

July 29, 1969

J. G. WISTREICH

3,457,748

ROLLING OF STRIP

Filed Oct. 11, 1966

2 Sheets-Sheet 1

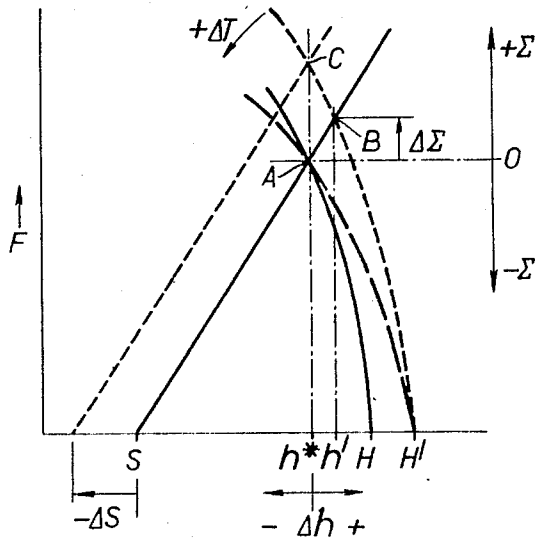


FIG. 1.

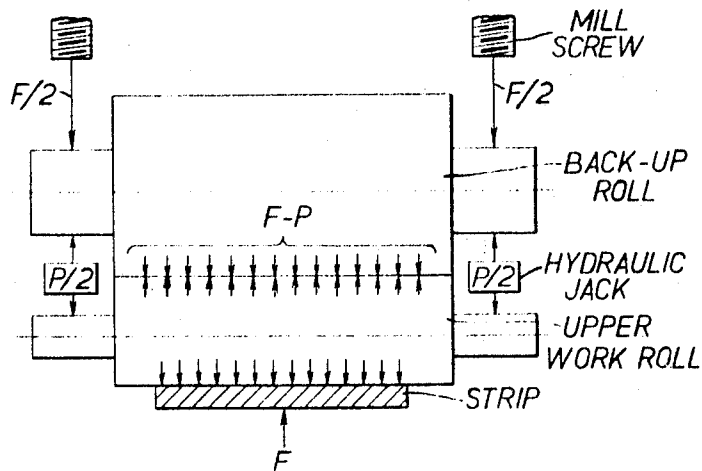


FIG. 2.

INVENTOR
JOHN GEORGE WISTREICH
BY
Bacon & Thomas
ATTORNEYS

July 29, 1969

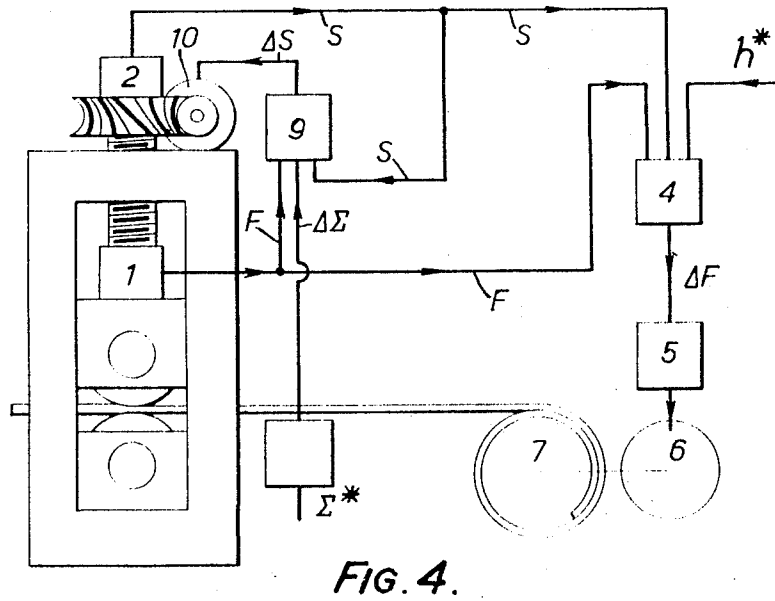
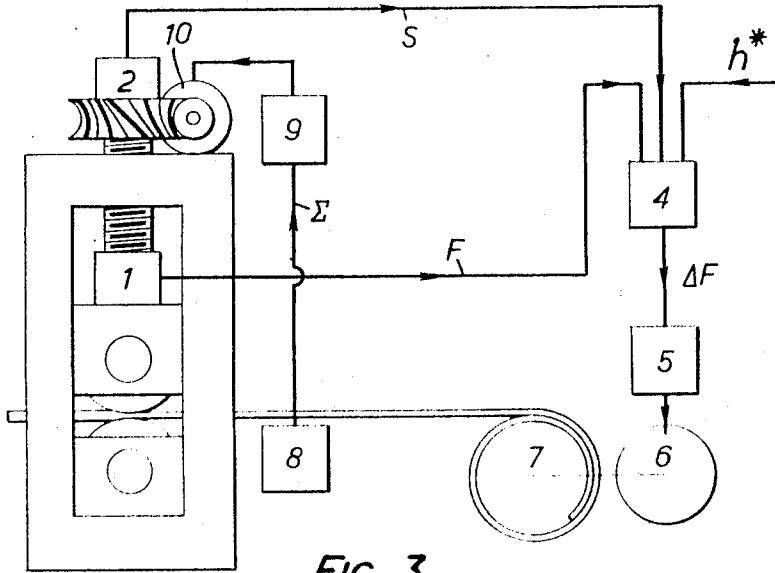
J. G. WISTREICH

3,457,748

ROLLING OF STRIP

Filed Oct. 11, 1966

2 Sheets-Sheet 2



INVENTOR
JOHN GEORGE WISTREICH
BY *Bacon & Thomas*
ATTORNEYS

1

2

3,457,748

ROLLING OF STRIP

John G. Wistreich, Belmont, Surrey, England, assignor to The British Iron and Steel Research Association
 Filed Oct. 11, 1966, Ser. No. 585,871
 Int. Cl. B21b 37/08

U.S. Cl. 72—8

6 Claims

ABSTRACT OF THE DISCLOSURE

A strip rolling apparatus strip gauge and shape sensing means and automatically responsive control means to control strip gauge by adjusting strip tension and to control strip shape by controlling roll screw down setting or mutual flattening between work roll and back-up roll by applying roll separating forces thereto. The tension control affecting shape and the shape control affecting gauge in mutually compatible senses.

This invention relates to the rolling of strip and is particularly concerned with the automatic control of strip gauge and shape, that is to say, strip thickness and flatness.

An object of the invention is to provide a method and apparatus for automatically regulating a strip rolling mill so that deviations from the desired gauge and shape of the rolled strip, which deviations arise naturally in the rolling process, are both maintained within narrow tolerances relative to the desired values.

A measure of strip shape can be defined as follows: perfectly flat strip has zero shape, expressed as $\Sigma=0$; strip with wavy edges or so-called long edges, has positive shape, $\Sigma>0$; and strip with a wavy middle or so-called, long middle, has negative shape $\Sigma<0$. In practice, if a mill is initially set up correctly so as to roll strip to some desired gauge, h^* , and to perfect flatness, $\Sigma^*=0$, inevitable disturbances of the conditions of rolling give rise to errors of gauge, $\Delta h=h-h^*$, and of shape, $\Delta\Sigma=\Sigma-\Sigma^*$. Theoretical considerations of the rolling process suggest, and experimental measurements confirm that the two errors occur together and are of the same sign.

Various proposals have in fact already been made in respect of automatic strip gauge control and this is commonly effected by regulation of the roll gap setting and/or strip tension as control factor or factors. One example of such control is represented by British patent specification No. 681,373 which describes a system wherein the gauge currently being rolled is computed from signals proportional to the rolling force and the roll gap setting, derived respectively from load cells situated between the roll chocks and mill screws, and from mill screw position detectors. This current gauge is represented by an electrical signal, and a similarly proportionate signal representing the desired gauge is subtracted therefrom to produce a difference, or error signal. The error signal is employed to regulate the front and/or back tension of the strip relative to the mill stand in question, and the magnitude and sense of such regulation is arranged to be such as to eliminate the gauge error. In the case of a single stand mill the front and/or back tension can be controlled by the motor or motors driving the associated coiler and/or uncoiler, respectively; while in the case of a tandem mill the relevant motor drive control may be associated with the rolls of a mill stand adjacent to that in question.

Turning to the question of shape control, a proposal has already been made in co-pending patent application No. 17,339/65 to provide a strip shape sensor device. Such device may take various forms, such as a plurality of rollers which are urged to engage the strip, from below, say, at different points transverse the strip path. In the case of strip having imperfect shape, the rollers will as-

sume different heights and an electrical signal representing such height difference can be employed to represent the corresponding error in shape. Other means can be employed to indicate the shape errors but some such arrangement as described above is preferred in that it not only detects manifest shape errors which are superficially apparent from local transverse undulations of the strip, but it also detects latent bad shape represented by transverse variations of longitudinal stresses in the strip. Also, the above described shape sensor device is readily made in robust form and does not require highly accurate signal generation for appropriate accuracy of shape sensing.

In any event, as in the case of gauge control, a shape error signal can be generated and applied to regulate one of the controlling factors of the rolling process, such as roll gap setting, strip tension or roll camber, to correct the process in respect of deviations from required shape.

However, while individual proposals may be made for automatic control of strip gauge and shape, it is an inherent feature of the process of rolling that shape and gauge errors generally arise together and it is an inherent feature of the devices for regulating shape and gauge that correction of errors in shape will cause a change in gauge which will interfere, to a greater or lesser extent, with the automatic control of gauge if that is also to be provided on the mill. Similarly, correction of gauge errors simultaneously causes the shape to change, as interfering with automatic shape control.

According to one aspect of the invention, there is provided an apparatus for automatically rolling strip material, comprising means for producing a signal indicative of the shape of the strip leaving the rolls, means for producing a signal indicative of the gauge of the strip leaving the rolls, and control means for varying the roll separating force in dependence on said gauge signal to maintain a substantially constant gauge leaving the rolls and in dependent on said shape signal to maintain a substantially constant shape of strip leaving the rolls.

According to another aspect of the invention, there is provided an apparatus for automatically rolling strip material, comprising means for producing an electrical signal indicative of the shape of the strip leaving the rolls, means for producing an electrical signal indicative of the gauge of the strip leaving the rolls, first electric control means for varying the tension at which the strip is pulled through the rolls, and hence the roll separating force, in dependence on said gauge signal to maintain a substantially constant gauge leaving the rolls, and second electric control means for simultaneously varying the roll separating force in dependence on said shape signal to maintain a substantially constant shape of strip leaving the rolls.

It is however, important to appreciate that the present invention does not merely consist in integrating any pair of automatic gauge and automatic shape control systems, and this is best demonstrated by a consideration, by way of example, of pairs of systems which are incompatible as well as other which are compatible.

In the drawings:

FIGURE 1 is a graph illustrating the relationship between changes in strip gauge and strip shape and the manner in which certain adjustments for changes in one affect the other and FIGURES 2, 3 and 4 are schematic illustrations of different embodiments of apparatus for practicing the present invention.

Referring to FIGURE 1 of the accompanying drawings, such figure shows the effects of gauge control by screw-down or tension adjustment on shape. In this figure the vertical axis represents rolling force F and also shape Σ , and the horizontal axis represents roll gap setting, ingoing gauge H , and outgoing gauge h . Point A represents the rolling conditions at a particular instant when the in-

going gauge is H and the roll gap screw setting is S . Point A is determined as the intersection of the straight line at which represents the effect of the mill spring on the roll gap, and the deformation curve AH which related the rolling force F to the outgoing thickness h .

Assuming that the conditions at that time are such that the desired gauge h^* and shape $\Sigma^*=0$ are obtained, relevant considerations are what happens if the ingoing gauge subsequently changes to H' and what is achieved by different attempts at corrective action of the resultant changes in rolling conditions. Firstly, considering the change in rolling conditions; the new situation is represented by point B which is seen to be represented by a positive gauge error and positive shape error, the latter being so since the rolling force increases and thereby subjects the rolls to increased bending thereby tending to produce a convex roll gap. Secondly, considering possible corrective actions: if screwdown action is initiated to reduce the gauge error, this is represented by translation of the mill spring line sA to the left by $-\Delta s$ and the point B will move along the new deformation curve $H'B$ until it coincides with a point C corresponding to the desired gauge h^* . It will be noted that the effect of such action is to increase the existing positive shape error $\Delta\Sigma$.

If instead, tension adjustment is initiated to vary the roll separating force and thereby to reduce the gauge error, this is represented by rotation of the deformation curve $H'B$ until point B coincides with A whereat the gauge error is reduced to zero. In this case it will be seen that the shape error is also reduced to zero.

This discussion in relation to FIGURE 1 is idealized to a certain extent, but nevertheless it does indicate that different forms of gauge control can have quite opposite effects on shape control. This arises from the fact that, in general, screwdown action causes the intersection of the mill spring line and deformation curve to move along the deformation curve, while tension adjustment tends to make the intersection move along the mill spring line.

Accordingly, correction of gauge errors by tension control, which can be referred to as $AGC(T)$, whether front or back tension tends also to correct the shape errors which have arisen from the same causes as the gauge errors. Correction by screwdown, $AGC(S)$, however, appears incompatible with automatic shape control, ASC , because it aggravates the shape errors already present.

Considering briefly some other modes of control for usefulness in connection with the present invention: shape control through tension, $ASC(T)$, is basically compatible with $AGC(T)$ as seen from the above discussion of FIGURE 1 since tension correction to reduce a positive or negative shape error produces a respectively negative or positive gauge variation thereby attenuating the shape error associated with the gauge error that is being corrected.

A further possibility is to employ roll bending devices in accordance with recent proposals, such as generally indicated in FIGURE 2 of the accompanying drawings, whereby pressure means in the form of hydraulic jacks are located between corresponding back-up and work roll ends. In operation for shape control, the force on the screws and mill stretch will not change, but the mutual flattening of back-up work and work roll will be reduced, effecting a narrowing of the roll gap and thereby causing a negative gauge error. This error will, however, be much smaller than is the case with tension regulation for shape control purposes and one may therefore usefully employ a combination of $AGC(T)$ and $ASC(JBW)$, the latter indicating "jacks between back-up and work rolls."

If, though, one contemplates use of $ASC(JWW)$,¹ that is the system in which the jacks are situated between the chocks of the work rolls, one can readily show from a consideration of the disposition of forces that correction for a positive shape error will increase the mill stretch and mutual flattening of the back-up rolls, whereby a positive gauge error ensues. Recalling that shape and gauge errors

normally occur in the same sense indicates that $ASC(JWW)$ will interfere with AGC .

Another possibility is shape control by regulation of the thermal camber and roll gap contour. In practice, it will be difficult to ensure a change of the camber without simultaneously changing the mean roll diameter and so, on face value, affecting gauge; moreover, the regulation is likely to be too slow acting for most practical purposes.

A further possible mode for shape control is by regulating longitudinal strip tension transversely of the strip, by pivotable tension rollers, say, but this will produce a corresponding variation in mill stretch. Thus, correction of a positive shape error will be associated with the introduction of a positive gauge error.

The above consideration indicates that if separate control systems for gauge and shape are to be employed, then compatibility is only achieved by careful consideration and choice of suitable systems in accordance with the invention. In fact, such consideration of a pair of control systems in parallel, as it were, suggests that only

$$AGC(T)+ASC(T) \text{ or } AGC(T)+ASC(JBW)$$

are compatible. Even then, the former pair may lead to hunting between the relevant systems in that $ASC(T)$ involves a transport time delay which varies with mill speed owing to the nature of the measurement of shape, whereas $AGC(T)$ does or does not depending on where the gauge is measured.

A further possibility arises from consideration of utilizing a pair of control systems connected in cascade, as it were. One such integrated cascade system which appears advantageous employs tension regulation of gauge and screwdown regulation of shape, and may be referred to as $AGSC(T/S)$. Thus $AGC(T)$ can be effected by the regulation of back and/or front tension, in accordance with specification No. 681,373, say, in a first control loop, and a shape control error signal is made to actuate the screwdown setting in similar manner to $AGC(S)$.

One example of $AGSC(T/S)$ is illustrated schematically in FIGURE 3 of the accompanying drawing. The gauge control is effective by a signal ΔF proportional to the deviation of the current rolling force from that force at which the current roll gap setting will produce the required gauge. This signal is electronically computed from a signal representing the current rolling force F and derived from the load cells 1, a signal representing the roll gap setting s and derived from the screw position detectors 2, and a signal h^* representing the desired gauge. The computation is carried out by a computer 4 in accordance with the equation $\Delta F = F - M(h^* - s)$, where M represents the mill spring modulus. The computed signal is applied via a torque regulator 5 to control the drive motor or motors 6 of the coiler or uncoiler 7.

Shape is corrected by use of a signal representing current strip shape Σ generated by a shape sensor device 8 according to application No. 17,339/65. Signal Σ is applied via a computer 9 to control the screwdown motors 10 and thereby to regulate the roll gap setting s . The computer 9 will control the screwdown motors 10 in predetermined manner in response to the signal Σ , such that the roll gap setting s is reduced or increased as $\Sigma > 0$ or < 0 , respectively.

In operation, a shape correction alters the roll gap setting, which in turn changes the rolling force and so brings the gauge control system into operation by regulation of tension in such a sense as to assist reduction of the original shape error and maintain correct gauge.

In another example of an $AGSC(T/S)$ system, the shape control computer may be responsive to variables additional to that of shape Σ , and such a system is illustrated schematically in FIGURE 4 of the accompanying drawings. The gauge control duplicates that of FIGURE 3, but the shape control is based on the following consideration:

Firstly, a measure of shape can be represented by the expression:

$$\Sigma = a \left(\frac{le - lc}{w \cdot lc} \right) \quad (1)$$

where a is a constant, lc is an outgoing length of strip measured along its centre line, le is the corresponding strip edge length, and w is the strip semi-width.

If the ingoing strip has perfect shape, represented by $Le = Lc$, Equation 1 can be rewritten as

$$l + \frac{w}{a} \cdot \Sigma = \frac{le/Le}{lc/Lc} \quad (2)$$

and in the absence of lateral spread, ingoing and outgoing thickness H and h , can be substituted on the basis of constant volume, $h \cdot l = H \cdot L$, whereby

$$l + \frac{w}{a} \cdot \Sigma = \frac{hc/he}{Hc/H} \quad (3)$$

Since the associated gauge control system will operate generally in respect of mean gauge \bar{h} , it is convenient to approximate Equation 3 as

$$l + \frac{b \cdot w}{a} \cdot \Sigma = \frac{hc/\bar{h}}{Hc/H} \quad (4)$$

where $b \cdot w$ is the distance from the strip centre line to the point at which $h = \bar{h}$, and the approximation is good if Σ is not excessively large.

Now the mean gauge \bar{h} is that determined by the control relationship

$$\bar{h} = s + F/M \quad (5)$$

If then one assumes that a mill stand with automatic gauge control is such that \bar{h} is maintained substantially constant, and that for a period of time strip of constant dimensions is fed into the mill whereby Hc/H is substantially constant: then if conditions in the roll gap are disturbed in such a way as to cause a change of roll force, ΔF , and thereby of shape of the outgoing strip, the situation is represented by partial differentiation of Equation 4, namely,

$$\Delta hc/\bar{h} = \frac{Hcb \cdot w}{Ha} \cdot \Delta \Sigma = c \cdot \Delta \Sigma \quad (6)$$

where

$$c = \frac{Hc \cdot bs}{H \cdot a} \quad (7)$$

Also, it can be deduced from beam theory that

$$\Delta hc = d \cdot \Delta F$$

where d is a constant depending on the strip width and roll dimensions. Thus, under the above conditions:

$$\Delta \Sigma = N \cdot \Delta F \bar{h} \quad (8)$$

where N is a constant equal to d/c , as can be derived from the foregoing equations and the accessory screw setting control can be determined, from Equations 5 and 6 as

$$\Delta s = - \frac{S + F/M}{NM} \cdot \Delta \Sigma \quad (9)$$

In alternative arrangements of those illustrated and described by way of FIGURES 3 and 4, computer 4 may be arranged to compute the current rolled gauge in accordance with Equation 5 above and to subtract from this the desired gauge h^* , so that the signal applied to regulator 5 represents $s + F/M - h^*$.

Again, the systems of FIGURES 3 and 4 may be provided with means, such as an X-ray gagemeter for providing a direct measure of the current outgoing gauge h , such means preferably being situated in close proximity to the shape sensor device. The gagemeter signal can then be compared with signal h^* whereby the resultant gauge error signal ($h - h^*$) can be applied to regulator 5, and in the case of FIGURE 3 the load cells and screw position detectors can be dispensed with.

Summarising the above overall consideration: it has been demonstrated that automatic control of both gauge and shape in a single strip mill is not achieved by combination of any two independent systems in a parallel arrangement, but rather a degree of compatibility must be found. Parallel combination of AGC(T) + ASC(T) or AGC(T) + ASC(JBW) appear advantageous from this point of view. Also, consideration of an integrated control with individual loops in cascade indicate that various forms of AGSC(T/S) are suitable.

Lastly, it is desirable that AGSC be preceded by use of a predictive or negative feedback AGC system such that the control of the present invention is not required to deal with excessive errors. It will be seen that this is compatible with the predominantly common factor AGC(T) in the above proposals, since such control is commonly employed on the last stand of a tandem mill and is well suited to use as a finishing control.

What we claim is:

1. Apparatus comprising opposed rolls for automatically rolling strip material, comprising means for sensing at locations spaced transversely of the strip the tension in the strip leaving the rolls and for producing a signal indicative of the shape thereof, means for producing a signal indicative of the gauge of the strip leaving the rolls, first control means, responsive to said signal indicative of gauge for varying the tension at which the strip is pulled through the rolls to maintain a substantially constant gauge leaving the rolls, and second control means, responsive to said signal indicative of shape, for simultaneously varying the magnitude of the roll separating forces to maintain a substantially constant shape of strip leaving the rolls.

2. Apparatus according to claim 1, wherein said second control means for varying the magnitude of the roll separating forces is arranged to control the screw down setting of the rolls.

3. Apparatus according to claim 2, wherein the first control means includes computing means for computing a change in roll separating force (ΔF) from the equation

$$\Delta F = F - M(h^* - s)$$

where

F represents the current rolling force

M is the mill spring modulus

h^* is the desired gauge, and

s is the roll gap setting.

4. Apparatus according to claim 3 wherein the screw-down setting of the rolls is varied in dependence on the equation

$$\Delta s = - \frac{S + F/M}{NM} \cdot \Delta \Sigma$$

where

Δs is the required change in the roll gap setting

N is a constant and

$\Delta \Sigma$ denotes a difference in the actual shape signal and the desired shape signal.

5. Apparatus comprising opposed work rolls for rolling strip material and back-up rolls therefor, means for sensing at locations spaced transversely of the strip the tension in the strip leaving the rolls and for producing a signal indicative of the shape thereof, means for producing a signal indicative of the gauge of the strip leaving the rolls, first control means, responsive to said signal indicative of gauge, for varying the tension at which the strip is pulled through the rolls to maintain a substantially constant gauge leaving the rolls, and second control means, responsive to said signal indicative of shape, for simultaneously varying the mutual flattening of the work and back-up rolls to maintain a substantially constant shape of strip leaving the rolls.

6. Apparatus according to claim 5, wherein the mutual flattening of the work and back-up rolls is varied by pres-

sure means located between corresponding back-up and work roll necks.

References Cited

UNITED STATES PATENTS

3,103,138	9/1963	Wallace	72-8	5
3,194,036	7/1965	Confor et al.	72-11	
3,315,506	4/1967	Schneider	72-12	

3,334,502	8/1967	Heindel et al.	72-9
3,334,508	8/1967	Martin	72-364

MILTON S. MEHR, Primary Examiner

U.S. Cl. X.R.