United States Patent [19]

Sterrett et al.

[11] **3,793,859**

[45] **Feb. 26, 1974**

[54] **METHOD AND APPARATUS FOR CONTROLLING CROWN IN A PLATE ROLLING MILL**

[75] Inventors: **John D. Sterrett**, Williamsville; **Alfred J. Baeslack**, East Aurora, both of N.Y.

[73] Assignee: **Westinghouse Electric Corporation**, Pittsburgh, Pa.

[22] Filed: **May 10, 1972**

[21] Appl. No.: **251,961**

[52] **U.S. Cl.** **72/8**, 72/20

[51] **Int. Cl.** **B21b 37/00**

[58] **Field of Search** 72/8, 19, 20, 21

[56] **References Cited**

UNITED STATES PATENTS

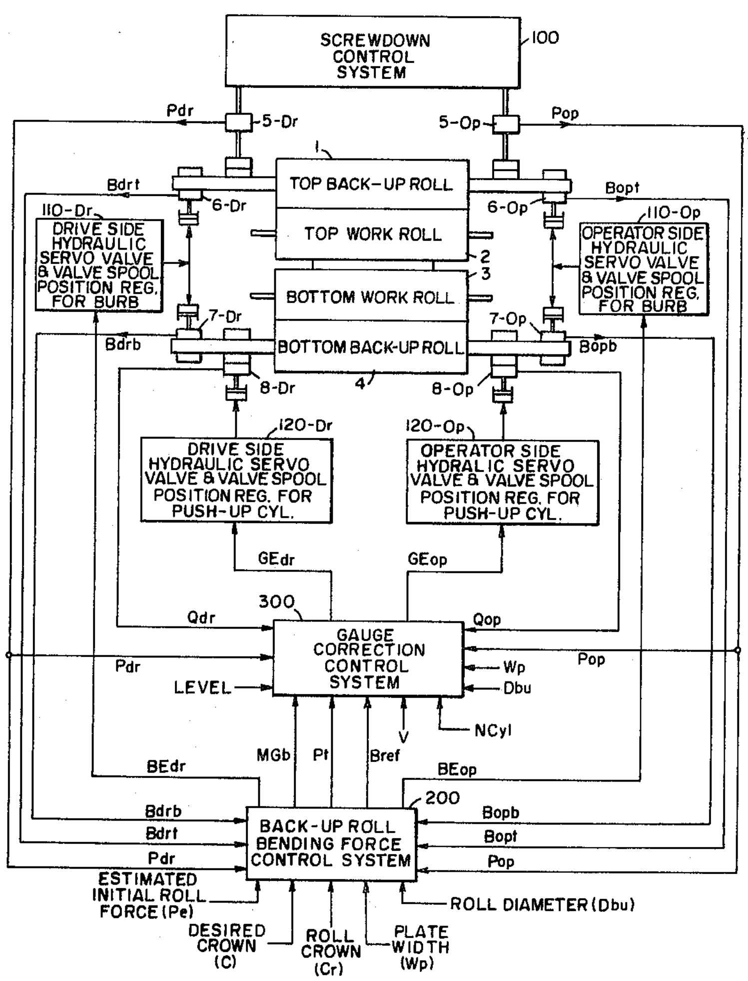
3,714,805	2/1973	Stone	72/8
3,518,858	7/1970	Kamata	72/19
3,625,036	12/1971	Fapiano	72/6
3,709,010	1/1973	Tatsumi	72/8
3,318,124	5/1967	Plaisted	72/8
3,531,960	10/1970	Stone	72/8

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

[57] **ABSTRACT**

Plate width and roll diameter input signals are translated into roll and bending force spring constant representations which are multiplied by total roll and bending force signals, respectively, and added to desired roll and crown representations to produce a crown error signal. The error signal is proportionally integrated to provide a bending force reference signal which is employed to develop the proper roll bending forces to produce the desired crown.

8 Claims, 12 Drawing Figures



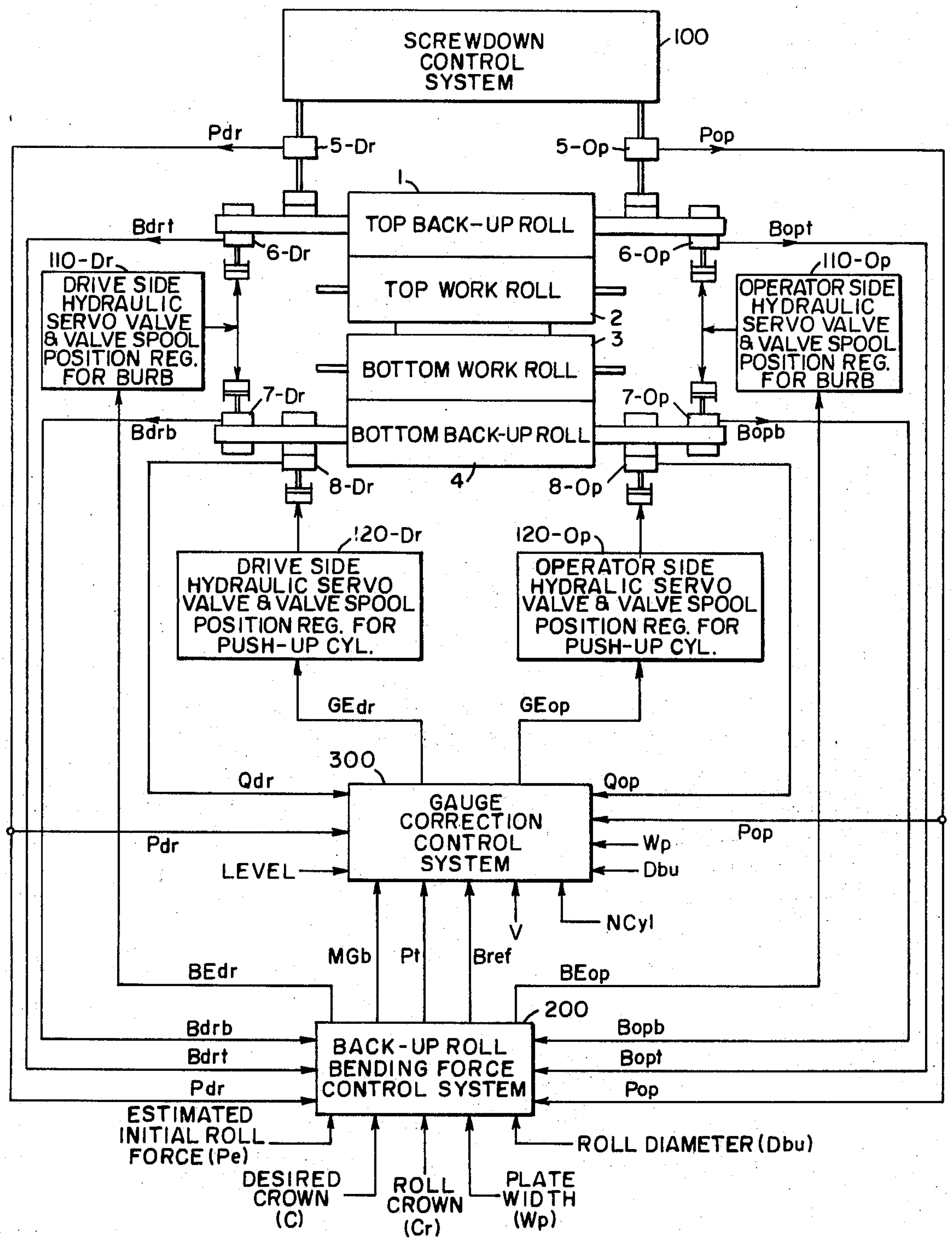

SCREWDOWN CONTROL SYSTEM
100
Pdr
5-Dr
5-Op
Pop
1
TOP BACK-UP ROLL
Bdrt
Bopt
6-Dr
6-Op
110-Dr
110-Op
DRIVE SIDE HYDRAULIC SERVO VALVE & VALVE SPOOL POSITION REG. FOR BURB
TOP WORK ROLL
OPERATOR SIDE HYDRAULIC SERVO VALVE & VALVE SPOOL POSITION REG. FOR BURB
2
3
BOTTOM WORK ROLL
7-Dr
7-Op
Bdrb
BOTTOM BACK-UP ROLL
Bopb
8-Dr
4
8-Op
120-Dr
120-Op
DRIVE SIDE HYDRAULIC SERVO VALVE & VALVE SPOOL POSITION REG. FOR PUSH-UP CYL.
OPERATOR SIDE HYDRALIC SERVO VALVE & VALVE SPOOL POSITION REG. FOR PUSH-UP CYL.
GEdr
GEop
300
Qdr
Qop
GAUGE CORRECTION CONTROL SYSTEM
Pdr
Pop
LEVEL
Wp
Dbu
NCyl
V
MGb
Pt
Bref
BEdr
BEop
200
Bdrb
Bopb
Bdrt
Bopt
Pdr
Pop
BACK-UP ROLL BENDING FORCE CONTROL SYSTEM
ESTIMATED INITIAL ROLL FORCE (Pe)
ROLL DIAMETER (Dbu)
DESIRED CROWN (C)
ROLL CROWN (Cr)
PLATE WIDTH (Wp)

FIG. 1.

PATENTED FEB 26 1974 3,793,859

SHEET 2 OF 6

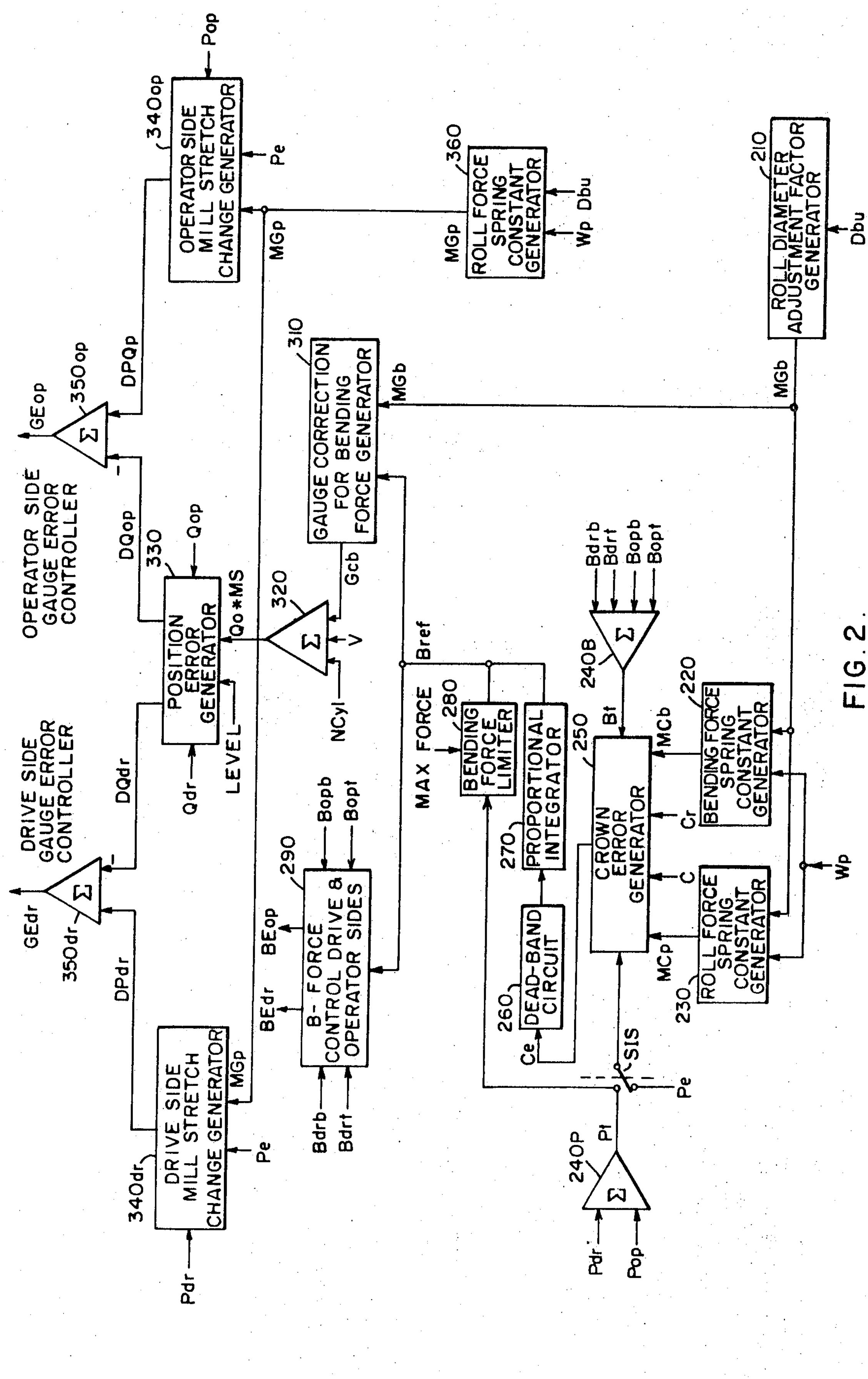


FIG. 2

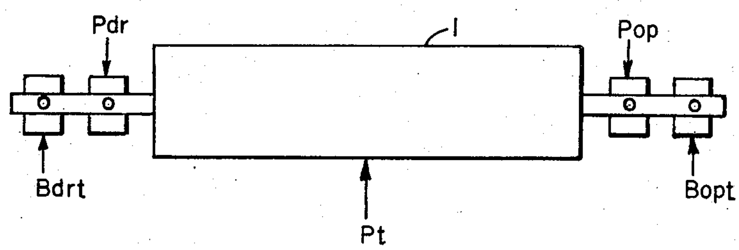


FIG. 3A

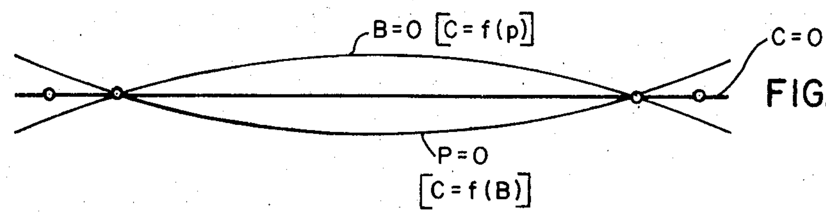


FIG. 3B

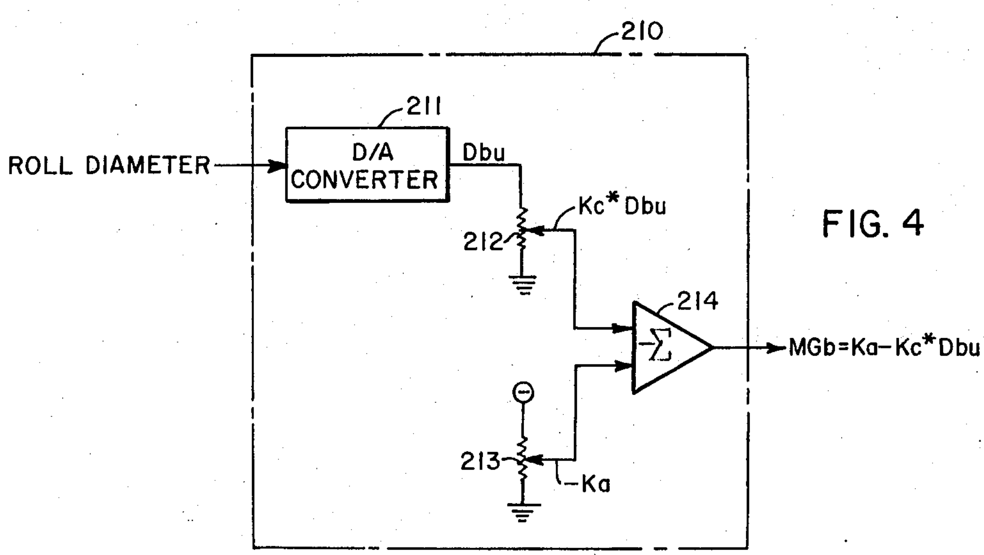


FIG. 4

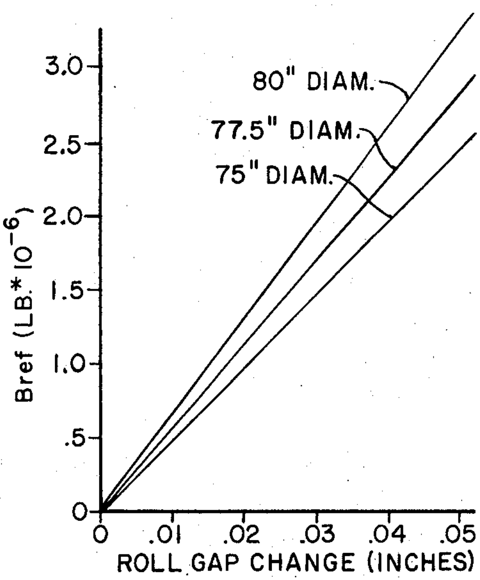

3.0
2.5
2.0
1.5
1.0
.5
0
Bref (LB.* 10^-6)
80" DIAM.
77.5" DIAM.
75" DIAM.
0 .01 .02 .03 .04 .05
ROLL GAP CHANGE (INCHES)

FIG. 4A

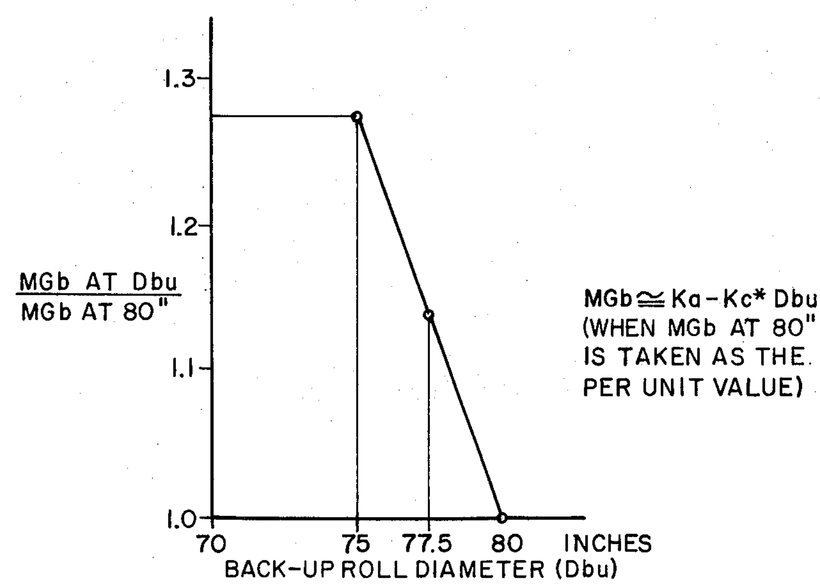

1.3
1.2
1.1
1.0
MGb AT Dbu / MGb AT 80"
70 75 77.5 80 INCHES
BACK-UP ROLL DIAMETER (Dbu)
MGb ≅ Ka - Kc* Dbu
(WHEN MGb AT 80"
IS TAKEN AS THE
PER UNIT VALUE)

FIG. 4B

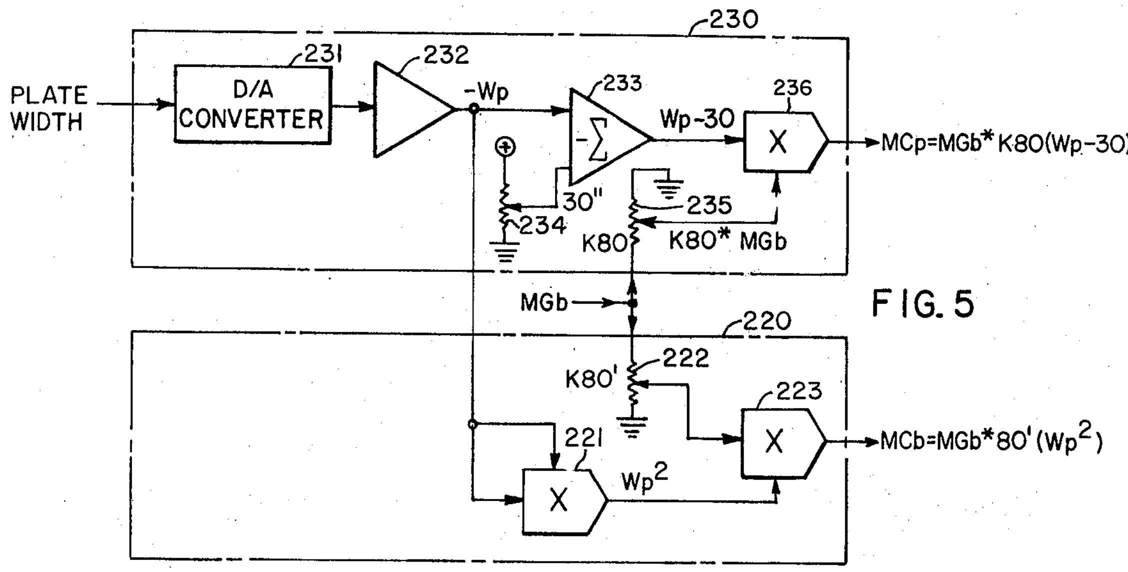


FIG. 5

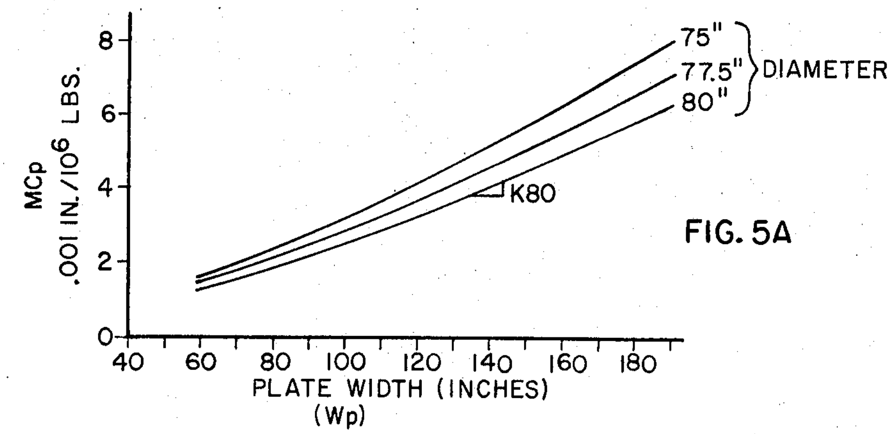


FIG. 5A

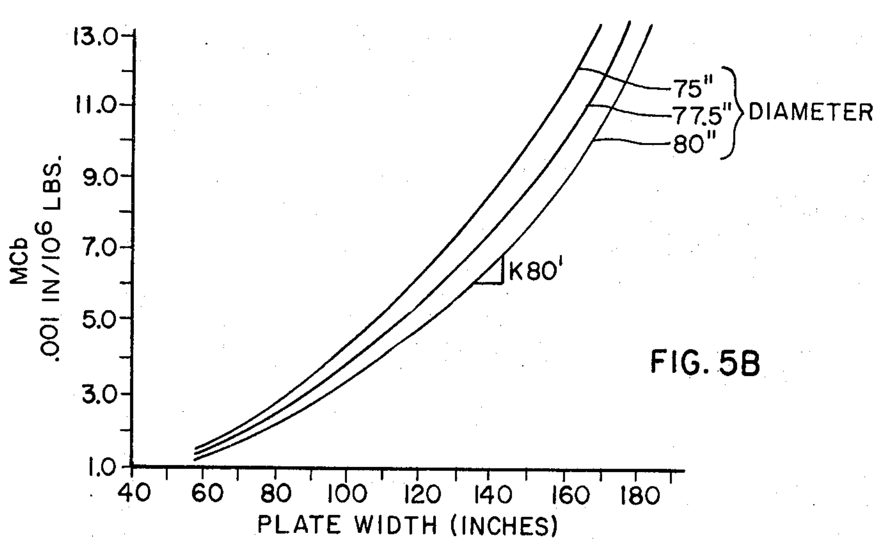


FIG. 5B

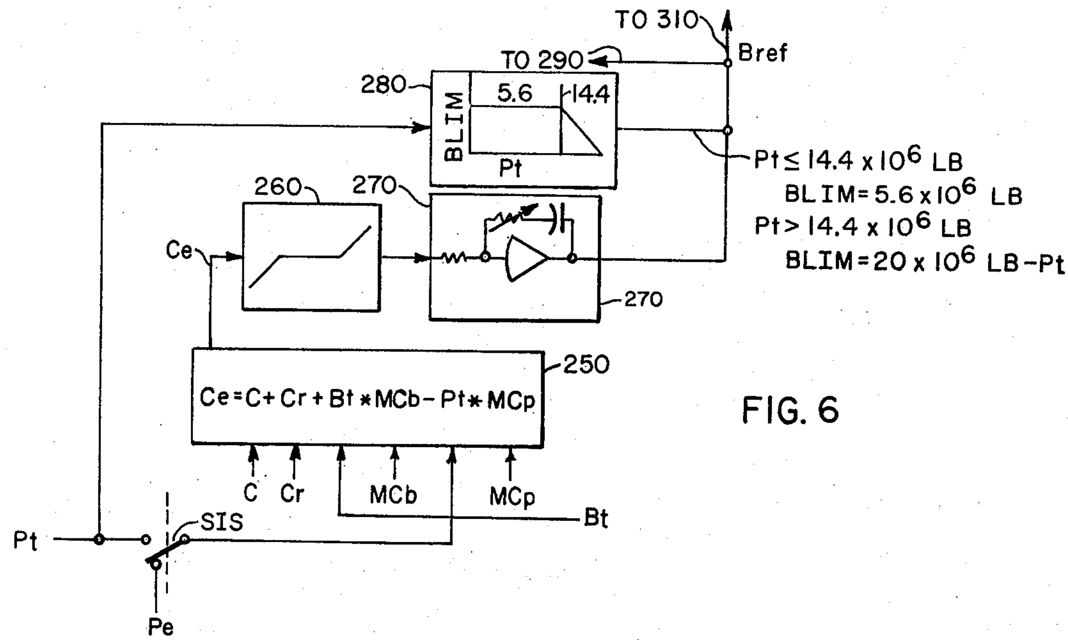

TO 310
Bref
TO 290
280
BLIM
5.6
14.4
Pt
260
270
Ce
270
Pt≤14.4 x 10^6 LB
BLIM=5.6 x 10^6 LB
Pt>14.4 x 10^6 LB
BLIM=20 x 10^6 LB-Pt
250
Ce=C+Cr+Bt*MCb-Pt*MCp
C
Cr
MCb
MCp
Bt
Pt
SIS
Pe

FIG. 6

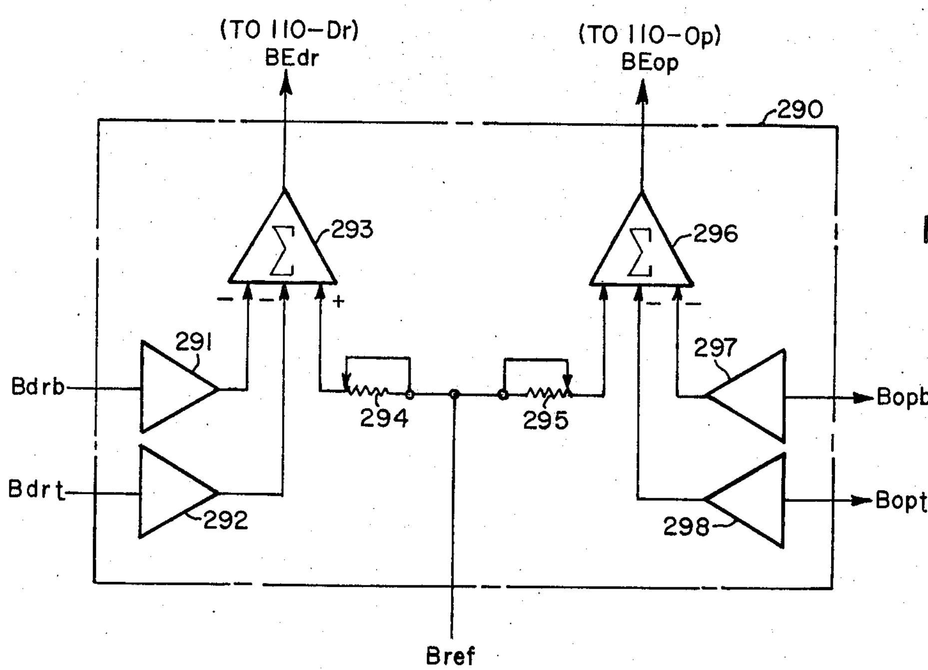

(TO 110-Dr)
BEdr
(TO 110-Op)
BEop
290
293
296
291
297
Bdrb
Bopb
294
295
Bdrt
Bopt
292
298
Bref

FIG.7

METHOD AND APPARATUS FOR CONTROLLING CROWN IN A PLATE ROLLING MILL

CROSS-REFERENCE TO RELATED APPLICATIONS

Application Ser. No. 251,963, filed May 10, 1972, entitled "System and Method for Controlling Gauge and Crown in a Plate Rolling Mill" by J. D. Sterrett and A. J. Baeslack.

BACKGROUND OF THE INVENTION

The prior art has provided many systems for controlling the gauge of strip or plate which is produced in a rolling mill. Typically, this is accomplished through the use of a mill screwdown control system which regulates the rolling forces applied to so-called back-up roll bearings (in a four-high mill) to establish a total rolling force considered to exist at the approximate center of the back-up rolls. It is known, however, that application of the rolling forces to the ends of the rolls results in gauge variations across the rolled plate due to bending force moments. This gauge variation is referred to as crown which is a measure of the maximum deviation of gauge from a straight-line drawn across the plate.

In order to compensate for the crown which is caused by the bending moments, the work rolls of some mills have been ground to have a predetermined amount of roll crown. However, since the bending moments vary with plate width and roll diameter, as well as changes in the roll and bending forces themselves, the roll crown does not provide complete compensation.

An analysis of the gauge and crown control problem is found in prior art patents 2,611,150; 2,903,926; 3,171,305; and 3,518,858. Particular reference will be made to U.S. Pat. No. 3,518,858 wherein a computer is utilized to provide automatic compensation for bending due to changes in the rolling force. In this system, experimental data relating bending forces to rolling loads or pressures is stored in the computer and then compensating bending force signals are generated to control crown. The system of the referenced patent, however, is limited in use as a means of compensation where the same roll crown as existed in the mill at the time of generating the experimental data is also present during the rolling. No provision is found for producing a representation of the "desired crown" as is present in the present disclosure.

It will further be noted that the prior art has not heretofore made provision to adjust the crown compensation as a function of the bending forces generated during crown control. This means that where a bending control is developed solely as a function of rolling force or pressure, no compensation is present to adjust for the actual bending moments which result from the generated force. The effectiveness of the control provided by the prior art has also been limited by the fact that the proper variation in control force as a function of roll diameter and plate width has not been introduced into the system.

It is apparent, then, that the prior art has not provided a method or apparatus for accurately and automatically generating the proper bending forces to obtain a desired crown where all of the following factors are taken into consideration: roll crown; roll diameter; plate width; crown changes due to total rolling force; and crown changes due to total bending force.

SUMMARY OF THE INVENTION

According to the method of the invention, data relating roll gap changes to bending forces and to rolling forces is translated into roll and bending force spring constants which vary as a function of plate width and back-up roll diameter. Representations of the spring constants (which may be in either analog or digital form) are functionally related to continuously measured representations of all of the various rolling and bending forces on both top and bottom rolls and on both the drive and operator's side of the mill. From these relationships, the proper compensation for crown changes due to both total rolling force and to total bending force are obtained and these compensating signals or representations are then combined with analog or digital representations of desired and roll crown to generate or to compute a crown error representation. The crown error representation is then translated into a bending force reference signal.

Since the invention may be practiced with either analog or digital components, the term signal as employed herein is generic to any representation of the particular quantity involved whether shown herein as produced by an analog or digital component. The term "representation" will be used to cover both analog and digital signals and is, therefore, the equivalent of signal. Since the method provided is for automatic control, however, representations (such as charts) which are not suitable for direct translation into automatic steps in the control are not considered to be equivalent.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

FIG. 1 is a block diagram of a system employing the invention;

FIG. 2 is a schematic diagram of a control system employing the present invention as well as the improved features of copending application constituting reference 1 above;

FIGS. 3A and 3B are presented to indicate the general relationship between roll and bending forces and crown;

FIG. 4 is a schematic diagram of one form of generator **210** shown in FIG. 2;

FIGS. 4A and 4B are charts setting forth the relationships which must be solved by generator **210**;

FIG. 5 is a schematic diagram illustrating suitable forms for spring constant generators **220** and **230** of FIG. 2;

FIGS. 5A and 5B are charts setting forth the relationships which must be solved by the generators of FIG. 5;

FIG. 6 is a schematic and functional diagram setting forth suitable means for producing the bending force reference signal; and

FIG. 7 is a schematic diagram of a bending force reference generator **290** of FIG. 2.

Reference is now made to FIG. 1 wherein a system employing the present invention is shown in block diagram form. The system includes a screwdown control **100** providing a means of positioning drive side and operator side bearings for the top back-up roll **1.** The metal to be rolled is passed between a top work roll **2** and a bottom work roll **3,** the position of which is controlled through a bottom back-up roll **4**. Rolling pressures which are caused by working the metal are measured by conventional means such as load cells referenced as **5**-Dr for the drive side and **5**-Op for the operator's side, producing signals Pdr and Pop, respectively. Roll bending forces for both top roll **1** and bottom roll **4** are developed through drive and operator side hydraulic servo valve and valve spool position regulators **110** which operate in a conventional manner to develop bending forces which are measured by top and bottom load cells **6** and **7**. The relationship between the load cells and bending forces measured is set forth in the following chart:

LOAD CELL	SIGNAL	REPRESENTATION
6-Dr	Bdrt	Drive-Side Top Bending Force
7-Dr	Bdrb	Drive-Side Bottom Bending Force
6-Op	Bopt	Operator-Side Top Bending Force
7-Op	Bopb	Operator-Side Bottom Bending Force

The height of bottom back-up roll **4** is controlled through conventional servo valve and valve spool position regulators **120** which receive gauge error reference signals GEdr and GEop with the position of roll **4** on the drive and operator sides being represented by load cells **8**-Dr and **8**-Op, respectively. The drive side and operator side position signals are referenced as Qdr and Qop, respectively. It will be understood that while the actual signal produced by load cell **8** may be representative of the positioning force, it is readily translated into a position representation as employed herein. Controllers **110**-Dr and **110**-Op receive drive and operator side roll bending force error signals BEdr and BEop, respectively, which are produced by back-up roll bending force control system **200**. **110**-Dr and **110**-Op respond to BEdr and BEop by allowing oil flow into or out of the bending cylinders until BEdr and BEop = 0.

System **200** receives the measured roll and bending force signals previously mentioned as well as representations of the following: desired crown (C); roll crown (Cr); plate width (Wp); roll diameter (Dbu); and estimated initial roll force (Pe).

In addition to providing the drive and operator side oil flow reference signals for controllers **110**, system **200** also provides certain signals utilized in gauge correlation control system **300**. In particular, a signal Bref (the required roll bending force) is produced which forms the basis for developing signals BEdr and BEop previously mentioned and signal MGb represents a factor which, when multiplied by Bref, enables system **300** to compensate for gauge changes caused by anticipated bending force. System **300** additionally receives a total bending force signal Pt corresponding to the summation of signals Pdr and Pop previously mentioned and signals V and NCyl defined below which are used in the gauge correction control. System **300** also receives signals Pdr and Pop directly as well as representations of plate width (Wp) and roll diameter (Dbu). A signal represented as LEVEL is utilized to permit adjustment of roll **4** to a horizontal position. Gauge correction signals GEdr and GEop are applied to controllers **120**-Dr and **120**-Op, respectively, to cause positioning of roll **4** through suitable push-up cylinders.

Reference is now made to FIG. **2** for a more specific description of control systems **200** and **300**. Bending force control system **200** includes means **210** for generating a roll diameter adjustment factor MGb as a function of an input representation of roll diameter (Dbu). Signal MGb is applied to spring constant generators **220** and **230** producing signals Mcb and Mcp as a function of signal MGb and a representation of plate width (Wp). Total rolling and bending signals Pt and Bt produced through summing circuits **240P** and **240B**, respectively, are used in a crown error generator **250** to produce a crown error signal Ce. Generator **250** receives an estimated initial rolling force signal Pe through a switch SIS to simulate the presence of bending due to rolling load before metal enters the mill so as to permit establishment of initial forces before the actual rolling begins. Switch SIS then represents the fact that the metal is in the mill and, when closed, presents signal Pt to generator **250** in place of the initial estimate Pe. The crown error signal Ce is generated in a manner more specifically described below and is applied to a dead-band circuit **260** which drives a proportional integrator **270** providing output signal Bref. The dead band may be omitted in some cases depending on the mill characteristics. Signal Bref is limited by a bending force limiter **280** which receives a representation of maximum force and signal Pt. The components thus far described are those included in system **200**. It will be understood that while terms generally considered to be analog have been used, the various functions of the components just described may be performed as well with a digital computer with wired logic or with a programmed computer.

Control system **200** also includes **290** and B-force control (see FIG. **7**) for the drive and operator sides. **290** has individual B-force controllers **293** for the drive side and **296** for the operator side. The drive side controller **293** matches the average of the two roll bending force signals Bdrb (**291**) and Bdrt (**292**) to the roll bending force reference Bref, as modified by rheostat **294**. The difference is the bending force error BEdr for the drive side. BEdr is the oil flow or spool position reference for **110-DR** the drive side hydraulic servo valve spool position regulator. The **110-DR** valve spool is positioned proportional to BEdr to control oil flow into or out of the roll bending cylinder as determined by the polarity of BEdr. The resulting oil flow changes Bdrb and Bdrt until the average force equals Bref and BEdr = 0. The operation of the operating side is the same. Rheostats **294** and **295** permit trimming of Bref to shift the center of the roll crown as required to balance the mill.

Signal Bref is utilized in both reference generator **290** and in gauge correction for bending force generator **310** which forms part of system **300**. Signal Gcb produced by generator **310** is combined with signals V and NCyl in a summing circuit **320** producing a signal referenced as Qo*Ms. Qo*Ms is the basic position reference for the bottom roll cylinders for an empty mill. The term Ms is a factor which is used to multiply a force representation to translate it into a position measurement. Thus signals Qdr and Qop are also multiplied by the factor Ms to translate the force measurement into a position signal. It will be understood that if transducers are utilized for the function of **8**-Dr and **8**-Op of FIG. **1** where a direct representation of position is possible, the multiplication by factor Ms is no longer required.

Signal NCyl represents nominal cylinder position at calibration and may be considered to be an initial reference positon whereas signal V represents roll gap variation due to bearing oil film thickness changes caused by mill speed and rolling force. The gap variation occurs primarily because the bearing oil thickness increases as a function of speed increase and decreases as rolling force increases. Signals LEVEL and Qo*Ms are utilized along with signals Qdr and Qop in generator **330** to produce drive side and operator side difference signals DQdr and DQop. These difference signals represent the position change from the actual measured cylinder positions and the position to correct for the factors introduced into summing circuit **320.** Gauge correction must also be made for mill stretch changes on both the drive and operator sides. Thus, generators **340**dr and **340**op are provided, both of which receive a signal MGp representing a roll force spring constant as produced by generator **360.** The spring constant MGp is produced as a function of both strip width (Wp) and roll diameter (Dbu) and is used to permit translation of actual rolling force measured signals into gap changes. A change in mill stretch during rolling is represented by difference signals (DPdr for the drive side and Dpop for the operator side) which are combined with corresponding position change signals produced by generator **330** in a suitable summing circuit **350.** Thus, circuits **350**dr and **350**op are the gauge error controllers and produce signals GEdr and GEop, respectively, as will be noted in FIG. **1.** To roll metal at a constant thickness, changes in DPdr and DPop must be balanced by changes in DQdr and DQop respectively to maintain a constant roll gap.

Since the present disclosure relates to the manner in which signal Bref is produced, the following detailed description relates only to the structure of control system **200.** The specific details as to suitable forms of circuits for providing the functions of system **300** are found in copending application constituting Reference (1) above. While the bending force control system of the present invention has been developed for specific use with the system of the copending application, it will be understood that it may as well be employed with any gauge correction control system of the general form illustrated in FIG. **2.**

Reference is now made to FIGS. **3A** and **3B** for a general description as to the relationship between crown and various forces in the system. In FIG. **3A**, the forces on roll **1** are represented by the signals previously defined with reference to FIG. **1.** Thus, drive and operator side rolling forces or pressures Pdr and Pop are shown as applied to inner bearings and top bending forces on the drive and operator sides Bdrt and Bopt are shown as being applied to respective outer bearings. As far as crown is concerned, the effect of forces Pdr and Pop is to develop a crown deviation in the direction of total rolling force Pt shown in FIG. 3A. Thus, as noted in FIG. **3B**, if the bending force B equals zero, the crown becomes a function of only rolling force. On the other hand, if the rolling force P equals zero, then crown becomes the function of bending force alone. In this case, it might be considered to be negative crown where the gauge at the center of the strip is less than that at the edges. A straight-line is shown to represent zero crown where the control necessary to obtain such a result must be a function of both the bending and the rolling forces.

In order to provide the proper correction for crown as a function of the bending and rolling forces, spring constants must be determined relating roll crown change to roll and bending forces as set forth in FIGS. **5A** and **5B**. The precise mathematical expressions for these relationships are quite complex and this disclosure relates to practicable means of obtaining the spring constants to the accuracy required by the rolling process. Although the precise equations differ, a study of these mill characteristic curves revealed a simplification was possible within the required accuracy. The factor which is found common to both the rolling and bending force spring constants for the bending of the roll is the change in slope as a function of back-up roll diameter. It was also found that the same factor could be used to express the relationship between roll bending force and roll gap contraction as a function of back-up roll diameter as shown in FIG. **4A**. The slope of these curves is Mgp = roll gap contraction/roll bending force. Consequently, it is the specific approach of the present invention to develop a common roll diameter adjustment factor in generator **210** shown in FIG. **4** where this factor may be utilized to adjust both the MCp and MCb constants as a function of diameter and also provides a suitable reference factor for use in generator **310** of system **300** as is more specifically discussed in copending application constituting reference 1. The development of the roll diameter adjustment factor will be considered first with reference to FIGS. **4A** and **4B** with the circuit FIG. **4** illustrating a suitable mechanization therefor and then FIGS. **5, 5A** and **5B** will be considered with respect to the development of signals MCp and MCb.

In FIG. 4A, the bending reference is scaled in pounds times 10^{-6} and the abscissa is scaled in terms of the roll gap change in inches which would result from a bending force corresponding to Bref. The roll diameter adjustment factor is then based upon the 80-inch diameter curve in FIG. 4A which is substantially a straight-line. The 80-inch diameter curve of FIG. 4A is used as a reference so that, in FIG. **4B**, the ratio of Mgb at Dbu/Mgb at 80 is shown as unity (1) for an 80-inch diameter. It will be noted then that the ratio is plotted in FIG. **4B** changes as an approximate linear function of Dbu expressed by the following equation:

Mgb at Dbu/Mgb at 80″ = 1 + 0.055(80-D) for a particular mill. Generalizing by letting Mgb at **80″** be the per unit slope.

MGb = Ka − Kc*Dbu

Suitable values for the constants Ka and Kc may be determined by substituting slope values for MGb as follows:

$$1 = Ka - Kc*80$$

$$1.275 = Ka - Kc*75$$

$$Kc = 0.055$$

$$Ka = 5.4$$

An analog circuit is shown in FIG. **4** for developing the MGb factor but it will be understood that a digital computer may be used for the same purpose and that a more precise relationship may be required in some mills to compensate for nonlinear changes due to roll diameter.

Generator **210** of FIG. **4** is shown as including a digital-to-analog converter **211** which receives a digital representation of roll diameter and produces signal Dbu applied to a potentiometer **212** providing the term Kc*Dbu which is applied to an inverting summing amplifier **214.** Amplifier **214** also receives a representation of −Ka from a potentiometer **213** and, after summation and inversion produces signal MGb.

The curves for spring constants MCp and MCb in FIGS. 5A and 5B have been developed from a typical rolling mill. The 80-inch diameter curves and the ratios of specific values of spring constants at different back-up roll diameters to the 80″ values are found to fall close to the line plotted in FIG. 4B. It has been determined that reasonable approximations for these spring constants are provided by the following equations:

$$MCp = MGb * K80(Wp-30)$$

$$MCb = MGB * K80'(Wp^2)$$

where K80 and K80′ are the reference slope factors for MCp and MCb respectively so thatthe previously derived value of MGb can be used as the roll diameter correction factor. MCp is found to be an approximate linear function of plate width (Wp), and MCb is found to be a function of plate width squared (Wp^2). A schematic diagram of generators **220** and **230** producing the spring constant signals are shown in FIG. **5** where a digital-to-analog converter **231** translates a plate width representation into signal Wp which is inverted in an amplifier **232.** The term Wp − 30 is produced by an inverting summing amplifier **233** which receives a representation of the 30-inch constant from potentiometer **234** and this is applied to a multiplier **236** which receives a signal representing K80*MGb to produce a representation of spring constant MCp. In generator **220,** K80′ is provided by a potentiometer **222** and a representation of Wp^2 is produced by multiplier **221** with a signal representing MCb being produced by a multiplier **223.** The analog arrangement of FIG. **5** may be replaced with a suitable digital equivalent.

Referring now to FIG. **6,** it will be noted that signals representating total rolling force (Pt), total bending force (Bt), spring constants MCb and MCp and representations of the desired crown (C) and roll crown (Cr) are applied to crown error generator **250** which produces the crown error signals Ce according to the following equation:

$$Ce = C + Cr + Bt*MCb - Pt*MCp.$$

The manner in which this equation may be solved with either an analog or a digital circuit or may be programmed in a general purpose computer will be apparent to those skilled in the art. The equation for crown error then takes into consideration all of the factors previously considered with automatic adjustment being made to compensate for changes in plate width or roll diameter. Signal Ce is then applied to a suitable dead-band circuit **260,** the output of which is applied to a proportional integrator **270** which produces signal Bref. The dead band may be omitted in some cases depending on the mill characteristics. The total rolling force signal Pt is also applied to a limiter **280,** the function of which is to limit the signal Bref to 5.6×10^6 pounds of bending force representation if force Pt represents a force less than or equal to 14.4×10^6 pounds. When force Pt exceeds 14.4×10^6 pounds, the limit is reduced to keep the total maximum force on any of the roll bearings to 20×10^6 pounds. These numbers change for different mills. The function of circuits **260, 270** and **280** may be obtained through conventional analog circuits or may be programmed in a digital computer.

Signal Bref is then used in the circuit of FIG. 7 to develop the drive side and operator side bending reference signals where provision is made through the use of potentiometer **294** and **295** to adjust the references to center of offset the crown as desired. Signal BEdr is produced by a summing amplifier **293** which receives an inversion of signal Bdrd provided by a scaling amplifier **291** and signal Bdrt produced by a sealing amplifier **292.** A similar function is performed in summing amplifier **296** which receives an inversion of signal Bopb through an amplifier **297** and inversion of signal Bopt through an inverting amplifier **298. 110**-Dr and **110**-Op regulate the oil flow to the bending cylinders so that BEdr and BEop become zero.

From the foregoing description, it should now be apparent that the present invention provides a system for automatically controlling crown to produce the desired crown considering all of the factors which are necessary.

We claim as our invention:

1. In a rolling mill where the gauge and crown of plate is controlled, the gauge control providing a measured rolling force signal, the combination comprising: first means for measuring roll bending forces and producing corresponding bending force signals; and second means responsive to input signals representing desired crown, roll crown, plate width, and roll diameter and to said rolling force and bending force signals, said second means including roll force and bending force spring constant generators responsive to representations of plate width and roll diameter for producing corresponding roll force and bending force spring constant signals, and further including an error signal generator responsive to said desired crown and roll crown input representations, and to said spring constant signals and said rolling force and bending force signals, for producing an error signal representing the change in bending force required to produce plate having the desired crown.

2. The combination of claim **1** wherein said error signal is proportionally integrated to produce a bending force reference signal corresponding to the bending force required to obtain the desired crown.

3. The combination of claim **2** wherein a bending force limiter is included responsive to a representation of total rolling force for limiting said bending force reference signal to prevent the total of rolling force and bending force from exceeding a predetermined limit.

4. The combination of claim **1** wherein said second means includes means for producing a roll diameter adjustment factor signal which is used in the means producing said spring constant signals to adjust said signals for changes in roll diameter.

5. The method of controlling bending forces in a rolling mill to obtain a desired plate crown comprising the steps: translating plate width and roll diameter input signals into roll force and bending force spring constant signals; generating an error signal as the function of desired crown and roll crown input signals and the product of rolling force times the roll force spring constant signal plus bending force times the bending force spring constant signal to produce a bending force reference signal.

6. The method of claim **5** wherein both of said spring constant signals are produced as functions of a signal representing a roll diameter adjustment factor.

7. The method of claim 6 wherein said roll force spring constant signal is generated as a function of said roll diameter adjustment factor signal and a signal representing the width of strip to be rolled.

8. The method of claim 6 wherein said bending force spring constant signal is generated as a function of said roll diameter adjustment factor signal and the square of a signal representing the width of strip to be rolled.

* * * * *