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Kubo et al.

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[45] **Sept. 4, 1973**

[54] **METHOD AND APPARATUS FOR CONTROLLING METAL STRIP SHAPE**

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[73] Assignees: **Nippon Kokan Kobushiki Kaisha,** Tokyo; **Tokyo Shibaura Electric Co., Ltd.,** Kawasaki-shi, Japan

[22] Filed: **Mar. 6, 1972**

[21] Appl. No.: **232,115**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 838,282, July 1, 1969, abandoned.

[30] **Foreign Application Priority Data**

July 3, 1968 Japan 43/46108

[52] **U.S. Cl.** **72/9,** 72/12

[51] **Int. Cl.** **B21b 37/12**

[58] **Field of Search** 72/8–12, 72/16

[56] **References Cited**

UNITED STATES PATENTS

3,475,935 11/1969 Kajiwara 72/9

3,496,744 2/1970 Mizuno et al. 72/12

Primary Examiner—Milton S. Mehr

Attorney—Robert D. Flynn, Leonard Holtz et al.

[57] **ABSTRACT**

A process and apparatus for rolling a metal strip whereby the waviness of the strip in the direction of the strip thickness is detected at a plurality of locations along the width of the strip, while the strip is under tension, during the rolling operation. The roll crown and/or the rolling load is selectively controlled in response to the detected waviness Δh in accordance with the relation $\Delta h = E_m b_{ij} + F$, where i and j are variables indicating the position of sensors, m is a parameter relating to tension of the strip, b is the output waviness under no tension and E and F are constants. The shape variations b in the resulting output metal strip, under no tension, which are not actually determined until after a very long period of time, such as during the next manufacturing process, are maintained within predetermined tolerances by said preliminary control during the rolling operation.

13 Claims, 11 Drawing Figures

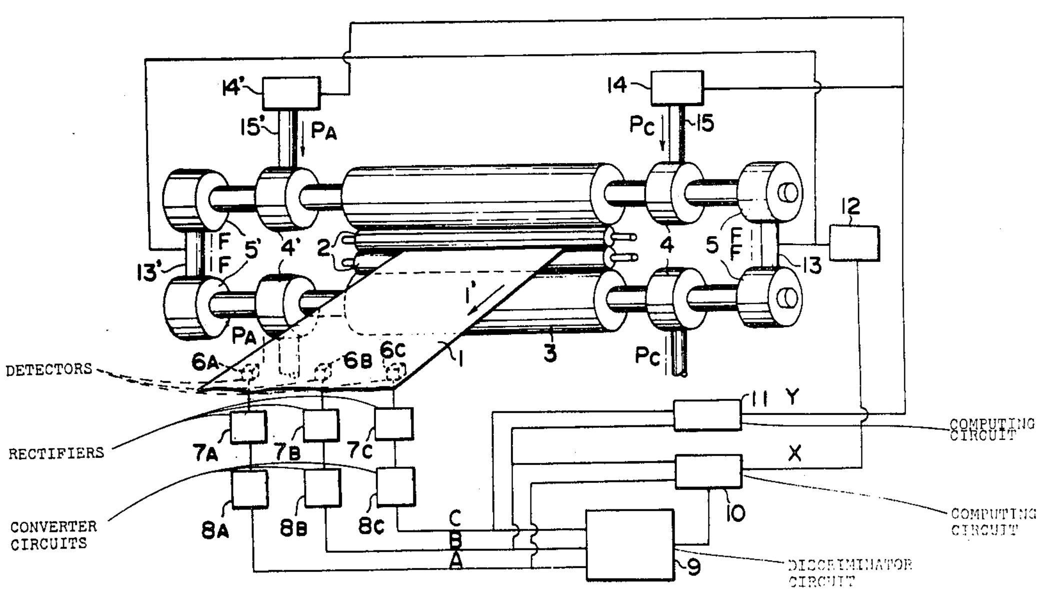


FIG.1

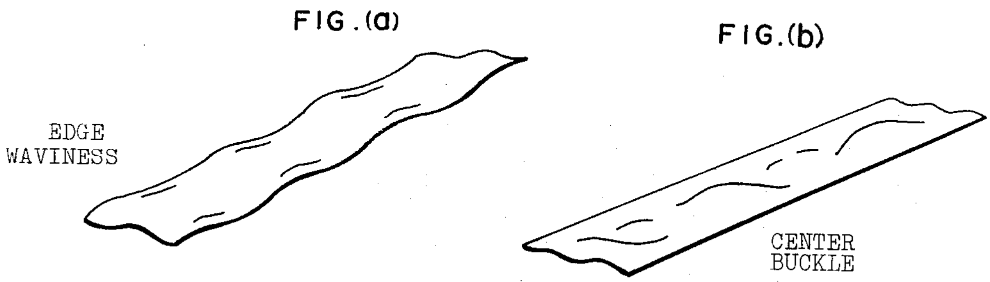


FIG.(a)
EDGE WAVINESS
FIG.(b)
CENTER BUCKLE

FIG.2

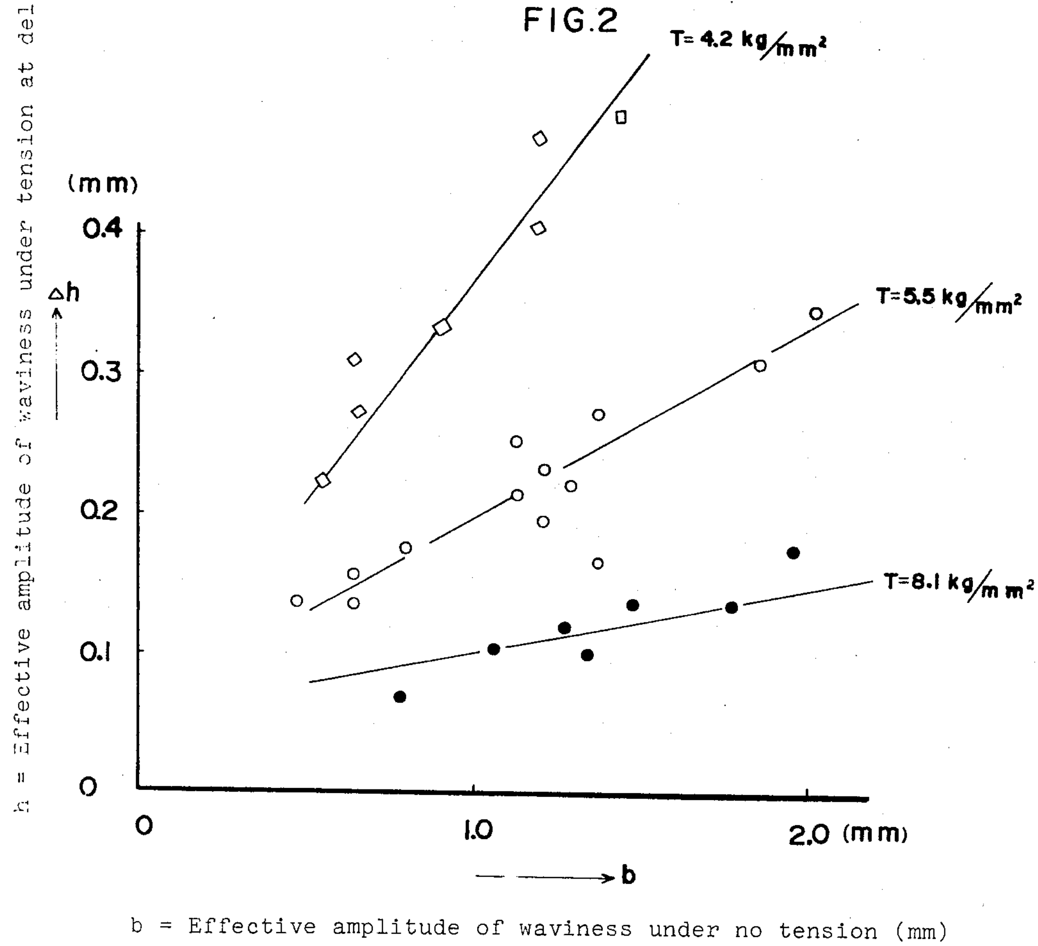

T= 4.2 kg/mm²
T=5.5 kg/mm²
T=8.1 kg/mm²
(mm)
0.4
0.3
0.2
0.1
0
Δh
0
1.0
2.0 (mm)
b
h = Effective amplitude of waviness under tension at delivery side of mill (mm)
b = Effective amplitude of waviness under no tension (mm)

FIG. 3

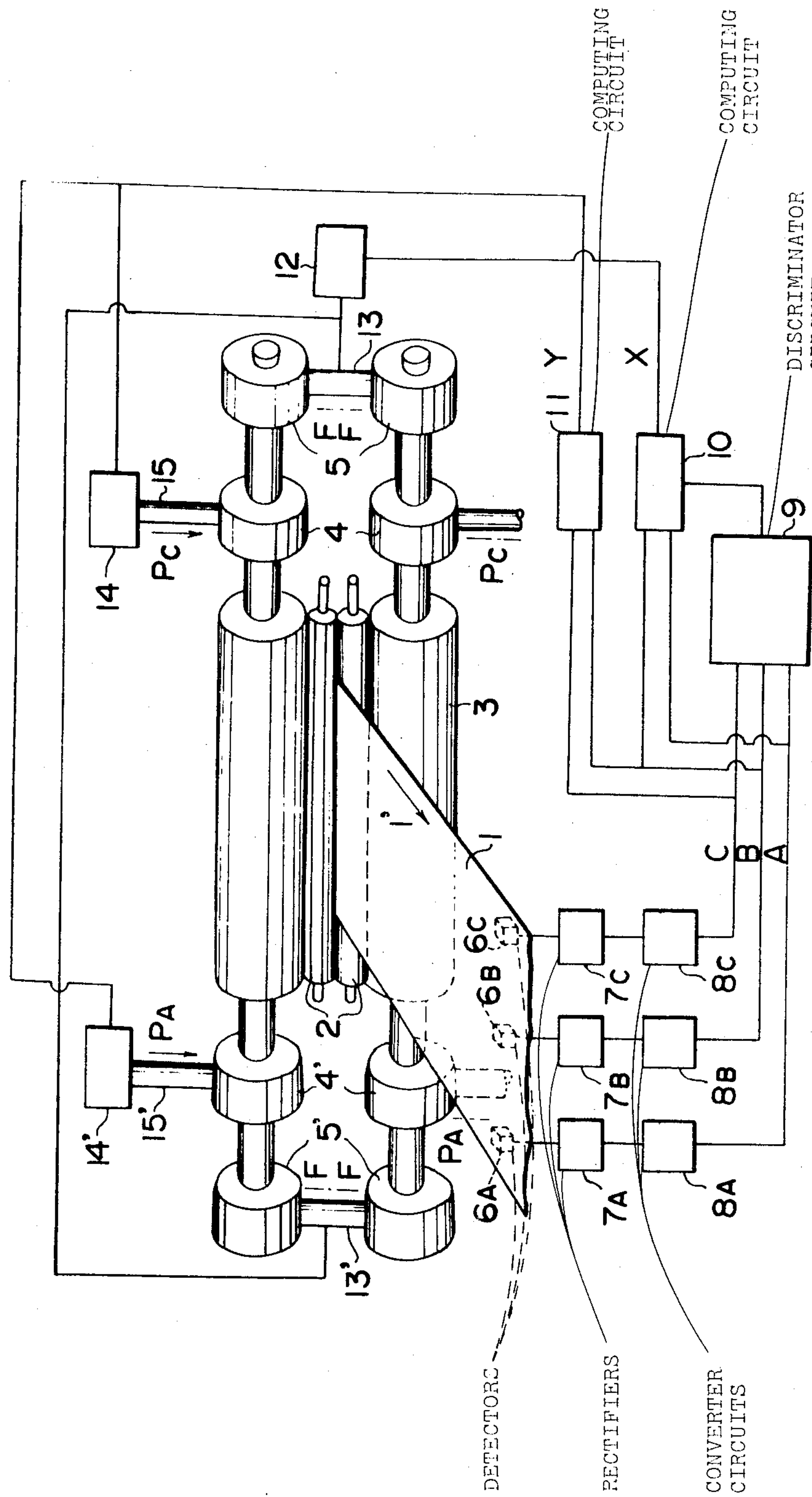

COMPUTING CIRCUIT
COMPUTING CIRCUIT
DISCRIMINATOR CIRCUIT
DETECTORS
RECTIFIERS
CONVERTER CIRCUITS
12
13
11 Y
X
10
9
15
14
Pc
4
5
F
3
1'
1
2
6C
6B
6A
7C
7B
7A
8C
8B
8A
C
B
A
PA
4'
5'
15'
14'
13'

FIG.4

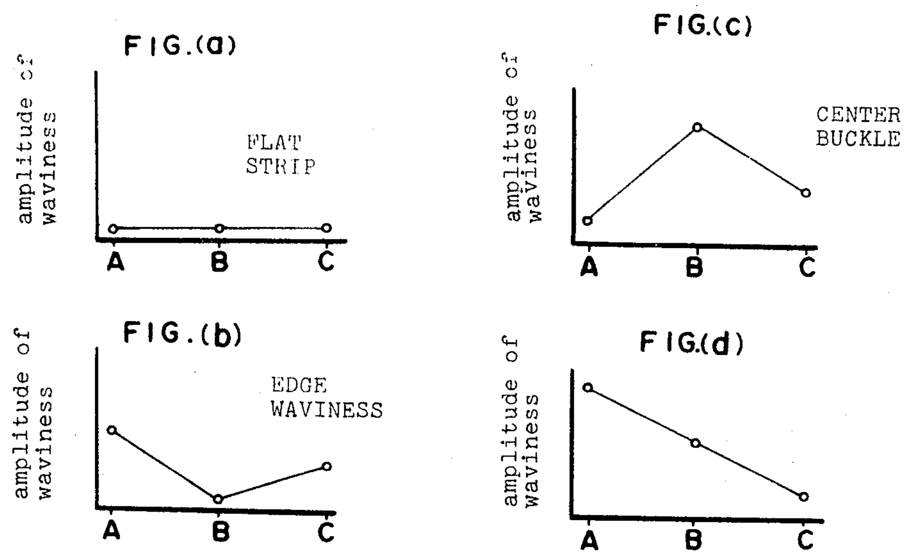
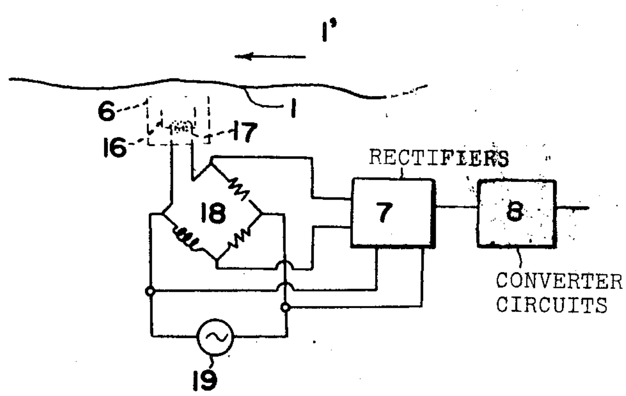


FIG.(a)
amplitude of waviness
FLAT STRIP
A
B
C
FIG.(c)
amplitude of waviness
CENTER BUCKLE
A
B
C
FIG.(b)
amplitude of waviness
EDGE WAVINESS
A
B
C
FIG.(d)
amplitude of waviness
A
B
C

FIG.5



1'
1
6
16
17
18
RECTIFIERS
7
8
CONVERTER CIRCUITS
19

FIG. 6

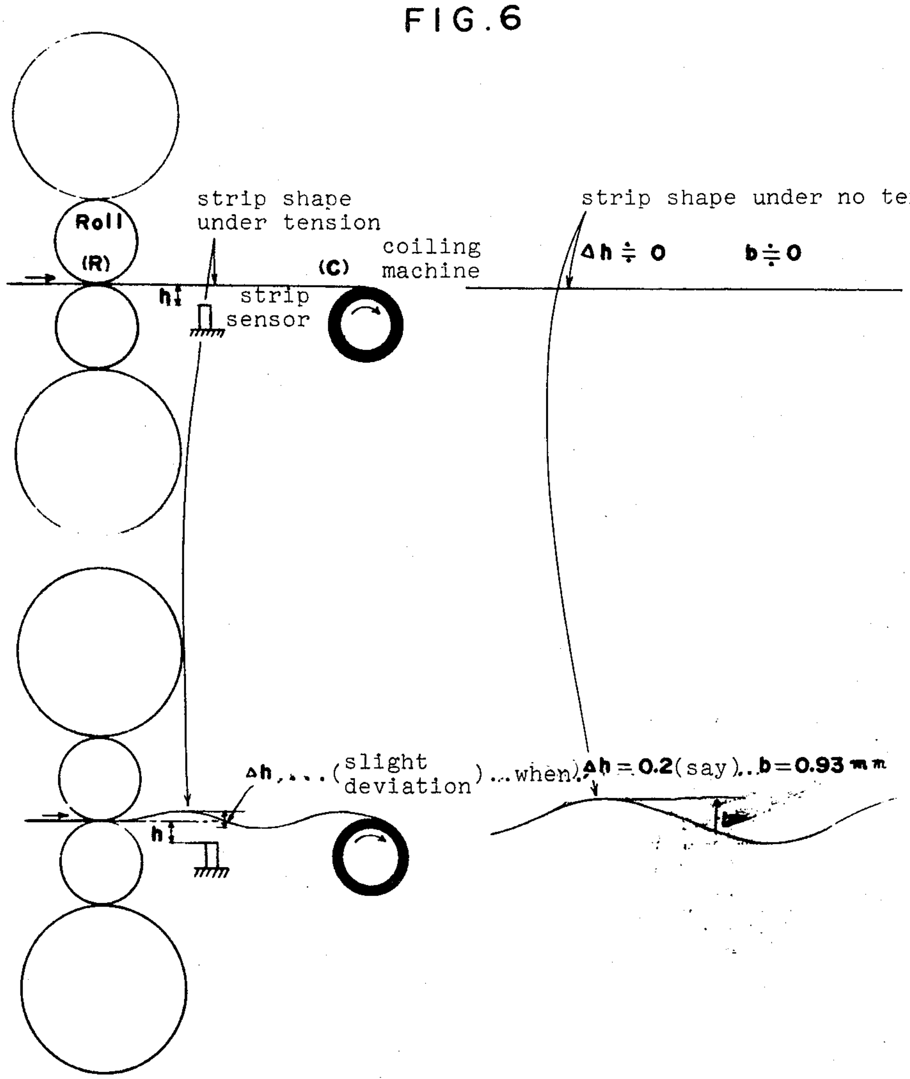
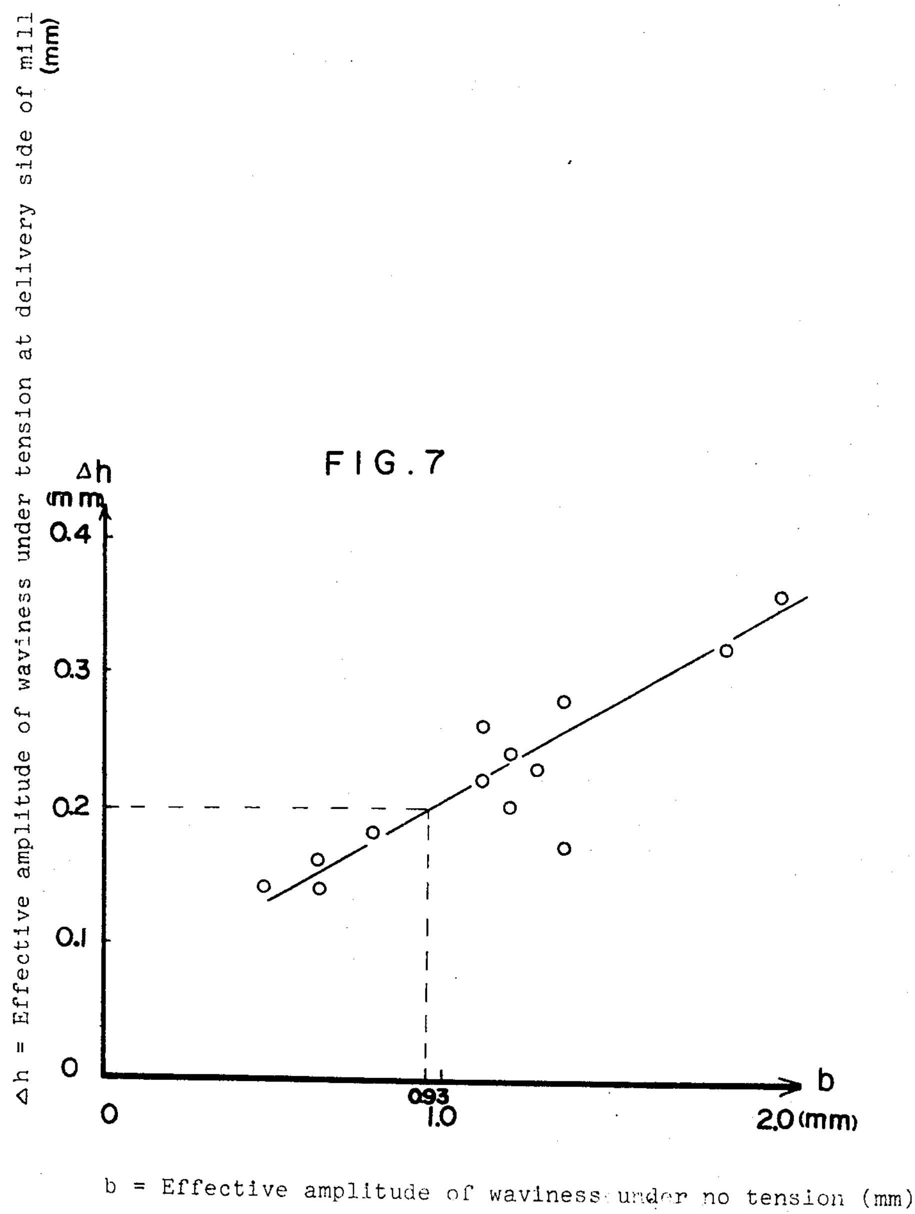

Roll
(R)
strip shape
under tension
h
strip
sensor
(C)
coiling
machine
strip shape under no tension
Δh ≑ 0
b ≑ 0
Δh, . . . (slight deviation) ... when Δh = 0.2 (say) .. b = 0.93 mm
h

FIG. 7


Δh = Effective amplitude of waviness under tension at delivery side of mill (mm)
Δh
(mm)
0.4
0.3
0.2
0.1
0
0
0.93
1.0
2.0 (mm)
b
b = Effective amplitude of waviness under no tension (mm)

METHOD AND APPARATUS FOR CONTROLLING METAL STRIP SHAPE

This is a continuation-in-part of U.S. Ser. No. 838,282, filed July 1, 1969 and now abandoned.

This invention relates to a method and apparatus for controlling the shape of a metal strip during rolling, and more particularly for obtaining a strip having good flatness.

In a process of rolling metal strip, various problems occur in controlling the gauge and shape of the strip. There is hardly any problem in controlling the lengthwise size of strip due to the development of a known AGC system. However, problems still exist in controlling the gauge in the direction of the width of the resulting strip. For example, a report, "Theory and Practical Aspects in Crown Control" has been published in the "Iron and Steel Engineer" August, 1965 edition to discuss means of solving such problems. There is however no means disclosed for detecting the lateral gauge and shape of the strip in the above report. A prior art solution of the lateral gauge and shape control, utilizing tension rolls and speed detecting rolls which are placed in the direction of the width of strip, is disclosed in Japanese Patent Publications No. 17429, 1967 and No. 1009, 1968. An experiment to place thickness meters in the direction of the width was carried out. However, it has been found that all of the above discussed and various other methods are unstable (that is, provide inconsistent results) and are not serviceable.

An object of this invention is to provide a method of detecting the strip shape or flatness in the direction of the width of the strip.

Another object of this invention is to provide apparatus for controlling the strip shape or flatness in the direction of the width of the product strip.

SUMMARY OF THE INVENTION

In accordance with this invention, the vibration or waviness of the strip in the direction of the thickness is detected at a plurality of locations along the width of the strip while the strip is under tension, and then the lateral gauge and shape of strip is controlled accordingly during the rolling operation. The detecting of the vibration of the strip may be accomplished by detecting a magnetic change, an electrostatic change, or the like, in the strip, without actually contacting the strip, and preliminary control is effected to control the flatness of the resulting product strip.

The term "vibrations" as used herein refers to variations of the shape of the strip in the direction of its thickness as the strip is moved past a fixed location. Thus, with respect to the fixed location, any undulations or variations in shape of the moving strip will be denoted as "vibrations." The greater the undulations of the strip, the greater will be the magnitude of the "vibrations."

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1*a* and 1*b*, show examples of poorly shaped strips, FIG. 1*a* illustrating edge waviness and FIG. 1*b* illustrating center buckle;

FIG. 2 is a graph illustrating the correlation between waviness of the strip in the direction of its thickness when the strip is under tension and the waviness of the strip when the strip is under no tension;

FIG. 3 is a diagrammatic illustration of an apparatus according to the present invention;

FIGS. 4*a*, 4*b*, 4*c* and 4*d* are graphs illustrating the relationship of typical strip shapes and the output vibration amplitude corresponding to said shapes;

FIG. 5 shows a circuit for detecting vibrations (i.e., waviness) in the direction of the strip thickness;

FIG. 6 shows a portion of the apparatus to illustrate how the waviness of the strip under tension is related to waviness of the strip under no tension; and

FIG. 7 is a simplified graph similar to that of FIG. 2.

It is generally well known that lack of flatness in the final product, especially in a cold reducing strip mill, is a frequent cause for rejection of the product. The typical causes for rejection are represented in FIGS. 1*a* and 1*b*. FIG. 1*a* illustrates waves formed at the edges of the strip while FIG. 1*b* illustrates center buckle. Such undesired shapes should be avoided by controlling the roll crown and/or the rolling force.

The present invention is the result of experiments which determined that the characteristics of wavy edges or center buckle in the resulting strip under tension during rolling are closely correlated with the vibrating waveform in the direction of the strip thickness. FIG. 2 shows the correlation between effective amplitude of waviness or undulations (Δh) during rolling and the waviness of the strip (b) under no tension, which was obtained as a result of many experiments.

In the experiments, the value Δh of the low carbon rimmed steel strips which are 0.193 mm thick and 768 mm wide is detected between the final stand of a five-stand tandem cold rolling mill and a coiling machine. After rolling of the coil is finished, the coiled strip is removed from the coiling machine and uncoiled under no tension, then the value b being detected. As the correlations between the vales Δh and b are different, depending upon the tension applied during the rolling operation, experiments were conducted with respect to three tensions.

According to FIG. 2, it is seen that the amplitude of the vibrating waveform (i.e., waviness) becomes larger as the magnitude and/or area of the strip waviness increases. Such changes in the vibrating waveform during rolling are detected and then in accordance with the present invention, the roll crown and rolling force are automatically adjusted as a function of the differences of the above-detected values. As a result, good flatness or shape will be easily obtained.

Referring to FIG. 6, the curves of FIG. 2 can be more easily understood. The strip between rolls (R) and coiling machine (C) is under tension. The amount of tension is not constant all through the strip. Even in one strip, when the tension to which the strip is subjected is varied, the relation between Δh (deviation under tension) and b (deviation under no tension) varies as tension in the strip itself varies. The relation is illustrated in FIG. 2 and is as follows:

$$\Delta h = E_m b_{ij} + F$$

where i and j are variables indicating the positions of the sensors, m is a parameter relating to tension, and E and F are constants.

Thus, the relation between Δh and b is defined by a family of curves, each member of which corresponds to a given portion (or position) of the strip.

In a simplified case, for a given tension in the strip, the curve of FIG. 7 applies. In FIG. 7 the equation Δh

$= E_m b_U + F$ applies, where E_m and F are constants. At a given tension, when $\Delta h = 0.2$, then $b = 0.93$ mm.

When control of the rolling mill is carried out in accordance with the present invention, the value Δh is detected by the sensors and fed to a computing device which then computes the amount of correction required to be applied to the roll crown and/or rolling load in order to reduce Δh to a small enough value so that the waviness (b) of the output strip under no tension will be within the desired limits. The value Δh is detected at various portions of the strip in the direction of its width and the roll crown and/or rolling load is varied in accordance with differences between the detected values of waviness at different respective positions along the width to reduce the shape variations in the resulting output strip. The precise amount of control of the various parameters in order to produce a flat output strip in accordance with the present invention will vary, of course, with the particular characteristics of the rolling mill and the particular characteristics of the material being rolled.

FIG. 3 shows an embodiment of the apparatus to carry out the above-described method in accordance with the present invention.

Referring now to FIG. 3, which shows in part a cold reducing mill, a strip of metal 1 (for example, steel) travels in the direction indicated by arrows 1 through a predetermined gap between rolls 2. Vibration (or waviness) detectors 6A, 6B and 6C which are connected with synchronous rectifier circuits 7A, 7B and 7C, respectively, are located at about the center portion and on each side of the strip 1, and are suitably spaced from strip 1. Changes of thickness or waviness in the direction of the thickness of the strip are detected at various positions along the width of the strip and are converted to electrical signals by means of the detectors 6A–6C. The outputs of the synchronous rectifier circuits 7A, 7B and 7C are fed to circuits 8A, 8B and 8C, respectively, which convert the rectifier circuit outputs into center-line values or into signals representing the effective value of the amplitude of the vibrating waveform. Differences between the magnitude of the amplitude of the vibrating waveform at the above three points are a function of the thickness or waviness of the strip at the three respective positions. A change of thickness in the direction of the width can be easily ascertained with the above-described device.

The outputs of circuits 8A–8C are applied to discriminating circuit 9, the output of which is fed to computing circuit 10. Computing circuit 10 also receives signals A and B from circuits 8A and 8B, respectively. Further provided is a computing circuit 11 which receives signals B and C from circuits 8B and 8C, respectively. Discriminator 9 disables computing circuit 10 when A > C or when A < C.

If a wavy edge occurs at one side of the strip, the amplitude of the vibrating waveform at this position will be larger than that of other locations. Each vibrating waveform amplitude, in the case of a wavy edge being formed on either side of the strip, becomes larger than that of the center portion. Conversely, the vibrating waveform amplitude in the case of center buckle becomes larger at the center than at both sides of the strip.

FIGS. 4a–4d show the relationship between vibrating amplitude and strip defect. The letters A, B and C of FIGS. 4a–4d represent the outputs of circuits 8A–8C, respectively. FIG. 4a shows that the amplitude of the output signals A, B and C are substantially the same and these absolute values are small in the case of a properly formed strip. FIG. 4b shows the case wherein the roll crown is too small. Accordingly, a wavy edge is formed at each side of the strip, as detected by the large vibration amplitude at the edges. In such a case, in accordance with the method of the present invention the following steps are automatically implemented:

First, the above outputs A and B of the amplitude circuit are introduced into a computing circuit 10 (see FIG. 3) wherein the following calculation is performed:

$$A - B = X$$

An adjusting device 12 (FIG. 3) receives the value X and causes the pressure of hydraulic cylinders 13 and 13' to increase in accordance with the value X. This causes the inter-chock pressure 5 and 5' of backup rolls 3 to increase. Consequently, the extending rate of the strip edge portion decreases and the extending rate of the strip at the center portion thereof increases.

Such automatic control is continued up to the time when said signal A becomes equivalent to signal B, as determined by the computing circuit 10.

In the case where the signal C is unequal to signal A, such relationship also must be dealt with in a similar manner. That is, both signals A and C are introduced into a computing circuit 11 (FIG. 3) wherein the following calculation is done:

$$A - C = Y$$

The adjusting device 14 and 14' for rolling load are caused to operate in response to the above Y value to adjust the screwdowns 15 and 15'. Such control is continued up to the time when signal C is equivalent to signal A, as detected by circuit 11.

Thus, the control of roll crown and rolling load can be automatically accomplished with ease.

FIG. 4c shows values of the vibration amplitude in the case wherein the roll crown is too large and center buckling occurs. Accordingly, the controlling steps are effected in reverse of the above-described controlling method.

FIG. 4d shows values of the vibration amplitude in the case wherein both rolling loads PA and PC are unbalanced. That is, the extending rate in the direction of the width increases accordingly. The three signals A, B, C have the following relationship:

A > B > C [not shown in FIG. 4] or A > B > C [as shown in FIG. 4(d)].

In this case, the automatic control system of this invention operates in the following manner:

First, the functioning of computing circuit 10 is inhibited by the discriminating circuit 9 which receives signals A, B and C. Secondly, the rolling loads PC and PA are made equal by operation of the computing circuit 11 which varies PC and/or PA to make $A - C = Y = 0$. Thirdly, when the output of the discriminating circuit 9 becomes zero, that is, when $A = C$, the functioning of the computing circuit 10 is no longer inhibited. Then the crown control is accomplished by means the same steps as mentioned above by adjustment via computing circuit 10 until $A = B$.

It should be clear that the above control functions A, B and C, i.e., b_U, are carried out such that the formula given below also applies:

$$\Delta h = E_m b_{ij} + F$$

The above controls are described with respect to eliminating edge waviness, center buckle, etc.

FIG. 5 is a view of an embodiment of a vibration sensor which comprises a magnetic core **16** and coil **17** for use as a detector **6A**, **6B** and **6C** in the above-described system. If such a detector **6** is placed below the strip **1** travelling in the direction of arrows **1'**, a change in the gap between the detector **6** and the strip **1**, will be brought about by vibration (or by variations of the thickness or shape) of the strip in the direction of the length of the strip. This vibration (or change of gap) is, of course, converted into a change of coil inductance. An alternating current bridge **18**, wherein one side of the bridge circuit includes the detecting coil, and which is energized by a power source **19**, then detects an unbalanced voltage corresponding to the above-mentioned vibration. This unbalanced voltage is then fed to rectifiers **7** and dealt with as mentioned above with reference to FIG. **3**.

As an alternative to the magnetic circuit of FIG. **5**, a circuit utilizing electro-static capacity, a circuit utilizing photo-electronics, or the like, can be employed to detect the vibrations in accordance with the present invention.

In summary, since the output waviness under no tension is a function of the waviness of the strip under tension during rolling, by means of the present invention the waviness under tension is measured at a number of points in the direction of the width of the strip and the roll stands are adjusted by a feed forward arrangement in order to equalize the waviness at the center and edges of the strip, thereby producing product strips having better flatness.

It should be clear that various modifications and alternations can be made within the scope of the appended claims.

We claim:

1. A method for controlling the output shape of a metal strip during a rolling operation comprising the steps of:

detecting, at the output of a roll stand, the waviness (Δh) of said strip in the direction of the strip thickness at a plurality of locations along the width of said strip; and

selectively controlling the roll crown and the rolling load in response to the function of b_{ij} in accordance with the relation $\Delta h = E_m b_{ij} + F$, where i and j are variables indicating the position of the sensors, m is a parameter which is a function of tension, b is the output waviness under no tension and E and F are constants, to thereby reduce said shape variations (b) in the resulting output metal strip to within predetermined limits.

2. The method according to claim **1** wherein said detecting step includes simultaneously detecting said waviness at substantially the center portion of said strip and at each side of said strip.

3. The method according to claim **1** wherein the tension in said strip varies along the length thereof and the waviness (Δh) during rolling varies along the length thereof and wherein the term i and j in the relation $\Delta h = E_m b_{ij} + F$ represent values for given positions along the length of said strip.

4. The method according to claim **2** including controlling the roll crown responsible to the difference between waviness by said center detector and side detector.

5. The method according to claim **2** including controlling said rolling load responsive to the difference between waviness by said side detectors.

6. Apparatus for controlling the shape of a metal strip during a rolling operation comprising:

a plurality of non-contact detectors located at different respective positions along the width of said strip and located at the output of a roll stand of a rolling mill, said detectors detecting the waviness (Δh) of said strip in the direction of the strip thickness during the rolling operation;

circuit means coupled to said non-contact detectors for generating signals representing said detected waviness;

a discriminating circuit coupled to the output of said circuit means; and

control means responsive to the outputs of said circuit means and to the output of said discriminating circuit for selectively controlling the roll crown and the rolling load in response to the function of b_{ij} in accordance with the relation $\Delta h = E_m b_{ij} + F$, *where* i and j are variables indicating the positions of the sensors, m is a parameter which is a function of tension, b is the output waviness under no tension and E and F are constants, to thereby reduce the waviness in the resulting output metal strip to within predetermined limits.

7. Apparatus according to claim **6** wherein said detectors are spaced from said strip.

8. Apparatus according to claim **6** wherein said detectors are located at substantially the center of said strip and at each side of said strip.

9. Apparatus according to claim **8** wherein said control means controls the roll crown responsive to the difference between the waviness detected by said center detector and side detector.

10. Apparatus according to claim **8** wherein said control means controls said rolling load responsive to the difference between the waviness detected by said side detectors.

11. Apparatus according to claim **8** wherein said discriminating circuit is responsive to predetermined variations in said waviness to inhibit controlling of said rolling load.

12. Apparatus according to claim **11** wherein said discriminating circuit is responsive to signals indicating that said waviness caused by maladjustment of roll crown have been substantially eliminated to cause said control means to control said rolling load to substantially eliminate waviness in said output strip.

13. Apparatus according to claim **6** wherein said control means includes first computing means responsive to predetermined waviness variations for controlling said roll crown and second computing means responsive to the other predetermined waviness variations for controlling said rolling load.

* * * * *