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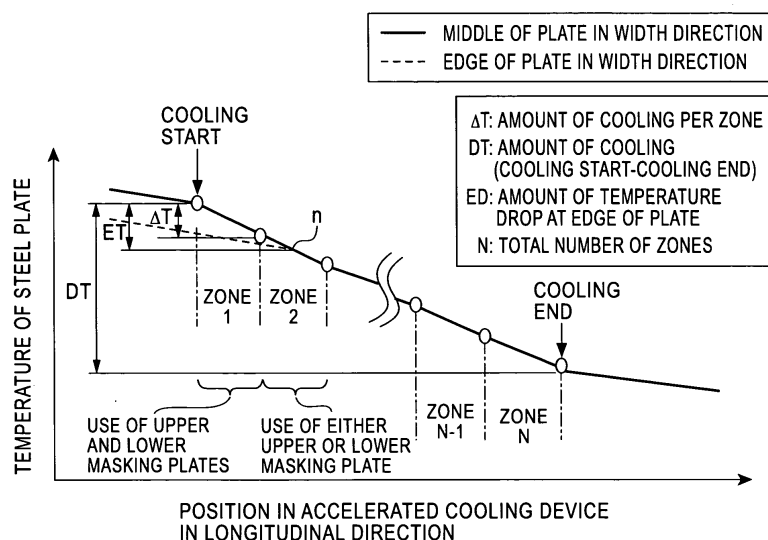
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(54) **CONTROLLABLE COOLING METHOD FOR THICK STEEL PLATE, THICK STEEL PLATE MANUFACTURED BY THE CONTROLLABLE COOLING METHOD, AND COOLING DEVICE FOR THE THICK STEEL PLATE**

(57) The present invention relates to a control cooling system (accelerated control cooling system) for a steel plate after completion of hot rolling and a cooling apparatus. To be specific, the present invention relates to a control cooling system for a steel plate after completion of hot rolling, including uniformizing the temperature dis-

tribution in the width direction of the steel plate before control cooling or in the initial stage of control cooling, and then cooling the steel plate at the same cooling rate across the width direction with a control cooling device, a steel plate produced by the control cooling system, and the cooling apparatus.

FIG. 10



Description

Technical Field

5 **[0001]** The present invention relates to a control cooling system (accelerated control cooling system) for a steel plate after completion of hot rolling, a steel plate produced by the accelerated control cooling system, and a cooling device therefor.

Background Art

10 **[0002]** In producing steel plates, in order to ensure mechanical properties, in particular, strength and toughness, a steel plate after rolling is subjected to control cooling with high cooling rate, in some cases. The control cooling is a technique for achieving a material having target mechanical properties and the like by rapidly cooling a steel plate in the transformation range from austenite to ferrite after hot rolling to control and adjust the transformation structure and the crystalline structure of the steel. Furthermore, to ensure homogeneity of the material across the entire steel plate and prevent the occurrence of strain of the steel plate after cooling, the entire surface of the steel plate is required to be cooled uniformly. However, in current control cooling techniques, the four periphery zones of the steel plate after cooling is supercooled compared with the middle of the steel plate. That is, the entire surface of the steel plate is nonuniformly cooled.

20 **[0003]** To satisfy the requirements, Japanese Unexamined Patent Application Publication No. 10-58026 discloses the following technique for cooling a hot steel plate: A plurality of cooling water screens are allowed to collide with the surface of the steel plate at high velocity, the plurality of cooling water screens being parallel to each other and formed at a predetermined angle to the traveling direction of the steel plate and at predetermined intervals in the width direction of the steel plate. The cooling water is allowed to collide with collision regions and then evenly splits up into right and left to form flow paths along the surface of the steel plate. The collision regions are disposed so that the ends of each of the collision regions do not overlap with each other but are continuous as seen from the traveling direction of the steel plate.

25 **[0004]** In Japanese Unexamined Patent Application Publication No. 6-184623 (Japanese Patent No. 2698305), as a method for cooling a steel plate in which wrinkles due to rolling is leveled by finishing rolling, a method of obliquely ejecting a high-pressure stream of water from a slit jet cooling nozzle with high cooling power to the steel plate to prevent a stream of water toward the edges of the steel plate in the width direction, the nozzle being disposed at the entry side of a control-cooling device, is proposed.

30 **[0005]** Japanese Unexamined Patent Application Publication No. 61-219412 discloses a method for uniformly cooling a steel plate, the method including measuring temperature distribution in the width direction of the rolled hot steel plate before cooling, calculating the distribution of the amount of water in the width direction of the hot steel plate on the basis of the resulting measurement, correcting the calculated distribution of the amount of water using temperature data after cooling of an advanced hot steel plate that has been cooled immediately before the hot steel plate, and adjusting the distribution of the amount of water fed in the width direction of the hot steel plate on the basis of the resulting corrected distribution of the amount of water.

35 **[0006]** Japanese Unexamined Patent Application Publication No. 58-32511 discloses a technique for cooling a steel plate after hot rolling, the technique including allowing cooling water to collide with the upper surface and the lower surface of the steel plate while the edges of the steel plate are blocked with canaliculated-type masking members to prevent the cooling water for the upper surface from directly colliding with the edges of the steel plate. That is, a method for cooling a steel plate, including calculating the masking width of the edges of the steel plate with the canaliculated-type masking members on the basis of the width of the steel plate, the amount of water for the upper and lower surfaces, and the temperature distribution in the width direction of the steel plate when cooling is started so that uniform temperature distribution is achieved in the width direction of the steel plate when cooling is completed; and controlling the positions of the canaliculated-type masking members on the basis of the calculation results so that such a masking width is obtained, is proposed.

40 **[0007]** Any of the methods disclosed in Japanese Unexamined Patent Application Publication Nos. 10-58026, 6-184623 (Japanese Patent No. 2698305), 61-219412, and 58-32511 is a method for preventing a supercooling phenomenon at the edges of the steel plate in the width direction in cooling. The effect can be expected to a certain extent. However, these methods are disadvantageous in that the entire steel plate is uniformly cooled. The technical concept of these methods as follows: supercooling generated at the edges of the steel plate in the width direction before or during cooling is eliminated by reducing the cooling rate only at the edges of the steel plate in the width direction during cooling to uniformize the temperature distribution in the width direction of the steel plate after cooling. Thus, according to the method, to uniformize the temperature distribution on the surface of the steel plate, the cooling rate is required to be reduced to a certain extent, thus leading to a bottle neck for improving a quality of material. Furthermore, according to these methods, uniform temperature distribution cannot be ensured at the top and tail ends of an in-process rolled

45 50 55

material, thus resulting in strain after cooling, in some cases. Furthermore, as will be described below, it is not considered the change of heat transfer mechanisms, for example, film boiling or transition boiling, during cooling. Thus, it is difficult to control the cooling rate at the edges of the steel plate. Parameters, such as the thickness of the steel plate, a temperature at which cooling is started, a temperature at which cooling is completed, and the amount of cooling water, can be adjusted under a specified condition. However, in another cooling condition, the parameters often cannot be adjusted. In addition, there is no specific description regarding this. Consequently, actual operation is difficult.

[0008] Japanese Unexamined Patent Application Publication No. 61-15926 discloses a method for water-flow-cooling the hot steel plate while the hot steel plate is pressed with a plurality of rollers from upper and lower sides, an on/off valve capable of desirably controlling opening time disposed on a header provided above and/or below the gap between the rollers. Furthermore, the method for cooling hot steel plate, further includes detecting means for detecting a passing position of the heat steel plate, detecting means for detecting temperature profile in the longitudinal direction of the hot steel plate before cooling, and cooling control calculation means; and a stop valve disposed at a header corresponding to a position through which top end and/or tail end of the hot steel plate during transferring is about to pass is on/off-controlled. In Japanese Unexamined Patent Application Publication No. 61-15926, in cooling, although supercooling at the top and tail ends of the steel plate in the longitudinal direction is prevented, the uniformity of the temperature at the middle of the rolled plate in the width direction cannot be ensured. There is no means for eliminating strain and residual stress at the edges of the steel plate after cooling.

[0009] Japanese Unexamined Patent Application Publication No. 11-267737 discloses a process for producing a steel plate by control-cooling a hot steel plate after hot rolling, the process including performing cooling with temperature distribution in the width direction of the steel plate with a cooling device disposed between a roughing mill and a finishing mill so that the amount of temperature drop at the edges of the steel plate, the temperature drop being generated from a heating furnace to completion of roughing rolling, and the amount of temperature drop estimated at the edges of the steel plate, the temperature drop estimated being caused during finishing rolling, are compensated; and performing control cooling under uniform cooling condition in the width direction of the steel plate after finishing rolling. In Japanese Unexamined Patent Application Publication No. 11-267737, although the compensation for the temperature at the edges of the steel plate in the width direction is performed at an early stage before finishing rolling, it is difficult to predict the temperature distribution before finishing rolling so that the temperature distribution becomes uniform in the width direction of the steel plate at completion of finishing rolling. During rolling, at the edges of the steel plate, cooling is performed by radiation from the upper and lower surfaces and the side faces and natural convection. In addition, during rolling, to control the shape and the surface state of the steel plate, descaling is performed with a water jet, thereby reducing the temperature. As a result, a variation in temperature distribution is likely to occur at the edges of the steel plate in the width direction and the top and tail ends of the steel plate in the longitudinal direction. In particular, an operator often determines whether descaling is performed or not depending on the state of the steel plate. Consequently, it is difficult to uniformize the temperature distribution at completion of finishing rolling with satisfactory reproducibility by controlling temperature distribution at completion of roughing rolling. Furthermore, in control cooling, a specific method for uniformizing temperature distribution in the width direction of the steel plate is not described, thus resulting in difficulty of realization.

[0010] Japanese Unexamined Patent Application Publication No. 2001-137943 discloses a method for controlling flatness, the method including heating the edges of the metal plate after completion of hot rolling, and then cooling the plate with water and/or heat-leveling the plate. However, in Japanese Unexamined Patent Application Publication No. 2001-137943, when heating is performed with a burner, a high-power burner must be used because of low heating efficiency, thereby increasing cost. Furthermore, the heated portion of the steel plate is oxidized, thus disadvantageously degrading surface characteristics. When heating is performed by induction heating, facility cost and heating cost are very high, which are impractical. Even if the temperature distribution in the width direction of the steel plate can be uniformized in some way before cooling, a method of cooling the steel plate so that the temperature distribution in the width direction of the steel plate is uniform is not described. Therefore, in some cooling devices, supercooling due to the above-described boiling phenomena occurs. Alternatively, the water accumulated on the upper surface of the steel plate falls from the edges to increase the amount of water passing through the edges, thereby causing supercooling.

Disclosure of Invention

[0011] To solve the above-described problems, in performing control cooling for a steel plate after completion of rolling, the present invention provides a control cooling process for a steel plate with high cooling rate as a whole, the temperature distribution on the surface of the steel plate being uniformized across the width direction and the longitudinal direction; a steel plate produced by the control cooling process; and an apparatus. Furthermore, the present invention provides a cooling process for a steel plate, the distribution of residual stress in the width direction and in the longitudinal direction of the steel plate being uniform, the odd shape of a processed product, for example, a camber after bar cutting, being prevented; a steel plate produced by the control cooling process; and an apparatus.

[0012] The present invention relates to a process for cooling a steel plate after completion of hot rolling, the process includes a first cooling step of cooling the steel plate while the temperature distribution in the width direction of the steel plate is uniformized, and a second cooling step of control-cooling the steel plate at the same cooling rate across the width direction of the steel plate after completion of the uniformization of the temperature distribution in the width direction of the steel plate.

[0013] In the process for control-cooling the steel plate after completion of hot rolling, the first cooling step includes cooling the steel plate while the amount of cooling water used for both edges of the steel plate in the width direction is limited at at least one entry-side cooling zone in a transfer-type control-cooling device including a plurality of independent cooling zones, and the second cooling step includes control-cooling the steel plate at the same cooling rate across the width direction of the steel plate at a cooling zone subsequent to the at least one entry-side cooling zone.

[0014] In the process for control-cooling the steel plate after completion of hot rolling, the first cooling step includes cooling the steel plate while the amount of cooling water used for both edges of the steel plate in the width direction is limited with an auxiliary cooling device, and the second cooling step includes control-cooling the steel plate at the same cooling rate across the width direction of the steel plate with a transfer-type control-cooling device disposed at the delivery side of the auxiliary cooling device, the transfer-type control-cooling device including a plurality of independent cooling zones.

[0015] In the process for control-cooling the steel plate described above, the amount of cooling water used for both edges of the steel plate in the width direction is limited with masking members disposed at the edges of the steel plate in the width direction.

[0016] In the process for control-cooling the steel plate described above, the amount of cooling water used for the top end and the tail end of the steel plate in the longitudinal direction is limited at the front section in the control-cooling device.

[0017] The process for control-cooling the steel plate described above, the amount of cooling water used for the top end and the tail end of the steel plate in the longitudinal direction is limited by the auxiliary cooling device or the auxiliary cooling device and the control-cooling device.

[0018] In the process for control-cooling the steel plate described above, the amount of cooling water used for the top end and the tail end of the steel plate in the longitudinal direction is limited by control means for controlling the amount of water, the control means operating for a predetermined period of time in response to a passing signal for each of the top end and the tail end of the steel plate in the longitudinal direction.

[0019] In the process for control-cooling the steel plate described above, the front section in the control-cooling device includes masking members capable of limiting the amount of water used for the edges of the steel plate in the width direction, the masking members being disposed at the edges of the steel plate in the width direction and disposed in each zone, and each of the masking members independently blocks cooling water for each of the edges of the steel plate in the width direction per zone, per upper surface, or per lower surface.

[0020] In the process for control-cooling the steel plate described above, the process further includes analyzing the amount of temperature drop at each of the edges of the steel plate in the width direction and the distance of a portion dropped in temperature from each of the edges of the steel plate in the width direction on the basis of the temperature distribution measured with a measuring means for measuring the temperature distribution of the steel plate in the width direction before control cooling; calculating the number of cooling zones where masking is performed and the amount of masking with masking members disposed in each zone in the front section of the control-cooling device on the basis of the analyzed results; and controlling the masking members on the basis of the calculation results.

[0021] In the process for control-cooling the steel plate described above, the process further includes measuring the temperature distribution in the width direction before auxiliary cooling; analyzing the amount of temperature drop at each of the edges of the steel plate in the width direction and the length of a portion generating a temperature drop from each of the edges of the steel plate in the width direction from the measured temperature distribution; calculating the amount of masking and a cooling time with the masking members in the auxiliary cooling device on the basis of the analyzed results; and controlling the masking members in the auxiliary cooling device and the transferring rate of the steel plate on the basis of the calculation results.

[0022] A steel plate is produced by the control-cooling process described above after hot rolling.

[0023] In a control-cooling apparatus for a steel plate, the control-cooling apparatus includes a transfer-type control-cooling device, the transfer-type control-cooling device including a plurality of independent cooling zones, cooling water can flow at a current density of 1,200 liter (hereinafter referred to as L)/min.m² or more at each of the cooling zones, and masking members for limiting the amount of cooling water used for both edges of the steel plate in the width direction are disposed in the cooling zone in the front section.

[0024] In a control-cooling apparatus for a steel plate, the control-cooling apparatus includes an auxiliary cooling device and a control-cooling device, the auxiliary cooling device and the control-cooling device being arranged in that order subsequent to the delivery side of a roll mill, the current density of cooling water in the auxiliary cooling device is 500 L/min.m² or less, masking members for limiting the amount of cooling water used for both edges of the steel plate in the width direction are disposed in the auxiliary cooling device, the control-cooling device is a transfer-type device

including a plurality of independent cooling zones, and cooling water in each cooling zone can flow at a current density of 1,200 L/min.m² or more.

[0025] In the control-cooling apparatus for the steel plate described above, the operation of the masking members is controlled so that the temperature distribution in the width direction of the steel plate is uniformized.

[0026] In the control-cooling apparatus for the steel plate described above, the control-cooling apparatus further includes control means for controlling the amount of water, the control means operating for a predetermined period of time in response to a passing signal for each of the top end and the tail end of the steel plate in the longitudinal direction.

[0027] In the control-cooling apparatus for the steel plate described above, the control-cooling apparatus further includes a slit jet cooling nozzle.

[0028] In the control-cooling apparatus for the steel plate described above, the auxiliary cooling device further includes a laminar-flow cooling nozzle, and the control-cooling device further comprising a slit jet cooling nozzle.

[0029] In the control-cooling apparatus for the steel plate described above, each of the masking members disposed in each cooling zone in the front section of the control-cooling device independently blocks cooling water for each of the edges of the steel plate in the width direction per zone, per upper surface, or per lower surface.

[0030] In the control-cooling apparatus for the steel plate described above, the control-cooling apparatus further includes analyzing means for analyzing the amount of temperature drop at each of the edges of the steel plate in the width direction and the length of a portion generating a temperature drop from each of the edges of the steel plate in the width direction from the temperature distribution measured with a measuring means for measuring the temperature distribution of the steel plate in the width direction before control cooling; calculating means for calculating the number of cooling zones where masking is performed and the amount of masking with masking members disposed in each zone in the front section of the control-cooling device on the basis of the analyzed results; and a controlling mechanism for controlling the masking members on the basis of the calculation results.

[0031] In the control-cooling apparatus for the steel plate described above, the control-cooling apparatus further includes measuring means for measuring the temperature distribution in the width direction before auxiliary cooling; analyzing means for analyzing the amount of temperature drop at each of the edges of the steel plate in the width direction and the distance of a portion dropped in temperature from each of the edges of the steel plate in the width direction on the basis of the measured temperature distribution; calculating means for calculating the amount of masking and a cooling time with the masking members in the auxiliary cooling device on the basis of the analyzed results; and a controlling mechanism for controlling the masking members in the auxiliary cooling device and the transferring rate of the steel plate on the basis of the calculation results.

[0032] In the control-cooling apparatus for the steel plate described above, a leveler is disposed before the control-cooling device or between the auxiliary cooling device and the control-cooling device.

Brief Description of the Drawings

[0033]

Fig. 1 shows the relationship between the surface temperature of a steel plate and value of heat flux in cooling high-temperature steel plate.

Fig. 2 shows the flow of water on the upper surface of a steel plate in cooling the steel plate.

Fig. 3 shows the temperature histories at the edges and the middle of a steel plate in the width direction when cooling for the edges of the steel plate in the width direction are controlled by a known process.

Fig. 4 shows the temperature histories at the edges and the middle of a steel plate in the width direction when cooling for the edges of the steel plate in the width direction are controlled by a process according to a first embodiment of the present invention.

Fig. 5 shows the temperature histories at the edges and the middle of a steel plate in the width direction when cooling for the edges of the steel plate in the width direction are controlled by a process according to a second embodiment of the present invention.

Fig. 6 is a conceptual view of a control-cooling device according to the first embodiment of the present invention.

Fig. 7 is a conceptual view of a control-cooling device according to the present invention.

Fig. 8 is a conceptual view of the arrangement of masking members for masking cooling water in the control-cooling device according to the present invention.

Fig. 9 shows the definition of supercooling for an edge of a steel plate in the width direction.

Fig. 10 shows a specific control process according to the first embodiment of the present invention.

Fig. 11 shows the temperature distributions in a steel plate in the width direction after cooling when the steel plate is cooled according to the first embodiment of the present invention and when the steel plate is cooled by another process.

Fig. 12 shows a structure of a control-cooling device for controlling an amount of water at the top end and tail end

of a steel plate in the longitudinal direction according to the first embodiment of the present invention.

Fig. 13 shows a structure of a control-cooling device for controlling an amount of water at the top and tail ends of a steel plate in the longitudinal direction according to the first embodiment of the present invention.

Fig. 14 shows the definition of supercooling at the top end and tail end of a steel plate in the longitudinal direction.

5 Figs. 15A and 15B each show the operation of cooling water in passing the top end of a steel plate in the longitudinal direction according to the first embodiment of the present invention.

Figs. 16A and 16B each show the operation of cooling water in passing the tail end of a steel plate in the longitudinal direction according to the first embodiment of the present invention.

10 Fig. 17 is a conceptual view of a control-cooling device for cooling a steel plate according to a second embodiment of the present invention.

Fig. 18 is a conceptual view of the arrangement of masking members for blocking cooling water in the control-cooling device according to the present invention.

Fig. 19 shows the operation of a laminar flow cooling device in passing the top end of a steel plate in the longitudinal direction.

15 Fig. 20 shows the operation of a laminar flow cooling device in passing the tail end of a steel plate in the longitudinal direction.

Fig. 21 is a layout view when a leveler 30 is disposed in the present invention.

Fig. 22 shows positions for cutting a steel plate after cooling according to an embodiment of the present invention.

20 Fig. 23 shows a method for measuring a camber when a cooled steel plate 52 is cut out according to an embodiment of the present invention.

Fig. 24 shows a method for measuring a camber when a cooled steel plate 55 is cut out according to an embodiment of the present invention.

Figs. 25 and 26 show the dimensions and arrangement of a control-cooling device according to an embodiment of the present invention.

25 Fig. 27 shows a structure of a masking member disposed in an auxiliary cooling device according to an embodiment of the present invention.

Fig. 28 shows the arrangement of the masking member in the auxiliary cooling device according to an embodiment of the present invention.

30 Reference Numerals

[0034]

- 1: rolling mill for steel plate
- 35 2: steel plate
- 3: roller table
- 10: laminar-flow cooling device
- 11: upper header
- 12: lower header
- 40 13 and 14: water flow
- 15: masking member
- 16: mechanism to move masking member forward and backward
- 17: photo cell
- 20: slit-jet cooling nozzle
- 45 21: upper header
- 22: lower header
- 23: upper slit jet cooling nozzle
- 24: lower slit jet cooling nozzle
- 25: front section of control-cooling device
- 50 26: rear section of control-cooling device
- 27: draining roller
- 28: upper masking member
- 29: lower masking member
- 30: thermometer at entrance of auxiliary cooling device
- 55 31: thermometer at entrance of control-cooling device
- 32: thermometer at exit of control-cooling device
- 41: flow controller
- 42: three-way valve

- 51: top-end specimen
 52: specimen for measuring camber of bar cut in width direction
 53: middle specimen in width and longitudinal directions
 54: tail-end specimen
 55: specimen for measuring camber of bar cut in longitudinal direction

Best Mode for Carrying Out the Invention

[0035] The technical principals of the present invention will be described in comparison with a known process. Fig. 3 shows temperature histories of a steel plate in a known process for preventing supercooling of edges of the steel plate in the width direction. In the known process, before control cooling, the temperature of the edges of the steel plate in the width direction is already lower than that of the middle of the steel plate. In subsequent control cooling, by disposing masking members above the edges of the steel plate in the width direction and adjusting the amount of cooling water, the amount of cooling water passing through the edges of the steel plate in the width direction is reduced. As a result, the cooling rate at the edges is reduced compared with that at the middle of the steel plate. In this known process, the temperatures at the edges of the steel plate in the width direction and at the middle of the steel plate are identical at the end of cooling. The known process is disadvantageous in that, as described below, the material quality at the edges of the steel plate in the width direction is different from that at the middle of the steel plate because the cooling rate at the edges of the steel plate in the width direction is lower than that at the middle of the steel plate.

[0036] It is believed that supercooling phenomenon at four periphery zones of the steel plate is generated by the following three mechanisms.

(1) Supercooling due to radiational cooling during rolling

In producing a steel plate by a general rolling process, the four periphery zones of the steel plate are cooled by radiational cooling (air cooling) from the side surfaces in addition to the upper and lower surfaces during rolling. Thus, the temperatures at the four periphery zones are lower than the temperature at the middle of the steel plate. Even when the entire surface of the steel plate is cooled by control cooling with uniform cooling power, this temperature distribution is still maintained after cooling because before cooling the four periphery zones of the steel plate are already supercooled compared with the middle of the steel plate.

(2) Supercooling due to boiling phenomenon during water cooling

If a variation in temperature distribution is present in a steel plate before cooling the steel plate, the variation in temperature distribution may be increased. This will be described in detail with reference to Fig. 1. Fig. 1 shows the relationship between surface temperature of the steel plate and heat flux (transition of heat flux per unit area and unit time) in a steel plate having a surface temperature of 700°C or more. Film boiling occurs at higher surface temperatures of the steel plate. Nucleate boiling occurs at lower surface temperatures of the steel plate. Transition boiling occurs at an intermediate temperature region between these. In film boiling, which occurs at higher surface temperatures of the steel plate, a vapor film is generated between the surface of the steel plate and cooling water. Heat transfers based on heat conduction in the vapor film, thus resulting in low heat flux (cooling power). In nucleate boiling, which occurs at lower surface temperatures of the steel plate, a complex phenomenon occurs as follows: The surface of the steel plate is in direct contact with cooling water. Cooling water is partially vaporized from the surface of the steel plate to form vapor bubbles. The resulting vapor bubbles are immediately condensed and disappear by cooling water around the vapor bubbles. The formation and disappearance of the vapor bubbles stir cooling water, thus resulting in significantly high heat flux (cooling power). As shown in Fig. 1, in regions where film boiling and nucleate boiling occur, there are heat transfer features in which higher temperatures of the steel plate result in higher heat flux (cooling power), and lower temperatures of the steel plate result in lower heat flux (cooling power). Therefore, there are heat transfer features in which, when a variation in temperature distribution is present in the steel plate before cooling, the higher temperature portions of the steel plate result in higher cooling rates, and the lower temperature portions of the steel plate result in lower cooling rates, thereby reducing the variation in temperature distribution before cooling. When the surface temperature of the steel plate is in the intermediate temperature region, both of film boiling and nucleate boiling occur, i.e., transition boiling occurs. In contrast to film boiling and nucleate boiling, in transition boiling, a phenomenon occurs in which heat flux (cooling power) increases with decreasing the temperature of the steel plate. That is, lower temperatures of the steel plate result in higher heat flux (cooling power). Thus, when a variation in temperature is present in the steel plate before cooling, a lower temperature portion of the steel plate is much cooler. As a result, the variation in temperature distribution after cooling is increased. As a dashed curve represented in Fig. 1, when the current density of cooling water is increased, the surface temperature T_{tf} , at which the boiling mechanism changes from film boiling to transition boiling, shifts to high temperatures. As a result, transition boiling starts at the initial stage of cooling. When the current density of cooling water is further increased, the steel plate can be cooled on the basis of nucleate boiling from the initial stage

of cooling. On the contrary, when the current density of cooling water is decreased, the surface temperature T_{tf} , at which the boiling mechanism changes from film boiling to transition boiling, shifts to lower temperatures. As a result, the steel plate can be cooled on the basis of film boiling during the entire cooling.

In general control cooling, this point is not into consideration. Cooling is often performed at a current density of cooling water that causes transition boiling, thereby increasing a variation in the temperature distribution in the steel plate after cooling, in some cases.

(3) Supercooling due to drainage on upper surface of steel plate

[0037] When a steel plate is disposed in a horizontal position and cooled as shown in Fig. 2, cooling water flows to the periphery of the upper surface of the steel plate and falls from edges of the plate. At edge point A of the upper surface of the steel plate, cooling is performed with cooling water flowing to the edges of the steel plate in addition to cooling water ejected from nozzles disposed above the steel plate. Consequently, the amount of cooling water passing through the edges of the upper surface of the steel plate is increased, thus increasing the cooling rate. At the lower surface of the steel plate, such a phenomenon does not occur because cooling water allowed to collide with the steel plate immediately falls off.

[0038] Each of the temperatures in the four periphery zones of the steel plate after cooling is lower than that in the middle of the steel plate on the basis of three mechanisms described above.

[0039] Therefore, even when a steel plate is uniform in shape immediately after completion of cooling, since a variation in temperature distribution of the steel plate, the value of heat shrinkage in the middle of the high-temperature steel plate is greater than that in each of the four periphery zones during a subsequent air-cooling step. Hence, residual stress is generated in the steel plate, thus generating strain in the steel plate. Even if strain is not generated, stress remains at the edges of the steel plate. When a customer cut the steel plate into a bar, a camber of a bar cut from the four periphery zones, what is called "camber of bar cut", of the steel plate is disadvantageously generated. Furthermore, the four periphery zones of the steel plate are cooled to temperatures lower than expected, and thus the material of the steel plate is changed, thereby disadvantageously leading to, for example, high strength. Accordingly, the present invention has the following two technical principals.

(1) The temperature distribution of a steel plate in the width direction is uniformized immediately before control cooling or at the initial stage of the control cooling.

(2) Control cooling is performed so that the same cooling rate is achieved from the edges of the steel plate to the middle of the steel plate in the width direction.

[0040] These will be specifically described with reference to Figs. 4 and 5. Fig. 4 shows temperature histories in uniformizing the temperature distribution of the steel plate in the width direction at the initial stage of control cooling and then uniformly performing control cooling so that the same cooling rate is achieved from the edges to the middle of the steel plate in the width direction. In the present invention, the amount of water passing through the edges of the steel plate in the width direction is adjusted with masking members at the initial stage of control cooling. At the middle of the steel plate, control cooling is usually performed. When the temperature at the middle of the steel plate becomes identical to that at the edges of the steel plate in the width direction, cooling is performed so that the same cooling rate is achieved from the edges to the middle of the steel plate in the width direction. In such a process, the cooling rates at the edges and the middle of the steel plate in the width direction are identical, and temperatures at which cooling is stopped at the edges and the middle of the steel plate in the width direction are also identical, thus resulting in uniform material of the steel plate in the width direction. Fig. 5 shows temperature histories in uniformizing the temperature distribution of a steel plate in the width direction with a auxiliary cooling device before control cooling and then performing control cooling so that the same cooling rate is achieved from the edges to the middle of the steel plate in the width direction. In this case, the cooling rates at the edges and the middle of the steel plate in the width direction are also identical during control cooling, thus achieving the same effect as that described in Fig. 4.

[0041] In a control-cooling device, to achieve the same cooling rate in a steel plate in the width direction, nucleate-boiling cooling is performed. As shown in Fig. 1, when the surface temperature of the steel plate is decreased to a temperature in transition boiling region with during cooling, a variation in temperature distribution after cooling is increased. However, in nucleate boiling region, higher temperatures result in higher cooling power (higher heat flux). Thus, even if a variation in temperature distribution is present before cooling, the variation is reduced. As a result, the difference of the power to cool the edges and the middle of the steel plate in the width direction can be reduced. In the present invention, since the temperature distribution of a steel plate is uniform, in other words, since no variation in temperature distribution is present in the steel plate, cooling can be performed in principle without a variation in temperature distribution after cooling.

[0042] In Fig. 2, the following explanation has been described above: At the edges of the upper surface of the steel plate, cooling is performed with cooling water flowing to the edges of the steel plate in addition to cooling water ejected from the nozzles disposed above the steel plate. As a result, the amount of cooling water passing through the edges of

the upper surface of the steel plate is increased, thus increasing the cooling rate. To circumvent the problem, nucleate-boiling cooling in which the momentum of cooling water is high is performed. Cooling water with high momentum discharged from the nozzles passes through the water film drained and then reaches the surface of the steel plate, thus permitting the break of the vapor film. Therefore, cooling is performed in the nucleate boiling region. In such cooling, cooling water discharged from the nozzles is dominant, and thus the effect of cooling water that is drained through the edges of the steel plate in the width direction is small. To perform nucleate-boiling cooling using cooling water with high momentum, a process for increasing the momentum of water by increasing the discharge pressure or the current density of cooling water should be employed. Alternatively, cooling nozzles for increasing the momentum of water, for example, slit jet cooling nozzles, should be used.

[0043] Examples of the cooling nozzle usable for the present invention include a spray nozzle, a mist nozzle, a circular tube, a slit laminar nozzle, a circular tube, or slit jet cooling nozzle. When the amount of water and the discharge pressure of water are reduced, the circular tube or the slit jet cooling nozzle, which can increase the momentum of water, are preferable.

[0044] Furthermore, use of such a nozzle that can increase the momentum of water is advantageous in that the difference between the power to cool the edges of the steel plate in the width direction and the power to cool the middle of the steel plate can be significantly increased by masking the edges of the steel plate in the width direction with masking members. As a result, the temperature difference between the edges and the middle of the steel plate in the width direction can be reduced for a very short period of time. Water drained through the edges of the steel plate in the width direction has no vertical momentum and thus cannot break the vapor film. Therefore, cooling is performed on the basis of film boiling. That is, by masking only the edges of the steel plate in the width direction from the injection of high-momentum cooling water discharged from above and below the steel plate, the edges of the steel plate in the width direction can be cooled on the basis of film boiling with low cooling power, and the middle of the steel plate can be cooled on the basis of nucleate boiling with high cooling power. In this way, the difference between the power to cool the edges of the steel plate in the width direction and the power to cool the middle of the steel plate can be increased, thus decreasing the variation in temperature distribution in the steel plate. Furthermore, it is possible to uniformly cool the steel plate in the width direction because of no cooling within the transition boiling region, which increases the variation in temperature distribution.

[0045] To realize the control cooling within the nucleate boiling region, for example, when slit jet cooling is employed, cooling water should be discharged at a water current density of 1,200 L/min.m² or higher. More preferably, at a water current density of 1,500 L/min.m² or higher, nucleate-boiling cooling can be achieved more successfully. From the viewpoint of facility cost and running cost, the water current density is preferably 3,000 L/min.m² or less. The term "slit jet cooling" means that cooling is performed by discharging a high-speed stream of water from a slit nozzle for discharging cooling water, i.e., a slit jet cooling nozzle. In slit jet cooling, the momentum of water and the cooling rate are relatively high. A cooling device including the slit jet cooling nozzle is referred to as "slit jet cooling unit".

[0046] In summary, if the temperature distribution of the steel plate in the width direction is uniformized before control cooling or at the initial stage of control cooling, the temperature distribution of the steel plate in the width direction is also uniform after control cooling. Furthermore, in control cooling, by using a cooling nozzle that can increase the momentum of water, cooling can be performed in the nucleate boiling region, thus achieving the same cooling rate.

[0047] The above-described concepts can be applied to not only the edges of the steel plate in the width direction but also the top and tail ends of the steel plate in the longitudinal direction.

[0048] The present invention will be described on the basis of the drawings.

[0049] Fig. 6 is a conceptual view of a control-cooling device of a steel plate according to an embodiment of the present invention. A transfer-type control-cooling device is used as a control-cooling device 20. The transfer-type control-cooling device is a device for cooling a steel plate while transferring the steel plate. The transfer-type control-cooling device advantageously has satisfactory temperature controllability compared with that of a fixed-type control-cooling device because zone control is available described below. For example, in the fixed-type control-cooling device, when the temperature of a steel plate reaches a predetermined temperature, the injection of cooling water is stopped. However, there is a delay in response of a stop valve in stopping. Therefore, precise control of cooling time is difficult. As shown in the figure, a material slab of a steel plate is rolled with a thick-plate rolling mill 1 to form a steel plate 2 having a predetermined thickness. The resulting steel plate is transferred with a roller table 3 into a control-cooling device 20 and is cooled to a temperature at which cooling is stopped at a predetermined cooling rate while transferring the plate. The control-cooling device 20 includes an upper header 21 above a pass line for the steel plate 2, a lower header 22 below the pass line, and slit jet cooling nozzles 23 and 24 for discharging high-pressure water attached to these upper and lower headers. The control-cooling device 20 has a function of rapidly cooling the steel plate with ultra-high-pressure discharged water allowed to collide with the surfaces of the steel plate 2. To measure the temperature of the steel plate before and after control cooling, thermometers 31 and 32 are disposed at the entrance side and the exit side of the control-cooling device 20.

[0050] Fig. 7 is a detail view of the control-cooling device 20. The control-cooling device 20 includes a plurality of

cooling zones. The cooling zones are separated with drain rolls 27. The amount of cooling water used in each zone can be individually adjusted. The cooling zones are referred to as "zone 1", "zone 2", and the like in that order from the roll mill. The slit jet cooling nozzles can discharge water at a water current density of 1,200 L/min.m² or more so that heat transfer due to nucleate boiling is caused and so that cooling can be performed at the same cooling rate across the width direction of the steel plate.

[0051] The control-cooling device 20 includes a front section 25 and a rear section 26. In the front section 25 of the control-cooling device, masking members are disposed at each cooling zone, and thus the amount of cooling water for the edges of the steel plate in the width direction can be adjusted. As shown in Fig. 8, which is a cross-sectional view taken along line A-A in Fig. 7, a pair of upper masking members 28 are disposed below an upper slit jet cooling nozzle 23 and disposed at positions corresponding to both the edges of the steel plate in the width direction, and a pair of lower masking members 29 are disposed above a lower slit jet cooling nozzle 24 and disposed at positions corresponding to both the edges of the steel plate in the width direction. The upper and lower masking members 28 and 29 are moved by a mechanism 16 for moving the masking members in the width direction of the steel plate 2. The upper and lower masking members 28 and 29 can be independently moved. For example, only the upper members or only the lower members can be moved. Alternatively, the upper and lower members can be moved at the same time. The upper and lower masking members 28 and 29 disposed at the front section 25 of the control-cooling device 20 can be independently moved in every cooling zone. For example, the masking members can be disposed above and under the edges of the steel plate at only one cooling zone. Alternatively, the masking members can be disposed above and under the edges of the steel plate at all cooling zones in the front section.

[0052] According to a first embodiment of the present invention, in a first step, cooling is performed while the amount of cooling water for both ends of the steel plate in the width direction in the cooling zones of the front section is limited so that the temperature at the edges of the steel plate in the width direction and the temperature at the middle of the steel plate are identical. Next, in a second step, control cooling is performed at the same cooling rate across the entire width direction of the steel plate at the cooling zones in the rear section.

[0053] In limiting the amount of water contacting the edges of the steel plate in the width direction, to determine the number of zones masked and the distance masked, with respect to information about the edges of the steel plate in the width direction before cooling, definitions are made as shown in Fig. 9. The term "temperature drop distance" is defined as the distance from an edge of a steel plate in the width direction to a position where the temperature gradient in the steel plate in the width direction is zero. The term "the amount of temperature drop" is defined as the difference between the temperature at an edge of the steel plate in the width direction and the temperature at the position where the temperature gradient in the steel plate in the width direction is zero.

[0054] The amount of temperature drop and the temperature drop distance vary depending on, for example, the thickness of a material plate and the heating conditions before rolling, the width of the steel plate after completion of rolling, the thickness of a product, and a temperature at which rolling is completed. In a typical rolled material, the amount of temperature drop at each of the edges of a steel plate in the width direction is in the range of about 40°C to 50°C, and the temperature drop distance at each of the edges of the steel plate in the width direction is in the range of about 100 to 300 mm. The amount of temperature drop measured at each of the edges of a steel plate in the width direction and the temperature drop distance measured at each of the edges of the steel plate in the width direction may be analyzed in terms of a parameter, such as the thickness of the material before rolling, to form a table. Alternatively, a scanning thermometer for measuring the temperature distribution of the entire surface of the steel plate may be disposed before the control-cooling device, and then the measured value may be processed with a computer.

[0055] In the front section of the control-cooling device, according to the resulting information, the middle of the steel plate in the width direction is subjected to usual cooling, and the edges of the steel plate in the width direction are air-cooled as much as possible by limiting the amount of cooling water used by using the masking members so that the temperature at the middle of the steel plate and the temperature at each of the edges of the steel plate in the width direction are identical. In this first cooling step, the target value of a variation in the temperature distribution of the steel plate in the width direction is 20°C or less and preferably 10°C or less.

[0056] With respect to the moving distance of the masking members, as shown in Fig. 9, the masking members should be moved so that the portions reduced in temperature at the edges of the steel plate in the width direction are masked. The number of cooling zones that require the masking members is determined as follows with reference to Fig. 10.

(1) The amount of cooling per zone ΔT is calculated using the following formula:

$$\Delta T = DT/N,$$

where N represents the total number of cooling zones in the front and rear sections of the control-cooling device

and DT represents the temperature difference (amount of cooling) between a target temperature at which cooling is started and a target temperature at which cooling is completed.

(2) The number of cooling zones n , in which the middle of the steel plate can be cooled by the amount of temperature drop ED at the edge of the steel plate in the width direction before cooling, is determined from the amount of cooling per zone ΔT and by using the following formula:

$$n = ED/\Delta T.$$

(3) The masking members are used from zone 1, which is the first zone in the front section of the control-cooling device, to zone n , which is determined in (2).

[0057] The number of cooling zones calculated is not always an integer. In this facility, masking can be performed with the upper masking members alone or the lower masking members alone. Thus, the cooling can be controlled on a 0.5-zone basis. For example, when the number of cooling zones is calculated to be 1.4, cooling should be performed in 1.5 zones. To be more specific, in zone 1, the upper and lower masking members are used, and, in zone 2, the upper masking members are used alone. Here, an optimum reduction in the length of the machine used in each cooling zone and an increase in the number of cooling zones improve temperature controllability at the edges of the steel plate in the width direction.

[0058] Furthermore, it is preferred that the edges of the steel plate in the width direction be substantially air-cooled by preventing the edges from being exposed to cooling water. As the temperature at each of the edges of the steel plate in the width direction approaches the temperature at the middle of the steel plate, the time required to uniformize the temperature distribution at the middle and the edges of the steel plate in the width direction is increased, thus increasing the number of cooling zones that require the masking members. As a result, the amount of cooling in the rear section of the control-cooling device is reduced. Therefore, the effect of the present invention, i.e., the advantage in that the cooling rate at each of the edges of the steel plate in the width direction is identical to that at the middle of the steel plate, is not satisfactorily achieved.

[0059] Fig. 11 shows the temperature distributions in a steel plate in the width direction before and after cooling when the cooling is performed by the above-described process as an example of the present invention. The steel plate has a thickness of 30 mm, a width of 3,200 mm, and a length of 25 m. Cooling of the steel plate was started at 750°C and stopped at 550°C at the middle of the steel plate in the width direction. Before cooling, the amount of temperature drop was 30°C at each of the edges of the steel plate in the width direction, and the temperature drop distance was 200 mm at each of the edges of the steel plate in the width direction. The cooling device used in an embodiment of the present invention has the above-described configuration, and the number of cooling zones is 10. The current density of cooling water discharged from both upper and lower nozzles was 1,800 L/min.m². The number of zones that require the masking members was calculated to be 1.5 according to the above-described method. The upper and lower masking members were used in zone 1, and only the lower masking members were used in zone 2. With respect to the moving distance of the masking members, since the temperature drop distance was 200 mm, each masking member was moved so that the masking member can mask a region ranging from the edge to a position 200 mm distant from the edge. In this case, the amount of temperature drop was 30°C at each of the edges of the steel plate in the width direction before cooling. After cooling, the temperature drop had been substantially eliminated. By way of comparison, cooling was performed without the masking member. After cooling, the amount of temperature drop was 60°C. A variation in the temperature distribution in the steel plate in the width direction was increased.

[0060] At the cooling zones in the front section, the top and tail end of a steel plate in the longitudinal direction are cooled while the amount of cooling water is limited so that the temperatures at the top and tail ends of the steel plate in the longitudinal direction are identical to that at the middle of the steel plate. At the cooling zones in the rear section, cooling is performed at the same cooling rate across the entire longitudinal direction of the steel plate.

[0061] In this case, a method similar to the above-described method for cooling the edges of the steel plate in the width direction is applicable. To performing control cooling for the top and tail ends of the steel plate in the longitudinal direction, as shown in Fig. 12, in the control-cooling device shown in Figs. 6 and 7, the passage of the top end of the steel plate 2 through the control cooling zones is detected with, for example, a photo cell 17. A timer is set so that a flow controller 41 including a flow meter and a flow-adjusting valve starts operating at a timing in which the steel plate enters the above-described separated cooling zones with reference to the time of the passage of the steel plate detected with the photo cell 17. As an alternative method for controlling the flow rate, as shown in Fig. 13, a three-way valve 42 is disposed at the front section of the control-cooling device. Cooling water may be stopped for the top and tail ends of the steel plate by introducing cooling water into the exterior.

[0062] In limiting the amount of water contacting the top and tail ends of the steel plate in the longitudinal direction,

to determine the number of zones masked and the distance masked, with respect to information about the top and tail ends of the steel plate in the longitudinal direction before cooling, definitions are made as shown in Fig. 14. The definitions of the amount of temperature drop and the temperature drop distance at each of the top and tail ends of the steel plate are the same as those at each of the edges of the steel plate in the width direction shown in Fig. 9. The amount of temperature drop and the temperature drop distance vary depending on, for example, the thickness of a material plate and the heating conditions before rolling, the width of the steel plate after completion of rolling, the thickness of a product, and a temperature at which rolling is completed. In a typical rolled material, the amount of temperature drop at each of the top and tail ends of the steel plate is about 40°C to 50°C, and the temperature drop distance at each of the top and tail ends of the steel plate is about 300 to 500 mm. The amount of temperature drop at each of the top and tail ends of the steel plate and the temperature drop distance at each of the top and tail ends may be analyzed in terms of a parameter, such as the thickness of a material before rolling, to form a table. Alternatively, a surface thermometer, such as a scanning thermometer or a spot thermometer, for measuring the temperature distribution of the entire surface of the steel plate may be disposed before the control-cooling device, and then the measured value may be processed with a computer.

[0063] In the front section of the control-cooling device, according to the resulting information, the middle of the steel plate in the longitudinal direction is subjected to usual cooling, and the top and tail ends of the steel plate in the longitudinal direction are air-cooled as much as possible by limiting the amount of cooling water used by using the masking members so that the temperature at the middle of the steel plate and the temperature at each of the top and tail ends are identical. In this case, a concept similar to the one when the masking members are used for the width direction of the steel plate is applicable. For example, to compensate the temperature reduced at the top end of the steel plate in the longitudinal direction, as shown in Fig. 15, the timer should be set as follows: At first, cooling water is stopped at each of the cooling headers in the control-cooling device 20 (Fig. 15A). At the timing in which the boundary between the top end with a reduced temperature and the middle of the steel plate enters each cooling zone, the flow controller 41 operates to discharge cooling water (Fig. 15B).

[0064] To compensate the temperature reduced at the tail end of the steel plate in the longitudinal direction, as shown in Fig. 16, the timer should be set as follows: At first, cooling water is discharged at each of the cooling headers in the control-cooling device 20 (Fig. 16A). At the timing in which the boundary between the tail end with a reduced temperature and the middle of the steel plate in the longitudinal direction enters each cooling zone, the flow controller 41 operates to stop cooling water (Fig. 16B).

[0065] The number of cooling zones in which the flow controller 41 operates is determined in the same way as for the control process for the steel plate in the width direction and as follows:

(1) The amount of cooling per zone ΔT is calculated using the following formula:

$$\Delta T = DT/N,$$

where N represents the total number of cooling zones in the front and rear sections of the control-cooling device and DT represents the temperature difference (amount of cooling) between a target temperature at which cooling is started and a target temperature at which cooling is completed.

(2) The number of cooling zones nL , in which the middle of the steel plate in the longitudinal direction can be cooled by the amount of temperature drop EDL at the top end or the tail end of the steel plate before cooling, is determined from the amount of cooling per zone ΔT and by using the following formula:

$$nL = EDL/\Delta T.$$

(3) The masking members are used from zone 1, which is the first zone in the front section of the control-cooling device, to zone nL , which is determined in (2).

[0066] The number of cooling zones calculated is not always an integer. For example, when the number of cooling zones is calculated to be 1.4, a near-integer zone, i.e., zone 1 is used. This is different from the case of the control of the steel plate in the width direction. For example, if cooling water is discharged to only the upper surface of the steel plate, warpage may occur because of the temperature difference between the upper and lower surfaces. The warpage at the top and tail ends in the longitudinal direction is not preferable because the warpage is difficult to correct with a roller leveler or the like in a subsequent correcting step. Also, in the longitudinal direction of the steel plate as in the case of the width direction of the steel plate, an optimum reduction in the length of the machine used in each cooling zone

and an increase in the number of cooling zones improve temperature controllability at the top and tail ends of the steel plate in the longitudinal direction. Furthermore, it is preferred that the top and tail ends of the steel plate in the longitudinal direction be substantially air-cooled by preventing the top and tail ends from being exposed to cooling water. As in the case of the control for the steel plate in the width direction, with the temperature at the edges of the steel plate in the width direction approaches the temperature at the middle of the steel plate, the time required to uniformize the temperature distribution at the middle and the top and tail ends of the steel plate in the longitudinal direction is increased, thus increasing the number of cooling zones in which flow control is performed. As a result, the amount of cooling in the rear section of the control-cooling device is reduced. Therefore, the effect of the present invention, i.e., the advantage in that the cooling rate at each of the top and tail ends of the steel plate in the longitudinal direction is identical to that at the middle of the steel plate in the longitudinal direction, is not satisfactorily achieved.

[0067] A cooling control for the above-described the top and tail ends with reduced temperatures of the steel plate in the longitudinal direction can be performed as in the same way for the edges of the steel plate in the width direction. Therefore, the steel plate can be uniformly cooled across the longitudinal direction.

[0068] This process is advantageous in that cooling for the steel plate in the width direction and cooling for the top and tail ends of the steel plate in the longitudinal direction can be independently controlled by controlling the number of zones that require the masking members to eliminate the temperature drop of the steel plate in the width direction and the number of cooling zones in which the flow rate of water at each of the top and tail ends of the steel plate in the longitudinal direction is controlled to eliminate the temperature drop at each of the top and tail ends in the longitudinal direction. Therefore, even when the amount of temperature drop at each edge and the amount of temperature drop at each of the top and tail ends are different (for example, the amount of temperature drop is 30°C at each of the edges of the steel plate in the width direction and the amount of temperature drop is 70°C at each of the top and tail ends of the steel plate in the longitudinal direction), the temperature distribution can be uniformized.

[0069] Fig. 17 is a conceptual view of a control-cooling device for cooling a steel plate according to a second embodiment of the present invention. The hot-rolled steel plate 2 is transferred with the roller table 3 into an auxiliary cooling device 10 and then the control-cooling device 20 and is cooled to a temperature at which cooling is stopped at a predetermined cooling rate.

[0070] The auxiliary cooling device 10 is a cooling device disposed before the control-cooling device in order to achieve the first cooling step of the present invention. The auxiliary cooling device 10 should have the ability to reduce the temperature at least about 40°C to 50°C, which is the amount of temperature drop at the edges of the steel plate in the width direction. The auxiliary cooling device 10 includes an upper header 11 above a pass line for the steel plate 2, a lower header 12 below the pass line, and nozzles (not shown) attached to these headers. Streams of water 13 and 14 discharged from the nozzles are allowed to collide with the upper and lower surfaces of the steel plate 2 to achieve laminar-flow cooling. The term "laminar-flow cooling" means a method for cooling a steel plate by generating a water film on the surface of the steel plate using a laminar flow, which is generated under a slow stream of water. The cooling rate obtained by the laminar-flow cooling is relatively low. A cooling device using laminar-flow cooling is referred to as a "laminar-flow cooling unit".

[0071] As in the case of the first embodiment of the present invention, the control-cooling device 20 includes an upper header 21 above a pass line for the steel plate 2, a lower header 22 below the pass line, and slit jet cooling nozzles 23 and 24 for discharging high-pressure water attached to these upper and lower headers. The control-cooling device 20 has a function of rapidly cooling the steel plate with ultra-high-pressure discharged water allowed to collide with the surfaces of the steel plate 2. Furthermore, as shown in Fig. 7, the control-cooling device 20 includes a plurality of cooling zones. The cooling zones are separated with drain rolls 27 (not shown). The amount of cooling water used in each zone can be individually adjusted. The cooling zones are referred to as "zone 1", "zone 2", and the like in that order from the roll mill. Cooling water can be discharged at a water current density of 1,200 L/min.m² or more so that heat transfer due to nucleate boiling is caused and so that cooling can be performed at the same cooling rate across the width direction of the steel plate.

[0072] To measure the temperature of the steel plate before and after cooling, thermometers 30, 31, and 32 are disposed at the entrance side of the auxiliary cooling device 10, and at the entrance and exit sides of the control-cooling device 20.

[0073] In a second embodiment of the present invention, the auxiliary cooling device 10 including the laminar flow unit and the control-cooling device 20 including the slit jet cooling unit having slit jet cooling nozzles are used together. In the auxiliary cooling device including the laminar flow unit, the amount of cooling water is controlled for the edges of the steel plate 2 in the width direction and the top and tail ends of the steel plate.

[0074] As shown in Fig. 18, which is a cross-sectional view taken along line A-A in Fig. 17, a pair of masking members 15 are disposed below the upper header 11, above the lower header 12, and at positions corresponding to both the edges of the steel plate in the width direction in the auxiliary cooling device 10. The masking members 15 are moved by the mechanism 16 for moving the masking members in the width direction of the steel plate 2 to control the amount of cooling water for the steel plate in the width direction.

[0075] In the second embodiment of the present invention, the function of the front section of the control-cooling device in the first embodiment is replaced with the auxiliary cooling device 10. In the auxiliary cooling device 10, the masking members are disposed across the longitudinal direction of the device, thus ensuring the uniformity of the temperature distribution of the steel plate in the width direction. Subsequently, in the control-cooling device 20, cooling is performed at the same cooling rate from the edges of the steel plate in the width direction to the middle of the steel plate in the width direction. As described in the first embodiment of the present invention, the amount of temperature drop at each of the edges of the steel plate in the width direction is about 40°C to 50°C. Thus, to uniformize the temperature distribution of the steel plate in the width direction, the middle of the steel plate in the width direction should be cooled by 40°C to 50°C without cooling the edges of the steel plate in the width direction. The target amount of cooling is very small. Therefore, the cooling rate is decreased to perform cooling for a relatively long period of time, thus resulting in ease of control with high accuracy. Thus, in the second embodiment of the present invention, the uniformity of the temperature distribution of the steel plate in the width direction can be higher than that in the first embodiment. In this process, facility that can decrease the temperature of the steel plate by about 40°C to 50°C should be disposed before the control-cooling device. Thus, the facility can be installed at low cost. As the control method, in the same way as for the first embodiment, the masking members may be used at cooling zones in the front section of the auxiliary cooling device. Alternatively, the masking members may be used at all cooling zones in the cooling device. When the masking members are used at the front section of the auxiliary cooling device as the former, the edges of the steel plate are cooled at the rear section of the auxiliary cooling device. Thus, the temperature at which control cooling is started is lower than that of the latter. Therefore, preferably, the masking members are used at all cooling zones in the cooling device as the latter, and then cooling is performed at an adjusted transferring rate of the steel plate.

[0076] In limiting the amount of water contacting the edges of the steel plate, to determine the cooling time and the distance masked, with respect to information about the edges of the steel plate before auxiliary cooling, definitions are made as shown in Fig. 9 in the first embodiment. The amount of temperature drop and the temperature drop distance, as in the case of the first embodiment described above, vary depending on, for example, the thickness of a material plate and the heating conditions before rolling, the width of the steel plate after completion of rolling, the thickness of a product, and a temperature at which rolling is completed. Thus, the measured values thereof may be analyzed to form a table. Alternatively, a surface thermometer, such as a scanning thermometer, for measuring the temperature distribution of the entire surface of the steel plate may be disposed before the control-cooling device, and then the measured value may be processed with a computer.

[0077] In the auxiliary cooling device, according to the resulting information, the middle of the steel plate in the width direction is subjected to usual cooling, and the edges of the steel plate in the width direction are air-cooled as much as possible by limiting the amount of cooling water used by using the masking members so that the temperature at the middle of the steel plate and the temperature at each of the edges of the steel plate in the width direction are identical. With respect to the moving distance of the masking members, as shown in Fig. 9, the masking members should be moved so that the portions reduced in temperature of the edges of the steel plate in the width direction are masked. The cooling time required to decrease the temperature of the steel plate by the amount of temperature drop at each of the edges of the steel plate in the width direction with the auxiliary cooling device 10 is calculated, and then the transferring rate of the steel plate should be determined from the cooling time and the length of the facility. This calculation is easier than that in the first embodiment. Furthermore, this embodiment is different from the first embodiment in that the cooling is not controlled on a 0.5-zone basis. That is, the cooling time can be continuously controlled, thus improving the uniformity of the temperature distribution in the width direction of the steel plate.

[0078] In the auxiliary cooling device, the current density of cooling water is preferably in the range of 100 to 500 L/min.m². As described in means for solving the problems, to perform cooling at a uniform cooling rate across the width direction of the steel plate, supercooling due to the drain from the edges of the steel plate in the width direction should be prevented. Thus, a cooling method with high momentum of water is preferable (to be more specific, a slit jet cooling nozzle having a current density of 1,200 L/min.m² or more is used). In this auxiliary cooling device, the same cooling rate cannot be achieved from the edges to the middle of the steel plate in the width direction. However, the amount of temperature drop at each of the edges of the steel plate in the width direction is very small (40°C to 50°C), and the temperature of the steel plate before control cooling should be uniformized across the width direction at high temperatures at which the material is not determined; hence, as shown in Fig. 1, the heat transfer characteristics in the film boiling region, which is present at a low flow rate and a high surface temperature, is applied. Under the presence of a variation in the temperature distribution in the steel plate in the width direction before cooling, in the transition boiling region shown in Fig. 1, lower surface temperatures of the steel plate result in higher cooling power (heat flux). Thus, at a low-temperature region, such as the edges of the steel plate in the width direction, before cooling, cooling power (heat flux) is increased at an accelerated pace. On the other hand, in the film boiling region, higher temperatures result in higher cooling power (heat flux); hence, the variation in the temperature distribution of the steel plate in the width direction is not increased. Therefore, in the auxiliary cooling device, when cooling is controlled so that cooling on the basis of film boiling is maintained, supercooling of the edges of the steel plate due to a change in boiling state can be prevented. As a result,

only supercooling due to amount of water increased by drain at the edges of the steel plate should be considered. Thus, the temperature distribution of the steel plate in the width direction can be uniformized with relative ease. Furthermore, in film boiling, since cooling power (heat flux) is low, there is an advantage in successfully controlling a decrease in temperature by 20°C to 30°C, which is the amount of temperature drop of the edges of the steel plate. To realize this, the current density of cooling water in the auxiliary cooling device 10 is in the range of 100 to 500 L/min.m², thereby achieving stable film boiling. Furthermore, to realize film boiling, the presence of a stable vapor film between the steel plate and cooling water is required. Thus, a cooling method in which the momentum of water is low, for example, spray cooling or laminar-flow cooling is preferably employed.

[0079] On the other hand, in the same way as in the first embodiment, the amount of cooling water for the top and tail ends of the steel plate is adjusted by cutting off the stream of water in passing the top and tail ends of the steel plate in the longitudinal direction. To be specific, as shown in Fig. 19, the upper header 11 in the laminar-flow cooling device 10 is divided into four segments: 11a to 11d (in Fig. 19). The passage of the top end of the steel plate 2 in the longitudinal direction through the laminar-flow cooling device 10 is detected with the photo cell 17. Timers T1 to T4 are set so that the divided upper header segments start operating with reference to the time of the passage of the steel plate detected with the photo cell 17. Then, the upper header 11 is operated in response to the travel stage of the steel plate shown in Fig. 19, thereby improving the cooling of the top end of the steel plate in the longitudinal direction. With respect to the control of the timing in which cooling water is discharged, the same control as that in the first embodiment should be performed on the basis of the temperature drop distance of the top end of the steel plate in the longitudinal direction, the temperature drop distance being determined in advance or measured before auxiliary cooling, in the same way as in the first embodiment. In a similar way, the amount of cooling water for the tail end of the steel plate in the longitudinal direction should be adjusted as shown in Fig. 20.

[0080] In this way, the cooling control of the top and tail ends of the steel plate in the longitudinal direction can be performed by the same method as that in the first embodiment of the present invention.

[0081] On the other hand, cutting off cooling water at the top and tail ends of the steel plate in the longitudinal direction is essentially no different from limiting the amount of cooling water for the edges of the steel plate in the width direction with the masking members to cool only the middle in the width direction. When the amount of temperature drop of the steel plate in the width direction and the amount of temperature drop of each of the top and tail ends of the steel plate in the longitudinal direction are identical, the temperature distribution can be uniformized across the entire surface of the steel plate. However, in the second embodiment, when the amount of cooling water for the edges of the steel plate in the width direction is limited along the entire auxiliary cooling device, either the temperature distribution of the steel plate in the width direction or the temperature distribution of the top and tail ends of the steel plate can be uniformized because cooling for the width direction of the steel plate and cooling for the longitudinal direction of the steel plate cannot be independently controlled.

[0082] Examples of a method for uniformizing both the temperature distribution of the steel plate in the width direction and the temperature distribution in the longitudinal direction include a process in which a plurality of cooling zones are disposed in the auxiliary cooling device in the same way as in the first embodiment, and then the amount of cooling water for the edges of the steel plate in the width direction is controlled at the front section of the auxiliary cooling device, and a process in which the temperature distribution of the steel plate in the width direction is uniformized with the auxiliary cooling device, and then control cooling described in the first embodiment is performed for the top and tail ends of the steel plate in the longitudinal direction in the subsequent control cooling device. The latter process is preferable. The former process is disadvantageous in that the cooling time cannot be continuously adjusted because of the control on the basis of the number of cooling zones in the auxiliary cooling device, thereby unsatisfactorily achieving the uniformity of the temperature distribution in the width direction with high accuracy. Furthermore, in uniformizing the temperature distribution in the longitudinal direction of the steel plate in the auxiliary cooling device, for example, when the amount of temperature drop at each of the top and tail ends of the steel plate is greater than the amount of temperature drop at each of the edges of the steel plate in the width direction, the middle of the steel plate in the width and longitudinal directions must be cooled corresponding to each of the top and tail ends, in which the amount of temperature drop is large. Therefore, control cooling must be performed from a lower temperature compared with the case in which the temperature distribution in the width direction of the steel plate is uniformized. However, from the standpoint of a material, control cooling is preferably performed from a higher temperature. When control cooling is performed from a low temperature, ferrite transformation occurs before control cooling, thereby reducing quench characteristics, in some cases. Furthermore, it is often the case that the uniformity of the temperature distribution at the edges of the steel plate in the width direction is important. Therefore, as the latter process, a process including uniformizing the temperature distribution in the width direction in auxiliary cooling and uniformizing the temperature distribution in the longitudinal direction of the steel plate in control cooling is preferable.

[0083] The process according to the first embodiment and the process according to the second embodiment have been described above. At least one process selected from the processes may be performed in accordance with a production line to be used and product characteristics. For example, when auxiliary cooling cannot be performed at the

initial stage of cooling from the standpoint of the material or when there is no space for installing an auxiliary cooling device, the process according to the first embodiment may be employed. When higher uniformity of the material of the steel plate in the width direction is achieved compared with the uniformity of the material of the steel plate in the longitudinal direction or when an auxiliary cooling device and a control cooling device are installed in series, the process according to the second embodiment may be employed.

[0084] Furthermore, in the first embodiment, a leveler 30 may be disposed before the control-cooling device 20. In the second embodiment, as shown in Fig. 21, the leveler 30 may be disposed between the auxiliary cooling device 10 and the control-cooling device 20. When the steel plate has poor flatness before cooling, the temperature uniformity may become slightly worse because of a variation in the distance between the nozzle and the steel plate depending on positions of the steel plate. By leveling the steel plate before control cooling, control cooling can be performed more uniformly. Furthermore, the leveler 30 may be disposed at the delivery side of the control-cooling device 20.

[0085] The masking member used in the present invention may have any structure, such as a block type, a plate, or a canaliculated type, as long as the masking member can prevent each of the edges of the steel plate in the width direction from being exposed to water discharged from the nozzle. However, preferably, the masking member is composed of a corrosion-resistant material and has a structure with high stiffness because high-pressure water always collide with the masking member. In view of ease of production and handleability of the masking member, the masking member is preferably in the form of a plate. When such a masking plate is used, preferably, the size of the masking plate is slightly longer than the maximum temperature drop distance at each of the edges of the steel plate. In the case of the masking plate having a length shorter than the distance, if the temperature drop distance at each of the edges of the steel plate is greater than the length of the masking plate, the masking plate cannot entirely cover the edge. On the contrary, in the case of an excessively long masking plate, the mechanism for moving the masking plate becomes excessively large, thus resulting in the difficulty of the installation of the masking plate in a narrow space, for example, in the control-cooling device. As described above, since a typical temperature drop distance at each of the edges of the steel plate is about 300 mm at a maximum, the length of the masking plate should be set at about 350 to 400 mm. Preferable examples of the material for the masking plate include a corrosion-resistant material, such as stainless steel, an anti-corrosion coated steel plate, and a carbon steel plate plated with zinc, chromium, or the like because cooling water used in the production line often contains a corrosive substance, such as chlorine.

EXAMPLES

[0086] Table 1 shows the operating conditions in performing control cooling according to the present invention and in performing control cooling according to known method (Comparative example). Table 2 shows the comparison between the effects thereof. The conditions of a steel plate treated are described as follows: A steel plate having a thickness of 25 mm, a width of 3,800 mm, and a length of 25 m was used. Control cooling was started from 750°C at the middle of the steel plate in the width direction and stopped at 550°C. The strength of the steel plate was 490 MPa level. The tolerance was in the range of 490 to 610 MPa. Before cooling, in Fig. 9, the amount of temperature drop at each of the edges of the steel plate in the width direction was 30°C, and the temperature drop distance at each of the edges of the steel plate in the width direction was 200 mm. In Fig. 14, the amount of temperature drop at each of the top and tail ends of the steel plate in the longitudinal direction was 50°C, and the temperature drop distance at each of the top and tail ends of the steel plate in the longitudinal direction was 500 mm. In Inventive examples 1 and 2, a masking member (hereinafter referred to as "masking plates") used in a control-cooling device, as shown in Figs. 25 and 26, was a Zn-Ni-plated steel plate. In each cooling zone, four masking plates were disposed on the left, right, top and bottom of the steel plate. Each of the masking plates had a length of 300 mm, a width of 350 mm, and a thickness of 7 mm. Each of the masking plates was disposed at 15° to horizontal so that cooling water blocked with the masking plates did not fall to the steel plate again. In Inventive examples 3 and 4, a masking plate used in an auxiliary cooling device was an L-shaped Zn-Ni-plated steel plate such that the masking members can block cooling water across the entire length (10 m) of the auxiliary cooling device. Each of the masking members had a length of 10 m, a width of 350 mm, a thickness of 7 mm, and a height of 50 mm. four masking plates were disposed on the left, right, top and bottom of the steel plate. In the auxiliary cooling device, since the masking member was significantly long, deflection due to its own weight may occur. To ensure the stiffness of the masking member, as shown in Fig. 27, the masking member was processed in L-shape, and ribs were attached at intervals of 500 mm. As shown in Fig. 28, the masking members were disposed so that each of the plate segments in the vertical direction was disposed inwardly in the width direction. Thus, cooling water blocked with the masking members did not fall to the steel plate.

[0087] Inventive example 1 is an example corresponding to the first embodiment. Cooling was performed with the apparatus described in Figs. 6 to 8. The control conditions will be described in detail based on Fig. 7. The number of cooling zones was 15, and the length of each zone was 1.0 m, the entire length of the control-cooling device was 15 m. In each zone, cooling water was discharged at a current density of 1,500 L/min.m². In this case, the cooling rate was about 30 °C/s. Cooling was started from 750°C and stopped at 550°C. Thus, the amount of cooling per zone was (750°C

- 550°C)/15 zones = 13.3°C. Hence, the number of zones required to use the masking members at the edges of the steel plate in the width direction was 30°C/13.3°C = 2.26 zones. In fact, the number of zones used was 2.5. In zone 1 and zone 2, the upper and lower masking members were used. In zone 3, only the lower masking members were used. With respect to the moving distance of the masking members, since the temperature drop distance was 200 mm, the moving distance was set so that the masking member can prevent a region ranging from the edge to a position 200 mm distant from the edge from being exposed to cooling water. On the other hand, the flow rate at each of the top and tail ends of the steel plate in the longitudinal direction was adjusted with a flow controller as shown in Fig. 12. The amount of temperature drop at each of the top and tail ends of the steel plate in the longitudinal direction was 50°C, and the number of zones required was 50°C/13.3°C = 3.8. Thus, the adjustment was performed from zone 1 to zone 4. In the top end of the steel plate in the longitudinal direction, as shown in Fig. 15, at first, cooling water did not discharged as shown in Fig. 15A. As shown in Fig. 15B, when the steel plate entered the cooling device by the temperature drop distance at the top end of the steel plate in the longitudinal direction, cooling water was discharged. As shown in Fig. 16, the control of flow rate for the tail end of the steel plate in the longitudinal direction was also performed in a similar way. The cooling rate with the control-cooling device was about 30 °C/s. The cooling time required for control cooling was (750°C - 550°C)/30°C/s = 6.6 sec. Thus, the transfer rate of the steel plate in the control-cooling device was (15 m/6.6 sec) × 60 = 134 mpm.

[0088] Inventive example 2 is another example corresponding to the first embodiment. Current density of cooling water was set at 1,200 L/min.m². The conditions other than the current density of cooling water were the same as that in Inventive example 1.

[0089] Inventive example 3 is an example corresponding to the second embodiment. The apparatus described in Fig. 17 was used. Cooling was performed with the auxiliary cooling device 10 so that a variation in the temperature distribution of the steel plate in the width direction was uniformized. Then, cooling was performed with the control-cooling device 20 so that a variation in the temperature distribution of the top and tail ends of the steel plate in the longitudinal direction was uniformized. The auxiliary cooling device 10 shown in Fig. 17 had a length of 10 m and can discharge cooling water at a current density of 100 L/min.m². In this case, the cooling rate was about 4°C/s. The temperature at the each of the edges of the steel plate in the width direction was 720°C. Thus, the time required for cooling the middle of the steel plate in the width direction from 750°C to 720°C was (750°C - 720°C)/4°C/s = 7.5 sec. Hence, the transfer rate of the steel plate in the auxiliary cooling device 10 was (10 m/7.5 sec) × 60 = 80 mpm. Furthermore, as shown in Figs. 19 and 20, after each of the top and tail ends of the steel plate in the longitudinal direction entered the auxiliary cooling device by the temperature drop distance (500 mm) of each of the top and tail ends of the steel plate in the longitudinal direction, cooling water was discharged sequentially. With respect to the moving distance of the masking members, since the temperature drop distance was 200 mm, the moving distance was set so that the masking member can prevent a region ranging from the edge to a position 200 mm distant from the edge in the width direction from being exposed to cooling water.

[0090] In the control-cooling device shown in Fig. 17, as in the case in Inventive example 1, the number of cooling zones was 15 zones. The machine length of each zone was 1.0 m. The entire length of the control-cooling device was 15 m. In each zone, cooling water was discharged at a current density of 1,500 L/min.m². In this case, the cooling rate was 30°C/s. In the control-cooling device 20, cooling was started at 720°C and stopped at 550°C. The amount of cooling per zone was (720°C - 550°C)/15 zones = 11.3°C. With respect to the adjustment of the flow rate at each of the top and tail ends of the steel plate in the longitudinal direction, the amount of temperature drop at each of the top and tail ends of the steel plate in the longitudinal direction was 50°C. By eliminating a variation in temperature distribution with the auxiliary cooling device by 30°C, the control-cooling device was required to control the amount of temperature drop (20°C) at each of the top and tail ends of the steel plate in the longitudinal direction. Therefore, the number of zones required 20°C/11.3°C = 1.8 zones. Thus, the adjustment of the flow rate was performed zone 1 and zone 2. In the top end of the steel plate in the longitudinal direction, as shown in Fig. 15, at first, cooling water did not discharged as shown in Fig. 15A. As shown in Fig. 15B, when the steel plate entered the cooling device by the temperature drop distance (500 mm) at the top end of the steel plate in the longitudinal direction, cooling water was discharged. As shown in Fig. 16, the control for the tail end of the steel plate in the longitudinal direction was also performed in a similar way. The cooling rate with the control-cooling device was about 30 °C/s. The cooling time required for control cooling was (720°C - 550°C)/30°C/s = 5.7 sec. Thus, the transfer rate of the steel plate during control cooling was (15 m/5.7 sec) × 60 = 158 mpm. The flow rate adjustment for the top and tail ends of the steel plate in the longitudinal direction was the flow controller shown in fig. 12.

[0091] Inventive example 4 is an example in which a leveler is disposed between the auxiliary cooling device and the control-cooling device in the second embodiment. The cooling conditions are the same as that in Inventive example 3.

[0092] In Comparative example 1, cooling was performed with the same facility as that in Inventive example 1. The transfer rate of the steel plate was also the same as that in Inventive example 1. The masking members for controlling the temperature at the edges of the steel plate in the width direction was not used, and flow control for adjusting the temperature at the top and tail ends of the steel plate in the longitudinal direction was not performed.

[0093] In Comparative example 2, cooling was performed with the same facility as that in Inventive example 2. The

transfer rate of the steel plate in the auxiliary cooling device and in the control-cooling device was the same as that in Inventive example 2. The masking members for controlling the temperature at the edges of the steel plate in the width direction was not used, and flow control for adjusting the temperature at the top and tail ends of the steel plate in the longitudinal direction was not performed.

[0094] In Comparative example 3, the same facility as in Inventive example 2 was used. Cooling was performed with the auxiliary cooling device alone. Flow control for the edges of the steel plate in the width direction and for the top and tail ends of the steel plate in the longitudinal direction were not performed. In this example, the auxiliary cooling device 10 shown in Fig. 17 had a length of 10 m. Cooling water was discharged at a current density of 500 L/min.m². In this case, the cooling rate was 14°C/s. The cooling time required for cooling the steel plate from 750°C to 550°C was 14.3 sec. Thus, the transfer rate of the steel plate was 42 mpm in the auxiliary cooling device. In this example, the amount of water was greater than that in Inventive example 3 to increase the cooling rate. This is because the material was determined with the auxiliary cooling device alone. Thus, a slightly high cooling rate was set. In this case, flow control for the top and tail ends of the steel plate in the longitudinal direction was not performed, and the masking members for the width direction of the steel plate were not used.

[0095] In comparative example 4, the same facility as that in Inventive example 3 was used. Cooling was performed with only the auxiliary cooling device as in Comparative example 3. Flow control for the edges of the steel plate in the width direction and for the top and tail ends of the steel plate in the longitudinal direction was performed. In this example, the transfer rate of the steel plate was the same as that in Comparative example 3. Cooling was performed at the same current density of cooling water as that in Comparative example 3. With respect to the moving distance of the masking members, since the temperature drop distance was 200 mm, the moving distance was set so that the masking member can prevent a region ranging from the edge to a position 200 mm distant from the edge from being exposed to cooling water. As shown in Figs. 19 and 20, after each of the top and tail ends of the steel plate in the longitudinal direction entered the auxiliary cooling device by the temperature drop distance (500 mm) of each of the top and tail ends of the steel plate in the longitudinal direction, cooling water was discharged sequentially.

[0096] In Comparative example 5, the same facility as that in Inventive example 1 was used. Flow control for the edges of the steel plate in the width direction and for the top and tail ends of the steel plate in the longitudinal direction was performed in all cooling zones. In this example, cooling is performed at the same transfer rate of the steel plate as that in Example 1 and at the same current density of cooling water as in Example 1. The masking members were used in all cooling zones. Flow control for the top and tail ends of the steel plate in the longitudinal direction was performed in all cooling zones.

[0097] With respect to the moving distance of the masking members, since the temperature drop distance was 200 mm, the moving distance was set so that the masking member can prevent a region ranging from the edge to a position 200 mm distant from the edge from being exposed to cooling water in all cooling zones. In the top end of the steel plate in the longitudinal direction, as shown in Fig. 15, at first, cooling water did not discharged as shown in Fig. 15A. As shown in Fig. 15B, when the steel plate entered the cooling device by the temperature drop distance (500 mm) at the top end of the steel plate in the longitudinal direction, cooling water was discharged. As shown in Fig. 16, the control for the tail end of the steel plate in the longitudinal direction was also performed in a similar way.

[0098] With respect to the edges of the steel plate in the width direction, definitions are made as shown in Fig. 9. The term "temperature drop distance" is defined as the distance from an edge of a steel plate in the width direction to a position where the temperature gradient in the steel plate in the width direction is zero. The term "the amount of temperature drop" is defined as the difference between the temperature at an edge of the steel plate in the width direction and the temperature at the position where the temperature gradient in the steel plate in the width direction is zero. Thus, when the temperature at the edge of the steel plate in the width direction is lower than that at the middle of the steel plate, the amount of temperature drop is a positive value. When the temperature at the edge of the steel plate in the width direction is higher than that at the middle of the steel plate, the amount of temperature drop is a negative value. With respect to ends of the steel plate in the longitudinal direction, definitions are made as shown in Fig. 14. This definition is identical to the definition made for the amount of temperature drop and the temperature drop distance in the width direction of the steel plate.

[0099] Fig. 22 shows positions for cutting a steel plate after cooling. A top-end specimen 51 and a tail-end specimen 54 of the steel plate were cut out at positions 150 mm distant from the top end and the tail end of the steel plate in the longitudinal direction, respectively. A middle specimen 53 was cut out from the middle of the steel plate in the width and longitudinal directions. Test pieces were cut out from these specimens, and tensile strength was measured. With respect to the strength at each of the edges of the steel plate, the middle specimen cut from the middle of the steel plate in the width and longitudinal directions was cut at a position 100 mm distant from an edge thereof to form a test piece, and tensile strength was measured.

[0100] As shown in Figs. 23 and 24, a specimen 52 for measuring a camber of a bar cut in the width direction of the steel plate and a specimen 55 for measuring a camber of a bar cut in the longitudinal direction of the top and tail ends of the steel plate were each cut in a rectangular shape. Fig. 23 shows a position for cutting out the specimen for measuring

a camber of a bar cut in the width direction of the steel plate and a position for measuring the camber. The specimen was cut out at a position 300 mm distant from an edge of the steel plate. The maximum amount of bowing of the resulting rectangular specimen was defined as the camber of the bar cut in the width direction. Fig. 24 shows a position for cutting out the specimen for measuring a camber of a bar cut in the longitudinal direction of the steel plate and a position for measuring the camber. The specimen was cut out at a position 300 mm distant from the tail end of the steel plate in the longitudinal direction. The maximum amount of bowing of the resulting rectangular specimen was defined as the camber of the bar cut in the longitudinal direction.

[0101] As shown in table 2, when the present invention was applied, in spite of the high cooling rate as a whole, the amount of temperature drop at the edge of the steel plate in the width direction after cooling was decreased (-4°C to 3°C) compared with the amount of temperature drop before cooling (30°C) before cooling. Furthermore, the amount of temperature drop at the top and tail ends of the steel plate in the longitudinal direction was also decreased (-7°C to 10°C) compared with the amount of temperature drop (50°C) before cooling. As a result, the residual stress in the width direction of the steel plate was reduced, and the camber after bar cutting was small. The tensile strength of the steel plate was about 550 MPa at the top and tail ends of the steel plate in the longitudinal direction, the edges of the steel plate in the width direction, and the middle of the steel plate in the width and longitudinal directions and was stable. In Inventive example 4, leveling was performed after auxiliary cooling, and then control cooling was performed. The shape of the steel plate before control cooling was significantly flat compared with those in Inventive examples 1 and 2. As a result, the uniformity of the temperature distribution obtained by control cooling was improved. Consequently, the amounts of temperature drops at the edges of the steel plate in the width direction and the top and tail ends of the steel plate in the longitudinal direction were reduced. The camber after bar cutting was further decreased.

[0102] On the contrary, in Comparative examples 1 to 3, water flow control for the edges of the steel plate in the width direction and for the top and tail ends of steel plate in the longitudinal direction was not performed. As a result, the amounts of temperature drops in the width direction of the steel plate and the top and tail ends of the steel plate in the longitudinal direction after cooling were increased compared with those before cooling, thereby resulting in a large camber after bar cutting. Furthermore, the tensile strength at the edges of the steel plate in the width direction and at the top and tail ends of the steel plate in the longitudinal direction was increased compared with that at the middle of the steel plate. In some cases, the tensile strength exceeded the upper limit of the allowable range.

[0103] In Comparative examples 4 and 5, water flow control for the edges of the steel plate in the width direction and for the top and tail ends of the steel plate in the longitudinal direction was performed, but was not a method according to the present invention. As a result, the temperatures at the top and tail ends of the steel plate in the longitudinal direction and the edges of the steel plate in the width direction after cooling became high compares with those at the middle of the steel plate in the width and longitudinal directions. Therefore, the tensile strength at the edges of the steel plate in the width direction and at the top and tail ends of the steel plate in the longitudinal direction was small compared with that at the middle of the steel plate in the width and longitudinal directions. In some cases, the tensile strength was below the upper limit of the allowable range. Furthermore, the cambers of the cut bars were improved compared with those in Comparative examples 1 to 3, but were greater than those in Inventive examples 1 to 3.

Industrial Applicability

[0104] According to the present invention, in control-cooling a steel plate after completion of the rolling, the uniform temperature distribution on the surface of the steel plate can be achieved across the width and longitudinal directions of the steel plate. Control cooling for the steel plate can be performed at high cooling rate as a whole. As a result, the homogeneity of the material can be ensured in the width direction and longitudinal direction of the steel plate. Furthermore, strain and residual stress generated in cooling can be reduced.

Table 1

	Leveler	Cooling device		Zone of masking member used		Zone of flow-rate control employed for top and tail ends		Transfer rate of plate (mpm)		Temperature measurements (middle in width and longitudinal directions) (°C)			Cooling rate (middle in width and longitudinal directions) (°C/s)	
		Auxiliary cooling	Control cooling	Auxiliary cooling	Control cooling	Auxiliary cooling	Control cooling	Auxiliary cooling	Control cooling	Entry side of auxiliary cooling device	Entry side of control-cooling device (delivery side of auxiliary cooling device)	Delivery side of control-cooling device	Auxiliary cooling	Control cooling
Inventive example 1	Unused	Unused	Used	Unused	1-2z: Upper and lower, 3z: Only lower	Unused	1-4z	-	134	-	751	543	-	31.0
Inventive example 2	Unused	Unused	Used	Unused	2-2z: Upper and lower, 3z: Only lower	Unused	1-4z	-	133	-	755	553	-	30.0
Inventive example 3	Unused	Used	Used	All zones	Unused	All zones	1-2z	80	158	750	719	551	4.1	29.5
Inventive example 4	Used	Used	Used	All zones	Unused	All zones	1-2z	80	158	753	723	552	4.0	30.1
Comparative example 1	Unused	Unused	Used	Unused	Unused	Unused	Unused	-	134	-	752	552	-	29.8
Comparative example 2	Unused	Used	Used	Unused	Unused	Unused	Unused	80	158	746	714	545	4.3	29.7
Comparative example 3	Unused	Used	Unused	Unused	Unused	Unused	Unused	42	-	751	550	-	14.1	-
Comparative example 4	Unused	Used	Unused	All zones	Unused	All zones	Unused	42	-	748	549	-	13.9	-
Comparative example 5	Unused	Unused	Used	Unused	All zones	Unused	All zones	-	134	-	753	550	-	30.2

Table 2

	Amount of temperature drop (°C)		Camber of cut bar (mm)		Tensile strength (MPa)		
	Edge in width direction	Top and tail ends in longitudinal direction	Edge in width direction	Top and tail ends in longitudinal direction	Middle in width and longitudinal directions	Edge in width direction	Top and tail ends in longitudinal direction
Inventive example 1	-4	10	9	5	553	551	547
Inventive example 2	-5	9	10	4	556	550	547
Inventive example 3	3	-7	7	4	551	549	553
Inventive example 4	-1	5	3	2	549	555	546
Comparative example 1	31	49	90	21	549	620	650
Comparative example 2	52	74	157	32	548	630	610
Comparative example 3	67	83	202	36	551	650	599
Comparative example 4	-30	-30	91	13	551	490	501
Comparative example 5	-40	-18	121	8	550	485	499

Claims

1. A process for cooling a steel plate after completion of hot rolling, the process comprising: a first cooling step of cooling the steel plate while the temperature distribution in the width direction of the steel plate is uniformized; and a second cooling step of control-cooling the steel plate at the same cooling rate across the width direction of the steel plate after completion of the uniformization of the temperature distribution in the width direction of the steel plate.
2. The process for control-cooling the steel plate after completion of hot rolling according to claim 1, wherein the first

cooling step comprises cooling the steel plate while the amount of cooling water used for both edges of the steel plate in the width direction is limited at at least one entry-side cooling zone in a transfer-type control-cooling device including a plurality of independent cooling zones, and the second cooling step comprises control-cooling the steel plate at the same cooling rate across the width direction of the steel plate at a cooling zone subsequent to the at least one entry-side cooling zone.

3. The process for control-cooling the steel plate after completion of hot rolling according to claim 1, wherein the first cooling step comprises cooling the steel plate while the amount of cooling water used for both edges of the steel plate in the width direction is limited with an auxiliary cooling device, and the second cooling step comprises control-cooling the steel plate at the same cooling rate across the width direction of the steel plate with a transfer-type control-cooling device disposed at the delivery side of the auxiliary cooling device, the transfer-type control-cooling device including a plurality of independent cooling zones.
4. The process for control-cooling the steel plate according to any one of claims 1 to 3, wherein the amount of cooling water used for both edges of the steel plate in the width direction is limited with masking members disposed at the edges of the steel plate in the width direction.
5. The process for control-cooling the steel plate according to claim 2 or 4, wherein the amount of cooling water used for the top end and the tail end of the steel plate in the longitudinal direction is limited at the front section in the control-cooling device.
6. The process for control-cooling the steel plate according to claim 3 or 4, wherein the amount of cooling water used for the top end and the tail end of the steel plate in the longitudinal direction is limited by the auxiliary cooling device or the auxiliary cooling device and the control-cooling device.
7. The process for control-cooling the steel plate according to claim 5 or 6, wherein the amount of cooling water used for the top end and the tail end of the steel plate in the longitudinal direction is limited by control means for controlling the amount of water, the control means operating for a predetermined period of time in response to a passing signal for each of the top end and the tail end of the steel plate in the longitudinal direction.
8. The process for control-cooling the steel plate according to any one of claims 2, 4, 5, and 7, wherein the front section in the control-cooling device comprises masking members capable of limiting the amount of water used for the edges of the steel plate in the width direction, the masking members being disposed at the edges of the steel plate in the width direction and disposed in each zone, and each of the masking members independently blocks cooling water for each of the edges of the steel plate in the width direction per zone, per upper surface, or per lower surface.
9. The process for control-cooling the steel plate according to claim 8, the process further comprising: analyzing the amount of temperature drop at each of the edges of the steel plate in the width direction and the distance of a portion dropped in temperature from each of the edges of the steel plate in the width direction on the basis of the temperature distribution measured with a measuring means for measuring the temperature distribution of the steel plate in the width direction before control cooling; calculating the number of cooling zones where masking is performed and the amount of masking with masking members disposed in each zone in the front section of the control-cooling device on the basis of the analyzed results; and controlling the masking members on the basis of the calculation results.
10. The process for control-cooling the steel plate according to any one of claims 3, 4, 6, and 7, the process further comprising: measuring the temperature distribution in the width direction before auxiliary cooling; analyzing the amount of temperature drop at each of the edges of the steel plate in the width direction and the length of a portion generating a temperature drop from each of the edges of the steel plate in the width direction from the measured temperature distribution; calculating the amount of masking and a cooling time with the masking members in the auxiliary cooling device on the basis of the analyzed results; and controlling the masking members in the auxiliary cooling device and the transferring rate of the steel plate on the basis of the calculation results.
11. A steel plate produced by the control-cooling process according to any one of claims 1 to 10 after hot rolling.
12. A control-cooling apparatus for a steel plate, the control-cooling apparatus comprising: a transfer-type control-cooling device, the transfer-type control-cooling device including a plurality of independent cooling zones, wherein cooling water can flow at a current density of 1,200 L/min.m² or more at each of the cooling zones, and masking members for limiting the amount of cooling water used for both edges of the steel plate in the width direction are disposed in

the cooling zone in the front section.

- 5 **13.** A control-cooling apparatus for a steel plate, the control-cooling apparatus comprising: an auxiliary cooling device and a control-cooling device, the auxiliary cooling device and the control-cooling device being arranged in that order subsequent to the delivery side of a roll mill, wherein the current density of cooling water in the auxiliary cooling device is 500 L/min.m² or less, masking members for limiting the amount of cooling water used for both edges of the steel plate in the width direction are disposed in the auxiliary cooling device, the control-cooling device is a transfer-type device including a plurality of independent cooling zones, and cooling water in each cooling zone can flow at a current density of 1,200 L/min.m² or more.
- 10 **14.** The control-cooling apparatus for the steel plate according to claim 12 or 13, wherein the operation of the masking members is controlled so that the temperature distribution in the width direction of the steel plate is uniformized.
- 15 **15.** The control-cooling apparatus for the steel plate according to any one of claims 12 to 14, the control-cooling apparatus further comprising: control means for controlling the amount of water, the control means operating for a predetermined period of time in response to a passing signal for each of the top end and the tail end of the steel plate in the longitudinal direction.
- 20 **16.** The control-cooling apparatus for the steel plate according to any one of claims 12, 14, and 15, the control-cooling apparatus further comprising: a slit jet cooling nozzle.
- 25 **17.** The control-cooling apparatus for the steel plate according to any one of claims 13, 14, and 15, the auxiliary cooling device further comprising a laminar-flow cooling nozzle, and the control-cooling device further comprising a slit jet cooling nozzle.
- 30 **18.** The control-cooling apparatus for the steel plate according to any one of claims 12, 14, 15, and 16, wherein each of the masking members disposed in each cooling zone in the front section of the control-cooling device independently blocks cooling water for each of the edges of the steel plate in the width direction per zone, per upper surface, or per lower surface.
- 35 **19.** The control-cooling apparatus for the steel plate according to claim 18, the control-cooling apparatus further comprising: analyzing means for analyzing the amount of temperature drop at each of the edges of the steel plate in the width direction and the length of a portion generating a temperature drop from each of the edges of the steel plate in the width direction from the temperature distribution measured with a measuring means for measuring the temperature distribution of the steel plate in the width direction before control cooling; calculating means for calculating the number of cooling zones where masking is performed and the amount of masking with masking members disposed in each zone in the front section of the control-cooling device on the basis of the analyzed results; and a controlling mechanism for controlling the masking members on the basis of the calculation results.
- 40 **20.** The control-cooling apparatus for the steel plate according to any one of claims 13, 14, 15, and 17, the control-cooling apparatus further comprising: measuring means for measuring the temperature distribution in the width direction before auxiliary cooling; analyzing means for analyzing the amount of temperature drop at each of the edges of the steel plate in the width direction and the distance of a portion dropped in temperature from each of the edges of the steel plate in the width direction on the basis of the measured temperature distribution; calculating means for calculating the amount of masking and a cooling time with the masking members in the auxiliary cooling device on the basis of the analyzed results; and a controlling mechanism for controlling the masking members in the auxiliary cooling device and the transferring rate of the steel plate on the basis of the calculation results.
- 45 **21.** The control-cooling apparatus for the steel plate according to any one of claims 12, 14, 15, 16, 18, and 19, wherein a leveler is disposed before the control-cooling device.
- 50 **22.** The control-cooling apparatus for the steel plate according to any one of claims 13, 14, 15, 17, and 20, wherein a leveler is disposed between the auxiliary cooling device and the control-cooling device.
- 55

FIG. 1

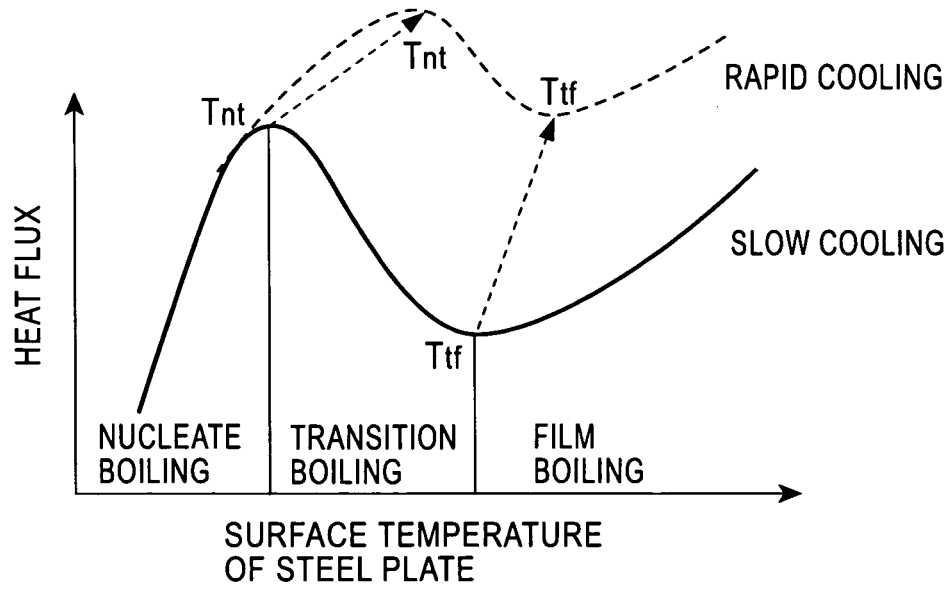


FIG. 2

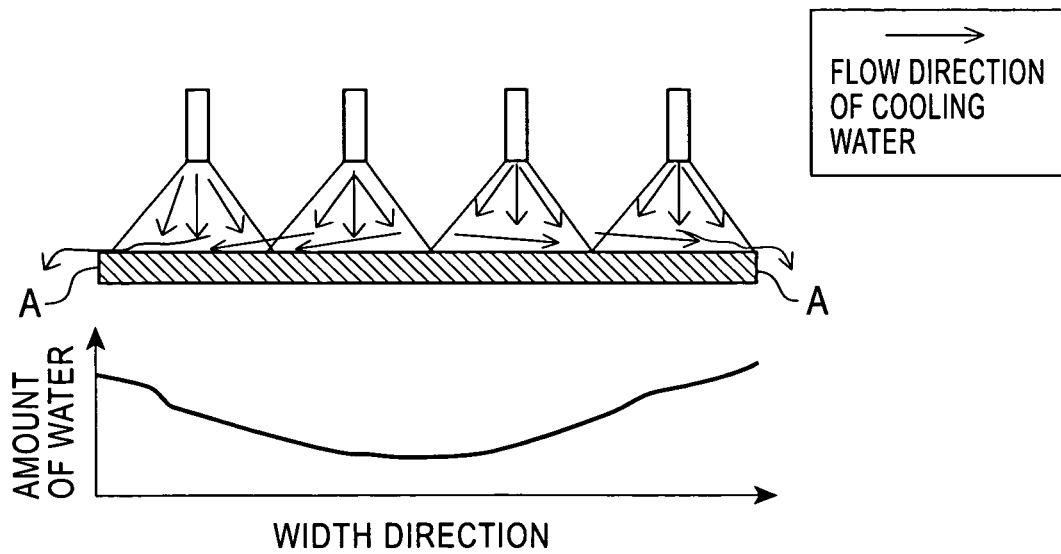


FIG. 3

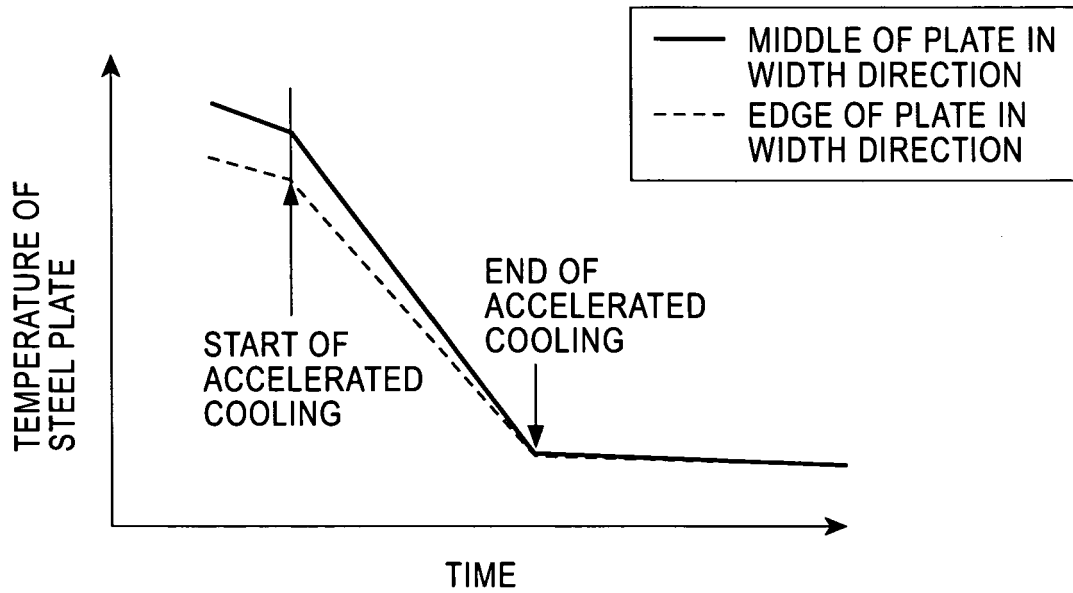


FIG. 4

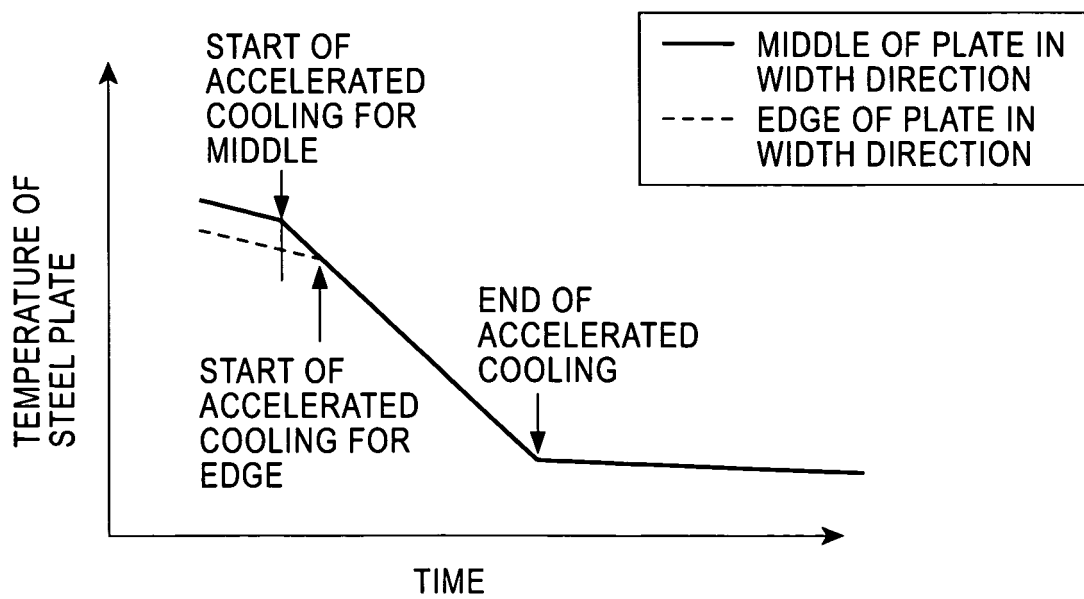


FIG. 5

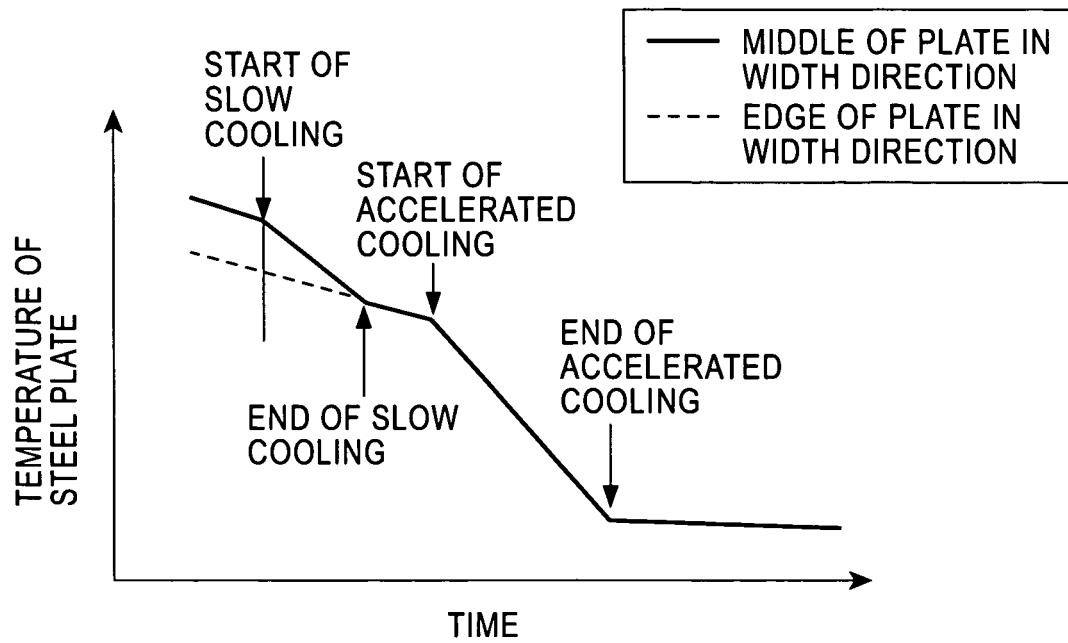


FIG. 6

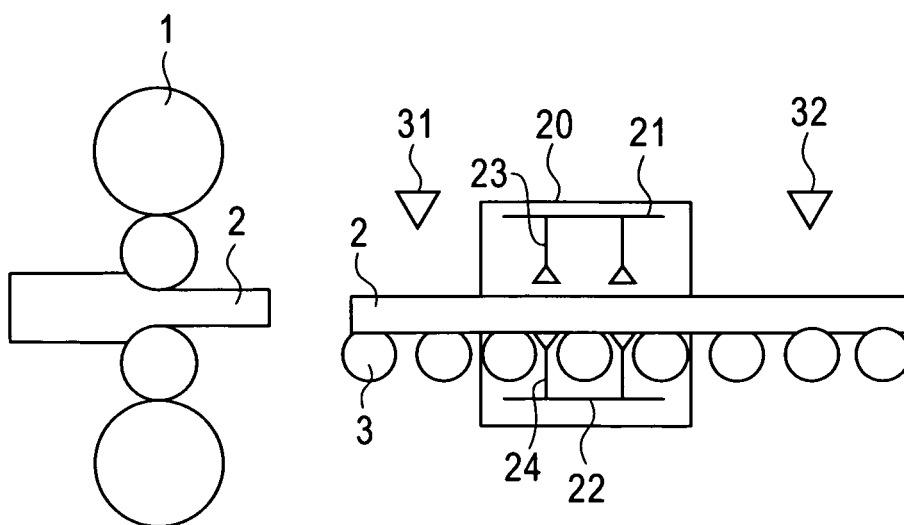


FIG. 7

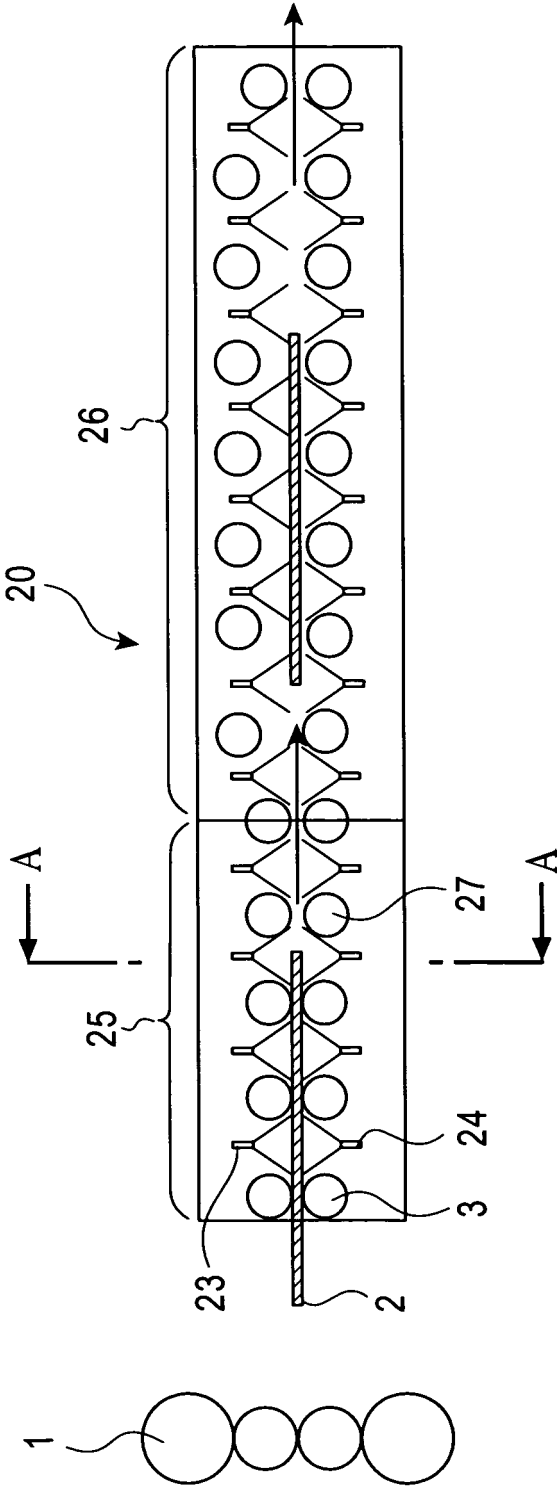


FIG. 8

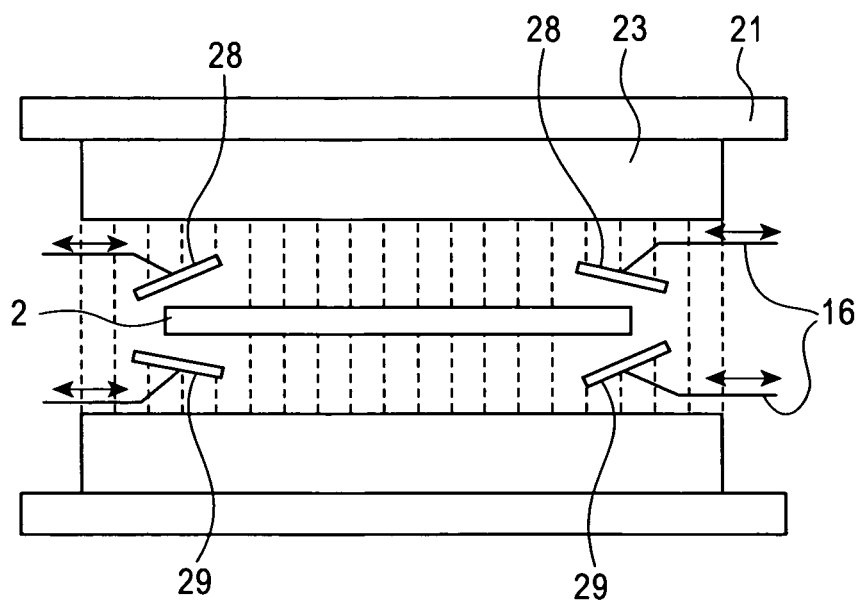


FIG. 9

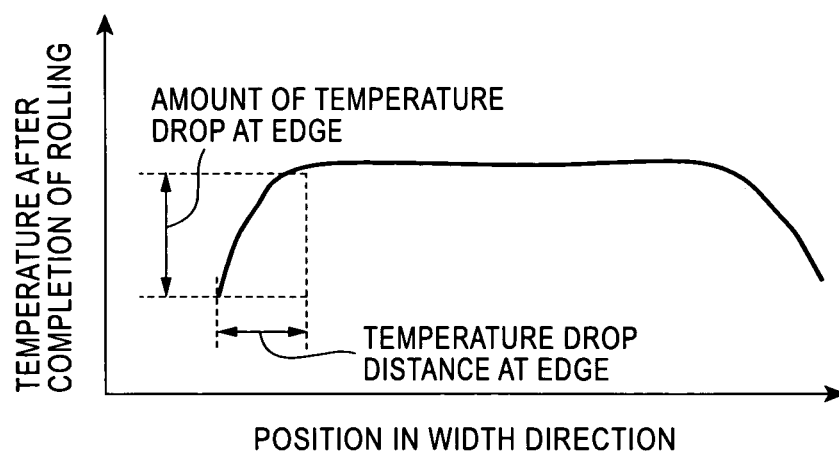


FIG. 10

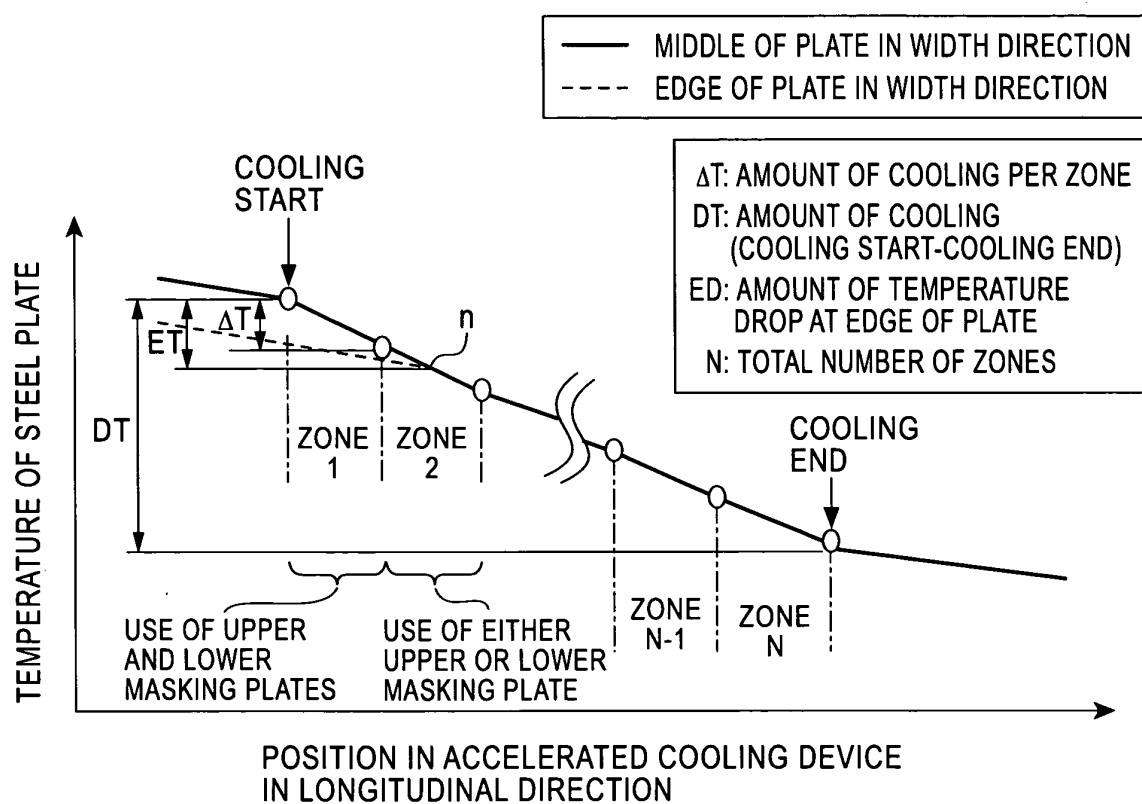


FIG. 11

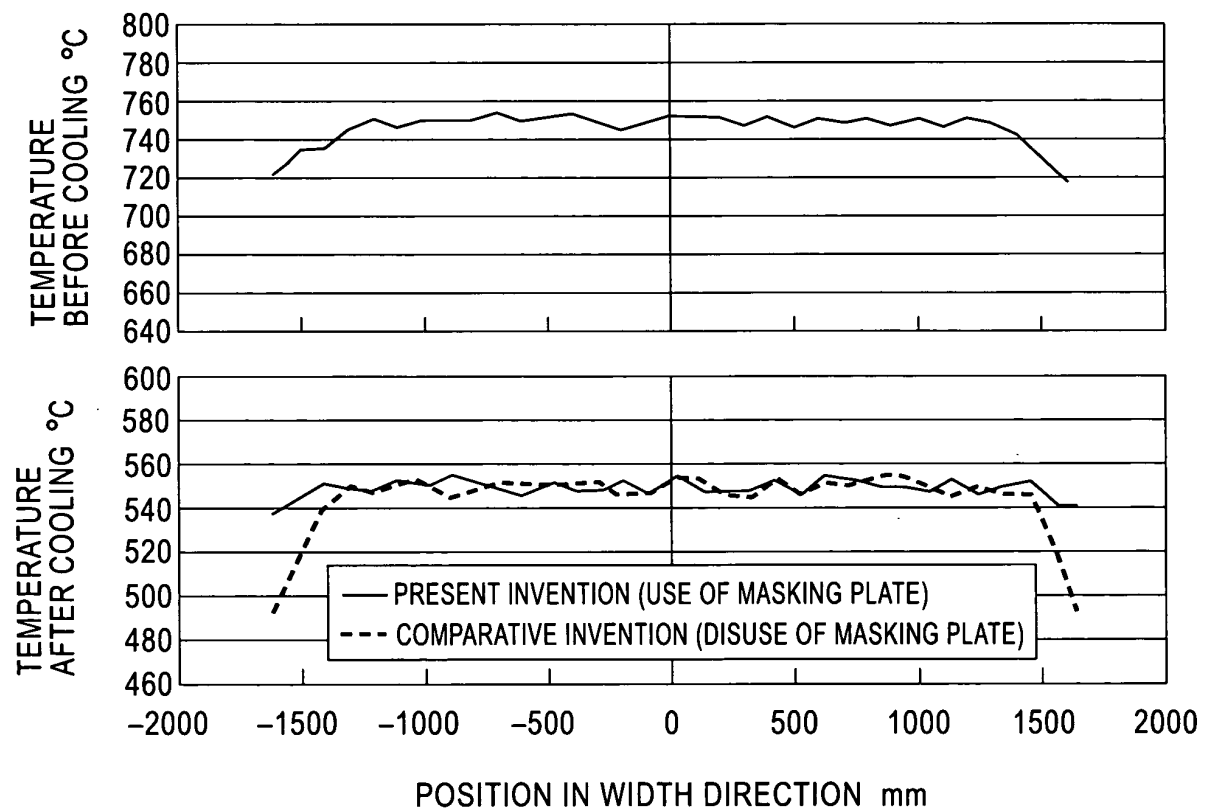


FIG. 12

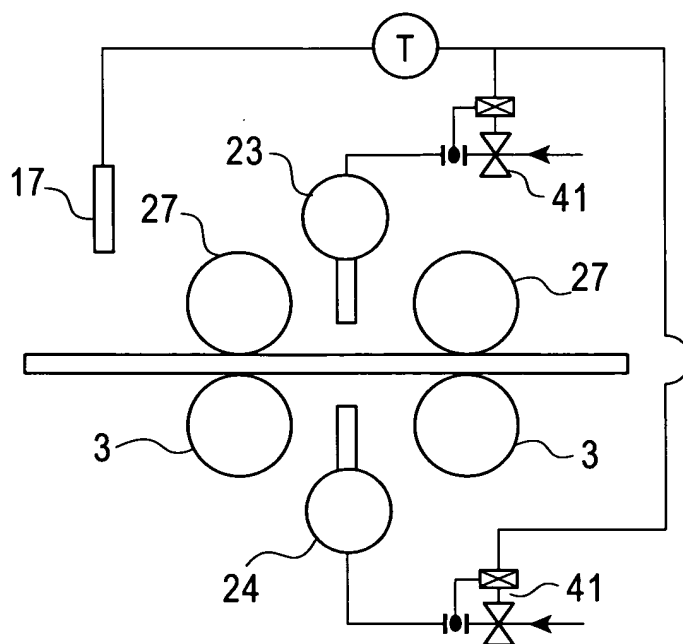


FIG. 13

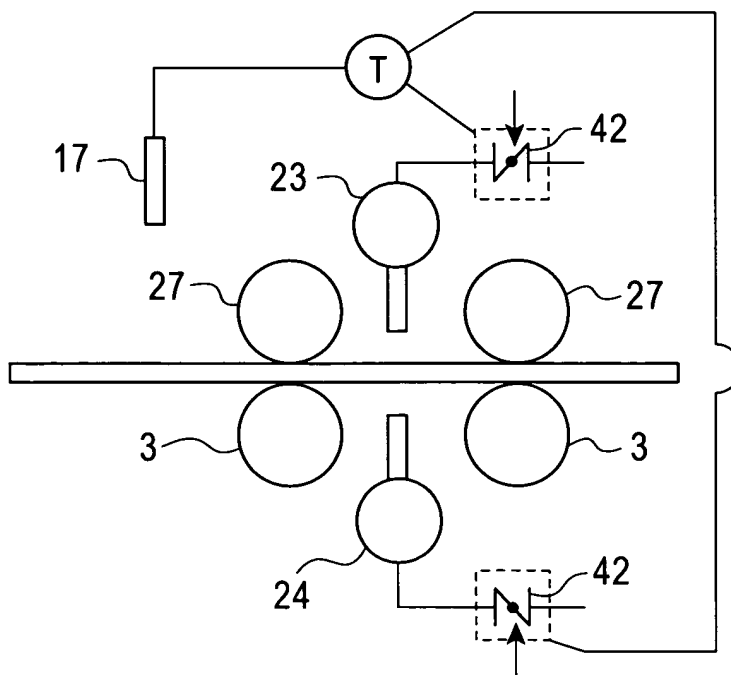


FIG. 14

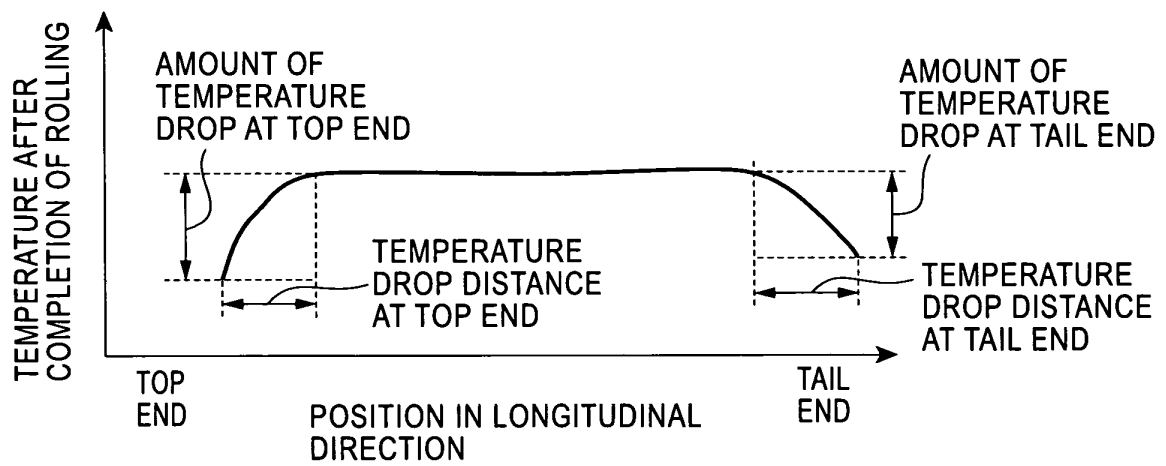


FIG. 15A

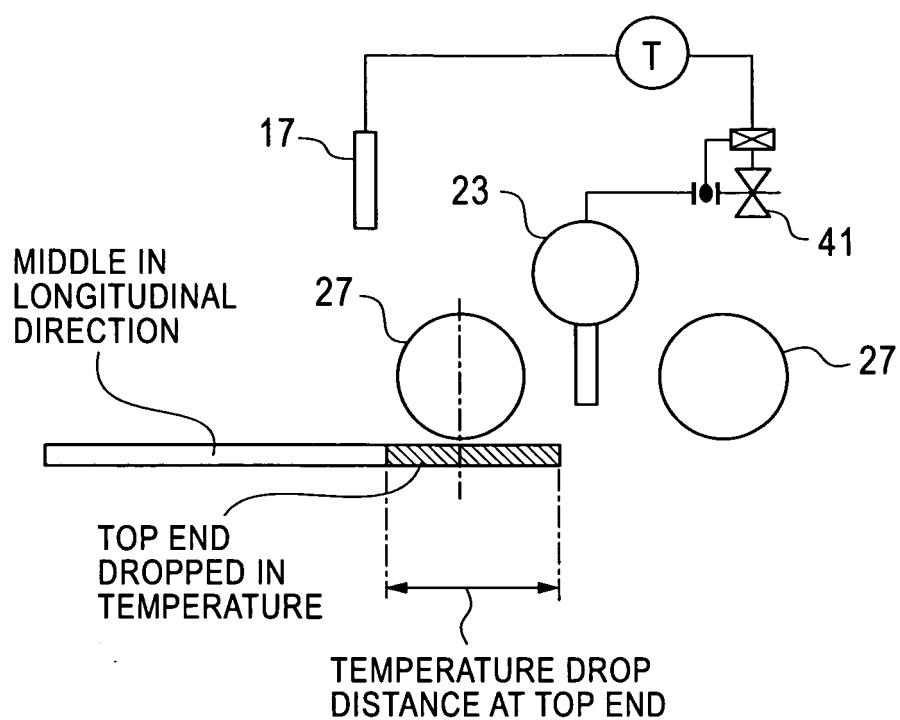


FIG. 15B

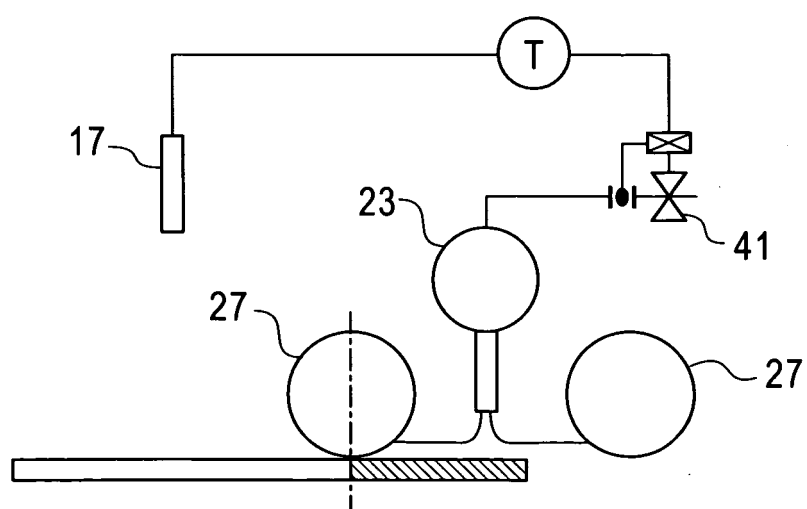


FIG. 16A

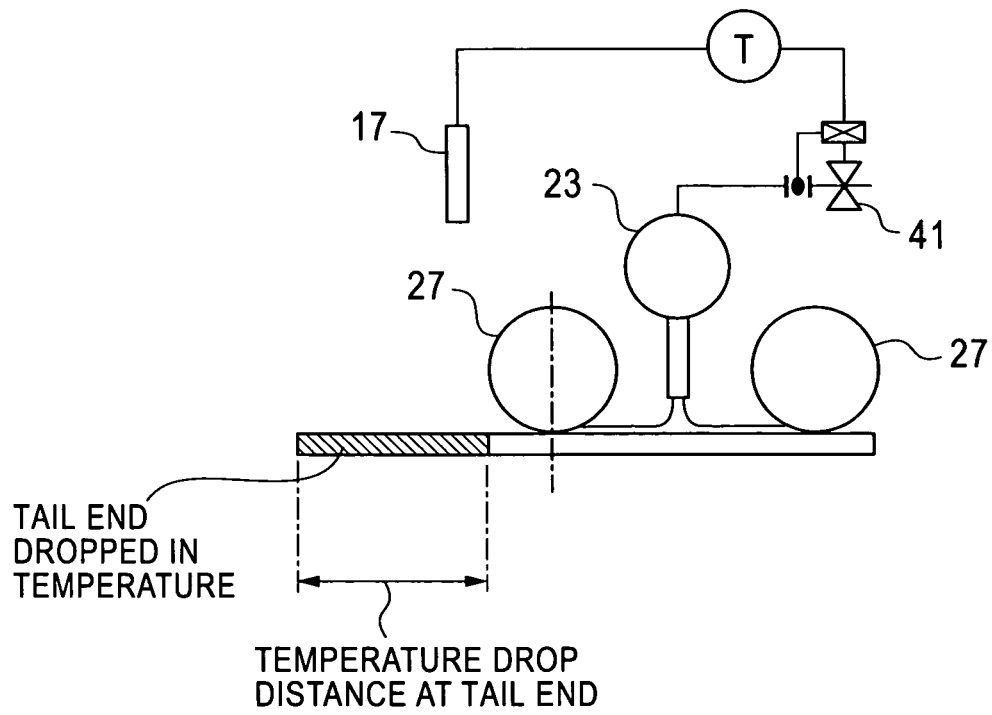


FIG. 16B

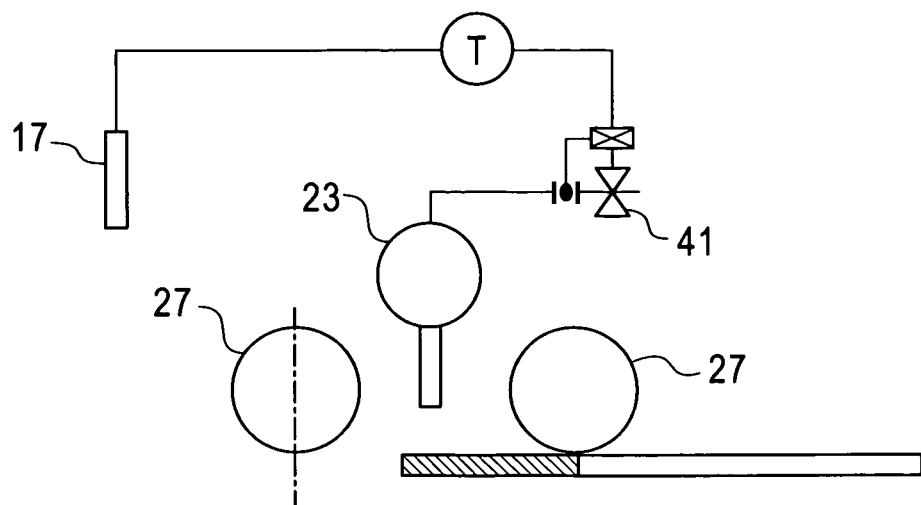


FIG. 17

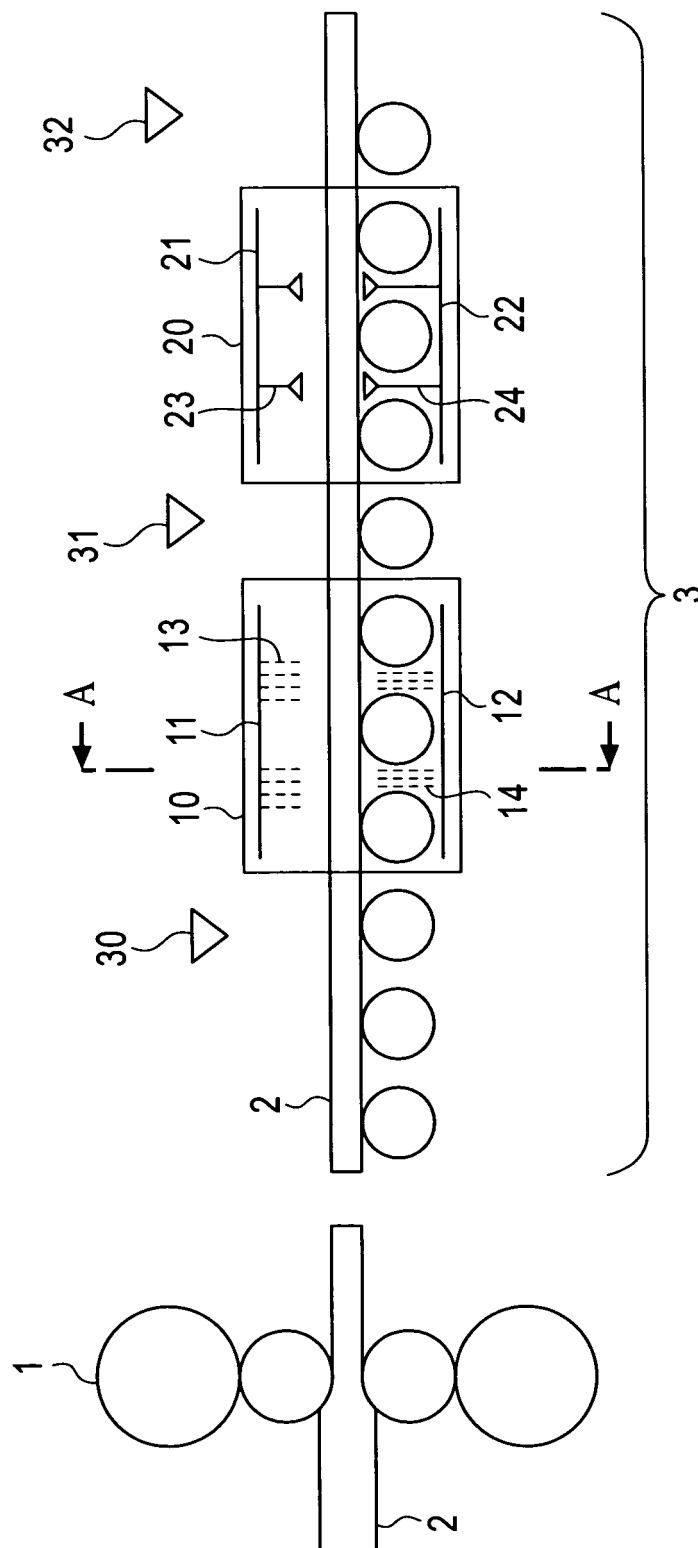


FIG. 18

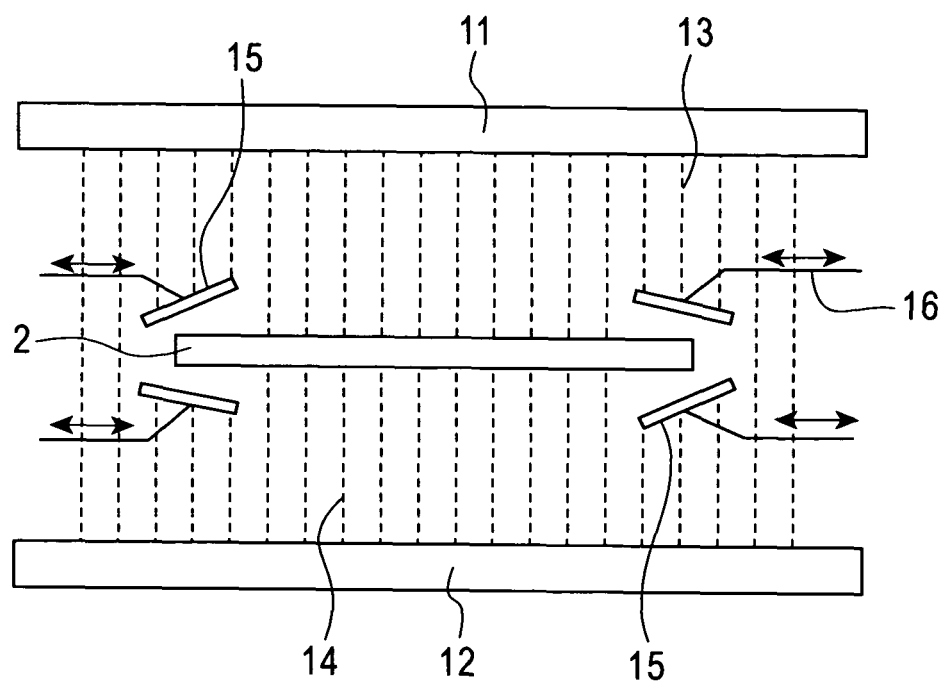


FIG. 19

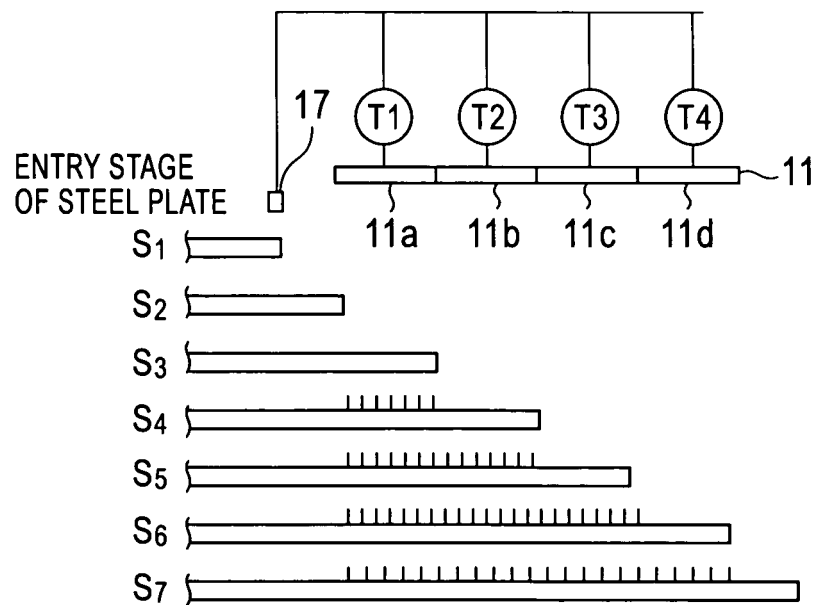


FIG. 20

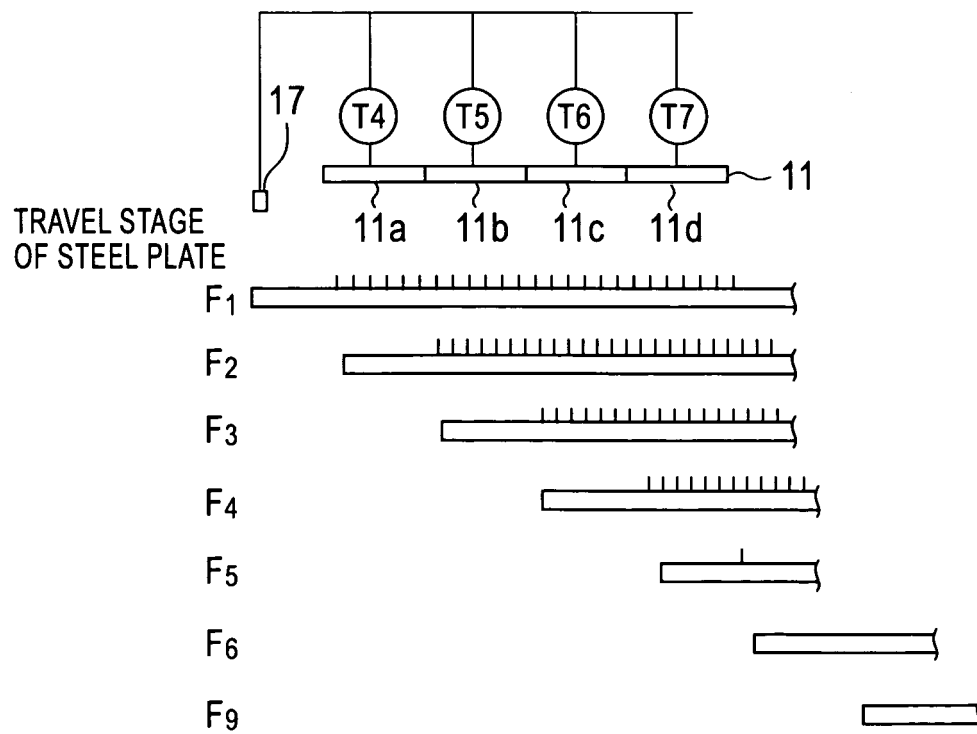


FIG. 21

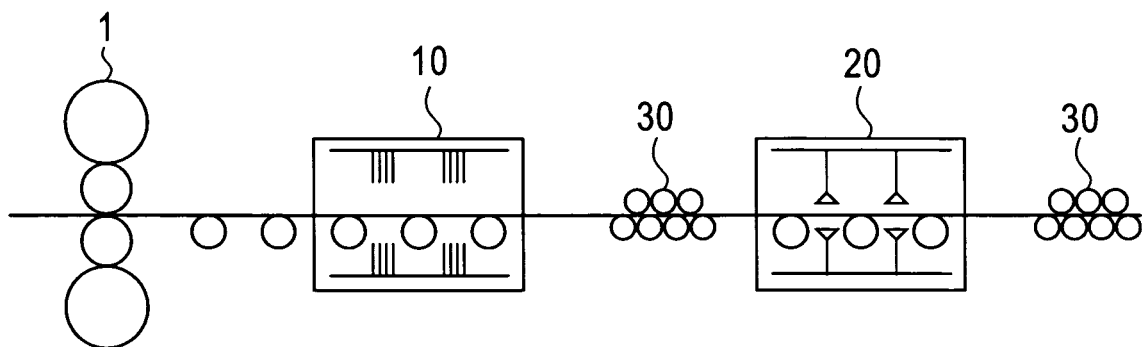


FIG. 22

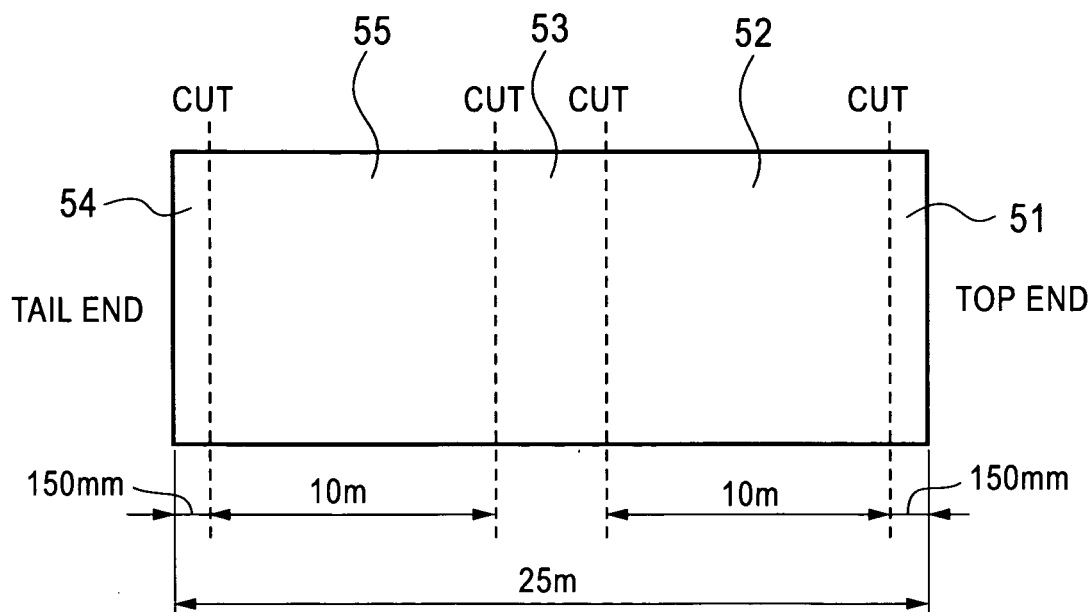


FIG. 23

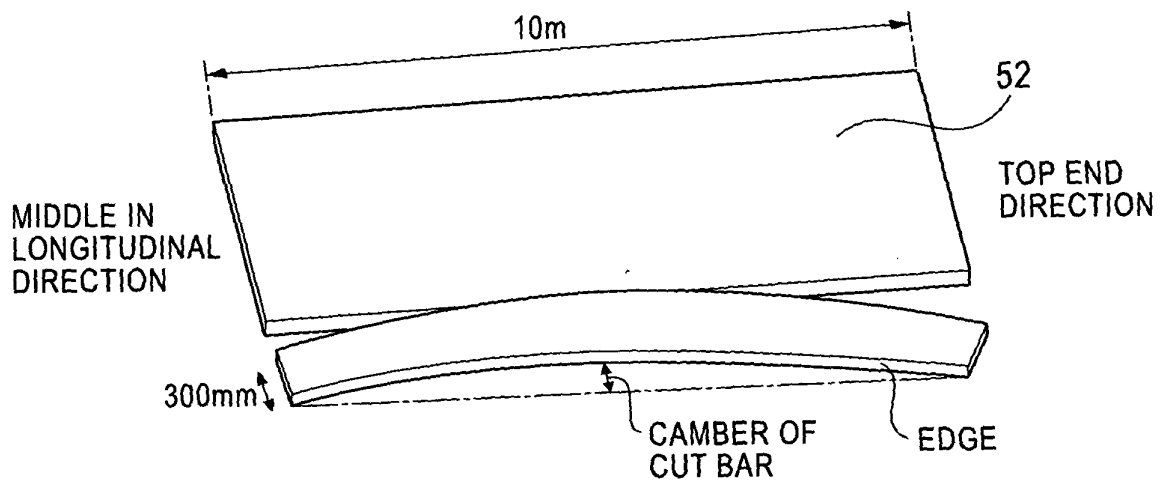


FIG. 24

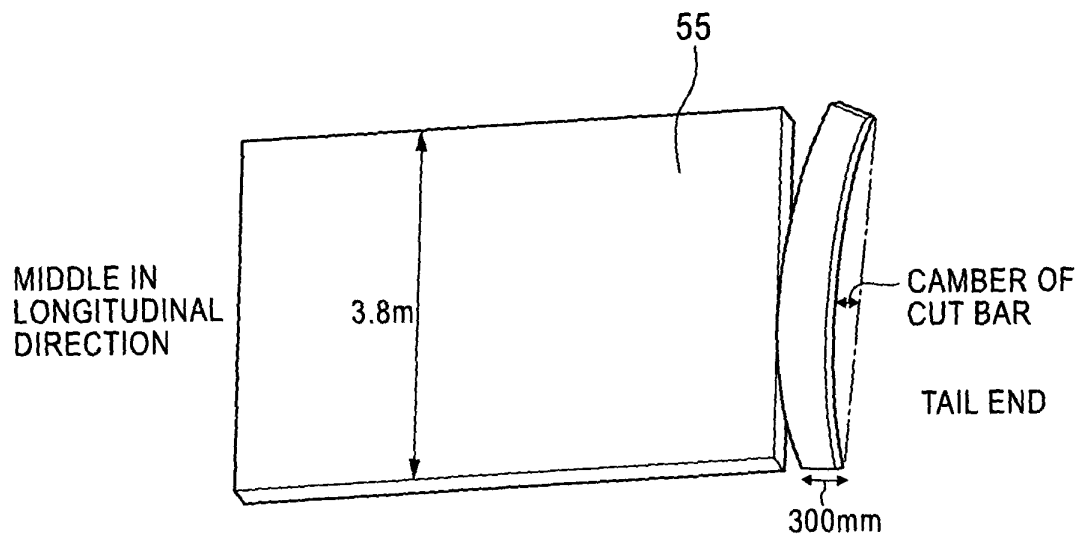


FIG. 25

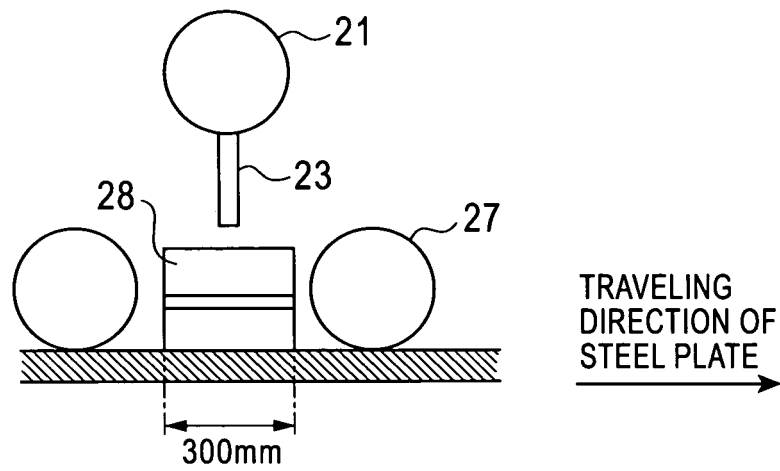


FIG. 26

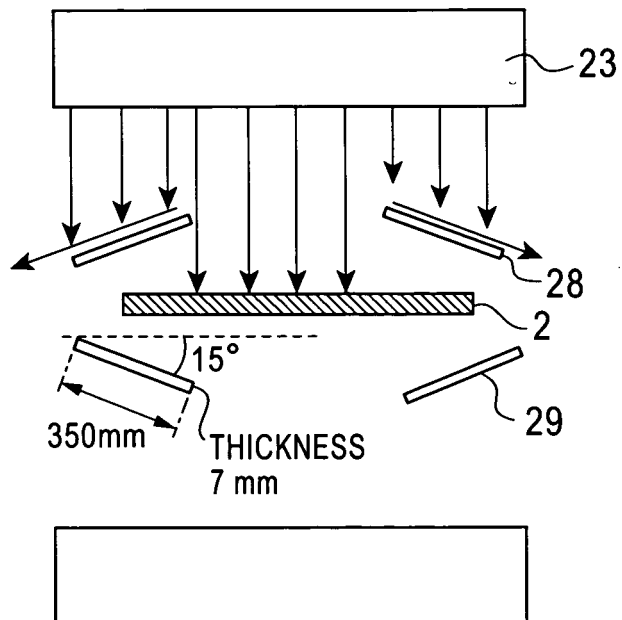


FIG. 27

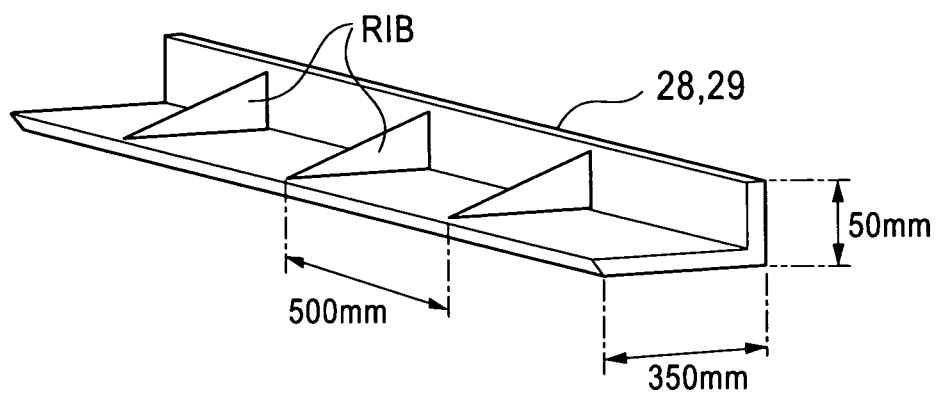
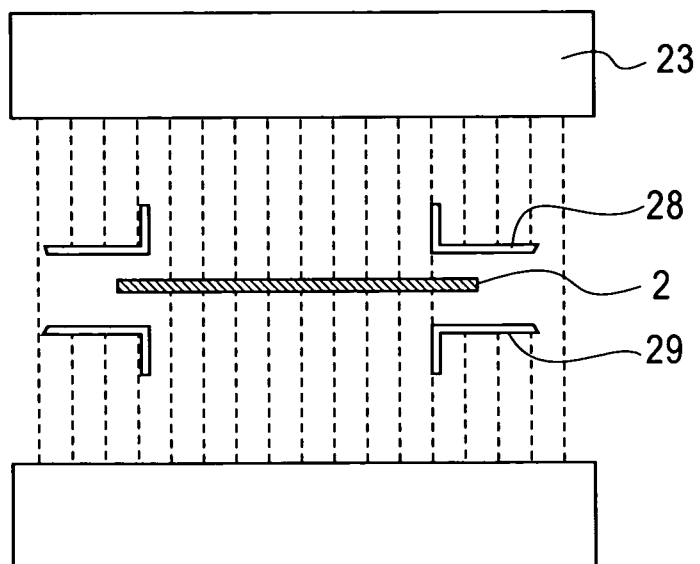


FIG. 28



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2004/008294

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl.⁷ B21B45/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl.⁷ B21B45/02Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1922-1996 Toroku Jitsuyo Shinan Koho 1994-2004
Kokai Jitsuyo Shinan Koho 1971-2004 Jitsuyo Shinan Toroku Koho 1996-2004

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 60-36625 A (Kawasaki Steel Corp.), 25 February, 1985 (25.02.85), Claims; Fig. 1 (Family: none)	1, 11 3-7, 10, 13-17, 20, 22
X Y	JP 6-63636 A (Kawasaki Steel Corp.), 08 March, 1994 (08.03.94), Claims; Figs. 1, 4 (Family: none)	1, 11 3-7, 10, 13-17, 20, 22
X Y	JP 62-112733 A (Nippon Steel Corp.), 23 May, 1987 (23.05.87), Claims; page 2, lower left column, line 1 to 4; Figs. 1, 2 (Family: none)	1, 2, 11 3-10, 12-22

☒ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"I" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
02 September, 2004 (02.09.04)Date of mailing of the international search report
21 September, 2004 (21.09.04)Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

Facsimile No.

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2004/008294

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 8-71630 A (Kawasaki Steel Corp.), 19 March, 1996 (19.03.96), Claims; Fig. 1 (Family: none)	3-22
Y	JP 7-150229 A (Kawasaki Steel Corp.), 13 June, 1995 (13.06.95), Claims; column 3, line 34 to column 4, line 5; Figs. 1, 2 (Family: none)	4-22
Y	JP 61-15926 A (Nippon Steel Corp.), 24 January, 1986 (24.01.86), Claims; Figs. 1, 4 (Family: none)	5-11, 15-22
Y	JP 61-264137 A (Kobe Steel, Ltd.), 22 November, 1986 (22.11.86), Claims; Fig. 1 (Family: none)	16-22
Y	JP 6-254616 A (Nippon Steel Corp.), 13 September, 1994 (13.09.94), Claims; Fig. 1 (Family: none)	21, 22

Form PCT/ISA/210 (continuation of second sheet) (January 2004)