United States Patent

[11] 3,568,637

[72] Inventor Andrew W. Smith, Jr.,
Mount Lebanon, Pittsburgh, Pa.
[21] Appl. No. 728,469
[22] Filed May 13, 1968
[45] Patented Mar. 9, 1971
[73] Assignee Westinghouse Electric Corporation
Pittsburgh, Pa.

[54] **TANDEM MILL FORCE FEED FORWARD ADAPTIVE SYSTEM**
18 Claims, 4 Drawing Figs.

[52] **U.S. Cl.** **72/8,** 72/16, 72/19
[51] **Int. Cl.** **B21b 37/02,** B21b 37/12
[50] **Field of Search** 72/7, 8, 16

[56] **References Cited**
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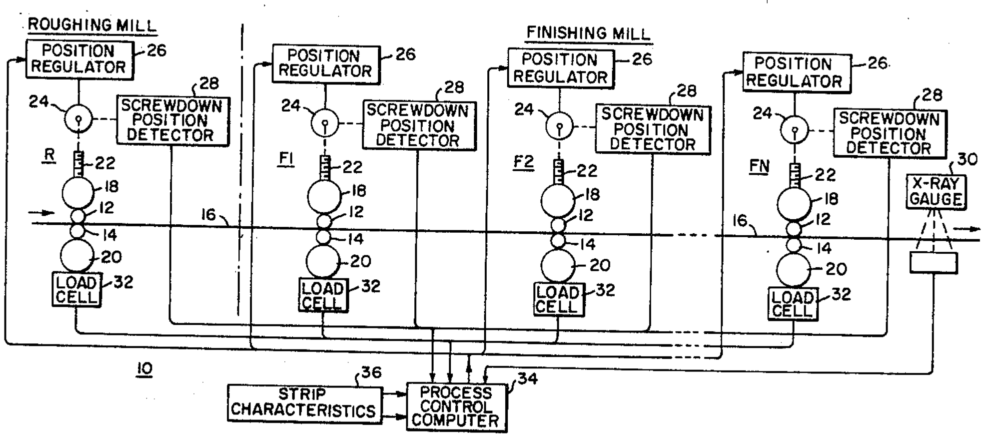
Primary Examiner—Milton S. Mehr
Attorneys—F. H. Henson and R. G. Brodahl

ABSTRACT: A feed forward screwdown control system is provided for use in a computer-controlled rolling mill to improve mill setup for subsequent workpieces as well as for the piece being rolled. Ratio comparisons are made between the measured force and the predicted force in each stand while a piece is being rolled which together with the ratios determined from the previous rolled workpiece will provide information for causing an on-gauge product for the present workpiece.



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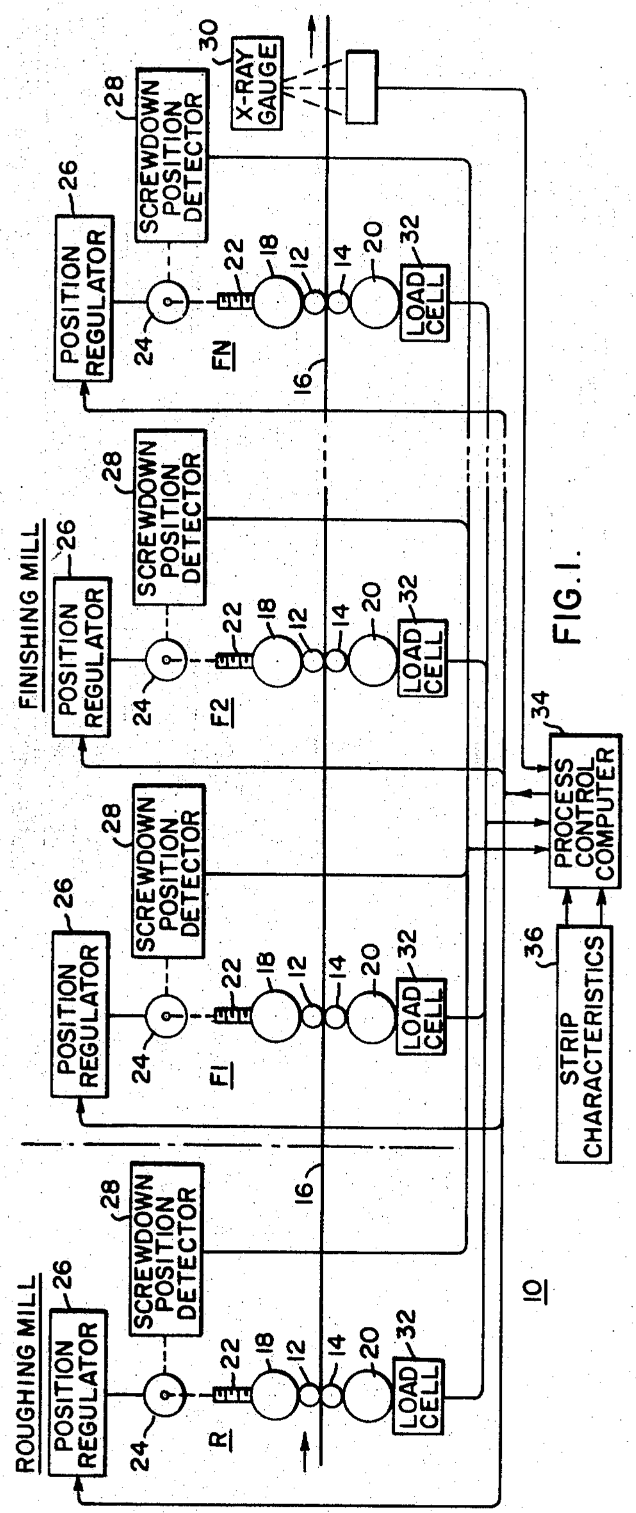

FIG. 1.

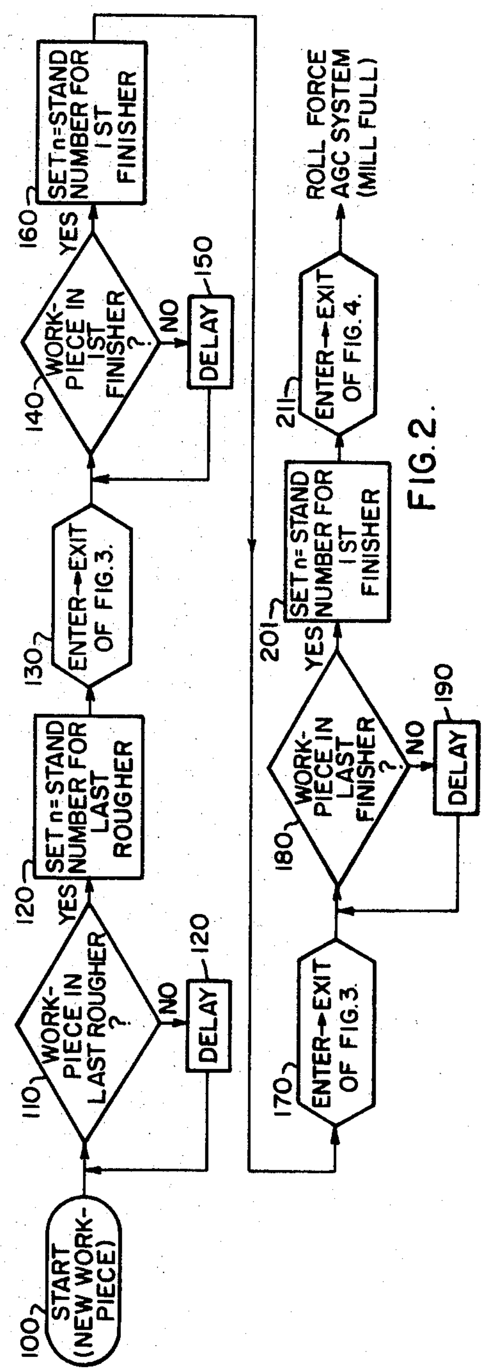

FIG. 2.

WITNESSES:

Bernard R. Gieguay

James T. Young

INVENTOR

Andrew W. Smith, Jr.

BY M.S. Brodahl

ATTORNEY

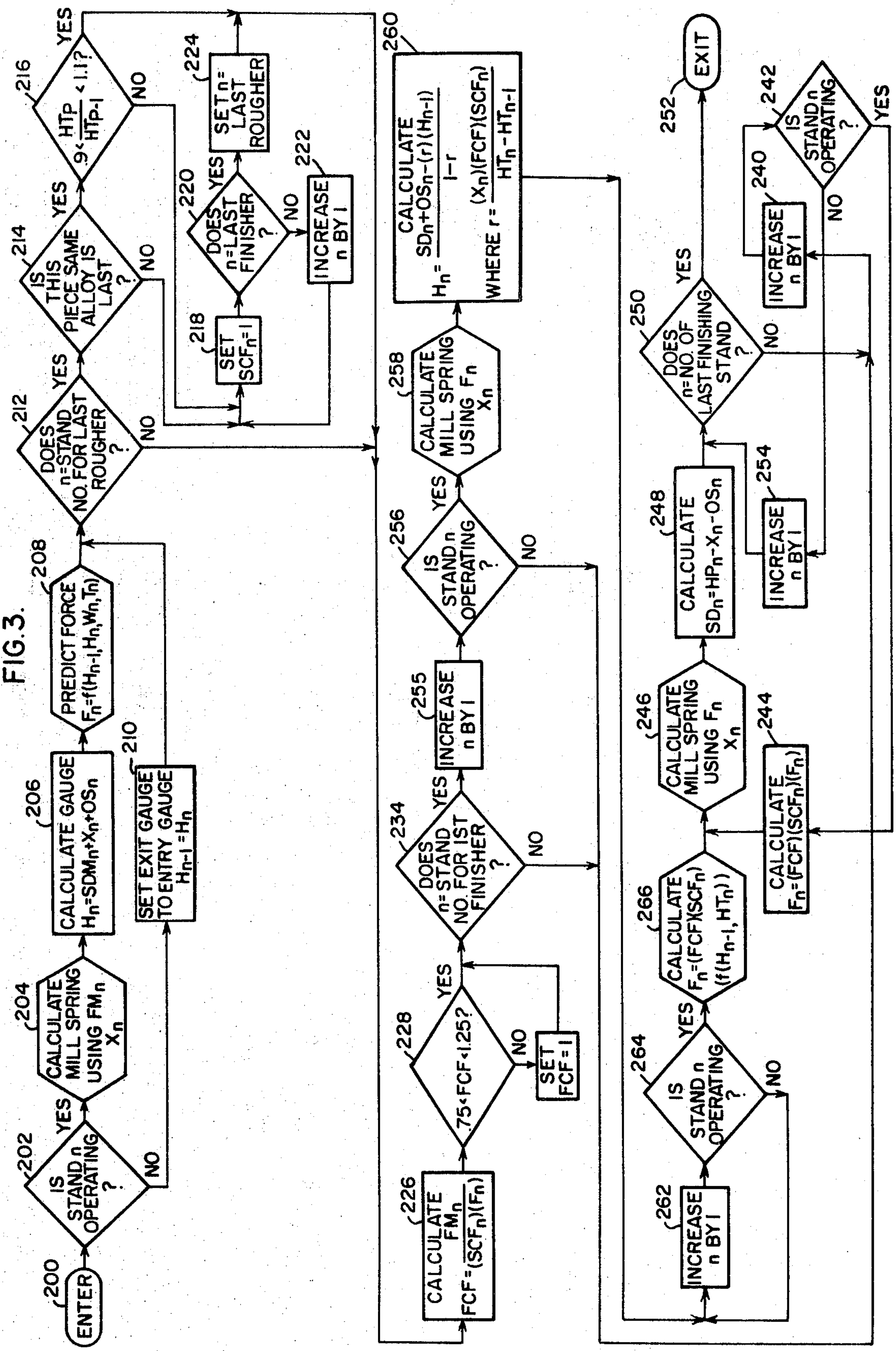
200 ENTER
202 IS STAND n OPERATING ?
YES
NO
204 CALCULATE MILL SPRING USING FMn Xn
206 CALCULATE GAUGE Hn=SDMn+Xn+OSn
208 PREDICT FORCE Fn=f(Hn-1,Hn,Wn,Tn)
210 SET EXIT GAUGE TO ENTRY GAUGE Hn-1=Hn
212 DOES n=STAND NO. FOR LAST ROUGHER ?
214 IS THIS PIECE SAME ALLOY IS LAST ?
216 .9<HTP/HTP-1<1.1?
218 SET SCFn=1
220 DOES n=LAST FINISHER ?
222 INCREASE n BY 1
224 SET n= LAST ROUGHER
226 CALCULATE FMn FCF=(SCFn)(Fn)
228 .75<FCF<1.25?
SET FCF=1
234 DOES n=STAND NO. FOR 1ST FINISHER ?
255 INCREASE n BY 1
256 IS STAND n OPERATING ?
258 CALCULATE MILL SPRING USING Fn Xn
260 CALCULATE Hn= (SDn+OSn-(r)(Hn-1))/(1-r) WHERE r = ((Xn)(FCF)(SCFn))/(HTn-HTn-1)
262 INCREASE n BY 1
264 IS STAND n OPERATING ?
266 CALCULATE Fn=(FCF)(SCFn)(f(Hn-1, HTn))
244 CALCULATE Fn=(FCF)(SCFn)(Fn)
246 CALCULATE MILL SPRING USING Fn Xn
248 CALCULATE SDn=HPn-Xn-OSn
254 INCREASE n BY 1
250 DOES n=NO. OF LAST FINISHING STAND ?
240 INCREASE n BY 1
242 IS STAND n OPERATING ?
252 EXIT

FIG. 3.

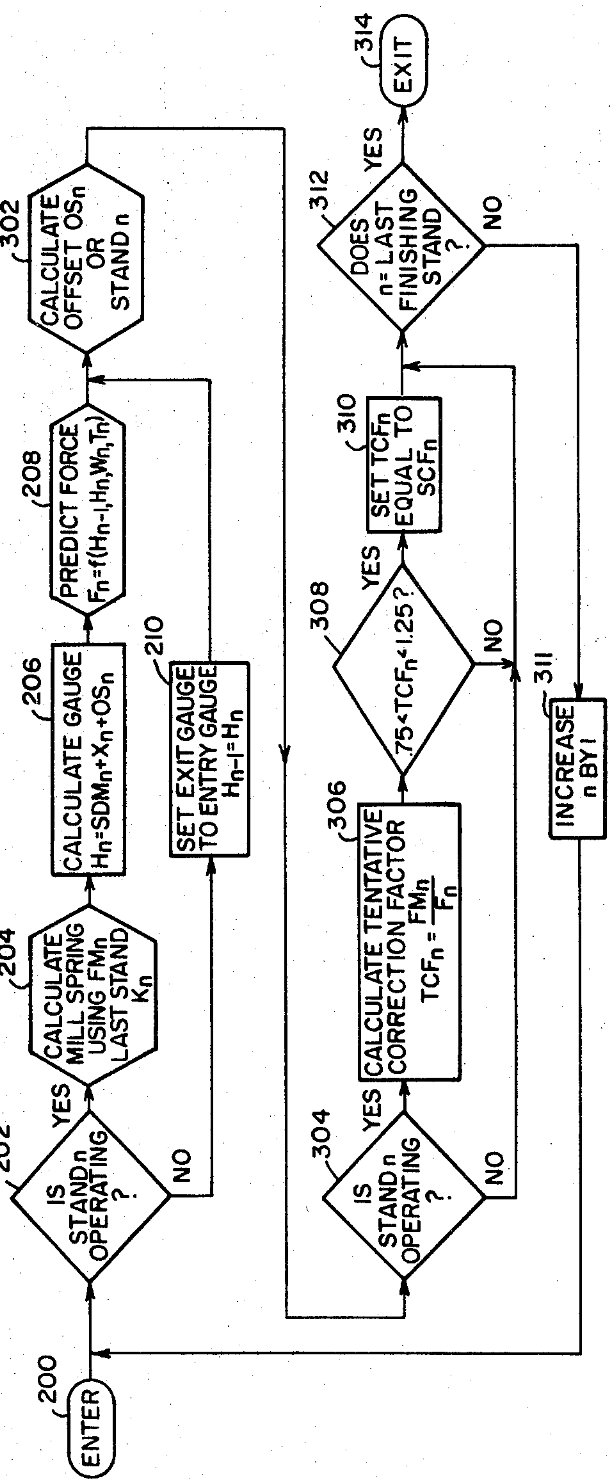
200
ENTER
202
IS STAND n OPERATING ?
YES
NO
204
CALCULATE MILL SPRING USING FMn LAST STAND Kn
206
CALCULATE GAUGE Hn=SDMn+Xn+OSn
208
PREDICT FORCE Fn=f(Hn-1,Hn,Wn,Tn)
210
SET EXIT GAUGE TO ENTRY GAUGE Hn-1=Hn
302
CALCULATE OFFSET OSn OR STAND n
304
IS STAND n OPERATING ?
YES
NO
306
CALCULATE TENTATIVE CORRECTION FACTOR TCFn = FMn / Fn
308
.75<TCFn<1.25 ?
YES
NO
310
SET TCFn EQUAL TO SCFn
311
INCREASE n BY 1
312
DOES n= LAST FINISHING STAND ?
YES
NO
314
EXIT

FIG. 4.

TANDEM MILL FORCE FEED FORWARD ADAPTIVE SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates to rolling mills and, more particularly, to provision of improved setup conditions based on workpiece history in cooperation with an online monitoring of predetermined mill parameters.

In the operation of a metal reversing or tandem rolling mill, both the unloaded roll opening and the speed for each tandem mill speed are set up either by an operator or by a computer to provide successive workpiece (strip or plate) reduction resulting in an on-gauge finished work product. It may be assumed that the loaded roll opening at a stand equals the stand delivery gauge since there is little or no elastic workpiece recovery.

Because the setup conditions may be in error and, in any event, since certain mill parameters affect the stand loaded roll opening during rolling and after setup conditions have been established, a stand gauge control system must be employed to closely control the stand delivery gauge. Thus, at the present state of the rolling mill art, a stand gauge control system is normally used for a reversing mill stand and for predetermined stands in tandem rolling mills.

Recent experience in tandem hot strip rolling mills and reversing plate mills has demonstrated that a roll force gauge control system is particularly effective. Briefly, the roll force gauge control system uses Hooke's law in controlling the screwdown position at a rolling stand, i.e., the loaded roll opening under rolling conditions equals the unloaded roll opening (screwdown position) plus the mill spring stretch caused by a separating force supplied to the rolls by the workpiece. To embody this rolling principle in the roll force gauge control system, a load call or other force detector measures the roll separating force. The screwdown position is then controlled to balance the roll force changes from a reference or setpoint value and thereby hold the loaded roll opening at a substantially constant value. Once the unloaded opening and the stand speed setup are determined by either the mill operator or the mill computer for a particular workpiece pass or series of passes, the rolling operation is begun; the screwdowns are then controlled to regulate the workpiece delivery gauge from the reversing mill stand or from each roll force control tandem mill stand. For a more detailed discussion of an automatic roll force gauge control system, reference is made to copending patent application filed Nov. 29, 1967, Ser. No. 686,783 entitled "compatible Roll Force Gauge Control Method and Apparatus for Metal Rolling Mills" by Calvin W. Eggers and John Csonka and assigned to the same assignee as the present invention. The application of the principles of the above-cited reference serve to maintain an on-gauge work produce once the mills is full, i.e., the workpiece is present in all stands. However, to further optimize the operation of the above system, it is highly desirable to provide setup conditions which, in addition to providing an on-gauge rolling of the head end of the workpiece strip, also establish mill operating conditions which are compatible with the takeover of the automatic roll force gauge control system once the mill becomes full. Moreover, it is intended that gauge regulation for the head end of a workpiece strip be controlled and monitored without provision of additional apparatus than would otherwise be required in a roll force gauge control system.

Previously, mill setup parameters have been set either by the operator or by a computer. But, as the rolling mill parameters have increased both in number and complexity, the computer has played the dominant role in determining mill setup with the operator serving as backup. The credibility of the computer has been established by causing it to monitor certain inputs according to a predetermined model and then, through functional relationships between these inputs, to provide proper operating conditions. As each workpiece is rolled, information is gathered from the various inputs which serve to improve the setup conditions for the rolling of the next workpiece. Such a system has proved satisfactory in that, even if the original setup conditions are poor, eventually the system will adapt to a proper setup by learning from the rolling of each previous workpiece. It should be noted, however, that the rolling of a workpiece is inherently dependent on information gained from previous rollings and that any error in conditions for that particular piece would go uncorrected for that particular piece.

SUMMARY OF THE INVENTION

It is, therefore, a general object of the present invention to provide a new and improved head-end gauge control system for rolling the head end of workpieces in a continuous strip rolling mill.

A further object of the present invention is to provide a new and improved head-end gauge control system wherein changes in the setup conditions for the workpiece being rolled may occur from information received from the last rougher and first finishing stand of the rolling mill.

An additional object of the present invention is to provide a new and improved head-end gauge control system wherein ratios between predicted and actual force are made at the last roughing stands and at the finishing stands to provide setup information for rolling of the next workpiece.

A still further object of the present invention is to provide a new and improved head-end gauge control system whereby subsequent stands are responsive to feed forward information for providing an on-gauge workpiece strip.

Yet a further object of the present invention is to provide a new and improved head-end gauge control system which is compatible with apparatus required in a conventional computer-controlled roll force gauge control system.

In accordance with the general principles of the present invention, a tandem strip rolling mill is under the control of a process computer for providing an on-gauge workpiece strip. During the rolling of the head end of a workpiece, a force feed forward system is operating whereby the pattern for the head end is held in storage whereby the pattern for the head end is held in storage as it is rolled to the last roughing stand and then the finishing stands. Measurements are then made on the head end of the next piece to determine whether the general force level will be higher or lower and corrections are made in the later stand screwdown references to compensate for the predicted change in roll separating force. The target thickness to be delivered from each stand is maintained the same as determined from the original schedule calculation so no change is required in the speed of the stands.

These and other objects of the present invention will become more apparent upon consideration of the following detailed description along with the attached drawings.

DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a schematic diagram of the last stand of a roughing mill and a portion of the finishing mill in a tandem hot steel strip rolling mill illustrating the inputs and outputs requisite to the head-end gauge control system which is the subject of this invention.

FIG. 2 represents the system operation for the rolling of a new workpiece from the time it enters the last rougher until the entire mill is full.

FIGS. 3 and 4 set forth the system operation in accordance with the head end of the workpiece entering certain predetermined stands within the rolling mill.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, a portion of a continuous strip rolling mill is shown and designated generally by the numeral 10. The last stand of the roughing mill is shown by the symbol R followed by the first two and the last stands of a finishing line designated respectively by the symbols F1, F2 and FN Each of the rolling stands includes a pair of work rolls 12 and 14. These work rolls are caused to provide a strip reduction as the workpiece 16 passes successively through each of the several stands. A set of backup rolls 18 and 20 provides pressure on the work rolls 12 and 14 in response to the operation of a screwdown 22. The regulation of the applied pressure is through a screwdown motor 24 whose operation is controlled by a position regulator 26. Screwdown position detectors 28 monitor the position of the screwdowns 22 by detecting the number of revolutions of the screwdown motors 24 and transmitting an output signal representative thereof. Following the last stand FN in the finishing mill, an X-ray gauge 30 is so positioned to detect the actual finished gauge of the workpiece and to provide a signal proportional thereto. Associated with each of the respective rolling stands is a load cell 32 which measures the separating roll force at each of the respective stands.

Control of the rolling process is provided by a process control computer 34 which provides communication between the rolling mill inputs and outputs in a predetermined manner. The exact mode of control is provided by an externally provided program which functionally relates an input or combination of inputs to provide controlled output signals which are commensurate with an on-gauge workpiece strip. The functional relationship between and among certain inputs as seems to exist within the process computer 34 will be discussed in detail herein. Other apparatus and structure necessary for the proper operation of a rolling mill is purposely left out for ease of illustration and would necessarily include such items as drive motors, potentiometers, speed controllers, temperature sensors etc.

Accurate online gauge control and regulation of the workpiece head end is achieved by the provision of reference signals from the process control computer 34 to the respective position regulators 26 corresponding to all the finishing stands when the workpiece is being measured in the last rougher and the third to last finishing stands when the workpiece is being measured in the first finishing stand. The reference signals are developed through a mathematical model provided in the process control computer 34 which is responsive to the analogue signals resulting from the respective load cells 32, the screwdown position detectors 28, and the X-ray gauge 30 as well as digital inputs pertaining to the strip characteristic shown in block 36 to effect adequate gauge control on the workpiece 16 until the mill becomes full. Once this condition has occurred the process control computer 34 is then free to provide control under a gauge control system as previously referenced in above-referenced Eggers et al. copending patent application. It is only upon the beginning of the rolling of another workpiece that the head-end gauge control system is again activated to provide proper on-gauge strip until the mill is once again full. The digital inputs relating to the strip characteristics in block 36 contains such items as strip width, desired or target gauge, and the type of strip alloy.

Online updating of the screwdown reference signals which are fed to the position regulators 26 is accomplished both when the workpiece enters the last rougher and when the workpiece enters the first finisher. Thus the screwdown for all of the succeeding stands are updated twice in a online fashion within the rolling cycle of the workpiece presently in the rolling mill. Then, once the workpiece has traversed to the last stand in the finishing mill, the screwdown reference signals are again updated to reflect the difference between the predicted and actual gauge of the workpiece at the point where gauge regulation of the head-end finishes and the gauge control program for the mill once full takes over.

Referring now to FIG. 2 a flow chart illustrating the timing sequence of the head-end gauge control system is illustrated. System operation is initiated at the start block 100 at some time as the workpiece is progressing through the roughing mill. As the workpiece is being successively reduced in the roughing mill, the last rougher is interrogated in block 110 to see if the workpiece has entered the rougher R. If not a finite delay period is initiated in block 120 whereupon a return is then made to block 110 to again interrogate to see if the workpiece has now entered the last rougher. Once the workpiece 16 has reached the last rougher stand R of FIG. 1 and is detected by a separating force which acts against the corresponding load cell 32 to provide a signal to the process control computer, a counter in the process control computer 34 which represents the stand number is set in block 120 to the stand number corresponding to the last rougher R whereupon the system then progresses to that part of the gauge control system corresponding to updating of the screwdown references while in the last roughing stand. This function is illustrated in block 130 by referring to the routine as shown in FIG. 3 progressing from the enter block proceeding through the exit block and then returning to block 140 which then interrogates the first finishing stand F1 to determine whether the workpiece has entered. If not, a finite delay is initiated in block 150 following which return is made to block 140 for a further interrogation of the first finishing stand F1. When the workpiece is detected in the first finisher, the stand counter in the process control computer 34 is then set to the stand number for the first finisher in block 160 as a prelude to again traversing through the system of FIG. 3 as shown in block 170 which provides updating of the screwdown following the entry of the workpiece into the first finishing stand F1.

Following the adjustments or updating of the screwdown references after the workpiece has entered the first finishing stand 2 it is then necessary to determine when the workpiece has entered the last finisher as shown in block 180. If the workpiece has yet to enter the last finishing stand FN, a finite delay system is set up in block 190 which then returns to block 180 for further interrogation. Once the workpiece has been detected, the stand counter n is then set in block 201 to the stand number for the first finishing stand for a final updating in block 211 by referring to the routine as set forth in FIG. 4 which is the final updating procedure for the screwdowns and provides the setup references for the next workpiece to be rolled. Once the workpiece has traversed through the last finishing stand, the mill is then considered full and control is then transferred to some roll force automatic gauge control system such as that previously mentioned in the above-referenced Eggers et al. copending patent application.

FIG. 3 illustrates the operation of the head-end gauge control system at such times when the workpiece has either entered the last rougher stand R or the first finisher stand F1. As previously mentioned this occurs at the blocks 130 and 170 of FIG. 2. The first block of FIG. 3 is block 200 which is the entry point to this segment of head-end gauge control system. At this time the stand counter is set to the proper stand number. In block 202 the stand is interrogated to see if it is actually producing a reduction in the strip gauge or on the other hand if it is merely providing a dummy operation. Providing that the stand n is operating properly, in block 204 the mill spring is calculated using the measured force FMn as determined from the load cell 32 corresponding to the stand number in the counter n. The mill spring Xn is equal to the negative of the fraction F_n /K where F_n is the measured force and K is equal to the mill spring constant for that particular stand. A more complete description and discussion of the mill stretch is to be found in the previously referenced Eggers et al. patent application. A previously determined screwdown offset OS_n which acts as a correction factor to steady state gauge errors is then added to the just-calculated mill spring X_n and the screwdown position SDM_n as determined by the screwdown position detector 28 of FIG. 1 to provide a calculated gauge H_n which corresponds to the actual thickness or the workpiece delivery gauge of the stand n. This calculation is represented by the block 206. Block 208 then predicts a force F_n corresponding to the stand n as a function of the entry gauge H_{n-1} the delivery gauge H_n the width of the strip W_n and the strip temperature T_n. Had the stand n been inoperable as determined in block 202 the exit gauge would then have been set equal to the entry gauge as shown in block 210. Blocks 202 through 210 are initiated each time that data has been collected on the head end of the workpiece in either the last rougher stand R or the first finishing stand F1. In this procedure, any difference between the measured roll force and screwdown setting and the predicted roll force and screwdown setting will cause a difference between the actual gauge delivered from the stand and the desired gauge. Blocks 202 through 210 calculate the actual gauge delivered from the particular stand and repredict the roll separating force for the actual draft taken in that stand. Once the predicted force F_n has been predicted, interrogation is made in block 212 to determine whether the stand counter is set for the last rougher stand or the first finishing stand. Providing that the stand number n is equal to that of the last rougher, interrogation is made in block 214 to determine whether the piece now being rolled is of the same alloy content as the previous piece. Providing the workpiece has the same alloy content, a check is made in block 216 to determine whether the ratio of the final target gauge HT_p for the previous piece to the final target gauge HT_{p-1} of the previous piece is within 10 percent. If the limit check in block 216 is satisfied, the procedure then follows to block 226 for a calculation of force correction factor. Referring now to block 214, if the present piece being rolled is a different alloy from that of the last piece, the stand correction factor $SCFn$ is set equal to 1 for all stands. The same procedure is followed if the limit condition suggested in block 216 is not satisfied.

Since the stand counter n is now equal to that of the first rougher, the action of block 218 serves to set the stand correction factor for the last rougher equal to 1 . In block 220 the stand counter is interrogated to see if it is presently equal to the stand number of the last finisher and if not the stand number n is increased by 1 in block 222 and return is then made to block 218 which then sets the current stand correction factor equal to 1 . This same process continues until the last finisher is detected in block 220 whereupon the stand number is again set to its initial position as that of the last rougher in block 224. Thus, it is seen that if the present workpiece being rolled is different in alloy or even having the same alloy is significantly different in desired target gauge the stand correction factor for all the finishing stands are reset to 1 and are not dependent on any past history.

Once a current set of stand correction factors corresponding to each of the finishing stands has been developed, it is now possible to compute a force correction factor FCF which is equal to the fraction $(FM_n)/SCFn)$ (F_n). If the force correction factor is within 25 percent as determined in block 228 the procedure is then continued in block 234. However, should the force correction factor be outside the 25 percent limit, it is set equal to 1 in block 232 before preceeding to the next sequential block 234. Assuming that the stand counter n is equal to the stand number for the last rougher as determined in block 234 the stand counter would be increased by 1 in block 240 and now be equal to the stand number for the first finisher. If this stand is operating and not dummied as determined in block 242, the force F_n is then repredicted in block 244 using the force correction factor FCF calculated from the last rougher the stand correction factor SCF determined from the previous piece rolled and the last predicted force F_n. Then, with the force repredicted for stand n the mill spring for stand n is then recalculated using this predicted force in block 246. A new and updated screwdown is then determined in block 248 by subtracting from the predicted gauge HP_n the mill spring X_n as a function of the predicted force F_n and the previously determined offset factor OS_n. This screwdown reference is then representative of the reference signal which should then be provided to the position regulator 26 for the first finishing stand F1 of FIG. 1. In block 250 the stand number n is then interrogated to determine whether it is at that of the last finish stand FN and if so, the procedure is completed at block 252. However, in this case since n is only equal to the of the first finishing stand the stand number is increased by 1 in block 240 and a determination as to whether the second finishing stand is operating as made in block 242. It necessarily follows that for each stand operating, a new screwdown reference signal SD_n will be provided for each of the remaining finishing stands in the mill. For any finishing stand that is inoperable as determined in block 242 the stand number is increased by 1 in block 254 and no updated screwdown reference is calculated for that inoperative stand.

Now referring to FIG. 2, block 170 again calls for the return to the system procedure of FIG. 3 with the only difference being that the stand number n is now equal to that of the first finishing stand F1. The same procedure beginning at block 200 is followed as when n was equal to the stand number of the last rougher except that beginning in block 212, if the stand number is equal to that of the first finisher the procedure immediately skips to block 226 for calculation of a force correction factor without providing any recomputation of the stand correction factor. Thus it is apparent that for all future computations the stand correction factor SCF_n will remain as calculated previously from the system sequence when the mill was full on the previous piece. A second variance in the procedure occurs following the computation of the force correction factor whereupon in block 234 n is now equal to the stand number for the first finisher and proceeds to block 255 which increases the stand number by 1 and is thus now equal to that of the second finishing stand F2. If the second finishing stand is not in operation as determined in block 256 the procedure advances immediately to block 240 where new roll force and screwdown setting are determined for the remaining finishing stands as previously described. If, however, the second finishing stand is in operation as determined in block 256 the mill spring is again recalculated in block 258 using the predicted force F_n. Then, in block 260 gauge thickness H_n is predicted out of the next stand using the unadjusted screw setting. This is done because there is not sufficient time to be sure that the second stand would be reset to a new value before the strip enters the rolls. The computation involved is set forth in detail in block 260 wherein HT_n equals the target exit gauge from the present stand and HT_{n-1} equals the target entry gauge at the present stand. The stand number is again increased by 1 in block 262 and a check is made in block 264 to see if this new stand is operating. If the stand is inoperable, the stand number is again increased and interrogated until some stand number is found to be operating. Having found an operable stand, in block 266 a roll force F_n is predicted using the predicted entry H_{n-1} and the target exit gauge HT_n the force correction factor FCF and the stand correction factor SCF_n. Once a new predicted force has been computed the procedure proceeds to block 246 and continues as previously described for the last roughing stand.

Again referring to FIG. 2, block 211 makes reference to the system procedure of FIG. 4 when the stand number has been set to that for the first finishing stand F1. It should be noted that in FIG. 4 blocks 200 through 210 are exactly equivalent to that of FIG. 3 and serve to predict a force for that particular stand n . In block 302 an offset factor OS_n is calculated for stand n which corresponds to a correction factor for offsetting the setting gauge error. Once the offset OS_n is computed, stand n is then interrogated in block 304 to see if it is operating. If not, no new stand correction factor is provided and in block 312 interrogation is made as to whether n is equal to the number of the last finishing stand. If not in block 311 the stand number is increased by 1 and the entire procedure is repeated beginning at block 202 until a new predicted force F_n and a stand correction factor SCF_n is computed for all the finishing stands. On the other hand, providing that the stand n was in operation as determined in block 304 a temporary correction factor is computed according to the relationship block 306. This temporary correction factor TCF_n is then checked to be within a 25 percent limit in block 308 and if so, in block 310 the temporary correction factor is then set equal to the new stand correction factor SCF_n. If the temporary correction factor TCF_n is without the predetermined limits as determined in block 308, the procedure immediately proceeds to block 312 which then proceeds to the next finishing stand leaving the previous stand correction factor unaltered. Once the last stand has received a new stand correction factor as determined in block **312**, the procedure is finished in block **314** and returned to begin the roll force AGC system as seen in FIG. **2**.

It should be noted that the calculations for offset in block **30** of FIG. **4** may either be calculated at this time or as a part of the roll force AGC system itself once the mill is full. A more complete and detailed description of providing an accurate offset is set forth in copending patent application Ser. No. 677,308 filed Oct. 23 1967 and entitled "Screwdown Offset System and Method for Improved Gauge Control" by Andrew W. Smith, Jr., and assigned to the same assignee as the present invention.

In summary this invention provides a system and method of making force measurement in all of these stands in a rolling mill as a piece is being rolled. Ratio comparisons are made between the measured force in each stand and predicted force and these ratios are then used to better predict forces for the rolling of the next workpiece. In addition, the measured force in an early stand as the next piece is being rolled is compared with the predicted force and this ratio along with the ratios calculated for each stand while rolling the previous piece are used to better predict the force roll opening to thus obtain a good mill setup and produce a proper on-gauge finish workpiece.

Since additional changes not herein specifically referred to may be made in the above-described system such as increasing or decreasing the limit checks, and different embodiments of the invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawing shall be interpreted as illustrative only and not in a limiting sense.

I claim:

1. A gauge control system for a rolling mill having at least one roll stand with a screwdown-controlled roll opening through which a first pass of a present workpiece is transported, said system comprising:

means for detecting the actual roll force at said one roll stand during said first pass;

means for determining the delivery work piece gauge leaving said roll stand after said first pass;

means for determining a predicted roll force for said first pass in relation to said delivery workpiece gauge;

means for determining a correction factor for a second pass of said present workpiece through a roll stand in accordance with a ratio of said actual roll force to said predicted roll force;

means for determining a screwdown setting in accordance with said correction factor for said second pass through a roll stand of said rolling mill; and

means for controlling the screwdown movement for said second pass in accordance with said screwdown setting to effect a desired reduction in the gauge of said present workpiece.

2. The gauge control system as set forth in claim **11**, wherein said system includes:

recording means for retaining the detected actual roll force at a roll stand during said first pass;

means for determining the delivery workpiece gauge for each pass of the workpiece through a roll stand of said rolling mill; and

means for determining if said present workpiece is different from a previous workpiece in relation to one of the alloy and the target gauge of said present workpiece for providing a unity stand correction factor when such a difference is determined.

3. The gauge control system as set forth in claim **1**, wherein said gauge control system is operative during the rolling of the head end of said present workpiece.

4. The gauge control system as set forth in claim **1**, including means for determining a respective stand correction factor for each of said roll stands in accordance with the equation

$$SCF_n=\frac{FM_n}{F_n}$$

where SCF_n is the determined stand correction factor for stand n, FM_n is the measured force relative to a present work piece passing through stand n and F_n is the predicted force for stand n in accordance with the actual reduction in the gauge of the present workpiece made by stand n and wherein said stand correction factor SCF_n is used to determine the respective stand n screwdown movement relative to a subsequent workpiece similar to said present workpiece.

5. The gauge control system as set forth in claim **1**, including means for determining a correction factor according to the equation

$$FCF=\frac{FM}{(SCF)(F)}$$

where FCF is the determined force correction factor for subsequent passes of said present workpiece, FM is the measured roll force of said one roll stand during said first pass of the present workpiece through said stand SCF is the stand correction factor in relation to a previous similar workpiece for said one roll stand, and F is the predicted roll force for said one roll stand in accordance with the actual reduction made in the gauge of the present workpiece by said stand, and wherein said correction factor is used to determine the respective corrective screwdown movements for subsequent passes in relation to said present workpiece.

6. The gauge control system as set forth in claim **4**, including means for providing a unity stand correction factor SCF_n for stand n when said subsequent workpiece is one of a different alloy and a different target gauge in relation to said present workpiece.

7. The gauge control system as set forth in claim **1**, including means for providing a unity correction factor when said correction factor is outside predetermined limits.

8. A workpiece gauge control system for a rolling mill having at least one roll stand with a screwdown controlled roll opening and into which a workpiece is passed, said system comprising:

means for sensing the actual roll force at said one roll stand during a first pass of said workpiece through said one roll stand;

means for determining the actual reduction taken in the gauge of said workpiece during said first pass through said one roll stand;

means for determining a predicted roll force for said one roll stand in accordance with said actual reduction during said first pass;

means for determine a correction factor in accordance with a ratio of said actual roll force to said predicted roll force, and

means determining determining a screwdown movement at least a second pass of said workpiece through a roll stand of force; rolling mill, with the latter said means being responsive to said correction factor for determining the screwdown movement for at least said second pass.

9. The gauge control system as set forth in claim **8**, including screwdown controlling means to effect a corrective screwdown movement in accordance with said correction factor for at least a second pass of said workpiece through a roll stand during the rolling of the head end of said workpiece.

10. The gauge control system as set forth in claim **8** wherein said means for determining a predicted roll force includes a digital computer, said computer having an input coupled to said actual roll force sensing means and an output coupled to said means for determining a screwdown movement.

11. The gauge control system as set forth in claim **8**, with said means for determining a correction factor being operative according to the equation

$$FCF=\frac{FM}{(SCF)(F)},$$

where FCF is the determined correction factor, FM is the sensed roll force relative to a present workpiece for said one roll stand, SCF is the stand correction factor determined for a previous similar workpiece prior to said present workpiece being loaded into said one roll stand, and F is the predicted force relative to said first pass of the present workpiece through said one roll stand.

12. The gauge control system as set forth in claim 8 including means for providing a unity correction factor when said correction factor is beyond predetermined value limits.

13. In a workpiece thickness control system for a rolling mill having at least one roll stand with a controlled roll opening and into which a workpiece is passed, the combination of:

means for sensing the actual roll force of said one roll stand of said rolling mill during a first pass of said workpiece through said one roll stand;

means for determining the actual delivery thickness of said workpiece after said first pass;

means for determining a predicted roll force for said first pass in accordance with the actual delivery thickness of said workpiece after said first pass;

means for determining an operation correction factor in accordance with a ratio between said actual roll force during said first pass and said predicted roll force during said first pass; and

means responsive to said operation correction factor for determining the roll opening for a subsequent pass of said workpiece through a roll stand of said rolling mill.

14. The control system of claim 13, with said means for determining the roll opening of a roll stand being operative to effect a desired reduction in the thickness of the head end of said workpiece during said second pass.

15. In the method of controlling the operation of a rolling mill for reducing the thickness of a workpiece, said rolling mill including at least one roll stand having a roll opening established in advance of a first pass of said workpiece through said one roll stand of said rolling mill, the steps of:

sensing the actual roll force during said first pass of said workpiece through said one roll stand;

establishing the actual reduction made in the thickness of said workpiece during said first pass;

establishing a predicted roll force in accordance with the reduction made in the thickness of said workpiece during said first pass of the workpiece through said one roll stand;

establishing an operation correction factor in accordance with a ratio of said actual for roll force and said predicted roll force; and

establishing in accordance with said correction factor the roll opening of a roll stand of said rolling mill for a second pass of the workpiece through the latter roll stand.

16. The method of claim 15, operative with particularly the head end of said workpiece.

17. The method of claim 15 operative with a rolling mill having a plurality of stands, said method being operative with the head end of said workpiece and until said workpiece has entered all stands of said rolling mill.

18. The workpiece thickness control system of claim 13, including:

means for sensing the actual roll force of the last said roll stand during an earlier pass of a previous workpiece through the latter roll stand;

means for determining a predicted roll force for said earlier pass in accordance with the actual delivery thickness of said previous workpiece after said earlier pass;

means for determining a stand operation correction factor for the latter roll stand in accordance with a ratio between the earlier pass actual roll force and the earlier pass predicted roll force relative to said previous workpiece

with said means for determining the roll opening being responsive to said stand operation correction factor when determining the roll opening of the latter roll stand.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,568,637 Dated March 9, 1971

Inventor(s) Andrew W. Smith, Jr.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 3, "online" should be -- on-line --.
Column 1, line 35, "call" should be -- cell --.
Column 1, line 48, "compatible" should be -- Predictive --
Column 1, line 53, "produce" should be -- product --.
Column 1, line 53, "mills" should be -- mill --.
Column 2, lines 39 and 40, remove "whereby the pattern for the head end is held in storage".
Column 2, line 73, after "FN" provide a period.
Column 3, line 2, "backup" should be -- back-up --.
Column 3, line 30, "online" should be -- on-line --.
Column 3, line 46, "above-referenced" should be -- above referenced --.
Column 3, line 53, "on line" should be -- on-line --.
Column 3, line 57, "on line" should be -- on-line --.
Column 4, line 61, "just-calculated" should be -- just calculated --.
Column 4, line 62, after "Hn-1" provide a comma.
Column 4, line 63, after "Hn" provide a comma.
Column 5, line 43, "(FMn)/SCFn)(Fn)" should be -- (FMn)/(SCFn)(Fn) --.
Column 5, line 68, "the" should be -- that --.
Column 5, line 69, after "stand" provide a comma.
Column 6, line 42, after "HTn" provide a comma.
Column 7, line 3, "30" should be -- 302 --.
Column 7, line 8, before "filed" provide a comma.
Column 7, line 8, after "23" provide a comma.
Column 7, line 33, "screwdown-controlled" should be -- screwdown controlled --.
Column 7, line 53, "11" should be -- 1 --.
Column 7, line 73, after the equation provide a comma.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,568,637 Dated March 9, 1971

Inventor(s) Andrew W. Smith, Jr.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 8, line 5, after "n" provide a comma.
Column 8, line 13, after the equation provide a comma.
Column 8, line 18, after "stand" provide a comma.
Column 8, line 50, cancel "determining", first occurrence, and substitute -- for --.
Column 8, line 50, before "at" insert -- for --.
Column 8, line 52, cancel "force;" and substitute -- said
Column 10, line 31, after "piece" provide a semicolon.

Signed and sealed this 16th day of November 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Acting Commissioner of Pate

FORM PO-1050 (10-69)