ABSTRACT: Method and apparatus for correcting and controlling the profile of the gap between loaded work rolls by first detecting differences in fractional reduction causing bad shape of rolled strip material leaving the work rolls, and then deriving in a particular way from the detected differences in fractional reduction, control signals to control a plurality of different rolling mill control means for adjusting the profile of the gap.
This invention relates to a method and apparatus for rolling strip material. Let us consider the rolling of strip material from an initial thickness to the final thickness through a series of passes in a single-rolling stand and/or through a tandem mill, and let us assume that the material to be rolled is of good shape and that its curvature is negligible. To this end and to the constancy of volume, the requirement of good shape in the rolled strip calls for a substantially uniform fractional reduction across the width of the strip. This means that initial and final transverse thickness profiles of the strip must be geometrically similar. In practice the above-mentioned profile similarity is also desirable between input and output profiles at intermediate stages of the total reduction. This is especially so in high quality products for example electrical steels.

The relevant transverse strip profile at all stages other than the initial entry is determined by the profile of the gap between the work rolls during the rolling process. To roll good shape therefore it is necessary that the loaded roll gap automatically adjust be of the correct geometrical form. In turn the actual roll gap profile depends upon such factors as the camber ground on the rolls, the roll wear, the roll deflection under the forces acting on them and the strains produced by the thermal gradients. Only by maintaining the resultant effect of all these factors within close limits may material of good shape be rolled.

Since it is difficult to maintain the roll gap profile constant because of thermal effects, changes in the rolling load and changes in the input profile, then it is desirable to have means whereby the roll gap may be automatically adjusted to correct any profile errors anticipated or detected therein during rolling.

According to the invention, there is provided a method of rolling strip material including the steps of anticipating or detecting during rolling the anticipated or actual errors respectively in the profile of the roll gap, expressing the symmetrical component of the profile errors as a combination of a plurality of curvatures of different geometric form, deriving the coefficients of said curves to provide error signals, and translating said error signals into control signals whereby to adjust by a plurality of different control means the deflection of the rolls so as to correct for the anticipated or measured errors in the profile of the roll gap and hence of the strip being rolled.

According to the invention, there is also provided apparatus for rolling strip material, comprising means for anticipating or detecting during rolling the errors in the profile of the roll gap, computer means programmed to express the symmetrical component of the profile errors as a combination of a plurality of curvatures of different geometric form, to derive the coefficients of said curves to provide error signals, and to translate said error signals into control signals; and a plurality of different control means operable in dependence of said control signals to adjust the deflection of the rolls so as to correct for the anticipated or measured errors in the profile of the roll gap and hence of the strip to be rolled.

We have found that in general the profile error across the width of the roll gap, and hence of the strip, can always be expressed in a polynomial form of this type:

$$E = L + x + P + Q + S + x^4 + ...$$

where:

$L$, $P$, $Q$, $S$, ... etc. are constants characterizing a particular error distribution;

$x$ is the lateral distance from the strip midwidth point; and

$E$ is the error in profile at point $x$.

From (1) it is seen that $L$, $P$, $Q$, $S$ etc. can be considered a measure of the profile error to be corrected. The error is fully corrected only if $L = P = Q = S = 0$. For rolling conditions symmetrical about the strip center ($L = 0$) and polynomial expression of $E$ contains only even power terms of $x$.

We have found that, by for example, differential movement of one of the two screws in the rolling stand, it is always possible to correct any initial asymmetrical profile error so that $E$ in (1) becomes substantially equal to zero. Hence in what follows the assumption is made that the shape error to be corrected is symmetrical, i.e.:

$$E = P + Q + S + x^4 + ...$$

We have found that for profile control purposes, in (2) the sixth and higher power terms are negligible so that the profile error $E$ can be practically expressed in the form:

$$E = P + Q + x^4 + ...$$

that is to say, as the sum of a parabolic curve and a quartic curve. Therefore correction of the profile error entails making $P = Q = 0$.

We have found that around given initial rolling conditions small changes in any one of the rolling factors such as tension, speed etc., cause linearly related changes in the coefficients $P$ and $Q$ of (3) that is:

$$\Delta P = K_1 \Delta T + K_2 \Delta S + ...$$

$$\Delta Q = K_3 \Delta T + K_4 \Delta S + ...$$

where $K_1$, $K_2$, etc. are constants which are characteristic of the rolling conditions and which can be determined either experimentally or theoretically; and $\Delta T$ is a small change in input rolling tension, $\Delta S$ is a small change in output rolling tension, $\Delta S$ is a small change in speed in rolling position, and $\Delta S$ is a small change in rolling bending force etc.

Hence if a profile error is present, numerical values $P^*$ and $Q^*$ can be specified for (3), and if control is available over at least two control factors, then from (4) rolling factor changes can be calculated such that:

$$\Delta P = -P^*$$

$$\Delta Q = -Q^*$$

We have found that by applying such rolling factor changes as calculated from (4) to the rolling mill, the shape error (3) is reduced to zero.

Further features and advantages of the present invention will be apparent from the following description of embodiments thereof given by way of example only in conjunction with the accompanying drawings, in which:

FIG. 1 shows diagrammatically a strip shape sensing arrangement of apparatus according to the invention.

FIG. 2 shows diagrammatically a roll gap or strip, profile defined by two component curves, FIG. 3 shows diagrammatically an alternative strip shape sensing arrangement, FIG. 4 is a graph of relationship between coefficients and two control means, and FIG. 5 shows diagrammatically apparatus according to the invention.

Let us consider first the case of correcting profile errors detected in the rolled strip. Such correction involves a strip shape sensing device which measures the differential elongation at points across the width of the rolled strip by means of odometry wheels 10 measuring the strip length, which measurements being fed to a computer 8. Assuming that the strip is symmetrical about its centerline then by using three wheels as shown in FIG. 1 two curves may be defined which will, for our purposes, adequately describe the elongation differential across the rolled strip width and which are related to the errors in the roll gap profile. The symmetrical component of the profile errors is expressed by computer 8 as a combination of two curvatures of different geometric form ($x^2$ and $x^4$), and the computer derives the coefficients $P$, $Q$ of these curves to provide from stored information such as that indicated in FIG. 4, error signals which are employed as control signals for two or more different control means which correct the measured profile errors by corresponding adjustments to the deflection of the rolls.
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Since asymmetric profile errors may occur in addition to the symmetrical errors, it is a preferred practical arrangement to derive the rolled strip shape measurement from five sensors spaced across the width of the strip and arranged as nearly symmetrical as possible about the centerline as is indicated in FIG. 3. It is then possible to deduce not only the dominant symmetrical component of the profile error but also to derive signals to detect asymmetry. Although in the above explanation odometer wheels are used to detect profile errors it is to be recognized that they are not universally applicable to all situations of measurement and that alternative means—for example those based on magnetic measurements relating to stress in the strip—are often to be preferred. As with the odometer measurements so may a multiplicity of other shape sensitive detectors be used to derive the two components of mill correction to be deduced. Where the shape measuring means are to provide measured values to operators as in one commercially developed instrument there is a distinct advantage in analyzing the measured profile in terms of components in the way indicated above.

The two coefficients of roll gap profile error can in general only be corrected by a minimum of two different control means of the rolling mill. These control means must be such that they independently produce changes in the form of the roll gap profile that are not affine. Referring to FIG. 5, two such control means are provided by a control 12 for adjusting the total tension on the strip as it leaves or enters the mill and a control 14 for controlling hydraulic jacks 16 between the chocks of the work roll and back up roll to vary the forces on the work roll. Since the curvature of roll gap is measured in simple parabolic and quartic curves both of these curves will change for independent adjustments of the rolling load and jack force but the quartic curve is less sensitive to changes in rolling load than to jack force and, within limits a pair of jack force and rolling load value $J_1$, $P_1$ may be determined by the computer 8 to make the required corrections to the mill (see FIG. 4). The mill also includes a control 18 for adjusting differentially the screwdown devices 20 of the roll to correct asymmetrical shape errors.

In the case of anticipating errors in the profile of the roll gap during rolling, the device 6 would assume a position (shown dotted in FIG. 5) on the input side of the rolls, and would be used in conjunction with a device (not shown) for detecting the thickness profile of the ingoing strip; in addition various relevant variables such as roll camber rolling load, roll support forces, the mechanical constants of the mill stand or stand would be monitored and fed to the computer 8. The translation of the measurements of the error in shape of the strip into signals to command variations in the tension (i.e., rolling load) and the jack force can be achieved by using techniques that are well known and which may demand only a relatively simple digital or analogue computing apparatus. The adjustments to the rolling load or jack force (and also most other conceivable methods of adjusting the mill) may have an effect on the gauge of the material that is being rolled, the effect depending on the position and method of measurements, and for this reason automatic gauge control adjustments by, for example, changes in the settings of the mill screwdown will usually be made simultaneously with adjustments to correct the shape.

What we claim is:

1. A method of rolling strip material in a rolling mill, including detecting during rolling differences in fractional reduction at locations spaced transversely of strip material leaving the gap between work rolls of the mill, deriving from the detected differences in fractional reduction an expression representa-

tive of the error in the profile of the gap between the work rolls as a combination of a plurality of curves of different geometric form defined by functions of transverse distance of said locations from the centerline of the strip, and deriving coefficients of said curves to provide control signals; and adjusting in response to said control signals a plurality of different rolling mill control means to correct for error in the profile of the gap between the work rolls.

2. A method as claimed in claim 1, in which the differences in fractional reduction are detected by detecting elongations in the strip material at locations transverse of the strip material.

3. A method as claimed in claim 2, in which the elongations are detected by odometer wheels contacting the strip material.

4. A method as claimed in claim 1, in which for symmetrical rolling conditions the combination of curves of different geometric form is a combination of a parabolic curve and a quartic curve, the curves being respectively functions of the second and fourth powers of the transverse distance of the strip material from its centerline.

5. A method as claimed in claim 1, in which the plurality of different rolling mill control means is equal to or greater than the number of the plurality of curves of different geometric form.

6. A method as claimed in claim 1, in which the plurality of different rolling mill control means includes at least tension control means for adjusting the total tension of the strip material passing into or leaving the work rolls; and hydraulic jack control means for adjusting hydraulic jacks for varying the bending forces on the work rolls.

7. A rolling mill for rolling strip material, including sensor means for detecting during rolling differences in fractional reduction at locations spaced transversely of strip material leaving the gap between work rolls of the mill; computer means for (a) deriving from the detected differences in fractional reduction an expression representative of the error in the profile of the gap between the work rolls in the form of a combination of a plurality of curves of different geometric form defined by functions of the transverse distance of said locations from the centerline of the strip and (b) deriving coefficients of said curves to provide control signals; and a plurality of different rolling mill control means adjustable in response to the control signals so as to correct for error in the profile of the gap between the work rolls.

8. A rolling mill as claimed in claim 7, in which the sensor means are adapted to detect elongations in the strip material at locations transverse of the strip material.

9. A rolling mill as claimed in claim 8, in which the sensor means include odometer wheels for contacting the strip material to detect the elongations.

10. A rolling mill as claimed in claim 7, in which for symmetrical rolling conditions the computer means is such that the combination of curves of different geometric form will be a combination of a parabolic curve and a quartic curve, the curves being respectively functions of the second and fourth powers of the transverse distances of the strip material from its centerline.

11. A rolling mill as claimed in claim 7, in which the plurality of different rolling mill control means is at least equal to the number of the plurality of curves of different geometric form.

12. A rolling mill as claimed in claim 7, in which the plurality of different rolling mill control means includes at least tension control means for adjusting the total tension of the strip material passing into or leaving the mill; and hydraulic jack control means for adjusting hydraulic jacks for varying the bending forces on the work rolls.