United States Patent

Arimura et al.

[15] **3,641,325**

[45] **Feb. 8, 1972**

[54] **METHOD OF COMPUTER CONTROL OF ROLLING MILLS**

[72] Inventors: **Tohru Arimura; Masamoto Kamata; Masaru Okado; Takarokuro Ichimaru**, all of Kawasaki, Japan

[73] Assignee: **Nippon Kokan Kabushiki Kaisha**, Tokyo, Japan

[22] Filed: **Feb. 19, 1970**

[21] Appl. No.: **12,775**

[30] **Foreign Application Priority Data**

Feb. 21, 1969 Japan....................................44/12571

[52] **U.S. Cl.**..**235/151.1,** 72/8

[51] **Int. Cl.**......................................**G05d 5/02,** B21b 37/12

[58] **Field of Search**..............235/151.1, 151.11, 151, 150.1, 235/150; 72/8, 28, 29

[56] **References Cited**

UNITED STATES PATENTS

3,096,670	7/1963	Stringer	235/151.11 X
3,478,551	11/1969	Alsop	72/8
3,015,974	1/1962	Orbom et al.	235/151.11 X
3,104,566	9/1963	Schurr et al.	235/151.11 X
3,169,424	2/1965	Branscom et al.	235/151.11 X
3,204,440	9/1965	Thompson	235/151.11 X
3,248,916	5/1966	Kenyon et al.	235/151.11 UX

OTHER PUBLICATIONS

"Determination of A Mathematical Model for Rolling Mill Control"–Schultz et al–*Iron and Steel Engineer*–May–1965.

"Theoretical Aspects of Hot Mill Automation"–McKenzie–Steel international–January 1968.

Primary Examiner—Joseph F. Ruggiero

Attorney—Flynn & Frishauf

[57] **ABSTRACT**

In a method of computer control of a rolling mill, various operating parameters thereof are divided into a number of groups, the mean value of each group is determined and deviations of the parameters from the respective mean value are corrected in accordance with linear equations.

8 Claims, 2 Drawing Figures

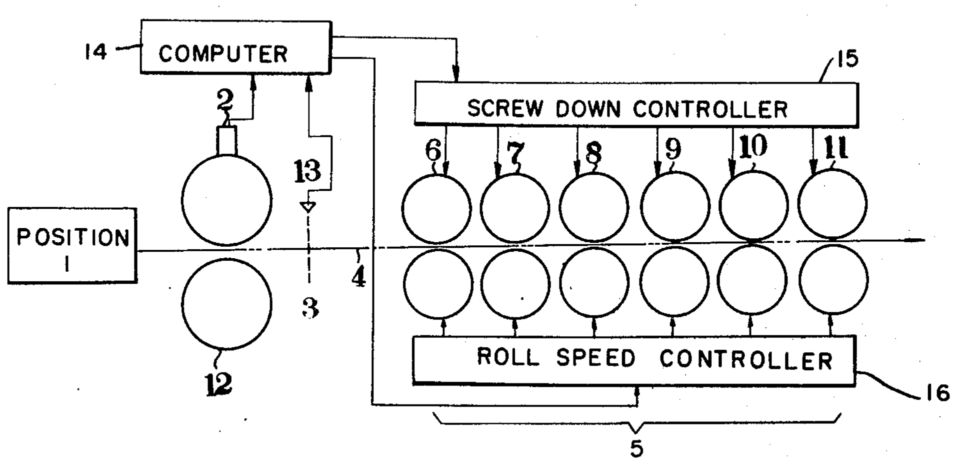
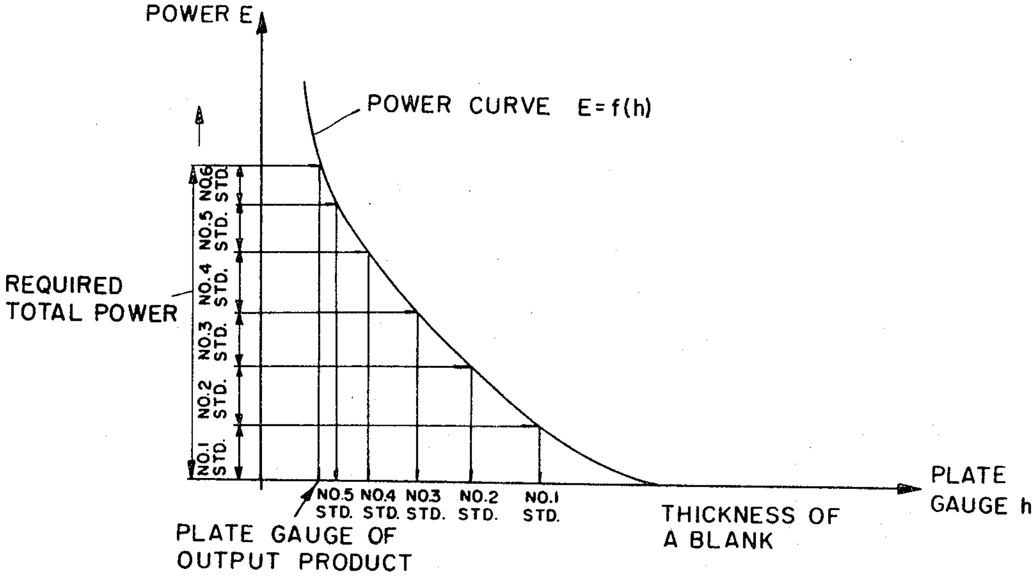


FIG.1


POWER E
POWER CURVE E=f(h)
REQUIRED TOTAL POWER
NO.6 STD.
NO.5 STD.
NO.4 STD.
NO.3 STD.
NO.2 STD.
NO.1 STD.
NO.5 STD. NO.4 STD. NO.3 STD. NO.2 STD. NO.1 STD.
PLATE GAUGE OF OUTPUT PRODUCT
THICKNESS OF A BLANK
PLATE GAUGE h

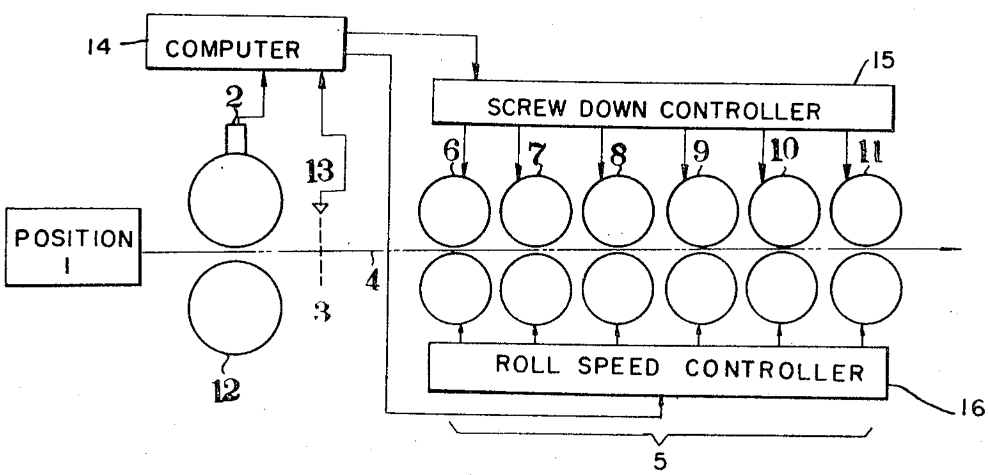

14
COMPUTER
15
SCREW DOWN CONTROLLER
2
13
6
7
8
9
10
11
POSITION I
4
3
12
ROLL SPEED CONTROLLER
16
5

FIG. 2

METHOD OF COMPUTER CONTROL OF ROLLING MILLS

BACKGROUND OF THE INVENTION

This invention relates to a method of computer control of a rolling mill wherein operating parameters thereof are divided into a number of groups (or ranges) and the derivation of the parameter from a mean value in each group (or range) is corrected by primary equations, thus providing a rapid and accurate control of the rolling mill.

Heretofore, a method of controlling a rolling mill, according to a power curve, has been generally used.

According to this prior art method, a curve representing the power required for reducing steel stock from a blank to the desired gauge is plotted by utilizing rolling data to suitably distribute the driving power to respective stands of a tandem rolling mill with due consideration of the capacity of the driving motors of respective stands. After distributing the driving powder among various stands in this manner, the output plate gauge of each stand is then determined from a power curve depicted in FIG. 1. Once the gauge is determined, the volume feed rate as well as the rolling speed of each stand can be determined under a fixed condition, and the rolling load can be calculated from the gauge and the speed. Thus, for example, by denoting a set value of a roll gap by Sr, the output gauge of the plate by h, the rolling load by P, stiffness of the mill by M (a proportionally constant representing the proportion of the increase in the roll gap caused by the rolling load, where the rolling mill is assumed to comprise a spring system), the set value of the down screw of each stand can be expressed by an equation

$$Sr = h - P/M$$

Thus, it is possible to determine the set value of the roll gap of each stand by subtracting the increment in the roll gap from the output gauge.

This prior art method is characterized in that, when programming a proper schedule for each gauge rolled by the rolling mill, the rolling load, the driving power, gauge at each stand, rolling speed, etc., can be obtained in terms of their absolute values. However, as it is necessary to individually determine absolute values of the roll gap and roll speed for each one of different gauges, computing equations are very complicated. On the other hand, with simplified equations the accuracy of the operation can not be assured using the prior art method.

In addition to the power curve method described above, various methods have been proposed. In any one of these prior methods, absolute values of the rolling power and rolling load are independently determined for each size of the product in order to determine required set values of a rolling mill.

In this manner, accurate and complicated calculations are required for conventional methods because according to them, absolute values of the rolling power and driving power are required. Accordingly, online calculations are also extremely complicated.

SUMMARY OF THE INVENTION

It is, therefore, an object of this invention to provide a novel method of computer control of a rolling mill which can readily and quickly maintain the operating parameters of the rolling mill in accordance with linear equations without the necessity of complicated calculations.

Another object of this invention is to provide an improved computer control method of a rolling mill which can not only preset the mill to produce the desired product but also dynamically correct the preset values during operation.

According to this invention, the above-mentioned objects can be accomplished by providing a novel computer method wherein various operating parameters of the mill are respectively divided into a number of groups (or ranges), and the deviation of a parameter from the mean value in each group (or range) corresponding to that parameter is utilized to correct the operation of the rolling mill. The deviation is computed in accordance with linear equations to increase the accuracy and speed of calculation.

BRIEF DESCRIPTION OF THE DRAWING

This invention can be more fully understood from the following detailed description taken in conjunction with the accompanying drawing in which:

FIG. 1 shows a plot of a power curve to explain a conventional method of determining the plate gauge at the exit of each mill stand, and

FIG. 2 is a diagram of a six-stand tandem hot mill employed to carry out this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 2, there is shown a six-stand hot tandem mill comprising a final roughening rolling mill **12**, a load cell **2** mounted on the roughening rolling mill **12**, a temperature measuring device **13** and a series of finishing mill stands **5** including six stands **6** through **11**. A computer shown generally at **14** receives data from load cell **2** and from temperature-measuring device **13** operates on this data and controls the screw down of stands **6–11** via screw down controller **15**. The computer controls the speed of the rolls at stands **6–11** via a speed controller **16**.

When presetting a rolling mill, the roll gap and roll speed of each stand should be set first. The setting of the roll gap is determined dependent upon the plate gauge, the rolling load and stiffness of particular mill stand.

Denoting the plate gauge at the exit between rolls by h, the stand number of the finishing mill by i, set value of the roll gap by Sr, rolling load by P and the stiffness of the mill by M, the following relation holds.

$$h_i = Sr_i + P_i/M \tag{1}$$

The roll speed can be determined from a condition that volume feed rate is constant. Thus,

$$v_i h_i = U \tag{2}$$

where v represents the speed of the material and U the volume feed rate.

As can be understood from equations 1 and 2, in order to determine operating parameters of a rolling mill, it is necessary to determine the plate gauge, rolling load and the stiffness of each mill stand.

In accordance with this invention, these parameters are determined in the following manner.

Assuming a gauge of the product of h_6, the following mean values are specified to obtain a gauge close to the set value.

Plate gauge at respective stands	h_{ki}	$i=1-6$
Load at respective stands	P_{ki}	$i=1-6$
Temperature at respective stands	T_{ki}	$i=1-6$
Roll speed at respective stands	V_{ki}	$i=1-6$
Set gap at respective stands	Sr_{ki}	$i=1-6$
Power for respective stands	HP_{ki}	$i=1-6$
Mean width of the plate	B_k	
Carbon equivalent of compounds contributing to mean resistance for deformation of the material	(C_T) C_{Tk}	
Mill stiffness, a function of the width of the material	$M=M(B)$	
Thickness of the finished product	h_6	
Carbon equivalent of the finished product	C_T	
Finishing temperature	T_6	
Width of the material	B	

Then, deviations from these mean values are:

$$\Delta h_6 = h_6 - h_{k6} \tag{3}$$

$$\Delta C_T = C_T - C_K \tag{4}$$

$$\Delta T_6 = T_6 - T_{k6} \tag{5}$$

$$b = B/B_k \tag{6}$$

Although it is necessary to vary the rolling schedule of respective stands according to these deviations from mean values represented by equations (3), (4), (5) and (6), such variations may be considered as small variations around mean values which can be determined according to linear graphs. As a consequence, the following relations hold:

Plate gauge at each stand

$$h_i = h_{ki} + \alpha_{1i} \cdot \Delta h_6 \quad (7)$$

Temperature at each stand

$$T_i = T_{ki} + \alpha_{2i} \cdot \Delta h_6 + \alpha_{6i} \Delta T_6 + \alpha_{10i} \cdot \Delta C_T \quad (8)$$

Roll speed at each stand

$$V_i = V_{ki} + \alpha_{4i} \Delta h_6 + \alpha_{8i} \Delta T_6 \quad (9)$$

It is easy to determine the plate gauge, temperature of the material and roll speed from equations (7), (8) and (9).

Based upon the plate thickness and the temperature thus obtained, the load and power at each stand can be obtained according to the following equations.

Rolling load at each stand

$$P_i = (P_{ki} + \alpha_{3i} \Delta h_6 + \alpha_{7i} \Delta T_6 + \alpha_{11i} \cdot \Delta C_T) \times b \quad (10)$$

Power at each stand

$$HP_i = (HP_{ki} + \alpha_{5i} \Delta h_6 + \alpha_{9i} \Delta T_6 + \alpha_{12i} \Delta C_T) \times b \quad (11)$$

In this manner, equation (7) gives the plate gauge at each stand and equation (10) gives the rolling load at each stand. Further, the mill stiffness is determined by experiment or theoretical calculation as a function of the width of the material

$$M = M(B) \quad (12)$$

Thus, by substituting these equations in equation (1), the set value of the roll gap at each stand can be readily determined.

$$Sr_i = h_i - P_{i/M}$$
$$= h_{ki} + \alpha_{1i} \cdot \Delta h_6 - (P_{ki} + \alpha_{3i} \Delta h_6 + \alpha_{7i} \Delta T_6 + \alpha_{11i} \cdot \Delta C_T) \times b/M$$
$$= Sr_{ki} + \alpha_{1i} \cdot \Delta h_6 - (\alpha_{3i} \Delta h_6 + \alpha_{7i} \Delta T_6 + \alpha_{11i} \cdot \Delta C_T) \times b/M_i \quad (13)$$

While the roll speed can be determined by equation (9), it is necessary to derive equation (9) to satisfy the condition of constant volume feed rate.

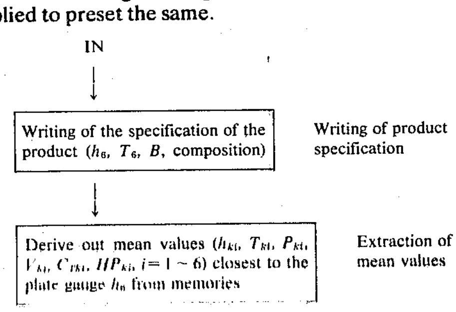
As is clear from equations (9) and (13), this invention is characterized in that both the set values of the roll gap Sr_i and roll speed V_i are obtained by adding linear correction values caused by minute changes (Δh_6, ΔT_6, ΔC_T, etc.) to mean values (Sr_{ki}, V_{ki}) so that even when the record of the correction factor (α_{mi}) is not absolutely correct, the schedule finally obtained is extremely accurate.

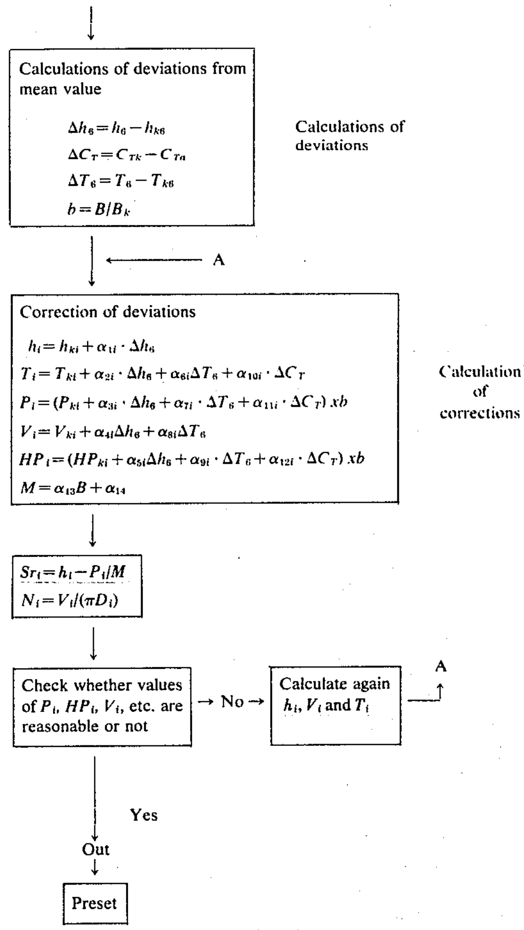
Since the data employed to obtain the mean values of Sr_{ki} and V_{ki} are derived by the analysis of rolling theory and the actual operation of the rolling mill in question, they are extremely accurate.

In dividing all parameters into several groups or ranges of values within the overall range of values of the respective parameters, and in determining the groups or ranges for the mean values which are to be set, it is necessary to pay due consideration to certain factors. Too small a number of groups or ranges of values whose mean values are to be set results in an increase in the width of the sections which are required to be corrected linearly, so that the result of the computation is not accurate unless the value of the correction factor is sufficiently accurate.

On the other hand, too large a number of groups whose mean values are to be set results in difficulty in applying adequate linear correction. For this reason, the number of the groups or ranges should be minimum so long as accurate linear correction can be assured. Under these conditions, once a pass schedule is determined for a product of particular size in accordance with above described equations (3) through (13), it is possible to obtain the result of computation at a high accuracy by an easy method of calculation such as a linear calculation.

The following diagram illustrates a flow chart of calculating and controlling a rolling mill when the invention is actually applied to preset the same.





This preset is performed at position 1 shown in FIG. 2, that is prior to the issue of the material from the roughening mill according to a card specifying the rolling operation.

FIG. 2 shows a computer connected in a mill. Product specifications h_6, T_6, and B are fed into the computer **14** and the computer **14** calculates the nearest possible mean value ($h_{ki} \cdot T_{ki} \cdot P_{ki} \cdot V_{ki} \cdot HP_{ki} \cdot G_k \cdot B_k$ i=1-6) to the said specification, and derives $\alpha_{1i}-\alpha_{12i}$ from out of a memory device therein. The computer calculates first $\Delta h_6 \cdot \Delta C_T \cdot \Delta T_6 \cdot b$ by equations (3) to (6), and computes the values of $h_i \cdot T_i \cdot P_i \cdot HP_i \cdot M$ by equations (7) to (12).

In addition to such a preset, this invention is also applicable to the dynamic control for correcting the error of the preset during the rolling operation. One such application to the rolling mill shown in FIG. 2 is as follows.

While there are a number of methods of dynamic control, in one example wherein the above-described flow chart for presetting is employed, after completion of the preset, the gauge and the temperature of the plate at the exit of the final pass of the roughening mill **12** are measured, and information regarding these measured parameters are utilized to correct the value of the previous preset. The specific manner of adjusting the preset of the rolls is apparent to those ordinarily skilled in the art, and is not shown herein so as not to unduly complicate the present disclosure. The details of the operation of this invention applied to this dynamic control are as follows.

Sr_i is computed by equation (13). The computer further checks that these values obtained are within the range of the mill capacity and presets the screw downs and the roll speed of the each stand by means of controllers **15** and **16**, respectively.

First the temperature and the gauge of the plate at the exit of the roughening mill **12** are measured directly or indirectly by a suitable gauge meter (not shown) and the thermometer **13** shown in FIG. 2. Further, the rolling load of the final stand of the roughening mill **12** is measured by the load cell **2**. The plate gauge at the exit of roughening mill **12** can also be calculated from the output from load cell 2 according to equation (1), in which case, the equation is modified as follows.

$$h_o = S_o + P_R/M_R \quad (14)$$

Denoting the material temperature by T_R, mean value (reference value) of the plate gauge at the entrance of finishing stands by h_{ko}, and the mean value of the material at the exit of the roughening mill 12 by T_{Rk}, then their deviations are expressed by

$$\Delta h_o = h_o - h_{ko} \quad (15)$$

$$\Delta T_R = T_R - T_{Rk} \quad (16)$$

In this case, the value of the previously calculated preset is corrected beforehand by distributing the error of the plate gauge expressed by equation (15) among various stands of the finishing mill and by anticipating the variations in the temperature drop at respective stands of the finishing mill caused by the error in the material temperature at the exit of the roughening mill. More particularly,

$$\Delta h_i = \beta_{1i}\Delta h_o + \beta_{2i}\Delta T_R \quad (17)$$

$$\Delta T_i = \beta_{3i}\Delta h_o + \beta_{4i}\Delta T_R \quad (18)$$

$$\Delta P_i = \beta_{5i}\Delta h_o + \beta_{6i}\Delta T_R \quad (19)$$

$$\Delta V_i = \beta_{7i}\Delta h_o + \beta_{8i}\Delta T_R \quad (20)$$

hence

$$\Delta Sr_i = \Delta h_i - \Delta P_i/M \quad (21)$$

In this manner, equations (20) and (21) give the correction value for the preset value so that it is possible to calculate and control the deviation from the mean value by a linear correction.

Dynamic change in the preset is effected when the leading end of the material arrives at a point 4 shown in FIG. 2 to the calculation and control of the dynamic control is performed by means of a computer coupled to the roll stands to adjust same in accordance with the correction signals derived as above. The actual control of the roll stands by the output signals from the computer may be implemented by one ordinarily skilled in the steel making and processing art. The computer is also coupled to load cell 2, to thermometer 13 and to a gauge meter (not shown) at the output of roughening mill 12. The dynamic control can be summarized as follows:

EXAMPLE OF DYNAMIC CONTROL

Material temperature T_R, and is measured at point 3 in FIG. 2. Rolling load P_R and roll gap S_0 are measured at point 2 in FIG. 2.–;	Measurement of rolling parameters
↓ Calculation of the gauge at the entrance of the finishing mill $h_0 = Sr_0 + P_R/M_R$	
↓ Calculations of the deviation of the gauge at the entrance of the finishing mill and the deviation of the temperature of the roughening mill $\Delta h_0 = h_0 - h_{k0}$; $\Delta T_R = T_R - T_{Rk}$	Calculations of deviations
↓ Calculations of correction values $\Delta h_i = \beta_{1i}\Delta h_0 + \beta_{2i}\Delta T_R$; $\Delta T_i = \beta_{3i}\Delta h_0 + \beta_{4i}\Delta T_R$; $\Delta P_i = \beta_{5i}\Delta h_0 + \beta_{6i}\Delta T_R$; $\Delta V_i = \beta_{7i}\Delta h_0 + \beta_{8i}\Delta T_R$; $\Delta Sr_i = \Delta h_i - \Delta P_i/M_n$; $\Delta N_i = \Delta V_i/\pi D_i$.	Calculations of correction values
↓ Corrections of preset values SrP_i and NP_i $Sr_i = SrP_i + \Delta Sr_i$; $N_i = NP_i + \Delta N_i$	Corrections of preset values
↓ Out	

As above described, in accordance with this invention since it is possible to readily derive and correct equations in addition to the preset and dynamic control of rolling mills, the invention can be applied to computer control of various mills such as a blooming mill, slab mill, cold tandem mill, cold reversible mill, tamper mill and the like. Further, since all controls are performed in accordance with primary equations, it is possible to perform the calculations in a short period of time so that the invention is most suitable for an online computer control. The mean value (reference value) of each group or range of values for respective operating parameters of the rolling mill is calculated in accordance with simple primary equations to correct deviations alone so that control of the rolling mill is provided at high accuracies.

While the invention has been shown and described in terms of a preferred embodiment thereof, many changes and modifications will be obvious to those skilled in the art without departing from the true spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A method of controlling a plural stand rolling mill by means of a computer comprising:

predetermining a plurality of ranges for each of a plurality of operating parameters of said rolling mill;

predetermining and storing in a storage means a respective mean value for each of said ranges of values;

predetermining and storing in a storage means a plurality of correction factors, the correction factors being stored as a function of the desired characteristics of the output of said rolling mill and as a function of the properties of the input material to said rolling mill; and

calculating and applying control signals to a plurality of stands of said rolling mill to simultaneously control at least one of the screw down and roll speed at said plurality of stands as a function of mean values and correction factors corresponding to a plurality of said operating parameters, said mean values and correction factors being at least a function of the properties of the input material to said rolling mill and of the desired characteristics of the output of said rolling mill.

2. The method of claim 1 wherein said control signals are calculated and applied to said stands prior to feeding in of the input material, thereby presetting said rolling mill to obtain a predetermined output product for a given input material.

3. The method of claim 1 wherein said control signals are calculated and applied to said stands during operation of said rolling mill.

4. The method of claim 1 wherein deviations in a plurality of said operating parameters are detected during operation of said rolling mill, and said control signals are further calculated in response to said detected deviations.

5. The method of claim 2 wherein said control signals are further calculated and applied to said stands during operation of said rolling mill to dynamically vary said preset values.

6. The method of claim 5 wherein deviations in a plurality of said operating parameters are detected during operation of said rolling mill, and said control signals are further calculated in response to said detected deviations.

7. The method of claim 6 wherein the gauge and temperature are detected at the output of a rolling stand during operation of said rolling mill, said control signals being calculated and fed forward to rolling stands downstream of the stand at which said parameters are detected.

8. The method of claim 1 wherein said operating parameters of said rolling mill comprise plate gauge, temperature of the material, rolling load, mill stiffness and roll gap.

* * * * *