

[54] ROLLING MILL CONTROL SYSTEM

3,296,513 1/1967 Morton.....72/10

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[22] Filed: Dec. 31, 1969

[21] Appl. No.: 889,665

[52] U.S. Cl.....72/12

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

[58] Field of Search.....72/8-12, 13

[56] References Cited

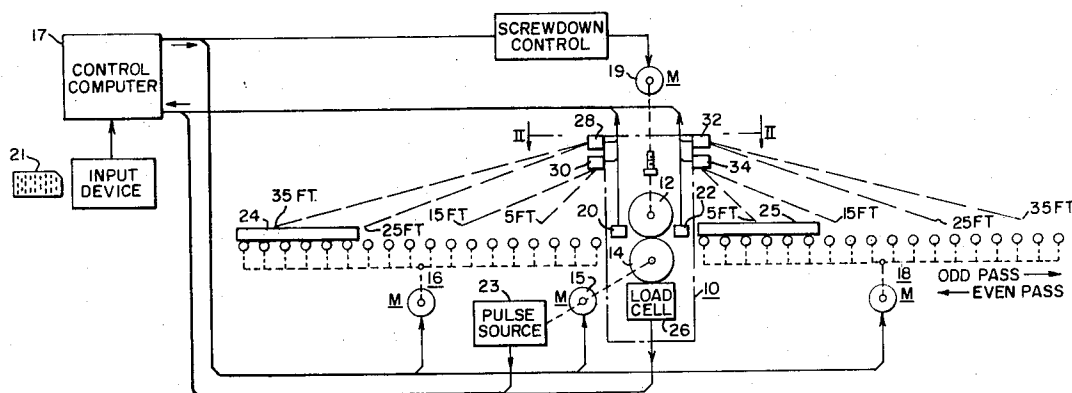
UNITED STATES PATENTS

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[57] ABSTRACT

A rolling mill stand, under particularly tandem workpiece rolling conditions where more than one workpiece passes through the stand for a given setting of that stand, is provided with a control system including a plurality of workpiece position sensors operative such that after a given workpiece has passed through the rolls of the mill stand the presence of any additional workpiece also desired to be passed through the stand with the same roll opening setting is sensed before the roll opening of the stand is changed to the next desired setting for any scheduled next workpiece passage through the stand.

6 Claims, 7 Drawing Figures



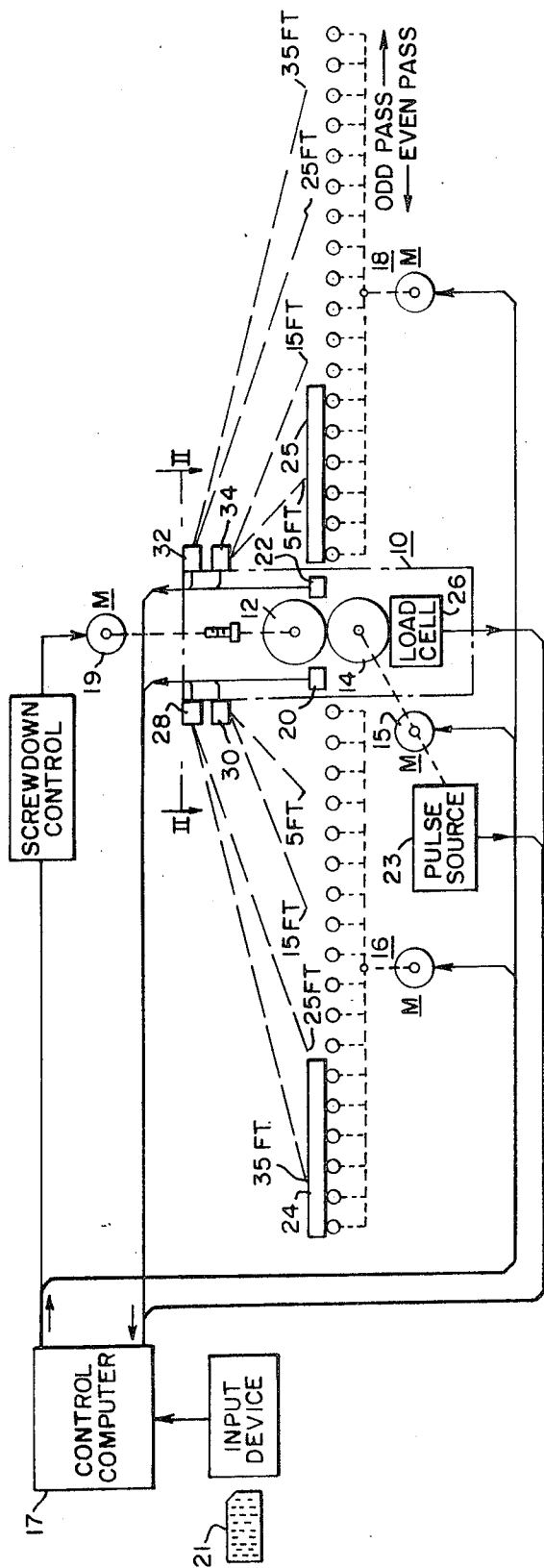


FIG. 1.

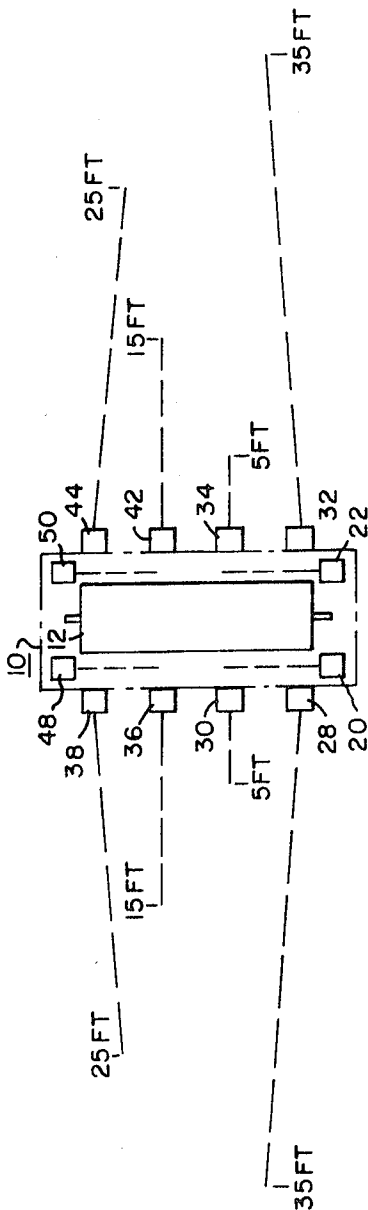


FIG. 2.

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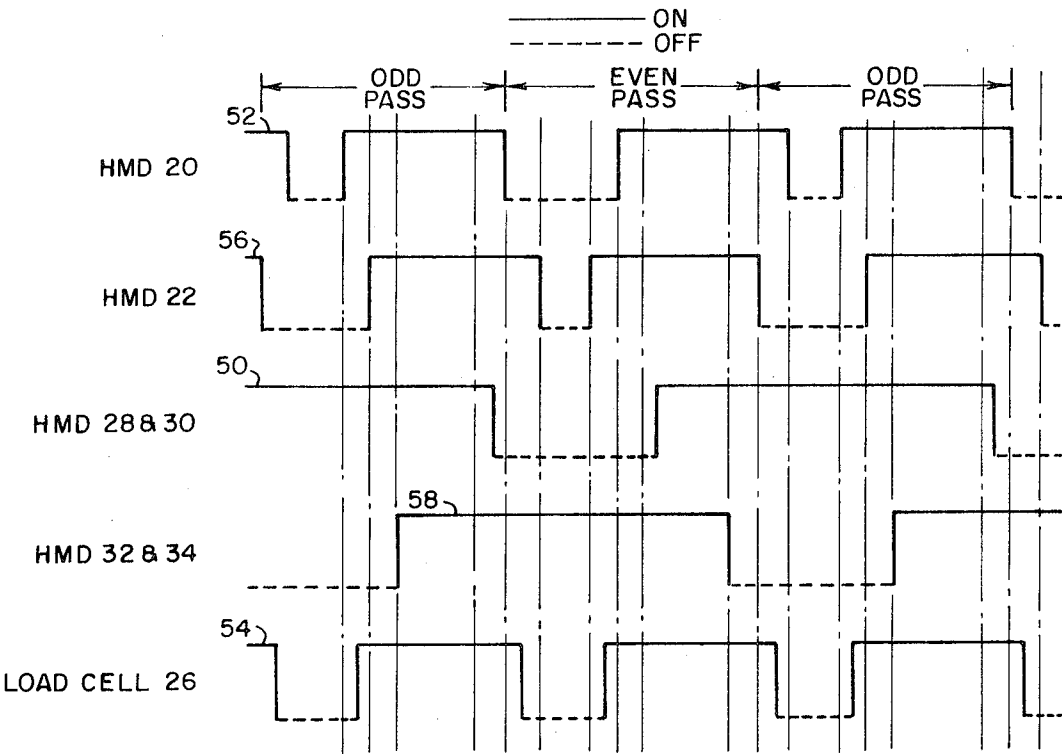


FIG. 3.

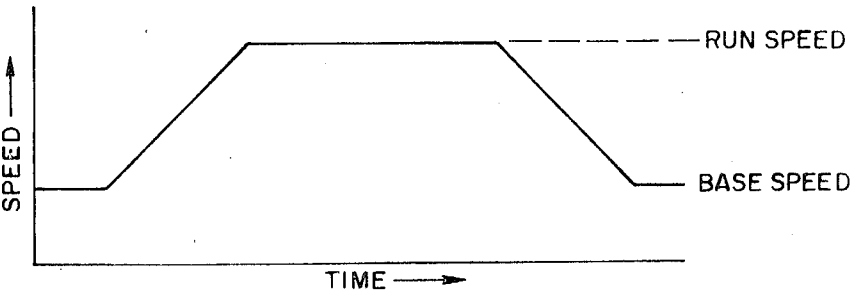


FIG. 6A.

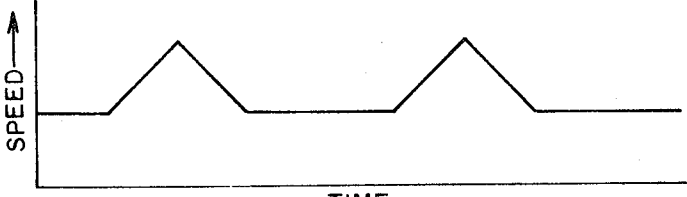


FIG. 6B.

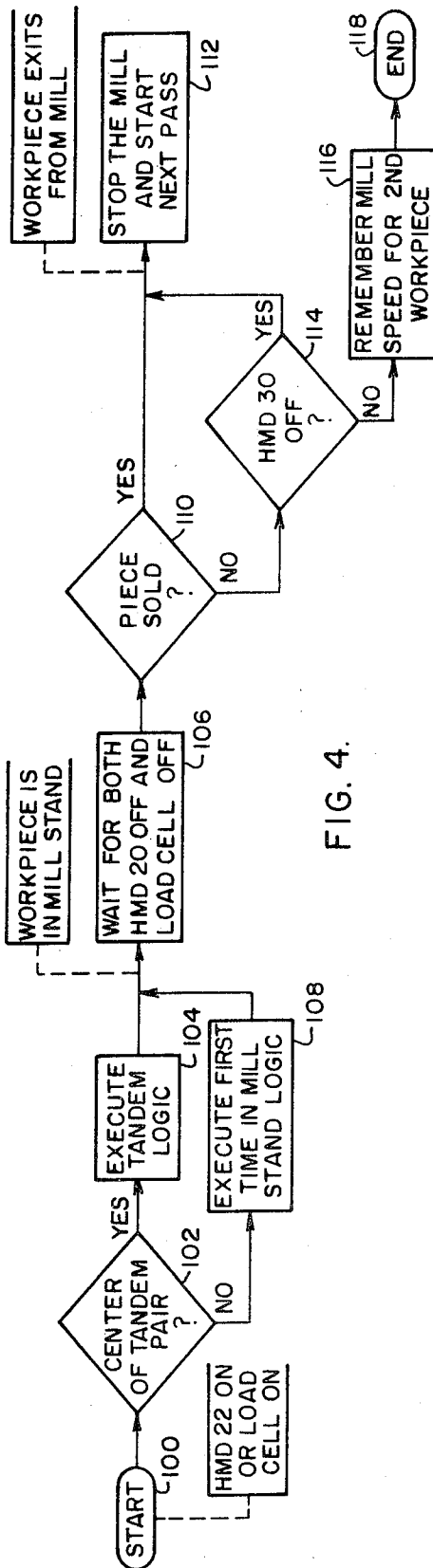


FIG. 4.

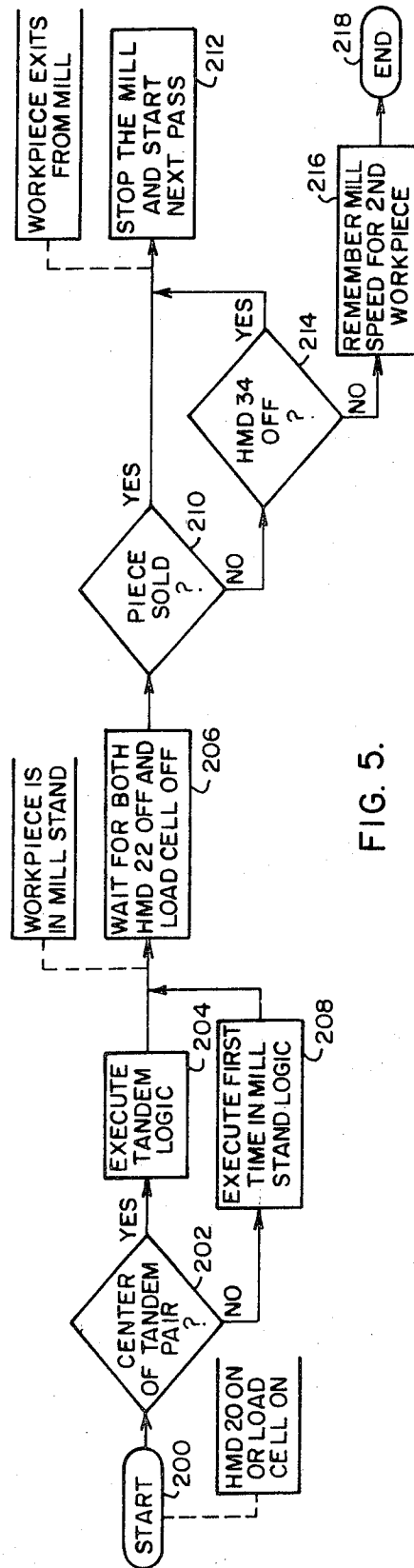


FIG. 5.

ROLLING MILL CONTROL SYSTEM

BACKGROUND OF THE INVENTION

The control of a rolling mill stand, and particularly a reversing slab mill, requires the reliable sensing of the workpiece passage, whether a solo workpiece or a tandem workpiece, through the mill stand. A punched input card supplies as input information to the control system that a particular workpiece pass through the rolls of the stand involves either a solo workpiece or a tandem combination of workpieces.

For automatic mode of slab mill control operation hot metal detectors function in conjunction with a mill stand load cell to sequence the desired succession of mill stand operations.

For screw position setting control as successive passages of the workpiece ingots are made, it is necessary to sense the completion of a present pass before a succeeding pass having a different roll gap is scheduled and undertaken.

A prior art digital computer control system for a slab mill is described in an article published by D. R. Jones and A. W. Smith which appeared in the *Iron and Steel Engineer Yearbook* for 1965 at pages 468 to 475. The general use of hot metal detectors to sense the positional movement of the workpieces and sequence the operation of the computer control system is described in that article.

The digital computer controls the necessary coordination for proper feeding of workpiece ingots to the rolling mill stand relative to the optimum performance of the mill stand. Main mill sequencing in a reversing slab mill is responsive to a stand load cell providing an ON signal when a workpiece ingot is positioned between the work rolls and providing an OFF signal when there is no workpiece ingot positioned between the work rolls. Hot metal detectors in the form of infrared energy sensing devices are operative in effect to backup the load cell to detect when a workpiece ingot is in the mill stand and in addition to sense the presence of a workpiece ingot adjacent to the mill stand and about ready to pass through the mill stand. A feedback signal from the mill drive motor indicates the direction of movement of the workpieces through the mill stand. The load cell OFF signal for an odd pass direction, backed up by hot metal detector 20 and hot metal detector 30, is used to initiate positioning of screwdown apparatus to the desired position for the next pass of a workpiece through the mill stand. The load cell OFF signal, backed up by hot metal detectors 22 and 34, is similarly operative for an even pass direction.

Rolling schedules can be stored in the computer memory, or read in from punched schedule cards, whenever the workpiece pass schedule should change. Depending upon the sensed position of any additional tandem workpieces during a desired tandem rolling operation, the next pass roll opening adjustment is not made until these additional workpieces have passed between the stand rolls.

A digital process control computer can include a central integrated process control or setup processor operative with a software sequentially stepped instruction program which is entered into and stored within the storage memory unit of the computer, and including associated input and output equipment such as generally described in an article entitled *Understanding Digital Computer Process Control* by B. H. Murphy which appeared in *Automation* for January 1965 at pages 71 to 76. Another article of interest here is entitled *Small Control Computers, a New Concept* by F.G. Willard which appeared in the *Westinghouse Engineer* for November 1964 at pages 174 to 179. Two other articles of interest in regard to the programming of a process control computer are of interest; one such article is published in the January 1965 *Westinghouse Engineer* at pages 13 to 19 by Paul E. Lego and the other was published in the 1966 *Iron and Steel Engineer Yearbook* at pages 328 to 334 by J.S. Deliyannides and A.H. Green. Each computer processor is associated with predetermined input systems not specifically shown which typically include an input system scanning process related signals representing the status of various process operating condi-

tions, a conventional analog input system which scans and converts process analog signals and operator controlled and other input devices in systems which could include tape readers, teletypewriter or dial input apparatus. Various kinds of information are entered into the computer control system through information input devices including for the example of the rolling mill the desired workpiece delivery thickness of metal being rolled, any selected workpiece plasticity information, hardware oriented programs and control programs for the programming system, and so forth. The input system interfaces the computer control system with the process through the medium of measured or detected signals. To effect desired control actions, output control devices are operated directly by means of an output system or by means of analog signals derived from the output system through a digital to analog converter. One such control action outputs from the computer control system the stand screwdown positioning command signals which are applied to the respective screwdown positioning regulator for each stand of the rolling mill to determine the operation of the screwdown motor for desired screw positional movement at each stand. A previously determined mill spring modulus for each stand is stored in the computer memory along with the calculated values of delivery thickness, theoretical length, length correction, and various other determined values. A suitable output display can be provided for operation with the computer control system in order to keep the process operator generally informed about the process operation and in order to signal the operator regarding an event or condition relative to any particular stand which may require some action on his part.

The use of an on-line digital computer control system may require that one or more model equations relating to the controlled process be stored in the memory unit of the computer to enable predictive operation and control of the process and adaptive control of the process relative to updating information obtained from actual operation of the process. For the example of a rolling mill stand to permit a prediction of the stand roll force relative to a given workpiece having a known grade, a suitable model equation is used to predict the roll force for a desired reduction to be made by that stand and the unloaded roll opening is predicted for each such stand. This general information is already known by persons skilled in this art and is covered by several publications, for example in the *Iron and Steel Engineering Yearbook* for 1962 at pages 587 to 592 is an article by A.W. Smith and L.P. Gripp generally dealing with this subject matter, and an article of interest can be found in the *Iron and Steel Engineering Yearbook* for 1965 at pages 461 to 467 by G. R.G. and A.W. Smith.

It is generally known and understood by persons skilled in this particular art of applying a process control computer system that a combined hardware and software process control computer system comprises a special purpose extended control computer machine, and is provided when a general purpose computer is operated under the control of the software instruction program. Such a process control computer system can be built if desired using hardware or wired logic programming, in view of the recognized general equivalence of a software programming embodiment and a hardware programming embodiment of substantially the same control system. However, when an involved industrial application such as here described becomes somewhat complex, the economics tend to favor the software approach due to the greater expense and lack of flexibility when logic circuits such as well known NOR or NAND logic circuits are wired together to provide the desired hardware programming circuit arrangement built up of such logic circuits to perform the sequential program steps set forth in the illustrated flow charts.

SUMMARY OF THE PRESENT INVENTION

Workpiece sensing devices are operative in conjunction with a control system coupled to at least one rolling mill stand for controlling the sequence operation of the rolling mill

stand. The workpiece sensing devices respond to the positional movement of each workpiece passing through the rolling mill stand, and are operative to sense the condition of separated tandem workpieces which are desired to pass through the stand with a given roll opening setting of that stand and before a change in the roll opening setting is made in relation to a desired succeeding pass of at least one workpiece through the stand. The roll force sensing load cell operative with the stand is used to sequence the roll opening settings of the stand for respective workpiece passes. However, when more than one workpiece is to be rolled in tandem through the stand, with the same roll opening setting of the stand, and those tandem workpieces become separated for some reason it is desired that the load cell roll force signal not be effective to change the stand roll opening setting before the succeeding tandem workpiece intended for the same roll opening setting passes through the stand. When the load cell indicates a reduction in roll force, the control system in addition monitors the positions of any other workpieces scheduled to pass through the roll stand before a change in the roll opening setting of the stand is made in response to that load cell signal.

Mill stand pass-by-pass tracking is obtained by the provision of at least one additional hot metal detector operative to scan each side of the mill stand for any additional workpieces. For the odd pass direction a hot metal detector is used as a backup for the load cell ON signal and a hot metal detector is used as a backup for the load cell OFF signal. On the even pass direction a hot metal detector is used as a backup for the load cell ON signal and a hot metal detector is used as a backup for the load cell OFF signal.

As compared to solo workpiece sequencing, tandem workpiece rolling is more difficult and requires the reliable provision of the hot metal detector signals such that a pass will not up-date and change the roll stand screwdown setting in the center of a tandem pair of workpieces. In some instances the separation between tandem workpiece ingots can be as great as 15 feet or more, if the second ingot happens to catch between the side guides ahead of the rolling mill stand. For this purpose additional hot metal detectors are used on each side of each controlled mill stand to provide backup workpiece position sensing signals.

For particularly large separations between tandem workpiece ingots, it is desired that the mill speed is controlled such that the second workpiece ingot enters the mill stand at base speed and then accelerates and decelerates in substantially the same manner as a solo workpiece ingot. In addition, optimum combinations of table and main mill stand drive speeds are provided so that ingot reversal is relatively fast yet the workpiece ingot reentry into the mill stand is in accordance with desired rolling practice. In addition, the start anticipate signal for workpiece ingot reentry through the mill stand is adjusted such that the zero error signal of the screwdown position regulator occurs just prior to the workpiece ingot entering the mill stand.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side view illustration of a single reversing mill stand including workpiece position sensing devices for monitoring the positional movement of workpieces to determine the desired operation of the rolling mill stand;

FIG. 2 is a top view illustration of the same mill stand and the workpiece position sensing devices;

FIG. 3 generally illustrates the sequential operation of the workpiece sensing devices to show the time relationship of the output signals provided by those devices;

FIG. 4 is a logic flow chart to indicate the provided sequential operation of the mill stand for a workpiece movement in the odd direction such as a first pass, a third pass, and so forth from left to right through the mill stand shown in FIG. 1;

FIG. 5 is a logic flow chart for a workpiece movement in the even direction such as a second pass, a fourth pass, and so forth through this same mill stand; and

FIGS. 6A and 6B illustrate the provided mill stand operational speed relationships.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

In FIG. 1 there is shown a reversing rolling mill stand 10, including a top work roll 12, a bottom work roll 14, and entry table 16, and a delivery table 18. It should be understood that for a workpiece movement from the left to the right in an odd direction as shown in FIG. 1, the table 16 is the entry table and the table 18 is the delivery table. However, for an even direction pass through the mill stand 10, the table 18 is the entry table for the stand and the table 16 becomes the delivery table. Operative with the mill stand 10 is a hot metal detector 20 operative to sense the position of the workpiece about to enter the mill stand 10 and a hot metal detector 22 operative to sense the head end of the workpiece 24 as it moves from the left to the right and after it has entered the position between the work rolls 12 and 14. An earlier workpiece 25 is shown after it has left the mill stand 10. A load cell 26 is operative to sense the roll separation force between the work rolls 12 and 14 when a workpiece is positioned between the rolls. The hot metal detector 28 and another hot metal detector 30 are operative in conjunction to sense the position of the workpiece 24 as generally indicated in FIG. 1 such that the hot metal detector 28 focuses on a remotely located workpiece 24, in the position as shown in FIG. 1, whereas the hot metal detector 30 focuses on a position of the workpiece closer to the mill stand 10. A hot metal detector 32 and another hot metal detector 34 are operative in conjunction to sense the position of the workpiece on the table 18 such that the hot metal detector 32 focuses on a position of the workpiece a greater distance from the mill stand 10 than does the hot metal detector 34. The orientation of these hot metal detectors should be such that the shortest workpiece scheduled to be passed through the stand will be sensed by the combination of the hot metal detectors 28 and 30 and by the combination of the hot metal detectors 32 and 34.

For example the hot metal detector 20 is operative to sense the workpiece 24 when it is about 1 foot from the centerline of the work rolls 12 and 14 whereas the hot metal detector 30 is operative to sense the position of a workpiece in the order of 5 feet from the centerline of the work rolls 12 and 14 whereas the hot metal detector 28 is operative to sense the position of the workpiece in the order of 35 feet from the centerline of the work rolls 12 and 14. It should be understood that additional hot metal detectors operate in conjunction with hot metal detectors 28 and 30 to scan the intermediate range between these locations, as shown in FIG. 2.

It should be additionally understood that each of the hot metal detectors 28 and 30 as well as 32 and 34 can include if desired a plurality of hot metal detectors combinedly focused generally to sense desired workpiece positions and connected through an equivalent to an OR logic circuit such that if one of the hot metal detectors in the group of hot metal detectors, including the hot metal detector 28, fails to operate another focused on a similar workpiece position will provide an output signal which can be sensed for controlling the operation of the mill stand 10.

In FIG. 2 there is shown a top view of the mill stand 10 including the top work roll 12 and showing a plurality of hot metal detectors 28, 30, 36 and 38 are all operative to sense respective positions of the workpiece at locations between 5 feet and 35 feet from the centerline of the work roll 12. The hot metal detectors 20 and 22 are shown operative in conjunction with hot metal detectors 48 and 50, respectively, for sensing a workpiece in the order of 1 foot from the centerline of the top work roll 12.

In FIG. 3 there is illustrated the sequential operation of the workpiece sensing devices to show the output signals provided by these devices for a movement of the workpiece through the mill stand 10. For example, when the workpiece 24 moves

from a location in the order of 10 feet from the centerline of the work rolls 12 and 14, moving in an odd direction from the table 16 toward the table 18, the head end of the workpiece 24 is initially sensed by the hot metal detector 20. Then as the workpiece 24 enters a position between the work rolls 12 and 14, the load cell 26 provides an ON signal and as the workpiece continues its movement in an odd direction the hot metal detector 22 provides an ON output signal. In addition it should be noted that the hot metal detector 30 was providing an ON signal before the head end of the workpiece arrived at the location of the hot metal detector 20, and as the head end of the workpiece passes the location of the hot metal detector 22 the hot metal detector 34 subsequently senses the infrared radiation from the workpiece and provides an indication that the head end of the workpiece has arrived at its focus position from the centerline of the work rolls 12 and 14. As the workpiece 24 moves in an odd direction, it moves along the table 16, enters the mill stand and then moves onto the table 18. The hot metal detector group including hot metal detector 28 first senses the position of the latter workpiece in the order of 35 feet or so from the centerline of the work rolls 12 and 14, and continues to sense the workpiece up to a position within about 5 feet of this centerline. Then the hot metal detector 20 senses the head end of the workpiece and provides an ON output signal as shown in curve 52. As the head end of the workpiece moves between the work rolls 12 and 14, the load cell 26 provides an ON output signal as shown by the curve 54. Then, as the head end of the workpiece passes the location of the hot metal detector 22 the latter device provides an ON output signal as shown by the curve 56. As the head end of the workpiece moves to a location on the tables 18 where the hot metal detector group including the hot metal detector 34 is operative, the latter group of devices provides an ON output signal as shown by the curve 58. When the tail end of the workpiece 24 leaves the mill stand 10, the load cell backed up by the hot metal detector 22 causes a reversal of the direction of the mill stand 10 and a reversal of the direction of the tables 18 such that the workpiece 24 is then moved in an even direction toward the mill stand 10 and the leading end of the workpiece 24 in its now moving even direction is first sensed and continues to be sensed by the hot metal detector group including the hot metal detector 34 as shown by the curve 58. As the leading end of the workpiece moves adjacent the hot metal detector 22, as shown by curve 56 an ON output signal is provided. As the leading end of the workpiece enters a position between the work rolls 12 and 14, the load cell ON output signal is provided as shown by curve 54. As the leading end of the workpiece moves adjacent the hot metal detector 20 an ON output signal as shown by curve 52 is provided, and finally as the leading end of the workpiece moves into the location on the table 16 where the hot metal detector group including the hot metal detector 30 is operative an ON output signal is provided by the hot metal detector group as shown by the curve 50. Thusly it will be seen from the curves as shown in FIG. 3, the sequential output signal relationship provided by the respective hot metal detector devices shown in FIG. 1.

In FIG. 4 there is shown a logic program flow chart for an odd direction workpiece movement through the mill stand 10 shown in FIG. 1. The program starts at step 100 upon the occurrence of an ON output signal from the load cell 26 or an ON output signal from the hot metal detector 22. The program then goes to the step 102, where a decision is made relative to determine if this is the center of a tandem pair of workpieces, which information is obtained from program step 116 only when a previous tandem workpiece has been rolled. If it is not the center of a tandem pair, such as would be true for the first workpiece, the program advances to the step 108 for the execution of predetermined rolling logic which can do any desired operations such as the following functions. (1) It causes the mill stand to accelerate toward run speed, and (2) applies the pulses from the mill stand pulse source 23, to a counter within the control computer 17 for determining the total length of workpieces rolled by the mill stand 10. For ex-

ample the pulses provided by the pulse source 23 coupled to the drive motor 15 of the mill stand 10 are effectively integrated in a signal counter beginning with the ON output signal from the load cell 26 and ending with the OFF output signal from the load cell 26. Knowing the diameter of the work rolls 12 and 14 this enables a calculation of the length of the workpieces which pass between the work rolls 12 and 14.

The workpiece is now in the mill stand and the program advances to step 106 which provides a waiting period until both the hot metal detector 20 OFF signal is provided and the load cell OFF signal is provided.

If the information relative to the center of the tandem pair as determined in decision step 102 was that a succeeding workpiece of tandem workpieces was passing through the mill stand 10 and caused the load cell ON signal, the program would advance to the step 104 for executing predetermined tandem rolling logic. This can generally include causing the mill stand to accelerate toward the remembered exit speed of the previous workpiece leaving the mill stand, and it could again apply the pulses from the pulse source 23 to the counter within the control computer 17. Then the program would advance to the step 106 providing for the effectively AND logic function when both the OFF signal from the hot metal detector 20 and the OFF signal from the load cell 26 indicated that the workpiece had left the mill stand 10. The program then advances to step 110 for a determination if the desired rolling schedule is for a solo workpiece. If it is, the solo workpiece effectively exits from the mill before the program step 112, which stops the mill for this particular pass, starts or initiates the next pass of a workpiece with a different roll separation through the mill stand 10, which may comprise a reversal of the workpiece movement to pass the same workpiece in an even direction between the same work rolls 12 and 14.

If the workpiece at step 110 was determined not to be a solo workpiece, the program advances to step 114 where a determination is made to see if the hot metal detector group including the hot metal detector 30 is providing an OFF signal. If it is providing an OFF signal, this means that any additional tandem workpieces are out of the way, and the program can advance to the step 112 previously described. On the other hand, if the hot metal detector group including hot metal detector 30 is providing an ON output signal, the program advances to step 116 where the control computer 17 remembers the mill stand exit speed of the previous workpiece leaving the mill stand such that the rolling operation for the succeeding tandem workpiece can be patterned after the rolling of the previous workpiece. The program then advances to step 118 which is the end of this particular flow chart program and the program returns to starting step 100 upon the further occurrence of either a load cell 26 ON signal or an ON signal from the hot metal detector 20, which would indicate another passage through the mill stand of a workpiece in an odd direction.

In FIG. 5 there is shown a generally similar flow chart, for the passage of workpieces in an even direction between the work rolls 12 and 14 of the mill stand 10. The program starts at step 200. It should be understood that the control computer 17 selects control program shown in FIG. 5 when the tables 16 and 18 are rotating in a direction to move the workpiece in an even direction through the mill stand 10 as well as the rotation of the mill stand 10 is in the direction for even pass rolling. Either the ON signal from the hot metal detector 20 or the load cell 26 ON signal starts the program operation.

One reason for providing an OR logic function to start the program at the step 200 as shown in FIG. 5 in this manner is if the reduction taken for a particular pass of the workpiece through the mill stand 10 is such that the ON signal threshold of the load cell 26 is not reached, which signal threshold can be in the order of one-half million pounds of roll force, the load cell 26 will not provide a reliable ON output signal, and for this reason the ON output signal from the hot metal detector 20 is used in effect as a backup signal to initiate the start of the sequential instruction program shown in FIG. 5.

After starting, the program advances to the step 202, where the determination is made if this is the center of a tandem pair of workpieces, which information is received from the input data card supplied to the control computer 17. If it is not the center of a tandem pair, the program advances to step 208 where the control computer 17 executes the predetermined rolling logic for a first workpiece of a tandem pair or for a solo workpiece and provides the desired operating speed of the mill stand drive motor and the desired operation of the tables 16 and 18, and so forth to move the workpiece through the mill stand in an even direction and to effect the desired reduction of that workpiece thereby. If step 202 determined that this was a succeeding workpiece of a tandem pair, then the program advances to step 204 for the execution of desired tandem rolling operation of the mill stand 10 as previously set forth in general relative to FIG. 4. The instruction program then advances to step 206 where the control computer 17 waits for both the OFF signal from the hot metal detector group including hot metal detector 22 and the OFF signal from the load cell 26. If the decision is made at program step 202, based upon previous workpiece passage information remembered at step 216, that this was the center of a tandem pair of workpieces the program advances to step 204 where the control computer 17 is caused to execute the desired tandem logic for rolling a succeeding tandem workpiece by passage between the work rolls 12 and 14, and the program then advances to the step 206 previously described. When both the OFF signal from the hot metal detector 22 and the OFF signal from the load cell 26 are received, the program advances to step 210 where the question is asked is a solo workpiece rolling operation involved? If it is, the program advances to step 212 where the rotation of the work rolls 12 and 14 by the drive motor 15 is stopped and the control computer 17 prepares the mill stand 10 for the next pass of a workpiece between the work rolls 12 and 14. On the other hand, if the decision in step 210 is that tandem workpiece rolling is involved, the program advances to step 214 where the question is asked is the hot metal detector group including hot metal detector 34 providing an OFF signal. If it is, the program advances to step 212 previously described. If it is not, the program advances to step 216 where the control computer 17 is instructed to remember the exit speed of the previous workpiece in the tandem group leaving the work stand for determining the rolling pattern of the next workpiece and the program then advances to the step 218 which is the end of this particular instruction program.

In FIG. 6A there is shown an illustration of a plot of the speed versus time for the operation of the mill stand 10 to illustrate an initial operation at base speed of the mill stand, and then an acceleration from base speed to run speed, followed by run speed for a time period determined by the length of the workpiece, and then decelerating back to base speed such that the workpiece exits from the mill stand 10 at base speed as well as enters into the mill stand 10 base speed. In this way the entry and exit to the mill stand 10 is accomplished at base speed and the permitted acceleration and deceleration determines the length of time that the workpiece passes through the mill stand 10 at run speed to effectively optimize the operation of the rolling mill 10 relative to the desired reduction of the workpiece for a given pass through the mill.

In FIG. 6B there is shown the situation for tandem workpiece rolling where a substantial gap or spacing occurs between the workpieces, such that the first workpiece enters the mill stand at base speed, accelerates at a similar acceleration rate but since the length of the first workpiece may not be long enough to reach run speed, FIG. 6B illustrates the workpiece leaving the mill stand and then the stand decelerates toward base speed. The mill continues at base speed until the second workpiece enters, and a similar acceleration pattern is provided and followed by a similar deceleration pattern back to the base speed such that the second workpiece exits from the mill stand 10 at base speed. The function of program step 116 for FIG. 4 and step 216 for FIG. 5 is to remember the mill

speed for determining the rolling pattern for the next workpiece. If the previous workpiece was long enough for the mill stand operation to reach run speed, or whatever speed is reached, this operational speed of the stand is remembered such that a similar rolling pattern takes place for the next tandem workpiece which is generally similar to the previous workpiece when a tandem pair of workpieces are rolled.

GENERAL OPERATION OF CONTROL SYSTEM

Thusly it will be seen that before the first pass which would be an odd pass, the workpiece is stopped on the entry table 16. A check is then made by the control computer 17 of the following. (1) Is the rolling schedule determined in relation to the reductions to be made and the number of passes to be taken? (2) Is the screwdown mechanism as determined by the screwdown motor 19, properly positioned for the next scheduled pass of the workpiece through the mill stand 10? Then the mill stand 10 and the tables 16 and 18 are started and the workpiece is moved toward the mill stand, with the workpiece moving from the table 16 toward the table 18. The instruction program operative with the control computer 17 waits for either the hot metal detector 22 to provide an ON signal or the load cell 26 to provide an ON signal and the instruction program shown in FIG. 4 for an odd pass direction is then followed. When the load cell 26 ON signal or the ON signal from hot metal detector 22 is provided, this indicates that the head end of the workpiece has entered the mill stand 10 and is positioned between the work rolls 12 and 14.

If tandem workpieces are being rolled, at step 116 the control computer 17 remembers the exit speed from the mill stand of the first workpiece. When the second workpiece enters the mill stand, depending upon the spacing between the workpieces, the ON signal from load cell 26 causes the control computer 17 to then accelerate the mill stand toward run speed up to the remembered exit speed of the first workpiece since the first workpiece is normally about the same length and size as the second workpiece and further since the pulse source 23 operative with the mill stand 10 provides pulse signals which are counted to provide an indication within the control computer 17 of the length of the first and second workpieces. This can permit the control computer 17 to determine the acceleration and deceleration operation of the mill stand 10.

For the first time in the mill stand logic as contemplated in step 108 of FIG. 4, the control computer 17 causes the mill stand 10 to accelerate to run speed for a time determined by the known length of the total workpieces including the first and second tandem workpieces if this is the case, and allowing the last workpiece to exit from the stand at base speed.

It should be realized that for tandem workpiece rolling, it is desired to have them substantially touching but the second workpiece can frequently separate from the first workpiece a distance of 6 inches to 3 feet or even 20 feet depending upon the second workpiece perhaps catching and sticking between the side guides leading to the mill stand. It is desired that if the second workpiece is lagging the first workpiece by 3 or more feet, and the OFF signal from the load cell 26 occurs since the first workpiece leaves the mill stand and the second workpiece is not yet entered, that the screwdown motor 19 not be operated to adjust the roll opening position in preparation for the subsequent pass through the mill stand 10 of the tandem workpieces. Instead it is desired that no change in the roll opening setting be made at this time in that the second workpiece will eventually pass between the work rolls 12 and 14 of the mill stand 10, and it is desired that the same reduction be made in both the first and the second workpieces.

The load cell 26 typically is operative such that even when tandem workpieces are substantially touching, the load cell will give an OFF signal indication at the time that the first of a tandem pair of workpieces exits from the roll gap between the work rolls 12 and 14 and before the substantially touching second workpiece of the tandem pair of workpieces enters

between and into the roll gap between the work rolls 12 and 14. Thusly it should be understood that the load cell 26 when it gives an OFF output signal will provide an indication to the control computer 17 that it is now time to adjust the roll opening between the work rolls 12 and 14 for the next succeeding workpiece pass schedule, unless the hot metal detector group including hot metal detectors 28 and 30 which are in effect coupled through an OR logic circuit provides an indication that an additional workpiece has not yet entered the gap between the work rolls 12 and 14.

When an odd pass of workpieces is scheduled which means that the workpieces moving in a direction from the table 16 toward the table 18, and an indication is provided that tandem workpiece rolling is taking place, an output or ON signal from the hot metal detector group including detectors 28 and 30 indicates that there is at least one additional workpiece to pass between the work rolls 12 and 14 before a succeeding pass roll opening setting should be undertaken. The control computer 17 during an odd pass and tandem workpiece rolling conditions by contact input senses any output signal provided by the hot metal detectors 28 and 30 to provide an indication when the tandem workpiece rolling pass is completed. In effect, the computer 17 is looking for an additional workpiece remaining on the table 16 before changing the roll opening after a scheduled odd pass of the workpieces.

In general it should be recognized that for an odd direction pass such as the first pass, third pass, fifth pass, and so forth the output signal from the hot metal detector group including detector 28 will first drop off, then the hot metal detector 20 will drop off and finally the load cell 26 will provide an OFF output signal and the hot metal detector 22 will provide an OFF output signal in a succession of signal events which can be sensed by the control computer 17 to determine the movement passage of the one or more workpieces in the odd direction. The hot metal detector group including detectors 34 and 32 will provide ON output signals, and will remain ON if the hot workpieces are stopped on the table 18 within their range of sensitivity in preparation for a reversal of the mill drive motor 15 and the drive motors for the tables 18 and 16. The workpieces will now move in an even direction for the second pass between the work rolls 12 and 14 from the table 18 back toward the table 16. The general signal logic operation performed by the control computer 17 is such that when the load cell 26 provides an OFF output signal, the computer 17 for an odd direction pass scans the output signals from the hot metal detector group including detectors 28 and 30 to see if any additional workpiece or workpieces remain to be passed in an odd direction between the work rolls 12 and 14. For a scheduled even direction pass, the control computer 17 scans the hot metal detector group including detectors 32 and 34 to see if one or more remaining workpieces remain on the table 18 to pass between the work rolls 12 and 14.

For particularly the early passes where the reduction may not be adequate for the load cell 26 to provide an ON output signal, the hot metal detector 20 is a backup for the load cell 26 for an even direction pass and the hot metal detector 22 is a backup for the load cell 26 for an odd direction pass. For the situation where the tandem workpiece ingots are separated by 8 feet or so, the operation logic illustrated by the flow chart in FIG. 4 for the odd direction pass of the workpieces between the work rolls 12 and 14 is such that when either the load cell 26 provides an ON signal or the hot metal detector 22 provides an ON signal the instruction program starts and at step 106 the instruction program waits for both the OFF signal from the load cell 26 and the OFF signal from the hot metal detector 20, to insure that at least the first workpiece has exited from between the work rolls 12 and 14. Then at step 110 a check is made by the control computer 17 of the input information from the input data card 21 to see if solo or tandem rolling is scheduled to take place, and in the event of tandem rolling the control computer 17 checks the hot metal detector group including detector 30, to see if any remaining workpiece is present on the roll table 16 and has not as yet passed

between the work rolls 12 and 14. If the latter hot metal detector group provides an OFF output signal this indicates that there is no remaining workpiece on the table 16 and therefore the instruction program advances to step 112.

For an even direction passage of the workpieces the logic flow chart shown in FIG. 5 operates in a similar manner for each of the workpieces to pass between the work rolls 12 and 14.

In general it should be noted that the hot metal detector group including detectors 28 and 30 have been provided to indicate the occurrence of the center of a tandem pair of workpieces as compared to the end of a single workpiece or the end of a tandem pair of workpieces when rolling in the odd direction, and the hot metal detector group including detectors 32 and 34 have been similarly provided for determining the center of a tandem pair of workpieces or the end of a single or a tandem pair of workpieces when rolling in an even direction. Thusly when the OFF signal from the hot metal detector 20 when rolling in an odd direction occurs the control computer 17 checks the output signals from the hot metal detector group including detectors 28 and 30 to determine if another workpiece is present on the table 16 and not yet entered the roll stand such that a tandem pair of workpieces is involved. Similarly when rolling in the even direction the hot metal detector group including detectors 32 and 34 have been added to provide the control computer 17 with an indication that an additional workpiece has not yet passed between the work rolls 12 and 14. If both the hot metal detector 20 provides an OFF signal and the hot metal detector group including detectors 28 and 30 provide OFF signals for an odd direction of rolling this is an indication to the control computer 17 that the end of a tandem pair has occurred. In general the signal from the load cell 26 is the controlling signal for determining a rescheduling of the roll setting between the work rolls 12 and 14.

In the prior art, the practice was to provide a load cell 26 backed up by one of the hot metal detectors 20 for an even direction rolling and backed up by the hot metal detector 22 for an odd direction rolling. This was sufficient for solo workpiece operation. For an even direction rolling the load cell 26 provided the control signal with the load cell 22 as a backup for the load cell ON signal when rolling in the odd direction and the hot metal detector 20 is used for the OFF signal. For an even direction rolling the hot metal detector 20 is used as a backup for the load cell ON signal and the hot metal detector 22 is used as a backup for the load cell OFF signal. On the other hand, for tandem workpiece rolling operation it is necessary to detect the center of the tandem pair from the end of a tandem pair, and further tandem workpiece ingots may not be close together so that the above solo logic operation is not adequate to distinguish between a solo ingot and a tandem pair of ingots. The present invention includes the use of the additional hot metal detector group including detectors 28 and 30 operative for odd direction rolling and the additional hot metal detector group including hot metal detectors 32 and 34 operative for even direction rolling. In the tandem operation if the workpiece is being rolled in an odd direction when the hot metal detector 20 goes OFF or the load cell OFF signal occurs, the hot metal detector group including detectors 28 and 30 are checked by the control computer 17. If the latter hot metal detector group is providing an ON signal this is an indication to the control computer 17 that the center of a tandem pair of workpieces has been sensed by the load cell 26. The odd pass of all workpieces is considered to be complete when the hot metal detector 20 is providing an OFF signal as well as the OR logic connected group of hot metal detectors 28 and 30 are providing off signals. A generally similar operation occurs for the even direction passes relative to the group of hot metal detectors 32 and 34.

I claim:

1. In control apparatus for a rolling mill stand having a pair of work rolls through which at least one of first and second workpieces is passed, the combination of:

control means operative with said rolling mill stand to determine the operation of said rolling mill stand in accordance with a first pass operation through said mill stand at a first roll setting and followed by a second pass operation through said mill stand at a second roll setting, means positioned to provide a first signal in response to each of said first and second workpieces that passes through said mill stand during said first pass, means positioned to provide a second signal in response to any portion of said workpieces being located a predetermined distance ahead of said work rolls of the mill stand during said first pass, with said control means being operative to schedule said first pass operation of said rolling mill stand while in response to the provision of said first signal and the provision of said second signal and being operative to schedule said second signal operation of said rolling mill stand when said first signal is no longer provided and said second signal is no longer provided.

2. The control apparatus of claim 1, with said means responsive to each of said workpieces that passes through said mill stand providing an ON first signal when a workpiece is passing through said mill stand and providing an OFF first signal when there is no workpiece passing through said mill stand, with said means responsive to any portion of said first and second workpieces being located a predetermined distance ahead of said work rolls providing an ON second signal when such a workpiece portion is so located and providing an OFF second signal when no such workpiece portion is so located, and with said control means being operative to maintain said first pass operation of said rolling mill stand until both an OFF first signal and an OFF second signal are provided.

3. The control apparatus of claim 1, with said means responsive to any portion of said first and second workpieces located

a predetermined distance ahead of said work rolls including a plurality of workpiece sensing devices which are respectively operative to monitor different and adjacent location distances ahead of said work rolls.

4. The method of controlling a rolling mill having a pair of work rolls through which at least one of first and second workpieces is passed, including the steps of

scheduling a first pass of at least said first workpiece between said work rolls at a first roll setting and a second pass of at least said first workpiece between said work rolls at a second roll setting,

sensing the passage of said first workpiece between said work rolls

sensing the presence of said second workpiece if said second workpiece is positioned within a predetermined location ahead of said work rolls,

and providing said first pass operation of said rolling mill after said first workpiece has passed between said work rolls when a second workpiece is sensed within said predetermined location ahead of said work rolls.

5. The method of claim 4, including the step of providing said second pass operation of said rolling mill after at least said first workpiece has passed between said work rolls during said first pass operation of said rolling mill and no additional workpiece is scheduled to pass between said work rolls during said first pass operation and is sensed within said predetermined location ahead of said work rolls.

6. The method of claim 4, with said predetermined location ahead of said work rolls being selected to be greater than the length of said first and second workpieces such that additional workpieces scheduled to pass between said work rolls during said first pass operation of said rolling mill will be sensed.

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