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Mueller

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[54] **ROLLING MILL CONTROL METHOD AND APPARATUS**

[75] Inventor: **George E. Mueller,** Bethlehem, Pa.

[73] Assignee: **Bethlehem Steel Corporation,** Bethlehem, Pa.

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[52] **U.S. Cl.** **72/8;** 72/14; 72/19; 72/21

[51] **Int. Cl.²** **B21B 37/08**

[58] **Field of Search** 72/6, 7, 8, 9, 14, 19, 72/20, 21

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Primary Examiner—Milton S. Mehr

Attorney, Agent, or Firm—Joseph J. O'Keefe; John I. Iverson; George G. Dower

[57] **ABSTRACT**

Rolling mill with computer programmed for absolute lock-on AGC control rolls material having absolute aim gage without using an active thickness gage in the control loop. Computer is programmed to calculate; (a) lock-on length of rolled material, (b) mill stretch using a simplified subroutine, (c) calibration-corrected roll gap, (d) a lock-on thickness error relative to aim gage, (e) a corrected roll gap reference signal as a function of a constant lock-on thickness error and other variable thickness errors caused by changes in mill stretch and roll gap occurring after lock-on, and (f) a rate-sensitive variable gain of the corrected roll gap reference signal to reduce thickness errors to substantially zero as rapidly as possible.

16 Claims, 3 Drawing Figures

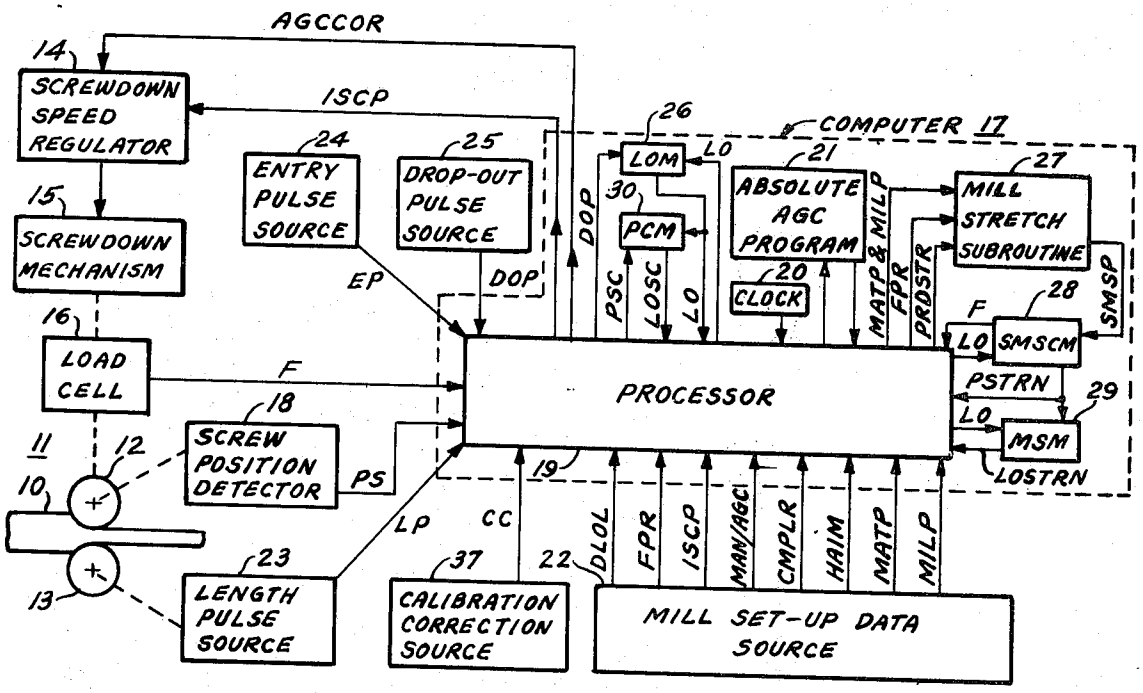


FIG. 1

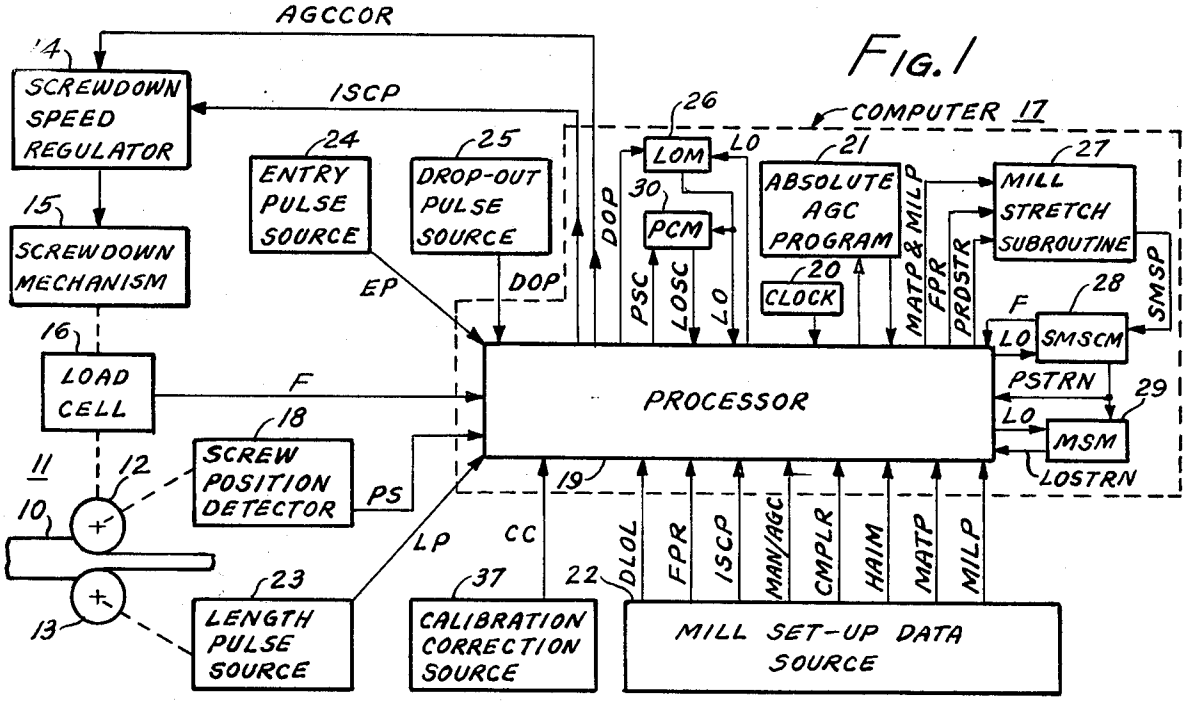
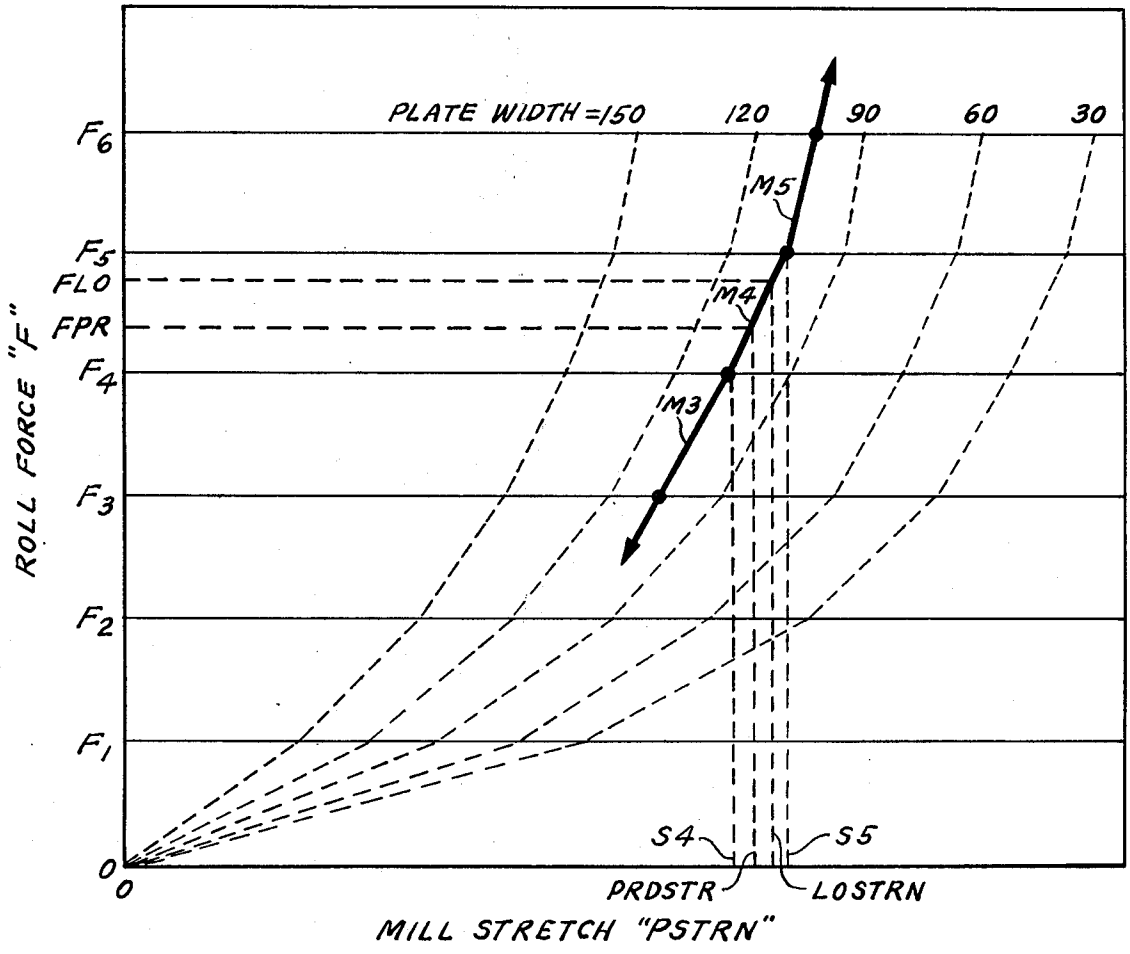

AGCCOR
14
SCREWDOWN SPEED REGULATOR
ISCP
26
COMPUTER 17
LOM
LO
21
ABSOLUTE AGC PROGRAM
27
MILL STRETCH SUBROUTINE
24
ENTRY PULSE SOURCE
25
DROP-OUT PULSE SOURCE
30
PCM
DOP
MATP & MILP
FPR
PRDSTR
SMSP
15
SCREWDOWN MECHANISM
EP
DOP
PSC
LOSC
LO
20
CLOCK
F
28
LO
SMSCM
16
LOAD CELL
F
PROCESSOR
PSTRN
29
LO
MSM
LOSTRN
18
SCREW POSITION DETECTOR
PS
11
12
10
19
LP
CC
DLOL
FPR
ISCP
MAN/AGC
CMPLR
HAIM
MATP
MILP
23
LENGTH PULSE SOURCE
37
CALIBRATION CORRECTION SOURCE
22
MILL SET-UP DATA SOURCE
13

FIG. 3


PLATE WIDTH = 150
120
90
60
30
F6
F5
FLO
FPR
F4
F3
F2
F1
0
M5
M4
M3
S4
S5
PRDSTR
LOSTRN
ROLL FORCE "F"
MILL STRETCH "PSTRN"

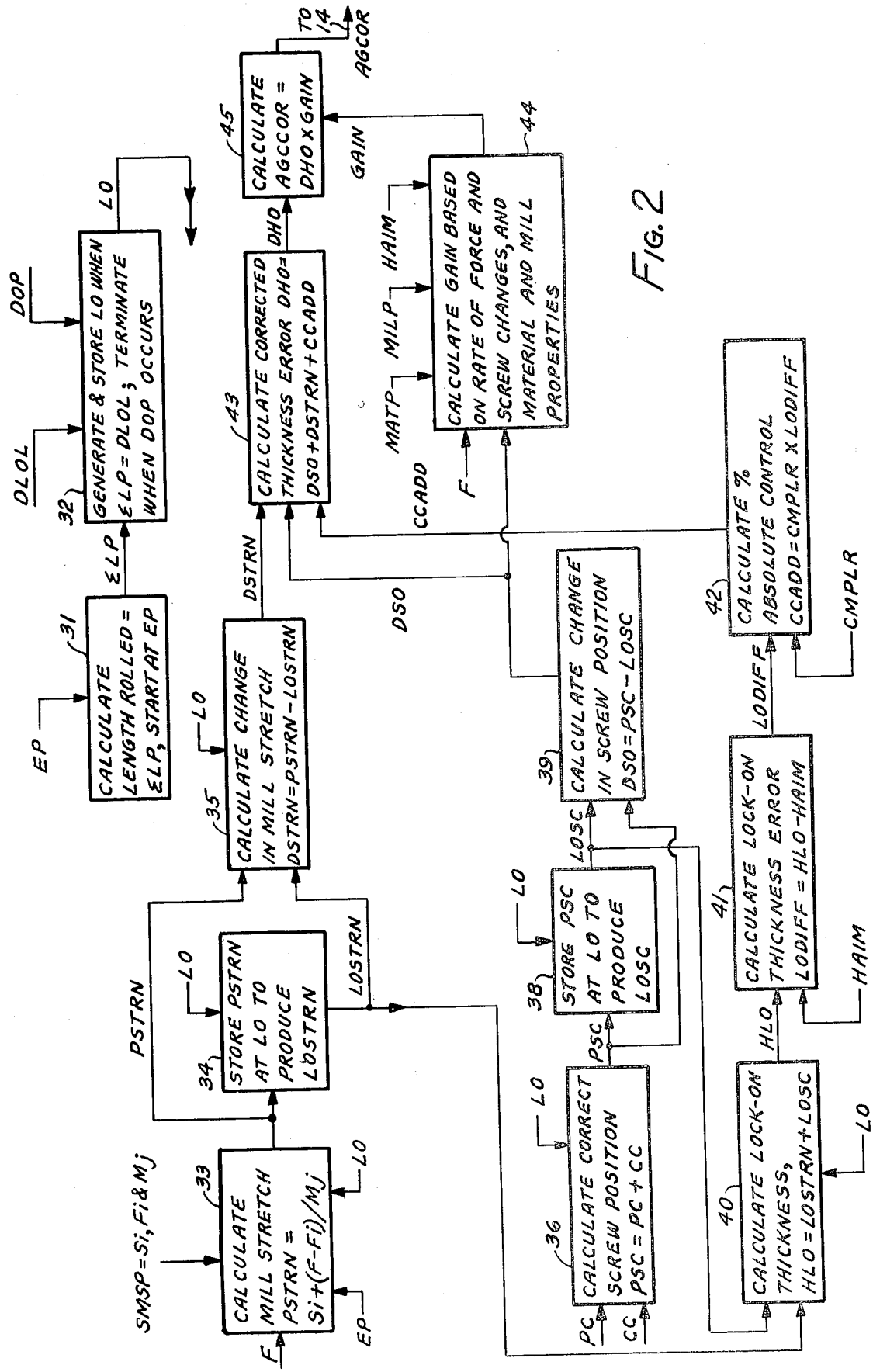

SMSP=Si, Fi & Mj
CALCULATE MILL STRETCH PSTRN = Si+(F-Fi)/Mj
33
PSTRN
STORE PSTRN AT LO TO PRODUCE LOSTRN
34
LOSTRN
CALCULATE CHANGE IN MILL STRETCH DSTRN=PSTRN-LOSTRN
35
DSTRN
CALCULATE LENGTH ROLLED = ℓLP, START AT EP
31
ℓLP
GENERATE & STORE LO WHEN ℓLP=DLOL; TERMINATE WHEN DOP OCCURS
32
DLOL
DOP
LO
EP
F
CALCULATE CORRECTED THICKNESS ERROR DHO= DSO+DSTRN+CCADD
43
DHO
CALCULATE GAIN BASED ON RATE OF FORCE AND SCREW CHANGES, AND MATERIAL AND MILL PROPERTIES
44
MATP
MILP
HAIM
CCADD
DSO
CALCULATE AGCCOR = DHO X GAIN
45
GAIN
AGCOR
TO 14
CALCULATE CHANGE IN SCREW POSITION DSO=PSC-LOSC
39
LOSC
STORE PSC AT LO TO PRODUCE LOSC
38
PSC
CALCULATE CORRECT SCREW POSITION PSC=PC+CC
36
PC
CC
CALCULATE % ABSOLUTE CONTROL CCADD=CMPLR X LODIFF
42
LODIFF
CMPLR
CALCULATE LOCK-ON THICKNESS ERROR LODIFF=HLO-HAIM
41
HLO
HAIM
CALCULATE LOCK-ON THICKNESS, HLO=LOSTRN+LOSC
40

FIG. 2

ROLLING MILL CONTROL METHOD AND APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates broadly to rolling mill control methods and apparatus. More particularly, this invention relates to rolling mill roll gap control methods and apparatus having an absolute lock-on AGC control system for rolling material to absolute aim gage. The term "absolute lock-on AGC control system" as used herein means a modified conventional lock-on automatic gage control system devoid of an active thickness gage in the control loop and one that rolls uniformly thick material after lock-on without the customary lock-on thickness error. The invention may be used in a reversing plate rolling mill, as will be referred to herein, or in continuous rolling mills for rolling bars, sheet or strip and the like.

2. Description of the Prior Art

Many rolling mills are equipped with computer-directed roll gap control systems. Control strategy includes setting roll gap initially to roll aim gage material using estimated values of both material properties and mill properties. In some instances after the material enters the mill rolls, the computer is programmed to direct a conventional lock-on AGC control system. That is, it locks on to head-end thickness and developes a corresponding roll gap reference signal that will cause a roll gap mechanism to maintain lock-on thickness uniformly along the length of material being rolled.

One major problem with a lock-on AGC control system in a reversing plate mill for example, is that the lock-on thickness of material exiting from rolls on a finishing stand is generally different for any given pass than the aim gage scheduled for that pass. Thickness errors occur in the roll gap reference signal because actual values of material properties at lock-on differ from the estimated values used to set roll gap initially. Such differences are attributable to locking-on the control system to a different gage material, a different temperature of material, a tapered or fish-tailed head-end, or over a furnace skidmark where the material is chilled locally. Any one or a combination of these situations may occur and each would require a different modification to the estimated values of roll force and mill stretch used to preset roll gap before lock-on. However, in conventional lock-on AGC control system only changes in roll force and mill stretch occuring after lock-on cause variations in the roll gap reference signal to maintain uniformity of lock-on material thickness. Consequently, it has been discovered that considerable off-gage material is rolled having a lock-on thickness error.

In conventional lock-on AGC control system, a thickness gage located downstream of a mill strand is required in the control loop to continuously feed back thickness error signals to compensate the roll gap reference signal for lock-on thickness errors. There are several drawbacks to using the conventional lock-on AGC control system in a reversing plate mill. First, because of serious damage from cobbles and other hazards, there has been no development for continuous thickness measuring gaging system with a gage located at the delivery ends of a finishing stand. Second, if a continuous thickness gaging system were available, the gage would have to be located a safe distance downstream

of the mill stand, thereby increasing the transport time of the plate and thickness signal so that a low-gain in the feedback loop would be necessary to prevent loop instability. Third, many plate lengths tend to be short and the plate could be out of a mill stand before reaching a downstream thickness gage, thereby rendering lock-on thickness error compensation inoperative.

SUMMARY OF THE INVENTION

One of the objects of this invention is to provide an improved method and apparatus for automatically controlling rolling mill roll gap to roll material having absolute aim gage.

Another of the objects of this invention is to provide an improved method and apparatus for automatically controlling rolling mill roll gap under a lock-on AGC control system which causes the production of rolled material devoid of lock-on thickness errors.

A further object of this invention is to provide a computer-directed method and apparatus for automatically controlling rolling mill roll gap with improved accuracy and speed of response.

The foregoing objects are attainable by a rolling mill roll gap control method and apparatus which includes a computer programmed for absolute lock-on AGC control without an active material thickness gage being used in the control loop. Absolute aim gage material is rolled by control means operatively associated with the computer and the computer program calculations include some or all of the following: (a) lock-on length of rolled material, (b) mill stretch using a simplified subroutine, (c) calibration-corrected roll gap spacing, (d) preferably a lock-on thickness error relative to aim gage, (e) preferably a corrected roll gap reference signal as a function of a constant lock-on thickness error and other variable errors caused by changes in mill stretch and roll gap occurring after lock-on, and (f) a rate-sensitive variable gain of the corrected roll gap reference signal to reduce thickness errors to substantially zero as rapidly as possible.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a reversing plate rolling mill having a computer-directed absolute lock-on AGC roll gap control embodiment of the present invention.

FIG. 2 is a flow diagram of a computer program for the computer shown in the FIG. 1 embodiment of the present invention.

FIG. 3 is a graph illustrating a family of roll force vs. mill stretch curves for a variety of plate widths (shown dotted) and a specific three-segment curve for a specific plate width and set of rolling conditions (shown solid).

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 illustrates diagrammatically plate material **10** being reduced in thickness in a conventional reversing plate rolling mill **11** between a pair of driven work rolls **12** and **13.** Work roll **12** is moveable vertically to provide roll gap adjustment between it and fixed work roll **13.**

Roll gap, as well as roll reducing forces, are controlled by screwdown speed regulator **14,** the latter being responsive to either of two computer-directed signals as described below. Screwdown speed regulator **14** energizes screwdown mechanism **15** which in turn

applies the roll forces through load cell **16** and work roll **12** to reduce the thickness of plate material **10.** Load cell **16** output signal is roll force F signal which is fed to and processed in computer **17** as described below.

Initial roll gap is determined by screw position detector **18** measuring screw travel of screwdown mechanism **15.** Detector **18** output signal is referred to hereinafter as screw position PS signal which is also fed to and processed in computer **17** as described below.

Computer **17** is preferably a general-purpose type having processor **19** which is adapted to receive the roll force F and screw position PS signals as well as other signals described below. Computer processor **19** includes conventional arithmetic, counting, general storage, specific storage to be described below and sequencing units to perform repetitive calculations at a cyclic frequency determined by computer clock **20.** Computer **17** also includes absolute AGC program **21** which directs processor **19** operations to produce a signal that is fed to screwdown speed regulator **14.** Absolute AGC program **21** is illustrated by the computer flow diagram shown in FIG. **2** and described below.

An additional group of computer **17** input signals are consolidated for ease of illustration and fed as mill set-up data **22** to processor **19** to initiate either initial roll gap setting or automatic gage control operation. In practice, mill set-up data **22** may be derived from various sources such as a computer, a mill operator and/or a predetermined operating schedule. Such sources provide input data which are characterized with individual signals and fed to processor **19** as follows: (a) roll gap control by either manual or automatic gage control is the MAN/AGC signal; (b) aim gage of plate material **10** for a given pass is the HAIM signal; (c) plate material **10** properties including known width and alloy or composition, and estimated values of mill entry thickness and temperature is the MATP signal; (d) plate mill **11** properties including roll diameter, roll crowns, roll material and mill spring constant is the MILP signal; (e) predicted roll force is the FPR signal; (F) initial roll gap set-up screw position is the ISCP reference signal; (g) desired length of plate material **10** beyond headend where lock-on AGC control takes over from initial roll gap set-up is the DLOL signal; and (h) predetermined constant of one or less selected to achieve the degree of absolute lock-on AGC control desired is the CMPLR signal.

Information concerning length of plate material **10** passing through mill stand **11** is initiated by coupling a well known rotary-pulse source **23** to work roll **13** and feeding length pulse LP signals to computer processor **19** for subsequent processing in relation to known diameter of work roll **13.** Pulse processing begins when the head end of plate material **10** is detected entering work rolls **12** and **13** and causes a well known source **24** to feed an entry pulse EP signal to processor **19.** The tail end of plate material **10** is detected leaving work rolls **12** and **13** by a well known source **25** which causes a drop-out pulse DOP signal to be fed to processor **19.**

Computer **17** is equipped with a number of specific memory and storage devices which, as described below, are operatively associated with processor **19** and are provided in addition to those devices mentioned above. Lock-on memory device **26** temporarily stores a lock-on LO signal generated at the beginning of AGC control and is reset by the DOP signal. Mill stretch subroutine **27** contains preferably a tabular means for permanently storing a family of curves representing mill stretch versus roll force for a number of different plate material **10** properties and valid for a particular combination of mill properties as illustrated by dotted line curves in FIG. **3.** Means are provided within subroutine **27** to correct the mill stretch calculations for combinations of the aforesaid mill properties other than those assumed in generating the stored table. When addressed with initial roll gap set-up values of FRP, MATP and MILP signals, processor **19** will cause mill stretch subroutine **27** to select and interpolate, if necessary, a set of specific mill stretch parameters SMSP having a constant nonlinear mill spring constant within an estimated roll force range equi-distant of the FPR signal. The SMSP parameters are stored temporarily in specific mill stretch curve memory device **28** where they characterize a specific three-segment mill stretch versus roll force F curve based on initial set-up conditions. This curve is shown by the solid line curve in FIG. **3** and identified by slopes M3, M4 and M5.

When roll force F signal is fed into memory device **28,** a mill stretch PSTRN signal is produced at is output. Mill stretch memory device **29** temporarily stores the PSTRN signal in response to the LO signal and produces a lock-on mill stretch LOSTRN signal. A corrected screw position PSC signal is temporarily stored in screw position memory device **30** in response to the LO signal and produces a lock-on screw position LOSC signal. Both the LOSTRN and LOSC signals are used in subsequent calculations under AGC control operations. It is to be noted that memory devices **28, 29,** and **30** are reset at the end of the LO signal.

OPERATION

Referring now to FIGS. **1, 2** and **3,** it will be assumed that initial roll gap is to be set up for a first pass of plate material **10** through reversing plate rolling mill **11** under manual operation of the roll gap control system. The MAN mode signal from data source **22** enables processor **19** to set-up manual roll gap control system while disabling the AGC control system. Ordinarily, processor **19** would direct the ISCP reference signal provided from data source **22** to screwdown speed regulator **14** and cause screwdown mechanism **15** to adjust roll gap until the PS signal is equal to the ISCP reference signal. When this would occur, the initial roll gap would be preset to equal aim gage rolled plate material **10** minus estimated mill stretch for a predicted value of roll force at lock-on.

However, it is preferred that computer **17** produce the ISCP reference signal during manual operation. This reference signal is produced simply by processor **19** directing the material and mill properties MATP and MILP signals, and the predicted roll force FPR signal, from data source **22** to mill stretch subroutine **27.** Here a selection is made of specific mill stretch parameters SMSP which are represented by the solid three-segment curve in FIG. **3** and are fed to memory device **28** for the duration of a given pass as described above. Also, the initial value of predicted mill stretch PRDSTR signal is calculated and cause to occur at the output of memory device **28.** Processor **19** directs the initial set-up value of the predicted PRDSTR signal to be substracted from the HAIM signal supplied from data source **22** to produce the ISCP reference signal which is fed to screwdown speed controller **14.** Screw-

down mechanism **15** then adjusts roll gap until screw position PS signal is equal to the ISCP reference signal, thereby establishing an initial roll gap set-up for plate mill **11.**

It will now be assumed that the MAN mode signal supplied from data source **22** has been replaced with the AGC mode signal and processor **19** has enabled the absolute lock-on AGC control system and disabled the manual roll gap control system. Hereinafter, absolute AGC program **21** will direct processor **19** to make changes in the initial roll gap set-up of plate mill **11.** Therefore, particular reference will now be made to FIG. **2.**

Many slabs requiring reduction in a plate mill have a head end that is tapered or fishtailed. In order to produce maximum yield of plate material **10** during rolling, one important factor to be developed is the exact point of lock-on for the AGC control system. That is, the point beyond the head end where full thickness and width of material **10** are being reduced by work rolls **12** and **13.** Step **31** in computer program **21** calls for calculating the length of rolled material **10** once per pass by summing length pulses LP from source **23** with the onset of entry pulse EP from source **24.** Step **32** calls for generating a lock-on LO signal once per pass when the sum of LP is equal to the desired lock-on length DLOL signal from data source **22.** The value of the DLOL signal is predetermined in relation to the estimated current thickness and length and the accumulative reductions having been performed on plate material **10** that is to enter plate mill **11.** Step **32** also calls for storing the LO signal, in lock-on memory device **30,** until reset by the occurance of the drop-out pulse DOP from source **25.** Thus, lock-on AGC control is established when the LO signal is generated and AGC control is terminated when the DOP signal is generated as the tail end of plate material **10** passes through plate mill **11.**

The next step in computer program **21** calls for step **33** to calculate a variable mill stretch PSTRN signal, this being done repetitively by starting with the onset of the LO signal and terminating at the end of the LO Signal. If during the above-described procedure of establishing the initial roll gap set-up the ISCP signal was derived from source **22,** then the first cycle in the mill stretch calculation would be to perform the preferred method described above for addressing mill stretch subroutine **27** and storing the SMSP signals in memory device **28** for each pass. The second and subsequent cycles of calculating mill stretch would be performed according to equation (1) below.

However, if the ISCP signal was obtained by the preferred method described above, then the SMSP signals would already be stored in memory device **28** for use during an entire pass. Therefore, the first and subsequent cycles in the mill stretch calculation in step **33** are to be performed by a simplified subroutine involving only roll force F and specific mill stretch parameter SMSP signals expressed as follows:

$$PSTRN = Si + (F-Fi)/Mj, \text{ where} \quad (1)$$

PSTRN = instantaneous value of mill stretch during AGC control,

Si, Fi and Mj = SMSP parameters stored in memory device **28.**

Si = mill stretch increment

F = roll force per signal

Fi = roll force increment

Mj = slope of mill spring constant which is shown by the solid curve in FIG. **3.** The specific mill stretch parameters for the three-segment solid curve illustrated in FIG. **3** are **F4, F5, S4, S5, M3, M4** and **M5.** For a given force F, the mill stretch corresponds to equation (**2**) as follows:

		Where i is	j is	
if $F \leq F4$,	then $PSTRN = S4 + (F-F4)(M3)$	4	3	(2)
$F4 < F \leq F5$,	then $PSTRN = S4 + (F-F4)(M4)$	4	4	
$F > F3$,	then $PSTRN = S5 + (F-F5)(M5)$	5	5	

and **M3, M4,** and **M5** are the slopes of the three segments in the solid curve shown in FIG. **3.**

The simplified mill stretch subroutine carried out in step **33** is permissable on a repetitive basis for two reasons. First, the mill spring constant Mj is considered to be a nonlinear constant that does not change during a given pass as opposed to changeable constants dealt with in some prior art AGC control systems. Any changes that may occur in mill housing dimensions during rolling, for example, are considered to be slowly varying linear changes, and if they do occur, are accounted for in corrected screw position PSC signal calculations described below. Second, there is no long computational procedure required on a repetitive basis to determine mill stretch PSTRN signals as are required in prior art AGC control systems.

In step **34** of computer program **21,** the mill stretch PSTRN signal is stored once per pass in memory device **26** in response to the lock-on LO signal to produce a constant lock-on value of mill stretch LOSTRN signal for each pass of plate material **10** through mill **11.**

It should be observed that FIG. **3** shows a difference between the lock-on roll force FLO signal and the predicted roll force FPR signal. There will be a corresponding difference between the lock-on mill stretch LOSTRN signal and the set-up mill stretch predicted PRDSTR signal and this difference in signals is a measure of the lock-on thickness error.

Step **35** calls for repetitively calculating a change in mill stretch after lock-on DSTRN signal which is equal to substracting the constant LOSTRN signal produced in step **34** from the variable PSTRN signal produced in step **33.**

In computer program **21,** step **35** calls for determining corrected roll gap by repetitively calculating a correct screw position PSC signal which is equal to adding a constant calibration correction CC signal to the variable screw position PC signal produced by detector **18.** The constant CC signal is produced by calibration correction source **37.** Source **37** may be an adjustable reference signal source set by a mill operator to account for slowly changing mill dimensions as well as observed thickness errors in rolled plate material **10** at the end of a given pass or series of passes. Constant thickness error data may also be supplied by nuclear gaging apparatus circuited outside of the absolute lock-on AGC control system. Such gages periodically gage plate ma-

terial 10 when at rest during a plate reversal between passes, stores a thickness error measurement while at rest, and then is returned off-line during movement of plate 10 through mill 11. Thus, the nuclear gaging apparatus does not play an active role in the lock-on AGC control system, but only measures and stores plate 10 thickness error at the end of any one or more passes of plate 10 through mill 11.

Step 38 calls for the corrected screw position PSC signal to be stored once per pass in memory device 30 in response to the lock-on LO signal to produce a constant lock-on screw position LOSC signal.

Step 39 calls for repetitively calculating a change in corrected screw position DSO signal which is equal to subtracting the LOSC signal from the PSC signal.

Step 40 in computer program 21 calls for a once per pass calculation of a plate material 10 constant lock-on thickness HLO signal, in response to the LO signal, which is equal to adding the LOSTRN signal stored in memory device 26 from step 34 to the LOSC signal stored in memory device 30 from step 38.

Step 41 calls for a once per pass calculation of a plate material 10 constant lock-on thickness error LODIFF signal, in response to the LO signal, which is equal to subtracting the HAIM signal provided by source 22 from the HLO signal produced in step 40. The LODIFF signal should correspond generally to the difference between the LOSTRN and predicted PRDSTR signals illustrated graphically in FIG. 3.

In order to provide the user with an adjustment in the degree of absolute lock-on AGC control desired, step 42 is provided in computer program 21 to call for a once per pass calculation of the percentage of absolute control CCADD signal. The CCADD signal is equal to multiplying the LODIFF signal produced in step 41 by the CMPLR signal provided by data source 22, the latter having a positive numerical value of one or less. If nothing less than 100% absolute lock-on AGC control is desired, then step 42 may be eliminated and computer program should advance to the next step.

Step 43 in computer program 21 is provided to call for repetitively calculating a corrected thicknes error DHO signal which will correspond to the corrected roll gap reference signal which eventially will become the second signal fed to regulator 14 as mentioned above. The DHO signal is equal to the sum of the change in screw position DSO signal produced in step 39, the change in mill stretch DSTRN signal produced in step 35, and the percentage of absolute control CCADD signal produced in step 42 if step 42 is used in computer program 21. Otherwise if step 42 is omitted, the LODIFF signal produced in step 41 should be substituted for the CCADD signal.

In order to achieve a rapid response to changes in the corrected thickness error DHO signal, and thereby maximize yield of rolled plate material 10, computer program 21 is provided with step 44 which calls for repetitively calculating a GAIN factor of the DHO signal. The GAIN factor is calculated in a conventional manner and is based on the rate of change in roll force F signal produced by load cell 16, the rate of change in screw position DSO signal produced in step 39, and the material properties MATP signal, the mill properties MILP signal and the aim gage HAIM signal, the latter three being fed from data source 22. The combined magnitude of these parameters determines the actual value of the GAIN factor.

Step 45 calls for the repetitive calculation of a corrected roll gap reference signal AGCCOR signal which is obtained by multiplying the corrected thickness error DHO signal produced in step 43 by the GAIN factor produced in step 44. The AGCCOR signal is fed to screwdown speed regulator 14 which causes screwdown mechanism 15 to continuously adjust roll gap to roll plate material 10 having absolute aim gage during operation of the absolute lock-on AGC control system.

When the tail end of plate material 10 exits from plate mill 11, the dropout DOP pulse terminates the lock-on LO signal, thereby terminating the absolute lock-on AGC control system.

I claim:

1. In a method of automatically con rolling rolling mill roll gap where a preset roll gap is adjusted in response to a roll gap reference signal, the improvement which comprises:

a. establishing a lock-on AGC control mode when the head-end of said material enters the mill rolls, including:

1. storing lock-on values of mill stretch and roll position signals generated during rolling of said material, and

2. thereafter adjusting roll gap to maintain material thickness according to a roll gap reference signal which is produced in response to changes in said mill stretch and roll position signals after lock-on,

b. producing a lock-on thickness error signal by comparing an aim gage signal with said stored lock-on values of said mill stretch and roll position signals, and

c. correcting the roll gap reference signal by a predetermined amount of the lock-on thickness error signal to cause the production of rolled material having absolute aim gage.

2. The method of claim 1 wherein step (a) includes:

1. generating a lock-on control signal after a predetermined head-end length of material enters the mill rolls and initiating the storage of lock-on values of said signals in response thereto.

3. The method of claim 1 wherein step (a) includes:

2. calculating the mill stretch signal prior to lock-on as a function of a predicted roll force signal and a mill spring constant signal, the latter signal determined from plural signal sources representing various sets of operating parameters.

3. recalculating the mill stretch signal at lock-on as a function of an actual roll force signal and a stored specific mill spring constant signal determined from a specific signal source representing a given set of operating parameters at lock-on.

4. The method of claim 1 wherein the mill stretch signal of step (a) is calculated for each different pass of material through the mill.

5. The method of claim 1 wherein step (a) inclues;

4. modifying the roll position signal by a calibration correction signal produced by an external source.

6. The method of claim 5 wherein the calibration correction signal is produced by detecting changes in one or more stored signals representing predetermined rolling mill properties.

7. The method of claim 5 wherein the calibration correction signal is produced by detecting and storing a thickness signal derived from a gage devoid of the AGC

control loop during one or more previous passes of material through the mill.

8. The method of claim **1** further including:

d. varying the gain of said roll gap reference signal to vary the speed of roll gap adjustment as a function one or more signals representing such parameters as material properties, and rate of change of roll force and roll position signals detected after lock-on.

9. A method of automatically controlling rolling mill roll gap to produce rolled material having absolute aim gage, which method comprises:

a. adjusting a screwdown mechanism to vary mill roll gap from an initial preset value to other values in response to a corrected screwdown reference signal,

b. establishing a lock-on AGC control mode when the head-end of said material enters the mill rolls, including storing lock-on values of mill stretch and roll position signals generated during rolling of said material, and thereafter adjusting the screwdown mechanism to maintain head-end material thickness according to a screwdown reference signal which is produced in response to changes in said mill stretch and roll position signals after lock-on,

c. producing a lock-on thickness error signal by comparing an aim gage signal with said stored lock-on values of said mill stretch and roll position signals, and

d. correcting the screwdown reference signal by a predetermined amount of the lock-on thickness error signal.

10. In apparatus for automatically controlling rolling mill roll gap where a preset roll gap is adjusted by means responsive to a roll gap reference signal, the improvement comprising:

a. means for producing a roll force signal,

b. means for producing a roll gap signal,

c. means for producing an aim gage signal,

d. computer means receiving said roll force, roll gap and aim gage signals and including:

1. programming means for establishing lock-on AGC control of roll gap,

2. means responsive to said roll force signal for producing a first signal representing a change in mill stretch after lock-on,

3. means responsive to said roll gap signal for producing a second signal representing a change in roll gap after lock-on,

4. means responsive to said aim gage signal lock-on values of mill stretch and roll gap signals for producing a third signal representing a lock-on thickness error function, and

5. means responsive to said first, second and third signals for producing a corrected roll gap reference which acts on said adjusting means to cause production of rolled material having absolute aim gage.

11. The apparatus of claim **10** including:

e. means for generating a lock-on control signal after a predetermined head-end length of material enters the mill rolls and controlling the storage of lock-on values of said mill stretch and roll force signals with said lock-on control signal.

12. The apparatus of claim **10** including:

f. means for producing a predicted roll force signal and plural signals representing various sets of operating parameters, and wherein computer means (d) includes:

21. means for storing a family of mill stretch curves,

22. means for storing a specific mill stretch curve, said 1 means programmed for computer means (d) to cause said 21 means to receive said means (f) signals prior to lock-on and to select a specific mill stretch curve in response thereto, and to store said selection in means 22, and said 1 means also programmed for computer means (d) to calculate mill stretch after lock-on as a function of the specific mill stretch curve stored in means 22 and the actual roll force signal of means (a).

13. The apparatus of claim **10** wherein computer means (d) is programmed by means 1 to calculate mill stretch for each different pass of material through said rolling mill.

14. The apparatus of claim **1** including:

g. means for producing a calibration correction signal, said signal modifying the roll gap signal in computer means *d*3 to provide a corrected second signal.

15. The apparatus of claim **1** including:

h. means for producing plural signals of corresponding plural operating parameters, and wherein computer means (d) further includes:

6. means receiving said means (a) signal, said means *d*3 second signal, and said means (h) signals for varying the gain of said means *d*5 corrected roll gap reference signal to vary the speed of roll gap adjustment as a function of one or more of said means (h) signals and the rate of change of said means (a) and *d*3 signals.

16. Apparatus for automatically controlling rolling mill roll gap to produce rolled material having absolute aim gage, comprising:

a. means including a screwdown mechanism for adjusting mill roll gap from an initial preset value to other values in response to a corrected roll gap reference signal,

b. means for producing a roll force signal,

c. means for producing a screw position signal,

d. means for producing an aim gage signal,

e. computer means receiving said roll force, screw position and aim gage signals and including:

1. programming means for establishing lock-on AGC control of roll gap,

2. means responsive to said roll force signal for producing a first signal representing a change in mill stretch after lock-on,

3. means responsive to said screw position signal for producing a second signal representing a change in screw position after lock-on,

4. means responsive to said aim gage signal and lock-on values of mill stretch and screw position signals for producing a third signal representing a lock-on thickness error function, and

5. means responsive to said first, second and third signals for producing a corrected roll gap reference which acts on said adjusting means.

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