and **75**. Signals taken from controls **42** and **43** are added in unit **76** which emits on line **77** a signal proportional to

$$\tfrac{1}{2}\ [F_A \text{ min.} + F_A \text{ max.}]$$

which is applied to the units **74** and **75**. Unit **74** is arranged to add its inputs to emit a signal proportional to

$$E_s'+\tfrac{1}{2}\ [F_A \text{ min.} + F_A \text{ max.}]$$

on line 80 while unit 75 is arranged to subtract its inputs to emit on line 81 a signal proportional to

$$F_s' - \tfrac{1}{2}\ [F_A \text{ min.} + F_A \text{ max.}]$$

The signals on these lines are taken to comparators 82, 83 respectively to both of which is applied a signal directly from transducer 30 on line 51 proportional to F_s, so that the output from comparator 82 is proportional to

$$F_s' + \tfrac{1}{2}\ [F_A \text{ min.} + F_A \text{ max.}] - F_s$$

and the output from comparator 83 is proportional to

$$F_s' - \tfrac{1}{2}\ [F_A \text{ min.} + F_A \text{ max.}] - F_s$$

The error signals on these outputs are applied through normally open contacts 84, 85 respectively, to line 86, which in turn connects with an amplifier 87 to adjust the pressure relief valve 27 by means of a motor 88 and gear box 89, to reduce the error signals to zero. Contacts 84, 85 are arranged to be closed by relays operated by signals from AND gates 64, 65 respectively. The relays close quickly and open after a preset delay such that with the normal characteristics of the servo setting units 87–89 the resetting action will be completed before either of the relays open and deenergise line 86. Line 86 is also connected to a relay to open contacts 68 between amplifier 67 and motor 70.

In operation, therefore, any change in prestress pressure is reflected through the motor and gear box combination 70, 71 onto the potentiometer 72. 72 therefore always produces a potential on line 73 proportional to the current value of prestress until either of AND gates 64, 65 is energised, in which case the contact 68 opens and the value of the potential on potentiometer 72 becomes fixed at the last value of the prestress pressure before either AND gate is energised. The error signal on line 86 will then act to adjust the prestress pressure by an increment which will restore the load on the abutment members to the middle of the predetermined permissible load range. The new prestress pressure set in valve 27 will then remain constant unless the load on the abutment members again goes out of range. It should be noted that the prestress pressure will only be altered under conditions when the mill speed is above the predetermined speed V′ and the gauge error is less than $\delta h'$.

I claim:

1. A rolling mill and control system therefor comprising a pair of roll assemblies forming a roll gap therebetween, prestressing means arranged to apply a prestressing force greater than the rolling load to urge the roll assemblies towards one another, abutment means which are arranged to resist the prestressing force to carry a load equal to the difference between the prestressing force and the rolling load and which are adjustable to vary the roll gap, means for obtaining a first signal dependent on the rolling load, means for obtaining a second signal dependent on the roll gap under no load, means for deriving a gauge error signal from the first and second signals, and control means for using the gauge error signal to control the abutment means to maintain substantially zero gauge error.

2. A rolling mill and control system according to claim 1 including means for obtaining a third signal dependent on the prestressing force and applying said third signal to the means for deriving a gauge error signal.

3. A rolling mill and control system according to claim 1 including means for maintaining the prestressing force constant under normal conditions.

4. A rolling mill and control system according to claim 1 in which the prestressing means are hydraulic.

5. A rolling mill and control system according to claim 1 in which the abutment means are located between the roll assemblies.

6. A rolling mill and control system according to claim 1 in which the abutment means are adjusted by an electro-hydraulic drive.

7. A rolling mill and control system according to claim 1 in which the prestressing means are hydraulic and include a first source of fluid at a constant pressure such as to apply a prestressing force greater than the rolling load and a second source of fluid at a constant relatively low pressure and means for automatically connecting the prestressing means to the first or second sources dependent on whether or not material is between the rolls.

8. A rolling mill and control system according to claim 2 including further control means for maintaining the load on the abutment means within a predetermined range.

9. A rolling mill and control system according to claim 8 in which the further control means include means for varying the prestressing force when the load on the abutment means exceeds a predetermined upper limit or falls below a predetermined lower limit.

10. A rolling mill and control system according to claim 8 in which the further control means is arranged to automatically return the load on the abutment means to the middle of the predetermined range if that load goes out of the range.

11. A rolling mill and control system according to claim 8 in which the further control means are arranged to vary the setting of a valve determining the constant prestress pressure in the prestressing means.

12. A rolling mill and control system according to claim 8 in which the further control means includes means for deriving a load error signal proportional to the change in prestress pressure required to change the load on the abutment means through half the predetermined range, plus the difference between the prestress pressure and the prestress pressure at the moment when the load goes out of range, and means operative only when the load goes out of range for varying the prestress pressure to bring the load error signal to zero.

13. A rolling mill and control system according to claim 8 in which the further control means is inoperative unless the speed of the mill exceeds a predetermined value and the gauge error is less than a predetermined value.

14. A rolling mill and control system according to claim 1 including means for rendering the control means inoperative when the mill speed is less than a predetermined value or the gauge error is greater than a predetermined value, and means operative under either of these conditions for controlling the abutment means to maintain the load or the adjustment means at or above a predetermined minimum value.

15. A rolling mill and control system according to claim 1 in which the prestressing force provides a stress in the mill housing in the range 1.5 to 7 tons/m.^{2}.

16. A rolling mill and control system therefor, comprising a pair of roll assemblies, adjustable spacers between the roll assemblies, adjustment means for adjusting the spacers, normally constant pressure hydraulic prestressing means arranged to prestress the roll assemblies onto the spacers, means for obtaining a first signal dependent on the rolling load, means for obtaining a second signal dependent on the roll gap under no load, means for deriving a gauge error signal from the first and second signals, and control means for using the gauge error signal to control the adjustment means to maintain substantially zero gauge error.

17. A rolling mill and control system therefor comprising a pair of roll assemblies, abutment means for determining the gap between the roll assemblies, means for adjusting the abutment means, means responsive to the load on said abutment means, prestressing means for urging the roll assemblies towards one another at a normally constant pressure, means for detecting the departure of the gauge of the material being rolled from a given value, a first automatic control system controlled by said de-

tecting means for adjusting the adjustment means to maintain gauge at said given value, and a further control means controlled by said load responsive means for varying the prestressing pressure incrementally if the load on the abutment means departs from a predetermined range.

18. A rolling mill and control system therefor, comprising a pair of roll assemblies between which material is to be rolled, abutment means for determining the gap between said roll assemblies, means for adjusting said abutment means and hence said gap, prestressing means for urging said roll assemblies towards one another at a normally constant pressure, means responsive to the load on said abutment means, means for generating signals dependent on the rolling load, the roll gap under no load, and the prestressing pressure respectively, means controlled by said generating means for deriving a gauge error signal, means for controlling said adjusting means by said gauge error signal to maintain constant the gauge

of the material being rolled, and further control means controlled by said responsive means for varying the prestressing pressure incrementally if the load on said abutment means departs from a predetermined range.

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U.S. Cl. X.R.

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