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(54) **ROLLING CONTROL DEVICE AND ROLLING CONTROL METHOD**

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Description

BACKGROUND

1. Field of the Invention

[0001] The present invention relates to a rolling control device and a rolling control method.

2. Description of the Related Art

[0002] In the rolling mill employing tension reels to unwind and wind a rolled material, the tension reel is operated under the constant torque control (under the constant current control). One disadvantageous problem which arises when the tension reel is subjected to the constant torque control is that, when the tension on the entry and/or exit sides of the rolling mill fluctuates, the fluctuation in the tension reel speed occurs to suppress the tension fluctuation so as to make the entry side speed of the rolling mill change, with the result that the fluctuation in the exit thickness thereof occurs.

[0003] To address this, for example, in the Japanese Unexamined Patent Application Publication No. 2010-240662, in the tension control using the tension reel speed as a control element, the tension reel is operated under the constant speed control to suppress the fluctuation in exit thickness. For that purpose, the tension fluctuation within a certain range is allowed.

[0004] Further, for example, Japanese Unexamined Patent Application Publication No. 2012-176428 discloses a method for controlling a running speed of a rolled material on the basis of a thickness of a rolled material and controlling a tension of the rolled material through control on a roll gap of a rolling mill, in order to control the wound side of the rolled material based on the rotation of either the tension reel or the rolling mill. This enables stable control, for example, even if control response is poor due to high moment of inertia of the tension reel.

[0005] Further, in a tandem rolling mill, a control element for a controlled variable is altered as appropriate when the influence coefficient of the rolling mill changes to a great extent owing to its operational state, which is disclosed in, for example, Japanese Unexamined Patent Application Publication No. 2012-176428. In the tandem rolling mills, typically, the inter-stand tension control in which the rolling reduction in the posterior roll stand is defined as a control element and the exit thickness control in which the speed of the anterior roll stand is defined as a control element are performed. On the other hand, in the invention disclosed in Japanese Unexamined Patent Application Publication No. 2012-176428, the effects of the thickness control and the tension control can be maximized by performing the exit thickness control in which the rolling reduction in the posterior roll stand is defined as a control element and the tension control in which the speed of the anterior roll stand is defined as a control element according to the rolling conditions.

[0006] Operating the unwinding tension reel and the winding tension reel under the constant torque control (under the constant current control) causes the fluctuation in the entry speed and exit speed in the rolling mill to bring about the fluctuation in the exit thickness in the rolling mill. This is because the torque of the tension reel is made constant under the constant torque control, so that the tension reel speed changes due to the inertia of the tension reel. This results in causing the fluctuation in the exit thickness according to the mass flow constant law.

[0007] The most importance for the rolled materials produced by the rolling mill is the exit thickness accuracy of the rolling mill, and the tension on the entry and exit sides of the rolling mill is essential just for stabilizing the rolling operation. However, there is no problem in terms of the rolling operation even if a tension somewhat might fluctuate for the sole purpose of maintaining the product thickness. Based on this way of thinking, in Japanese Unexamined Patent Application Publication No. 2010-240662, as regard a deviation from the set tension values within a predetermined range, making the tension reel speed constant is prioritized, and the fluctuation in the tension reel speed is suppressed without the tension deviation being corrected, in which the tension reel is operated under the constant speed control.

[0008] In this case, there is no problem just if the tension deviation falls within the predetermined range, but according to the rolling conditions or the matrix conditions, in some cases the tension deviation may go beyond the range. This effects a change in tension reel speed, resulting in a change of the entry speed of the rolling mill, and in turn, occurrence of exit thickness fluctuation.

[0009] Further, in some cases the influence coefficient of the rolling mill may change according to the rolling conditions, so that the tension control using the tension reel speed as a control element and the exit thickness control using the roll gap of the rolling mill as a control element become unstable. In this case, the stable control is hard to be realized under present circumstances just with the exit thickness control using the gap roll a control element, the tension speed control in which the tension reel is operated under the constant speed control and the constant tension torque control in which the tension reel is operated under the constant torque control, resulting in the vibration of the exit thickness of the rolling mill.

[0010] On the other hand, for example, Japanese Unexamined Patent Application Publication No. 2014-113629 discloses a method of performing the tension control using the roll gap in predetermined conditions and the thickness control by the speed control of the tension reel based on the timing of the rolling operation.

[0011] EP 2087948 A1 relates to cold rolled material manufacturing equipment comprising: an unwinding device for unwinding a hot rolled coil after acid pickling; joining means, disposed on the exit side of the unwinding device, for joining the tail end of a preceding coil to the leading end of a succeeding coil unwound from the unwinding device; a rolling mill for continuously rolling the coils, with the leading end and the tail end of the coils being joined, in one direction; a strip storage device, disposed between the joining means and the rolling mill, for storing a strip S in order to perform continuous rolling by the rolling mill during joining of the preceding coil and the succeeding coil by the joining means; a strip cutting device for cutting the strip to a desired length; a winding device for winding the rolled coil; transport means for withdrawing the coil from the winding device, and transporting the coil to the unwinding device.

[0012] EP 0435595 A2 relates to a rolling mill with a hydraulic roll-gap control system for setting the roll gap between two work rolls of the rolling mill and a mill modulus control unit for supplying a correction signal (Cp) to the hydraulic roll-gap control system based on the difference between a reference rolling pressure and the actual rolling pressure during rolling detected by a load cell.

SUMMARY

[0013] The single-stand rolling mill requires control performed on an entry tension, an exit tension and an exit thickness in the rolling mill, in which an entry tension-reel speed, an exit tension-reel speed and a roll gap of the rolling mill are used as control elements. The roll gap may be used as a control element for controlling the entry tension. The entry tension-reel speed may be used as a control element for the exit thickness. The exit tension-reel speed may be used as a control element for the exit tension.

[0014] For example, Japanese Unexamined Patent Application Publication No.2012-176428 describes a method of performing the exit thickness control using the roll gap in a predetermined state and the tension control by the tension-reel speed control depending on the rolling conditions because an influence coefficient of the rolling mill is changed according to the rolling conditions.

[0015] A basic principle underlying rolling is a mass flow constant law which states that the volume of a rolled material flowing into a rolling mill and the volume of a rolled material flowing out of the rolling mill are constant. According to the mass flow constant law, when the entry thickness and the exit thickness are constant, the entry speed and the exit speed are also constant. In other words, the entry tension-reel speed and the exit tension-reel speed are constant.

[0016] A ratio between an exit speed and a roll speed of the rolling mill is called a forward movement ratio, and a ratio between an entry speed of a roll speed of the rolling mill is called a backward movement ratio. The forward movement ratio and the backward movement ratio fluctuate according to the rolling conditions. Upon fluctuation of the forward movement ratio and the backward movement ratio, the exit speed and the entry speed in the rolling mill fluctuate, and the entry tension and the exit tension fluctuate.

[0017] As described above, if the exit tension-reel speed is used as a control element for the exit tension, upon exit-tension fluctuation, the exit tension control manipulates the exit tension-reel speed, so that exit-thickness fluctuation occurs according to the mass flow constant law.

[0018] In Japanese Unexamined Patent Application Publication No. 2010-240662, the thickness fluctuation is prevented by tolerating the tension fluctuation within a predetermined range to minimize the tension-reel speed manipulation. However, if the tension fluctuation falls outside the permissible range by acceleration/deceleration and/or the like, the exit thickness fluctuation occurs.

[0019] The tension applied to the rolled material on the entry and exit sides of the rolling mill is important for the operation stability. Upon large fluctuation in tension, the rolling conditions become unstable, causing snaking of the rolled material and/or a plate break resulting from shape failure. Accordingly, the measure of tolerating a tension fluctuation as disclosed in Japanese Unexamined Patent Application Publication No. 2010-240662 should not be taken as much as possible.

[0020] However, the techniques disclosed in Japanese Unexamined Patent Application Publication No. 2012-176428 or No. 2014-113629, include the timing for switching between the entry tension control by the thickness control using the roll gap and the tension-reel speed control (hereinafter referred to as the "first control method") and the exit thickness control by the entry tension control using the roll gap and the seed control (hereinafter referred to as the "second control method"). If a deviation of an actual value of a tension from a target value occurs at the timing, the control value after the switching is excessive, the thickness fluctuation may not be suppressed to a sufficient degree. This event is likely to take place especially when the switching between the control methods is performed during increase or decrease in rolling speed.

[0021] An object of the present invention is to suppress an influence on an exit thickness of a rolled material when fluctuation of entry or/and exit tension of the rolled material is controlled using entry or/and exit tension-reel speed of the rolled material.

[0022] To solve the problems, the features of the independent claims are suggested. Preferred developments are in the dependent claims.

[0023] According to the present invention, when the entry or/and exit tension fluctuation of a rolled material is controlled by an entry or/and exit tension-reel speed of the rolled material, suppression of the influence on the exit thickness of the rolled material is made possible. The foregoing and other objects, configuration, feature and advantages of s of the present invention will be become more apparent from the following detailed description, which proceeds with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] Non-limiting and non-exhaustive s of the present s are described with reference to the following figures, wherein like reference signs refer to like parts throughout the various views unless otherwise specified.

FIG. 1 is a diagram illustrating the entire configuration of a rolling mill and a rolling control device according to a first embodiment of the present invention.
FIG. 2 is a diagram showing neutral-point fluctuation between operational rolls of the rolling mill and basic equations for rolling.
FIG. 3 is a diagram showing fluctuation of a forward movement ratio and a rearward movement ratio in simulation according to the first embodiment.
FIG. 4 is a graph showing the rolling simulation result when tension control is not performed in the event of occurrence of the neutral point fluctuation.
FIG. 5 is a graph showing the rolling simulation result when entry tension control using a roll gap is performed in the event of occurrence of the neutral point fluctuation.
FIG. 6 is a graph showing the rolling simulation result when entry tension control using a roll gap and exit tension control using an exit TR speed are performed in the event of occurrence of the neutral point fluctuation.
FIG. 7 is a graph showing the rolling simulation result when entry tension control using an entry TR speed, exit tension control using an exit TR speed and rolling reduction thickness control are performed in the event of occurrence of the neutral point fluctuation.
FIG. 8 is a graph showing the rolling simulation result when entry tension control using a roll gap, exit tension control using an exit TR speed are performed and exit tension non-interference is performed in the event of occurrence of the neutral point fluctuation.
FIG. 9 is a graph showing the rolling simulation result when the tension control is not performed, in the event of occurrence of a deviation in the same direction as the rolling-mill roll speed about the entry TR speed and the exit TR speed.
FIG. 10 is a graph showing the rolling simulation result when the entry and exit tension control and thickness control are performed, in the event of occurrence of a deviation in the same direction as the rolling-mill roll speed about the entry TR speed and the exit TR speed.
FIG. 11 is a graph showing the rolling simulation result when the entry and exit tension control and thickness control are performed and the exit tension non-interference is performed, in the event of occurrence of a deviation in the same direction as the rolling-mill roll speed about the entry TR speed and the exit TR speed.
FIG. 12 is a graph showing the rolling simulation result when the tension control is not performed, in the event of occurrence of a deviation in the opposite direction to the rolling-mill roll speed about the entry TR speed and the exit TR speed.
FIG. 13 is a graph showing the rolling simulation result when the entry and exit tension control and thickness control are performed, in the event of occurrence of a deviation in the opposite direction to the rolling-mill roll speed about the entry TR speed and the exit TR speed.
FIG. 14 is a graph showing the rolling simulation result when the entry and exit tension control and thickness control are performed and the exit tension non-interference control is performed, in the event of occurrence of a deviation in the opposite direction to the rolling-mill roll speed about the entry TR speed and the exit TR speed.
FIG. 15 is a diagram illustrating the function configuration of the thickness control and the tension control according to the first embodiment.
FIG. 16 is a diagram illustrating the function configuration of optimum control selection device according to the first embodiment.
FIG. 17 is a diagram illustrating the example operation of optimum control selection device according to the first embodiment.
FIG. 18 is a diagram illustrating the example operation of optimum control selection device according to the first embodiment.
FIG. 19 is a table illustrating a database of control methods according to the first embodiment.
FIG. 20 is a diagram illustrating internal functions of a control output selection device according to the first embodiment

FIG. 21 is a diagram illustrating the function configuration of an exit correction determination device according to the first embodiment.

FIG. 22 is a diagram illustrating the hardware configuration of the rolling control device according to the first embodiment.

FIG. 23 is a graph showing deviations of the exit thickness and the entry tension when the switching of the control method is performed under acceleration/deceleration.

FIG. 24 is a diagram illustrating the operation overview of an entry tension deviation correction device according to the first embodiment.

FIG. 25 is a diagram illustrating the operation concept of an entry tension deviation correction device according to the first embodiment.

FIG. 26 is a graph showing deviations of the exit thickness and the entry tension when the switching of the control method is performed under acceleration/deceleration by the rolling control according to the first embodiment.

FIG. 27 is a diagram illustrating the functions of an entry TR control device according to the first embodiment.

FIG. 28 is a diagram illustrating the entire configuration of a rolling mill and a rolling control device according to an example useful for understanding the invention.

FIG. 29 is a diagram illustrating the internal functions for rolling reduction thickness control, speed thickness control, speed tension control and rolling reduction tension control according to the example.

FIG. 30 is a diagram illustrating the internal functions of a control method selection device according to the example.

FIG. 31 is a diagram illustrating the internal functions of a control output selection device according to the example.

FIG. 32 is a diagram illustrating the functions of an entry TR speed instruction device according to the example.

FIG. 33 is a diagram illustrating the entire configuration of a rolling control device according to a reference example.

FIG. 34 is a diagram showing an example of the rolling phenomenon according the reference example.

FIG. 35 is a diagram showing an example of the entry tension rolling phenomenon system according to the reference example.

Fig. 36 is a graph showing an example of a time series of each parameter according to the reference example.

FIG. 37 is a diagram showing the relationship between an control element and a control variable in a single-stand rolling mill according to the reference example.

FIG. 38 is a diagram showing an example of the single-stand rolling phenomenon according to the reference example.

FIG. 39 is a schematic diagram showing a cross response of the single-stand rolling mill according to the reference example.

FIG. 40 is a diagram showing a relationship example between the control element and the controlled variable in the single-stand rolling mill.

FIG. 41 is a diagram showing the relationship between the control element and the controlled variable with a cross term taken into account.

DETAILED DESCRIPTION

[0025] The present invention will now be described in detail using, as an example, a single-stand rolling mill which is a typical rolling mill using a tension reel to unwind and wind a rolled material.

[0026] FIG. 33 is a diagram illustrating the control configuration of a single-stand rolling mill S100 as a reference example. The single-stand rolling mill S100 includes a rolling mill 1 with a pair of rolls, and has an entry tension reel 2 (hereinafter, referred to as 'entry TR 2') provided on the entry side of the rolling mill 1 in the rolling direction (shown by the arrow in FIG. 33) to feed and insert a rolled material, and also has an exit tension reel 3 (hereinafter, referred to as 'exit TR 3') provided on the exit side to wind up the rolled material rolled by the rolling mill 1.

[0027] The entry TR 2 and the exit TR 3 are each driven by an electromotor, and equipped with the electromotors and an entry TR control device 66 and an exit TR control device 86 which are provided respectively as devices for the driving control of the electromotors. With this arrangement, in the rolling operation in the single-stand rolling mill S100, after the rolled material unwound from the entry TR 2 is rolled with the rolling mill 1, the rolled material is wound up on the exit TR 3.

[0028] In the rolling mill 1, a roll gap control device 7 is provided to change a roll gap corresponding to the distance between an upper operational roll Rs1 and a lower operational roll Rs2 in order to control the thickness of the rolled material (product thickness), and also a rolling mill speed control device 4 is provided to control the speed of the rolling mill 1 (peripheral velocity of the upper and lower operational rolls Rs1 and Rs2). During the rolling operation, a speed instruction is outputted from a rolling speed setting device 10 to the rolling mill speed control device 4, so that the rolling mill speed control device 4 controls to keep the speed of the rolling mill 1 constant (peripheral velocity of the upper and lower operational rolls Rs1 and Rs2). In other words, the rolling mill speed control device 4 functions as a rolling-mill rotation control unit.

[0029] On the entry side of the rolling mill 1 (on the left-hand side of the rolling mill 1 in FIG. 33) and the exit side (on the right-hand side thereof in FIG. 33), the rolling is stably and efficiently performed by applying tension to the rolled material. For this purpose, an entry tension setting device 11 and an exit tension setting device 12 are provided to calculate a required tension. Further, based on entry and exit tension set values calculated by the entry tension setting device 11 and the exit tension setting device 12, an entry tension current transformation device 15 and an exit tension current transformation device 16 determine current values to obtain a electromotor torque of the electromotors of the respective entry TR 2 and exit TR 3 required to apply the set tension to the rolled material on the entry side and the exit side. Then, the determined current values are supplied respectively to the entry TR control device 66 and the exit TR control device 86.

[0030] The entry TR control device 66 and the exit TR control device 86 control the current of the respective electromotors to reach the current supplied, so that a predetermined tension is applied to the rolled material by the electromotor torque provided respectively to the entry TR 2 and the exit TR 3. The entry tension current transformation device 15 and the exit tension current transformation device 16 calculate current set values (set values of the electromotor torque) to result in the tension set values based on the models of the TR (tension reel) mechanical system and the TR (tension reel) control device.

[0031] However, since such a controlling model has an error, a correction is made for the tension set values by an entry tension control 13 and an exit tension control 14 by use of actual tensions measured by an entry tension meter 8 and an exit tension meter 9 respectively disposed on the entry side and the exit side of the rolling mill 1. Then, the corrected values are supplied to the entry tension current transformation device 15 and the exit tension current transformation device 16. Thereby, the entry tension current transformation device 15 and the exit tension current transformation device 16 modify the current values set for the entry TR control device 66 and the exit TR control device 86.

[0032] Further, since the thickness of the rolled material is important in light of the product quality, the thickness control is exercised. Concretely speaking, an exit thickness control device 18 controls the roll gap control device 7 based on the actual thickness detected by an exit thickness meter 17, in order to control the roll gap which is the distance between the rolls of the rolling mill 1 for control of the thickness on the exit side of the rolling mill 1 (on the right-hand side of the rolling mill 1 in FIG. 33).

[0033] The exit TR 3 and the entry TR 2 used for winding-up and unwinding in the single-stand rolling mill S100 are controlled by the constant torque control in which the torques generated by the respective electromotors are made constant. Concretely speaking, the current instructions for the electromotors are corrected based on the actual tensions detected by the entry tension meter 8 and the exit tension meter 9, in order to maintain the tension applied to the rolled material constant. It should be noted that the electromotor torques of the electromotors of the respective entry TR 2 and exit TR 3 are provided by the electromotor current, so that the constant torque control may be referred to as the constant current control.

[0034] When the TR (tension reel) control is exercised under the constant torque control, interference with the thickness control applied to the rolling mill 1 inconveniently occurs to cause a decrease in thickness precision on the exit side. Because the influence on the exit thickness is larger on the entry tension than on the exit tension, the inconvenient points on the entry TR 2 and the rolling mill 1 are explained as follows.

[0035] FIG. 34 is a conceptual illustration showing the rolling phenomenon between the entry TR 2 and the rolling mill 1 of the single-stand rolling mill S100. As shown in FIG. 34, in the entry TR 2, the sum of electromotor torque 22 which is the output from the entry TR control device 66 and entry tension torque 25 which is determined by an entry tension 24 (Tb) and mechanical conditions (a reel diameter D and a reel gear ratio Gr), in other words, the sum of the electromotor torque 22 and the entry tension torque 25 is integrated in order to determine an entry TR (tension reel) speed 20. It should be noted that J denotes the moment of inertia (kg·m2) of the entry TR 2.

[0036] In the rolling mill 1, an exit thickness 26 is determined based on an integrated value of a roll-gap change amount 23 (=ΔS) and a predetermined coefficient ($M/(M+Q)$) as shown in FIG. 34 and an integrated value of an entry tension 24 of the rolling mill 1 and a predetermined coefficient ($(\partial P/\partial Tb)/(M+Q)$) as shown in FIG. 34. Then, a rolling-mill entry speed 21 is determined based on the determined exit thickness 26 by the mass flow constant law. Then, the integral of the difference between the rolling-mill entry speed 21 and the entry TR speed 20 results in the entry tension 24. In FIG. 34, it should be noted that M is a mill constant M (kN/m), Q is a plasticity constant Q (kN/m), and ($(\partial P/\partial Tb)/(M+Q)$) is an influence coefficient (kb) to the exit thickness 26 associated with the fluctuation of a rolling load (kN) according to the fluctuation of the entry tension 24.

[0037] The mass flow constant law is used as a basic law in the rolling mill 1. This can be expressed by the following equation (A) because the rolled material is continuous from the entry side of the rolling mill 1 (on the left-hand side of the rolling mill 1 in FIG. 33) to the exit side thereof (on the right-hand side thereof in FIG. 33).

$$H \cdot Ve = h \cdot Vo \quad \ldots \quad (A)$$

where H is an entry thickness in the rolling mill 1, h is an exit thickness in the rolling mill 1, Ve is an entry speed in the rolling mill 1, and Vo is an exit speed in the rolling mill 1.

[0038] The equation (A) of the mass flow constant law means that, when the entry thickness H is constant, the exit thickness h fluctuates as the entry speed Ve fluctuates. In the case of the single-stand rolling mill S100 (the single rolling mill 1 shown in FIG. 33), the entry speed Ve corresponds to the entry TR speed 20. The entry TR 2 changes the entry TR speed 20 such that the tension torque 25 corresponds to the electromotor torque 22. However, the change is caused by the inertia of the entry TR 2, the rolling mill 1 and the rolling phenomenon, so that there is no control means to inhibit the change of the entry TR speed 20.

[0039] Thus, in the rolling mill 1, upon manipulation of the ΔS of the roll-gap change amount 23 in order to make the exit thickness 26 (the thickness of the rolled material on the exit side of the rolling mill 1) constant by the thickness control, the rolling-mill entry speed 21 (the running speed of the rolled material on the entry side of the rolling mill 1) changes accordingly, generating a deviation ΔTb of the entry tension 24. In order to reduce the deviation, the entry TR speed 20 changes, and in turn, this change causes exit thickness fluctuations. An entry tension suppression system 27 managed by the entry TR 2 may entail a large time constant depending on the rolling conditions, possibly causing the fluctuations in exit thickness with large undulation.

[0040] The entry tension 24 is also suppressed by the rolling phenomenon. As the entry tension 24 fluctuates, the rolling load P of the rolling mill 1 changes, and accordingly the rolling-mill entry speed 21 fluctuates. The entry tension 24 fluctuates also by the entry tension rolling phenomenon system 28. The response of the entry tension rolling phenomenon system 28 is far faster than that of the entry tension suppression system 27, so that the entry rolling phenomenon as shown in FIG. 34 can be converted into that shown in FIG. 35.

[0041] It is seen from FIG. 35 that the roll-gap change amount 23 (=ΔS) of the rolling mill 1 appears as a deviation ΔTb of the entry tension 24 in the same phase, which is then integrated at the entry TR 2 to cause the entry TR speed 20 to change. Accordingly, the deviation ΔTb of the entry tension 24 from the roll-gap change amount 23 (=ΔS), the change in the entry TR speed 20 and the change in the exit thickness 26 have a relationship as shown in FIG. 36. FIG. 36 is a graph showing the relationship among the roll-gap change amount 23, the entry tension 24 (Tb), the entry TR speed 20 and the exit thickness 26.

[0042] As shown in FIG. 36, as the roll-gap change amount 23 is changed, the entry speed of the rolling mill 1 changes and then the entry tension 24 changes. With a change of the entry tension 24, the entry TR speed 20 changes by the movement of the entry TR 2 due to its inertia, since the entry TR 2 is under the constant torque control. When the entry TR speed 20 changes, the fluctuation in the exit thickness occurs according to the mass flow constant law represented by the equation (A). When the fluctuation in the exit thickness occurs, an exit thickness control device 18 manipulates the roll-gap change amount 23 to make the exit thickness 26 constant. The series of operations continues, and then the exit thickness 26 results in vibrating as shown in FIG. 36.

[0043] It should be noted that, because the exit thickness meter 17 is placed away from the rolling mill 1 in reality, there is a time lag until the exit thickness 26 controlled by the exit thickness control device 18 is detected, but the time lag can be ignored if the time lag is sufficiently short for the period of vibration of the exit thickness 26.

[0044] To prevent such a vibration of the exit thickness 26, in a possible method, while the tension between the tension reel and the rolling mill is controlled to be maintained at a desired value, higher priority is placed on the tension reel speed being made constant with respect to a deviation from a tension set value within the preset range, and the fluctuation of the tension reel speed is suppressed without correcting the tensional deviation. However, in the method, even if the change in speed of the tension reel is suppressed, this may possibly not allow the fluctuation of the rolling-mill exit thickness to be suppressed.

[0045] In the rolling mill 1, there are two control elements, that is, a roll gap and a roll speed, and two controlled state variables, that is, the exit thickness 26 of the rolling mill 1 and the entry (or exit) tension of the rolling mill 1. When the two control elements are manipulated, they affect respectively the two controlled state variables so that the controlled state variables change. FIG. 36 is a graph showing such a relationship between the control elements and the controlled state variables in the case of the single-stand rolling mill S100. The rolling phenomenon of the single-stand rolling mill S100 is as shown in FIG. 37, the conceptual illustration of which is shown in FIG. 38.

[0046] In the case of the single-stand rolling mill S100, the control elements include the roll-gap change amount 23 and the entry TR speed 20. The controlled state variables include the exit thickness 26 and the entry tension 24 of the rolling mill 1. When the roll-gap change amount 23 is changed, this causes changes of the exit thickness 26 due to a (roll gap to exit thickness) influence coefficient 503 and of the entry tension 24 due to a (roll gap to entry tension) influence coefficient 501. Moreover, when the entry TR speed 20 is changed, this causes changes of the entry tension 24 due to a (entry TR speed to entry tension) influence coefficient 502 and of the exit thickness 26 due to the (entry TR speed to exit thickness) influence coefficient 504.

[0047] In the single-stand rolling mill 1, as shown in FIG. 38, the control in terms of the exit thickness 26 of the rolling mill 1 is exercised by the exit thickness control device 18 changing the roll-gap change amount 23. Further, the control in terms of the entry tension 24 is exercised by the entry tension suppression system 27 changing the entry TR speed 20 as shown in FIG. 38.

[0048] When the (roll gap to exit thickness) influence coefficient 503 and the (entry TR speed to entry tension) influence coefficient 502 are far larger than the (roll gap to entry tension) influence coefficient 501 and the (entry TR speed to exit thickness) influence coefficient 504, there is no problem with the control system. However, as disclosed in Japanese Patent Application Laid-Open Publication No. 2012-176428, when the (roll gap to exit thickness) influence coefficient 503 and the (entry TR speed to entry tension) influence coefficient 502 are smaller than the (roll gap to entry tension) influence coefficient 501 and the (entry TR speed to exit thickness) influence coefficient 504, the stable control is not exercised disadvantageously.

[0049] If such conditions arise, even when the exit thickness control device 18 may manipulate the roll-gap change amount 23 to control the exit thickness 26, the entry tension 24 may largely fluctuate. In turn, to control the large fluctuations, the entry tension suppression system 27 may change the entry TR speed 20. This may cause the exit thickness 26 to largely fluctuate. Upon change in exit thickness 26, the exit thickness control device 18 may manipulate the roll-gap change amount 23. As a result, the exit thickness 26, the entry tension 24, the entry TR speed 20 and the roll gap change amount 23 may be in a state of vibrating with the same period.

[0050] The entry rolling phenomenon of the single-stand rolling mill S100 is as shown in FIG. 35. FIG. 35, which is a block diagram similar to FIG. 34, shows the entry TR speed 20 and the roll-gap change amount 23 as control elements and the exit thickness 26 and the entry tension 24 as controlled state variables, with the entry tension suppression system 27 by the entry TR 2 being removed. As in the case of conversion from FIG. 34 to FIG. 35, the entry tension rolling phenomenon 28 is bundled into an entry tension influence coefficient 101. Although the primary delay time constant Tr is omitted in FIG. 34 because a response time is amply short in comparison with the entry tension suppression system 27 by the entry TR 2, the primary delay time constant Tr is shown in FIG. 35. From FIG. 35, in correspondence to the influence coefficients 501, 502, 503 and 504 shown in FIG. 34, influence coefficients 111, 112, 113 and 114 shown in FIG. 38 are obtained.

[0051] Here, it is seen that, because Ve corresponds to the entry TR speed 20 and h corresponds to the exit thickness 26 of the rolling mill 1, when the exit thickness 26 is small and the entry TR speed 20 is fast, the (entry TR speed to exit thickness) influence coefficient 114 and the (entry TR speed to entry tension) influence coefficient 112 become small. Further, the primary delay time constant Tr included in the entry tension influence coefficient 101 becomes small. Thus, the (roll gap to exit thickness) influence coefficient 113 becomes small. Also, the response of the (roll gap to entry tension) influence coefficient 111 becomes fast. In other words, when the exit thickness 26 is small and the entry TR speed 20 is fast, in the manipulation of the roll-gap change amount 23, the exit thickness 26 of the rolling mill 1 becomes hard to change, while the entry tension 24 becomes easy to change. That is to say, the (roll gap to entry tension) influence coefficient 111 becomes larger than the (roll gap to exit thickness) influence coefficient 113. Further, in the manipulation of the entry TR speed 20, the entry tension 24 and the exit thickness 26 become hard to change as well.

[0052] As to the entry tension 24, a rolling phenomenon term kb is included. The rolling phenomenon term kb also changes according to the rolling speed and the exit thickness 26, but when the rolling phenomenon term kb becomes large, the (entry TR speed to entry tension) influence coefficient 112 becomes smaller than the (entry TR speed to exit thickness) influence coefficient 114.

[0053] It is seen from the above that there may be a case where, as the exit thickness 26 becomes small and the entry TR speed 20 becomes fast, the (roll gap to exit thickness) influence coefficient 113 becomes smaller than the (roll gap to entry tension) influence coefficient 111 while the (entry TR speed to entry tension) influence coefficient 112 becomes smaller than the (entry TR speed to exit thickness) influence coefficient 114. In such a case, when it is attempted that the exit thickness 26 is controlled by the exit thickness control device 18 and the entry tension 24 is controlled by the entry tension suppression system 27 as shown in FIG. 38, the influence of the cross term is so large that the stable control is impossible to be achieved.

[0054] In this case, as shown in FIG. 41, the exit thickness 26 and the entry tension 24 can be stably controlled by adopting a speed thickness control device 50 to control the exit thickness 26 with the entry TR speed 20 and a rolling reduction tension control 51 to control the entry tension 24 with the roll gap change amount 23. In order to realize such stable control, it is required that the operation of the entry TR 2 is changed from under the constant torque control (under the constant current control) to under the constant speed control.

[0055] Even if the response of the entry tension suppression system 27 is deteriorated, the entry TR 2 is required to be operated under the constant speed control. The entry tension suppression system 27 as shown in FIG. 35 turns out to be the primary delay system of the time constant Tq by equivalent conversion. Here, the time constant Tq is in proportion to the entry TR speed 20 and in inverse proportion to the exit thickness 26 of the rolling mill while being in proportion to the rolling phenomenon term kb. Accordingly, as the rolling phenomenon term kb becomes large, the time constant Tq of the entry tension suppression system 27 becomes large, so that the response of the entry tension suppression system 27 is deteriorated. Further, in this case, because the (roll gap to entry tension) influence coefficient 111 shown in FIG. 40 does not become large, it is considered that the stable control is feasible with the thickness control by the aforementioned roll-gap change amount 23 and the tension control by the entry tension suppression system 27.

[0056] In the rolling equipment, various kinds of rolled materials are rolled to various thicknesses, and also at various rolling speeds. Accordingly, there are three modes as follows to permit the exit thickness 26 and entry tension control 13 to be stably exercised according to the rolling conditions:

A) Thickness control to manipulate the roll gap and tension control by the entry tension suppression system of the entry TR 2 which is operated under the constant torque control;
B) Thickness control to manipulate the roll gap and speed tension control to manipulate the speed of the entry TR 2 which is operated under the constant speed control; and
C) Rolling-reduction tension control 51 to manipulate the roll gap and the speed thickness control to manipulate the speed of the entry TR which is operated under the constant speed control.

[0057] In order to stably exercise the thickness control and the tension control of the rolling mill 1, switching among the above three control modes are required for use according to the rolling conditions. An embodiment is described to realize the above switching. The embodiment according to the present invention will be described below by using embodiments 1 and 2.

First Embodiment

[0058] FIG. 1 shows the control configuration of a single-stand rolling mill S100 according to a first embodiment of the present invention. FIG. 1 is a block diagram showing the control configuration of a single-stand rolling mill S100 according to the first embodiment.

[0059] The single-stand rolling mill S100 according to the first embodiment has an entry tension reel 2 (hereinafter, referred to as 'entry TR 2') provided on the entry side of the rolling mill 1 in the rolling direction (shown by the arrow in FIG. 1) to feed and insert a rolled material into the rolling mill 1, and also has an exit tension reel 3 (hereinafter, referred to as 'exit TR 3') provided on the exit side to wind up the rolled material rolled by the rolling mill 1.

[0060] The entry TR 2 and the exit TR 3 are driven respectively by electric motors, and equipped with the electric motors and an entry TR control device 66 and an exit TR control device 86 which are provided respectively for the driving control of the electric motors. With this arrangement, in the rolling operation in the single-stand rolling mill S100, after the rolled material unwound from the entry TR 2 is rolled with the rolling mill 1, the rolled material is wound up on the exit TR 3.

[0061] In the rolling mill 1, a roll gap control device 7 is provided to change a roll gap corresponding to the distance between an upper operational roll Rs1 and a lower operational roll Rs2 in order to control the thickness of the rolled material (product thickness) or the tension applied to the rolled material, and also a rolling mill speed control device 4 is provided to control the speed of the rolling mill 1 (peripheral velocity of the upper and lower operational rolls Rs1 and Rs2). During the rolling operation, a speed instruction is outputted from a rolling speed setting device 10 to the rolling mill speed control device 4, so that the rolling mill speed control device 4 controls to keep the speed of the rolling mill 1 constant (to keep peripheral velocity of the upper and lower operational rolls Rs1 and Rs2 constant).

[0062] On the entry side of the rolling mill 1 (on the left-hand side of the rolling mill 1 in FIG. 1) and the exit side (on the right-hand side thereof in FIG. 1), the rolling is stably and efficiently performed by applying tension to the rolled material. For this purpose, an entry tension setting device 11 and an exit tension setting device 12 are provided to calculate a required tension. Further, based on entry and exit tension set values calculated by the entry tension setting device 11 and the exit tension setting device 12, an entry tension current transformation device 15 and an exit tension current transformation device 16 determine current values to obtain a electromotor torque of the electromotors of the respective entry TR 2 and exit TR 3 required to apply the set tension to the rolled material on the entry side and the exit side. Then, the determined current values are supplied respectively to the entry TR control device 66 and the exit TR control device 86.

[0063] The entry TR control device 66 and the exit TR control device 86 control the current of the respective electromotors to reach the current supplied, so that a predetermined tension is applied to the rolled material by the electromotor torque provided respectively to the entry TR 2 and the exit TR 3. The entry tension current transformation device 15 and the exit tension current transformation device 16 calculate current set values (set values of the electromotor torque) to result in the tension set values based on the models of the TR (tension reel) mechanical system and the TR (tension reel) control device.

[0064] However, since such a controlling model has an error, a correction is made for the tension set values by an entry tension control 13 and an exit tension control 14 by use of actual tensions measured by an entry tension meter 8 and an exit tension meter 9 respectively disposed on the entry side and the exit side of the rolling mill 1. Then, the corrected values are supplied to the entry tension current transformation device 15 and the exit tension current transformation device 16. Thereby, the entry tension current transformation device 15 and the exit tension current transformation device 16 modify the current values set for the entry TR control device 66 and the exit TR control device 86.

[0065] Further, since the thickness of the rolled material is important in light of the product quality, the thickness control is exercised. In typical control form, the entry TR 2 and the exit TR 3 may be operated under the constant torque control (constant current control) for the tension control on the entry side of the rolling mill through the constant torque processing. In this case, if the thickness of the rolled material is small and the rolling speed is high, a phenomenon of long-period vibrations of the rolling-mill exit thickness occurs. If such a phenomenon occurs, the tension reel is operated under the constant speed control for the thickness control using the speed at the entry TR 2 as a control element.

[0066] The exit TR 3 is used to control the exit tension of the rolling mill 1. In this respect, if the exit TR 3 is operated under the constant torque control, the speed varies with actual tensions at the exit, causing the fluctuations of the exit thickness by the mass flow constant law. To avoid this, the exit TR 3 is also operated under the constant speed control for the exit tension control using the speed of the exit TR 3 as a control element. For the exit TR 3, when the entry TR 2 is operated under the constant speed control, the exit TR 3 is also operated under the constant speed control. When the entry TR 2 is operated under the constant torque control, the exit TR 3 is also operated under the constant torque control.

[0067] The relationship between the neutral point, forward movement ratio and backward movement ratio in the rolling will now be described with reference to FIG. 2. For the rolling process, the rolled material u is passed through between the upper operational roll Rs1 and the lower operational roll Rs2. At this time, a slip occurs between the rolled material u and the upper and lower operational rolls Rs1 and Rs2, and a point at which the roll speed coincides with the speed of the rolled material u (neutral point) is generated in an area in which the upper and lower operational rolls Rs1 and Rs2 and the rolled material u come into contact with each other.

[0068] The slip occurring between the rolled material u and the upper and lower operational rolls Rs1, Rs2 means that the rolled material u is pressed to be stretched, causing the surface of the rolled material u to slip on the upper and lower operational rolls Rs1, Rs2. At this time, in a position on which a largest force acts when the rolled material u is pressed by the upper and lower operational rolls Rs1, Rs2, the surface of the rolled material u comes into a state of being at rest relative to the upper and lower operational rolls Rs1, Rs2. This position is the neutral point.

[0069] The running speed at the starting point of the contact between the upper and lower operational rolls Rs1 and Rs2 and the rolled material u corresponds to an entry speed V_e. The running speed at the ending point of the contact between the upper and lower operational rolls Rs1 and Rs2 and the rolled material u corresponds to an exit speed V_o. A forward movement ratio f is determined by subtracting 1 from a ratio (V_o/V_R) between an exit speed V_o and a neutral-point speed V_R, and a backward movement ratio b is determined by subtracting 1 from a ratio (V_e/V_R) between an entry speed V_e and a neutral-point speed V_R.

[0070] Basic equations for the rolling include the mass flow constant law, an entry tension equation and an exit tension equation. When the exit speed V_o and an exit TR speed V_{DTR} coincide with each other, the exit tension has a constant value given by the exit tension expression. The same holds true for the entry side. Further, if the entry thickness and the exit thickness are constant without any change over time, the ratio between the entry speed V_e and the exit speed V_o is constant.

[0071] The position of the neutral point is varied according to the rolling conditions. For example, the position of the neutral point is varied by a change in rolling speed, a change in the coefficient of friction or deformation resistance, and/or a change in tension on the entry/exit side. As illustrated in FIG. 2, when the position of the neutral point is changed from a neutral point A to a neutral point B, a portion of the rolled material u rolled toward the exit is decreased and a portion rolled toward the entry is increased. That is, the forward movement ratio f is smaller and the backward movement ratio b is larger.

[0072] The position of the neutral point is a position in which the speed of the upper and lower operational rolls Rs1 and Rs2 coincides with the speed of the rolled material u. Therefore, if the rolling speed is not changed before and after the changing from the neutral point A to the neutral point B, the entry speed is reduced by an increase in backward movement ratio b. Further, the exit speed is reduced by a decrease in forward movement ratio f. Note that the rolling speed is equal to the speed of the operational roll.

[0073] Because the basic expressions for the rolling have held for the respective values at the neutral point A, moving the neutral point to the neutral point B results in changes in the entry TR speed V_{ETR} and/or the exit TR speed V_{DTR}. Specifically, because the backward movement ratio b increases, the entry speed V_e is reduced to be lower than the entry TR speed V_{ETR}, resulting in a lower entry tension T_b. Further, because the forward movement ratio f decreases, the exit speed V_o is reduced to be lower than the exit TR speed V_{DTR}, resulting in a higher exit tension T_f.

[0074] Further, the neutral point varies with the entry tension T_b and/or the exit tension T_f. Upon increase in exit tension T_f and decrease in entry tension T_b, the neutral-point position moves toward the neutral point A. In other words, when the entry tension T_b and the exit tension T_f change, even if the entry TR speed V_{ETR} and the exit TR speed V_{DTR} are the same, the rolling phenomenon places the neutral-point position back to the neutral point B, so that the entry speed V_e, the exit speed V_o, the entry thickness and the exit thickness are maintained at the same values.

[0075] The following description is given of simulation results of the exit thickness, the entry tension T_b and the exit tension T_f when the neutral point changes from the neutral point A to the neutral point B as shown in FIG. 2 because of application of disturbance. The disturbance causing the neutral point to vary refers to, for example, disturbance causing changes in conditions of friction between the rolling-mill rolls and the rolled material u. Specifically, the disturbance includes, for example, a change in roll speed, a change in concentration of lubricating oil applied between the rolling-mill rolls and the rolled material u. The fluctuations of the backward movement ratio according to fluctuations of the neutral point are fluctuations according to a ratio determined based on the entry thickness and/or the exit thickness as shown in Fig. 3.

[0076] FIG. 4 shows simulation results when the entry tension control and the exit tension control are not exercised. In FIG. 4, a thin dotted line indicates fluctuation predicted values of the neutral-point positions given as disturbance, while a thick dotted line indicates a track of actual neutral-point positions. When the tension control is not exercised, the rolling phenomenon as described earlier causes the entry tension T_b to decrease and the exit tension T_f to increase for suppression of fluctuation of the neutral-point position, resulting in no change in exit thickness. In consequence, if a tension fluctuation is a certain level, the tension fluctuation can be permitted in order to suppress the fluctuation of the exit thickness.

[0077] FIG. 5 shows simulation results when only the entry tension control using a roll gap is exercised. As compared with the aspect in FIG. 4, the decrease in entry tension T_b is reduced because of the entry tension control, so that the reduction effect on the changes of the neutral-point position is eliminated. Correspondingly, the exit tension T_f changes greatly to suppress the fluctuation of the neutral-point position. As a result, the exit thickness is little changed.

[0078] In the case of FIG. 5, the fluctuation of the exit thickness is suppressed, but the fluctuation of the exit tension is larger than the case of FIG. 4, making stable rolling operation difficult. Accordingly, the aspect of FIG. 5 is unacceptable as a matter of practicality.

[0079] FIG. 6 shows simulation results when the exit tension control using the exit TR speed V_{DTR} is exercised in addition to the control in FIG. 5. As a result of reducing the decrease of the exit tension T_f in addition to the decrease of the entry tension T_b, the fluctuation of the neutral point is not suppressed, causing the fluctuation of the exit thickness. For the increase of the exit tension T_f, the exit TR speed V_{DTR} is controlled as a rule to maintain the tension. As a result, the exit speed reduces. Because of this, the exit thickness increases according to the mass flow constant law.

[0080] When the exit thickness control is executed using the entry TR speed V_{ETR}, because the entry tension T_b decreases, the roll gap is opened up in the rolling reduction tension control. Thus, the entry tension T_b and the exit tension T_f are increased and the exit thickness increases. The thickness control reduces the entry TR speed V_{ETR} to decrease the exit thickness. Because of this, interference occurs between the tension control and the thickness control, giving rise to the exit thickness fluctuation.

[0081] FIG. 7 shows simulation results when the exit thickness is controlled by use of the roll gap. In this case, the entry tension T_b is controlled by use of the speed of the entry TR 2 and the exit tension T_f is controlled by use of the speed of the exit TR 3. Upon a decrease in the entry tension T_b, the entry TR speed V_{ETR} is reduced. Thus the exit thickness decreases according to the mass flow constant law. At the same time, the roll gap is narrowed through the thickness control.

[0082] As a result, the entry tension T_b and the exit tension T_f are decreased, so that the exit thickness is smaller. Because of this, interference hardly occurs between the tension control and the thickness control, hardly causing the exit thickness fluctuations. However, if the thickness is small and the rolling speed is high, the thickness control using the roll gap has not so much influence. Thus, the aspect in FIG. 7 cannot be used in effect.

[0083] In this manner, during the execution of the thickness control in which the entry TR speed V_{ETR} is manipulated, if the exit TR speed V_{DTR} is manipulated in the exit tension control, the thickness control and the tension control interfere with each other, causing the exit thickness fluctuations. This is an inconvenient event caused by individual acting of the exit TR speed control based on the exit tension T_f, the entry TR speed control based on the exit thickness, and the roll-gap control based on the entry tension T_b.

[0084] To avoid such inconvenience, when the exit TR speed V_{DTR} is controlled through the exit tension control, the entry TR speed is corrected such that the mass flow constant law is kept, which is a key point according to the embodiment. Such a correction control is hereinafter referred to as the "exit tension non-interference control". By the control, not only the exit thickness fluctuation is suppressed, but also the entry tension fluctuation is suppressed, thus enabling the improvement in thickness accuracy in addition to the rolling operation with high stability maintained.

[0085] FIG. 8 shows simulation results when the exit tension non-interference control is applied to the aspect in FIG.6. As shown in FIG. 8, the exit thickness fluctuation is suppressed and also the entry tension fluctuation is suppressed.

[0086] Conceivable factors of the thickness and tension fluctuations occurring at acceleration/deceleration of the rolling mill 1 include imperfect speed uniformity in the entry TR 2, the exit TR 3 and the operational rolls of the rolling mill 1 in addition to the aforementioned neutral-point fluctuations. Such a phenomenon may occur, for example, when the rolling speed is increased/reduced due to a difference of characteristics between the mill motor for driving the rotation of the upper and lower operational rolls Rs1 and Rs2 of the rolling mill 1 and the tension reel motors for respectively driving the rotations of the entry TR 2 and the exit TR 3. In this case, as shown in FIG. 3, an entry TR speed deviation ΔV_{ETR} and an exit TR speed deviation ΔV_{DTR} are given as deviations from the entry speed and the exit speed of the rolling mill 1 determined based on the mass flow constant law.

[0087] FIG. 9 shows simulation results when the entry TR speed deviation ΔV_{ETR} and the exit TR speed deviation ΔV_{DTR} fluctuate in the same direction. In this case, behaviors are exhibited as in the case of the neutral-point fluctuation occurring as described earlier, and accordingly the entry tension T_b and the exit tension T_f fluctuate in the opposite directions.

[0088] FIG. 10 shows simulation results when the entry rolling reduction tension control, the exit TR speed tension control and the entry TR speed thickness control are executed in the aspect of FIG. 9. As shown in FIG. 10, the interference occurring in the control system causes the exit thickness fluctuation.

[0089] FIG. 11 shows simulation results when the exit tension non-interference control is performed in the aspect of FIG. 10. As shown in FIG. 11, the exit tension non-interference control makes it possible to suppress the exit thickness fluctuation.

[0090] FIG. 12 shows simulation results when the entry TR speed deviation ΔV_{ETR} and the exit TR speed deviation ΔV_{DTR} fluctuate in the opposite directions. In this case, the exit thickness fluctuation occurs according to the mass flow constant law. FIG. 13 shows simulation results when the entry rolling reduction tension control, the exit TR speed tension control and the entry TR speed thickness control are executed in the aspect of FIG. 12. It is seen that, as shown in FIG. 13, the exit thickness fluctuation is suppressed, but still be large.

[0091] FIG. 14 shows simulation results when the exit tension non-interference control is performed in the aspect of FIG. 13. It is seen that, as shown in FIG. 14, the exit thickness fluctuation is suppressed. In this case, the output direction of the exit tension non-interference control is required to be opposite to the case illustrated in FIG. 12.

[0092] Summarizing the simulations shown in FIG. 4 to FIG. 14, in the neutral point fluctuation, the entry TR speed V_{ETR} and the exit TR speed V_{DTR} fluctuate in the same direction. Accordingly, the direction of the exit tension non-interference control is the same as the control direction of the exit TR speed.

[0093] On the other hand, if the speed uniformity is imperfect in the entry TR 2, the exit TR 3 and the operational rolls of the rolling mill 1, the control is required to be performed according to the direction of entry TR speed deviation ΔV_{ETR} and the exit TR speed ΔV_{DTR}. When the directions of the entry TR speed deviation ΔV_{ETR} and the exit TR speed ΔV_{DTR} are the same, the direction of the exit tension non-interference control is the same as the control direction of the exit TR speed. When the directions of entry TR speed deviation ΔV_{ETR} and the exit TR speed ΔV_{DTR} are opposite to each other, the direction of the exit tension non-interference control is opposite to the control direction of the exit TR speed.

[0094] Therefore, if the correction direction of the non-interference control is changed in response to the changed direction of the exit thickness and the exit tension T_f, the exit thickness fluctuations caused by any disturbance can be controlled to be suppressed. In other words, when the exit tension non-interference control is performed, the control direction is required to be changed in accordance with a form of the disturbance.

[0095] Using an exit thickness deviation Δh detected by the exit thickness meter 17 illustrated in FIG. 1, a manipulation instruction $\Delta\Delta S_{AGC}$ for the roll gap is generated in the rolling reduction thickness control 61, and a manipulation instruction $\Delta\Delta V_{AGC}$ for the entry TR speed is generated in the speed thickness control 62. Further, using a deviation (entry tension deviation) ΔT_b between an actual entry tension measured by the entry tension meter 8 and a set entry tension set at the entry tension setting device 11, a manipulation instruction $\Delta\Delta V_{ATR}$ for the entry TR speed V_{ETR} is generated in the speed tension control 63, and a manipulation instruction $\Delta\Delta S_{ATR}$ for the roll gap is generated in the rolling reduction tension control 64.

[0096] Further, when the entry TR 2 is operated under the constant torque control, a control output from the entry tension control 13 to manipulate an entry tension set value by the deviation between the actual entry tension and the entry tension set value is added to an entry tension set value by the entry tension setting device 11, and then the sum is transformed to a current instruction for the entry TR 2 by the entry tension current transformation device 15 to make a current instruction to the entry TR control device 66.

[0097] A control method selection device 70 selectively determines, according to the rolling conditions, which of the control methods A, B and C described earlier should be applied to abate at the maximum the exit thickness fluctuation and the entry tension fluctuation. Then, the control method selection device 70 outputs a roll-gap manipulation instruction to the roll gap control device 7 based on the selection result. To manipulate the entry TR speed V_{ETR}, a speed manipulation instruction is outputted to the entry TR speed instruction device 65. In the entry TR speed instruction device 65, the entry TR speed instruction is made based on an entry TR reference speed output from a reference speed setting device 19 and an entry-TR-speed change amount from the control method selection device 70, for outputting to the entry TR control device 66.

[0098] The entry TR control device 66 has an operation mode in which the constant torque control (constant current control) according to a current instruction is performed and another operation mode in which the constant speed control according to a speed instruction is performed, and switches between the modes for operation according to the instruction from the control method selection device 70.

[0099] FIG. 15 shows, as an example, a block diagram of the rolling reduction thickness control 61, the speed thickness control 62, the speed tension control 63 and the rolling reduction tension control 64. This is just one example of various control configurations, and another method may be used to configure another control system. For instance, in the example in FIG. 15, each control system is configured to use Integral Control (I Control), but may use Proportional Integral Control (PI Control) or Proportional Integral Differential Control (PID Control).

[0100] The rolling reduction thickness control 61 is designed using Integral Control (I Control) in which the exit thickness deviation $\Delta h = h_{fb} - h_{ref}$ that is a difference between an actual exit thickness h_{fb} and an exit thickness set value h_{ref} is input, and the input exit thickness deviation Δh is multiplied by an adjustment gain and a transformation gain from the exit thickness deviation Δh to the roll gap, which is then integrated. A control output $\Delta\Delta S_{AGC}$ is derived from a deviation between the output after the integration and the previous value.

[0101] Further, the speed thickness control 62 is designed using Integral Control (I Control) in which the exit thickness deviation Δh is input, and the input exit thickness deviation Δh is multiplied by an adjustment gain and a transformation gain from the exit thickness deviation Δh to the entry speed, which is then integrated. A deviation between the output after the integration and the previous value is determined and control output is determined from the following expression (1).

$$\Delta\left(\frac{\Delta V}{V}\right)_{AGC} \quad \ldots (1)$$

Where M is a mill constant for the rolling mill and Q is a plasticity constant of the rolled material. An instruction of the speed thickness control is output as a speed change ratio to the set speed.

[0102] The rolling reduction tension control 64 is designed using Integral Control (I Control) in which the entry tension deviation $\Delta T_b = T_{bfbb} - T_{bref}$ that is a difference between an actual entry tension T_{bfbb} and an entry tension set value T_{bref} is input, and the input entry tension deviation ΔT_b is multiplied by an adjustment gain and a transformation gain from the entry tension deviation ΔT_b to the roll gap, which is then integrated. A control output $\Delta\Delta S_{ATR}$ is derived from a deviation between the output after the integration and the previous value.

[0103] The speed tension control 63 is designed using Integral Control (I Control) in which the entry tension deviation ΔT_b is input, and the input entry tension deviation ΔT_b is multiplied by an adjustment gain and a transformation gain from the entry tension deviation ΔT_b to the entry speed, which is then integrated. A deviation between the output after the integration and the previous value is determined and control output is determined from the following expression (2).

$$\Delta\left(\frac{\Delta V}{V}\right)_{ATR} \quad \ldots (2)$$

[0104] The exit speed tension control 84 is designed using Integral Control (I Control) in which the exit tension deviation ΔT_f is input, and the input exit tension deviation ΔT_f is multiplied by an adjustment gain and a transformation gain from the exit tension deviation ΔT_f to the exit speed, which is then integrated. A deviation between the output after the integration and the previous value is determined and control output is determined from the following expression (3).

$$\Delta\left(\frac{\Delta V}{V}\right)_{DATR} \quad \ldots. (3)$$

[0105] FIG. 16 illustrates the overview of the control method selection device 70. The control method selection device 70 includes an optimum control method determination device 71 and a control output selection device 72. The optimum control method determination device 71 determines which of the control methods A, B and C is used for control. The control output selection device 72 selects any one of the outputs of the rolling reduction thickness control 61, the speed thickness control 62, the speed tension control 63 and the rolling reduction tension control 64 for use. Then, control instructions are output to the roll gap control device 7, the entry TR speed instruction device 65, and the entry TR control device 66.

[0106] The exit thickness fluctuation caused by the aforementioned interference between the thickness control and the tension control hardly occurs during the action of the exit thickness control under rolling reduction. Accordingly, the aforementioned exit tension non-interference control is used in the exit thickness control using the entry TR speed as a control element, that is, the aforementioned control method C.

[0107] FIG. 17 shows the overview of the operation of the optimum control method determination device 71. In this example, in the positive state in which the influence of the roll gap control on the entry tension is large, the control method C is used to perform the tension control under rolling reduction and the thickness control under reel speed. In the state of a large tension modification time constant of the entry tension suppression system for controlling the entry TR speed based on the entry tension, the control method B is used to perform the thickness control under rolling reduction and the entry tension control to manipulate the TR speed. Otherwise, the control method A illustrated as a reference example is selected

[0108] Which is selected among the above three control methods is determined as follows. It is deemed that the optimum control method changes according to the type of steel of the rolled material u, the exit thickness and the rolling speed. Because of this, the rolling speed is substantially divided into the three stages, that is, low speeds, intermediate speeds and high speeds, in accordance with a change in type of steel and in exit thickness. Then, when the rolling speed reaches a corresponding rolling speed during the rolling operation, the changes of the entry tension and the exit thickness are checked by changing the roll gap in a stepwise manner. In this case, if the roll-gap change amount is changed step-by-step to the extent that the product quality of the rolled material u is not affected, the roll gap change is executable even during the rolling operation of the product material. In this regard, when the roll gap is changed in a stepwise manner, the aforementioned control method A is selected.

[0109] It should be noted that, in the embodiment, as shown in FIG. 17, the rolling speed is changed in a stepwise manner in the order of a low speed, an intermediate speed and a high speed. This stepwise change of the rolling speed is executed to select any one of the aforementioned three control methods. However, when the actual rolling operation starts, the rolling speed is raised in a stepwise manner as shown in FIG. 17 as well. Thus, the manipulation illustrated in FIG. 17 is executable along with the regular rolling operation, and also is executable without a reduction in productivity.

[0110] A fluctuation amount of the entry tension and a fluctuation amount of the exit thickness immediately after the roll gap is changed in a stepwise manner are measured, in order to determine whether the influence coefficient of the roll gap control on the entry tension or the influence coefficient of the roll gap control on the exit thickness is greater. In this regard, the response time of the entry tension suppression system for controlling the entry TR speed on the basis of the entry tension is determined from the entry tension change when the roll gap is operated in a stepwise manner.

[0111] For instance, as shown in FIG. 17, a low speed zone, an intermediate zone and a high speed zone are defined according to the rolling speed. For this definition manner, the rolling speed may be divided equally into three parts up to the maximum speed or the rolling speed may be divided according to the other appropriate criteria. When the rolling speed enters the zones, the roll gap is subjected to a stepwise disturbance. Subjecting the roll gap to such disturbance causes the entry tension and the exit thickness to fluctuate.

[0112] Then, as shown in FIG. 18, based on the actual deviation between the entry tension and the exit thickness, parameters dT_b, dh and T_{bT} are determined. The parameters dT_b, dh and T_{bT} can be determined through signal processing from the fluctuation conditions of the actual values in the time direction. Based on the magnitude relationship among the determined parameters dT_b, dh and T_{bT}, any one of the control methods A, B and C is selected.

[0113] For selecting any one of the control methods A, B and C, as shown in FIG. 18, a determination is made based on the comparison between a value calculated based on the aforementioned parameters dT_b, dh and T_{bT} and a prescribed threshold value. For example, when a value calculated by $(dh/h_{ref})/(dT_b/T_{bref})$ is equal to or smaller than a selection value for the control method C which is a predetermined threshold value, the control method C is selected.

[0114] Further, when the parameter T_{br} is equal to or greater than a selection value for the control method B which is a predetermined threshold value, the control methods B is selected. As for the selection values for the control methods C and B, the selection values may be previously determined to be preset through the past actual values, the simulations of the rolling mill and/or the like.

[0115] If the optimum control method selection processing is performed on the stepwise changes 1, 2 and 3 in low speed, intermediate speed and high speed, in the case illustrated in FIG. 17, the results is that the control method A is selected as an optimum control method at low speed; the control method B is selected as an optimum control method at intermediate speed; and the control method C is selected as an optimum control method at high speed.

[0116] The control method selection device 70 executes the optimum control method determination procedures as described above to switch the control method to a determined optimum control method. In this case, because the control method A, the control method B and the control method C are different in a control method for the entry TR 2, the control method may not be switched during the rolling operation. In this event, the rolling operation is continued according to the control method A, and then the control method may be switched when a next rolled material u of the same type of steel and the same width is to be rolled. The determined optimum control method is stored in a database with search criteria including types of steel of rolled materials u, exit thickness and rolling speeds. When the same type of a rolled material u in a next rolling process, the rolling process is controlled according to an optimum control method stored in the database.

[0117] An example of the stored data in the database is illustrated in FIG. 19. Some rolling equipment may be incapable of performing switching between the control method A, the control method B and the control method C during the rolling operation, but the control method B can be used instead of the control method A. In this way, for a rolled material u optimally by the control method A in low speeds and by the control method C in high speeds, stable and high-precision rolling is feasible over the all speed zones by selecting the control method B in low speeds and by selecting control method C in high speeds.

[0118] The above-described method is just one example of the optimum control method determination procedures, and other methods may be adopted. By way of one example, it is also possible to select an optimum control method based on the magnitude relationship between influence coefficients of the influence of the roll gap control on the exit thickness and/or the entry tension and influence coefficients of the influence of a entory TR speed on the exit thickness and/or the entry tension, the influence coefficients being numerically obtained by use of the rolling phenomenon model from the actual figures of the rolling.

[0119] FIG. 20 shows the overview of the operation of a control output selection device 72. The control output selection device 72 is fed: outputs from the rolling reduction thickness control 61, the speed thickness control 62, the speed tension control 63, the rolling reduction tension control 64 and the exit speed tension control 84; a control method selection result from the optimum control method determination device 71; and an exit tension non-interference control gain G_{DTRIC} determined by an exit correction decision device 88. Also, the control output selection device 72 outputs control instructions to the roll gap control device 7, the entry TR speed instruction device 65, the entry TR control device 66, an exit TR speed instruction device 85 and the exit TR control device 86.

[0120] As shown in FIG. 20, at the control output selection device 72, outputs from the rolling reduction thickness control 61, the speed thickness control 62, the speed tension control 63, the rolling reduction tension control 64 and the exit speed tension control 84 are input respectively to gain controllers 73, 74, 75, 76 and 77. The gain controllers 73 to 77 are signal adjustment sections in which the outputs from the rolling reduction thickness control 61, the speed thickness control 62, the speed tension control 63, the rolling reduction tension control 64 and the exit speed tension control 84 are respectively multiplied by gains for output. The gains of the gain controllers 73 to 77 are adjusted based on the control method selection result from the optimum control method determination device 71.

[0121] The output from the exit correction decision device 88 is input to an exit tension non-interference control 89. The exit tension non-interference control 89 generates an adjustment signal for adjusting the control instruction for the entry TR speed instruction device 65.

[0122] When the control method A is selected, the output from the rolling reduction thickness control 61 undergoes integral processing to be output to the roll gap control device 7. Further, the constant torque control mode selection is output to the entry TR control device 66 and the exit TR control device 86.

[0123] For that purpose, according to the control method selection result by the optimum control method determination device 71, the gains of the gain controllers 74 to 77 are set at zero, as well as the gain of the gain controller 73 is adjusted, so that integration processing is applied to the output from the rolling reduction thickness control 61 by an integral processing section 90. Further, from the control method selection result by the optimum control method determination device 71, the constant torque control mode selection is output to the entry TR control device 66 and the exit TR control device 86.

[0124] When the control method B is selected, the output from the rolling reduction thickness control 61 undergoes integration processing to be output to the roll gap control device 7, as well as the output from the speed tension control 63 undergoes integration processing to be output to the entry TR speed instruction device 65. Further, the output from the exit speed tension control 84 undergoes integration processing to be output to the exit TR speed instruction device 85.

[0125] For that purpose, from the control method selection result by the optimum control method determination device 71, the gains of the gain controllers 74 and 75 are set at zero, as well as the gains of the gain controllers 73, 76 and 77 are adjusted, so that integration processing is applied to the output from the rolling reduction thickness control 61 by the integral processing section 90. Further, integration processing is set to be applied to the output from the speed tension control 63 by the integral processing section 91. Integration processing is also set to be applied to the output from the exit speed tension control 84 by the integral processing section 93.

[0126] When the control method C is selected, the output from the speed thickness control 62 undergoes integration processing to be output to the entry TR speed instruction device 65, as well as the output from the rolling reduction tension control 64 undergoes integral processing to be output to the roll gap control device 7. The output from the exit speed tension control 84 undergoes integration processing to be output to the exit TR speed instruction device 85.

[0127] For that purpose, from the control method selection result by the optimum control method determination device 71, the gains of the gain controllers 73 and 76 are set at zero, as well as the gains of the gain controllers 74, 75 and 77 are adjusted, so that the output from the rolling reduction tension control 64 undergoes integration processing by the integral processing section 90, as well as the output from the speed thickness control 62 undergoes integration processing by the integral processing section 91.

[0128] In other words, a control path leading from the rolling reduction tension control 64 through the integral processing section 90 to the roll gap control device 7 functions as a roll gap control section. Further, a control path leading from the speed thickness control 62 through the integral processing section 91 to the entry TR speed instruction device 65 functions as a speed control section.

[0129] Further, integration processing is applied to the output from the exit speed tension control 84 by the integral processing section 93, which is then input to the exit TR speed instruction device 85 and also input to the integral processing section 91 after having undergone integration processing at the exit tension non-interference control 89. Therefore, the exit correction decision device 88 sets a gain to be multiplied by a signal from the integral processing section 93 in the exit tension non-interference control 89. In other words, a control path leading from the exit speed tension control 84 through the integral processing section 93 to the exit TR speed instruction device 85 functions as an exit speed control section.

[0130] In the exit tension non-interference control 89, integration is performed after a difference of $1+(\Delta V_{DTR})/(V_{DTR})$ output to the exit TR speed instruction device 85 from the exit speed tension control 84 is multiplied by an exit tension non-interference control gain G_{DTRIC} which is a determination result given by the exit correction decision device 88. As a result, the exit tension non-interference control 89 determines an exit tension non-interference control output represented by the following expression (4).

$$\left(1+\sum \Delta\left(\frac{\Delta V}{V}\right)_{DTRIC}\right) \quad \ldots (4)$$

[0131] The exit tension non-interference control output represented by expression (4) is used as an element in the integral processing section 91 as shown in FIG. 20. As a result, the contents of the control output given to the exit TR speed instruction device 85 by the exit speed tension control 84 are factored into the control output to the entry TR speed instruction device 65 as a function of the exit tension non-interference control gain G_{DTRIC}. Accordingly, the exit tension non-interference control 89 can be implemented as described earlier. That is, the exit tension non-interference control 89 functions as a non-interference control section and the output is used as a non-interference control variable. Also, the exit correction decision device 88 functions as an exit correction determination section.

[0132] Next, the operation of the exit correction decision device 88 is described with reference to FIG. 21. The exit correction decision device 88 determines, from the rolling conditions of the rolled material u by the rolling mill 1 such as change directions of a rolling-mill exit thickness h and an exit tension T_f and/or the like, whether or not the exit tension non-interference control 89 is required to be corrected. The result is set as a control gain G_{DTRIC} in the control method selection device 70. Because the neutral-point fluctuation and the speed-uniformity fluctuation of the entry TR 2 and the exit TR 3 of the rolling mill 1 occur under acceleration/deceleration of the rolling mill 1, the exit correction decision device 88 makes a determination only when the roll speed V_R of the rolling mill 1 is fluctuated, and does not make correction when a roll speed fluctuation does not occur. In short, G_{DTRIC} = zero results.

[0133] A time change amount of the rolling-mill roll speed V_R (a deviation from the preceding value) is represented by the following expression (5).

$$\frac{\partial V_R}{\partial t} \quad \ldots (5)$$

[0134] A time change amount of the exit thickness h is represented by the following expression (6).

$$\frac{\partial h}{\partial t} \quad \ldots (6)$$

[0135] A time change amount of the exit tension T_f is represented by the following expression (7).

$$\frac{\partial T_f}{\partial t} \quad \ldots (7)$$

[0136] The exit correction decision device 88 uses membership functions as shown in rolling-mill speed determination processing 881, exit thickness determination processing 882, and exit tension determination processing 883 in FIG. 21 to calculate, from the above values, a positive large degree VRP for the time change of the rolling-mill roll speed, a negative large degree VRM for the time change of the rolling-mill roll speed, a positive large degree SHP for the time change of the exit thickness, a negative large degree SHM for the time change of the exit thickness, a positive large degree TFP for the time change of the exit tension , and a negative large degree TFM for the time change of the exit tension, respectively.

[0137] From the above degrees, inference rule is used in inference processing 885 to perform inference for calculation of degree DTRI required for desired exit tension non-interference control 89. In this respect, if the degree DTRI is positive, the entry TR speed V_{ETR} is corrected in the same direction as the manipulated direction of the exit TR 3. On the other hand, if the degree DTRI is negative, the entry TR speed V_{ETR} is corrected in the opposite direction to the manipulated direction of the exit TR 3.

[0138] The inference processing 885 determines, based on the degrees VRM, VRP input from the rolling-mill roll speed V_R determination processing 881, whether the rolling-mill roll speed V_R is being increased or decreased. If the rolling-mill roll speed V_R is being increased/decreased, the inference processing 885 decides the degree DTRI based on a combination of the degrees SHP, SHM, TFP, TFM input from the exit thickness determination processing 882 and the exit tension determination processing 883.

[0139] For example, as regard inference rule (a) shown in FIG. 21, during acceleration/deceleration of the rolling-mill roll, when the exit thickness h fluctuates in the positive direction and the exist tension T_f fluctuates in the positive direction, the degree to which the control output of the exit tension control is required to be corrected to the entry TR in the same direction is 1.0. The inference rule shown in FIG. 21 is just an example. For example, the same rule is applied to the rolling-mill speed time changes in the positive direction (acceleration) and in the negative direction (deceleration), but different rules may be applied separately for acceleration and deceleration.

[0140] Upon determination of the degree DTRI, finally, the control gain setting 886 transforms the degree DTRI to an exit tension non-interference control gain G_{DTRIC}. By way of example, in FIG. 25, a dead band is imposed for the degree DTRI to set the exit tension non-interference control gain $_{GDTRIC}$ of ± 1.0.

[0141] The exit thickness fluctuation occurring under acceleration/deceleration is varied by machine configuration of the rolling mill 1 (speed-uniformity fluctuation between the rolling mill 1 and, the entry TR 2 and the exit TR 3, due to a response of the electric motor and/or the hydraulic rolling-reduction device, and the like), material properties of the rolled material u, rolling oil (occurrence conditions of neutral-point fluctuations), and the like. However, it is conceivable that the exit thickness fluctuations under acceleration/deceleration occur in similar conditions for similar reasons. In consequence, without using the method as illustrated in FIG. 21 for determination, a database with search criteria including material properties of rolled materials u, rolling schedules and the like may be created, and the exit tension non-interference control gain G_{DTRIC} may be determined based on the search results from the database.

[0142] The operation of the exit correction decision device 88 described above is just an example. Another method may be used to determine whether or not a speed correction from the exit tension control to the entry TR 2 is required. For example, in one of possible methods, the determination may be made factoring the fluctuations of the entry tension T_b in addition to the exit thickness h and the exit tension T_f.

[0143] Using the method as illustrated in FIG. 20 makes it possible to switch among the control methods A, B and C, for example, depending on the rolling speed even during the rolling operation. By applying the exit tension non-interference control 89, the exit thickness fluctuation caused by acting of the exit tension control is prevented.

[0144] The entry TR speed instruction device 65 acquires the entry TR speed V_{ETR} generated at the reference speed setting device 19 shown in FIG. 1 with taking a backward movement ratio b on the entry side of the rolling mill into account. Then, the entry TR speed instruction device 65 uses the control instruction from the control method selection device 70 and the acquired entry TR speed V_{ETR} to create an entry TR speed instruction V_{ETRref}, for outputting to the entry TR control device 66.

[0145] From the rolling mill speed V_{MILL} determined at the rolling speed setting device 10 manually manipulated by the operator, the reference speed setting device 19 determines the entry TR speed V_{ETR} with taking the rolling-mill entry backward movement ratio b.

[0146] The entry TR control device 66 is fed the entry TR speed instruction V_{ETRref} from the entry TR speed instruction device 65, the entry TR current instruction I_{ETRref} from the entry tension current transformation device 15, and the constant torque control mode from the control method selection device 70. Then, the entry TR control device 66 outputs a current to the entry TR 2. In this connection, the entry TR 2 includes the TR machine device and the electric motor for operating the TR machine device, and the current to the entry TR 2 means the current to the electric motor.

[0147] The entry TR control device 66 includes a speed control function for creating a current instruction to achieve agreement between the speed instruction V_{ETRref} and the actual speed V_{ETRfb}, and a current control function for controlling to achieve agreement between the created entry TR current instruction I_{ETRref} and a current I_{ETRfb} flowing through the electric motor of the entry TR 2. When the constant torque control mode is selected, the control is performed based on the entry TR current set value I_{ETRset} received from the entry tension current transformation device 15. On the other hand, when the constant torque control mode is not selected, the control is performed based on the speed instruction V_{ETRref}.

[0148] The exit TR speed instruction device 85 acquires the exit TR speed V_{DTR} generated at the reference speed setting device 19 shown in FIG. 1 with taking the rolling-mill exit forward movement ratio f into account. Then, the exit TR speed instruction device 85 uses the control instruction from the control method selection device 70 and the acquired exit TR speed V_{DTR} to create an exit TR speed instruction V_{DTRref}, for outputting to the exit TR control device 86.

[0149] From the rolling mill speed V_{MILL} determined at the rolling speed setting device 10 manually manipulated by the operator, the reference speed setting device 19 determines an exit TR speed V_{DTR} with taking the rolling-mill exit forward movement ratio f.

[0150] The exit TR control device 86 is fed the exit TR speed instruction V_{DTRref} from the exit TR speed instruction device 85, the current instruction I_{DTRset} from the exit tension current transformation device 16, and the constant torque control mode from the control method selection device 70. Then, the exit TR control device 86 outputs a current to the exit TR 3. In this connection, the exit TR 3 includes the TR machine device and the electric motor for operating the TR machine device, and the current to the exit TR 3 means the current to the electric motor.

[0151] The exit TR control device 86 includes a speed control function for creating a current instruction to achieve agreement between the speed instruction V_{DTRref} and the actual speed V_{DTRfb}, and a current control function for controlling to achieve agreement between the created exit current instruction I_{DTRref} and a current I_{DTRfb} flowing through the electric motor of the exit TR 3. When the constant torque control mode is selected, the control is performed based on the exit TR current set value I_{DTRset} received from the exit tension current transformation device 16. On the other hand, when the constant torque control mode is not selected, the control is performed based on the speed instruction V_{DTRref} .

[0152] As described up to this point, in the rolling control in the single-stand rolling mill S100 according to the embodiment, if the control method of controlling the entry TR speed V_{ETR} on the basis of the exit thickness h and controlling the exit TR speed V_{DTR} on the bases of the exit tension T_f is used, when the exit TR speed V_{DTR} is manipulated in response to the exit tension fluctuation, the entry TR speed V_{ETR} is also manipulated in order to suppress the exit thickness fluctuation to keep the mass flow constant law. As a result, when the exit tension fluctuation T_f of the rolled material u is controlled by means of the exit tension reel speed of the rolled material u, the influence on the exit thickness of the rolled material u is suppressed.

[0153] As described in FIG. 4, if the fluctuations of the exit tension T_f and the entry tension T_b are permitted, the neutral point fluctuation is reduced by the tension fluctuation, resulting in a reduction in thickness fluctuations. In consequence, in the event of tension fluctuations exceeding permissible limits after the tension fluctuations within the predetermined range have been permitted, the tension control is preferably performed by the speed tension control 63 and the exit speed tension control 84.

[0154] In this case, the speed tension control 63 and the exit speed tension control 84 each have a predetermined dead band for an actual tensile value input from the entry tension meter 8, exit tension meter 9. And, if the range of fluctuations of the actual tension value falls within the dead band, a signal indicating no tension fluctuations is output. On the other hand, if the range of fluctuations of the actual tension value falls outside the dead band, a signal indicating tension fluctuations is output to the control output selection device 72 shown in FIG. 20.

[0155] Through the control as described above, the neutral point fluctuations can be reduced by permitting the tension fluctuations within the bounds of not compromising the stability of the rolling operation, and therefor the exit thickness fluctuations can be minimize. Further, for the tension fluctuations making stable rolling operation difficult, both the tension control and the non-interference control are performed to minimize the exit thickness fluctuations.

[0156] In the above embodiment, as shown in FIG. 20, the setting of a gain at zero for unused output according to the control method among the outputs of the rolling reduction thickness control 61, the speed thickness control 62, the speed tension control 63, the rolling reduction tension control 64 and the exit speed tension control 84 is described as an example. In another example, by setting the respective gains to smaller values rather than to zero, the outputs of the rolling reduction thickness control 61, the speed thickness control 62, the speed tension control 63, the rolling reduction tension control 64 and the exit speed tension control 84 may be mixed in proportion to the gains, making the combined adoption of the control methods A, B and C possible.

[0157] In the embodiment, the exit tension non-interference control gain G_{DTRIC} of 1.0 or -1.0 is described as an example, but this is one example. The purpose of the exit tension non-interference control 89 is to keep the mass flow constant law when the exit TR speed V_{DTR} is manipulated in response to the exit tension fluctuations. Accordingly, the exit tension non-interference control gain G_{DTRIC} is preferably set as appropriate in accordance with the influences on the mass flow constant law when the exit TR speed V_{DTR} is manipulated.

[0158] In the embodiment, as described in FIG. 17 and FIG. 18, the control method is switched among the control methods A, B and C in accordance with the actual rolling. However, any one of the control methods may be selected in advance for use without change to comply with machine specifications and/or product specification of the rolled material u. In this case, the use of the database described in FIG. 19 is possible.

[0159] The influence of the exit tension control 14 on the exit thickness h is able to be removed by the aforementioned method. Using the method as described in FIG. 20 achieves smooth changes of the roll gap instruction for the rolling mill 1 and the speed instruction for the entry TR 2 even when the control elements of the thickness control and the tension control are switched. However, in some cases, the exit thickness fluctuation may not be suppressed due to the influence of the entry tension control 13 when the control elements are switched. An operation method of the single-stand rolling mill S100 of interest of the embodiment is illustrated in FIG. 23.

[0160] The rolling mill 1 is accelerated from a stop to perform rolling at high speeds, and finally is decelerated to terminate the rolling of a length of the rolled material u (e.g., coil). Hence, switching from the control method B to the control method C is performed during acceleration and switching from the control method C to the control method B is performed during deceleration. For example, when the speed of the rolling mill 1 is reduced, the switching from the control method C to the control method B takes place. This switches from the exit thickness h control previously using the speed of the entry TR 2 to the control using the roll gap of the rolling mill 1. Likewise, the input tension T_b control using the roll gap of the rolling mill 1 is switched to the control using the speed of the entry TR 2.

[0161] As the roll speed (rolling speed) of the rolling mill 1 increases (accelerates), the exit thickness h is smaller as the rolling phenomenon. In step with this, the entry speed reduces because of the mass flow constant law, so that the entry tension T_b drops. To suppress this, in the control method B, the exit thickness control using the roll gap of the rolling mill 1 and the entry tension control 13 using the speed of the entry TR 2 are performed.

[0162] In this respect, the entry tension control 13 includes an action of reducing the speed of the entry TR 2 (decelerating the entry TR 2) because of a smaller entry tension T_b. A reduction of the speed of the entry TR 2 results in a decrease in exit thickness h. The exit thickness control opens up the roll gap of the rolling mill 1 to maintain the exit thickness h. At this time, in the exit thickness control, it is required to control the amount of decrease in exit thickness caused by the acceleration of the rolling mill 1 and the amount of decrease in exit thickness caused by the entry tension control 13 manipulating the speed of the entry TR 2.

[0163] In this case, the exit thickness control opens up the roll gap of the rolling mill 1. As a result, the entry tension T_b rises, which is satisfactory operation status in terms of the entry tension control 13. Because of this, the entry tension T_b and the exit thickness h can be controlled satisfactorily in the conditions of the control method B.

[0164] In this state, upon switching to the control method C, the entry tension control 13 manipulates the roll gap of the rolling mill 1, and the exit thickness control manipulates the speed of the entry TR 2. In this case, upon acceleration of the entry TR 2, the entry tension T_b drops. Because of this, the roll gap of the rolling mill 1 is narrowed by the entry tension control 13. As a result, because of a decrease in the exit thickness h, the speed of the entry TR 2 is increased by the exit thickness control.

[0165] Increasing the speed of the entry TR 2 effects a drop of the entry tension T_b. Because of this, in the entry tension control 13, it is required to control both the entry tension reduction as the rolling phenomenon and the entry tension reduction caused by the thickness control manipulating the speed of the entry TR 2. In this case, the entry tension control 13 opens up the roll gap of the rolling mill 1 to increase the entry tension T_b. However, if a coefficient of influence of a change in roll gap of the rolling mill 1 on the entry tension T_b is small, the exit thickness h fluctuates while the entry tension T_b cannot be controlled to a sufficient degree. For example, a condition in which the roll gap is excessively opened up and the exit thickness h is large may result.

[0166] Similar to the foregoing, as the roll speed (rolling speed) of the rolling mill 1 decreases (decelerates), the exit thickness h is larger as the rolling phenomenon. In step with this, the entry speed T_b increases because of the mass flow constant law, so that the entry tension increases. To suppress this, in the control method C, the tension control using the roll gap of the rolling mill 1 and the thickness control using the speed of the entry TR 2 are performed. In this connection, in the exit thickness control, the exit thickness h is larger, so that the speed of the entry TR 2 is reduced (decelerated).

[0167] Reducing the speed of the entry TR 2 results in an increase in entry tension T_b. Therefore, the entry tension T_b is increased under deceleration by the rolling phenomenon and also by the exit thickness control manipulating the speed of the entry TR 2. In the entry tension control 13, the roll gap of the rolling mill 1 is manipulated, but in a small coefficient of influence from the roll gap of the rolling mill 1 to the entry tension T_b, the increase of the entry tension T_b cannot be controlled satisfactorily, so that the entry tension T_b may become larger than a set tension.

[0168] In this condition, upon switching to the control method B, the entry tension control 13 manipulates the speed of the entry TR 2 and the exit thickness control manipulates the roll gap of the rolling mill 1. In this case, because the entry tension T_b is larger than the set value, the entry tension control 13 increases the speed of the entry TR 2, resulting in an increase in exit thickness deviation Δh. The exit thickness control manipulates (narrows) the roll gap of the rolling mill 1 to attempt to suppress the exit thickness fluctuation, but the entry tension T_b is smaller, causing the entry tension control 13 to act to eliminate the decrease in the entry tension T_b. The thickness deviation is not eliminated by the mass flow constant law until the speed of the entry TR 2 returns to the previous speed.

[0169] Because of the foregoing, if switching between the control method B and the control method C is not done during the condition of a sufficiently large coefficient of influence from the roll gap of the rolling mill 1 to the entry tension T_b, the entry tension cannot be adequately controlled, possibly causing the exit thickness fluctuation. Accordingly, switching between the control method B and the control method C is required to be done while the coefficient of influence from the roll gap of the rolling mill 1 to the entry tension T_b is sufficiently large. However, because the reason for using the control method C is that the thickness fluctuation caused by the speed fluctuation of the entry TR 2 is eliminated, the control method C is required to be used until the speed becomes as low as possible.

[0170] The state of the exit thickness deviation Δh and the state of the entry tension when the above-described event occurs are illustrated in a lower portion of the FIG. 23. The exit thickness fluctuation occurs immediately after switching from the control method B to the control method C under acceleration, and immediately after switching from the control method C to the control method B under deceleration. Contrarily, instead of switching between the control method B and the control method C under acceleration/deceleration, if the switching is performed during the rolling process at a uniform speed, the above phenomenon can be avoided. However, the operation at a uniform speed is required until the control becomes stable, leading to reduced efficiency of operation.

[0171] The accuracy of the exit thickness h is important in terms of the quality of the rolled material u that is product, in which somewhat fluctuation in entry tension T_b is insignificant in maintaining the stability of the operation as long as the exit thickness h is stable. Accordingly, by applying correction to the operation of the entry tension control 13, the accuracy of the exit thickness h is required to be maintained even when the coefficient of the influence from the roll gap of the rolling mill 1 to the entry tension T_b is not sufficiently large. In this case, a plate break, snaking and/or the like occur if the entry tension T_b falls outside a fixed range, so that the entry tension T_b is required to fall within a predetermined range of permissible values in terms of operational stability.

[0172] Given these circumstances, the rolling control device according to the embodiment includes an entry tension deviation correction device 95 as shown in FIG. 1. FIG. 24 is a diagram illustrating the overview of the operation of the entry tension deviation correction device 95. As illustrated in FIG. 24, the entry tension deviation correction device 95 includes an upper-limit tolerance setting device 92, a lower-limit tolerance setting device 93 and a deviation correction section 94. If a value of the entry tension deviation ΔT_b input to the deviation correction section 94 falls within an upper limit and a lower limit respectively set by the upper-limit tolerance setting device 92 and the lower-limit tolerance setting device 93, the deviation correction section 94 corrects the entry tension deviation ΔT_b to zero for output. Thus, the corrected value of the entry tension deviation ΔT_b is input to each of the speed tension control 63 and the rolling reduction tension control 64.

[0173] In consequence, even if an entry tension deviation ΔT_b occurs, appearance of no occurrence of deviation is given to the speed tension control 63 and the rolling reduction tension control 64, in order to suppress the action of the tension control executed by the entry TR speed instruction device 65. In short, the entry tension deviation correction device 95 functions as a tension control suppression section. Further, the upper-limit tolerance setting device 92 and the lower-limit tolerance setting device 93 function as a tension control suppression setting section for supplying a permissible limit of the tension deviation. The above-described operation of the entry tension deviation correction device 95 is performed immediately after switching from the control method B to the control method C and immediately after switching from the control method C to the control method B as described earlier. This makes it possible to eliminate disadvantages as described earlier.

[0174] FIG. 25 is a diagram illustrating the operational concept of the entry tension deviation correction device 95. In FIG. 25, a target value of the tension setting is indicated by a slender dashed line, and the permissible limits set by the upper-limit tolerance setting device 92 and the lower-limit tolerance setting device 93 are indicated by a thick dashed line. As shown in FIG. 25, the upper-limit tolerance setting device 92 and the lower-limit tolerance setting device 93 respectively set an upper-limit tolerance ΔT_{bmax} and a lower-limit tolerance ΔT_{bmin} for the deviation correction section 94 at timing to at the point in time when the switching from control method B to the control method C is done or at the point in when the switching from control method C to the control method B is done. The values of the upper-limit tolerance ΔT_{bmax} and a lower-limit tolerance ΔT_{bmin} are the permissible limits of the entry tension deviation ΔT_b, that is, a dead band for the entry tension control 13.

[0175] Then, the deviation correction section 94 makes the upper-limit tolerance ΔT_{bmax} and a lower-limit tolerance ΔT_{bmin} smaller with the passage of time. This makes the permissible range of the entry tension deviation ΔT_b narrower with the passage of time. Then, the upper-limit tolerance ΔT_{bmax} and a lower-limit tolerance ΔT_{bmin} reach zero at timing t_1, so that the tension control by the entry TR speed instruction device 65 returns from the inactive state to the normal tension control state. The period from timing to to timing t_1 is about some seconds, for example, 10 seconds, and an optimum period varies according to conditions such as material properties of the rolled material u, a rolling speed, a rolling reduction ratio and the like.

[0176] FIG. 26 is a diagram showing the control state when the entry tension deviation correction device 95 executes the processing as shown in FIG. 24, FIG. 25, corresponding to FIG. 23. The suppression of the entry tension deviation ΔT_b at the switching between the control methods B and C effects a reduction in fluctuation of the exit thickness deviation Δh as compared with the case of FIG. 23, as shown in FIG. 26.

[0177] The upper-limit tolerance setting device 92 and the lower-limit tolerance setting device 93 access the optimum control method database, as described in FIGs. 18 and 19, based on the entry TR reference speed input from the reference speed setting device 19, to detect the timing of switching between the control method B and the control method C, the rolling mill 1 under acceleration, and the rolling mill under deceleration. Then, based on the detected results, the devices 92 and 93 respectively calculate an upper-limit tolerance ΔT_{bmax} and a lower-limit tolerance ΔT_{bmin} shown in FIG. 25, to set them in the deviation correction section 94.

[0178] The setting of the upper-limit tolerance ΔT_{bmax} and the lower-limit tolerance ΔT_{bmin} by the upper-limit tolerance setting device 92 and the lower-limit tolerance setting device 93 is not limited to a form of the above-described setting manner based on the entry TR reference speed output from the reference speed setting device 19, and another manner may be used for the setting. For example, when the optimum control method determination device 71 of the control method selection device 70 switches the control method, the upper-limit tolerance setting device 92 and the lower-limit tolerance setting device 93 may be instructed to use respectively the upper-limit tolerance ΔT_{bmax} and the lower-limit tolerance ΔT_{bmin}.

[0179] The deviation correction section 94 adjusts the upper-limit tolerance ΔT_{bmax} and the lower-limit tolerance ΔT_{bmin} with the passage of time as shown in FIG. 11. Then, if a value of the input entry tension deviation ΔT_b is larger than the upper-limit tolerance ΔT_{bmax} at the input time, the deviation correction section 94 outputs a value obtained by subtracting the upper-limit tolerance ΔT_{bmax} from the input entry tension deviation ΔT_b as a corrected entry tension deviation ΔT_b.

[0180] Alternatively, if a value of the input entry tension deviation ΔT_b is smaller than the upper-limit tolerance ΔT_{bmax} and larger than the lower-limit tolerance ΔT_{bmin}, zero is output as a corrected entry tension deviation ΔT_b. Still alternatively, if a value of the input entry tension deviation ΔT_b is smaller than the lower-limit tolerance ΔT_{bmin} at the input time, a value obtained by subtracting the lower-limit tolerance ΔT_{bmin} from the input entry tension deviation ΔT_b is output as a corrected entry tension deviation ΔT_b.

[0181] FIG. 27 shows the overview of the entry TR control device 66. The entry TR control device 66 is fed the entry TR speed instruction V_{ETRref} from the entry TR speed instruction device 65, the entry TR current instruction I_{ETRref} from the entry tension current transformation device, and the constant torque control mode from the control method selection device 70. Then, the entry TR control device 66 outputs a current to the entry TR 2. In this connection, the entry TR 2 includes the TR machine device and the electric motor for operating the TR machine device, and the current to the entry TR 2 means the current to the electric motor.

[0182] The entry TR control device 66 includes a P controller 661 and an I controller 662 for creating a current instruction to achieve agreement between the speed instruction V_{ETRref} and the actual speed V_{ETRfb}, and a current controller 663 for controlling to achieve agreement between the created entry TR current instruction I_{ETRref} and a current I_{ETRfb} flowing through the electric motor of the entry TR 2. When the constant torque control mode is selected, the I control 662 is replaced based on the entry TR current set value I_{ETRset} received from the entry tension current transformation device 15. On the other hand, when the constant torque control mode is not selected (the constant speed control), the P control 661 and the I control 662 are changed in accordance with the entry TR speed deviation.

[0183] In this state, when the constant torque control mode is selected, the entry TR current instruction I_{ETRref} is corrected by the current correction 664 to be prevented from changing discontinuously. By the configuration designed in this manner, the control mode for the entry TR control device 66 is able to be flexibly switched from the constant torque control to the constant speed control, and from the constant speed control to the constant torque control even during the rolling operation, leading to flexible switching between the control method A and the control method B and the control method C.

[0184] By using the control configuration as described up to this point, when the switching between the control methods B and C is performed under acceleration/deceleration of the rolling speed, a certain level of the tension deviation is permitted to give a higher priority to the stability of the exit thickness. As a result, the switching between the control methods B and C is enabled without a decrease in accuracy of the exit thickness during increase/decrease in the rolling speed, leading to a higher degree of operation efficiency.

[0185] In the embodiment, the entry tension deviation ΔT_b is corrected using a deadband to produce a corrected value of the entry tension deviation. However, any method, such as a change in tension control gain in accordance with the tension deviation and the like, may be used as long as the action of the entry tension control 13 is suppressed at the switching between the control methods and, when the tension deviation is large, the tension control is active. For a change of the tension control gain, it is possible to decrease the gains of the gain controller 74, 76 described in FIG. 20 in order to suppress the control value for the control based on the tension fluctuation to be smaller.

[0186] In the aforementioned embodiment, by way of example, the entry tension meter 8 is provided for the tension control. However, the present invention is not limited to this. A tension may be estimated based on a difference between an actual value of the output current by the entry TR control device 66 and a current instruction value output by the entry tension current transformation device 15. For example, because, when the actual value is larger than the instruction value, the entry TR control device 66 is in an effort to decrease the tension of the rolled material u, the tension at this time can be estimated to be higher than a tension set by the entry tension setting device 11.

[0187] In the aforementioned embodiment, the control method for the entry TR 2 is described, but a similar configuration may be applied to the control method for the exit TR 3. In this case, the exit tension deviation correction device 96 in FIG. 1 may have equivalent functions to those of the entry tension deviation correction device 95 in FIG. 24.

[0188] Further, in the embodiment, the description is given on the assumption of the single-stand rolling mill S100. However, a rolling mill is not limited to the single-stand rolling mill S100. For example, the present invention is applicable to a multi-stand tandem rolling mill with a tension reel on the entry side or the exit side. In other words, if the entire multi-stand tandem rolling mill is regarded as a rolling mill, it is possible to perform controls, as in the case of the foregoing, on the tension between the foremost rolling mill of the stand rolling mills and the tension reel and/or on the tension between the rearmost rolling mill and the tension reel.

[0189] Furthermore, the rolling control device centered on the control method selection device 70 explained with reference to FIG. 1 is realized by the combination of software and hardware. Here, the hardware for implementing each function of the rolling control device embodied herein will be described with reference to FIG. 22. FIG. 22 is a block diagram showing the hardware configuration of an information processing device included in the rolling control device according to the embodiment. As shown in FIG. 22, the rolling control device according to the embodiment has similar configuration to that of typical information processing terminals such as a server, PC (Personal Computer) and/or the like.

[0190] That is, in the rolling control device according to the embodiment, a CPU (Central Processing Unit) 201, a RAM (Random Access Memory) 202, a ROM (Read Only Memory) 203, an HDD (Hard Disk Drive) 204, and an I/F 205 are connected via a bus 208. Furthermore, an LCD (Liquid Crystal Display) 206 and an operating unit 207 are connected to the I/F 205.

[0191] The CPU 201 serves as calculating means for controlling the operations of the rolling control device as a whole. The RAM 202 is a volatile storage medium from/on which information is read/written at high speed, and is used as a working area when the CPU 201 processes the information. The ROM 203 is a read-only nonvolatile storage medium, in which programs, such as firmware, are stored.

[0192] The HDD 204 is a readable/writable-information nonvolatile storage medium storing an OS (Operating System), various kinds of control programs, application programs, etc.. The I/F 205 connects the bus 208 to various kinds of hardware, networks, etc. for control. The I/F 205 is also used as an interface for the individual devices to exchange information or input information to the rolling mill.

[0193] The LCD 206 is a visual user interface for an operator to check the state of the rolling control device. The operating unit 207 is a user interface, such as a keyboard or mouse, for an operator to input information into the rolling control device. In the hardware configuration, the program stored in the ROM 203, the HDD 204 or on a recording medium such as an optical disk not shown is read by the RAM 202, causing the CPU 201 to perform operations, thereby constituting a software control unit. The functions of the rolling control device according to the embodiment are realized by the combination of the software control unit configured in this manner and the hardware.

Example

[0194] To implement stable thick control and stable tension control for the rolling mill 1 as described above, it is necessary to switch the aforementioned control method A or C for use depending on the rolling conditions. To implement this, FIG. 28 illustrates the control configuration of a single-stand rolling mill S100 according to an example useful for understanding the invention.

[0195] As in the case of the first embodiment illustrated in FIG. 1, the single-stand rolling mill S100 according to the example has the entry TR 2 provided on the entry side of the rolling mill 1 in the rolling direction (shown by the arrow in FIG. 28) of the rolling mill 1 to feed and insert a rolled material into the rolling mill 1, and also has the exit TR 3 provided on the exit side to wind up the rolled material rolled by the rolling mill 1. The entry TR 2 and the exit TR 3 are driven respectively by the electric motors, and equipped with the electric motors and the entry TR control device 66 and the exit TR control device 86 which are provided respectively for the driving control of the electric motors. With this arrangement, in the rolling operation in the single-stand rolling mill S100, after the rolled material unwound from the entry TR 2 is rolled with the rolling mill 1, the rolled material u is wound up on the exit TR 3. The example is identical in arrangement with the first embodiment.

[0196] In the control configuration shown in FIG. 28, using an exit thickness deviation Δh detected by the exit thickness meter 17, a manipulation instruction $\Delta\Delta S_{AGC}$ for the roll gap is generated in the rolling reduction thickness control 61, and a manipulation instruction $\Delta\Delta V_{AGC}$ for the entry TR speed is generated in the speed thickness control 62. Further, using a deviation (entry tension deviation) ΔT_b between an actual entry tension which is an actual measured value of an entry tension measured by the entry tension meter 8 and a set entry tension set at the entry tension setting device 11, a manipulation instruction $\Delta\Delta V_{ATR}$ for the entry TR speed is generated in the speed tension control 63, and a manipulation instruction $\Delta\Delta S_{ATR}$ for the roll gap is generated in the rolling reduction tension control 64.

[0197] Further, when the entry TR 2 is operated under the constant torque control, a control output from the entry tension control 13 to manipulate an entry tension set value by the deviation between the actual entry tension and the entry tension set value is added to an entry tension set value by the entry tension setting device 11, and then the sum is transformed to a current instruction for the entry TR 2 by the entry tension current transformation device 15 to create a current instruction to the entry TR control device 66.

[0198] The control method selection device 70 selectively determines, according to the rolling conditions, which of the control methods A, B and C described earlier should be applied to abate at the maximum the exit thickness fluctuation and the entry tension fluctuation. Then, the control method selection device 70 outputs a roll-gap manipulation instruction to the roll gap control device 7 based on the selection result. To manipulate the entry TR speed, a speed manipulation instruction is output to the entry TR speed instruction device 65. In the entry TR speed instruction device 65, the entry TR speed instruction is made based on an entry TR reference speed output from the reference speed setting device 19 and an entry-TR-speed change amount from the control method selection device 70, and then is output to the entry TR control device 66.

[0199] The entry TR control device 66 has an operation mode in which the constant torque control (constant current control) is performed according to a current instruction, and another operation mode in which the constant speed control is performed according to a speed instruction, and switches between the modes for operation in response to the instruction from the control method selection device 70.

[0200] FIG. 29 shows, as an example, a block diagram of the rolling reduction thickness control 61, the speed thickness control 62, the speed tension control 63 and the rolling reduction tension control 64. This is just one example of various control configurations, and another method may be used to configure another control system. For instance, in the example in FIG. 29, each control system is configured to use Integral Control (I Control), but may use Proportional Integral Control (PI Control) or Proportional Integral Differential Control (PID Control).

[0201] The rolling reduction thickness control 61 is designed to use Integral Control (I Control) in which the exit thickness deviation $\Delta h = h_{fb} - h_{ref}$ that is a difference between an actual exit thickness h_{fb} and an exit thickness set value h_{ref} is input, and the input exit thickness deviation Δh is multiplied by an adjustment gain and a transformation gain from the exit thickness deviation Δh to the roll gap, which is then integrated. A control output $\Delta\Delta S_{AGC}$ is derived from a deviation between the output after the integration and the previous value. Further, the speed thickness control 62 is designed to use Integral Control (I Control) in which the exit thickness deviation Δh is input, and the input exit thickness deviation Δh is multiplied by an adjustment gain and a transformation gain from the exit thickness deviation Δh to the entry speed, which is then integrated. A deviation between the output after the integration and the previous value is determined and control output is determined from the expression (1) shown in the first embodiment.

[0202] In the expression, M is a mill constant for the rolling mill 1 and Q is a plasticity constant of the rolled material. An instruction of the speed thickness control is output as a speed change ratio to the set speed.

[0203] The rolling reduction tension control 64 is designed to use Integral Control (I Control) in which the entry tension deviation $\Delta T_b = T_{bfbb} - T_{bref}$ that is a difference between an actual entry tension T_{bfbb} and an entry tension set value T_{bref} is input, and the input entry tension deviation ΔT_b is multiplied by an adjustment gain and a transformation gain from the entry tension deviation ΔT_b to the roll gap, which is then integrated. A control output $\Delta\Delta S_{ATR}$ is derived from a deviation between the output after the integration and the previous value.

[0204] The speed tension control 63 is designed to use Integral Control (I Control) in which the entry tension deviation ΔT_b is input, and the input entry tension deviation ΔT_b is multiplied by an adjustment gain and a transformation gain from the entry tension deviation ΔT_b to the entry speed, which is then integrated. A deviation between the output after the integration and the previous value is determined and control output is determined from the expression (2) described in the first embodiment.

[0205] FIG. 30 illustrates the overview of the control method selection device 70. The control method selection device 70 includes the optimum control method determination device 71 and the control output selection device 72. The optimum control method determination device 71 determines which of the control methods A, B and C is used for control. The control output selection device 72 selects any one of the outputs of the rolling reduction thickness control 61, the speed thickness control 62, the speed tension control 63 and the rolling reduction tension control 64 for use. Then, control instructions are output to the roll gap control device 7, the entry TR speed instruction device 65, and the entry TR control device 66. In short, the optimum control method determination device 71 functions as a control mode determination section.

[0206] The operational overview of the optimum control method determination device 71 is as described with reference to FIG. 17 and FIG. 18 in the first embodiment. The control method selection device 70 executes the optimum control method determination procedures as described above to switch the control method to a determined optimum control method. In this case, because the control method A, the control method B and the control method C are different in a control method for the entry TR 2, the control method may not be switched during the rolling operation. In this event, the rolling operation is continued by the control method A, and then the control method may be switched when a next rolled material of the same type of steel and the same width is to be rolled. The determined optimum control method is stored in a database with search criteria including types of steel of rolled materials, exit thickness and rolling speeds. When the same type of a rolled material is to be rolled in a next rolling process, the rolling process is controlled according to an optimum control method stored in the database.

[0207] An example of the stored data in the database is as illustrated in FIG. 19 in the first embodiment. The above-described method is just one example of the optimum control method determination procedures, and other methods may be adopted as described in the first embodiment. By way of one example, it is also possible to select an optimum control method based on the magnitude relationship between the influence coefficients, shown in FIG. 40, which are numerically obtained by use of the rolling phenomenon model from the actual figures of the rolling.

[0208] FIG. 31 shows the overview of the operation of the control output selection device 72. The control output selection device 72 is fed: outputs from the rolling reduction thickness control 61, the speed thickness control 62, the speed tension control 63 and the rolling reduction tension control 64; and a control method selection result from the optimum control method determination device 71. Also, the control output selection device 72 outputs control instructions to the roll gap control device 7, the entry TR speed instruction device 65 and the entry TR control device 66.

[0209] As shown in FIG. 31, at the control output selection device 72, the outputs from the rolling reduction thickness control 61, the speed thickness control 62, the speed tension control 63 and the rolling reduction tension control 64 are input respectively to the gain controllers 73, 74, 75 and 76. The gain controllers 73 to 76 are signal adjustment sections in which the outputs from the rolling reduction thickness control 61, the speed thickness control 62, the speed tension control 63 and the rolling reduction tension control 64 are respectively multiplied by gains for output. The gains of the gain controllers 73 to 76 are adjusted based on the control method selection result from the optimum control method determination device 71.

[0210] When the control method A is selected, the output from the rolling reduction thickness control 61 undergoes integration processing to be output to the roll gap control device 7. Further, the constant torque control mode selection is output to the entry TR control device 66. For that purpose, from the control method selection result by the optimum control method determination device 71, the gains of the gain controllers 74 to 76 are set at zero, as well as the gain of the gain controller 73 is adjusted, so that the output from the rolling reduction thickness control 61 is set to undergo integration processing by the integral processing section 77. Further, from the control method selection result by the optimum control method determination device 71, the constant torque control mode selection is output to the entry TR control device 66. In this case, the entry TR control device 66 functions as a tension reel torque control section.

[0211] When the control method B is selected, the output from the rolling reduction thickness control 61 undergoes integration processing to be output to the roll gap control device 7, as well as the output from the speed tension control 63 undergoes integration processing to be output to the entry TR speed instruction device 65. For that purpose, from the control method selection result by the optimum control method determination device 71, the gains of the gain controllers 74 and 75 are set at zero, as well as the gains of the gain controllers 73 and 76 are adjusted. Therefore, integration processing is set to be applied to the output from the rolling reduction thickness control 61 by the integral processing section 77, and also, integration processing is set to be applied to the output from the speed tension control 63 by the integral processing section 78.

[0212] When the control method C is selected, the output from the speed thickness control 62 undergoes integration processing to be output to the entry TR speed instruction device 65, as well as the output from the rolling reduction tension control 64 undergoes integral processing to be output to the roll gap control device 7. For the purpose, from the control method selection result by the optimum control method determination device 71, the gains of the gain controllers 73 and 76 are set at zero, as well as the gains of the gain controllers 74 and 75 are adjusted, so that the output from the rolling reduction tension control 64 undergoes integration processing by the integral processing section 77, as well as the output from the speed thickness control 62 undergoes integration processing by the integral processing section 78.

[0213] In other words, a control path leading to the integration processing section 77 and the roll gap control device 7 functions as a roll gap control section. Further, a control path leading to the integral processing section 78 and the entry TR speed instruction device 65 functions as a speed control section.

[0214] Using the method as illustrated in FIG. 31 makes it possible to switch among the control methods A, B and C, for example, depending on the rolling speed even during the rolling operation. As shown in FIG. 32, from the rolling mill speed V_{MILL} determined at the rolling speed setting device 10 manually manipulated by the operator, an entry TR speed V_{ETR} is generated at the reference speed setting device 19 with taking a backward movement ratio b on the entry side of the rolling mill into account. The entry TR speed instruction device 65 uses the entry TR speed V_{ETR} thus generated and the control instruction from the control method selection device 70 to create an entry TR speed instruction V_{ETRref}, for outputting to the entry TR control device 66.

[0215] Using the method as described in FIG. 31 achieves smooth changes of the roll gap instruction for the rolling mill 1 and the speed instruction for the entry TR 2 even when the control elements of the thickness control and the tension control are switched. However, in some cases, the exit thickness fluctuation may not be suppressed due to the influence of the entry tension control 13 when the control elements are switched. An operation method of the single-stand rolling mill S100 of interest of the embodiment is similar to the method described with reference to FIG. 23 in the first embodiment.

[0216] The state of the exit thickness deviation Δh and the state of the entry tension when the above-described event occurs are illustrated in a lower portion of the FIG. 23. The exit thickness fluctuation occurs immediately after switching from the control method B to the control method C under acceleration, and immediately after switching from the control method C to the control method B under deceleration. Contrarily, instead of switching between the control method B and the control method C under acceleration/deceleration, if the switching is performed during the rolling process at a uniform speed, the above phenomenon can be avoided. However, the operation at a uniform speed is required until the control becomes stable, leading to reduced efficiency of operation.

[0217] The accuracy of the exit thickness is important in terms of the quality of the rolled material that is product, in which somewhat fluctuation in entry tension is insignificant in maintaining the stability of the operation as long as the exit thickness is stable. Accordingly, by applying correction to the action of the entry tension control 13, the accuracy of the exit thickness is required to be maintained even when the coefficient of the influence from the roll gap of the rolling mill 1 to the entry tension is not sufficiently large. In this case, a plate break, snaking and/or the like occur if the entry tension falls outside a fixed range, so that the entry tension is required to fall within a predetermined range of permissible values in terms of operational stability.

[0218] Given these circumstances, the rolling control device according to the embodiment includes an entry tension deviation correction device 95 as shown in FIG. 28. The overview of the operation of the entry tension deviation correction device 95 is as described with reference in FIG. 24 in the first embodiment. The operational concept of the entry tension deviation correction device 95 is as described with reference to FIG. 25. The control state when the entry tension deviation correction device 95 performs the processing is as described with reference to FIG. 26. Further, the overview of the entry TR control device 66 is as described with reference to FIG. 27.

[0219] By using the control configuration as described up to this point, in the embodiment, the switching between the control method A, the control method B and the control method C is able to be performed according to the rolling conditions to make a selection of the control configuration best suited to the exit thickness control and the entry thickness control, leading to significant improvements in the exit thickness accuracy and the working operation efficiency. When the switching between the control methods B and C is performed under acceleration/deceleration of the rolling speed, a certain level of the tension deviation is permitted to give a higher priority to the stability of the exit thickness. As a result, the switching between the control methods B and C is enabled without a decrease in accuracy of the exit thickness during increase/decrease in the rolling speed, leading to a higher degree of working operation efficiency.

[0220] In the embodiment, the entry tension deviation ΔT_b is corrected using a deadband to produce a corrected value of the entry tension deviation. However, any method, such as a change in tension control gain in accordance with the tension deviation and the like, may be used as long as the action of the entry tension control 13 is suppressed at the switching of the control method and, when the tension deviation is large, the tension control is active. For a change of the tension control gain, it is possible to decrease the gains of the gain controller 74, 76 described in FIG. 31 in order to suppress the control value for the control based on the tension fluctuation to be smaller.

[0221] In the embodiment, by way of example, the entry tension meter 8 is provided for the tension control. However, the present invention is not limited to this. As in the case of the first embodiment, in the example, a tension can be estimated based on a difference between an actual value of the output current by the entry TR control device 66 and a current instruction value output by the entry tension current transformation device 15. For example, because, when the actual value is larger than the instruction value, the entry TR control device 66 is in an effort to decrease the tension of the rolled material, the tension at this time can be estimated to be higher than a tension set by the entry tension setting device 11.

[0222] In the embodiment, as described with reference to FIG. 17 and FIG. 18, the switching between the control method A, the control method B and the control method C is performed based on the actual rolling. However, any one of the control methods may be selected in advance for use without switching to comply with machine specifications and/or product specification of the rolled material. In this case, the use of the database described in FIG. 19 is possible.

[0223] In the embodiment the control method for the entry TR 2 is described, but the present invention may be applied to the control method for the exit TR 3. If an influence of the exit tension on the thickness becomes large depending on types of rolling mills 1 and types of rolled material, manipulating the exit TR 3 may increase efficiency.

[0224] Further, in the embodiment, the description is given on the assumption of the single-stand rolling mill S100. However, as in the case of the first embodiment, a rolling mill is not limited to the single-stand rolling mill. For example, the present invention is applicable to a multi-stand tandem rolling mill with a tension reel on the entry side or the exit side.

[0225] In the example, similar or the same components to or as the first embodiment are designated by the same reference signs, and descriptions are omitted as appropriate.

[0226] The first embodiment and the example have been described using an example of the rolling control device including all the functions. However, all the functions may be implemented in a single information processing device, or alternatively, each function may be implemented in a distributed manner among a larger number of information processing devices.

Claims

1. A rolling control device for a rolling mill (1) that includes a roll pair to roll a rolled material, comprising:

    a roll gap control section configured to control a gap between rolls of the roll pair;
    an entry side speed control section configured to control a running speed of the rolled material fed into the rolling mill (1) ;
    a control-method switching section (70) configured to perform switching between a first control method and a second control method, wherein the first control method controls an entry side running speed of the rolled material on the basis of a tension of the rolled material fed into the rolling mill (1) and controls a roll gap on the basis of a thickness of the rolled material passing through the rolling mill (1), wherein the second control method controls the roll gap of the rolled material on the basis of a tension of the rolled material fed into the rolling mill (1) and controls an entry side running speed of the rolled material on the basis of a thickness of the rolled material;
    an exit side speed control section configured to control an exit side running speed of the rolled material passing through the rolling mill (1), on the basis of a tension of the rolled material passing through the rolling mill (1); and
    an exit tension non-interference control section (89) configured to generate and output a non-interference control variable used for controlling the entry side running speed of the rolled material fed into the rolling mill (1), when controlling a running speed of the rolled material passing through the rolling mill (1) during use of the second control method;
    the rolling control device further comprising an exit correction determination section determining to cause the exit tension non-interference control section to generate and output the non-interference control variable on the basis of rolling conditions of the rolled material by the rolling mill (1),
    wherein the exit correction determination section causes the non-interference control variable to be generated and output on the basis of a time change amount of a thickness of the rolled material and a time change amount of a tension of the rolled material passing through the rolling mill (1), in condition that a speed of the rolls of the rolling mill (1) changes in excess of a predetermined time change amount.

2. The rolling control device according to claim 1, wherein the exit correction determination section determines a sign of the non-interference control variable on the basis of a combination of signs of a time change amount of a thickness of the rolled material and a time change amount of a tension of the rolled material passing through the rolling mill (1), in condition that a speed of the rolls of the rolling mill changes in excess of a predetermined time change amount.

3. The rolling control device according to claim 1, wherein:

    the exit speed control section (85) controls a running speed of the rolled material passing through the rolling mill (1) when a fluctuation amount of a tension of the rolled material passing through the rolling mill (1) exceeds a predetermined permissible range; and
    the exit tension non-interference control section generates and outputs the non-interference control variable when a running speed of the rolled material passing through the rolling mill (1) is controlled because a fluctuation amount of a tension of the rolled material passing through the rolling mill (1) exceeds a predetermined permissible range.

4. The rolling control device according to claim 1, further comprising a tension control suppression section suppressing a control value for control based on fluctuation of a tension of the rolled material to be smaller, for the switching between the first control method and the second control method.

5. A rolling control method, comprising the steps of:

    controlling a gap between a pair of rolls of a rolling mill (1) to roll a rolled material;
    controlling a running speed of the rolled material fed into the rolling mill (1);
    controlling switching between a first control method and a second control method, the first control method of controlling an entry side running speed of the rolled material on the basis of a tension of the rolled material fed into the rolling mill (1) and controlling a roll gap on the basis of a thickness of the rolled material, the second

control method of controlling the roll gap of the rolled material on the basis of a tension of the rolled material fed into the rolling mill (1) and controlling an entry side running speed of the rolled material on the basis of a thickness of the rolled material;
controlling an exit side running speed of the rolled material passing through the rolling mill (1), on the basis of a tension of the rolled material passing through the rolling mill (1) ;
generating and outputting a non-interference control variable used for controlling the entry side running speed of the rolled material fed into the rolling mill, when controlling a running speed of the rolled material passing through the rolling mill (1) during use of the second control method; and
causing the non-interference control variable to be generated and output on the basis of a time change amount of a thickness of the rolled material and a time change amount of a tension of the rolled material passing through the rolling mill (1), in condition that a speed of the rolls of the rolling mill (1) changes in excess of a predetermined time change amount.

Patentansprüche

1. Walzsteuervorrichtung für ein Walzwerk (1), das ein Walzenpaar zum Walzen eines Walzmaterials enthält, wobei die Walzsteuervorrichtung Folgendes umfasst:

   einen Walzspalt-Steuerabschnitt, der dafür konfiguriert ist, einen Spalt zwischen Walzen des Walzenpaars zu steuern;
   einen Eintrittsseiten-Geschwindigkeitssteuerabschnitt, der dafür konfiguriert ist, eine Laufgeschwindigkeit des dem Walzwerk (1) zugeführten Walzmaterials zu steuern;
   einen Steuerverfahren-Umschaitabschnitt (70), der dafür konfiguriert ist, das Umschalten zwischen einem ersten Steuerverfahren und einem zweiten Steuerverfahren auszuführen, wobei das erste Steuerverfahren eine Eintrittsseiten-Laufgeschwindigkeit des Walzmaterials auf der Grundlage einer Zugspannung des dem Walzwerk (1) zugeführten Walzmaterials steuert und einen Walzspalt auf der Grundlage einer Dicke des durch das Walzwerk (1) gehenden Walzmaterials steuert, wobei das zweite Steuerverfahren den Walzspalt des Walzmaterials auf der Grundlage einer Zugspannung des dem Walzwerk (1) zugeführten Walzmaterials steuert und eine Eintrittsseiten-Laufgeschwindigkeit des Walzmaterials auf der Grundlage einer Dicke des Walzmaterials steuert;
   einen Austrittsseiten-Geschwindigkeitssteuerabschnitt, der dafür konfiguriert ist, eine Austrittsseiten-Laufgeschwindigkeit des durch das Walzwerk (1) gehenden Walzmaterials auf der Grundlage einer Zugspannung des durch das Walzwerk (1) gehenden Walzmaterials zu steuern; und
   einen Abschnitt (89) zur störungsfreien Steuerung der Austrittszugspannung, der dafür konfiguriert ist, eine Variable zur störungsfreien Steuerung zu erzeugen und auszugeben, die dafür verwendet wird, die Eintrittsseiten-Laufgeschwindigkeit des dem Walzwerk (1) zugeführten Walzmaterials zu steuern, wenn eine Laufgeschwindigkeit des durch das Walzwerk (1) gehenden Walzmaterials gesteuert wird;
   wobei die Walzsteuervorrichtung ferner einen Austrittskorrektur-Bestimmungsabschnitt umfasst, der bestimmt, dass veranlasst wird, dass der Abschnitt zur störungsfreien Steuerung der Austrittszugspannung die Variable zur störungsfreien Steuerung auf der Grundlage der Walzbedingungen des durch das Walzwerk (1) gewalzten Materials erzeugt und ausgibt,
   wobei der Austrittskorrektur-Bestimmungsabschnitt veranlasst, dass die Variable zur störungsfreien Steuerung unter der Bedingung, dass sich eine Drehzahl der Walzen des Walzwerks (1) über eine vorgegebenen Zeitänderungsbetrag hinaus ändert, auf der Grundlage eines Zeitänderungsbetrags einer Dicke des Walzmaterials und eines Zeitänderungsbetrags einer Zugspannung des durch das Walzwerk (1) gehenden Walzmaterials erzeugt und ausgegeben wird.

2. Walzsteuervorrichtung nach Anspruch 1, wobei der Austrittskorrektur-Bestimmungsabschnitt ein Vorzeichen der Variable zur störungsfreien Steuerung unter der Bedingung, dass sich eine Drehzahl der Walzen des Walzwerks über einen vorgegebenen Zeitänderungsbetrag hinaus ändert, auf der Grundlage einer Kombination von Vorzeichen eines Zeitänderungsbetrags einer Dicke des Walzmaterials und eines Zeitänderungsbetrags einer Zugspannung des durch das Walzwerk (1) gehenden Walzmaterials bestimmt.

3. Walzsteuervorrichtung nach Anspruch 1, wobei:

   der Austrittsgeschwindigkeits-Steuerabschnitt (85) eine Laufgeschwindigkeit des durch das Walzwerk (1) gehenden Walzmaterials steuert, wenn ein Schwankungsbetrag einer Zugspannung des durch das Walzwerk (1) gehenden Walzmaterials einen vorgegebenen zulässigen Bereich übersteigt; und der Abschnitt zur störungsfreien Steuerung der Austrittszugspannung die Variable für zerstörungsfreie Steuerung erzeugt und ausgibt, wenn eine Laufgeschwindigkeit des durch das Walzwerk (1) gehenden Walzmaterials gesteuert wird, da ein Schwankungsbetrag einer Zugspannung des durch das Walzwerk (1) gehenden Walzmaterials einen vorgegebenen zulässigen Bereich übersteigt.

4. Walzsteuervorrichtung nach Anspruch 1, die ferner einen Zugspannungssteuerungs-Unterdrückungsabschnitt umfasst, der zum Schalten zwischen dem ersten Steuerverfahren und dem zweiten Steuerverfahren einen Steuerwert für die Steuerung auf der Grundlage einer Schwankung einer Zugspannung des Walzmaterials unterdrückt, damit er kleiner wird.

5. Walzsteuerverfahren, das die folgenden Schritte umfasst:

Steuern eines Spalts zwischen einem Paar Walzen eines Walzwerks (1) zum Walzen eines Walzmaterials;
Steuern einer Laufgeschwindigkeit des dem Walzwerk (1) zugeführten Walzmaterials;
Steuern des Schaltens zwischen einem ersten Steuerverfahren und einem zweiten Steuerverfahren, wobei das erste Steuerverfahren eine Eintrittsseiten-Laufgeschwindigkeit des Walzmaterials auf der Grundlage einer Zugspannung des dem Walzwerk (1) zugeführten Walzmaterials steuert und einen Walzspalt auf der Grundlage einer Dicke des Walzmaterials steuert und wobei das zweite Steuerverfahren den Walzspalt des Walzmaterials auf der Grundlage einer Zugspannung des dem Walzwerk (1) zugeführten Walzmaterials steuert und eine Eintrittsseiten-Laufgeschwindigkeit des Walzmaterials auf der Grundlage einer Dicke des Walzmaterials steuert;
Steuern einer Austrittsseiten-Laufgeschwindigkeit des durch das Walzwerk (1) gehenden Walzmaterials auf der Grundlage einer Zugspannung des durch das Walzwerk (1) gehenden Walzmaterials;
Erzeugen und Ausgeben einer Variablen zur störungsfreien Steuerung, die dafür verwendet wird, die Eintrittsseiten-Laufgeschwindigkeit des dem Walzwerk zugeführten Walzmaterials zu steuern, wenn eine Laufgeschwindigkeit des durch das Walzwerk (1) gehenden Walzmaterials während der Verwendung des zweiten Steuerverfahrens gesteuert wird; und
Veranlassen, dass die Variable zur störungsfreien Steuerung auf der Grundlage eines Zeitänderungsbetrags einer Dicke des Walzmaterials und eines Zeitänderungsbetrags einer Zugspannung des durch das Walzwerk (1) gehenden Walzmaterials erzeugt und ausgegeben wird, unter der Bedingung, dass sich eine Drehzahl der Walzen des Walzwerks (1) über einen vorgegebenen Zeitänderungsbetrag hinaus ändert.

Revendications

1. Dispositif de commande de laminage pour un laminoir (1) qui inclut une paire de cylindres pour laminer un matériau à laminer, comprenant :

une section de commande d'intervalle de laminage configurée pour commander un intervalle entre des cylindres de la paire de cylindres ;
une section de commande de vitesse côté entrée configurée pour commander une vitesse de déplacement du matériau à laminer alimenté dans le laminoir (1) ;
une section de commutation de méthode de commande (70) configurée pour effectuer une commutation entre une première méthode de commande et une seconde méthode de commande, dans lequel la première méthode de commande assure la commande d'une vitesse de déplacement côté entrée du matériau à laminer sur la base d'une tension du matériau à laminer alimenté dans le laminoir (1) et assure la commande d'un intervalle de laminage sur la base d'une épaisseur du matériau à laminer qui passe à travers le laminoir (1), dans lequel la seconde méthode de commande assure une commande de l'intervalle de laminage du matériau à laminer sur la base d'une tension du matériau à laminer alimenté dans le laminoir (1) et la commande d'une vitesse de déplacement côté entrée du matériau à laminer sur la base d'une épaisseur du matériau à laminer ;
une section de commande de vitesse côté sortie configurée pour commander une vitesse de déplacement côté sortie du matériau à laminer qui passe à travers le laminoir (1), sur la base d'une tension du matériau à laminer qui passe à travers le laminoir (1) ; et
une section de commande d'absence d'interférence de tension en sortie (89) configurée pour générer et pour fournir une variable de commande d'absence d'interférence utilisée pour commander la vitesse de déplacement côté entrée du matériau à laminer alimenté dans le laminoir (1), lors de la commande d'une vitesse de déplacement du matériau à laminer qui passe à travers le laminoir (1) pendant l'utilisation de la seconde méthode de commande ;
le dispositif de commande de laminage comprenant en outre une section de détermination de correction de

sortie qui détermine afin d'amener la section de commande d'absence d'interférence de tension en sortie à générer et à fournir la variable de commande d'absence d'interférence sur la base des conditions de laminage du matériau à laminer par le laminoir (1),

dans lequel la section de détermination de correction de sortie provoque la génération de la variable de commande d'absence d'interférence et sa fourniture sur la base d'un temps de changement quantitatif d'une épaisseur du matériau à laminer et d'un temps de changement quantitatif de tension du matériau à laminer qui passe à travers le laminoir (1), dans une condition selon laquelle une vitesse des cylindres de laminoir (1) change de manière à excéder un temps de changement quantitatif prédéterminé.

2. Dispositif de commande de laminage selon la revendication 1, dans lequel la section de détermination de correction de sortie détermine un signe de la variable de commande d'absence d'interférence sur la base d'une combinaison des signes d'un temps de changement quantitatif d'une épaisseur du matériau à laminer et d'un temps de changement quantitatif d'une tension du matériau à laminer qui passe à travers le laminoir (1), dans une condition selon laquelle une vitesse des cylindres du laminoir change de manière à excéder un temps de changement quantitatif prédéterminé.

3. Dispositif de commande de laminage selon la revendication 1, dans lequel :

la section de commande de vitesse de sortie (85) commande une vitesse de déplacement du matériau à laminer qui passe à travers le laminoir (1) quand une fluctuation quantitative d'une tension du matériau à laminer qui passe à travers le laminoir (1) excède une plage permissible prédéterminée ; et

la section de commande d'absence d'interférence de tension en sortie génère et délivre la variable de commande d'absence d'interférence quand une vitesse de déplacement du matériau à laminer qui passe à travers le laminoir (1) est commandée parce qu'une fluctuation quantitative d'une tension du matériau à laminer qui passe à travers le laminoir (1) excède une plage permissible prédéterminée.

4. Dispositif de commande de laminage selon la revendication 1, comprenant en outre une section de suppression de commande de tension qui supprime une valeur de commande pour la commande sur la base d'une fluctuation de la tension du matériau à laminer afin de la rendre plus petite, pour la commutation entre la première méthode de commande et la seconde méthode de commande.

5. Procédé de commande de laminage, comprenant les étapes consistant à :

commander un intervalle entre une paire de cylindres d'un laminoir (1) pour laminer un matériau à laminer ;

commander une vitesse de déplacement du matériau à laminer alimenté dans le laminoir (1) ;

commander la commutation entre une première méthode de commande et une seconde méthode de commande, la première méthode de commande consistant à commander une vitesse de déplacement côté entrée du matériau à laminer sur la base d'une tension du matériau à laminer alimenté dans le laminoir (1) et à commander un intervalle de laminage sur la base d'une épaisseur du matériau à laminer, la seconde méthode de commande consistant à commander l'intervalle de laminage du matériau à laminer sur la base d'une tension du matériau à laminer alimenté dans le laminoir (1) et à commander une vitesse de déplacement côté entrée du matériau à laminer sur la base d'une épaisseur du matériau à laminer ;

commander une vitesse de déplacement côté sortie du matériau à laminer qui passe à travers le laminoir (1), sur la base d'une tension du matériau à laminer qui passe à travers le laminoir (1) ;

générer et délivrer une variable de commande d'absence d'interférence utilisée pour commander la vitesse de déplacement côté entrée du matériau à laminer alimenté dans le laminoir, lors de la commande d'une vitesse de déplacement du matériau à laminer qui passe à travers le laminoir (1) pendant l'utilisation de la seconde méthode de commande ; et

entraîner la génération de la variable de commande d'absence d'interférence et sa fourniture sur la base d'un temps de changement quantitatif d'une épaisseur du matériau à laminer et d'un temps de changement quantitatif d'une tension du matériau à laminer qui passe à travers le laminoir (1), dans une condition selon laquelle une vitesse des cylindres du laminoir (1) change de manière à excéder un temps de changement quantitatif prédéterminé.

FIG. 1

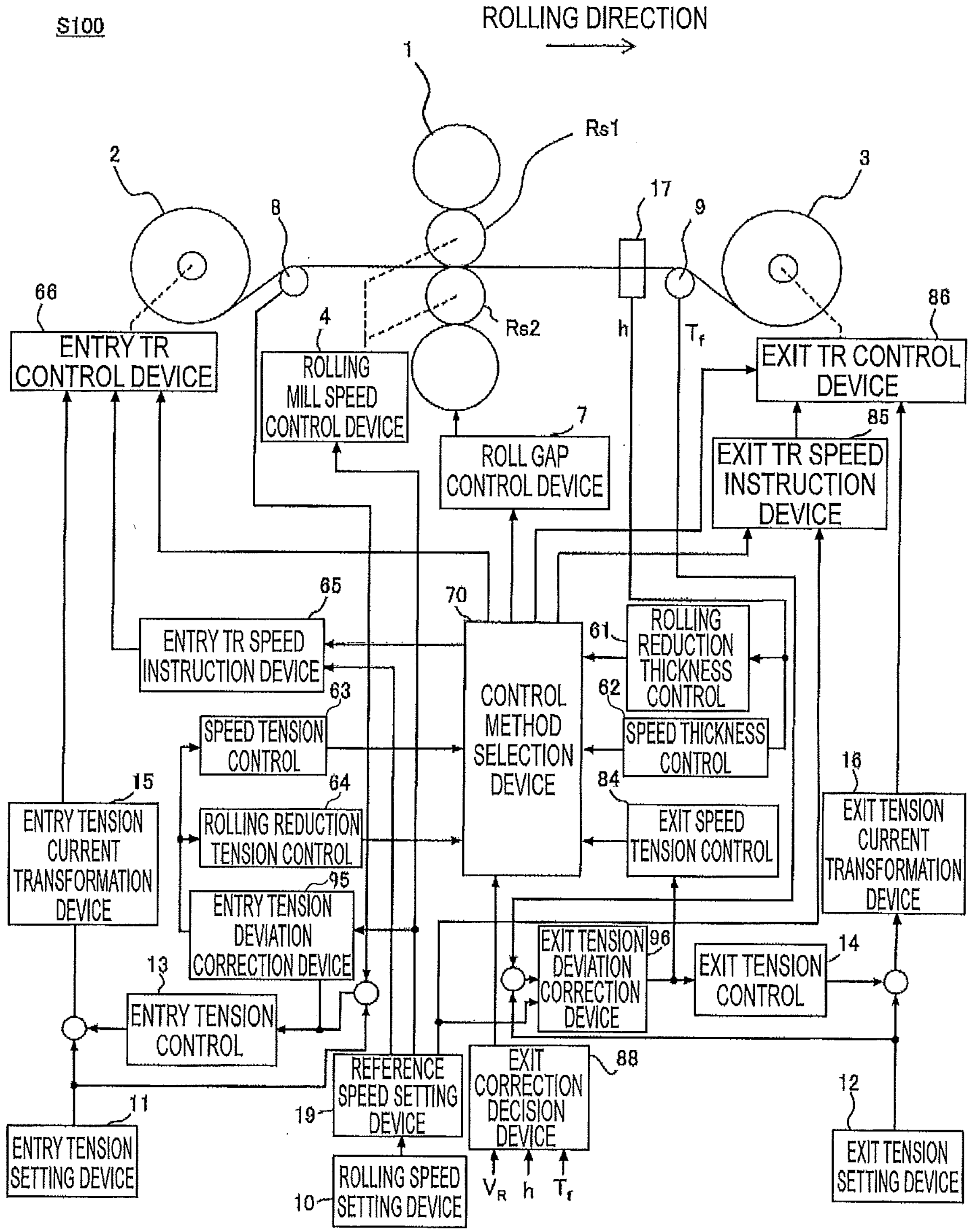
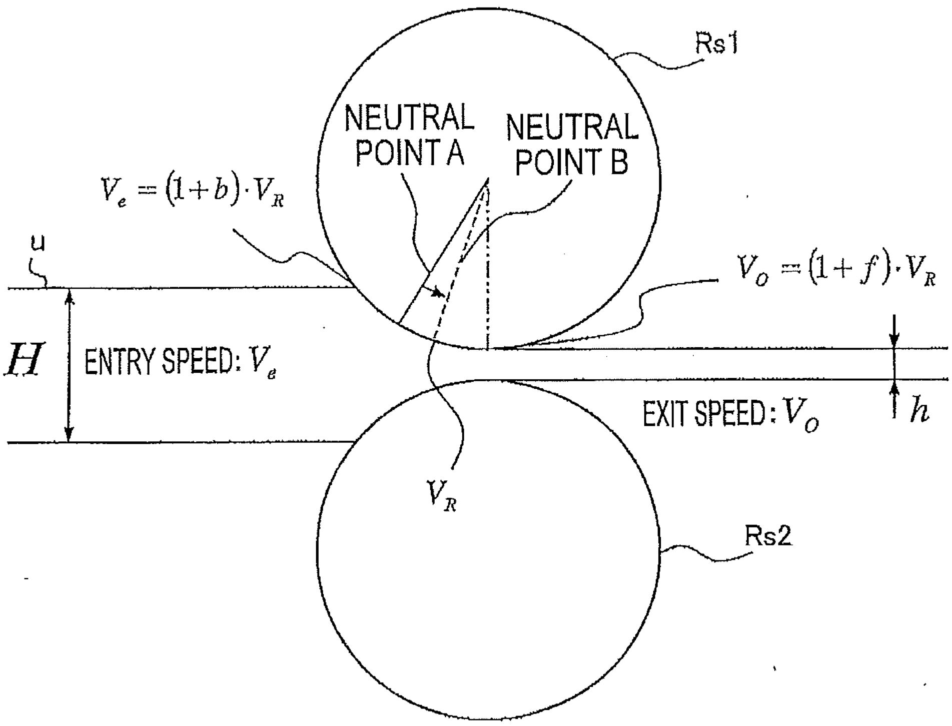

S100
ROLLING DIRECTION
1
2
3
8
9
17
Rs1
Rs2
h
T_f
66
ENTRY TR CONTROL DEVICE
4
ROLLING MILL SPEED CONTROL DEVICE
7
ROLL GAP CONTROL DEVICE
86
EXIT TR CONTROL DEVICE
85
EXIT TR SPEED INSTRUCTION DEVICE
65
ENTRY TR SPEED INSTRUCTION DEVICE
70
CONTROL METHOD SELECTION DEVICE
61
ROLLING REDUCTION THICKNESS CONTROL
62
SPEED THICKNESS CONTROL
63
SPEED TENSION CONTROL
64
ROLLING REDUCTION TENSION CONTROL
84
EXIT SPEED TENSION CONTROL
15
ENTRY TENSION CURRENT TRANSFORMATION DEVICE
16
EXIT TENSION CURRENT TRANSFORMATION DEVICE
95
ENTRY TENSION DEVIATION CORRECTION DEVICE
96
EXIT TENSION DEVIATION CORRECTION DEVICE
13
ENTRY TENSION CONTROL
14
EXIT TENSION CONTROL
19
REFERENCE SPEED SETTING DEVICE
88
EXIT CORRECTION DECISION DEVICE
V_R h T_f
11
ENTRY TENSION SETTING DEVICE
10
ROLLING SPEED SETTING DEVICE
12
EXIT TENSION SETTING DEVICE

FIG. 2

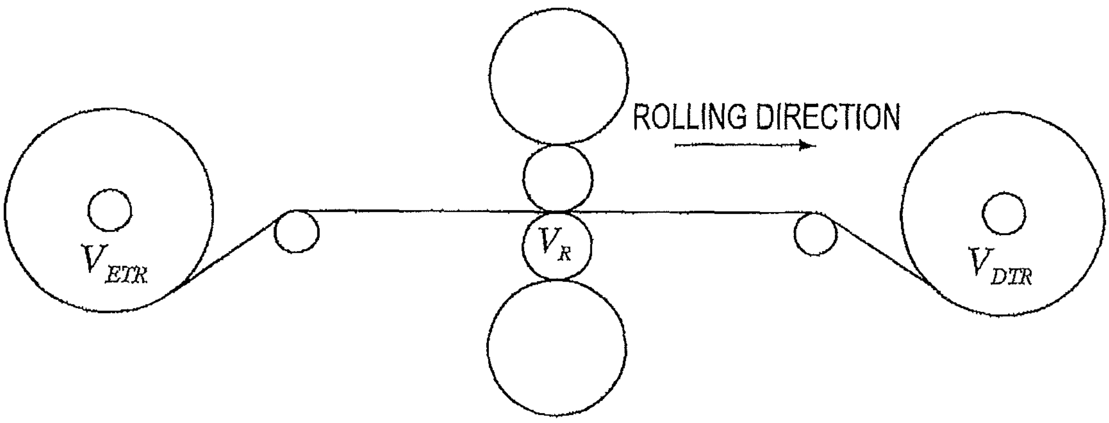


MASS FLOW CONSTANT LAW: $H \cdot V_e = h \cdot V_O$

ENTRY TENSION EQUATION: $T_b = \frac{EbH}{L}\frac{1}{S}(V_e - V_{ETR})$

EXIT TENSION EQUATION: $T_f = \frac{Ebh}{L}\frac{1}{S}(V_{DTR} - V_O)$

FIG. 3



ROLLING PHENOMENON FLUCTUATION
(NEUTRAL POINT FLUCTUATION)

FLUCTUATION OF FORWARD MOVEMENT RATIO, BACKWARD MOVEMENT RATIO TO ESTABLISH $H \cdot \Delta b = h \Delta f$

SPEED UNIFORMITY FLUCTUATION BETWEEN ROLLING MILL AND ENTRY TR,EXIT TR

$$V_{ETR} = V_R \cdot (1+b) + \Delta V_{ETR}$$

$$V_{DTR} = V_R \cdot (1+f) + \Delta V_{DTR}$$

DEVIATION OF ENTRY TR,EXIT TR FROM EXIT SPEED, ENTRY SPEED CAUSED BY ROLLING-MILL SPEED AND ROLLING-MILL PHENOMENON

FIG. 4

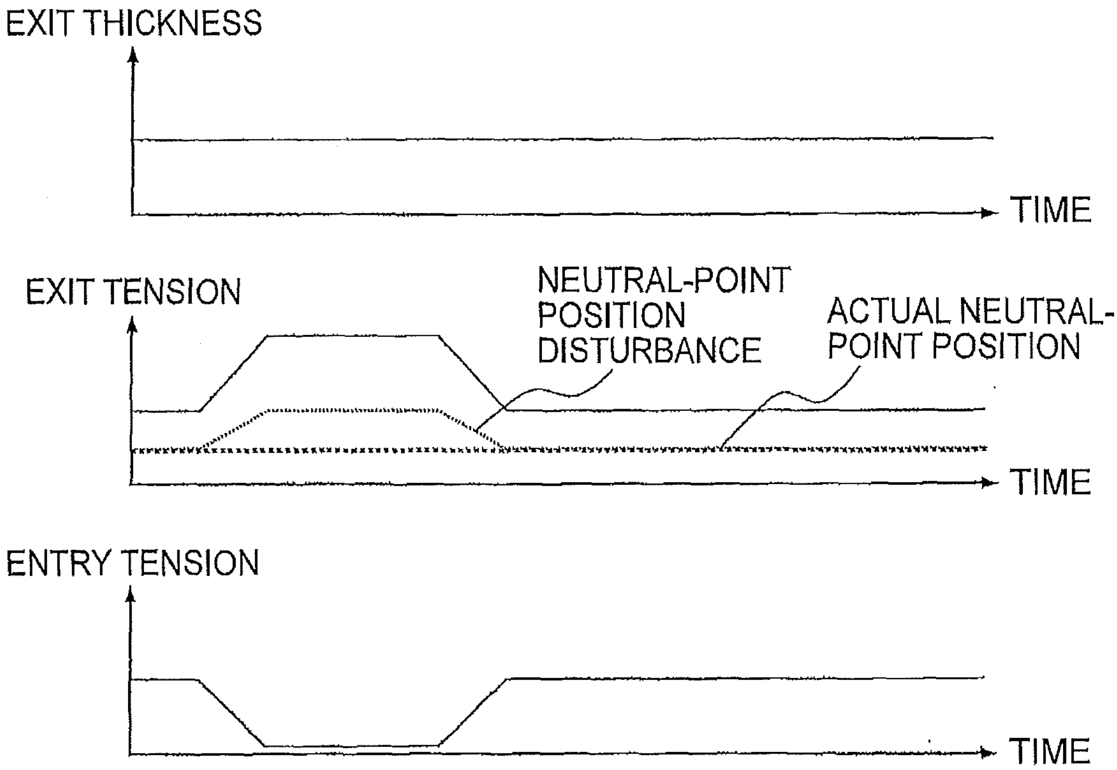

EXIT THICKNESS
TIME
EXIT TENSION
NEUTRAL-POINT POSITION DISTURBANCE
ACTUAL NEUTRAL-POINT POSITION
TIME
ENTRY TENSION
TIME

FIG. 5

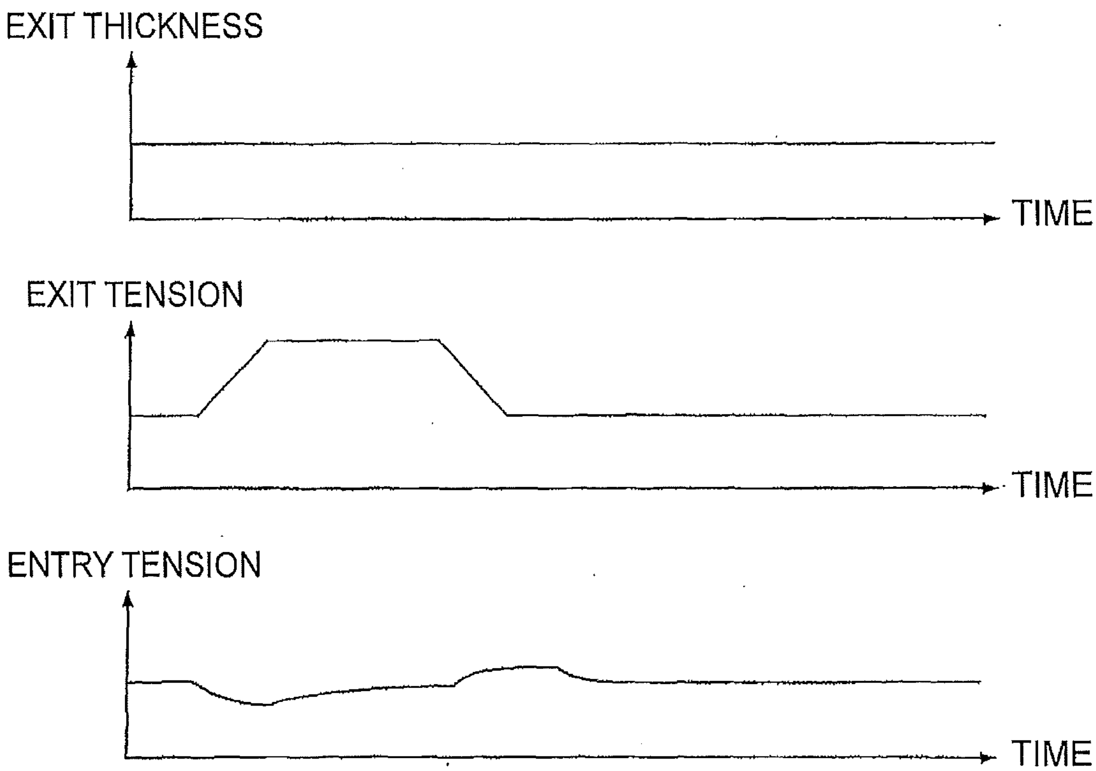

EXIT THICKNESS
TIME
EXIT TENSION
TIME
ENTRY TENSION
TIME

FIG. 6

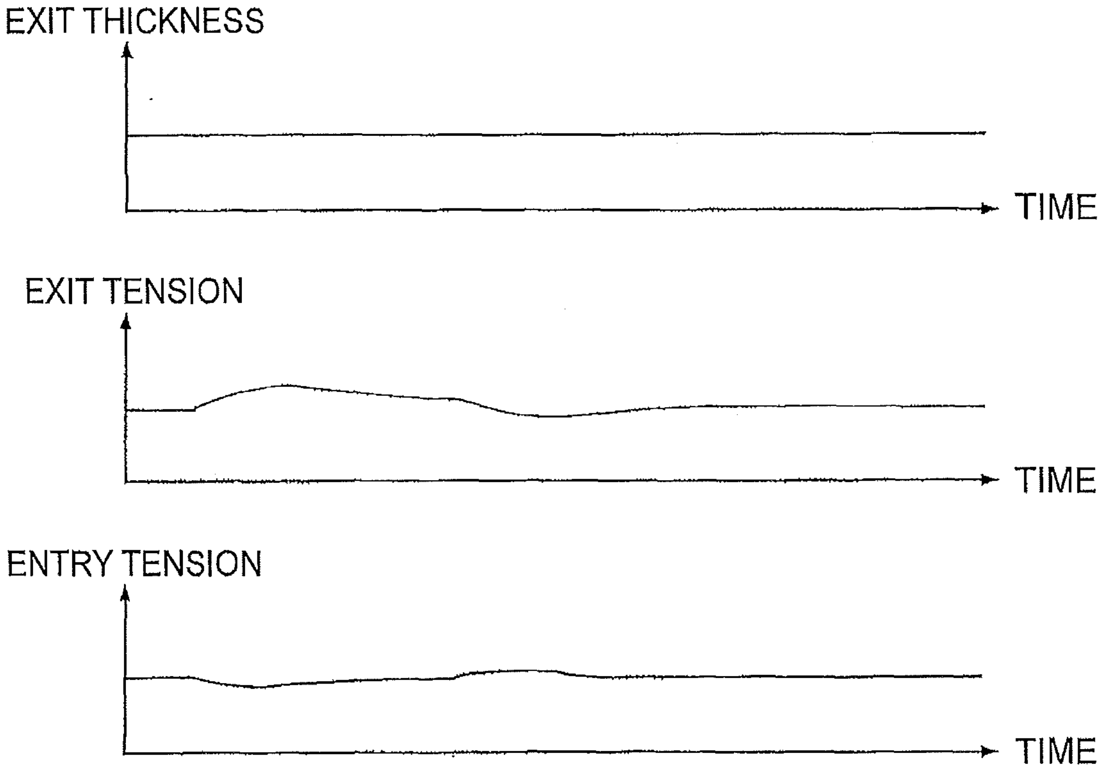

EXIT THICKNESS
TIME
EXIT TENSION
TIME
ENTRY TENSION
TIME

FIG. 7

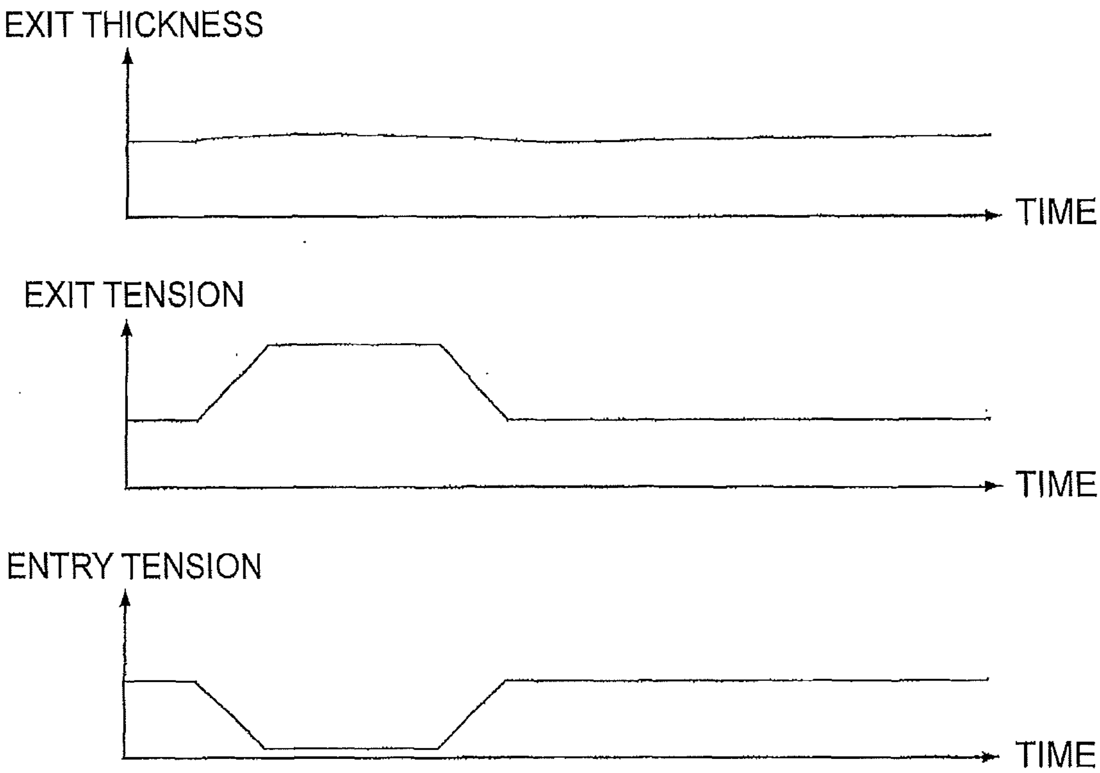

EXIT THICKNESS
TIME
EXIT TENSION
TIME
ENTRY TENSION
TIME

FIG. 8

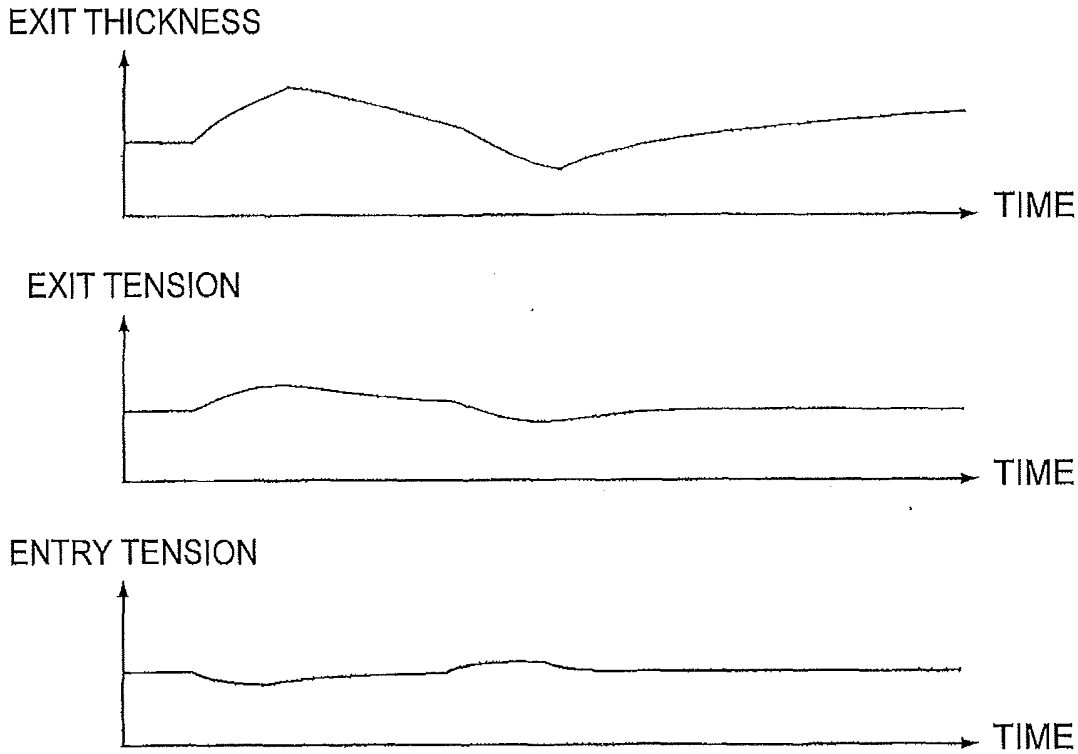

EXIT THICKNESS
TIME
EXIT TENSION
TIME
ENTRY TENSION
TIME

FIG. 9

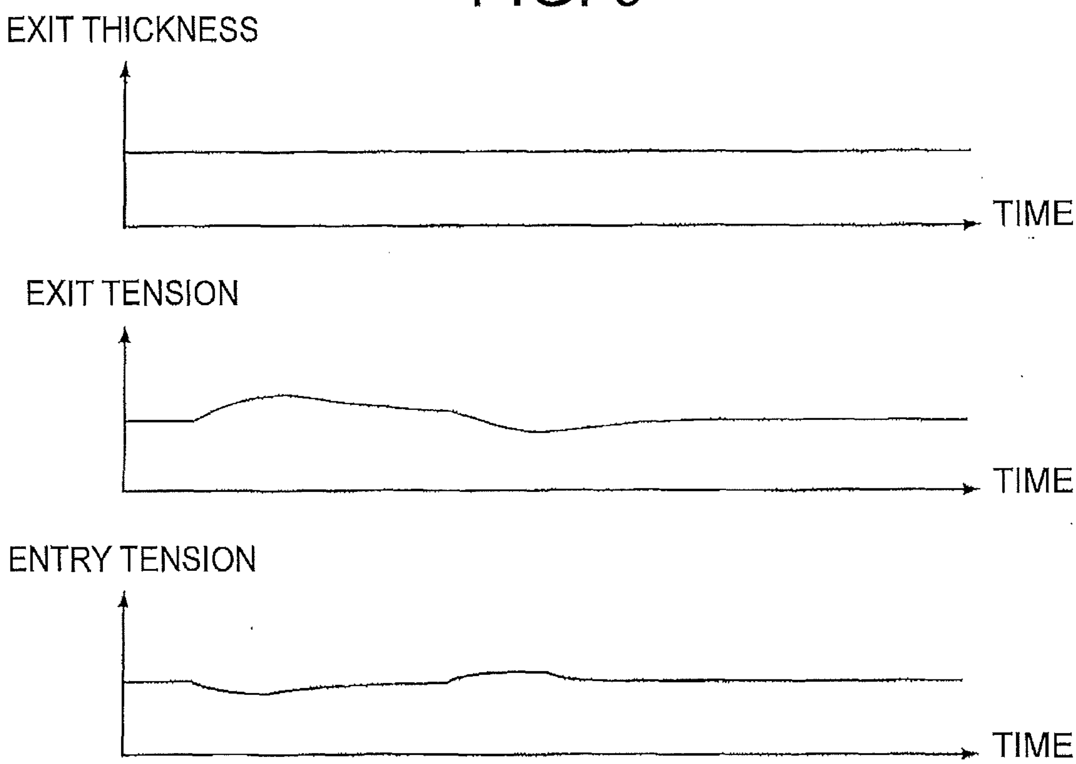

EXIT THICKNESS
TIME
EXIT TENSION
TIME
ENTRY TENSION
TIME

FIG. 10

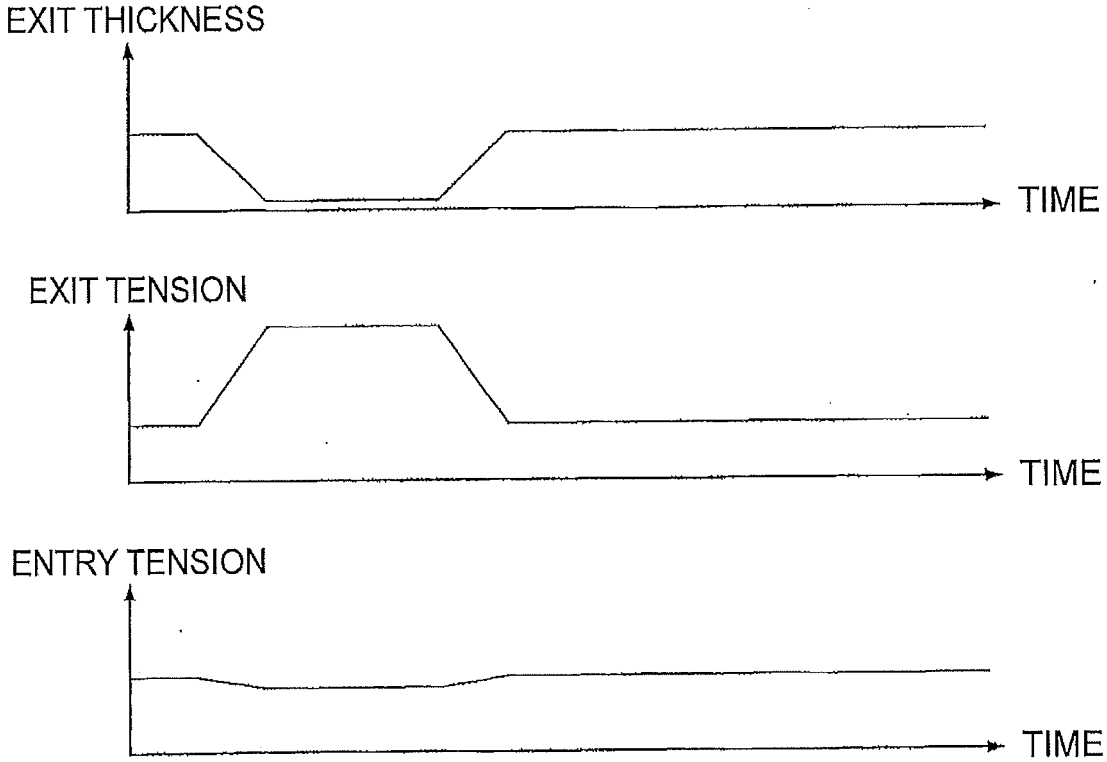

EXIT THICKNESS
TIME
EXIT TENSION
TIME
ENTRY TENSION
TIME

FIG. 11

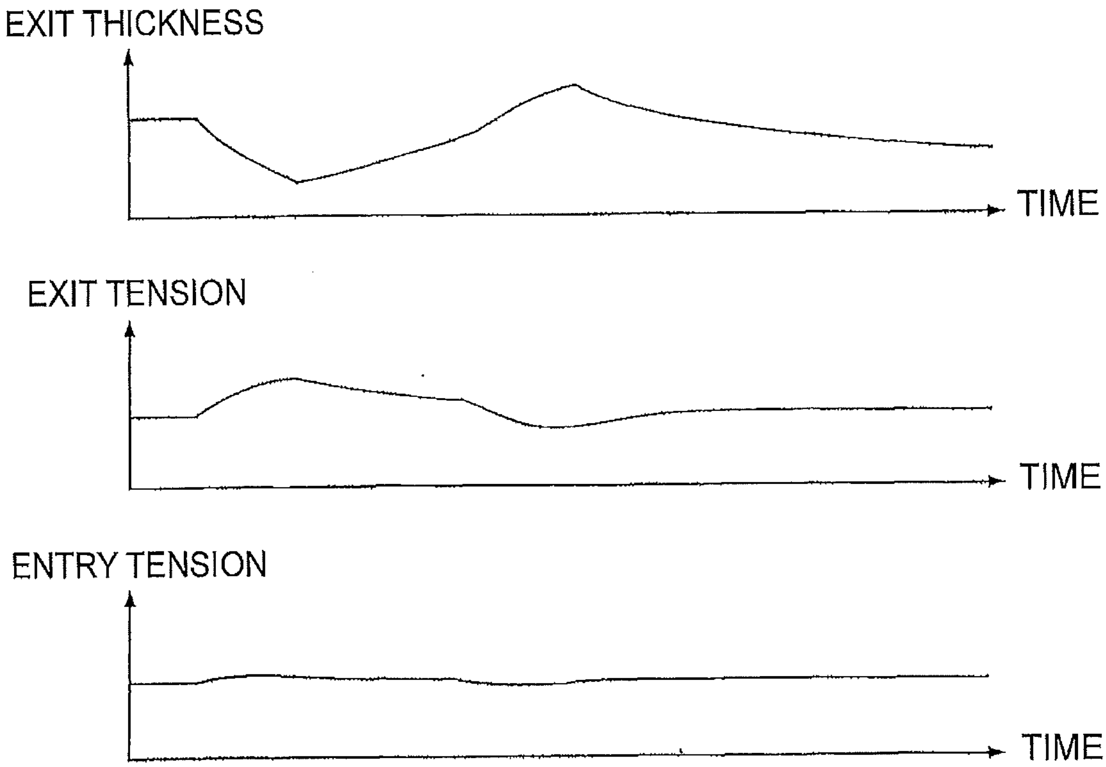

EXIT THICKNESS
TIME
EXIT TENSION
TIME
ENTRY TENSION
TIME

FIG. 12

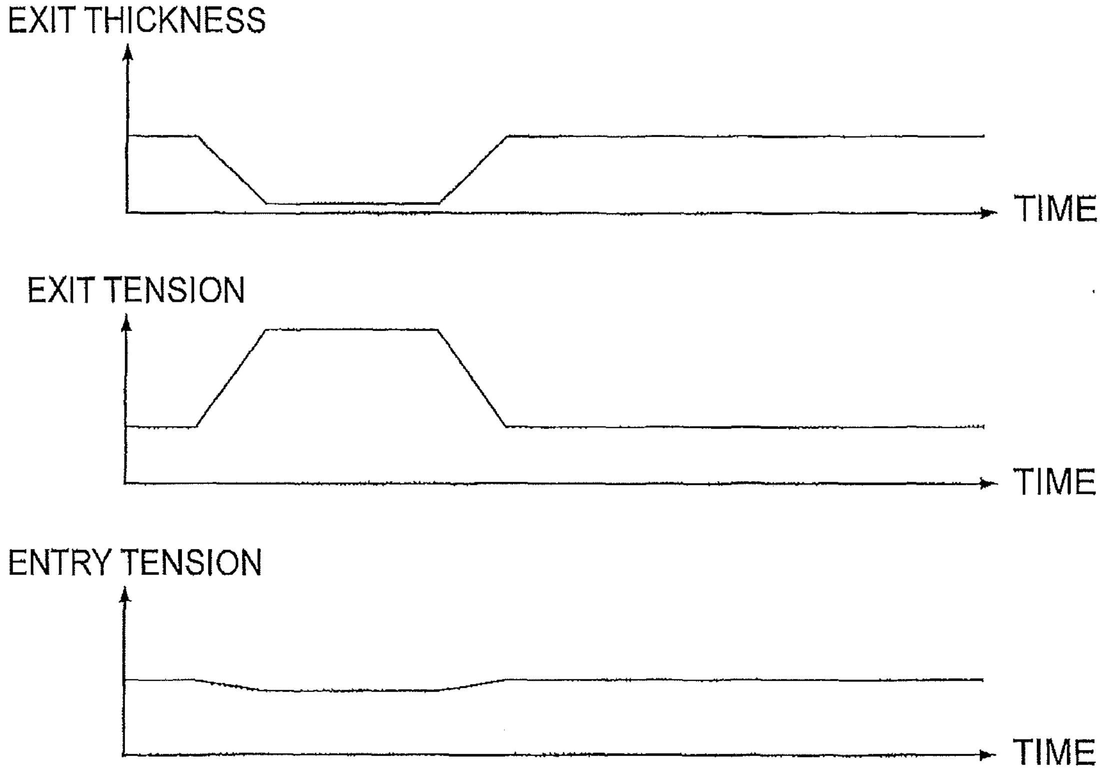

EXIT THICKNESS
TIME
EXIT TENSION
TIME
ENTRY TENSION
TIME

FIG. 13

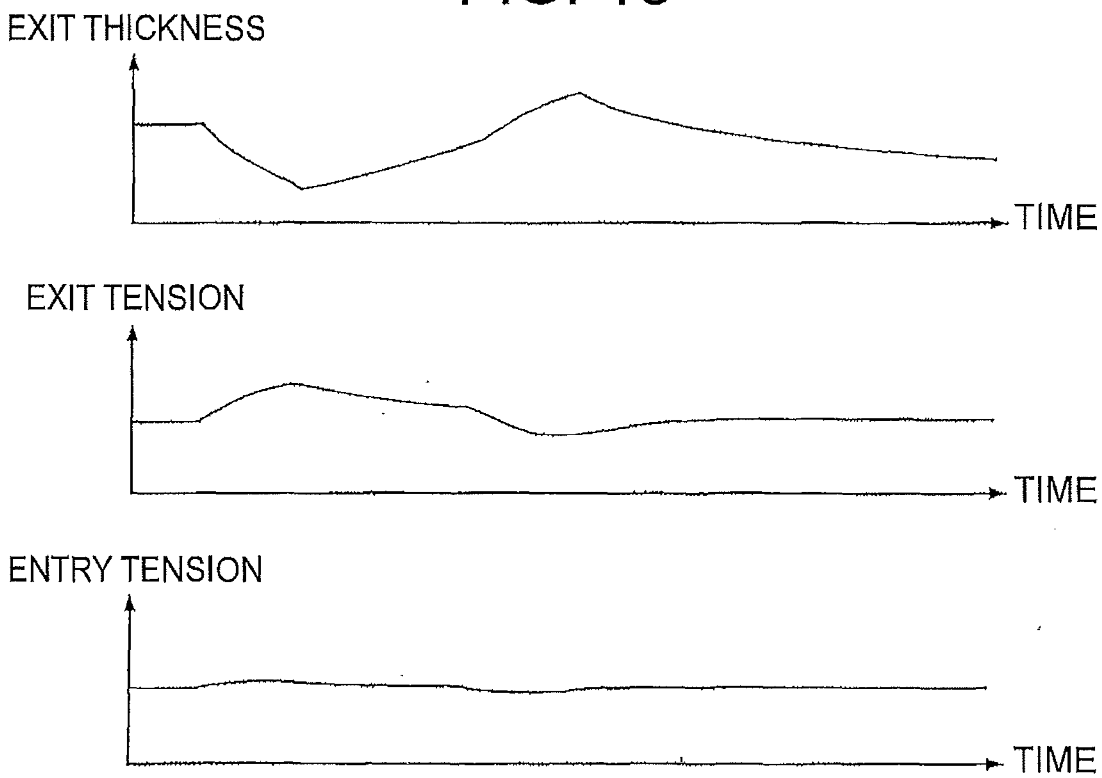

EXIT THICKNESS
TIME
EXIT TENSION
TIME
ENTRY TENSION
TIME

FIG. 14

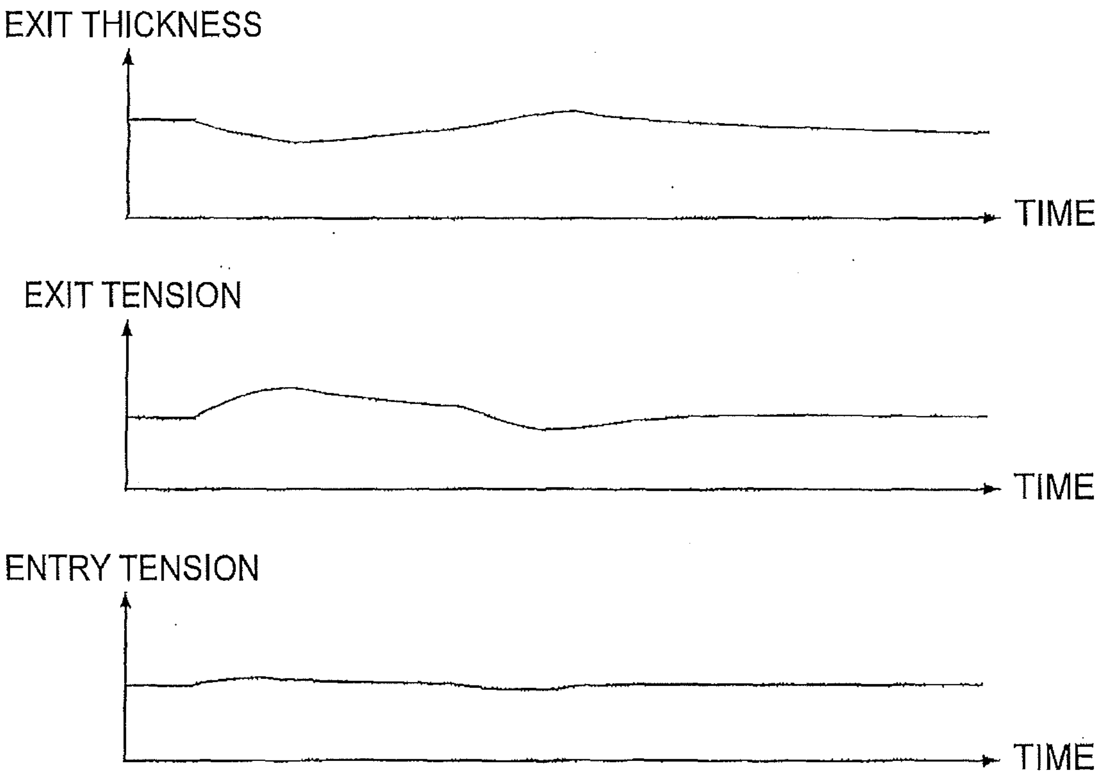
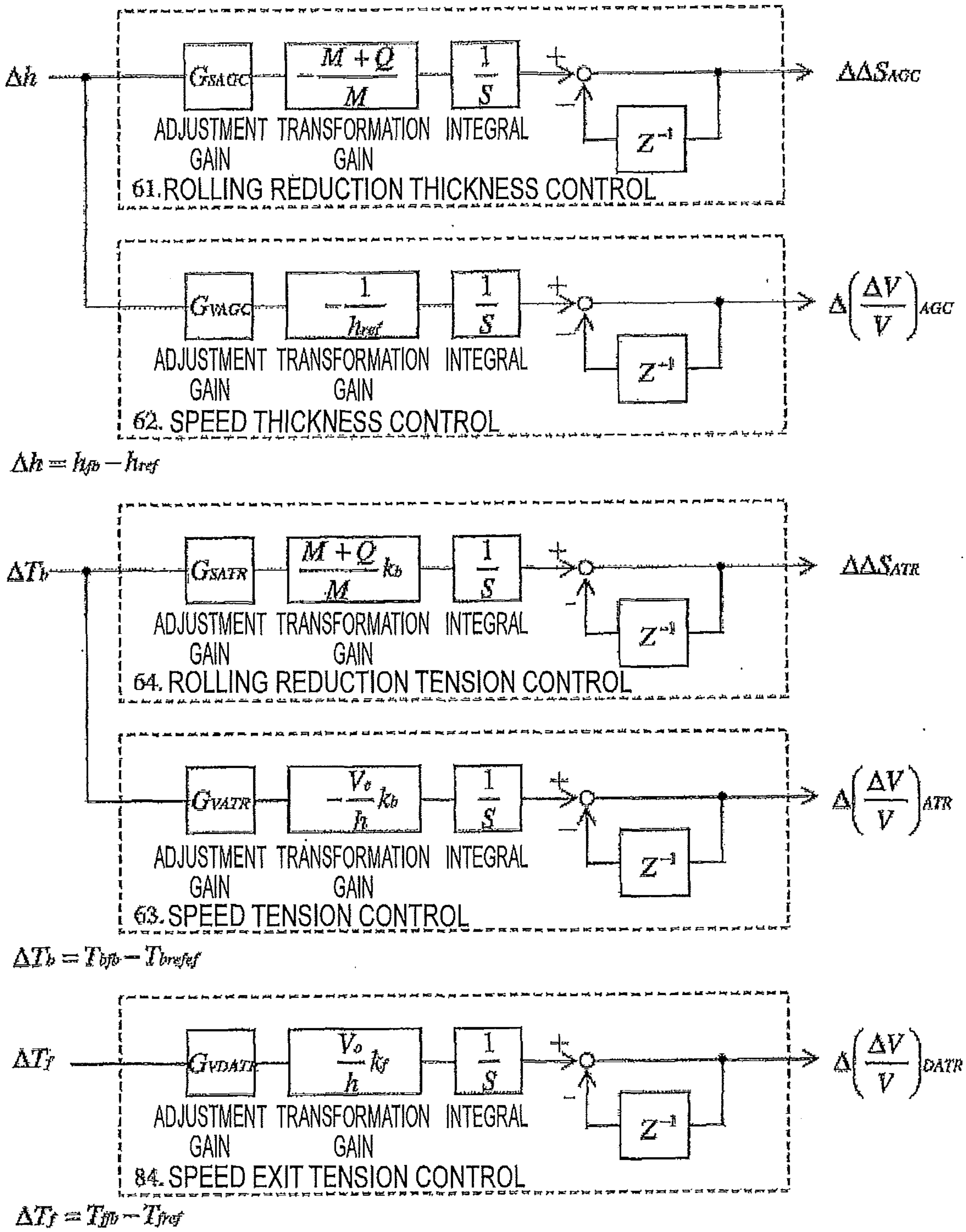


FIG. 15



Δh
GSAGC
−(M+Q)/M
1/S
+
−
Z⁻¹
ΔΔS_AGC
ADJUSTMENT GAIN
TRANSFORMATION GAIN
INTEGRAL
61. ROLLING REDUCTION THICKNESS CONTROL
GVAGC
−1/h_ref
Δ(ΔV/V)_AGC
62. SPEED THICKNESS CONTROL
Δh = h_fb − h_ref
ΔTb
GSATR
(M+Q)/M kb
ΔΔS_ATR
64. ROLLING REDUCTION TENSION CONTROL
GVATR
−(Vo/h) kb
Δ(ΔV/V)_ATR
63. SPEED TENSION CONTROL
ΔTb = Tbfb − Tbref
ΔTf
GVDATR
(Vo/h) kf
Δ(ΔV/V)_DATR
84. SPEED EXIT TENSION CONTROL
ΔTf = Tffb − Tfref

FIG. 16

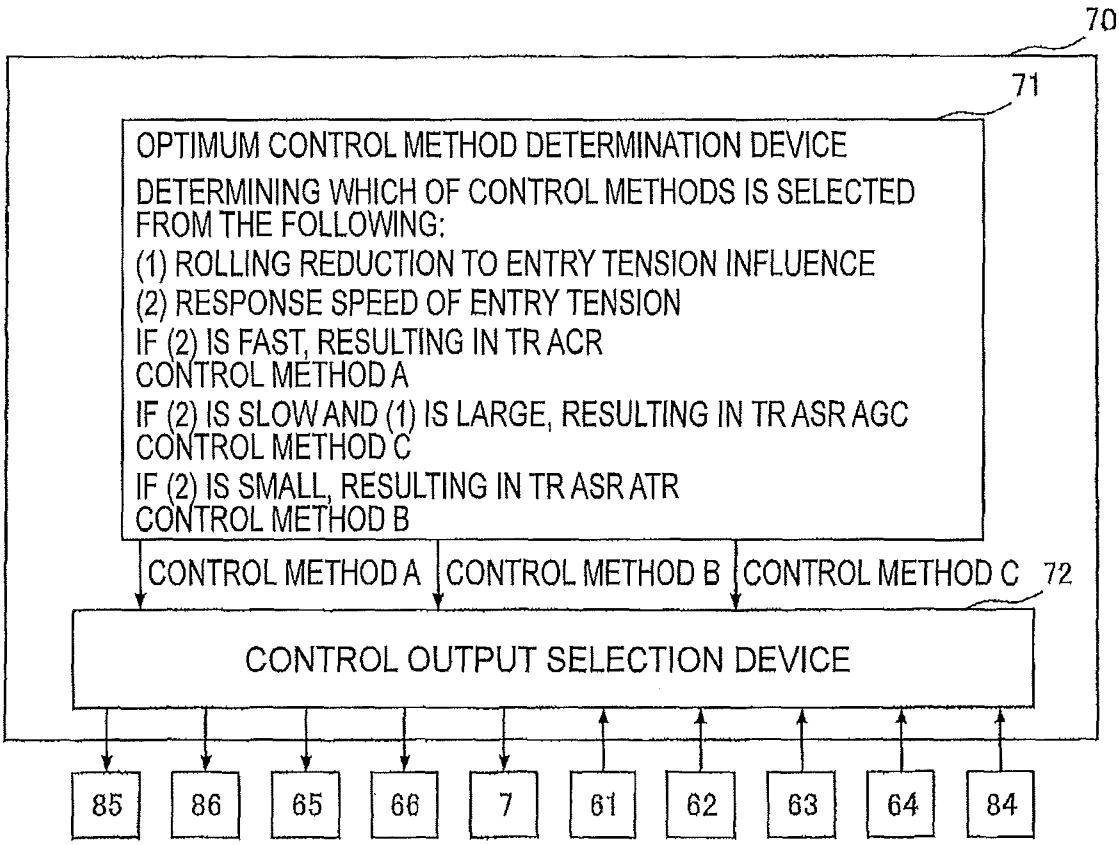

70
71
OPTIMUM CONTROL METHOD DETERMINATION DEVICE
DETERMINING WHICH OF CONTROL METHODS IS SELECTED FROM THE FOLLOWING:
(1) ROLLING REDUCTION TO ENTRY TENSION INFLUENCE
(2) RESPONSE SPEED OF ENTRY TENSION
IF (2) IS FAST, RESULTING IN TR ACR
CONTROL METHOD A
IF (2) IS SLOW AND (1) IS LARGE, RESULTING IN TR ASR AGC
CONTROL METHOD C
IF (2) IS SMALL, RESULTING IN TR ASR ATR
CONTROL METHOD B
CONTROL METHOD A
CONTROL METHOD B
CONTROL METHOD C
72
CONTROL OUTPUT SELECTION DEVICE
85
86
65
66
7
61
62
63
64
84

FIG. 17

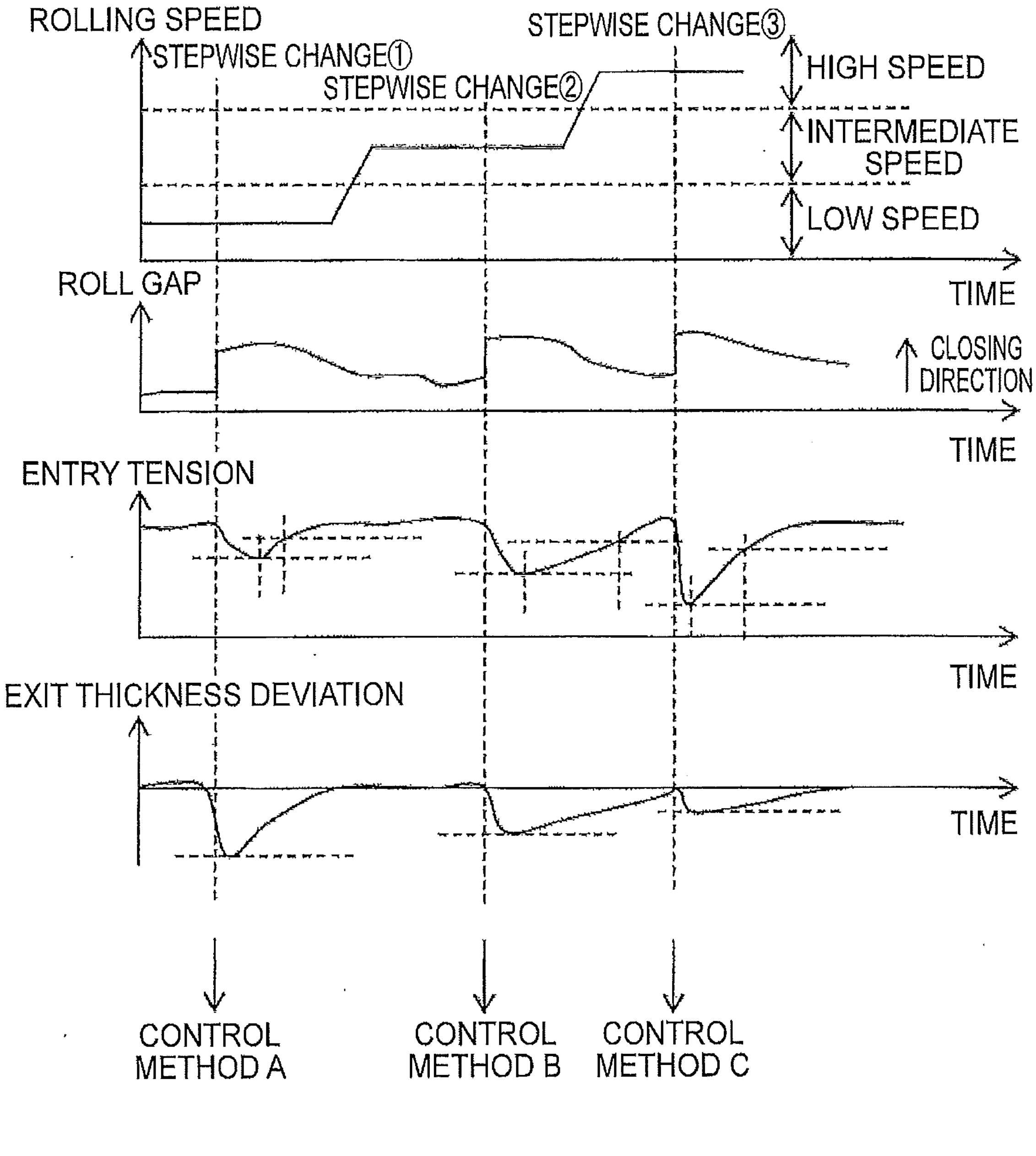

ROLLING SPEED
STEPWISE CHANGE①
STEPWISE CHANGE②
STEPWISE CHANGE③
HIGH SPEED
INTERMEDIATE SPEED
LOW SPEED
TIME
ROLL GAP
CLOSING DIRECTION
TIME
ENTRY TENSION
TIME
EXIT THICKNESS DEVIATION
TIME
CONTROL METHOD A
CONTROL METHOD B
CONTROL METHOD C

FIG. 18

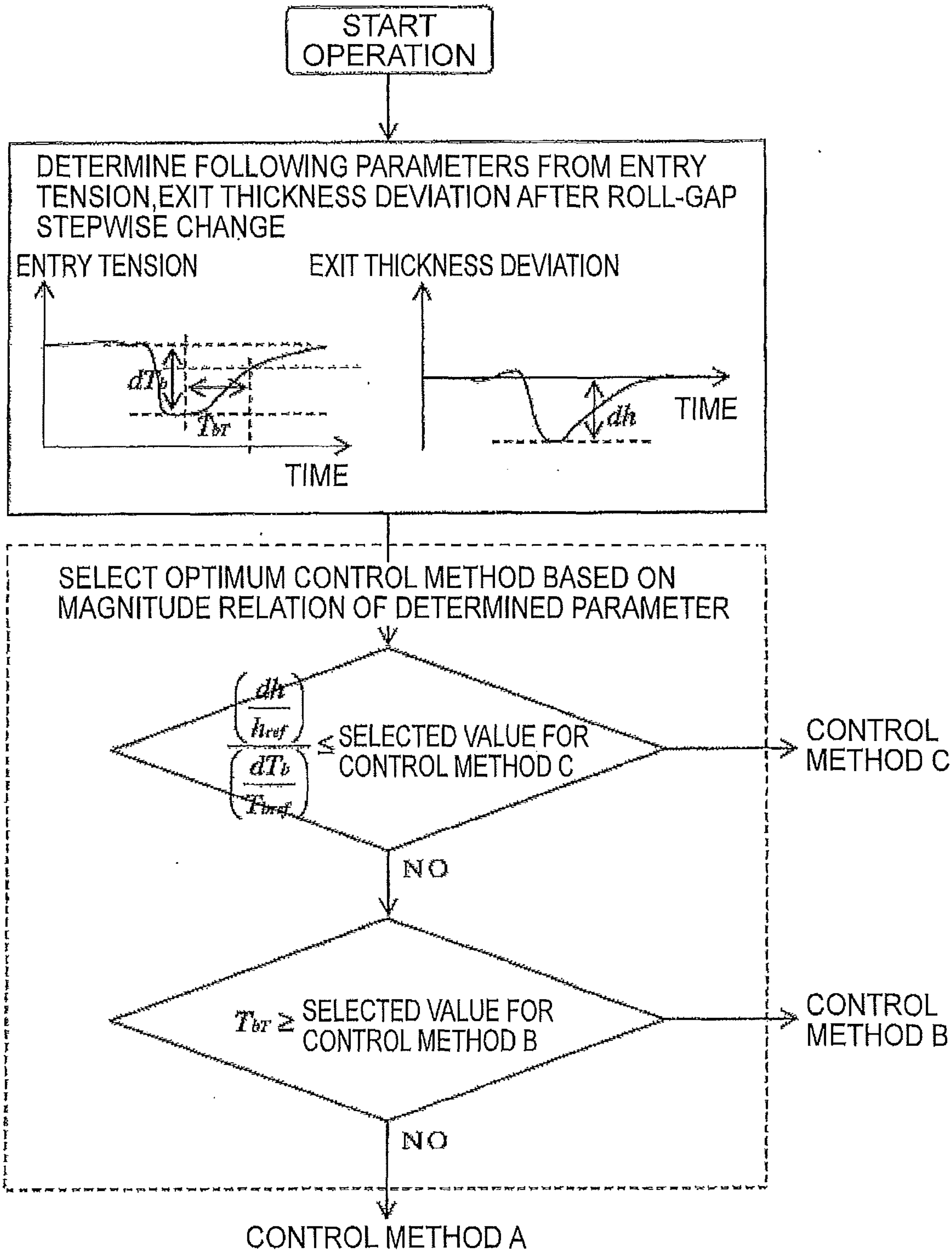

START OPERATION
DETERMINE FOLLOWING PARAMETERS FROM ENTRY TENSION,EXIT THICKNESS DEVIATION AFTER ROLL-GAP STEPWISE CHANGE
ENTRY TENSION
dTb
TbT
TIME
EXIT THICKNESS DEVIATION
dh
TIME
SELECT OPTIMUM CONTROL METHOD BASED ON MAGNITUDE RELATION OF DETERMINED PARAMETER
$\frac{\left(\frac{dh}{h_{ref}}\right)}{\left(\frac{dT_b}{T_{bref}}\right)} \leq$ SELECTED VALUE FOR CONTROL METHOD C
CONTROL METHOD C
NO
$T_{bT} \geq$ SELECTED VALUE FOR CONTROL METHOD B
CONTROL METHOD B
NO
CONTROL METHOD A

FIG. 19

TYPE OF STEEL	EXIT THICKNESS	SPEED ZONE	OPTIMUM CONTROL METHOD
TYPE OF STEEL A	0.5 mm	LOW SPEED	CONTROL METHOD A
		INTERMEDIATE SPEED	CONTROL METHOD B CONTROL METHOD B'
		HIGH PEED	CONTROL METHOD C CONTROL METHOD C'

SEARCH KEYS

FIG. 20

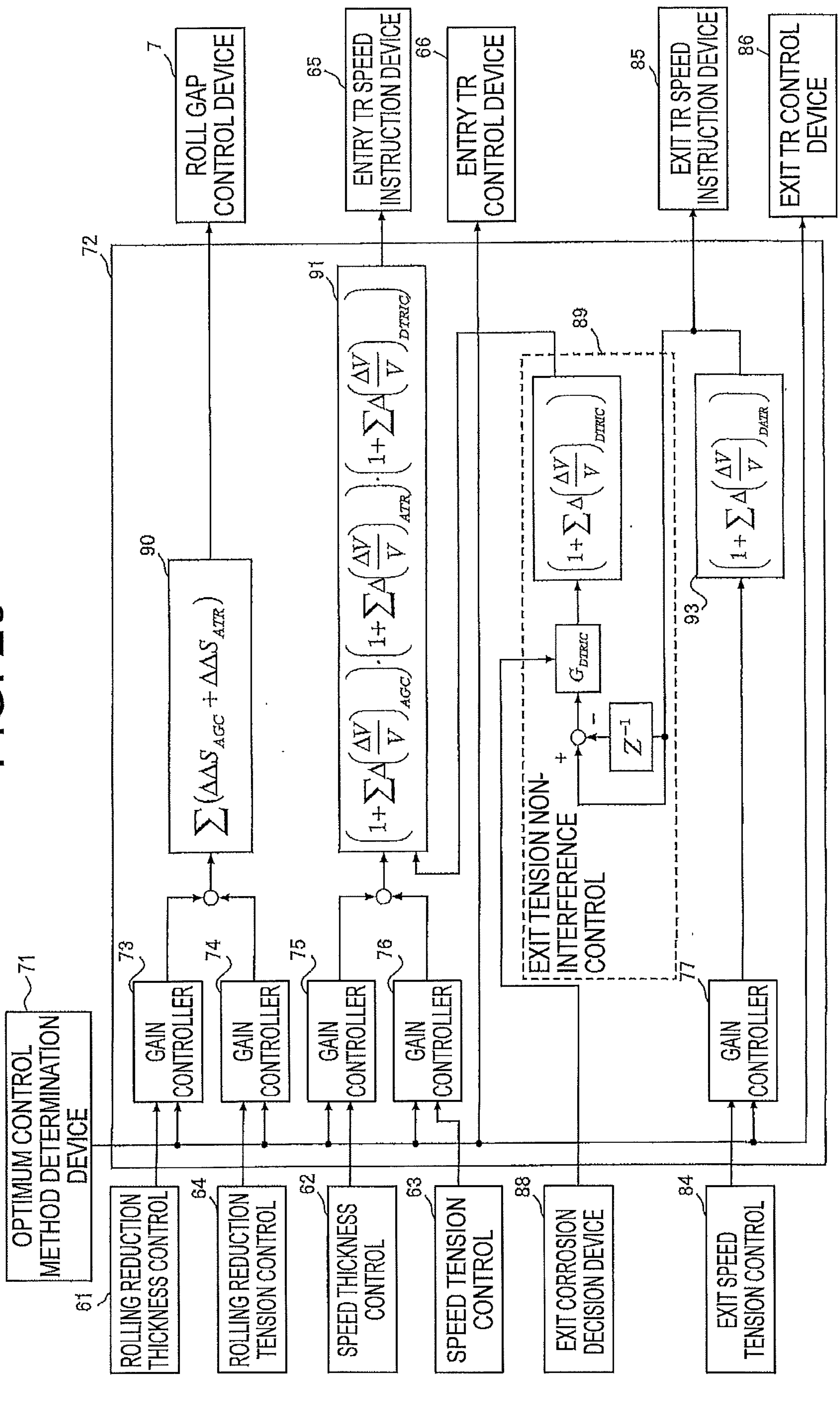

OPTIMUM CONTROL METHOD DETERMINATION DEVICE
71
ROLLING REDUCTION THICKNESS CONTROL
61
ROLLING REDUCTION TENSION CONTROL
64
SPEED THICKNESS CONTROL
62
SPEED TENSION CONTROL
63
EXIT CORROSION DECISION DEVICE
88
EXIT SPEED TENSION CONTROL
84
GAIN CONTROLLER
73
74
75
76
77
72
EXIT TENSION NON-INTERFERENCE CONTROL
89
90
91
93
ROLL GAP CONTROL DEVICE
7
ENTRY TR SPEED INSTRUCTION DEVICE
65
ENTRY TR CONTROL DEVICE
66
EXIT TR SPEED INSTRUCTION DEVICE
85
EXIT TR CONTROL DEVICE
86

FIG. 21

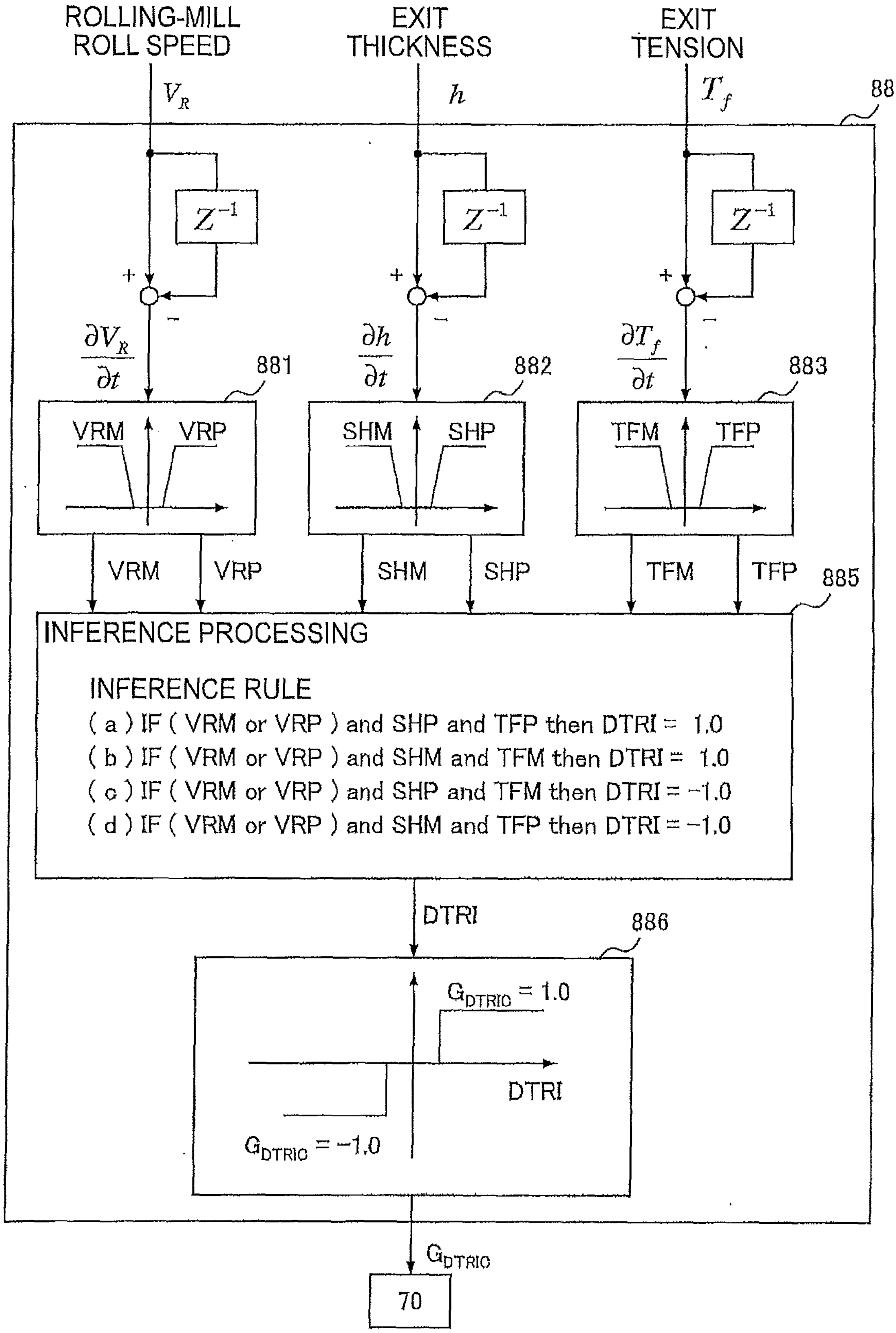

ROLLING-MILL ROLL SPEED
EXIT THICKNESS
EXIT TENSION
V_R
h
T_f
88
Z^{-1}
Z^{-1}
Z^{-1}
+
−
$\frac{\partial V_R}{\partial t}$
$\frac{\partial h}{\partial t}$
$\frac{\partial T_f}{\partial t}$
881
882
883
VRM
VRP
SHM
SHP
TFM
TFP
885
INFERENCE PROCESSING
INFERENCE RULE
(a) IF (VRM or VRP) and SHP and TFP then DTRI = 1.0
(b) IF (VRM or VRP) and SHM and TFM then DTRI = 1.0
(c) IF (VRM or VRP) and SHP and TFM then DTRI = −1.0
(d) IF (VRM or VRP) and SHM and TFP then DTRI = −1.0
DTRI
886
G_{DTRIC} = 1.0
DTRI
G_{DTRIC} = −1.0
G_{DTRIC}
70

FIG. 22

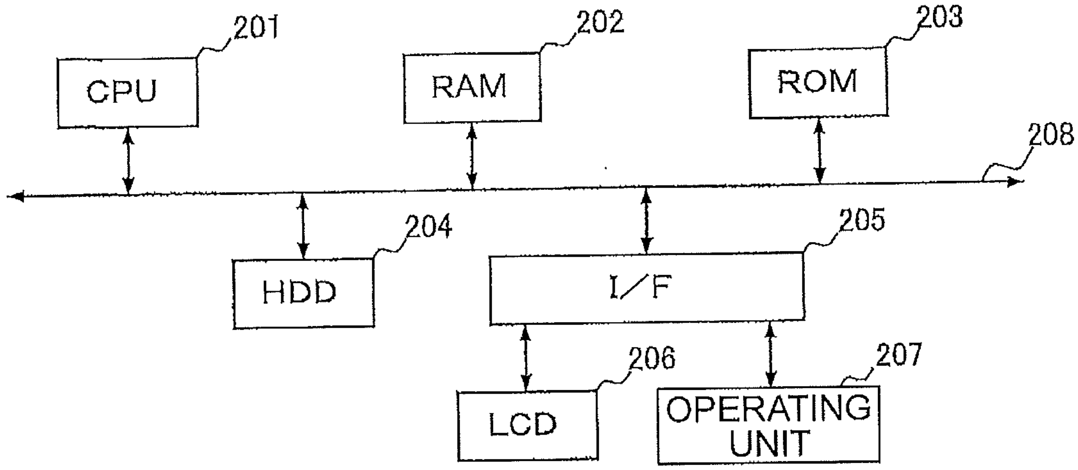

201
CPU
202
RAM
203
ROM
208
204
HDD
205
I/F
206
LCD
207
OPERATING UNIT

FIG. 23

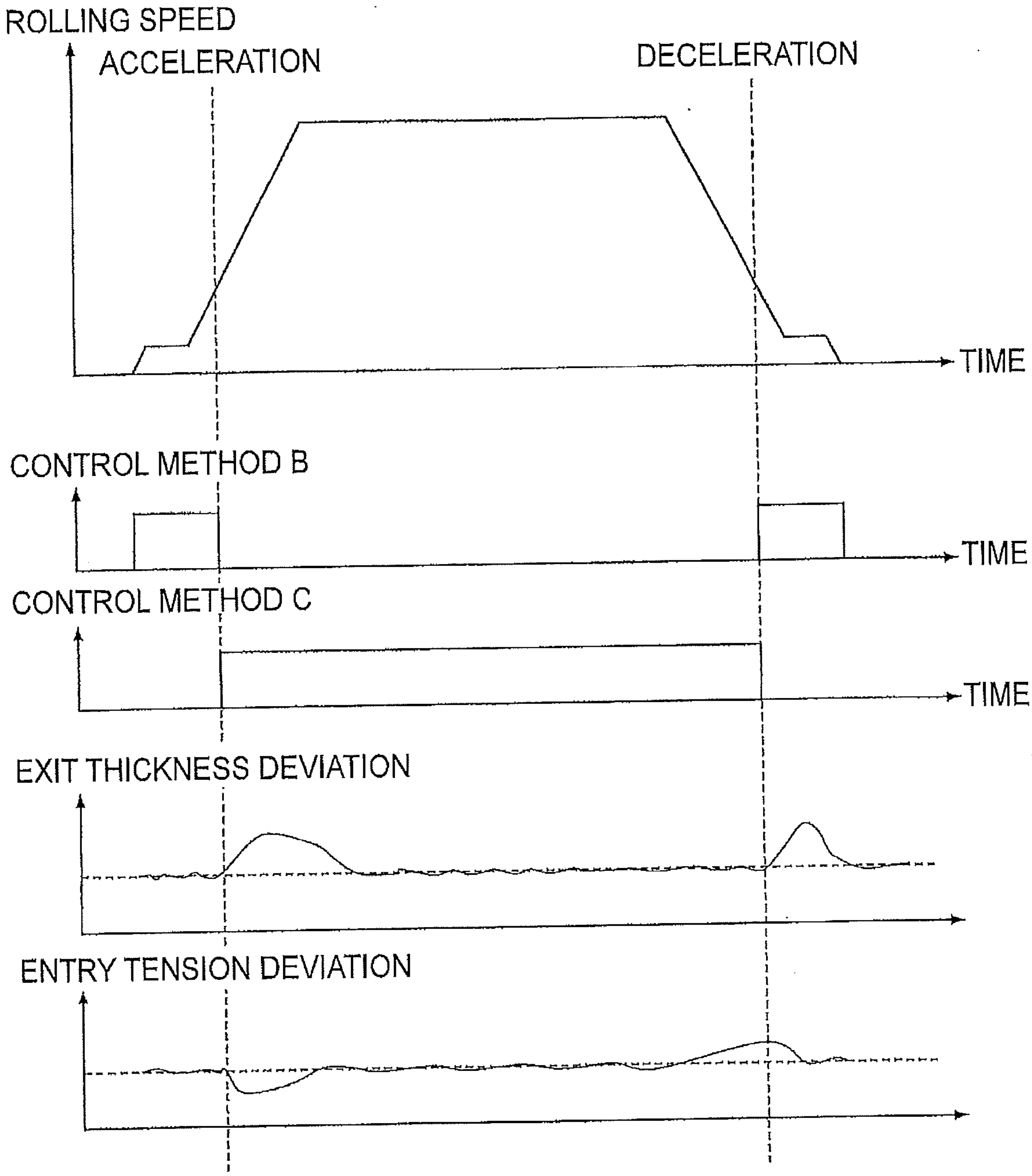

ROLLING SPEED
ACCELERATION
DECELERATION
TIME
CONTROL METHOD B
TIME
CONTROL METHOD C
TIME
EXIT THICKNESS DEVIATION
ENTRY TENSION DEVIATION

FIG. 24

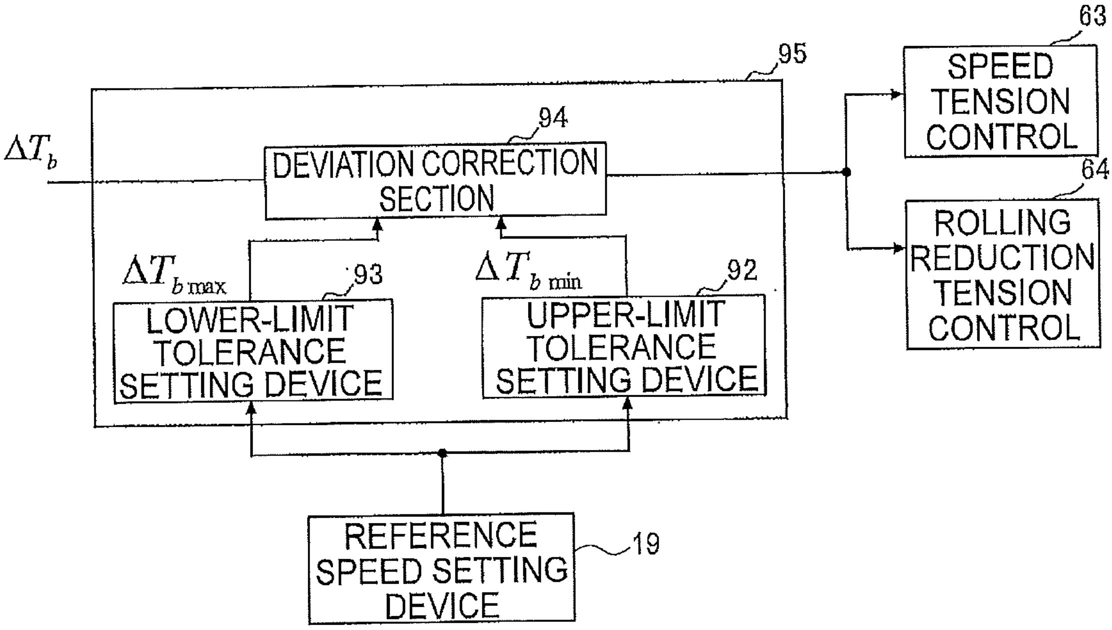

ΔT_b
95
94
DEVIATION CORRECTION SECTION
$\Delta T_{b\,max}$
93
LOWER-LIMIT TOLERANCE SETTING DEVICE
$\Delta T_{b\,min}$
92
UPPER-LIMIT TOLERANCE SETTING DEVICE
63
SPEED TENSION CONTROL
64
ROLLING REDUCTION TENSION CONTROL
REFERENCE SPEED SETTING DEVICE
19

FIG. 25

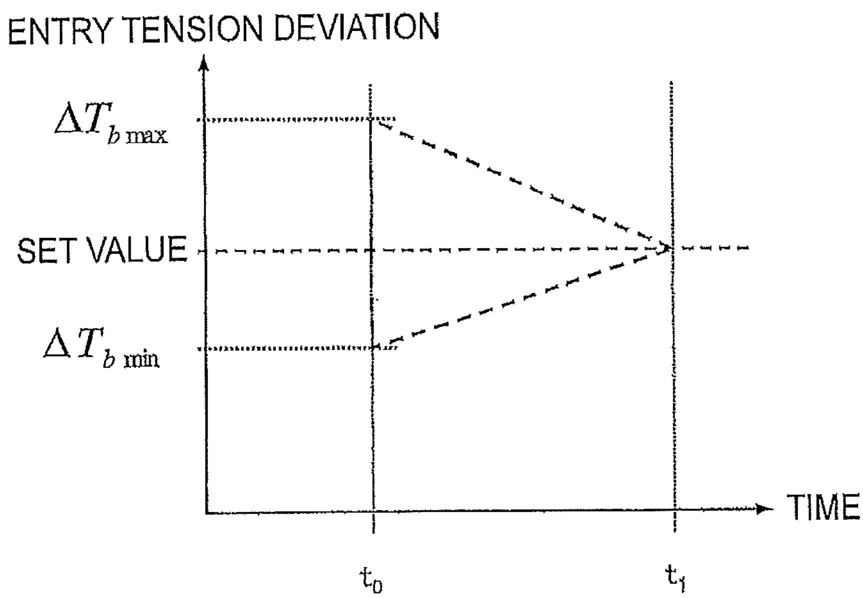

ENTRY TENSION DEVIATION
$\Delta T_{b\,max}$
SET VALUE
$\Delta T_{b\,min}$
TIME
t_0
t_1

FIG. 26

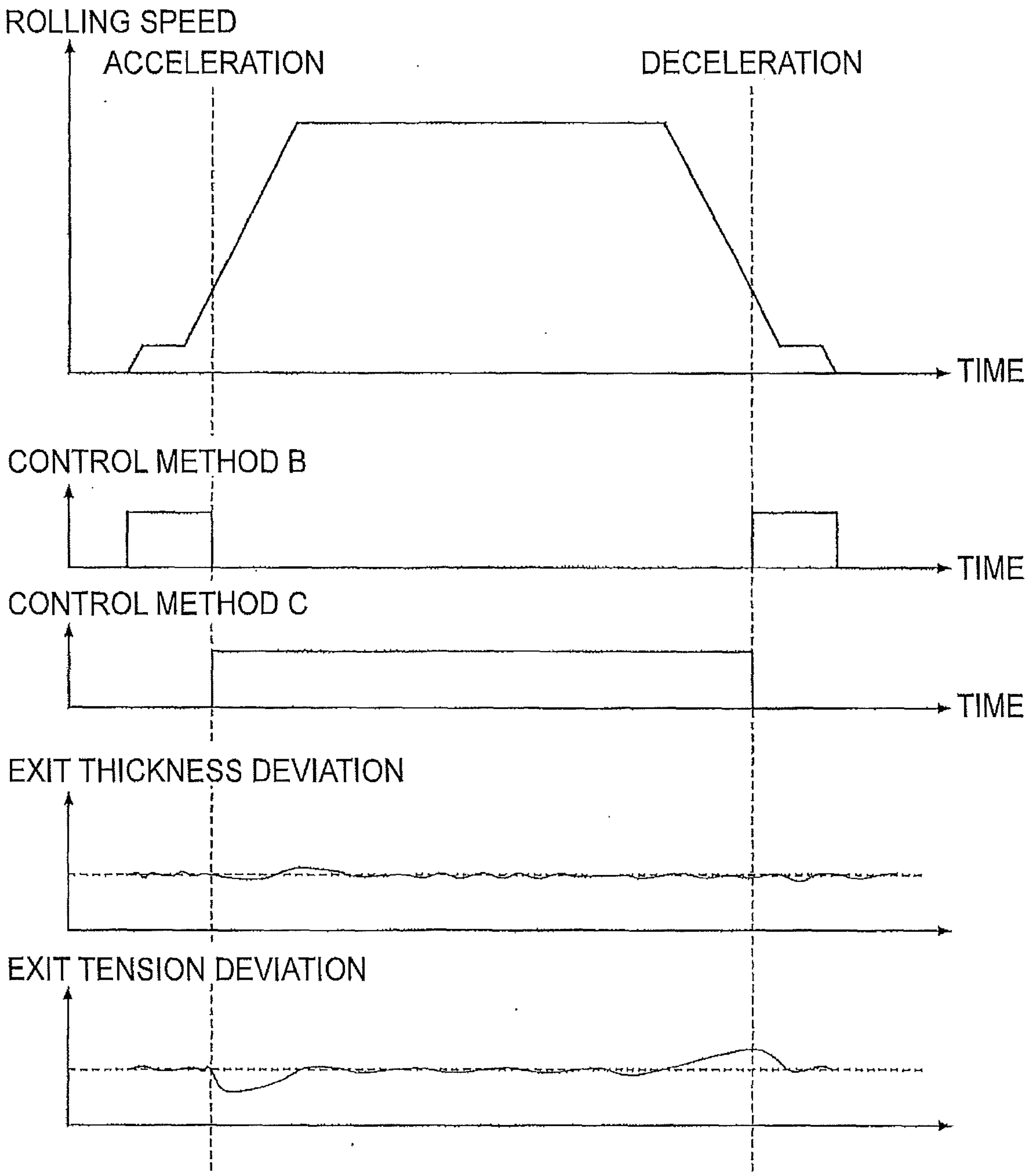
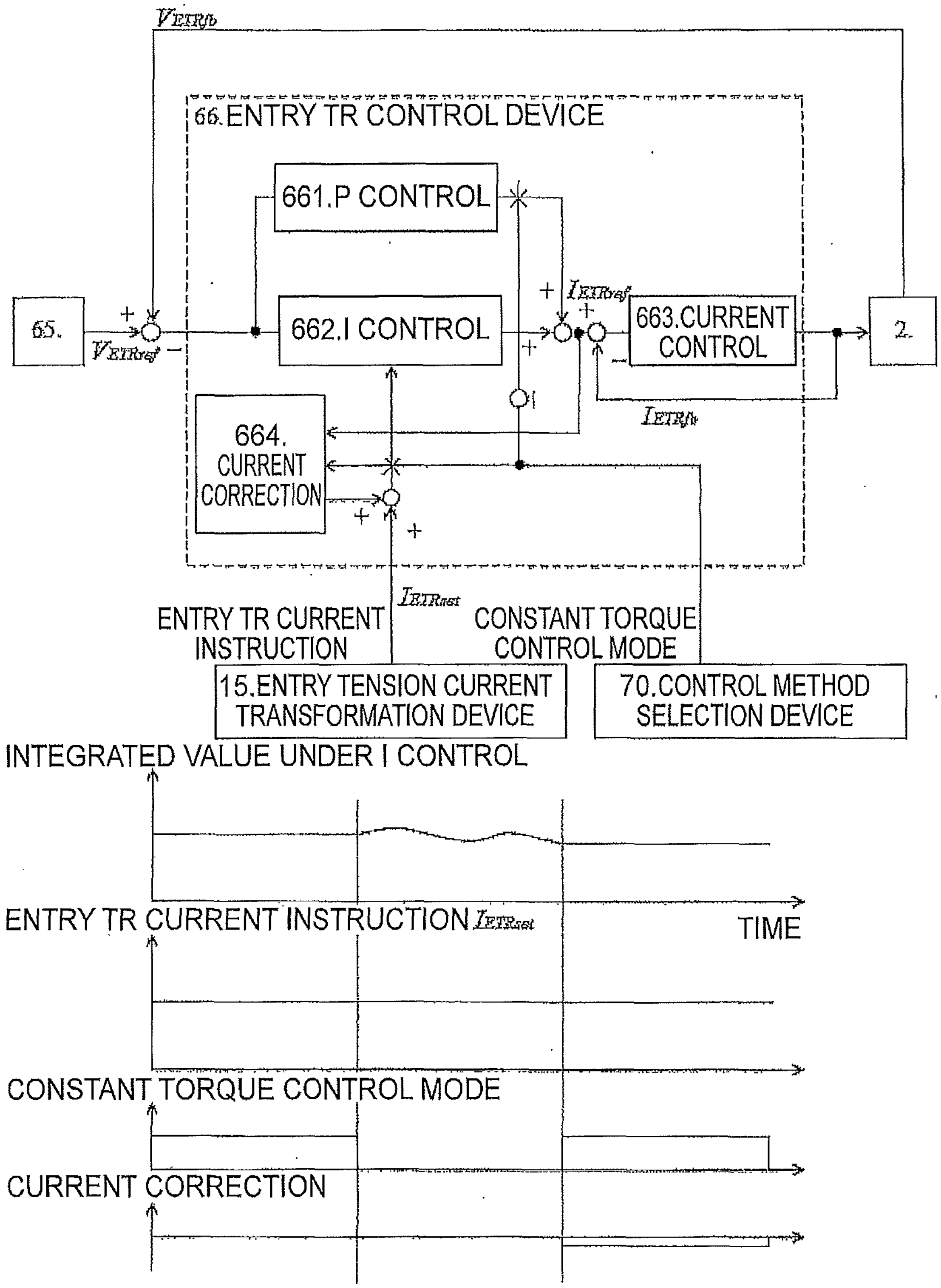

ROLLING SPEED
ACCELERATION
DECELERATION
TIME
CONTROL METHOD B
TIME
CONTROL METHOD C
TIME
EXIT THICKNESS DEVIATION
EXIT TENSION DEVIATION

FIG. 27



V ETRfb
66. ENTRY TR CONTROL DEVICE
661.P CONTROL
662.I CONTROL
663.CURRENT CONTROL
664. CURRENT CORRECTION
65.
2.
V ETRref
I ETRref
I ETRfb
I ETRcst
ENTRY TR CURRENT INSTRUCTION
CONSTANT TORQUE CONTROL MODE
15.ENTRY TENSION CURRENT TRANSFORMATION DEVICE
70.CONTROL METHOD SELECTION DEVICE
INTEGRATED VALUE UNDER I CONTROL
ENTRY TR CURRENT INSTRUCTION I ETRcst
TIME
CONSTANT TORQUE CONTROL MODE
CURRENT CORRECTION

FIG. 28

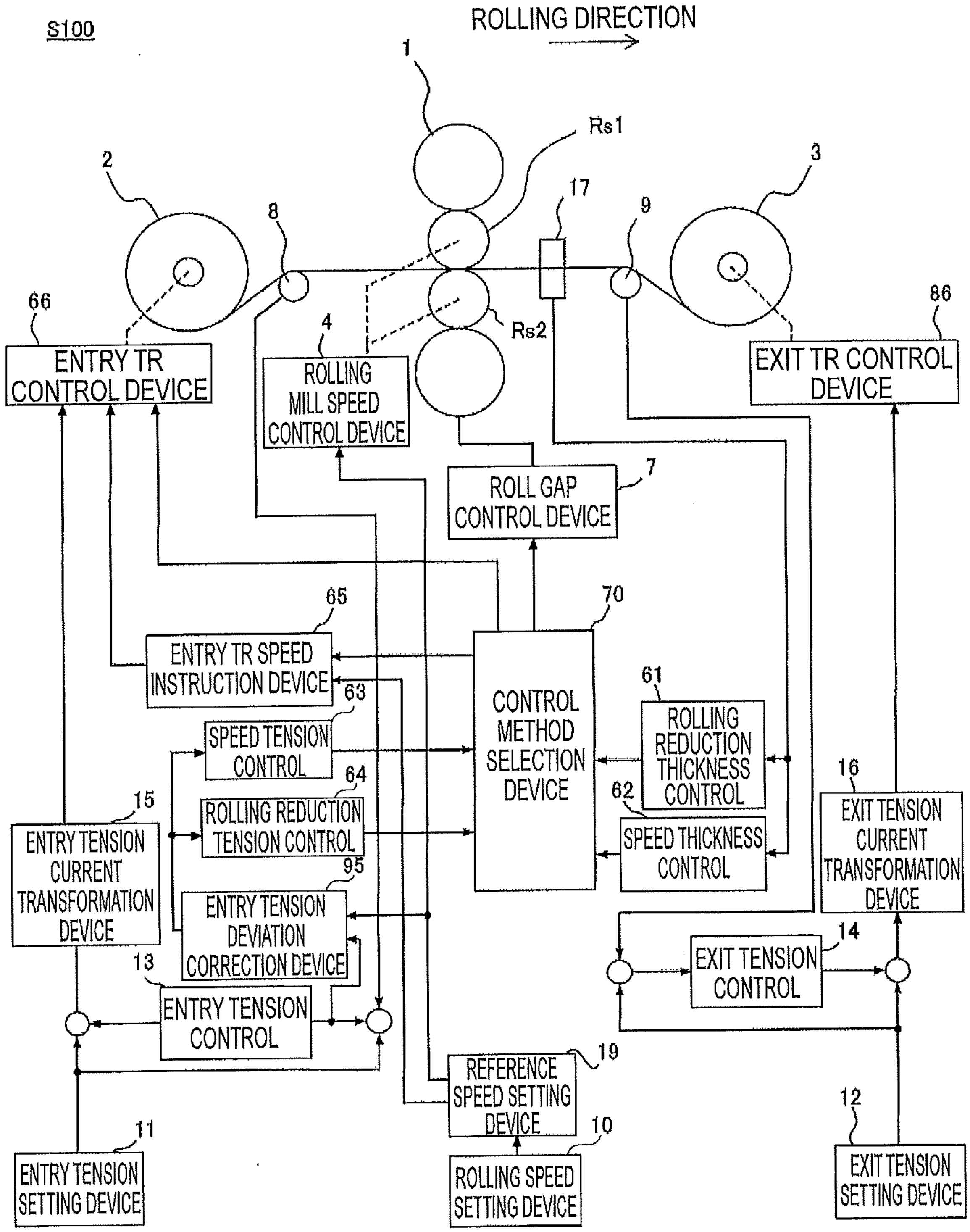

S100
ROLLING DIRECTION
1
Rs1
2
3
17
9
8
66
86
4
Rs2
ENTRY TR CONTROL DEVICE
ROLLING MILL SPEED CONTROL DEVICE
EXIT TR CONTROL DEVICE
ROLL GAP CONTROL DEVICE
7
65
70
ENTRY TR SPEED INSTRUCTION DEVICE
63
CONTROL METHOD SELECTION DEVICE
61
SPEED TENSION CONTROL
ROLLING REDUCTION THICKNESS CONTROL
64
16
15
ROLLING REDUCTION TENSION CONTROL
62
SPEED THICKNESS CONTROL
ENTRY TENSION CURRENT TRANSFORMATION DEVICE
95
EXIT TENSION CURRENT TRANSFORMATION DEVICE
ENTRY TENSION DEVIATION CORRECTION DEVICE
14
EXIT TENSION CONTROL
13
ENTRY TENSION CONTROL
19
REFERENCE SPEED SETTING DEVICE
12
11
10
ENTRY TENSION SETTING DEVICE
ROLLING SPEED SETTING DEVICE
EXIT TENSION SETTING DEVICE

FIG. 29

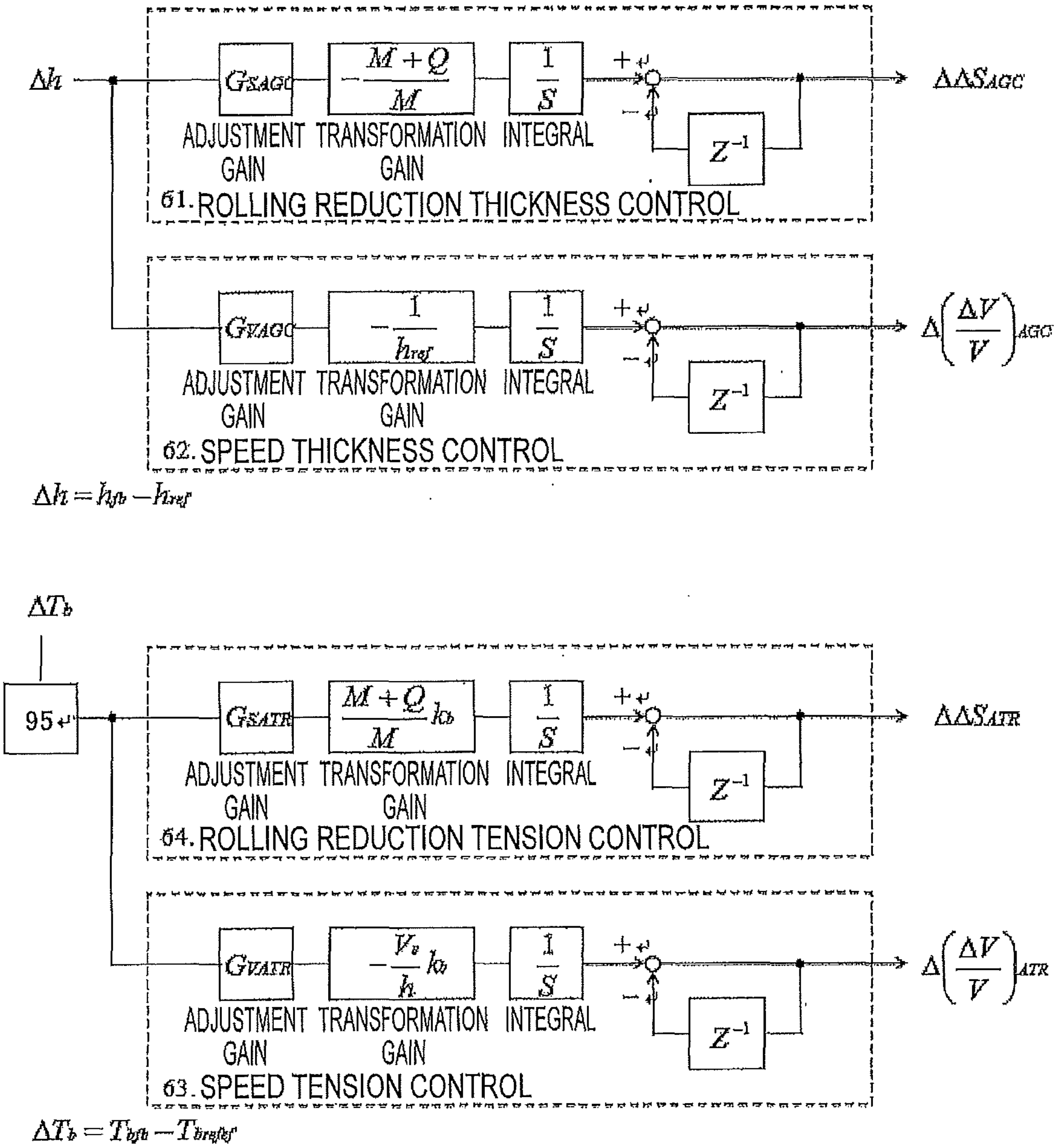

Δh
G_SAGC
−(M+Q)/M
1/S
+
−
Z^-1
ΔΔS_AGC
ADJUSTMENT GAIN
TRANSFORMATION GAIN
INTEGRAL
61. ROLLING REDUCTION THICKNESS CONTROL
G_VAGC
−1/h_ref
Δ(ΔV/V)_AGC
62. SPEED THICKNESS CONTROL
Δh = h_fb − h_ref
ΔT_b
95
G_SATR
(M+Q)/M k_b
ΔΔS_ATR
64. ROLLING REDUCTION TENSION CONTROL
G_VATR
−V_e/h k_b
Δ(ΔV/V)_ATR
63. SPEED TENSION CONTROL
ΔT_b = T_bfb − T_bref

FIG. 30

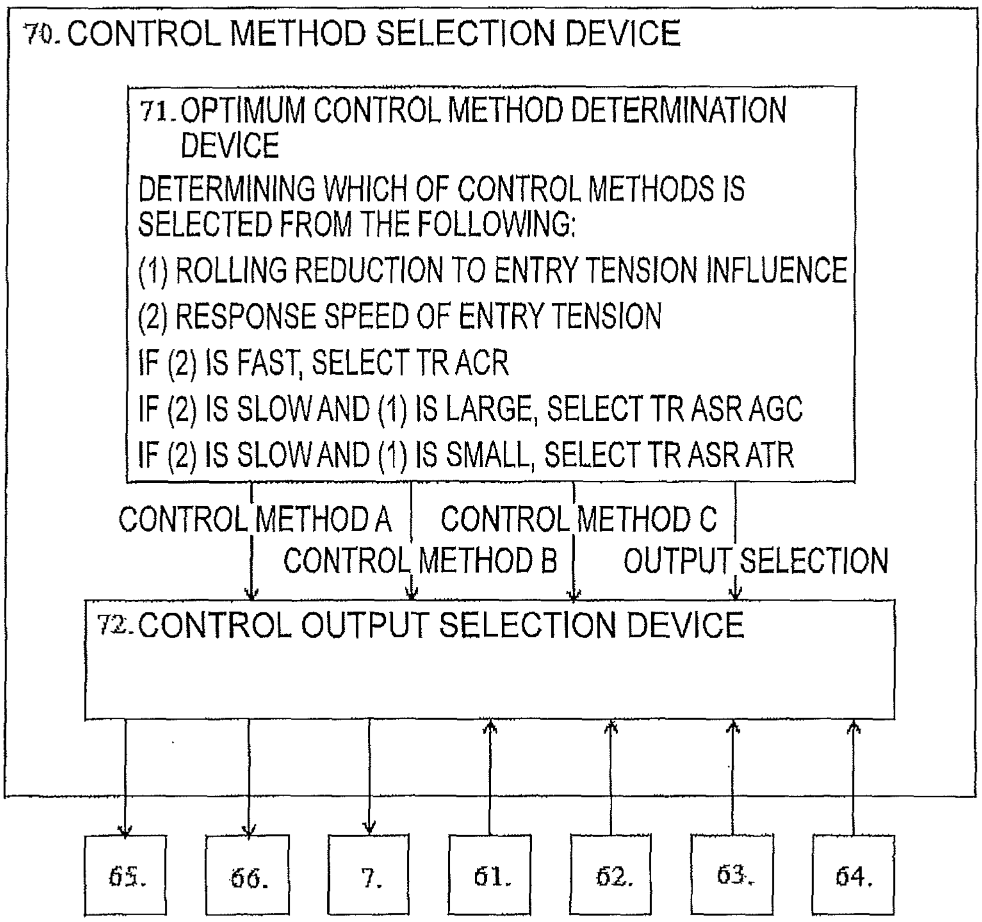

70. CONTROL METHOD SELECTION DEVICE
71. OPTIMUM CONTROL METHOD DETERMINATION DEVICE
DETERMINING WHICH OF CONTROL METHODS IS SELECTED FROM THE FOLLOWING:
(1) ROLLING REDUCTION TO ENTRY TENSION INFLUENCE
(2) RESPONSE SPEED OF ENTRY TENSION
IF (2) IS FAST, SELECT TR ACR
IF (2) IS SLOW AND (1) IS LARGE, SELECT TR ASR AGC
IF (2) IS SLOW AND (1) IS SMALL, SELECT TR ASR ATR
CONTROL METHOD A
CONTROL METHOD C
CONTROL METHOD B
OUTPUT SELECTION
72. CONTROL OUTPUT SELECTION DEVICE
65.
66.
7.
61.
62.
63.
64.

FIG. 31

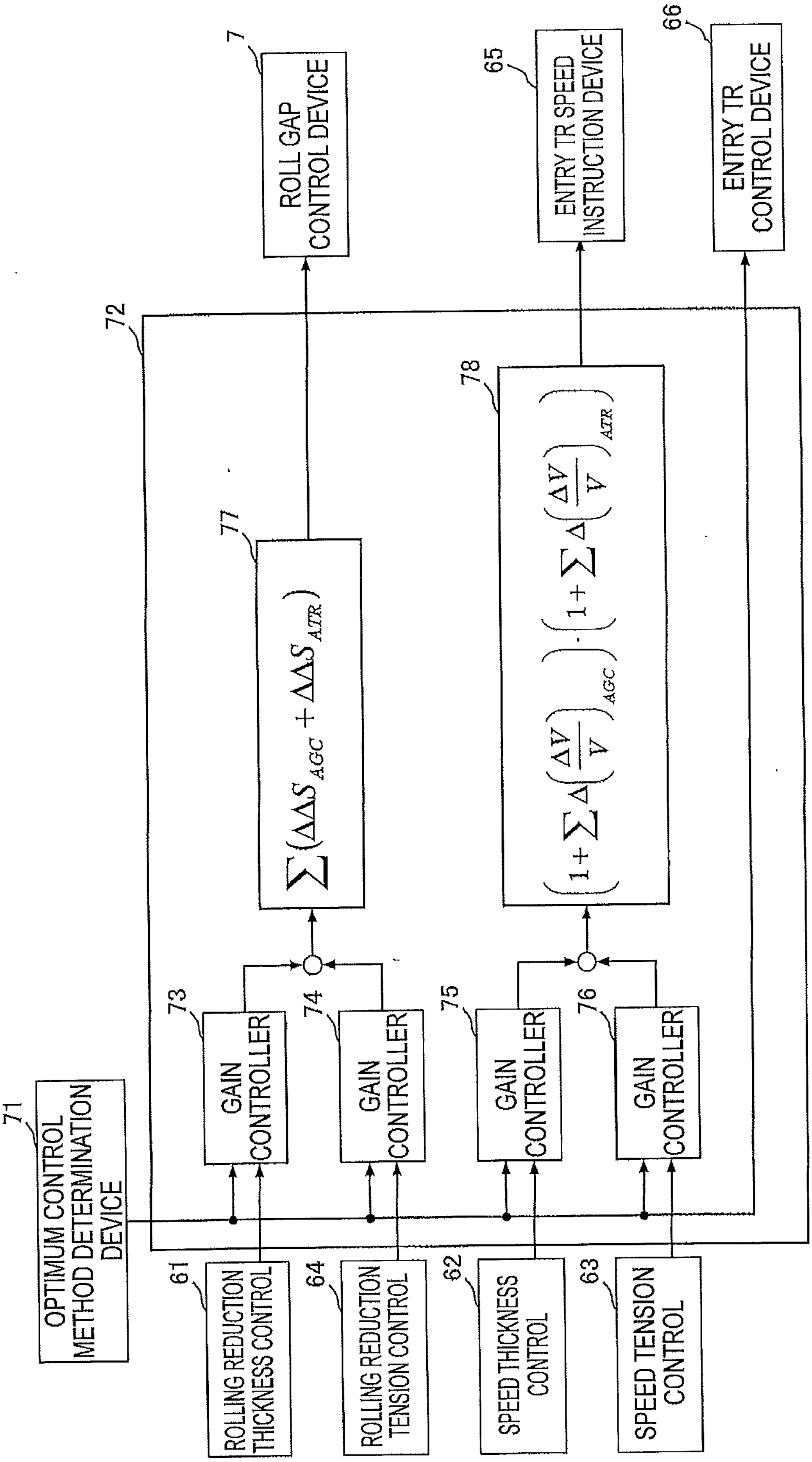

7
ROLL GAP CONTROL DEVICE
65
ENTRY TR SPEED INSTRUCTION DEVICE
66
ENTRY TR CONTROL DEVICE
72
77
$\sum(\Delta\Delta S_{AGC} + \Delta\Delta S_{ATR})$
78
$\left(1+\sum\Delta\left(\frac{\Delta V}{V}\right)_{AGC}\right)\cdot\left(1+\sum\Delta\left(\frac{\Delta V}{V}\right)_{ATR}\right)$
71
OPTIMUM CONTROL METHOD DETERMINATION DEVICE
73
GAIN CONTROLLER
74
GAIN CONTROLLER
75
GAIN CONTROLLER
76
GAIN CONTROLLER
61
ROLLING REDUCTION THICKNESS CONTROL
64
ROLLING REDUCTION TENSION CONTROL
62
SPEED THICKNESS CONTROL
63
SPEED TENSION CONTROL

FIG. 32

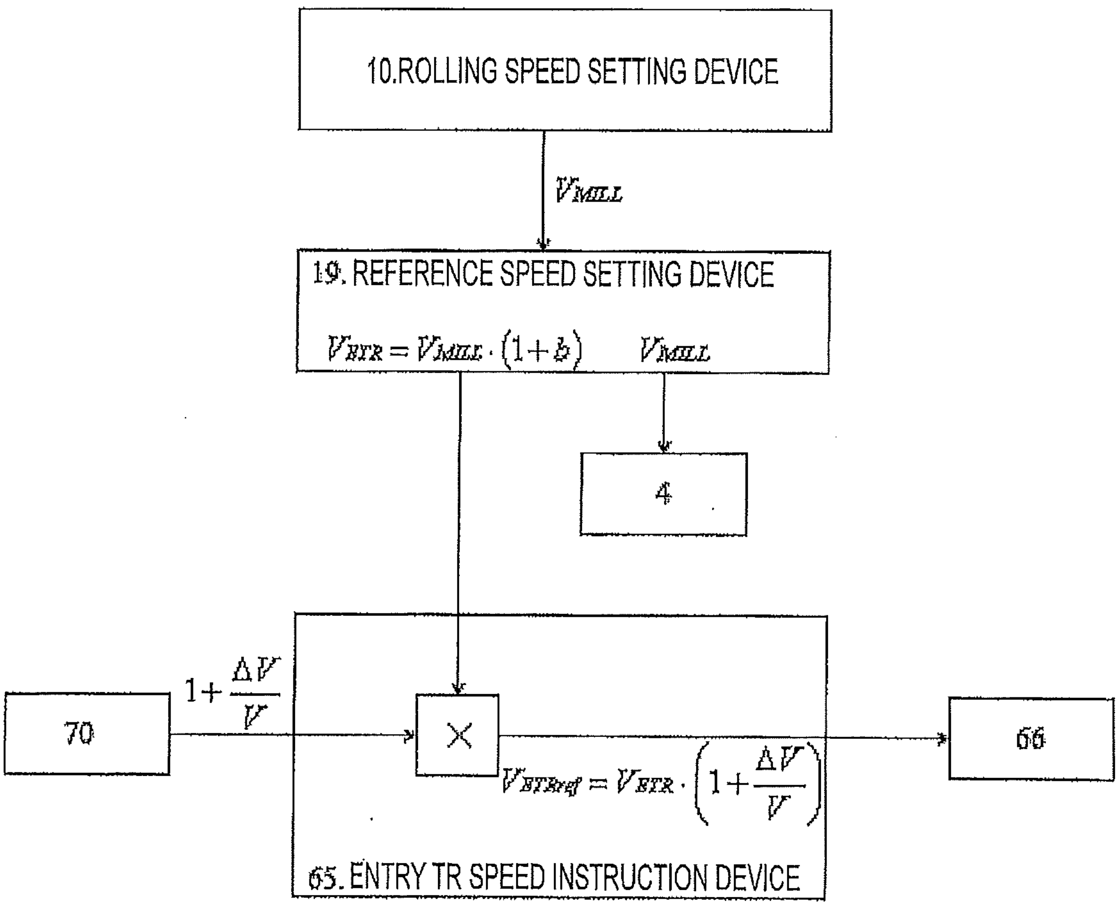

10.ROLLING SPEED SETTING DEVICE
V_{MILL}
19. REFERENCE SPEED SETTING DEVICE
$V_{ETR} = V_{MILL} \cdot (1+b)$
V_{MILL}
4
70
$1+\frac{\Delta V}{V}$
×
$V_{ETRref} = V_{ETR} \cdot \left(1+\frac{\Delta V}{V}\right)$
66
65. ENTRY TR SPEED INSTRUCTION DEVICE

FIG. 33

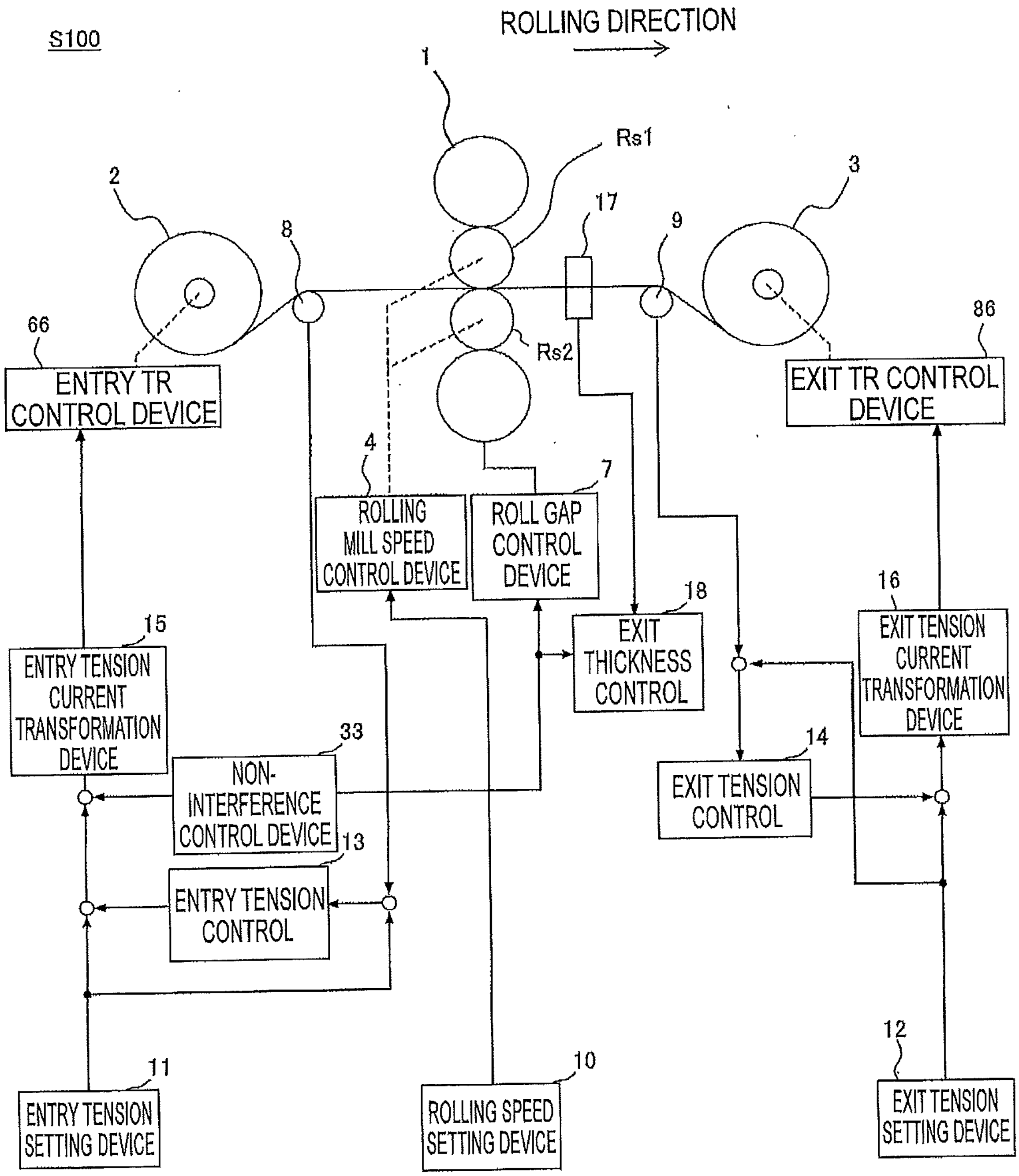
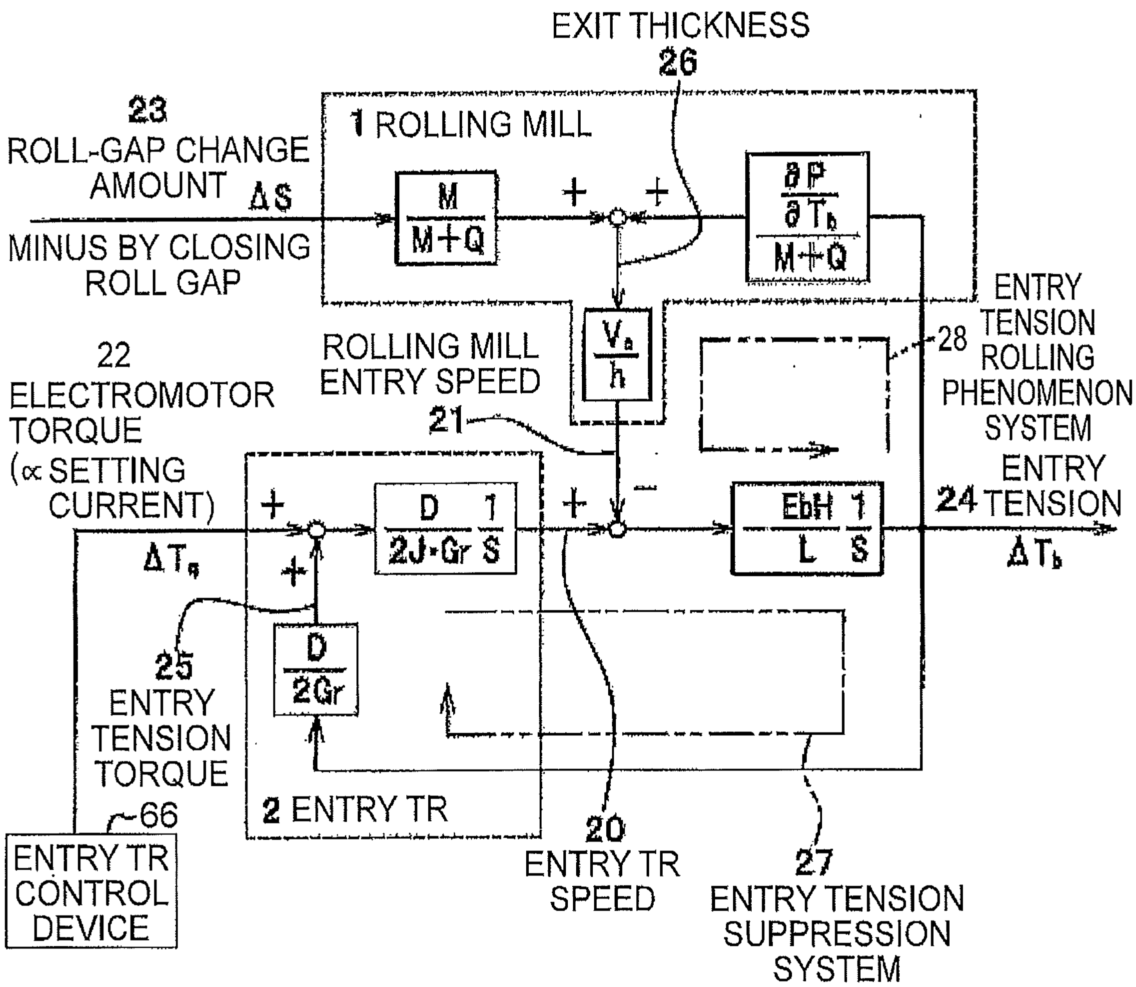

S100
ROLLING DIRECTION
1
Rs1
2
3
17
9
8
66
86
Rs2
ENTRY TR CONTROL DEVICE
EXIT TR CONTROL DEVICE
4
7
ROLLING MILL SPEED CONTROL DEVICE
ROLL GAP CONTROL DEVICE
18
16
15
EXIT THICKNESS CONTROL
ENTRY TENSION CURRENT TRANSFORMATION DEVICE
EXIT TENSION CURRENT TRANSFORMATION DEVICE
33
14
NON-INTERFERENCE CONTROL DEVICE
EXIT TENSION CONTROL
13
ENTRY TENSION CONTROL
12
11
10
ENTRY TENSION SETTING DEVICE
ROLLING SPEED SETTING DEVICE
EXIT TENSION SETTING DEVICE

FIG. 34



Tb:ENTRY TENSION (kN)	E:YOUNG'S MODULUS (Pa)
P:ROLLING LOAD (kN)	b:WIDTH (m)
M:MILL CONSTANT (kN/m)	H:ENTRY THICKNESS (m)
Q:PLASTICITY CONSTANT (kN/m)	h:EXIT THICKNESS (m)

FIG. 35

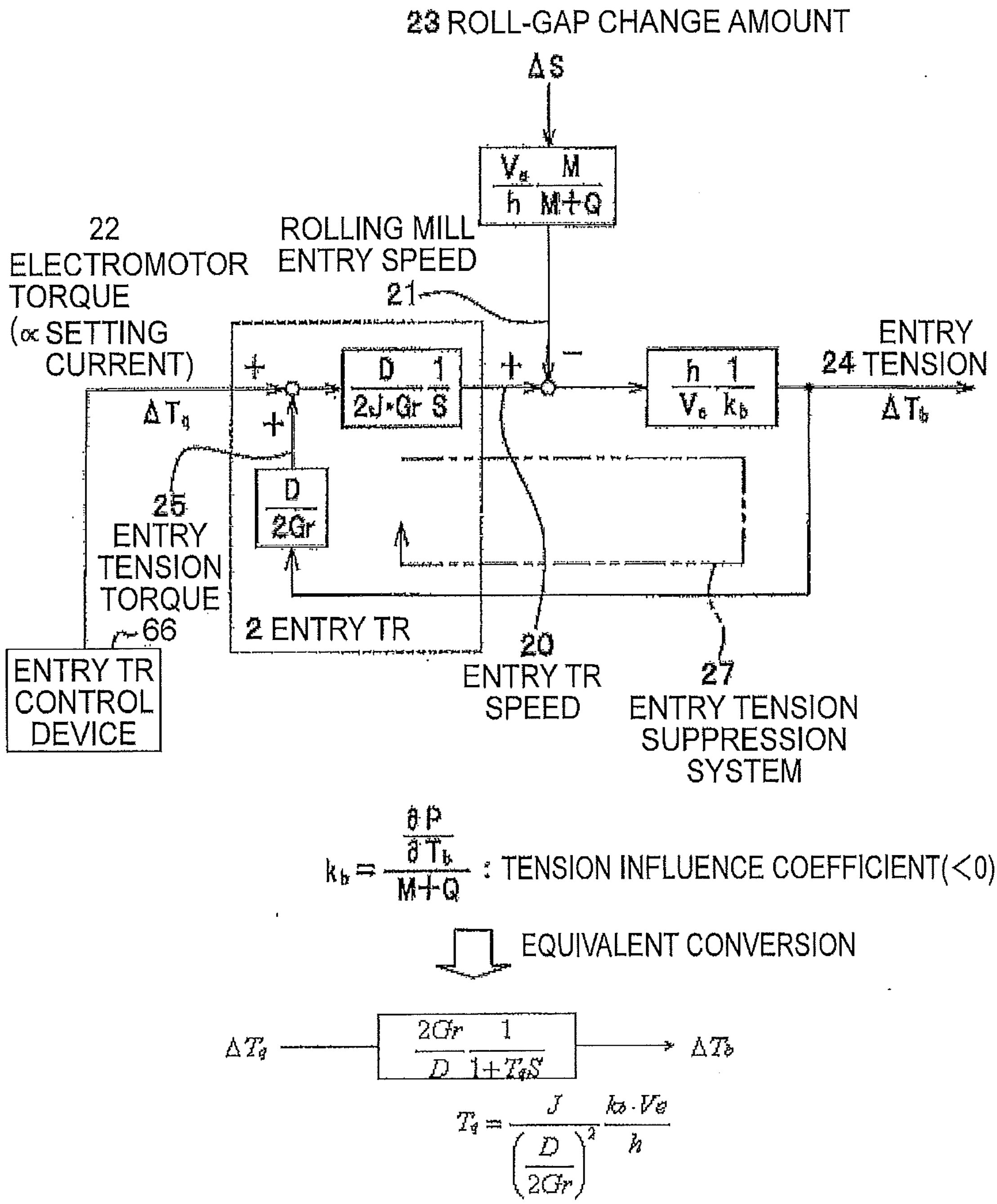

23 ROLL-GAP CHANGE AMOUNT
ΔS
22
ELECTROMOTOR TORQUE
(∝ SETTING CURRENT)
ΔTq
ROLLING MILL ENTRY SPEED
21
25
ENTRY TENSION TORQUE
66
ENTRY TR CONTROL DEVICE
2 ENTRY TR
20
ENTRY TR SPEED
27
ENTRY TENSION SUPPRESSION SYSTEM
ENTRY
24 TENSION
ΔTb
: TENSION INFLUENCE COEFFICIENT(<0)
EQUIVALENT CONVERSION
ΔTq
ΔTb

FIG. 36

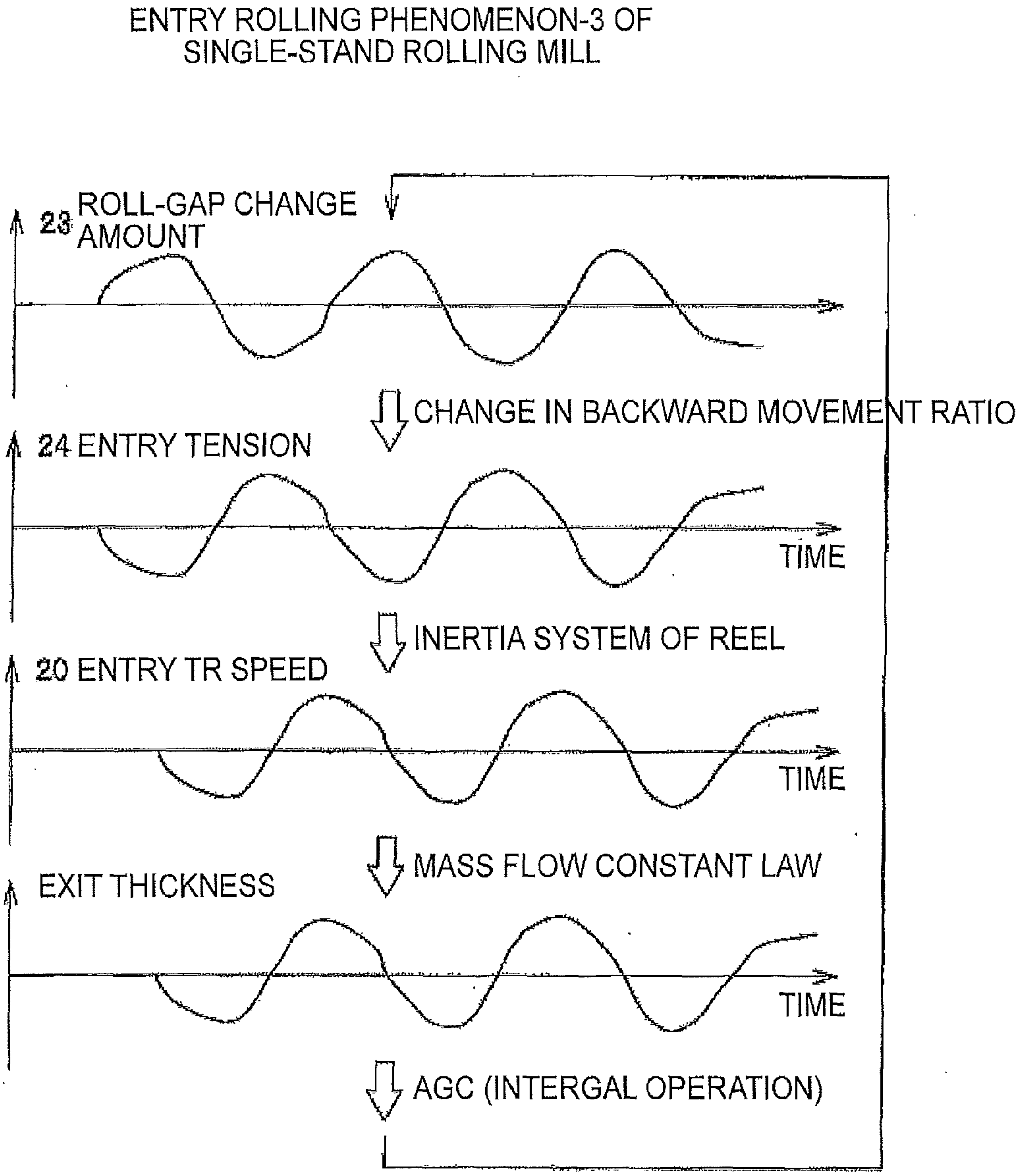

ENTRY ROLLING PHENOMENON-3 OF
SINGLE-STAND ROLLING MILL
23 ROLL-GAP CHANGE
AMOUNT
CHANGE IN BACKWARD MOVEMENT RATIO
24 ENTRY TENSION
TIME
INERTIA SYSTEM OF REEL
20 ENTRY TR SPEED
TIME
MASS FLOW CONSTANT LAW
EXIT THICKNESS
TIME
AGC (INTERGAL OPERATION)

FIG. 37

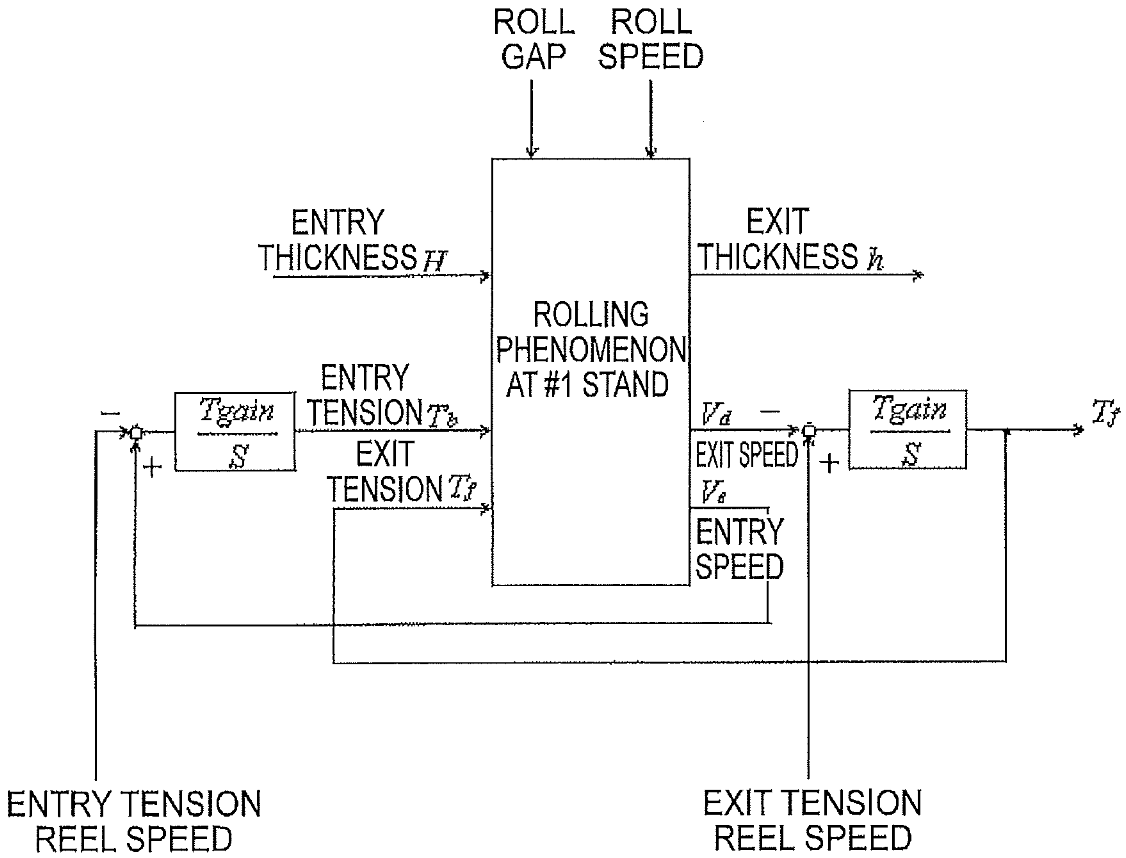
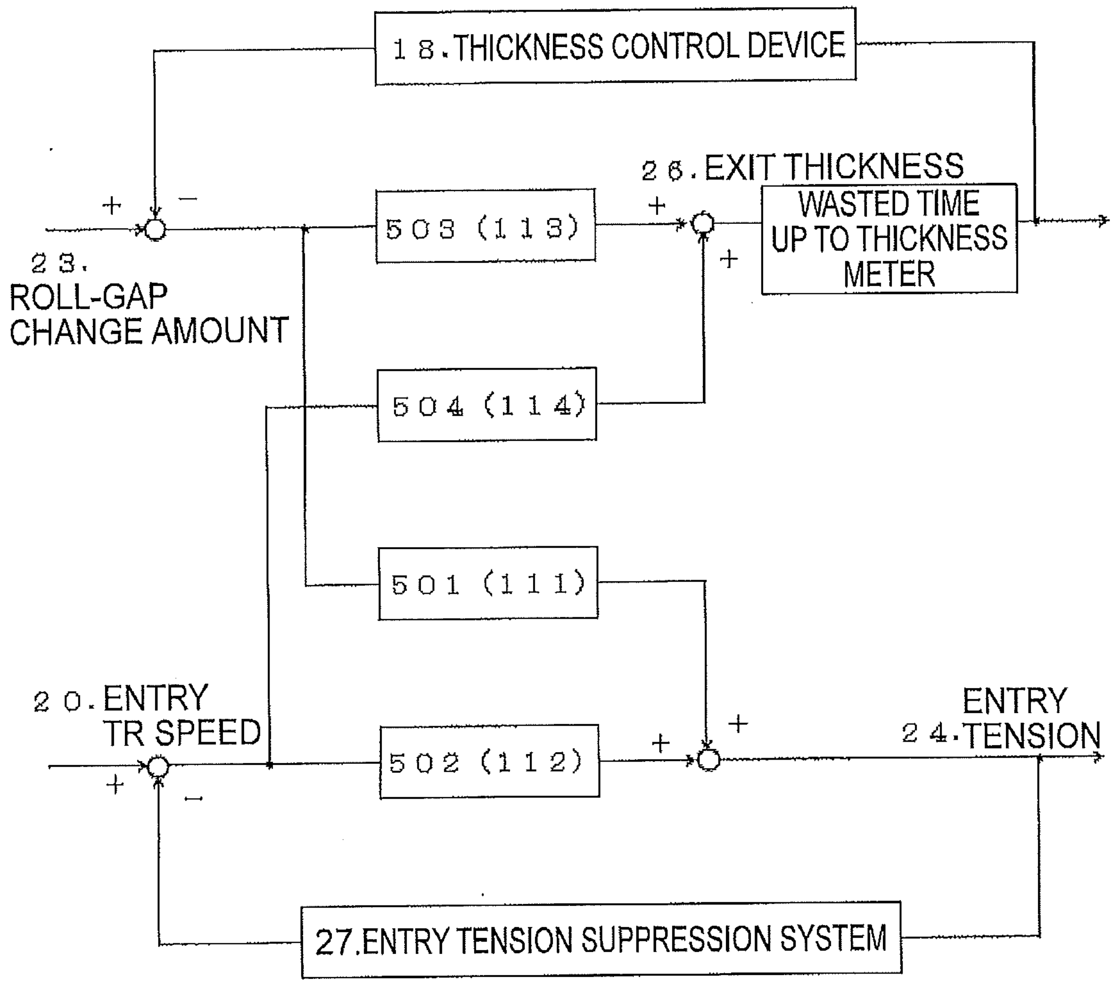
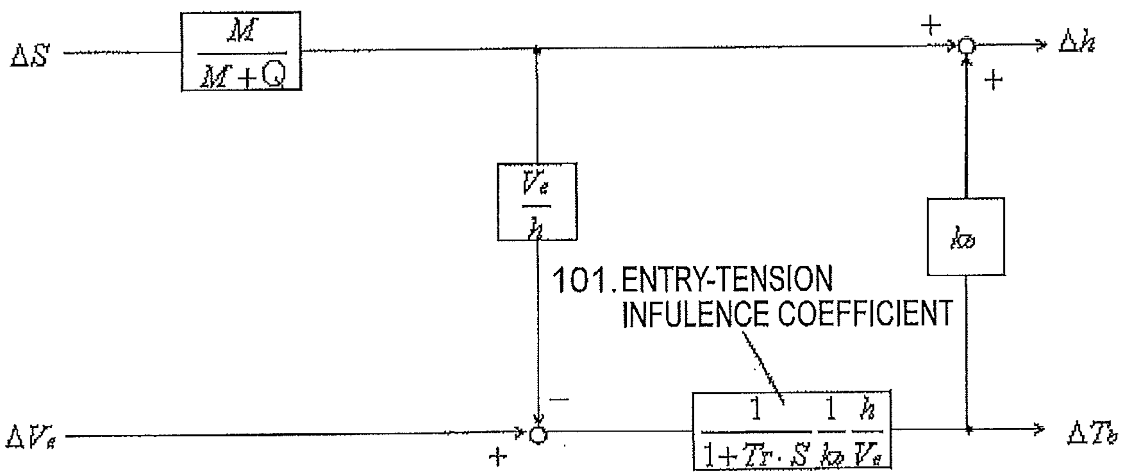

ROLL GAP
ROLL SPEED
ENTRY THICKNESS H
EXIT THICKNESS h
ROLLING PHENOMENON AT #1 STAND
ENTRY TENSION Tb
EXIT TENSION Tf
Tgain / S
Tgain / S
Vd
EXIT SPEED
Ve
ENTRY SPEED
Tf
−
+
−
+
ENTRY TENSION REEL SPEED
EXIT TENSION REEL SPEED

FIG. 38



18.THICKNESS CONTROL DEVICE
26.EXIT THICKNESS
WASTED TIME UP TO THICKNESS METER
23.
ROLL-GAP CHANGE AMOUNT
503 (113)
504 (114)
501 (111)
502 (112)
20.ENTRY TR SPEED
ENTRY
24.TENSION
27.ENTRY TENSION SUPPRESSION SYSTEM
+
−

FIG. 39



$$k_b = \frac{1}{M+Q}\frac{\partial P}{\partial T_b}$$

$$T_r = -\frac{L}{EbH}\frac{1}{k_b}\frac{h}{V_e}$$

$$Q = -\frac{\partial P}{\partial h}$$

FIG. 40

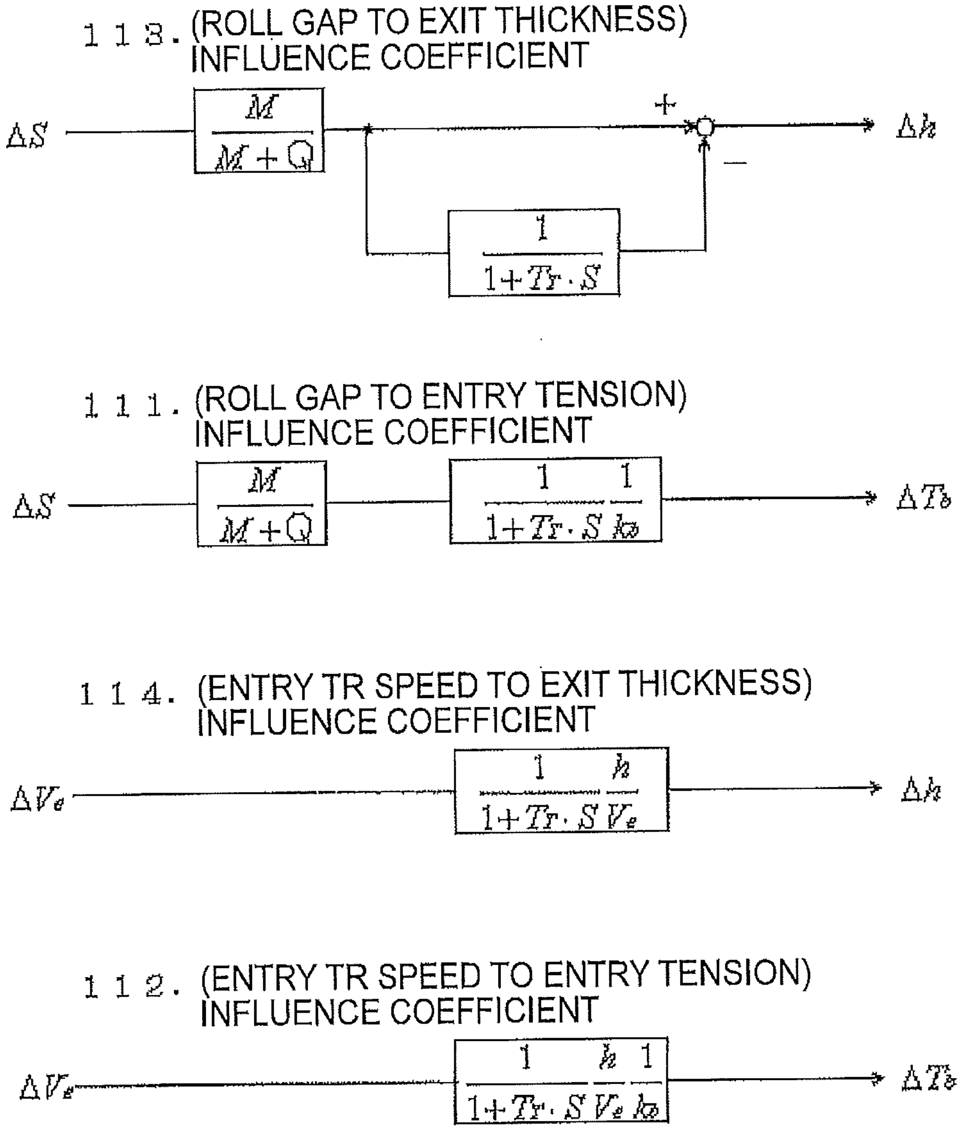
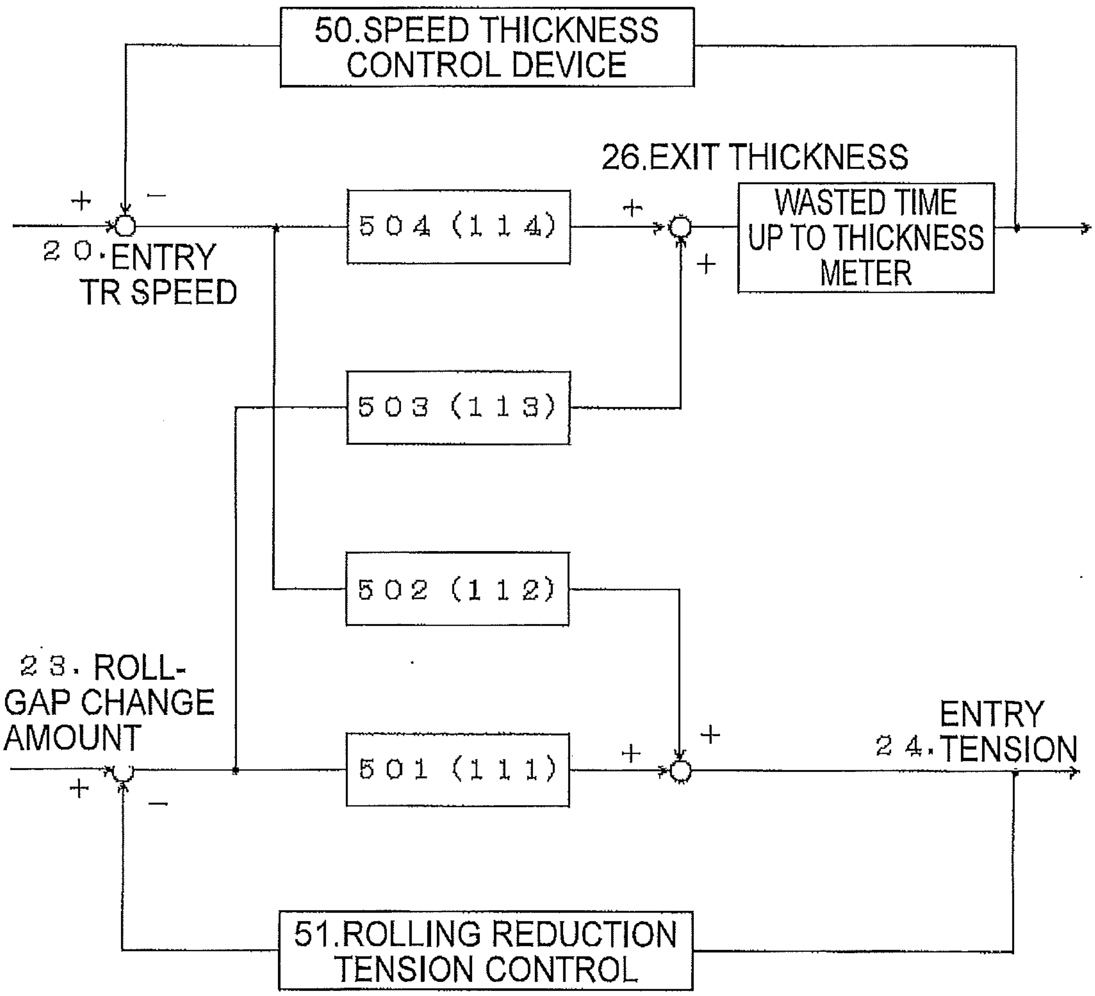

113. (ROLL GAP TO EXIT THICKNESS) INFLUENCE COEFFICIENT
ΔS
M / (M+Q)
1 / (1+Tr·S)
+
−
Δh
111. (ROLL GAP TO ENTRY TENSION) INFLUENCE COEFFICIENT
ΔS
M / (M+Q)
1 / (1+Tr·S) · 1 / kb
ΔTb
114. (ENTRY TR SPEED TO EXIT THICKNESS) INFLUENCE COEFFICIENT
ΔVe
1 / (1+Tr·S) · h / Ve
Δh
112. (ENTRY TR SPEED TO ENTRY TENSION) INFLUENCE COEFFICIENT
ΔVe
1 / (1+Tr·S) · h / Ve · 1 / kb
ΔTb

FIG. 41


50.SPEED THICKNESS CONTROL DEVICE
26.EXIT THICKNESS
+
−
20.ENTRY TR SPEED
504 (114)
+
+
WASTED TIME UP TO THICKNESS METER
503 (113)
502 (112)
23. ROLL-GAP CHANGE AMOUNT
501 (111)
+
+
+
−
ENTRY
24.TENSION
51.ROLLING REDUCTION TENSION CONTROL

REFERENCES CITED IN THE DESCRIPTION

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- JP 2012176428 A **[0004] [0005] [0014] [0020] [0048]**
- JP 2014113629 A **[0010] [0020]**
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- EP 0435595 A2 **[0012]**