June 11, 1968 A. W. SMITH, JR 3,387,470

METHOD FOR MEASURING ROLL CROWN AND IMPROVING THE OPERATION OF A ROLLING MILL

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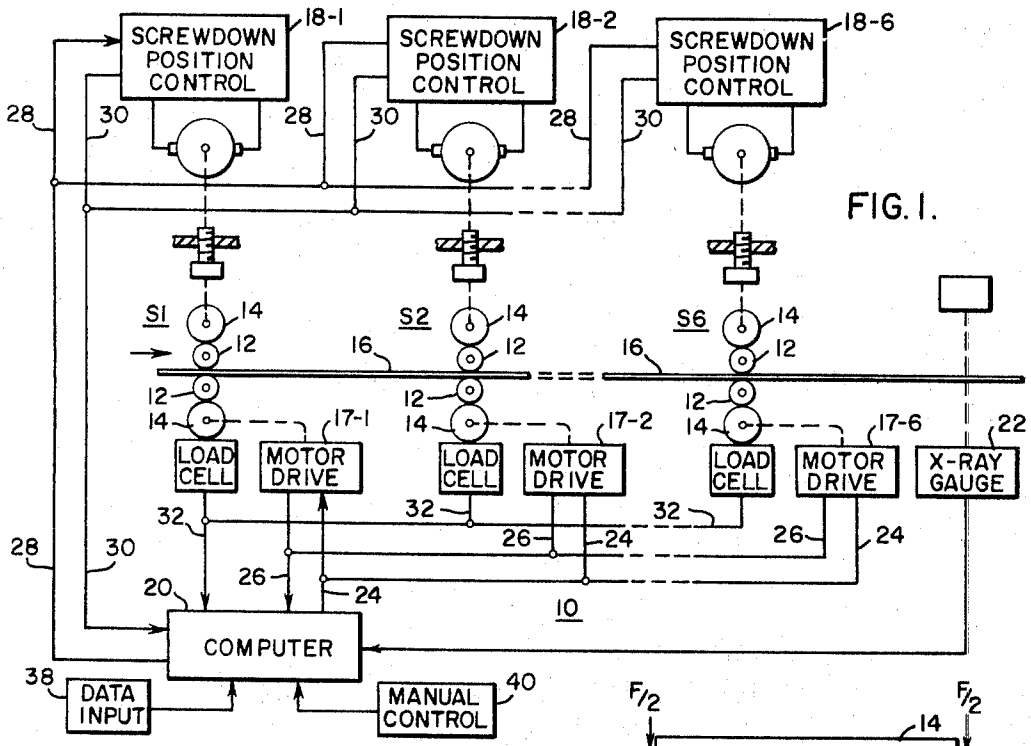

FIG. 1.

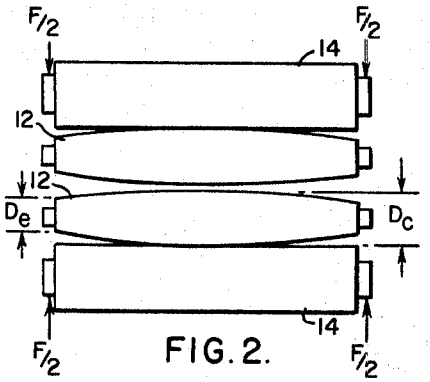

FIG. 2.

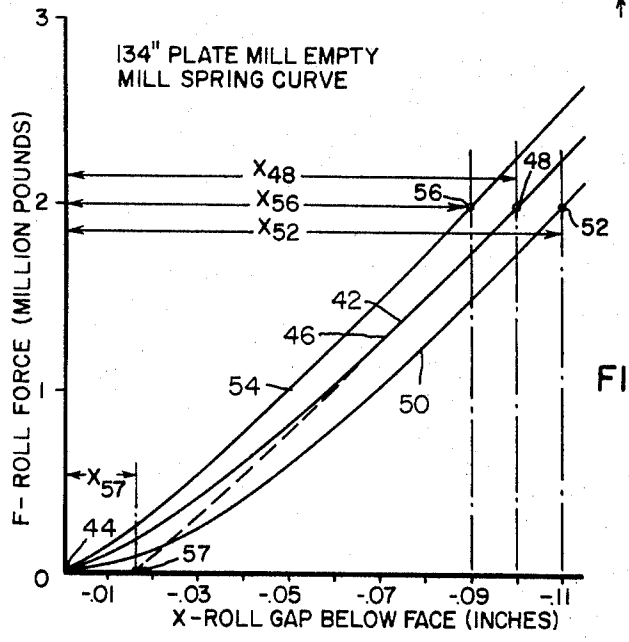

FIG. 3.

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METHOD FOR MEASURING ROLL CROWN AND IMPROVING THE OPERATION OF A ROLLING MILL

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ABSTRACT OF THE DISCLOSURE

The roll crown of work rolls at a steel mill rolling stand is determined from time to time during stand use. Use is made of the roll crown in setting screwdown position for desired strip crown and desired delivery gauge.

The present invention relates to reduction rolling mills and more particularly to methods for measuring roll crown so as to provide improvement in controlling the shape of rolled strip products.

Roll crown is a mill operating parameter which is one of numerous determinants of the shape of rolled product from the mill. Normally, the work rolls are originally formed with a crown in that the diameter of each work roll is enlarged at the center of the roll and decreases toward each end of the roll to smaller roll end diameters.

Generally, roll crown provides shape control in offsetting the effects of roll bending produced by strip transported between the rolls. In turn, the extent of roll bending is determined by the magnitude of the applied roll force which depends on the roll opening, the properties and characteristics of the material being rolled, and other parameters. The strip gauge reduction or draft produced by the rolls is also determined by the applied roll force and the properties and characteristics of the material being rolled and certain other parameters, and desired strip gauge and shape are both realized only when the variables including roll crown are suitably accounted for or controlled.

Percent strip crown is defined as the extent to which the strip thickness along its center line exceeds the strip thickness along its edge lines divided by the average strip thickness times 100. Desirably, the strip cross-section shape is controlled to have about 1% crown so that the strip can be guided stably between the work rolls substantially without side movement. In a multistand mill, the percent strip crown is preferably held substantially constant at least throughout the last few passes so that differential elongation and buckling or non-flatness are avoided in the finished product.

The roll crown varies as a function of roll temperature changes and wear, and strip shape accordingly also varies at desired gauge unless suitable correction is made. The wear of back-up rolls produces a generally equivalent effect on strip shape since the geometry of the back-up rolls affects the extent to which the work rolls are bent under a given separting force.

In U.S. Patent 3,248,916 "Work Piece Shape Control with a Rolling Mill" and issued on May 3, 1966 to A. F. Kenyon and the present inventor and assigned to the present assignee, a computer control system is arranged to operate a rolling mill such that strip product is rolled with improved gauge and shape control. Successive gauge reductions or drafts at successive stands are set by the computer within constraint limits of roll force, drive motor torque, maximum percentage draft and maximum inches draft while strip crown is controlled such that substantially flat on gauge product is produced.

In the referenced computer control system, roll crown

variance is accounted for in the computer program by the insertion of an equation correction factor estimated after visual observation of any tendency for non-flatness to occur in the rolled product. In other less automated control systems, the mill operator may normally rely on his accumulated experience in determining when and to what extent mill settings must be altered to offset the changing roll crown variable during mill use. For example, in a hot strip steel mill it is generally known that, after the first hour or so of use of a new set of work rolls, the roll crown increases due to initial differential heating between the center and edges of the work rolls. Thereafter, the roll crown decreases from wear until the roll set must be replaced with a new roll set, perhaps after eight to sixteen hours of use. As previously noted, the back-up rolls also play a part in determining the effectiveness of the work roll crown, and the wear history of the back-up rolls in use may be considered by the operator in judging the settings to be made as the rolling mill continues in operation.

In both the computer and the operator control systems, only the original or starting work roll crown is known and subsequent mill settings are determined from estimates of the roll crown. Although the experiential factor in compensating for variable work roll crown can prove to be an acceptable mode for mill operation, it is generally undesirable since commercial and economic factors demand a more scientific approach.

In accordance with the broad principles of the present invention, an improved rolling mill operating method is provided and includes a unique method for measuring work roll crown during the use of the work rolls. The operating method further includes using the in process crown measurement in a computer or other mill control system substantially to provide desired strip guage and shape.

It is therefore an object of the invention to provide a novel method for operating a rolling mill so as to produce strip product with improved shape control.

Another object of the invention is to provide a novel method for operating a rolling mill wherein work roll crown is measured periodically for use in controlling the strip shape.

A further object of the invention is to provide a novel method for measuring roll crown in a rolling mill so that the actual roll crown can be made known for control use during the mill operation.

These and other objects of the invention will become more apparent upon consideration of the following detailed description along with the attached drawings, in which:

FIG. 1 is a schematic diagram of a multistand rolling mill which can be controlled in accordance with the principles of the invention;

FIG. 2 shows an elevational view of a set of work rolls and a set of back-up rolls employed at the various stand locations in the mill shown in FIG. 1; and

FIG. 3 shows an exemplarly plot of roll force versus roll gap, and it is useful in the measurement of work roll crown during the operation of a rolling mill in accordance with the principles of the invention.

More specifically, there is shown in FIGURE 1 a multistand reduction rolling mill comprising a plurality of roll stands S1 and S2 through S6. At each stand location, a pair of work rolls **12** and a pair of back-up rolls **14** are provided for rolling in this instance hot steel strip **16**. The rolling mill **10** can be arranged to roll other plastically deformable materials and other forms of material such as plates, slabs, etc. Suitable motor drives **17**, such as variable speed DC motors, operate the rolls **12** and **14** at the respective stand locations under suitable control by

a conventional speed control system (not specifically shown).

A conventional screwdown position control **18** is employed at each stand location so as to control the force applied to the back-up rolls **14** and thereby control the gauge and shape of the strip **16** as it passes through the opening between the work rolls **12** as is well known in the art. Generally, the roll force is controlled in accordance with the well known roll force principle so as to maintain a substantially constant predetermined roll opening through control of the screwdown position. Strip shape is generally controlled by establishing a roll opening which results in the roll bending required for desired strip crown at a particular roll crown value. A conventional tension control system (not shown) can also be provided if desired so as to regulate the motor drive speeds to retain strip tension in a desired range.

Each of the screwdown position controls **18** is in this instance controlled by a central digital process computer **20** in conjunction with suitable analog-to-digital and digital-to-analog conversion circuitry. Screw position and roll force signals as indicated by the reference characters **30** and **32** are transmitted to the computer **20** from each screwdown position control **18** for use with a gauge monitor signal from a delivery thickness or X-ray gauge **22** in computing corrective screwdown position changes. The computer **20** is suitably designed and programmed to achieve the control required to produce substantially on gauge product. It is also suitably arranged generally to control the overall operation of the mill **10** including the mill drive speed through control of the drive speed control subsystem as indicated by the reference character **24**. The previously mentioned tension control subsystem and other provided subsystems are also amenable to computer control if desired.

In addition to the gauge control signals, various other signals related to on-going process variables are connected to the computer input so as to achieve the desired output controls. For example, speed signals indicated by the reference character **26** are so connected. The computer **20** also provides output control in response to a data input device such as a commercially available tape reader **38** or a suitable manual input control **40** which generates suitable data representative of the characteristics of the particular strip being rolled. Operating restraints similar to those previously indicated can be programmed in the computer **20** if desired. Initial data for the overall computer program can include workpiece entry thickness and length, temperature, width (which directly affects roll bending) and type of material.

Since work roll crown is a determinant of rolled strip shape, it is included as a factor in the program of the computer **20**. Flat rolled product can thus be obtained at substantially desired gauge and with substantially desired shape. To the extent that the crown of the work rolls **12** changes at any particular stand location, the screwdown position control **18** at that stand can be operated by the computer **20** (as indicated by the reference character **28**) so as to adjust the screwdown position and the work roll setting in the interest of maintaining desired strip crown.

An enlarged view is shown in FIGURE 2 so as to illustrate the original crown provided for the work rolls **12**. Thus, each work roll **12** is provided with a center diameter D_c and with respective end diameters D_e. Roll force is applied to the work rolls **12** by means of the back-up rolls **14**. Half of the total roll force is applied at each end of each back-up roll **14**, and the total roll force is applied to the work rolls **12** over the intersurface contact area between the work rolls **12** and the back-up rolls **14**. As indicated previously, the original work roll crown is ordinarily precisely known since it is accurately formed on the work rolls **12** before they are placed in service.

In order to measure the work roll crown during mill service, a relationship between total roll force and roll gap below face is employed. By roll gap below face, it is meant

to refer to screw position movement following first contact between the work rolls **12**.

The roll force and roll gap data are taken in the absence of strip or other forms of rolled material between the work rolls **12**. Thus, the roll force and roll gap data form an empty mill spring curve as exemplary shown in FIGURE 3 for a 134 inch plate mill.

In the mill operating and roll crown measuring methods of the invention, new work rolls **12** are submitted to a roll crown test as indicated by the mill spring curve **42**. Roll force and roll gap below face are determined by suitable signals such as the signals **30** and **32**. Work roll contact is first established as indicated by the reference character **44**, and total roll force F increases nonlinearly as the roll gap below face increases until play in the screw threads and other support structure is taken up. The relationship between total roll force and roll gap below face then becomes linear as indicated by the reference character **46**. In the initial test, roll force is increased until an arbitrary force value is realized, for example 2 million pounds as indicated by the reference character **48**. The roll gap below face is noted at that point to be .10 inch.

The linear portion of the line, if extended, intersects the X axis at reference character **57**. The distance X57 is determined by several fixed conditions such as play in the screw threads and other support structure and the variable work roll and backup roll crown. The detection of the variation in the nonlinear portion of this line is in essence the basis of determining variation in roll crown.

After the work rolls **12** are placed in use, the empty mill spring curve can be periodically redetermined so as to provide an indication of a change in the roll crown. The test can be quickly made between plate or strip or other workpiece passes. For example, after two hours of use or when it is otherwise expected that the work roll crown will have increased as a result of differential roll heating, a new test is run to determine a new empty mill spring curve **50**, and when the roll force reaches the preselected figure of 2 million pounds, as indicated by the reference character **52**, the roll gap below face X_{62} is noted to be .11 inch. The change in roll gap below face is given by the following:

$$\Delta X = X_{48} - X_{52} = -.10 - (-.11) = .01$$

In turn, the change in roll crown is given by the following formula:

$$(D_c - D_e)_{48} - (D_c - D_e)_{52} = \Delta(D_c - D_e) = \tfrac{1}{2}\Delta X$$

It is ordinarily safely assumed that the total change in roll crown measured by the described procedure is approximately equally divided between the two work rolls **12**.

At a later time in the mill operation when it is expected that the work roll crown will have decreased due to roll wear, another test can be made to produce an empty mill spring curve indicated by the reference character **54**. When the roll force reaches the preselected value of a 2 million pounds as indicated by the reference character **56**, the roll gap below the face X_{56} is again noted and in this case it is .09 inches. The change in roll crown is in this case

$$\tfrac{1}{2} \times \Delta X = \tfrac{1}{2} \times (-.10) - (-.09) = -.01$$

inch. The minus sign indicates a decrease in roll crown from the original value.

The roll crown measurement test can be performed as often as desired during the operation of the rolling mill. It can be performed for the single set of rolls in a reversing mill or for preselected sets of rolls or each set of rolls in a multistand rolling mill. The roll crown measurement test can be manually instituted and the results can be employed by the operator of a non-computerized mill for the purpose of adjusting the screwdown position settings to maintain desired strip crown while work roll

crown varies during mill operation. Further, the test results can be used to operate a suitably designed analog feedback control (not shown) especially arranged to produce the same compensatory control of the screwdown settings.

In a computerized mill, such as the mill of FIG. 1, the computer **20** can be programmed to institute roll crown tests at the various roll stands and at various times during the mill operation. During the roll crown tests, the screw position setting signals **30** and the roll force signals **32** generate the necessary mill spring curve data for the computer memory. When the roll crown change is calculated for each stand as previously indicated, a new roll crown parameter is made available to update the computer control equations for the various stands. The computer **20** thereby applies feedback control to the screwdown position controls **18** as indicated by the reference character **28** so as to compensate for roll crown change in response to the roll crown test results. For example, the computer **20** can contain a program including in part the following general equation which is used for each stand location:

$$F=(\Delta s\times h+k_r)F_r$$

where:

h=entry strip thickness in inches;
Δs=percent strip crown desired;
k_r=updated roll crown in inches;
F_r=modulus of elasticity for roll bending, pounds/inch;
F=force required to produce enough roll bending to remove the roll crown and impart enough additional bending to produce the desired strip crown.

Updated values of k_r for each stand location cause changes in command value for roll force at that stand. Screwdown position is therefore varied to provide the command roll force and the programmed compensation for changes in work roll crown. From an overall standpoint, the computer **20** prescribes a general draft pattern for the successive mill stands in accordance with the workpiece input characteristics, and controls the draft or gauge reduction taken at each stand in the mill so that substantially desired delivery gauge is realized while strip shape is adequately maintained at the various stand locations to result in flat on-gauge product. Although roll force changes made to compensate for roll crown changes and to control strip shape from a particular stand have an effect on strip gauge from that stand, the computer **20** interrelates the functioning of the various stands so as substantially to provide the desired finished product.

When the roll crown tests are conducted with empty work rolls, the mill spring constant can vary from time to time as a result of wear of the back-up rolls **14**. Since back-up rolls characteristically have a life of one week or more, it can be safely assumed that the slope of the mill spring constant is substantially constant for the relatively short period of time during which comparative tests are made for the work rolls.

In summary, an improved method is provided for operating a reduction rolling mill so that better shape control is provided in the finished product. The method includes a unique procedure for determining actual work roll crown after the work rolls are installed for operation and using the test results for automatic or other adjustment of the mill control system in producing rolled product of substantially desired gauge and shape.

The foregoing description has been presented only to illustrate the principles of the invention. Accordingly, it is desired that the invention not be limited by the embodiment described, but, rather, that it be accorded an interpretation consistent with the scope and spirit of its broad principles.

What is claimed is:

1. A method for operating a reduction rolling mill subject to gauge and shape control and having at least one reduction stand with at least one pair of work rolls, said method comprising the steps of determining at least a reference point on the empty mill spring curve for the reduction stand at a predetermined point in the life of the work rolls, determining at least a point on the empty mill spring curve for the reduction stand at a point in the roll life after the work rolls have undergone subsequent use, determining any change in work roll crown from the test points, and using any determined roll crown change in prescribing the setting of the work rolls.

2. A method for operating a reduction rolling mill subject to gauge and shape control and having at least one reduction stand with at least one pair of work rolls, said method comprising the steps of determining at least a reference point on the empty mill spring curve for the reduction stand at a predetermined point in the life of the work rolls, determining at least respective points on the empty mill spring curve for the reduction stand at various points in the roll life after the work rolls have undergone subsequent use, determining any changes in work roll crown from the test points, and using any determined roll crown change in prescribing the setting of the work rolls.

3. A method for operating a reduction rolling mill subject to gauge and shape control and having at least one reduction stand with at least one pair of work rolls, said method comprising the steps of determining at least a reference point on the empty mill spring curve for the reduction stand prior to any significant rolling use of the work rolls, determining at least a point on the empty mill spring curve for the reduction stand at a point in the roll life after the work rolls have undergone subsequent use, determining any change in the work roll crown from the test points, and using any determined roll crown change in prescribing the setting of the work rolls.

4. A method for operating a reduction rolling mill subject to gauge and shape control and having at least one reduction stand with at least one pair of work rolls, said method comprising the steps of determining at least a reference point on the empty mill spring curve for the reduction stand prior to any significant use of the work rolls, determining at least a point on the empty mill spring curve for the reduction stand at a point in the roll life after the work rolls have undergone subsequent use and have expectedly acquired an increased crown due to differential roll heating, determining at least a point on the empty mill spring curve for the reduction stand at a point in the roll life after the rolls have undergone additional subsequent use and have acquired an expectedly decreased crown due to roll wear, determining any change in work roll crown from the test points, and using any determined roll crown change in prescribing the setting of the work rolls.

5. A method for operating a reduction rolling mill subject to gauge and shape control and having at least one reduction stand with at least one pair of work rolls, said method comprising the steps of determining at least a reference point on the empty mill spring curve for the reduction stand at a predetermined point in the life of the work rolls, determining at least a point on the empty mill spring curve for the reduction stand at a predetermined point in the roll life after the work rolls have undergone subsequent use, determining any change in work roll crown from the test points, and operating an automatic gauge and shape feedback control system in response to any roll crown change in determining the setting of the work rolls.

6. A method for operating a reduction rolling mill subject to gauge and shape control and having at least one reduction stand with at least one pair of work rolls, said method comprising the steps of determining at least a reference point on the empty mill spring curve for the reduction stand at a predetermined point in the life of the work rolls, determining at least respective points on the empty mill spring curve for the reduction stand at various points in the roll life after the work rolls have undergone

subsequent use, determining any changes in work roll crown from the test points, and operating an automatic gauge and shape feedback control system in response to any roll crown change in determining the setting of the work rolls.

7. A method for operating a reduction rolling mill subject to gauge and shape control and having at least one reduction stand with at least one pair of work rolls, said method comprising the steps of determining the roll gap below face produced by a predetermined roll force at a predetermined point in the life of the work rolls, determining the roll gap below face produced by the same predetermined roll force at a point in the roll life after the work rolls have undergone subsequent use, determining any change in work roll crown from any change in the roll gap below face measurements, and using any determined roll crown change in prescribing the setting of the work rolls.

8. A method for operating a tandem reduction rolling mill subject to gauge and shape control and having a plurality of tandem reduction stands each with at least one pair of work rolls, said method comprising the steps of determining at least a reference point on the empty mill spring curve for at least preselected ones of the reduction stands at a predetermined point in the life of the work rolls associated with the preselected stands, determining at least a point on the empty mill curve for the same reduction stands at a point in the respective roll lives after the respective work rolls have undergone subsequent use, determining any change in the roll crown of the respective work rolls from the respective sets of test points, and using any determined roll crown change data in prescribing the setting of the work rolls.

9. A method for operating a reduction rolling mill as set forth in claim 8 wherein the method further includes the steps of determining at least a point on the mill spring curve for the preselected reduction stands at a plurality of

points in the lives of the respective sets of work rolls associated with the preselected stands and after the respective sets of work rolls have undergone subsequent use, and operating programming a programmed computer included in an automatic gauge and shape feedback control system for the mill so as to operate a control system in prescribing the setting of the work rolls in response to any determined roll crown change.

10. A method for determining the change in roll crown after a set of reduction mill work rolls have undergone a period of use, said method comprising the steps of determining at least a reference point on the empty mill spring curve prior to any significant use of the work rolls, determining at least a point on the empty mill spring curve at a point in the roll life after the work rolls have undergone subsequent use, and determining any change in work roll crown from the test points.

11. A method for determining the change in roll crown after a set of reduction mill work rolls have undergone a period of use, said method comprising the steps of determining the roll gap below face produced by a predetermined roll force prior to any significant rolling use of the work rolls, determining the roll gap below face produced by the same predetermined roll force at a point in the roll life after the work rolls have undergone subsequent use, and determining any change in work roll crown by multiplying any difference in the roll gap below face measurement by one half.

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