United States Patent [19]

Mannaka et al.

[11] **3,763,677**

[45] **Oct. 9, 1973**

[54] **AUTOMATIC PLATE-THICKNESS CONTROL METHOD FOR ROLLING MILL**

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[22] Filed: **Mar. 17, 1972**

[21] Appl. No.: **235,588**

[30] **Foreign Application Priority Data**

Mar. 19, 1971 Japan 46/15125

[52] **U.S. Cl.** **72/8,** 72/16

[51] **Int. Cl.** **B21b 37/00,** B21b 37/02

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

[56] **References Cited**

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[57] **ABSTRACT**

Incoming and outgoing plate-thickness deviations for the same point of a sheet passing through a reduction rolling mill are determined for a plurality of rolling speeds so as to calculate the outgoing plate deviation component attributable to the inherent characteristics of the rolling mill upon deceleration and acceleration, such as changes in the oil film and in the coefficient of friction. The thus determined outgoing plate-thickness deviation component is stored as information corelated to the speed at which it was determined, so that it may be selectively retrieved to be applied as a correction factor in the screw-down of the rolls upon automatic operation at the corresponding speeds of subsequent roll passes.

9 Claims, 2 Drawing Figures

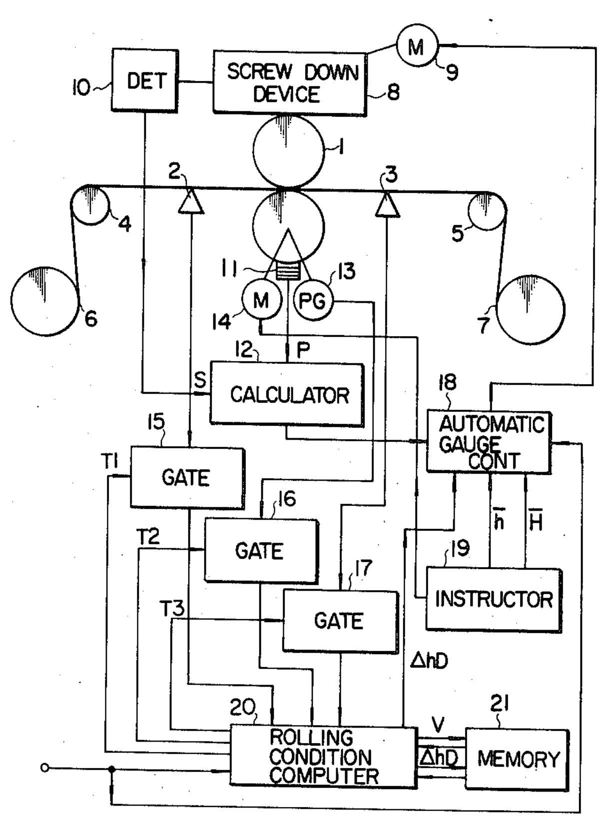


FIG. 1

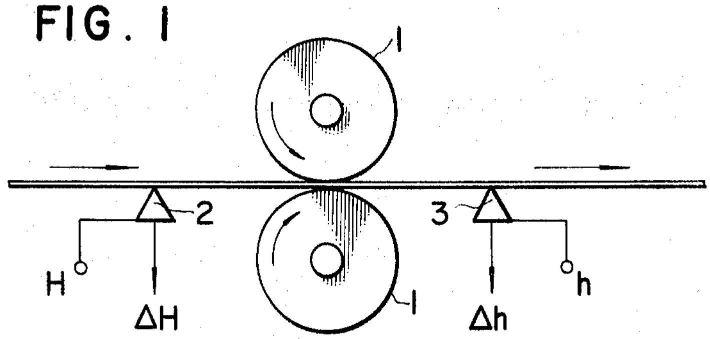
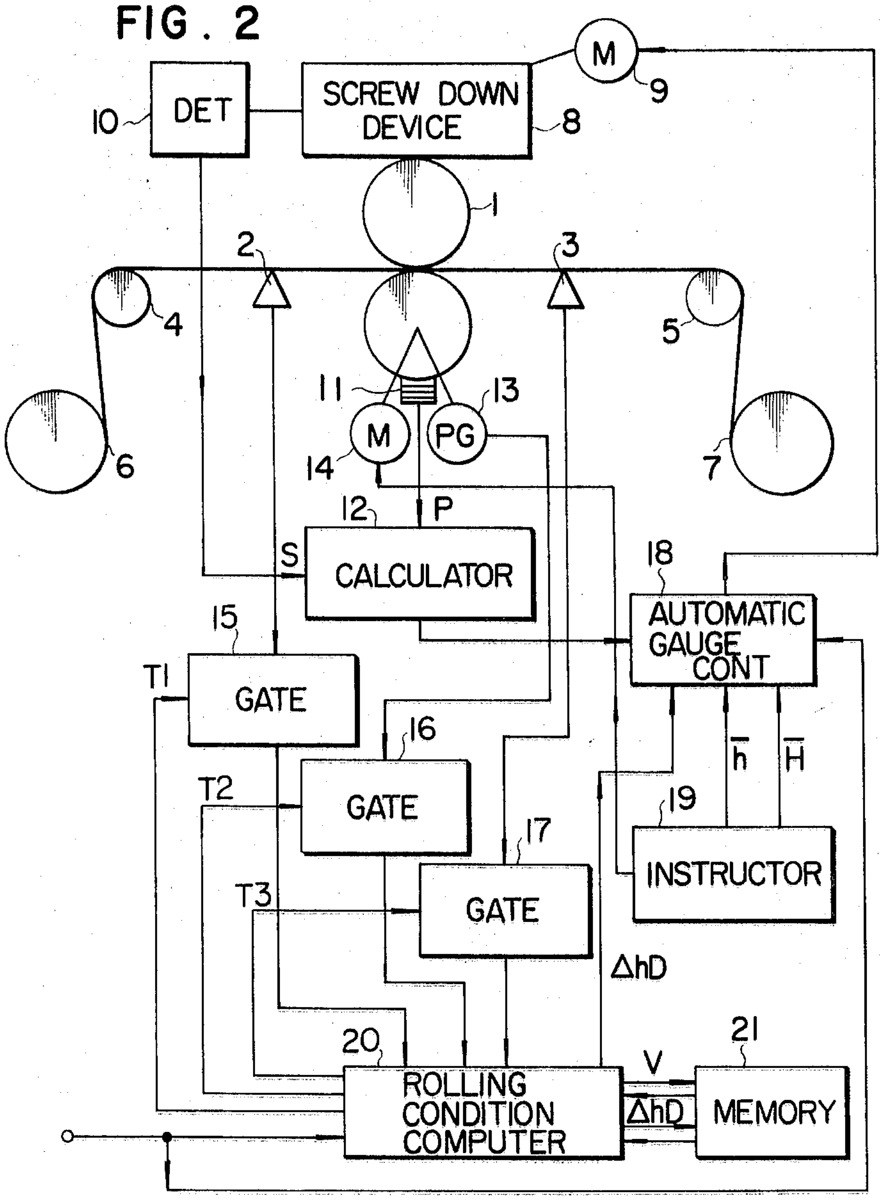

1
2
3
H
h
ΔH
Δh
1

FIG. 2


DET
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SCREW DOWN DEVICE
8
M
9
1
2
3
4
5
6
7
11
13
M
PG
14
12
P
S
CALCULATOR
18
AUTOMATIC GAUGE CONT
15
T1
GATE
16
GATE
T2
h
H
19
INSTRUCTOR
17
T3
GATE
ΔhD
20
21
V
ROLLING CONDITION COMPUTER
ΔhD
MEMORY

AUTOMATIC PLATE-THICKNESS CONTROL METHOD FOR ROLLING MILL

BACKGROUND OF THE INVENTION

In general, the generation of off-gauge at acceleration and deceleration in rolling mills have been a considerable problem in the past, that has not been completely solved. Even with modern rolling mills, the cause of the decrease in the rate of on-gauge greatly depends on the generation of the off-gauge at acceleration and deceleration.

Automatic rolling has been accomplished by mathematically evaluating or experimentally approximating the effects of bearing oil films, the coefficients of friction, and similar inherent rolling mill characteristics as a function of rolling mill speed, to obtain a functional approximation of the real values. With this information, open-loop rolling reduction or correction control is obtained by a program and a function generator.

With such methods, there are many factors attributable to the correcting-function approximating procedure, which are quite large in themselves. Accordingly, they do not always sufficiently absorb the generation of off-gauge at acceleration and deceleration in a rolling mill. Particularly in the case where a desired plate-thickness of a product is quite thin, the generation of a plate-thickness deviation at acceleration or deceleration is directly related to the decrease in the rate of on-gauge, and is a very serious problem.

SUMMARY OF THE INVENTION

The present invention relates to an automatic plate-thickness control method for a rolling mill, and the apparatus for carrying out the method, which system controls the plate-thickness by regulating the rolling mill to on-gauge. The present invention has as an object to overcome the above mentioned problems, particularly with the provision of an automatic plate-thickness control system taking into consideration the influences upon the plate-thickness at the acceleration and deceleration of a rolling mill.

Particularly, incoming plate-thickness deviation from a normal plate-thickness are measured along with outgoing plate-thickness deviations from a normal reduced plate-thickness for a particular point on sheet material as it passes through a rolling mill, which process is repeated for a plurality of speeds. There will be a first outgoing plate-thickness deviation corelated to the incoming plate-thickness deviation, which may be determined according to a relationship including the known normal incoming and outgoing plate-thicknesses, and in addition the outgoing plate-thickness deviation will have a component attributable to the inherent characteristics of the rolling mill corelated to the particular speed at which it was measured, which characteristics include changes in oil film thickness within bearings and coefficients of friction. Thus, the outgoing plate-thickness deviation component attributable to the inherent characteristics of the rolling mill is determined and stored as information corelated to the particular speed at which it was measured. During subsequent passes or rolling, the stored information is retrieved that corresponds to the rolling mill speed at that time so as to be used in correcting the rolling mill gap in compensating for the inherent characteristics of the rolling mill at the speed.

BRIEF DESCRIPTION OF THE DRAWING

Further objects, features and advantages of the present invention will become more clear from the following detailed description of the drawing, wherein:

FIG. 1 is a diagram useful in explaining the present invention; and

FIG. 2 is a schematic representation of a system for accomplishing the present invention.

DETAILED DESCRIPTION OF THE DRAWING

Where plate products are obtained, for example, in a reversing rolling mill, the oil film, particularly in bearings, and the various coefficients of friction, and the like inherent characteristics, of the rolling mill are factors influencing the plate-thickness, which factors change during acceleration and deceleration of the rolling mill. The system of the present invention accurately determines the influences or effects of these factors upon the product.

The diagram in FIG. 1 is useful for evaluating the deviations in the plate-thickness, particularly those deviations attributable to the inherent characteristics of the rolling mill for acceleration or deceleration, particularly those attributable to oil films and coefficients of friction. As seen, plate material, particularly sheet metal, will pass from left to right in FIG. 1 through the gap between the rolling mill rolls **1**. The incoming and outgoing plate-thickness will be measured, respectively, by the thickness meters **2** and **3**, which are preferably X-ray gauge meters. In this manner, an actual plate thickness H on the incoming side of the rolling mill is detected by the thickness meter **2** on the incoming side. This actual plate thickness H is a combination of a plate-thickness deviation ΔH and the desired incoming plate-thickness $\bar{H}$. Similarly, the thickness meter **3** on the outgoing side of the rolling mill will determine the actual outgoing plate-thickness h, which will be a combination of the outgoing plate-thickness deviation Δh and the desired outgoing plate-thickness $\bar{h}$.

For purposes of evaluation, let it be assumed that the roll opening S is set for the rolls **1** of the mill and the plate material to be rolled is such as to produce a normal steady state rolling speed; the roll opening S would thus be the gap between the rolls **1** that would produce the outgoing-side plate-thickness at the desired value $\bar{h}$, when the incoming-side plate-thickness is at the value $\bar{H}$. Thus for purposes of this evaluation, the roll opening S will be that to produce the desired outgoing plate-thickness $\bar{h}$ at a normal rolling speed.

Consideration will be given now to the incoming-side plate-thickness H, which is not necessarily coincident with the desired or normal value $\bar{H}$ as measured in the lengthwise direction of the material to be rolled. With reference to FIG. **1**, it will be seen that the plate-thickness deviation ΔH as measured by the incoming-side thickness meter **2** will produce a corresponding plate-thickness deviation Δh on the outgoing-side as measured by the plate-thickness meter **3**. It is thus seen that:

$$H = \bar{H} + \Delta H \quad (1)$$

$$h = \bar{h} + \Delta h \quad (2)$$

In the rolling, the incoming plate-thickness Δh will be reduced to the outgoing plate-thickness deviation Δh in the same proportion as the incoming normal plate-thickness $\bar{H}$ would be reduced to the outgoing normal plate-thickness $\bar{h}$. Thus, if there were no automatic plate-thickness control system in operation, the following relationship would hold true:

$$\Delta h = \overline{h/H} \cdot \Delta H \qquad (3)$$

While the above analysis has been with respect to a somewhat ideal situation at a single speed, acceleration and deceleration happens in the actual operation of a rolling mill. With such acceleration and deceleration, a deviation $\Delta h'$ will be measured by the outgoing-side thickness meter **3** from the desired plate-thickness h, when there is no automatic plate-thickness control. This actual plate-thickness deviation with acceleration and deceleration is the particular concern of the present invention and may be expressed according to the following equation:

$$\Delta h' = \Delta h + \Delta hD \qquad (4)$$

In the above equation, $\Delta h'$ would be the outgoing plate-thickness deviation for acceleration and deceleration of an actual rolling mill, Δh would be the previously described outgoing plate-thickness deviation attributable to the incoming plate-thickness deviation ΔH, and ΔhD would be the outgoing plate-thickness deviation component attributable to the inherent characteristics of the rolling mill, such as oil film thicknesses and coefficients of friction, which will change with a change in rolling speed.

In the above mentioned equation 4, it is a particular feature of the present invention that the first term on the right hand side of the equation, that is, Δh corresponds to the outgoing-side thickness deviation component resulting from the incoming-side plate-thickness deviation, and may be determined from equation 3. Thus by substituting the relationship of equation 3 in equation 4 and transposing some terms, we obtain:

$$\Delta hD = \Delta h' - (\overline{h/H}) \cdot \Delta H \qquad (5)$$

In equation 5, $\Delta h'$ is the outgoing plate-thickness deviation as detected by the outgoing-side thickness meter **3**, ΔH is the plate-thickness deviation as detected by the incoming-side thickness meter **2**, $\bar{h}$ is the known desired outgoing plate-thickness, and $\bar{H}$ is the known desired incoming plate-thickness. Hence, ΔhD may be determined from equation 5 by the above known and measured values.

According to one form of the present invention, the automatic plate-thickness control system will not be operated for a first or optional pass of the plate through the rolling mill so that the thicknesses of a number of points along the plate may be monitored by the plate-thickness meters 2,3 during the normal acceleration and deceleration, so that the plate-thickness deviation ΔhD may be accurately determined for each rolling speed by the equation 5. With this information, the amount of correction ΔSD of the roll opening to make the necessary corrections in platethickness reduction as determined by the deviation ΔhD may be obtained for each rolling speed encountered during the first pass. This information is stored and retrieved during the next pass for subsequent rolling operation by an automatic plate-thickness control system according to the present invention put into operation after the above mentioned first pass, so that the roll opening will be controlled by the above mentioned correction ΔSD. Thus, the inherent effects of the rolling mill that vary for different speeds may be compensated for by the present invention.

Since outputs of detectors, such as the plate-thickness meters **2, 3** vary according to many different disturbances if not otherwise processed, the present invention employs statistical procedures or the like, for smoothing out these outputs. Particularly, a satisfactory smoothing of the meter outputs is obtained, for example, by taking in values at several different points during the first or optional pass or period to be compared as corelated with the point speeds, and excess values and deficient values are corrected so as to obtain linearity. Thus smoothed take in signals are received in the storage device of the computer in correspondence with the take in speeds.

A particular embodiment of the present invention will be described in detail with respect to FIG. **2**, which discloses a reversing rolling mill by way of example, although it is understood that the system of the present invention may be similarly applied for plate-thickness control with multiple sheets or multiple sheet portion in a tandem rolling mill.

With respect to FIG. **2**, the rolling mill rolls **1** are between the incoming and outgoing plate-thickness meters **2, 3**, respectively for acting upon the indefinite length plate material passed around tension rolls **4, 5** to be wound and unwound from winding and unwinding reels **6, 7.** The gap between the rolls **1** is determined by the reduction of screw down device **8** as powered by a screw down motor **9**, and may be accurately measured or determined by the roll-opening detector **10**, in a conventional manner. The rolling load is determined by the meter **11**, which feeds its information to a plate-thickness calculator **12**, which calculator will determine the outgoing-side plate-thickness from inputs received from the roll-opening detector **10** and the rolling-load meter **11.** A pilot generator or the like **13** may be used to determine the actual rolling speed of the rolls **1** as powered by the mill driving motor **14.**

The control circuitry of the present invention includes gate circuits **15, 16, 17**, which are conventional in structure, an automatic plate-thickness or gauge control device **18**, a manual or programmed automatic instructor or settor **19**, a rolling condition computer **20**, and a storage or memory device **21.**

According to the operation of the present invention, with reference to FIG. **2**, the outgoing and incoming side plate-thicknesses are measured by the meters **3** and **2**, and the rolling speed is measured by the speed detector **13** for a plurality of sample points spaced in the lengthwise direction of the material to be rolled, or continuously for a predetermined period for a particular plate pass or pass portion during which the automatic plate-thickness control system is not operated. With the above information an equation number 5, the plate-thickness deviation ΔhD due to the inherent characteristics of the rolling mill, for example oil films and coefficients of friction, may be calculated during acceleration and deceleration of the rolling. These deviations are then pattern stored in the storage or memory device **21** in corelation with the rolling speeds at which the measurements were taken. Thereafter, in further rolling or during the next pass when the automatic plate-thickness control system is in operation, the information within the memory or storage device **21** will be retrieved according to rolling speed during the acceleration and deceleration of the rolling, so that the information may be processed and employed by the automatic plate-thickness control device 18 to compensate for the inherent characteristics of the rolling mill. In this case, the automatic plate-thickness control device 18 will compute the amount of roll-opening correction that must be added to compensate for the ΔlD obtained from the system as above mentioned, so that the rolling reduction or screw down as determined by device 8 will be regulated in response to the computed amount of correction needed.

More specifically, the operation of the present inventive system will render the automatic plate-thickness control inoperative during the first pass of the plate material through the rolling mill. This condition will be dictated or commanded by the computer 20 to turn off the automatic plate-thickness control device 18 before and during the rolling of the first pass. The predetermined roll opening may be automatically or manually set by the settor or instructor 19 at one value for the entire rolling of the first pass. During the rolling of the first pass, the computer 20 will periodically generate pulse signals for opening the gate circuits 15, 16, 17. These pulse signals T1, T2, and T3 preferably are not simultaneously generated, but are produced with certain time differences so that the respective detectors 2, 13, 3 may detect an identical point in the lengthwise direction of the material to be rolled. That is, the point at which the thickness is detected by the meter 2 will reach the nip of the rolls 1 for speed detection by the device 13 and travel to the meter 3 for its detection so that the three characteristics may be measured for the same point, which operation is repeated for many different points. The pulse signal T1 will operate the gate 15 to allow entry of the output of the meter 2 into the rolling condition computer 20 for the incoming-side thickness; after the above mentioned predetermined time sufficient for the point on the material to reach the nip of the rollers 1, the pulse signal T2 will operate the gate 16 to allow the speed signal output of the device 13 to pass to the rolling condition computer 20; and after a period sufficient for the same point to reach the meter 3, the rolling condition computer 20 will produce pulse signal T3 to operate the gate 17 and permit the outgoing plate-thickness signal from meter 3 to pass into the rolling condition computer 20.

With the above information, the computer 20 will calculate the previously discussed inherent characteristic deviations ΔhD according to the equation 5 for each of the points with respect to which the measurements were taken, on the basis of the detected values. These calculated values of ΔhD will be stored in the storage or memory device 21 in correspondence with the respective rolling speeds. Thus a plurality of actual outgoing plate-thickness deviations ΔhD with the speeds at which they were determined will be obtained and stored during the first pass of the material being rolled.

When rolling of the second pass begins, the automatic plate-thickness control 18 will be placed in operation by the rolling condition computer 20. Further, the computer 20 will read out the stored value of ΔhD, which was obtained according to the preceding paragraph operation, for the rolling speed closest to the actual rolling speed being measured by the device 13 during the acceleration or deceleration of the rolling, which read out value ΔhD is obtained from the deviation stored along with their speeds in the memory device 21. Thereafter, the rolling condition computer 20 will feed the thus retrieved value of plate-thickness component ΔhD to the automatic plate-thickness device 18, which automatic plate-thickness control device 18 will appropriately adjust the roll opening. The retrieved values of ΔhD may be changed into corresponding values of ΔSD by the computer 20 or the automatic gauge control device 18; also, the values of ΔSD may be computed from the corresponding values of ΔhD during the first pass and stored in the memory device 21 so that upon retrieval they may be directly fed as values ΔSD to the screw down motor 9 and device 8 through the rolling condition computer 20 and automatic gauge control 18. The automatic plate-thickness control device 18 will adjust the roll opening so that the additional deviation between (1) a deviation $\Delta h2$ between an output of the outgoing-side thickness calculator 12 and the desired value at the second pass, and (2) the deviation ΔhD fed from the computer 20 may become zero. Thus, there will not appear a plate-thickness deviation due to the inherent characteristcs of the rolling mill, for example oil films, and the coefficients of friction caused by the acceleration or deceleration of the rolling during the second pass. This control is similarly carried out at and after the third pass. In this way, every pass is adequately controlled so as to eliminate the plate-thickness deviation caused by acceleration and deceleration of the rolling due to the inherent characteristics of the rolling mill.

In the foregoing analysis of the system according to the present invention, the acceleration and deceleration disturbance values or plate-thickness deviations are separately calculated and received in a storage device, as determined by actual measured values, during the first pass. At and after the second pass, the corresponding acceleration or deceleration disturbance or deviation values are retrieved from the storage device according to the rolling speed. The correction of the plate-thickness deviation which would be generated by the acceleration or deceleration, is thus carried out.

While the above has been set forth as a specific preferred embodiment of the present invention, further systems are contemplated. For example, the acceleration and deceleration disturbance values or plate-thickness deviations may be preestimated, for example from actual results of manufactured articles as previously programmed into the storage or memory device. According to this second embodiment, during the first pass the corrections for the plate-thickness due to acceleration and deceleration affecting the inherent characteristics of the rolling mill will be made by using these preestimated values as retrieved from the storage device. During this first pass, the plate-thicknesses at identical points of the material being rolled on the outgoing and incoming-sides of the roll housing will be taken in along with the rolling speed, and the plate-thickness deviations ΔhD will be determined for each speed. The excess or deficiency in the amount of control for the rolling mill will be calculated from comparing the preestimated values and the values determined from the measured information; in this manner, the acceleration and deceleration disturbance values programmed in the memory device 21 will be corrected during the first pass. At and after the second pass, the acceleration and deceleration disturbance or deviation values as corrected during the first pass will be retrieved from the memory device 21 so that off gauge due to acceleration or deceleration may be reduced as compared with the first pass.

As a further variation, with respect to the present invention being applied to continuous rolling, the correction of the roll opening may be carried out as follows. The automatic plate-thickness control system may be turned off with respect to the passage of the first plate, a portion of the first plate, the first several plates, or any other predetermined time. During this time that the automatic plate-thickness control system is turned off, the rolling speeds and plate thicknesses on the outgoing and incoming sides of the rolling mill during the acceleration and deceleration will be measured for a plurality of points. In the manner previously described, the values of ΔhD (plate-thickness deviations due to acceleration and deceleration) will be calculated, and these calculated values will be stored along with their rolling speeds in the memory device **21.** During subsequent rolling when the automatic plate-thickness system is in operation, the values of ΔhD will be retrieved from the memory device **21** according to the rolling speeds for processing in the automatic plate-thickness control system to eliminate the deviations inherent in the rolling mill due to acceleration and deceleration.

The plate-thickness deviations ΔhD due to the acceleration and deceleration during rolling that are received and stored have a satisfactory reproducibility, so that fine corrections of gains, etc., may be made with the advance of passes by a variety of variables such as set plate-thickness values, rolling loads, rolling tensions, and rolling speeds.

As described above according to the present invention, plate-thickness deviations ΔhD due to the changes in the oil films, the coefficients of friction, and the like inherent characteristics in the rolling mill due to acceleration and deceleration are precisely evaluated on the basis of detected values, and the control of the rolling mill is correspondingly accomplished so as to eliminate the plate-thickness deviations ΔhD. Hence, the products produced by the present invention will have an extremely high accuracy in plate-thickness. The present invention is remarkably effective particularly with respect to the rolling of very thin plates, which heretofore has presented considerable problems with respect to accuracy.

While a preferred system according to the present invention has been shown and described in detail along with various modifications, further modifications, embodiments and variations are contemplated within the spirit and scope of the present invention as defined by the following claims.

We claim:

1. A method of operating an automatic plate-thickness control rolling mill system to compensate for inherent rolling mill effects that are variable with speed, comprising the steps of: operating the rolling mill for the reduction of plate material for a first predetermined period of operation; measuring the plate-thickness going into the rolling mill, measuring the plate-thickness leaving the rolling mill and measuring the rolling speed, during the first rolling period; comparing the measured incoming and outgoing plate-thicknesses for the measured speed during the first rolling period to determine the plate-thickness deviation due solely to the inherent characteristics of the rolling mill for the measured speed; and thereafter rolling for a second period and using the previously determined plate-thickness deviation during the second rolling period to correct the rolling reduction.

2. The method of claim **1,** wherein the incoming and outgoing plate-thicknesses and rolling speed are measured for a single point on the material being rolled by successively taking the measurements.

3. The method of claim **1,** wherein a plurality of incoming and outgoing plate-thickness measurements are taken for a plurality of corresponding rolling speeds; correspondingly a plurality of plate-thickness deviation values due solely to the inherent characteristics of the rolling mill are determined from the measured plate-thickness values for each of the plurality of speeds during the first rolling period; and during the second period of rolling the previously determined plate-thickness deviation value for the speed closest to the actual speed is used for roll reduction correction.

4. The method of claim **3,** wherein said determined plate-thickness deviation values are stored during the first rolling period and retrieved as needed during the second rolling period.

5. The method of claim **1,** including automatically varying the roll reduction only during the second period of rolling in response to incoming plate-thickness deviations from a normal incoming plate thickness in addition to varying the rolling reduction in accordance with the determined values of plate-thickness deviation due to the inherent characteristics of the rolling mill.

6. The method of claim **1,** wherein the step of comparing includes comparing the total outgoing plate thickness deviation $\Delta h'$ with the incoming plate thickness deviation ΔH, the normal outgoing plate-thickness $\bar{h}$, and the normal incoming plate-thickness $\bar{H}$ to determine the outgoing plate-thickness deviation component ΔhD that corresponds to the inherent characteristics of the rolling mill separately from the outgoing plate thickness deviation component Δh that is caused by incoming plate-thickness deviation ΔH according to the relationship:

$$\Delta hD = \Delta h' - (\overline{h/H}) \cdot \Delta H$$

7. The method according to claim **6,** including storing a plurality of the thus determined plate-thickness deviation components ΔhD due to the inherent characteristics of the rolling mill according to the corresponding speeds at which the measurements were taken during the first rolling period; during the second rolling period automatically measuring the incoming plate-thickness deviation ΔH from normal incoming plate-thickness H and correcting the rolling mill reduction to eliminate the outgoing plate-thickness deviation component Δh from the normal outgoing plate-thickness h that would otherwise be caused by the incoming plate-thickness deviation ΔH; and simultaneously additionally automatically correcting the rolling mill reduction in response to the plate-thickness deviation value ΔhD retrieved from storage that corresponds closest to the actual rolling speed to reduce the plate-thickness deviations caused by the inherent rolling mill characteristics.

8. A plate rolling mill, including: at least two opposed rolls forming therebetween a reduction gap; means for measuring the rolling speed; means for measuring the incoming plate-thickness; means for measuring the outgoing plate-thickness; means for adjusting the roll gap; an automatic plate-thickness control means for controlling the roll gap adjusting means to eliminate outgoing plate-thickness deviations caused by incoming plate-thickness deviations; means to compare the incoming plate-thickness, the outgoing plate-thickness, the normal predetermined incoming plate-thickness, and the normal predetermined outgoing plate-thickness to obtain an outgoing plate-thickness deviation component corresponding only to the inherent effects of the rolling mill corelated to the rolling speed, including variations in oil film thickness and coefficients of friction according to speed, each for a plurality of points along the plate being rolled; means for storing a plurality of the thus determined plate-thickness deviation components due to the inherent rolling mill characteristics according to their rolling speeds; and means for retrieving the stored plate-thickness deviation component that is corresponding in speed closest to the actual rolling speed, and for adjusting the rolling reduction gap in response to the retrieved plate-thickness deviation component.

9. The plate rolling mill of claim **8**, where said means to compare includes separate gate means in series with each of said incoming plate thickness measuring means, said rolling speed measuring means and said outgoing plate-thickness measuring means; and means for successively applying gate control signals to said gate means spaced in time corresponding to the time intervals that it would take a point on the plate being rolled to pass from said incoming plate thickness measuring means to said rolling speed measuring means and said outgoing plate-thickness measuring means respectively.

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