

[54] **ROLLING OF STRIP OR PLATE MATERIAL**

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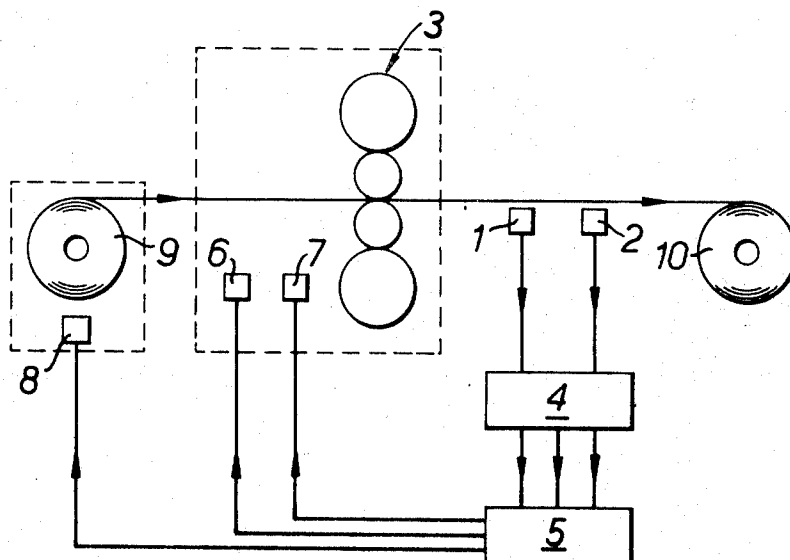
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[57] **ABSTRACT**

Strip or plate material being rolled under symmetrical rolling conditions is simultaneously corrected for gauge and shape errors in a single integrated gauge and shape control system, by detecting its gauge and shape upon leaving the rolling mill; expressing detected shape as a defined combination of different curves and deriving defined error signals from coefficients of the curves; deriving an error signal from detected gauge; translating said error signals into defined control signals; and feeding each control signal to a respective one of a plurality of different rolling mill control means.

20 Claims, 2 Drawing Figures



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2 Sheets-Sheet 1

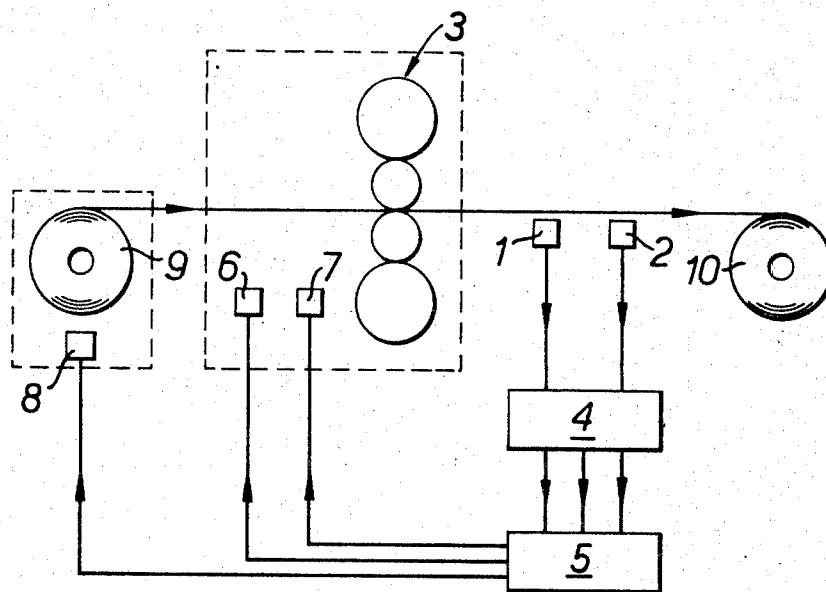
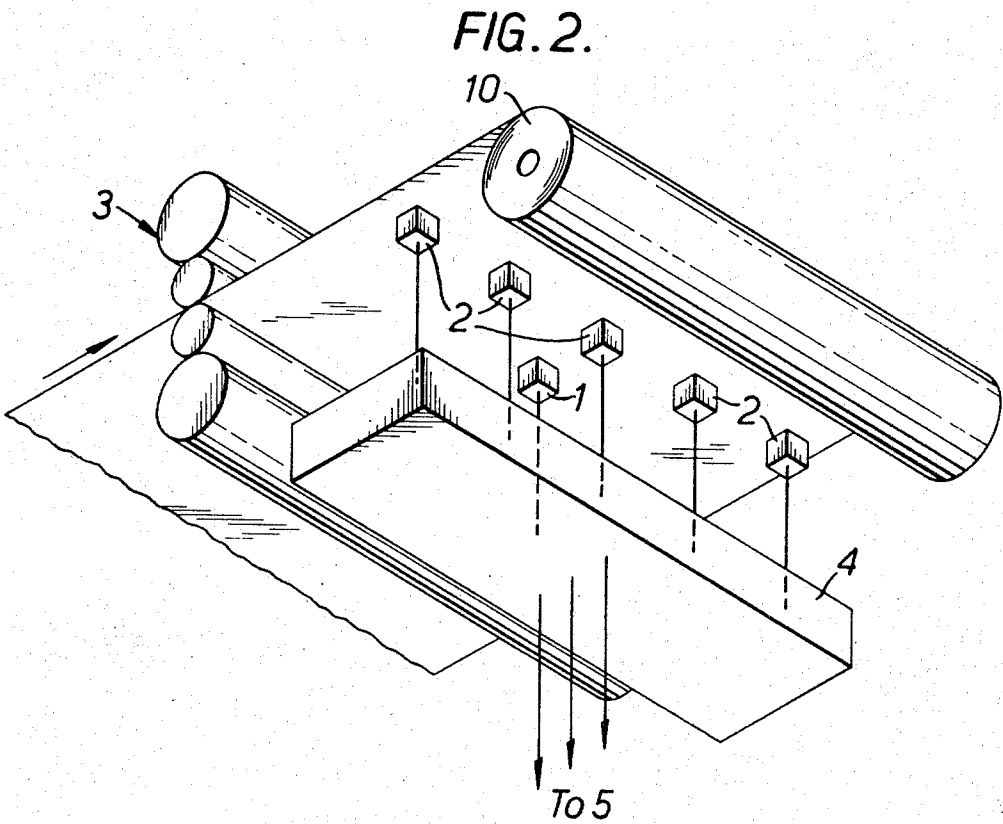


FIG. 1

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ROLLING OF STRIP OR PLATE MATERIAL

This invention relates to rolling of strip or plate material. Strip material includes sheet material.

Modern requirements for flat roller strip or plate material make it desirable to control the rolling operation so that the product has the desired thickness (namely the correct gauge) and is free from buckles and internal stresses (namely is of good shape). Separate control of gauge and shape has not been practical because of their interacting nature. For example, a gauge correcting action by rolling stand screw adjustment has an effect on shape. Alternatively, as another example, a shape correcting action on roll bending control means or strip tension control means has an effect on gauge. Depending on the degree of interaction between gauge and shape, control of the rolling operation with separate control means for gauge and shape, once initiated, may take a long time or never be achieved.

It has now been found in accordance with the present invention that simultaneous control of gauge and shape of strip or plate material may be provided to obtain strip or plate material of desired thickness and shape.

According to one aspect of the present invention, a method for controlling gauge and shape of strip or plate material during rolling thereof in a rolling mill under symmetrical rolling conditions includes detecting gauge of strip or plate material leaving the mill; detecting shape of strip or plate material leaving the mill; expressing the detected shape as a combination of at least two curves of different geometrical form and deriving at least two error signals from the coefficients of the curves, each error signal corresponding to a respective one of the coefficients; deriving an error signal from the detected gauge; translating said error signals into control signals equal in number to the number of error signals and for correcting simultaneously gauge and shape errors; and feeding each control signal to a respective one of a plurality of different mill control means to make simultaneous correction of gauge and shape errors.

According to another aspect of the invention, apparatus for controlling gauge and shape of strip or plate material during rolling thereof in a rolling mill under symmetrical rolling conditions includes sensor means for detecting gauge of strip or plate material leaving the mill; sensor means for detecting shape of strip or plate material leaving the mill; a computer for (a) expressing the detected shape as a combination of at least two curves of different geometrical form and deriving at least two error signals from the coefficients of the curves, each error signal corresponding to a respective one of the coefficients, and (b) deriving an error signal from the detected gauge; a controller for translating said error signals into control signals equal in number to the number of error signals and for correcting simultaneously gauge and shape errors; and a plurality of different mill control means for receiving at each respective one of the control means each control signal to make simultaneous correction of gauge and shape errors.

The sensor means for detecting gauge may be or include an X-ray gauge on the output side of the rolling mill. Alternatively or additionally, the sensor means may be or include a load cell under rolling stand adjust-

ment screws. The sensor means for detecting shape may be or include a tension distribution meter. Preferably, the meter is one described in our U.K. Pat. specification No. 1,138,822. This meter includes at least five probes for positioning at spaced points across the strip or plate material leaving the rolling mill and detecting tension in that material at those points. The gauge and shape sensor means may be located above and/or below the strip or plate material leaving the rolling mill. The choice will be according to the circumstances. Each sensor means should be as close as possible to the rolling mill.

The gauge and shape errors at a point distant x from the mid-width line of the material measured transversely thereof are components of the total profile error $E(x)$ of the strip or plate material at that point. $E(x)$ may be expressed in accordance with the present invention by equation 1:

$$E(x) = E_c + F_1(x) + F_2(x) \dots + F_n(x). \quad (1)$$

in which

- E_c is the total profile error at the mid-width line where x is 0. E_c represents the gauge error component, from which preferably one error signal may be derived by a computer.
- $F_1(x) + F_2(x) \dots + F_n(x)$ are homogenous functions of x , chosen on the basis of theoretical and practical considerations to obtain a description of $E(x)$ sufficiently accurate for practical purposes.

For symmetrical rolling conditions, which are the conditions required by the present invention, the total profile error $E(x)$ will be symmetrical about the mid-width line of the strip or plate material. If there should be asymmetry in $E(x)$, symmetry can be provided by differential movement of rolling stand adjustment screws, in which one screw is raised or lowered with respect to the other screw. With $E(x)$ symmetrical about the mid-width line, and on the basis of theoretical considerations supported by measurement on rolled material, the functions $F_1(x) \dots F_n(x)$ of equation 1 may be represented as:

$$F_1 = K_1 x^2$$

$$F_2 = K_2 x^4 \dots F_n = K_n x^{2n}$$

in which $K_1 \dots K_n$ are constants. Thus, $E(x)$ may then be represented by equation 2:

$$E(x) = E_c + K_1 x^2 + K_2 x^4 \dots + K_n x^{2n} \quad (2)$$

In this equation, the terms $K_1 x^2 \dots K_n x^{2n}$ represent the component of shape error in n dimensions under symmetrical rolling conditions. This may be called the symmetrical component of shape error in n dimensions. Thus, the control of gauge error and shape error will be provided by the elimination of $(n+1)$ error parameters, namely $E_c, K_1, K_2 \dots K_n$. These parameters depend on the adjustable parameters of the rolling mill, for example the positions of rolling stand adjustment screws, rolling tension and roll bending force. For practical purposes, it is generally sufficient to consider the component of shape error as the simpler equation 3:

$$\text{Shape error component} = K_1 x^2 + K_2 x^4 \quad (3)$$

Given equations 2 and 3, the components of shape error (for one or more transverse positions x of the

material) may be expressed as a combination of at least two curves of different geometrical form. Therefore, shape error may be expressed in terms of at least the two coefficients K_1 , K_2 . At least two error signals may then be derived by a computer from these coefficients.

A mill control means may serve to control for example position of a roll adjustment screw, S ; roll bending force, J ; front rolling tension, T_f ; or back rolling tension, T_b . Small changes ΔS , ΔT , ΔJ in these controlling factors cause linearly related changes in the error parameters E_c , K_1 , K_2 . . . K_n . These changes for the case of equation 3 above are expressed by the equations 4:

$$\begin{cases} E_c = a_1 \Delta S + a_2 \Delta T + a_3 \Delta J \\ K_1 = a_4 \Delta S + a_5 \Delta T + a_6 \Delta J \\ K_2 = a_7 \Delta S + a_8 \Delta T + a_9 \Delta J \end{cases} \quad (4)$$

In which a_1, a_2 . . . a_9 are constants referred to as Mill Parameters. These parameters may be determined theoretically or experimentally. They measure the sensitivity of the corresponding error parameters E_c , K_1 , K_2 . . . K_n to the controlling factors ΔS , ΔT , ΔJ . Control signals corresponding to ΔS , ΔT , ΔJ may be produced by a controller translating error signals from a computer as described above. The control signals may then be fed to the plurality of mill control means.

The plurality of mill control means preferably includes rolling stand adjustment screw control means; roll bending control means; or, especially when strip material is being processed, tension control means. Any combination of mill control means may be used. Preferably for strip material, each of the specific mill control means just mentioned may be used. Tension control means may control a coiler and/or decoiler for strip material. Roll bending control means may be provided by hydraulic jacks acting on the necks of rolls in the mill.

A schematic embodiment of the present invention in accordance with equation 3 above will now be described by way of example with reference to the accompanying drawings wherein:

FIG. 1 is a diagrammatic side view of a rolling mill provided with control apparatus according to the invention, and

FIG. 2 is an enlarged, fragmentary perspective view showing the shape sensors feeding into the computer.

In the drawing, apparatus according to the invention includes a gauge sensor 1 and a shape sensor 2 for detecting under symmetrical rolling conditions gauge and shape respectively of strip material leaving the rolls 3 of the rolling mill. The sensors may be located above and/or below the material as required and as close as possible to the rolling mill.

The gauge sensor 1 may be an X-ray gauge on the output side of the rolls 3 or a load cell under rolling stand adjustment screws (not shown). The shape sensor 2 may be a tension distribution meter. Preferably, this meter is one described in our U.K. Pat. specification No. 1,138,322, which includes at least five probes for positioning at spaced points across the strip material leaving the rolls 3 and for detecting the tension in that material at those points.

The output signals of the sensor 1, 2 pass respectively into a computer 4, programmed with the required

gauge of the strip material and the desired zero shape error. The computer derives an output error signal from the output signal of the gauge sensor 1. The error signal represents the gauge error coefficient E_c . The computer also expresses the output signal from the shape sensor 2 as a combination of two curves of different geometrical form, and derives two output error signals, one for coefficient of each curve. To do this, the computer employs standard curve-fitting or regression techniques which are known in themselves to one skilled in the art.

Each output error signal from the computer passes into a controller 5. The controller translates these signals in combination into an equal number of output control signals, ΔS , ΔT , ΔJ , by means of an algorithm based on equations 4. The controller utilizes the mill parameters mentioned with reference to the equations 4 and the time responses of the measuring device together with any transport delays associated with them. Each output control signal passes into a respective one of a plurality of different mill control means. These means are respectively rolling stand adjustment screw control means 6, to which the ΔS control signal is fed; roll bending control means 7, to which the ΔJ control signal is fed; and tension control means 8, to which the ΔT control signal is fed. These means may operate simultaneously. The roll bending control means 7 control rolling stand hydraulic jacks (not shown). The tension control means 8 controls a decoiler 9 from which strip material passes into the rolling mill. Alternatively or additionally, the means 8 may control a coiler 10 which coils the product strip material. The tension control means 8 could have been omitted if plate material had been rolled instead of strip material.

The controller 5 enables simultaneous corrections for gauge and shape to be implemented without undesirable interaction as would occur with separate independent controls for gauge and shape.

We claim:

1. A method for controlling gauge and shape of strip and plate materials in a single integrated gauge and shape control system during rolling thereof in a rolling mill under symmetrical rolling conditions, characterized in that the method includes detecting gauge of said material leaving the mill; detecting shape of said material leaving the mill; expressing the detected shape as a combination of at least two curves of different geometrical form defined by algebraic equations; deriving a gauge error signal from the detected gauge; translating said gauge error and a coefficient from each of the equations in combination into control signals equal in number to the number of said coefficients plus said gauge error for correcting simultaneously gauge and shape errors; and feeding each control signal to a respective one of a plurality of different mill control means to make simultaneous correction of gauge and shape errors.

2. A method as claimed in claim 1, characterized in that gauge is detected by an X-ray gauge (1) on the output side of the rolling mill.

3. A method as claimed in claim 1, characterized in that gauge is detected by a load cell (1) under rolling stand adjustment screws.

4. A method as claimed in claim 1, characterized in that shape is detected by a tension distribution meter (2).

5. A method as claimed in claim 4, characterized in that the tension distribution meter (2) includes at least five probes, positioned at spaced points across the strip or plate material leaving the rolling mill and detecting tension in that material at those points.

6. A method as claimed in claim 1, characterized in that the plurality of different mill control means includes at least two different mill control means chosen from rolling stand adjustment screw control means (6), roll bending control means (7) and tension control means (8).

7. A method as claimed in claim 6, characterized in that each of said control means (6,7,8) is present.

8. Apparatus for controlling gauge and shape of strip and plate materials during rolling thereof in a rolling mill under symmetrical rolling conditions, characterized in that the apparatus includes sensor means (1) for detecting gauge of said material leaving the mill; sensor means (2) for detecting shape of said material leaving the mill; a computer (4) for receiving the outputs of the first and second sensor means and (a) expressing the detected shape as a combination of at least two curves of different geometrical form defined by algebraic equations, and providing at least two signals representative of a coefficient of each equation, and (b) deriving an error signal from the detected gauge; a controller (5) for receiving said signals in combination and translating them into control signals equal in number to the total number of said signals and for correcting simultaneously gauge and shape errors; and a plurality of different mill control means (6, 7, 8) for receiving at each respective one of the control means each control signal to make simultaneous correction of gauge and shape errors.

9. Apparatus as claimed in claim 8, characterized in that the sensor means (1) for detecting gauge includes at least an X-ray gauge on the output side of the mill.

10. Apparatus as claimed in claim 8, in which the sensor means (1) for detecting gauge includes at least a load cell under rolling stand adjustment screws.

11. Apparatus as claimed in claim 8, characterized in that the sensor means (2) for detecting shape includes at least a tension distribution meter.

12. Apparatus as claimed in claim 11, characterized in that the tension distribution meter (2) includes at

least five probes for positioning at spaced points across the strip or plate material leaving the mill and for detecting tension in that material at those points.

13. Apparatus as claimed in claim 8, characterized in that the plurality of different mill control means includes at least two different mill control means chosen from rolling stand adjustment screw control means (6), roll bending control means (7) and tension control means (8).

14. Apparatus as claimed in claim 13, characterized in that each of said control means (6,7,8) is present.

15. A method as claimed in claim 1 characterized in that said coefficients and said gauge error are each expressible as a function of control factors equal in number to said coefficients plus said gauge error, and wherein said translating step comprises calculating said control factors and providing said control signals in response to each of said control factors.

16. A method as claimed in claim 1 characterized in that the said equations are functions of X where X is the distance of a point on the strip or plate from the longitudinal center line thereof.

17. A method as claimed in claim 16 characterized in that the said equations are of the form $F_1 = K_1 X^2$, $F_2 = K_2 X^4$, ... $F_n = K_n X^{2n}$.

18. A method as claimed in claim 1 characterized in that said coefficients and said gauge error are each expressible as a linear combination of control factors equal in number to said coefficients plus said gauge error, and wherein said translating step comprises calculating said control factors and providing said control signals in response to each of said control factors.

19. Apparatus as recited in claim 8 characterized in that said signals are each expressible as a function of control factors equal in number to said total number of said signals, and wherein said controller generates said control factors and provides said control signals corresponding to each control factor.

20. Apparatus as recited in claim 8 characterized in that said signals and gauge error signal are each expressible as a linear combination of control factors equal in number to said total number of signals, and wherein said controller generates said control factors and provides said control signals corresponding to each control factor.

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