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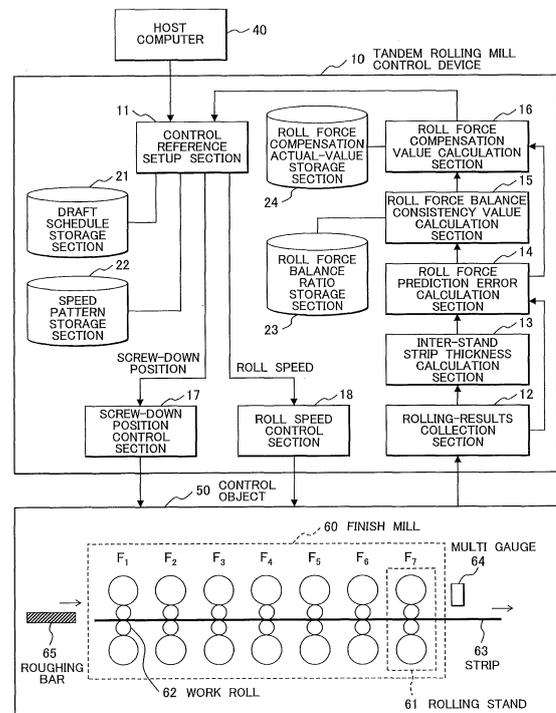
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(54) **CONTROL DEVICE OF TANDEM ROLLING MILL AND CONTROL METHOD**

(57) A roll force prediction error calculation section estimates roll forces in rolling stands utilizing rolling actual values acquired at the time when a strip is rolled, and calculates roll force prediction errors from the estimated roll forces and the rolling actual values. A roll force balance consistency value calculation section (15) calculates roll force balance consistency values that indicate the degree of differences between the roll force prediction errors in the rolling stands and roll force prediction errors in neighboring rolling-stands. A roll force compensation value calculation section (16) calculates roll force compensation values from the roll force prediction errors and the roll force balance consistency values. A control reference setup section estimates a roll force of a strip to be next rolled, compensates the estimated roll forces by the roll force compensation values which are calculated in the roll force compensation value calculation section, and calculates screw-down positions to be set in the respective rolling stands, utilizing the compensated roll forces.

FIG. 1



Description

BACKGROUND OF THE INVENTION

5 Field of the Invention

[0001] The present invention relates to a control device of a tandem rolling mill and a control method which are suitable for qualitative improvement of a strip.

10 Description of Prior Art

[0002] In the past, in hot strip tandem rolling mill control of a strip, a method is generally employed which comprises, prior to rolling, predicting a rolling condition of a strip to be rolled, determining a screw-down position (corresponding to a clearance between upper and lower work rolls) and a roll speed, controlling a head end of strip, and thereafter gradually compensating the screw-down position and the roll speed to suitable values by utilizing a strip thickness and a strip tension between rolling stands, which are obtained from a detector. In this control method, in order to adjust a strip thickness of the head end to a target value with accuracy and to stabilize the rolling at the time when the head end is bitten by the respective rolling stands of a finish mill, it is required to set the screw-down positions of the respective rolling stands and a reference value of the roll speed to suitable values by prediction calculation. In that case, what is particularly important for obtaining of a target strip thickness at a delivery of final rolling stand is the screw-down position. In order to properly determine the screw-down position, it is required to raise prediction accuracy of roll force.

[0003] Rolling control methods for improving prediction accuracy are disclosed in the following Patent Literature 1 to 3, for example.

[0004] In Patent Literature 1 (Japanese Patent Application Laid-Open No. Hei. 10-263640), an example of a rolling control method is disclosed which comprises determining a learning coefficient on the basis of a roll force actual value P_{act} and a roll force prediction model calculated-value P_{cal} found by substituting the roll force actual value for a roll force prediction model P , separating the learning coefficient into a first learning coefficient Z_{pk} of a component to learn an error intrinsic to a material to be rolled and a second learning coefficient Z_{pm} of a component to learn an error due to the time variance of a rolling machine, and learning the both components separately.

[0005] Also, in Patent Literature 2 (Japanese Patent Application Laid-Open No. 2013-226596), an example of a roll force prediction model is disclosed in which, in addition to processing to learn an estimated error of deformation resistance of a material, to be rolled, on the basis of rolling results, processing to learn an estimation error of a friction coefficient is performed on the basis of rolling results in connection with a friction phenomenon between rolling rolls and the material to be rolled, whereby prediction accuracy of the deformation resistance and friction coefficient is improved and prediction accuracy of the roll force is enhanced.

[0006] While the above-mentioned two example are characterized in that the concept of learning is introduced into the estimation of the roll forces of respective rolling stands, a method is disclosed in Patent Literature 3 (Japanese Patent Application Laid-Open No. 2009-113101) in which taking notice of a relationship among roll forces of a plurality of rolling stands, prediction accuracy of the roll forces are raised. That is, in Patent Literature 3, a rolling control method is disclosed in which using errors of the roll forces in the respective rolling stands which are calculated on the basis of roll force actual values in the respective rolling stands and a roll force prediction model calculation value found by substituting a rolling condition actual value, change of errors between an upstream rolling stand and a downstream rolling stand are modeled and, further, variations in roll force prediction errors among the rolling stands are suppressed using the model.

[0007] However, in the rolling control methods disclosed in Patent Literature 1 to 3, the following problems exist.

[0008] For example, the roll force prediction model disclosed in Patent Literature 1 is estimated by separating the estimation error of the roll force (a difference between the roll force actual value P_{act} and the roll force prediction model calculation value P_{cal}) into an inherent error component of a strip to be rolled (an error predicted using the first learning coefficient Z_{pk}) and an error component due to time variance of a rolling mill (an error predicted using the second learning coefficient Z_{pm}). However, the separation of the error factor is impossible from the first.

[0009] Referring to Patent Literature 1, it describes that the separation of the error factor is possible since inclination of the time variance of the rolling mill is small. However, in a case where, for example, changes in a strip thickness and a strip width of a strip to be continuously rolled are small, the estimation value of the roll force does not considerably vary. Therefore, there was a case where the inherent error of the strip to be rolled which had been generated was mistakenly separated as the error due to time variance of the rolling mill. Therefore, a problem occurs in which the first learning coefficient Z_{pk} and the second learning coefficient Z_{pm} in the roll force prediction model are improperly learned and the prediction accuracy of the roll force is deteriorated.

[0010] Moreover, in the method disclosed in Patent Literature 2, it is actually impossible to discriminate whether, for example, increase of the roll force depends upon increase of the deformation resistance or increase of friction. Therefore,

similarly to the case of Patent Literature 1, a problem occurs in which the deformation resistance and the friction coefficient which are used in the roll force prediction model are improperly learned and the prediction accuracy of the roll force is deteriorated.

5 [0011] Moreover, the characteristics of the roll force prediction models disclosed in Patent Literature 1 and 2 reside in that learning to be utilized for the prediction is independently performed in the respective rolling stands, on the basis of roll force results obtained in the respective rolling stands. Therefore, there is a case where a learning value in a specific rolling-stand becomes large and, by its reaction, the learning coefficients in neighboring rolling stands become small, and the both are considerably different in learning values. As a result, the roll forces in the respective rolling stands are compensated at large values or small values, so that a problem occurs in which roll force balance specially between the neighboring rolling stands collapses. If the roll force balance between the neighboring rolling stands collapses, a problem occurs in which increase and reduction in strip tensions among the rolling stand become unbalanced and rolling becomes unstable.

10 [0012] In the technology disclosed in Patent Literature 3, the roll force error change model is configured based on the errors of the roll forces in the respective rolling stands and the learning values in the respective rolling stands are calculated in accordance with the model. As a result, a learning value in a certain rolling stand is not considerably different from that in another rolling stand, so that roll force balance among the respective rolling stands can be maintained. On the other hand, the processing to configure the roll force error change model is required, so that there is a problem in which computational complexity is increased.

15 [0013] Moreover, generally, in the tandem rolling mill, there is a case where the characteristics of the roll force prediction error complexly varies as the strip is advanced from an upstream rolling stand side to a downstream rolling stand. For example, there is a case where when a comparison between the prediction roll force and the result roll force is made, the result roll force is large in the upstream and downstream rolling stands, and the prediction roll force is large in a middle rolling-stand. That is, there is a case where the prediction error leans on the upstream and downstream rolling stands, for example, to a plus side, and to a minus side at a middle portion.

20 [0014] In contrast, the roll force error change model disclosed in Patent Literature 3 is linear approximation, so that it cannot respond to such non-linear characteristics of the roll force prediction errors. Thus, if a model that responds to the non-linearity is introduced, a problem occurs in which the model becomes complex and computational complexity. In addition, a problem occurs in which the prediction results of the roll forces vary according to the complexity of the above-mentioned model.

30 SUMMARY OF THE INVENTION

[0015] The present invention has been made in order to solve the problems of the above-mentioned prior art, and the object of the present invention is to provide a control device of a tandem rolling mill and a control device which make it possible to realize balance consistency among a plurality of rolling stands with simple processing.

35 [0016] In order to achieve the above-mentioned object of the present invention, there is provided a control device of a tandem rolling mill for continuously rolling a strip with a plurality of rolling stands, which comprises a roll force prediction error calculation section estimating roll forces in the respective rolling stands, utilizing rolling actual values acquired in the respective rolling stands when the strip is rolled, and calculating roll force prediction errors in the respective rolling stands on the basis of roll force actual values acquired in connection with the rolling, a roll force balance consistency value calculation section calculating balance consistency values with respect to the respective rolling stands, the balance consistency values indicating the degree of differences between the roll force prediction errors in the respective rolling stands and the roll force prediction errors in rolling stands neighboring to the respective rolling stands, which are calculated by the roll force prediction error calculation section, a roll force compensation value calculation section calculating roll force compensation values in the respective rolling stands from the roll force prediction errors in the respective rolling stands, which are calculated by the roll force prediction error calculation section, and the roll force balance consistency values in the respective rolling stands, which are calculated by the roll force balance consistency value calculation section, and/or a control reference setup section estimating roll forces in the respective rolling stands regarding a strip to be next rolled, compensating the estimated roll forces in the respective rolling stands with the roll force compensation values in the respective rolling stands which are calculated in the roll force compensation value calculation section, and calculating screw-down positions, which are to be set to the respective rolling stands, by using the compensated roll forces.

40 [0017] According to the present invention, there are provided a tandem rolling mill control device and a control device which make it possible to realize balance consistency among a plurality of rolling stands with simple processing.

55 BRIEF DESCRIPTION OF THE DRAWINGS

[0018]

Fig. 1 is a view illustrating examples of configurations of a tandem rolling mill control device and of a control object, according to an embodiment of the present invention;

Fig. 2 is a view illustrating an example of a processing flow of processing which a control reference setup section executes;

5 Fig. 3 is a view illustrating an example of a configuration of a draft schedule table which is stored in a draft schedule storage section;

Fig. 4 is a view illustrating an example of a configuration of a speed pattern table which is stored in a speed pattern storage section;

10 Fig. 5 is a view illustrating an example of a processing flow of processing which an inter-stand strip thickness calculation section executes;

Fig. 6 is a view illustrating an example of a processing flow of processing which a roll force prediction error calculation section executes;

Fig. 7 is a view illustrating an example of a processing flow of processing which a roll force balance consistency value calculation section executes;

15 Fig. 8 is a view illustrating an example of a configuration of a roll force balance ratio table which is stored in a roll force balance ratio storage section;

Fig. 9 is a view illustrating an example of a processing flow of processing which a roll force compensation value calculation section executes;

20 Fig. 10 is a view illustrating an example of a configuration of a roll force compensation actual value table which is stored in a roll force compensation actual value storage section;

Fig. 11 is a view illustrating an example of a configuration of a tandem rolling mill control device according to a second embodiment of the present invention;

Fig. 12 is a view illustrating an example of a processing flow of processing which a steel grade-similarity calculation section executes; and

25 Fig. 13 is a view illustrating an example of a similarity-number table which is stored in a similarity-number storage section.

DETAILED DESCRIPTION OF THE INVENTION

30 **[0019]** Embodiments of the present invention will be described hereinafter in detail with reference to the drawings.

(First Embodiment)

35 **[0020]** Fig. 1 is a view which shows examples of configurations of a tandem rolling mill control device 10 and of a control object 50, according to an embodiment of the present invention. As shown in Fig. 1, the tandem rolling mill control device 10 obtains signals indicative of various states from the control object 50 and outputs various control signals to the control object 50. Incidentally, in Fig. 1, signals connecting respective blocks are indicated by arrows regardless of the type and number of signals.

40 **[0021]** First of all, referring to Fig. 1, a configuration of the control object 50 is explained. In this embodiment, the control object 50 is a hot strip tandem rolling mill provided with a finish mill 60. The finish mill 60 is configured by a plurality of rolling stands 61, rolls a roughing bar 65, which was rolled in a roughing mill (not shown) at a pre-stage and has a thickness of about 30 mm, for example, and produces a thin strip 63.

45 **[0022]** In the example of Fig. 1, the finish mill 60 has a configuration in which seven rolling stands 61 are continuously arranged, and the strip 63 (roughing bar 65) is rolled while being moved from the left to the right. Specifically, the strip 63 (roughing bar 65) is sequentially processed thinly by rolling in the respective rolling stands 61 (F_1 to F_7) and is discharged as an approximately 1 mm to 15 mm thickness strip 63 from an delivery of the rolling stand 61 (F_7).

50 **[0023]** Incidentally, in the finish mill 60, direct rolling of the roughing bar 65 and the strip 63 is performed by work rolls 62 of the respective rolling stands 61. Incidentally, the roughing bar 65 is sometimes referred to as other names such as a roughing bar, an incoming bar, a transfer bar, etc. Moreover, in this application, the roll speed means a circumferential speed of the work roll 62.

55 **[0024]** At the delivery of the final rolling stand 61 (F_7) of the finish mill 60, a multi gauge 64 that measures a strip thickness, a strip width, temperature, etc. of the strip 63 is disposed. Moreover, though omitted in Fig. 1, various detectors for detecting the states of the roughing bar 65 and the strip 63, such as a thermometer measuring the temperature of the roughing bar 65 and strip 63, a shapemeter measuring flatness of the strip 63, a crop profile gauge measuring head and tail end shape images of the roughing bar 65, a surface inspection equipment detecting a surface flaw of the strip 63, etc., are actually arranged in different places as needed.

[0025] Next, the configuration of the tandem rolling mill control device 10 is described. As shown in Fig. 1, the tandem rolling mill control device 10 is configured to include a control reference setup section 11, a rolling result collection section

12, an inter-stand strip thickness calculation section 13, a roll force prediction error calculation section 14, a roll force balance consistency value calculation section 15, a roll force compensation value calculation section 16, a screw-down position control section 17, a roll speed control section 18, a draft schedule storage section 21, a speed pattern storage section 22, a roll force balance ratio storage section 23, a roll force compensation actual value storage section 24, etc.

5 **[0026]** The control reference setup section 11 receives information required for rolling, such as the steel grade, target strip thickness, target strip width, etc. of the strip 63 to be rolled, which are transmitted from a host computer 40. Then, according to the received information, the roll force, screw-down position (roll gap), roll speed, etc. in each rolling stand 61 are calculated utilizing information and the like which is obtained from the draft schedule storage section 21 and the speed pattern storage section 22. Though the details will be described hereinafter, a roll force compensation value that is calculated in the roll force compensation value calculation section 16 is taken into consideration in this calculation of the roll force.

10 **[0027]** The control reference setup section 11 further outputs calculation results of the roll force, screw-down position, roll speed, etc. in each rolling stand 61 to the screw-down position control section 17 and the roll speed control section 18, respectively, as control references of the screw-down position and roll speed. Then, on the basis of the control references, the screw-down position control section 17 outputs a control value for controlling the roll force and screw-down position to each rolling stand 61. Similarly, on the basis of a roll speed reference, the roll speed control section 18 outputs a control value for controlling the roll speed to each rolling stand 61.

15 **[0028]** The rolling results collection section 12 collects a rolling-actual value of the strip, that is detected via the multi gauge 64 or the like, and control reference values (roll force, screw-down position, roll speed, etc.) that are outputted to the control object 50 from the screw-down position control section 17, the roll speed control section 18, etc.

20 **[0029]** The inter-stand strip thickness calculation section 13 estimates an inter-stand strip thickness of the strip 63 among the respective rolling stands 61 utilizing the data which the rolling results collection section 12 collects. Moreover, the roll force prediction error calculation section 14 predicts roll forces of the respective rolling stands 61 utilizing the inter-stand strip thickness estimated in the inter-stand strip thickness calculation section 13, and calculates deviations between them and actual roll forces (hereinafter referred to as roll force prediction errors).

25 **[0030]** Moreover, the roll force balance consistency value calculation section 15 calculates a roll force balance consistency value for maintaining roll force balance among the respective rolling stands 61, utilizing a roll force prediction error of a remarkable rolling stand 61, a roll force prediction error of a rolling stand 61 neighboring thereto, and a ratio acquired from the roll force balance ratio storage section 23 (a roll force balance ratio referred to in Fig. 8, etc.), among the roll force prediction errors calculated in the roll force prediction error calculation section 14.

30 **[0031]** Moreover, the roll force compensation value calculation section 16 calculates a roll force compensation value, that should be outputted to the control reference setup section 11, by utilizing the roll force prediction error calculated by the roll force prediction error calculation section 14, the roll force balance consistency value calculated by the roll force balance consistency value calculation section 15, and a roll force compensation value stored in the roll force compensation actual value storage section 24 and calculated in connection with the rolling in the past.

35 **[0032]** Specific hardware of the tandem rolling mill control device 10 which is configured as described above is realized by a computer provided with an arithmetic processing unit and a storage unit, and a work station. Functions of the respective sections such as the control reference setup section 11, the rolling-results collection section 12, the inter-stand strip thickness calculation section 13, the roll force prediction error calculation section 14, the roll force balance consistency value calculation section 15, the roll force compensation value calculation section 16, the screw-down position control section 17, the roll speed control section 18, etc. which are shown in Fig. 1 are realized by execution of predetermined program stored in the storage unit comprising a semiconductor memory, a hard disk drive, etc., by the arithmetic processing unit. Moreover, the storage sections, such as the draft schedule storage section 21, the speed pattern storage section 22, the roll force balance ratio storage section 23, the roll force compensation actual value storage section 24, etc., are realized by storage of predetermined data into a region which is assigned to a part of the storage unit.

40 **[0033]** Operation of the respective sections constituting the tandem rolling mill control device 10 will be in turn described in detail hereinafter. First of all, referring to Figs. 2 to 4, the operation of the control reference setup section 11 is explained. Fig. 2 is a view illustrating an example of a processing flow of processing which the control reference setup section 11 executes. Also, Fig. 3 is a view illustrating an example of a configuration of a draft schedule table 211 that is stored in the draft schedule storage section 21, and Fig. 4 is a view illustrating an example of a configuration of a speed pattern table 221 that is stored in the speed pattern storage section 22.

45 **[0034]** When the strip 63 (refer to Fig. 1) is rolled in the finish mill 60, roll force in the respective rolling stands 61 and screw-down position of the work rolls 62 are required to be suitable in order to obtain a desired thickness of a head end portion of the strip 63. Moreover, in order to stabilize behavior at the time when the strip 63 is bitten by downstream rolling stands 61, the roll speeds of the respective rolling stands 61 are required to be well-balanced, without any disturbance of a mass flow of the strip 63 (product of the strip thickness and the strip speed).

50 **[0035]** Therefore, the control reference setup section 11 receives information of the steel grade, target strip thickness,

target strip width, etc. of the strip 63 to be rolled now, which are transmitted from the host computer 40, and calculates a control reference such as the screw-down position, the roll speed, etc. to be required in order to roll the strip 63 according to the target.

[0036] As shown in Fig. 2, the control reference setup section 11 first refers to the draft schedule table 211 (refer to Fig. 3) stored in the draft schedule table storage section 21 to acquire a draft schedule table corresponding to the steel grade, target strip thickness and target strip width of the strip, that is a rolling object, which are transmitted from the host computer 40, and calculates screw-down ratios of the respective rolling stands 61 (Step S11).

[0037] As shown in Fig. 3, the draft schedule table 211 is configured by a draft schedule in which the steel grade, target strip thickness, target strip width, etc. of the strip 63 to be rolled are categorized. The draft schedule is information indicating how much the roughing bar 65 or the strip 63 is rolled in each of the rolling stands 61 (F_1 to F_7), namely, information indicating a draft (ratio of a difference between an entry strip thickness and an delivery strip to the entry strip thickness) in percent.

[0038] For example, a case where a roughing bar 65 whose steel grade is SS400 and which has a thickness of 35 mm is rolled to make a strip 63 whose target strip thickness and target strip width are 2.5 mm and 900 mm, respectively, is assumed. In the draft schedule table 211 of Fig. 3, this strip 63 is categorized as a strip which has a target strip thickness of 2.0 to 3.0 mm and a target strip width equal to or less than 1000 mm. Therefore, the roughing bar 65 having a strip thickness of 35 mm is rolled by 14 mm equivalent to 40 % of the strip thickness thereof, and consequently, a strip 63 which has an delivery strip thickness of 21 mm is produced. Similarly, in the rolling stand 61 (F_2), the strip 63 having the entry strip thickness of 21 mm is rolled by 35% of the thickness thereof to make a strip 63 having an delivery strip thickness of 13.65 mm.

[0039] Incidentally, some deviations are produced between the delivery strip thickness acquired in the final rolling stand 61 (F_7) in this way and the target strip thickness of 2.5 mm but the deviations can be cancelled by compensation of the deviations by the control reference setup section 11 according to drafts in the respective rolling stands 61.

[0040] The explanation is again returned to the processing flow shown in Fig. 2. Successively to the processing in Step S11, the control reference setup section 11 refers to the speed pattern table 221 (refer to Fig. 4) stored in the speed pattern storage section 22 to acquire a speed pattern which correspond to the steel grade, target strip thickness, and target strip width of the strip 63 that is the rolling object, and calculates a rolling speed (strip speed) at the delivery of the final rolling stand 61 (F_7) (Step S12).

[0041] As shown in Fig. 4, the speed pattern table 221 is configured by a speed pattern table that is categorized by the steel grade, target strip thickness, target strip width, etc. of the strip 63 to be rolled. The speed pattern is information about a speed at the time when the strip 63 that is the rolling object is discharged from the final rolling stand 61 (F_7), for example, means information which comprises an initial speed, a first acceleration rate, a second acceleration rate, a regular speed, a deceleration rate, and a final speed.

[0042] Moreover, the initial speed is a speed at the time when the head end of the strip 63 is discharged from the final rolling stand 61 (F_7), the first acceleration rate is an acceleration rate at the time when the speed of the strip 63 is increased after discharging of the head of the strip 63, the second acceleration rate is an acceleration rate until the strip 63 reaches the regular speed after it is bitten by a down coiler (omitted in Fig. 1) that is post-stage facility, the deceleration rate is a deceleration rate at the time when the strip 63 stably passes through the respective rolling stands 61 and decelerated to the final speed, and the final speed is a speed at the time when a tail end of the strip 63 is discharged from the final rolling stand 61(F_7).

[0043] Incidentally, in the example of Fig. 4, in the event of a strip 63 whose steel grade, target strip thickness, and target strip width are SS400, 1.2 to 1.4 mm, and 1000 mm or less, respectively, the initial speed is 650 mpm (meter per minute), the first acceleration rate is 2 mpm/s, the second acceleration rate is 12 mpm/s, the regular speed is 1100 mpm, the deceleration rate is 6 mpm/s, and the final speed is 700 mpm.

[0044] The explanation is again returned to the processing flow shown in Fig. 2. Successively to the processing in Step S12, the control reference setup section 11 executes processing to estimate temperature of the respective rolling stands 61 (Step S13). At this time, the temperature of the roughing bar 65 and strip 63 is estimated by combining temperature detected by thermometers (not shown in Fig. 1) installed at the respective sections of the control object 50, heat transfer by radiation, heat transfer, heat generation by plastic deformation due to deformation of the strip 63 by rolling, heat conduction between rolls that is taken away by roll surfaces at the time of rolling, etc. Incidentally, many temperature estimation methods are introduced in thermodynamic literatures and the like. Moreover, since temperature change in rolling of the strip 63 is described in detail in, for example, "Theory and Practice of Strip Rolling", (Iron and Steel Institute of Japan, issued on September, 2010), Chapter 6 "Temperature Change in Rolling", its detailed explanation is omitted.

[0045] Next, the control reference setup section 11 calculates deformation resistance that is a value corresponding to hardness of the strip 63 to be rolled in the respective rolling stands 61 (Step S14). Methods of calculating deformation resistance are described in various literatures and described in detail in chapter 7 (Deformation Resistance) of the above-mentioned literature "Theory and Practice of Strip Rolling", for example. Incidentally, according to the formula 7.54 of the above-mentioned literature "Theory and Practice of Strip Rolling", deformation resistance K_f can be calculated by

the following formula (1).

$$Kf = k \cdot \varepsilon^n \cdot (d\varepsilon/dt)^m \cdot \exp(A/T) \quad (1),$$

where T is rolling temperature of the strip 63 that is estimated, ε is strain, $d\varepsilon/dt$ is a strain speed, and k, n, m, and A are constants depending upon the steel grade.

[0046] Next, the control reference setup section 11 calculates roll speeds in respective rolling stands 61 (Step S15). Since the strip speed at the delivery of the final rolling stand 61 (F_7) is found in Step S12, here, on the basis of this, the strip speeds V_{S_i} at the delivery of the respective rolling stand 61 is first calculated by using the following formula (2).

$$V_{S_i} = V_{S_7} \cdot h_i / h_7 \quad (2),$$

where V_{S_i} is a strip speed at the delivery of the rolling stand (F_i), V_{S_7} is a strip speed at the delivery of the rolling stand (F_7) (final rolling stand), h_i is a strip thickness at the delivery of the rolling stand (F_i), and h_7 is a strip thickness at the delivery of the rolling stand (F_7) (final rolling stand).

[0047] Subsequently, the control reference setup section 11 calculates the roll speeds in the respective rolling stands 61 from the strip speeds V_{S_i} at the deliveries of the respective rolling stands 61, using the concept of a forwarding slip. Here, the forwarding slip is a value that corresponds to a ratio of circumferential speeds of the work rolls 62 to the delivery speeds of the strip 63 to be rolled in the work rolls 62. For example, it has been known that the forwarding slip f is expressed as a function of a plurality of parameters as shown in the following formula (3) (for details, refer to the above-mentioned literature "Theory and Practice of Strip Rolling").

$$f = F(H, h, R', Kf, t_b, t_f) \quad (3),$$

where H is an entry strip thickness, h is an delivery strip thickness, R' is a deformed roll diameter, Kf is deformation resistance, t_b is entry tension, and t_f is delivery tension.

[0048] Therefore, if a forwarding slip f_i in an i-th rolling stand 61 (F_i) is used, a roll speed V_{r_i} in the rolling stand 61 (F_i) can be calculated by the following formula (4), using the strip speed V_{S_i} at the delivery of the rolling stand (F_i).

$$V_{r_i} = V_{S_i} / f_i \quad (4).$$

[0049] Moreover, the control reference setup section 11 calculates roll force prediction values P in the respective rolling stands 61 (Step S16). As described in detail in the above-mentioned literature "Theory and Practice of Strip Rolling", for example, it has been known that a formula for calculating the roll force prediction value P is expressed as a function of a plurality of parameters such as the following formula (5).

$$P = G(w, Kf, Q_p, t_f, t_b, R', H, h, \mu) \quad (5),$$

where w is a strip width, Kf is deformation resistance, Q_p is a draft force function, μ is a friction coefficient, t_b is entry tension, t_f is delivery tension, H is an entry strip thickness, h is an delivery strip thickness, and R' is a deformed roll diameter.

[0050] Incidentally, divergence is generated between the roll force prediction value P calculated by the formula (5) and a roll force applied to in actual rolling. Therefore, in order to reduce the divergence and raise accuracy of the roll force prediction value P, a roll force which is obtained by multiplying the roll force prediction value P calculated by the formula (5) by a suitable compensation coefficient (referred to as a roll force compensation value in this application) is employed as an actual roll force. A detailed explanation of the calculation of this compensation coefficient will be provided in description of processing by the roll force compensation value calculation section 16 (refer to Fig. 9).

[0051] Finally, the control reference setup section 11 calculates screw-down positions (roll gaps) of the work rolls 62 in the respective rolling stands 61 (Step S17). Incidentally, the screw-down position S of the work roll 62 can be basically found by the following formula (6). However, practically, various supplementary terms are often added.

$$S = h - P/K \quad (6),$$

where P is a roll force prediction value, K is a mill spring-constant, and h is an delivery strip thickness.

[0052] As described above, the control reference setup section 11 outputs control references for the screw-down position and the roll speed, which are calculated with respect to the strip 63 to be rolled from now, to the screw-down position control section 17 and the roll speed control section 18. The screw-down position control section 17 executes the screw-down control with respect to the control reference of the screw-down position, which the control reference setup section 11 outputs, in such a manner that the screw-down positions of the work rolls 62 become a value pursuant to the control reference. Similarly, the roll speed control section 18 executes the speed control with respect to the control reference of the roll speed, which the control reference setup section 11 outputs, in such a manner that the roll speeds of the work rolls 62 become a value pursuant to the control reference.

[0053] While the processing in the control reference setup section 11 which has been described are executed with respect to the strip 63 to be rolled from now, processing in the inter-stand strip thickness calculation section 13, the roll force prediction error calculation section 14, the roll force balance consistency value calculation section 15, and the roll force compensation value calculation section 16 is executed utilizing various rolling actual values acquired through the rolling, at a timing as the rolling is finished. In this application, rolling to be executed in the processing is hereinafter referred to as the said rolling, and a strip 63 to be produced in the said rolling is hereinafter referred to as the said strip 63.

[0054] Fig. 5 is a view illustrating an example of a processing flow of processing which the inter-stand strip thickness section 13 executes. As shown in Fig. 1, the multi gauge 64 is disposed only at the delivery of the final rolling stand 61 (F₇) and is not disposed at a midway stage of the respective rolling stands 61 (F₁ to F₇). Therefore, the inter-stand strip thickness calculation section 13 estimates the strip thickness of the said strip 63 at an intermediate position of the respective rolling stands 61 (F₁ to F₇) (hereinafter referred to as an inter-stand strip thickness).

[0055] Incidentally, the inter-stand strip thickness t_i at the intermediate position between the rolling stand 61 (F_i) and the rolling stand 61 (F_{i+1}) (i = 1 to 6) shall be same as an entry strip thickness t_{i+1} at the rolling stand 61 (F_{i+1}) in the following explanation. Moreover, in a case where a detector that detects a strip thickness of the roughing bar 65 is not provided, a strip thickness to of the roughing bar 65 (i.e., an entry strip thickness at the rolling stand 61 (F₁) is also estimated

[0056] Therefore, as shown in Fig. 5, the inter-stand strip thickness calculation section 13 first acquire, via the rolling results collection section 12, an delivery strip thickness t₇, detected by the multi gauge 64 disposed at the delivery of the final rolling stand 61 (F₇), and the roll speeds Vr₁ to Vr₇ of the work rolls 62 in the respective rolling stands 61 (F₁ to F₇) (Step S21).

[0057] Next, the inter-stand strip thickness estimation section 13 estimates an entry strip thickness t₆ from the delivery strip thickness t₇ at the rolling stand 61 (F₇) on the basis of a so-called constant mass-flow theory (Step S22). Here, the mass flow constant regulation means that the product of the delivery strip thickness t_i and an delivery strip speed Vs_i at the rolling stand 61 (F_i) becomes equal to the product of an entry strip thickness and an entry strip speed (in short, an delivery strip thickness t_{i-1} and an delivery strip speed Vs_{i-1}) at the rolling stand 61 (F_{i-1}).

[0058] In other words, the inter-stand strip thickness calculation section 13 calculates the entry strip thickness t₆ at the rolling stand 61 (F₇) on the basis of the following formula (7). Incidentally, this entry strip thickness t₆ corresponds to the inter-stand strip thickness t₆ between the rolling stand 61 (F₆) and the rolling stand 61 (F₇).

$$t_6 = t_7 \cdot V_7 \cdot (1+f_7) / \{V_6 \cdot (1+f_6)\} \quad (7),$$

where t₇ is the delivery strip thickness at the rolling stand (F₇), V₇ is the roll speed of the work roll at the rolling stand (F₇) (circumferential speed), f₇ is the forwarding slip of the rolling stand (F₇), V₆ is the roll speed of the work roll at the rolling stand (F₆) (circumferential speed), and f₆ is the forwarding slip of the rolling stand (F₆).

[0059] Incidentally, the forwarding slips f₆, f₇ are calculated by the control reference setup section 11 according to the formula (3) prior to rolling of the said strip 63. Since the forwarding slips f₆, f₇ are estimated and calculated, utilizing the formula (3), a value to be calculated includes a certain error. Therefore, the entry strip thickness t₆ that is calculated utilizing the forwarding slips f₆, f₇ also includes an error.

[0060] The inter-stand strip thickness t₆ between the rolling stand 61 (F₆) and the rolling stand 61 (F₇) are estimated as discussed above, and this inter-stand strip thickness t₆ is also the delivery strip thickness t₆ at the rolling stand 61 (F₆). Therefore, similarly to the Step S22, the inter-stand strip thickness calculation section 13 estimates an entry strip thickness t₅ at the rolling stand 61 (F₆) from the delivery strip thickness t₆ at the rolling stand 61 (F₆) (Step S23).

[0061] Similarly to the above, the inter-stand strip thickness calculation section 13 estimates an entry strip thickness t₄ at the rolling stand 61 (F₅) (Step S24), estimates an entry strip thickness t₃ at the rolling stand 61 (F₄) (Step S25), estimates an entry strip thickness t₂ at the rolling stand 61 (F₃) (Step S26), estimates an entry strip thickness t₁ at the rolling stand 61 (F₂) (Step S27), and further estimates an entry strip thickness to at the rolling stand 61 (F₁) (Step S28). Incidentally, the entry strip thickness to corresponds to the strip thickness to of the roughing bar 65.

[0062] Though the example in which the entry strip thicknesses at the respective rolling stands 61 are in turn found

from the downstream rolling stand has been discussed above, they may be also calculated at one time from a relationship among the measured rolling stand 61 (F_7), the forwarding slip f_7 of the rolling stand 61 (F_7), and the forwarding slips f_i and roll speeds V_{ri} of the respective rolling stands 61 (F_i).

[0063] Fig. 6 is a view illustrating an example of a processing flow of processing which the roll force prediction error calculation section 14 executes. As shown in Fig. 6, the roll force prediction error calculation section 14 first selects one of the seven rolling stands 61 (F_1 to F_7) (Step S31). In this case, though the order of the selection is not especially limited, for example, the selection may be performed in turn from the upstream rolling stand 61.

[0064] Next, the roll force prediction error calculation section 14 acquires, via the rolling-results collection section 12, an actual roll force at the selected rolling stand 61 (Step S32). Moreover, the roll force prediction error calculation section 14 acquires the entry strip thickness and delivery strip thickness at the selected rolling stand 61 from the inter-stand strip thickness calculation section 13, and calculates an estimated roll force at the rolling stand 61 according to the above formula (5) (Step S33).

[0065] Incidentally, in the calculation by the formula (5), as the delivery tension t_f and the entry tension t_b which can be directly measured, actual values which are measured are directly used. Also, calculation formulas for the width w , the deformation resistance K_f , the roll force force function Q_p , the deformed roll diameter R' , and the friction coefficient μ are described in the above-mentioned literature "Theory and Practice of Strip Rolling" and the like. According to the formulas, they are calculated on the basis of actual values of various detectors which are acquired via the rolling-results collection section 12. At this time, calculation of the strip width w and the deformation resistance K_f further requires rolling temperature and, as the rolling temperature, temperature is used which is estimated on the basis of a value that is detected by a temperature detector (not shown in Fig. 1), considering a distance between an installation position of the temperature detector and the said rolling stand 61, and the like.

[0066] Next, the roll force prediction error calculation section 14 calculates a roll force prediction error that is a ratio of the actual roll force acquired in Step S32 to the estimated roll force estimated in Step S33 (Step S34). In other words, a roll force prediction error Z_{pli} of the rolling stand 61 (F_i) is calculated according to the following formula.

$$Z_{pli} = P_{ai}/P_{si} \quad (8) ,$$

where P_{ai} is an actual roll force at the rolling stand (F_i), and P_{si} is an estimated roll force based on various actual values at the rolling stand (F_i).

[0067] Next, the roll force prediction error calculation section 14 determines whether or not the processing calculating the roll force prediction errors Z_{pli} with respect to all rolling stands 61 (F_1 to F_7) is ended (Step S35) and, unless the processing is ended ("No" in Step S35), repeatedly executes the processing in Step S31 and the subsequent Steps. Moreover, if the processing calculating the roll force prediction errors Z_{pli} with respect to all rolling stands 61 (F_1 to F_7) has been ended ("Yes" in Step S35), the processing calculating the roll force prediction errors Z_{pli} with respect to the said strip 63 is ended.

[0068] Fig. 7 is a view illustrating an example of a processing flow of processing which the roll force balance consistency value calculation section 15 executes. Meanwhile, in the control reference setup section 11, the roll force prediction values P in the respective rolling stands 61 are calculated with respect to a strip 63 to be next rolled. In order to raise the prediction accuracy, processing compensating the calculated roll force prediction values P is executed. At that time, the roll force prediction errors Z_{pli} can be directly used as a roll force compensation value. However, the roll force prediction error Z_{pli} is calculated per rolling stand 61, so that there is a case where they vary considerably among the plurality of rolling stands 61. As a result, the degree of compensation of the roll force prediction values P in the respective rolling stands 61 also varies.

[0069] The compensated roll force prediction values P are actually used in calculation of the roll forces in the respective rolling stands 61, namely, in calculation of the screw-down positions. Therefore, even if the roll force prediction values P are compensated, if a variation is left between neighboring rolling stands 61, a problem that balance may be lost due the variation occurs. Therefore, in processing by the roll force balance consistency value calculation section 15 which will be explained hereinafter, a value for suppressing collapse of the balance between the neighboring rolling stands 61 (hereinafter referred to as a roll force balance consistency value) is calculated.

[0070] As shown in Fig. 7, the roll force balance consistency value calculation section 15 first selects one 61 (F_i) of the seven rolling stands 61 (F_1 to F_7) (Step S41). In this case, though the order of the selection is not especially limited, for example, the selection may be in turn performed from the upstream rolling stand 61.

[0071] Next, the roll force balance consistency value calculation section 15 acquires a roll force prediction error Z_{pli} of the selected rolling stand 61 (F_i) from the processing-results in the roll force prediction error calculation section 14 (Step S42), and acquires a roll force prediction error Z_{pli+1} of the neighboring rolling stand 61 (F_{i-1} , F_{i+1}) (Step S43). Here, the neighboring rolling stands 61 (F_{i-1} , F_{i+1}) mean the rolling stand 61 (F_{i-1}) on the upstream of the rolling stand

(F_i) and the rolling stand 61 (F_{i+1}) on the downstream of the rolling stand (F_i).

[0072] Incidentally, understandably, a rolling stand 61 which is neighboring to the upmost stream side rolling stand 61 (F_1) is the rolling stand 61 (F_2) only. Also, a rolling stand 61 which is neighboring to the downmost stream side rolling stand 61 (F_7) is the rolling stand 61 (F_6) only. Though these exceptions exist upmost stream and downmost stream, the rolling stand 61 which is neighboring to the rolling stand 61 (F_i) is indicated as the rolling stand 61 (F_{i-1} , F_{i+1}) in this application.

[0073] Next, the roll force balance consistency value calculation section 15 calculates a roll force balance consistency value $Zplb_i$ of the selected rolling stand 61 according to the following formula (9), for example.

When $i = 2$ to 6 ,

$$Zplb_i = \alpha \cdot \{ (Zpli_{i-1} - Zpli_i) + (Zpli_{i+1} - Zpli_i) \} / 4,$$

when $i = 1$,

$$Zplb_i = \alpha \cdot (Zpli_{i+1} - Zpli_i) / 3, \text{ and}$$

when $i = 7$,

$$Zplb_i = \alpha \cdot (Zpli_{i-1} - Zpli_i) / 3 \quad (9),$$

where $Zpli_i$ is the roll force prediction error, and α is the roll force balance ratio.

[0074] In accordance with the formula (9), the roll force balance consistency value $Zplb_i$ is equivalent to an average of differences between the roll force prediction error $Zpli$ of the rolling stand 61 (F_i) and the roll force prediction errors $Zpli_{i-1}$, $Zpli_{i+1}$ of the rolling stands (F_{i-1} , F_{i+1}) neighboring thereto. Therefore, when the roll force prediction error $Zpli$ of the rolling stand 61 (F_i) is larger than the roll force prediction errors $Zpli_{i-1}$, $Zpli_{i+1}$ of the neighboring rolling stands 61 (F_{i-1} , F_{i+1}), the roll force balance consistency value $Zplb_i$ becomes a negative value. Also, when the roll force prediction error $Zpli$ of the rolling stand 61 (F_i) is smaller than the roll force prediction errors $Zpli_{i-1}$, $Zpli_{i+1}$ of the neighboring rolling stands 61 (F_{i-1} , F_{i+1}), the roll force balance consistency value $Zplb_i$ becomes a positive value. Moreover, when the roll force prediction error $Zpli$ of the rolling stand 61 (F_i) is substantially same to the roll force prediction errors $Zpli_{i-1}$, $Zpli_{i+1}$ of the neighboring rolling stands 61 (F_{i-1} , F_{i+1}), the roll force balance consistency value $Zplb_i$ becomes a value close to 0 (zero).

[0075] Next, the roll force balance consistency value calculation section 15 determines whether or not the processing calculating the roll force balance consistency values $Zplb_i$ with respect to all rolling stands 61 (F_1 to F_7) is ended (Step S45) and, unless the processing is ended ("No" in Step S45), repeatedly executes the processing in Step S41 and the subsequent Steps. Moreover, if the processing calculating the roll force balance consistency values $Zplb_i$ with respect to all rolling stands 61 (F_1 to F_7) has been ended ("Yes" in Step S45), the processing calculating the roll force balance consistency values $Zplb_i$ with respect to the said strip 63 is ended.

[0076] In the formula (9), the roll force balance ratio α is a parameter that indicates how much ratio of compensation for the roll force prediction error $Zpli$ to consistency of the roll force balance are to be balanced. The roll force balance ratio α is stored in the roll force balance ratio storage section 23. This roll force balance ratio α becomes a value between 0 and 1 and indicates that the consistency of the roll force balance is not considered when it is 0. On the other hand, when α is 1, the consistency of the roll force balance is maximally considered. At this time, the roll force balance consistency value $Zplb_i$ is considered with a ratio equivalent to the roll force prediction error $Zpli$.

[0077] Fig. 8 is a view illustrating an example of a configuration of a roll force balance ratio table 231 which is stored in the roll force balance ratio storage section 23. As shown in Fig. 8, the roll force balance ratio table 231 is configured by values of the roll force balance ratio α which are categorized by the steel grade, target strip thickness, target strip width, etc. of the strip 63 to be rolled. For example, when the steel grade is SS400, the target strip thickness is 2.0 to 3.0 mm, and the target strip width is 1000 mm or less, the roll force balance ratio α is 1.0. Also, when the steel grade is SS400, the target strip thickness is 12.0 mm, and the target strip width is 1400 mm or more, the roll force balance ratio α is 0.4.

[0078] Fig. 9 is a view illustrating an example of a processing flow of processing which the roll force compensation value calculation section 16 executes. Utilizing the roll force prediction error $Zpli$ calculated in the roll force prediction error calculation section 14 and the roll force balance consistency value $Zplb_i$ calculated in the roll force balance consistency value calculation section 15, the roll force compensation value calculation section 16 calculates roll force compensation values (a first roll force compensation value and a second roll force compensation value that will be

hereinafter referred to) to be used when accuracy of the roll force prediction value which the control reference setup section 11 predicts is raised.

[0079] As shown in Fig. 9, the roll force compensation value calculation section 16 first selects one of the seven rolling stands 61 (F_1 to F_7) (Step S51). In this case, though the order of the selection is not especially limited, for example, the selection may be in turn performed from the upstream rolling stand 61.

[0080] Next, the roll force compensation value calculation section 16 acquires the roll force prediction error $Zpli$ of the selected rolling stand 61 (F_i) from the processing-results in the roll force prediction error calculation section 14 (Step S52) and further acquires the roll force balance consistency value $Zplbi$ of the selected rolling stand 61 (F_i) from the processing-results in the roll force balance consistency value calculation section 15 (Step S53).

[0081] Moreover, the roll force compensation value calculation section 16 calculates the first roll force compensation value $Zpni$ corresponding to the said strip 63 in the selected rolling stand 61 (F_i) in accordance with the following formula (10) (Step S54).

$$Zpni = Zpli + Zplbi \quad (10),$$

where $Zpni$ is the first roll force compensation value, $Zpli$ is a roll force prediction error, and $Zplbi$ is the roll force balance consistency value.

[0082] As described above, the roll force balance consistency value $Zplbi$ is equivalent to an average of differences between the roll force prediction error $Zpli$ of the rolling stand 61 (F_i) and the roll force prediction errors $Zpli_{i-1}$, $Zpli_{i+1}$ of the rolling stands (F_{i-1} , F_{i+1}) neighboring thereto. Therefore, when the roll force prediction error $Zpli$ of the rolling stand 61 (F_i) is larger than the roll force prediction errors $Zpli_{i-1}$, $Zpli_{i+1}$ of the neighboring rolling stands 61 (F_{i-1} , F_{i+1}), the roll force balance consistency value $Zplbi$ becomes a negative value. In accordance with the formula (10), the first roll force compensation value $Zpni$ is found by adding the roll force balance consistency value $Zplbi$ to the roll force prediction error $Zpli$, so that the first roll force compensation value $Zpni$ becomes smaller than the roll force prediction error $Zpli$.

[0083] On the other hand, when the first roll force compensation values $Zpni_{i-1}$, $Zpni_{i+1}$ of the neighboring rolling stands 61 (F_{i-1} , F_{i+1}) are calculated, a relatively large roll force prediction error $Zpli$ of the rolling stand 61 (F_i) acts, so that the first roll force compensation values $Zpni_{i-1}$, $Zpni_{i+1}$ of the rolling stands 61 (F_{i-1} , F_{i+1}) become larger than the roll force prediction errors $Zpli_{i-1}$, $Zpli_{i+1}$.

[0084] In other words, a value of the first roll force compensation values $Zpni$, $Zpni_{i+1}$ of the neighboring rolling stands 61 (F_{i-1} , F_{i+1}) whose roll force prediction errors $Zpli_{i-1}$, $Zpli_{i+1}$ are relatively small reduces. In contrast, a value of the first roll force compensation value $Zpni$ of the rolling stand 61 (F_i) whose roll force prediction error $Zpli$ is relatively large relative to the neighboring rolling stands 61 (F_{i-1} , F_{i+1}) increase. As a result, between the rolling stand 61 (F_i) and the neighboring rolling stands 61 (F_{i-1} , F_{i+1}), variations in the first roll force compensation values $Zpni$, $Zpni_{i+1}$, $Zpli_{i+1}$ thereof are reduced. This means that roll force balance between a certain rolling stand 61 (F_i) and the neighboring rolling stands 61 (F_{i-1} , F_{i+1}) is maintained.

[0085] The case where the roll force prediction error $Zpli$ of the rolling stand 61 (F_i) is larger than the average of the roll force prediction errors $Zpli_{i-1}$, $Zpli_{i+1}$ of the neighboring rolling stands 61 (F_{i-1} , F_{i+1}) and the roll force balance among the rolling stands 61 (F_{i-1} , F_i , F_{i+1}) is improved has been described, and vice versa. That is, in a case where the roll force prediction error $Zpli$ of the rolling stand (F_i) is smaller than the roll force prediction errors $Zpli_{i-1}$, $Zpli_{i+1}$ of the neighboring rolling stands 61 (F_{i-1} , F_{i+1}), roll force balance between the rolling stand 61 (F_i) and the neighboring rolling stands 61 (F_{i-1} , F_{i+1}) is also maintained.

[0086] Moreover, when the roll force prediction error $Zpli$ of the rolling stand 61 (F_i) is substantially equal to the roll force prediction errors $Zpli_{i-1}$, $Zpli_{i+1}$ of the neighboring rolling stands 61 (F_{i-1} , F_{i+1}), the roll force balance consistency value $Zplbi$ becomes a value close to 0, so that the first roll force compensation value $Zpni$ becomes a substantially same value as the roll force prediction error $Zpli$. In this case, it can be said that the roll force balance between the rolling stand 61 (F_i) and the neighboring rolling stands 61 (F_{i-1} , F_{i+1}) is naturally maintained.

[0087] Subsequently, returning to the explanation of the processing flow of Fig. 9, Fig. 10 is explained. In Fig. 9, the roll force compensation value calculation section 16 acquires, as processing subsequent to Step S54, a roll force compensation actual value $Zppi$, that corresponds to the previous rolling results of the rolling stand 61 (F_i) selected in Step S51, from the roll force compensation actual value storage section 24 (Step S55).

[0088] Fig. 10 is a view illustrating an example of a configuration of a roll force compensation actual value table 241 which is stored in the roll force compensation actual value storage section 24. As shown in Fig. 10, the roll force compensation actual value table 241 is configured by roll force compensation actual values $Zppi$ of the respective rolling stands 61 (F_i) that are categorized by the steel grade, target strip thickness, target strip width, etc. of the said strip 63. Here, the roll force compensation actual value $Zppi$ is a value that stores the second roll force compensation values Zpi of the respective rolling stands 61 (F_i) which are outputted to the control reference setup section 11 from the roll force

compensation value calculation section (refer to Step S6) when the strips 63 belonging to the respective categories are rolled in the past. For example, in the example of Fig. 10, in the event of a strip 63 whose steel grade is SS400 and whose target strip thickness is 1.6mm or less, the roll force compensation actual values Z_{pp_i} which respectively corresponds to 1.11, 1.08, 0.94, 0.98, 1.04, 0.99, and 1.03.

[0089] Moreover, as shown in Fig. 9, utilizing the first roll force compensation value Z_{pn_i} calculated in Step S54 and the roll force compensation actual value Z_{pp_i} calculated in Step S54, the roll force compensation value calculation section 16 calculates, as processing subsequent to Step S55, a second roll force compensation value Z_{p_i} with respect to the rolling stand 61 (F_i) selected in Step S51 in accordance with the following formula (11), and output the calculated second roll force compensation value Z_{p_i} to the control reference setup section 11 (Step S56).

$$Z_{p_i} = \beta \cdot Z_{pn_i} + (1 - \beta) \cdot Z_{pp_i} \quad (11),$$

where Z_{p_i} is the second roll force compensation value of the rolling stand (F_i), Z_{pn_i} is the first roll force compensation value of the rolling stand (F_i), Z_{pp_i} is the roll force compensation actual value of the rolling stand (F_i), and β is a distribution coefficient.

[0090] Incidentally, the distribution coefficient β is a coefficient that, when the second roll force compensation value Z_{p_i} of the rolling stand 61 (F_i) is calculated, determines a distribution ratio between the roll force compensation actual value Z_{pp_i} based on the previous rolling results stored in the roll force compensation actual value storage section 24, and the first roll force compensation value Z_{pn_i} calculated in connection with rolling of the strip 63 in the immediate past (hereinafter, the immediate past means the closest past), and becomes a value between 0 and 1. That is, when the distribution coefficient β is 0, the first roll force compensation value Z_{pn_i} estimated in connection with rolling of the said strip 63 is ignored and the second roll force compensation value Z_{p_i} is determined according to the roll force compensation actual value Z_{pp_i} based on the previous rolling results stored in the roll force compensation actual value storage section 24.

[0091] In contrast, when the distribution coefficient β is 1, the roll force compensation actual value Z_{pp_i} based on the previous rolling results is ignored and the second roll force compensation value Z_{p_i} is determined according to the first roll force compensation value Z_{pn_i} estimated in connection with rolling of the said strip 63. Moreover, when the distribution coefficient β is an intermediate value between 0 and 1 ($0 < \beta < 1$), the first roll force compensation value Z_{pn_i} and the roll force compensation actual value Z_{pp_i} are proportionally distributed with a ratio according to the value of the distribution coefficient β and the second roll force compensation value Z_{p_i} is determined. For example, when $\beta = 0.5$, the first roll force compensation value Z_{pn_i} and the roll force compensation actual value Z_{pp_i} are proportionally distributed with the same ratio and the second roll force compensation value Z_{p_i} is determined.

[0092] Moreover, as shown in Fig. 9, the roll force compensation value calculation section 16 causes the second roll force compensation values Z_{p_i} of the rolling stand 61 which it calculates in Step S56 and outputs to the control reference setup section 11, to be stored in the roll force compensation actual value storage section 24 as the roll force compensation actual values Z_{pp_i} of the rolling stand 61 (F_i) which it selects in the category to which the said strip 63 belongs (Step S57).

[0093] Subsequently, the roll force compensation value calculation section 16 determines whether or not the processing from the Step S51 to the Step S57 in connection with all rolling stands 61 (F_1 and F_7) has been ended (Step S58) and, unless the processing has been ended ("No" in Step S58), repeatedly executes the processing in Step S51 and the subsequent Steps. Also, if the processing from the Step S51 to the Step S57 in connection with all rolling stands 61 (F_1 to F_7) has been ended ("Yes" in Step S58), the processing that calculates the second roll force compensation value Z_{p_i} and the like and is shown in Fig. 9 is ended.

[0094] The second roll force compensation value Z_{p_i} that is calculated as discussed above and outputted to the control reference setup section 11 is used for improving the prediction accuracy of the roll force prediction value P in the control reference setup section 11. In other words, in Step S16 of the processing flow of Fig. 2, the control reference setup section 11 calculates the roll force prediction value P in accordance with the formula (5) and, when receiving the second roll force compensation value Z_{p_i} from the roll force compensation value calculation section 16, compensates the roll force prediction value P , estimated utilizing the formula (5), by the second roll force compensation value Z_{p_i} .

[0095] In other words, the control reference setup section 11 calculates a roll force setting value P_{set_i} for calculation of the screw-down position references and the like with respect to the respective rolling stands 61 (F_i), in accordance with the following formula (12).

$$P_{set_i} = Z_{p_i} \cdot G (w_i, K_{f_i}, Q_{p_i}, t_{f_i}, t_{b_i}, R'_{i}, H_i, h_i, \mu_i)$$

(12),

where w_i , Kf_i , Qp_i , tf_i , tb_i , $R'i$, H_i , h_i , and μ_i are the strip width of the strip 63 in the respective rolling stands 61 (F_i), the deformation resistance, the draft force function, the entry tension, the delivery tension, the deformed roll diameter, the entry strip thickness, the delivery strip thickness, and the friction coefficient, respectively.

[0096] Therefore, even if a variation in the roll force prediction value P calculated according to the formula (5) is generated, between the actual rolling stand 61 (F_i) and the neighboring rolling stands 61 (F_{i-1} , F_{i+1}), a variation in the roll force setting value $Pset_i$ that is supplied to the actual rolling stand 61 (F_i) via the screw-down position control section 17 (refer to Fig. 1) and the like is reduced. Therefore, the roll force balance among the plurality of rolling stands 61 (F_i) is prevented from collapsing. That is, the roll force balance is maintained.

[0097] Incidentally, in the embodiment described above, the roll force balance ratio α is used in the calculation in the roll force balance consistency value calculation section 15 (refer to the formula (9)). However, after removing α from the formula (9), the following formula (13) is substituted for the formula (10) and may be used in the processing in the roll force compensation value calculation section 16.

$$Zpn_i = Zpl_i + \alpha \cdot Zplb_i \quad (13),$$

where Zpn_i is the first roll force compensation value, Zpl_i is the roll force prediction error, and $Zplb_i$ is the roll force balance consistency value.

[0098] As discussed above, according to the embodiment of the present invention, the roll force balance consistency values $Zplb_i$ of the respective rolling stands 61 (F_i) are calculated depending upon the magnitude relationship between the roll force prediction error Zpl_i in the rolling stand 61 (F_i) and the roll force prediction errors Zpl_{i-1} , Zpl_{i+1} in the neighboring rolling stands 61 (F_{i-1} , F_{i+1}) (refer to the formula (9)). In that case, if the roll force prediction error Zli in the rolling stand 61 (F_i) is larger than the roll force prediction errors Zpl_{i-1} , Zpl_{i+1} in the neighboring rolling stands 61 (F_{i-1} , F_{i+1}), the balance consistency value $Zplb_i$ becomes a negative value. Also, in the event of the contrary case, it becomes a positive value. In other words, the first roll force compensation value Zpn_i that is obtained by adding the roll force balance consistency value $Zpbi$ to the roll force prediction error $Zpli$ (refer to the formula (10)) results in suppression of the variation in the roll force prediction error $Zpli$.

[0099] Moreover, by performing a learning process to the first roll force compensation value Zpn_i , the second roll force compensation value Zp_i (refer to the formula (11)) is found. By using the second roll force compensation value Zp_i , the roll force setting value $Pset_i$ that is actually set to the rolling stand 61 (F_i) is calculated (refer to the formula (12)). Therefore, even if any variation in the roll force prediction value P_i is generated, the variation is suppressed in the roll force setting value $Pset_i$. Therefore, in the embodiment of the present invention, the problem that the roll force balance among the plurality of rolling stands 61 (F_i) collapses is prevented from occurring.

[0100] Moreover, in the embodiment of the present invention, the roll force compensation value (the second roll force compensation value Zpp_i) of the rolling stand 61 (F_i) is basically determined, depending only upon the magnitude relationship of the roll force prediction error Zpl_i of the rolling stand 61 (F_i) and the roll force prediction errors Zpl_{i-1} , Zpl_{i+1} of the neighboring rolling stands 61 (F_{i-1} , F_{i+1}). Therefore, it is unnecessary to configure the roll force error change model like the one disclosed in Patent Literature 3, for example. Namely, in the embodiment of the present invention, an effect of allowing the roll force balance consistency among the plurality of rolling stands 61 (F_i) with simple processing is expected. Moreover, while the roll force error change model disclosed in, for example, the Patent Literature 3 is a linear model, the variation of the roll force prediction error Zpl_i in the embodiment of the present invention is not limited to the linear model and can respond to various variation modes.

[0101] Therefore, in the tandem rolling mill control device 10 according to the embodiment of the present invention, when prior to rolling of the strip 63, the roll forces in the respective rolling stands 61 (F_i) that roll the strip 63 to a desired strip thickness are predicted, it is possible to estimate the roll forces with high accuracy, using simple calculation processing and considering the roll force balance among the plurality of rolling stands 61 (F_i). As a result, the strip which has a thickness with higher accuracy can be obtained, and the rolling can be stabilized.

(Second Embodiment)

[0102] Fig. 11 is a view illustrating an example of a configuration of a tandem rolling mill control device 10a according to a second embodiment of the present invention. The configuration of the tandem rolling mill control device 10a according to the second embodiment is different from that of the tandem rolling mill control device 10 of Fig. 1 in that it further includes a steel grade-similarity calculation section 31, a distribution coefficient calculation section 32, and a similarity-number storage section 35 which are newly added. Only this difference will be explained hereinafter. Incidentally, components which are similar to those of the tandem rolling mill control device 10 of Fig. 1 are denoted by like reference signs.

[0103] In the tandem rolling mill control device 10a according to the second embodiment, a function is added in which

the distribution coefficient α used in the formula (11) is made variable according to similarity numbers of strips 63 rolled one after the other. Namely, regarding the steel grade of a strip 63 to be rolled in the immediate past and the steel grade of a strip 63 to be next rolled, the steel grade-similarity calculation section 31 refers to the similarity-number storage section 35 to acquire their similarity-numbers and outputs them to the distribution coefficient calculation section 32. The distribution coefficient calculation section 32 calculates the distribution coefficient β on the basis of the similarity-numbers of the last and next strips 63, which it acquires from the steel grade-similarity calculation section 31, and outputs the distribution coefficient β to the roll force compensation value calculation section 16. In the processing of Step S56, the roll force compensation value calculation section 16 executes the calculation of the formula (11) using the distribution coefficient β which it receives from the distribution coefficient calculation section 32.

[0104] Fig. 12 is a view illustrating an example of a processing flow of processing which the steel grade-similarity calculation section 31 executes. Also, Fig. 13 is a view illustrating an example of a similarity-number table 351 which is stored in the similarity-number storage section 35. As shown in Fig. 13, the similarity-number table 351 is configured by defining similarity-numbers with respect to the respective steel grades of the strips 63. Here, the closer the similarity-numbers of the steel grades of the strips 63 are, the further similar the properties of the strips 63 such as deformation resistance and the like are, and the further away the similarity-numbers are, the properties of the strips 63 are different.

[0105] For example, in the example of Fig. 13, the similarity-number of a strip 63 whose steel grade is SS400 is 4 and the similarity-number of a strip 63 whose steel grade is SS490 is 5. Therefore, it can be said that these steel plates 63 are very close in similarity of steel grades thereof. On the other hand, the similarity-number of a strip 63 whose steel grade is SS400 is 4 and the similarity-number of a strip 63 whose steel grade is SPHC is 2. Therefore, similarity of these strips 63 in steel grades is not as high as that of the strip 63 whose steel grade is SS400 and of the strip 63 whose steel grade is 490. Moreover, the similarity-number of a strip 63 whose steel grade is SS400 is 4 and the similarity-number of a strip 63 whose steel grade is DP is 25, so that these strips 63 are considerably different in similarity of steel grades thereof. Therefore, it should be now said that these strips 63 are different strips.

[0106] Therefore, as shown in Fig. 12, the steel grade-similarity calculation section 31 refers to the similarity-number storage section 35 to acquire a steel grade-similarity number and a steel grade similarity number which correspond to the steel grade of a strip 63 rolled in the immediate past and the steel grade of a strip to be next rolled, respectively (Step S51). Next, a similarity V is calculated from a difference between the similarity-numbers of the two strips 63 in accordance with the following formula (14) (Step S52). Incidentally, the smaller the value of the similarity V defined in the formula (14) is, the larger the similarity is, and the larger the value is, the smaller the similarity is.

$$V = |Vn_i - Vn_j| \quad (14),$$

where Vn_i is the similarity-number of the steel grade of the strip 63 rolled in the immediate past, and Vn_j is the similarity-number of the steel grade of the strip 63 to be next rolled.

[0107] Next, the steel grade-similarity calculation section 31 outputs the selected similarity V to the distribution coefficient calculation section 32 (Step S53) and ends the processing.

[0108] Subsequently, the distribution coefficient calculation section 32 calculates the distribution coefficient β in accordance with the following formula (15), for example.

$$\beta = 1 - (V/V_c) \quad (15).$$

[0109] Incidentally, when $V_c < V$, $V = V_c$, and V_c is a similarity corresponding to $\beta = 0$.

[0110] According to the formula (15), the higher the similarity of the strips 63 to be rolled one after the other is (the similarity V is small), the distribution coefficient β becomes a value close to 1 and the smaller the similarity is (similarity V is large), the distribution coefficient β becomes a value close to 0. Moreover, when the similarity V is larger than V_c , the distribution coefficient β is 0. The calculation of the formula (11) is performed using this distribution coefficient β .

[0111] The second embodiment which has been discussed above is the example in which the calculation of the distribution coefficient is concretely performed using the distribution coefficient β used in the formula (11) and whose effect is substantially identical to that of the above-mentioned embodiment.

[0112] Moreover, while the tandem rolling mill control devices 10, 10a of the above-mentioned embodiment and second embodiment of the present invention are applied to hot-rolling, they can be applied to cold-rolling.

[0113] Incidentally, the present invention is not limited to the above-mentioned embodiments and includes various modifications. The above-mentioned embodiments have been explained in detail in order to explain the present invention simply and the present invention is not necessarily limited to any embodiment with all configurations described above. Moreover, a portion of a configuration of a certain embodiment can be replaced with a portion of a configuration of

another embodiment. Moreover, addition of a configuration of a certain embodiment to a configuration of another embodiment is possible.

5 Claims

1. A control device of a tandem rolling mill for continuously rolling a strip with a plurality of rolling stands, the control device (10) comprising:

10 a roll force prediction error calculation section (14) estimating roll forces in the respective rolling stands, utilizing rolling actual values acquired in the respective rolling stands when the strip is rolled, and calculating roll force prediction errors in the respective rolling stands on the basis of roll force actual values acquired in connection with the rolling;

15 a roll force balance consistency value calculation section (15) calculating balance consistency values with respect to the respective rolling stands, the balance consistency values indicating the degree of differences between the roll force prediction errors in the respective rolling stands and the roll force prediction errors in rolling stands neighboring to the respective rolling stands, which are calculated by the roll force prediction error calculation section;

20 a roll force compensation value calculation section (16) calculating roll force compensation values in the respective rolling stands from the roll force prediction errors in the respective rolling stands, which are calculated by the roll force prediction error calculation section (15), and the roll force balance consistency values in the respective rolling stands, which are calculated by the roll force balance consistency value calculation section; and
 25 a control reference setup section (11) estimating roll forces in the respective rolling stands regarding a strip to be next rolled, compensating the estimated roll forces in the respective rolling stands with the roll force compensation values in the respective rolling stands which are calculated in the roll force compensation value calculation section, and calculating screw-down positions, which are to be set to the respective rolling stands, by using the compensated roll forces.

- 30 2. The control device of the tandem rolling mill according to claim 1, further including a roll force balance ratio storage section (23) that associates a roll force balance ratio, that indicates significance of the roll force balance consistency values and is a constant equal to or higher than 0 and equal to or lower than 1, with at least one of a steel grade, a target strip thickness, and a target strip width of the strip, wherein
 35 the roll force compensation value calculation section (16) acquires the roll force balance ratio associated with the steel grade, target strip thickness, and target strip width of the rolled strip from the roll force balance ratio storage section (23) and calculates the roll force compensation values by adding a value, that is found by multiplying the roll force balance consistency values by the acquired roll force compensation ratio, and the roll force prediction error values.

- 40 3. The control device of the tandem rolling mill according to claim 1 or 2, further including a roll force compensation actual value storage section (24) that associates the roll force compensation values calculated in the past rolling results with the steel grade, the target strip thickness, and the target strip width to store the roll force compensation values; wherein
 45 the roll force compensation value calculation section (16) calculates roll force compensation values, to be outputted to the control reference setup section, from the roll force prediction error values calculated by the roll force prediction error calculation section, the roll force compensation values calculated by using the roll force balance consistency values calculated by the roll force balance consistency value calculation section (15), and the roll force compensation values that are calculated in the past rolling and acquired from the roll force compensation value storage section (16).

- 50 4. The control device of the tandem rolling mill according to at least one of claims 1 to 3, further including an inter-stand strip thickness calculation section (13) which, on the basis of a strip thickness of the strip, which is detected by a strip thickness measuring means provided on an delivery of a final rolling stand of the tandem rolling mill, and roll speeds that are circumferential speeds of work rolls of the respective rolling stand, in turn calculates inter-stand strip thicknesses, which are strip thicknesses on entries sides of the respective rolling stands, from the final rolling stand toward an upstream, wherein
 55 the roll force prediction error calculation section (14) estimates the roll forces in the respective rolling stands by utilizing the inter-stand strip thickness calculated in the inter-stand strip thickness calculation section (13), when it estimates the roll forces in the rolling, on the basis of the rolling results of the rolled strip.

5. The control device of the tandem rolling mill according to claim 1, further including:

5 a similarity-number storage section (35) which associates a similarity-number with a steel grade of the strip to store the similarity-number, wherein the larger similarity of characteristics of the strip, the similarity number becomes an approximate value;

a strip similarity calculation section that acquires a similarity-number of the rolled strip and a similarity-number of a strip to be next rolled from the similarity-number storage section and calculates a difference between the two acquired similarity-numbers as similarity; and

10 a distribution coefficient calculation section (32) that calculates a distribution coefficient, that is a constant equal to or more than 0 and equal to or less than 1; wherein

15 the roll force compensation value calculation section (16) further compensates the calculated roll force compensation values to values that are found by proportionally distributing the roll force compensation values and the roll force compensation actual value acquired from the roll force compensation actual value storage section (24) with the calculated distribution coefficient and adding them.

6. The control device of the hot strip tandem rolling mill according to claim 5, wherein the distribution coefficient calculation section (32) calculates the distribution coefficient in such a manner that the smaller the similarity is, the larger the distribution coefficient becomes, and the larger the similarity is, the distribution coefficient becomes.

20 7. A control method of a tandem rolling mill wherein a computer that controls a tandem mill rolling a strip with a plurality rolling stand executes:

25 a roll force prediction error calculation step of estimating roll forces in the respective rolling stands, utilizing rolling actual values acquired in the respective rolling stands when the strip is rolled, and calculating roll force prediction errors in the respective rolling stands on the basis of roll force actual values acquired in connection with the rolling;

30 a roll force balance consistency value calculation step of calculating balance consistency values with respect to the respective rolling stands, the balance consistency values indicating the degree of differences between the roll force prediction errors in the respective rolling stands and the roll force prediction errors in rolling stands neighboring to the respective rolling stands, which are calculated by the roll force prediction error calculation section;

35 a roll force compensation value circulation step of calculating roll force compensation values in the respective rolling stands from the roll force prediction errors in the respective rolling stands, which are calculated by the roll force prediction error calculation section, and the roll force balance consistency values in the respective rolling stands, which are calculated by the roll force balance consistency value calculation section; and

40 a control reference setup step of estimating roll forces in the respective rolling stands regarding a strip to be next rolled, compensating the estimated roll forces in the respective rolling stands with the roll force compensation values in the respective rolling stands which are calculated in the roll force compensation value calculation section, and calculating screw-down positions, which are to be set to the respective rolling stands, by using the compensated roll forces.

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FIG. 1

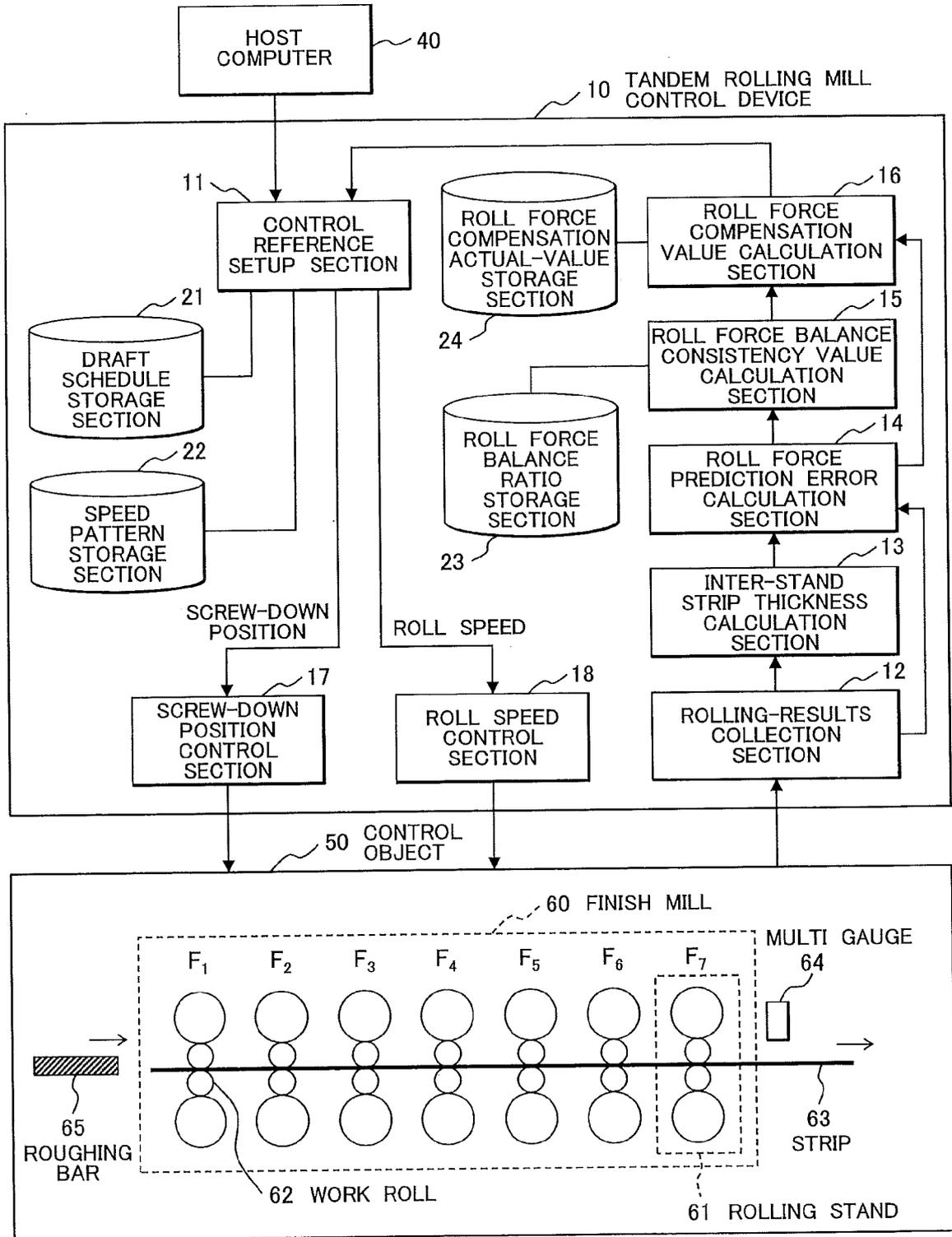


FIG. 2

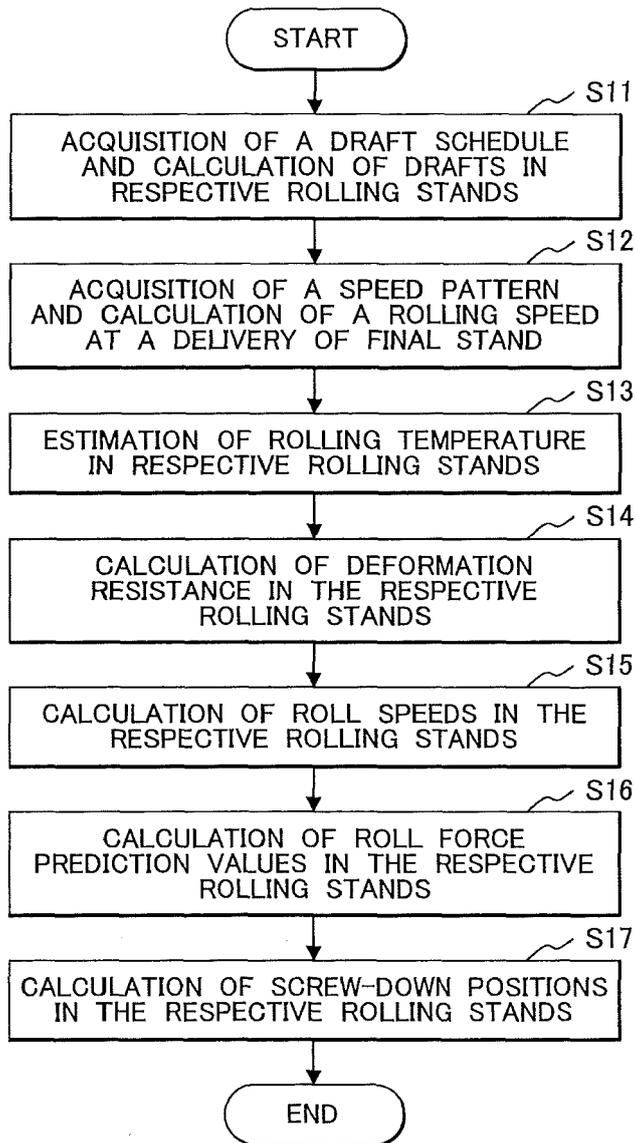


FIG. 3

211 DRAFT SCHEDULE TABLE

STEEL GRADE	TARGET STRIP THICKNESS (mm)	TARGET STRIP WIDTH (mm)	F ₁	F ₂	F ₃	F ₄	F ₅	F ₆	F ₇	
SS400	2.0~3.0	~1000	40	35	31	26	20	16	14	
		1000~2000	41	34	30	25	21	17	15	
		1400~	42	34	31	26	20	17	15	

	
	
	12.0~	~1000	48	41	38	34	32	29	24	
		1000~2000	47	41	38	35	32	29	25	
		1400~	47	42	37	34	31	27	24	

FIG. 4

221 SPEED PATTERN TABLE

STEEL GRADE	TARGET STRIP THICKNESS (mm)	TARGET STRIP WIDTH (mm)	INITIAL SPEED (mpm)	FIRST ACCELERATION RATE (mpm/s)	SECOND ACCELERATION RATE (mpm/s)	REGULAR SPEED (mpm)	DECELERATION RATE (mpm/s)	FINAL SPEED (mpm)	
SS400	1.2~1.4	~1000	650	2	12	1100	6	700	
		1000~2000	650	2	12	1050	6	700	
		1400~	650	2	12	1000	6	700	

	
	
	12.0~	~1000	250	2	3	450	6	280	
		1000~2000	250	2	3	420	6	280	
		1400~	250	2	3	400	6	280	

FIG. 5

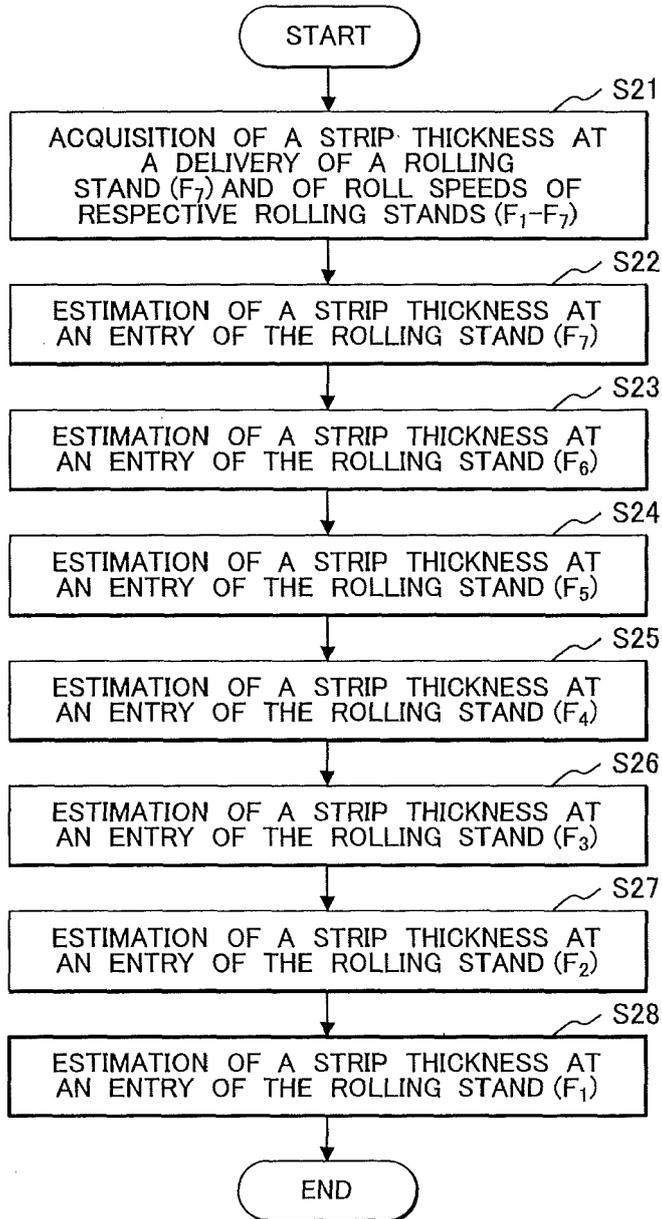


FIG. 6

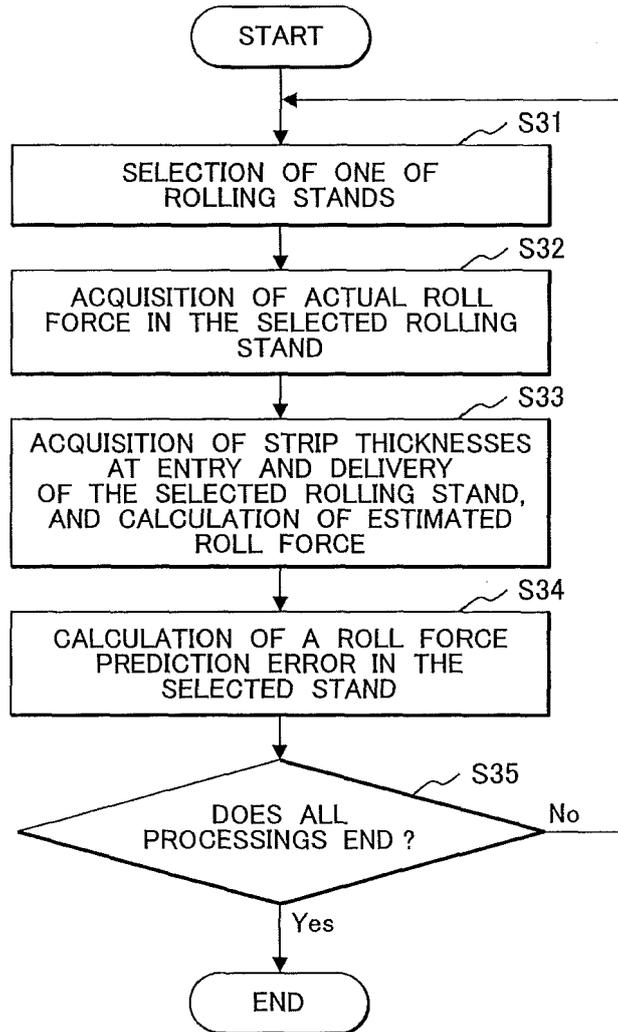


FIG. 7

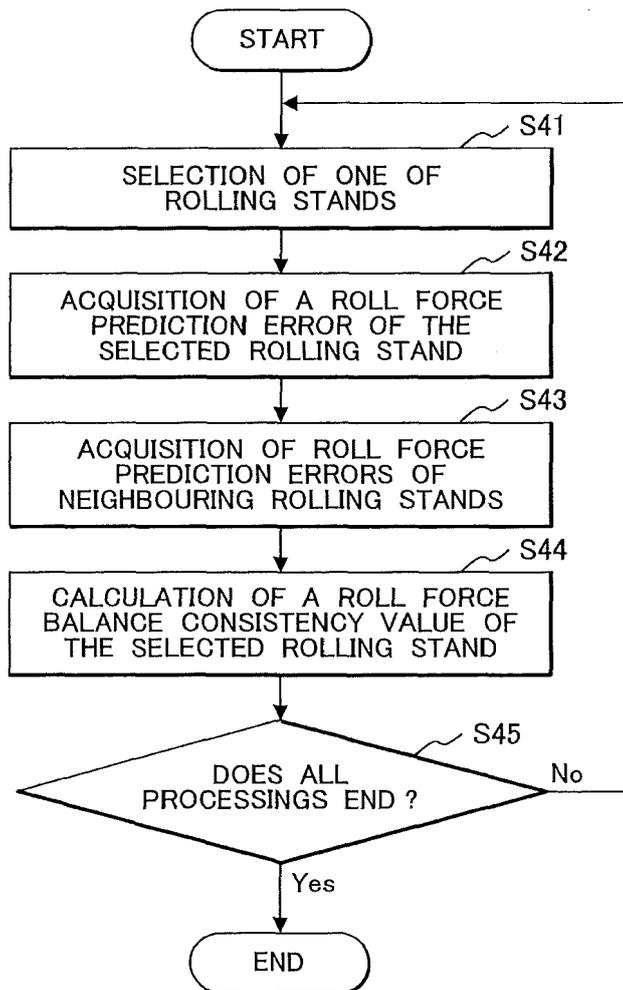


FIG. 8

231 ROLL FORCE BALANCE RATIO TABLE

STEEL GRADE	TARGET STRIP THICKNESS (mm)	TARGET STRIP WIDTH (mm)	ROLL FORCE BALANCE RATIO
SS400	2.0~3.0	~1000	1.0
		1000~2000	0.9
		1400~	0.8

	
	
	12.0~	~1000	0.6
		1000~2000	0.5
		1400~	0.4
...
	
	

FIG. 9

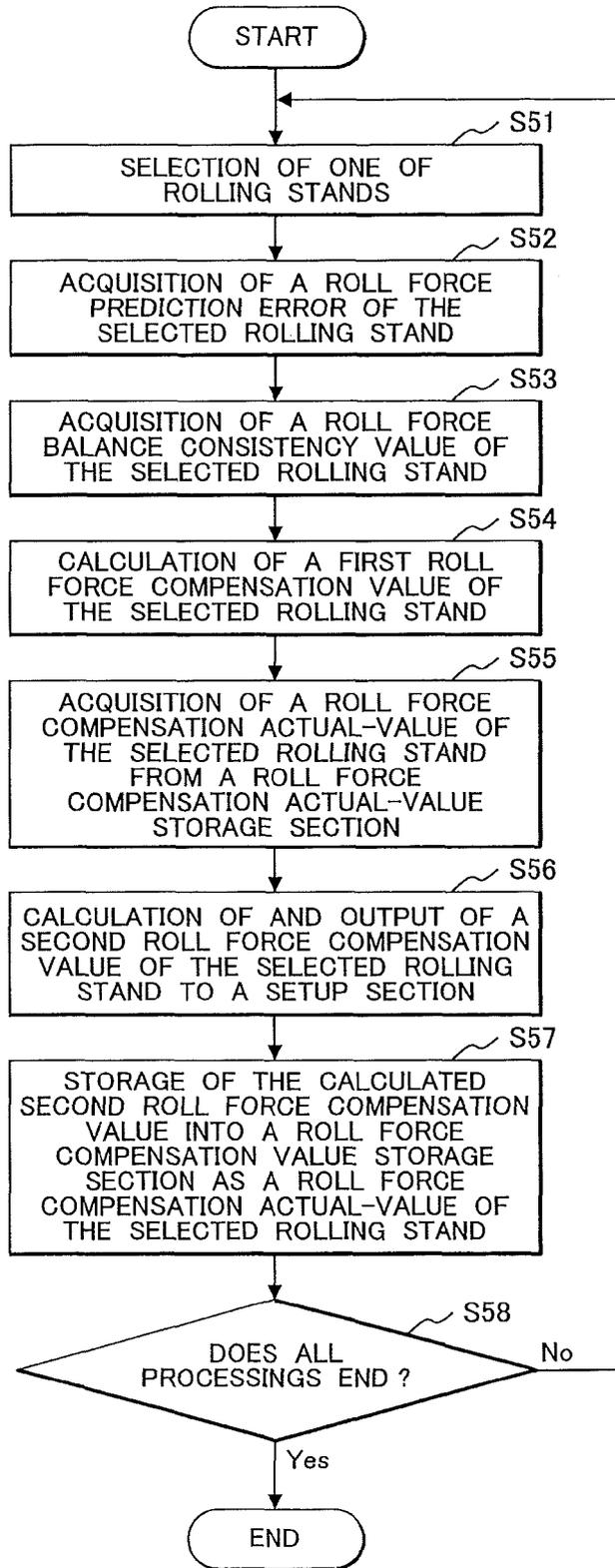


FIG. 10

241 ROLL FORCE COMPENSATION ACTUAL-VALUE TABLE

STEEL GRADE	TARGET STRIP THICKNESS	
SS400	~1.6	
SS490	1.6~2.0	
SPHC	2.0~3.0	
...	...	
...	...	
SPHC	12~	

ROLLING STAND	F ₁	F ₂	F ₃	F ₄	F ₅	F ₆	F ₇
ROLL FORCE COMPENSATION ACTUAL-VALUE	1.11	1.08	0.94	0.98	1.04	0.99	1.03

FIG. 11

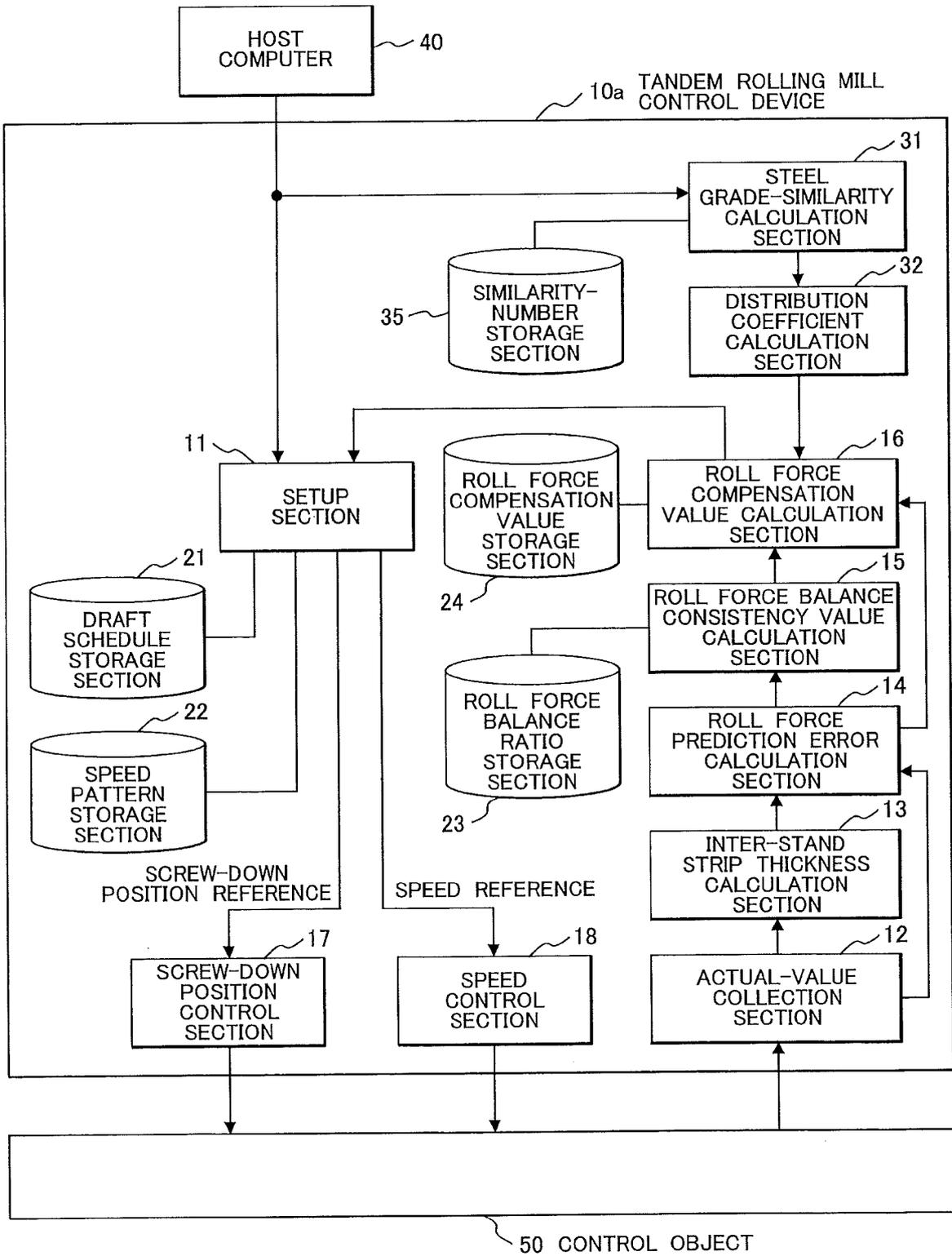


FIG. 12

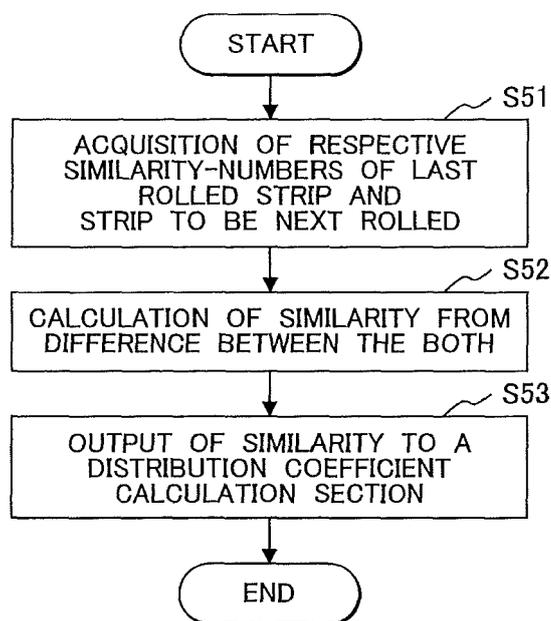


FIG. 13

351 SIMILARITY-NUMBER TABLE

STEEL GRADE	SIMILARITY-NUMBER
SS400	4
SS490	5
SS540	7
SPHC	2
...	...
...	...
DP	25
TRIP	30



EUROPEAN SEARCH REPORT

Application Number
EP 15 18 8340

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			B21B
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Munich		16 December 2015	Forciniti, Marco
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