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(54) COOLING DEVICE AND COOLING METHOD FOR THICK STEEL SHEET, AND PRODUCTION EQUIPMENT AND PRODUCTION METHOD FOR THICK STEEL SHEET

(57) It is an object to provide a cooling device and a cooling method which are used to cool a steel plate, in which the cooling rate can be adjusted over a wide range by adjusting the amount of cooling water over a wide range while the shape of the steel plate is controlled, and which, when the cooling device is used in particular for a roller quenching type cooling apparatus in which the above cooling device is disposed between steel plate restraining rolls, is effective in a narrow cooling space.

The ratio P/D of a restraining roll pitch P and a restraining roll diameter D is 2.5 or less, and each of the cooling headers is connected to one of at least two cooling water supply systems. A regulating valve is attached to each of the cooling water supply systems so that ON/OFF control of water supply and flow rate control in the each of the cooling water supply systems can be performed independently of those in the rest of the cooling water supply systems. A plurality of cooling spray nozzles arranged in a width direction of the steel plate are attached to each of the cooling headers, and adjacent ones of the cooling spray nozzles that are adjacent to each other in the width direction of the steel plate are connected to respective ones of the cooling headers belonging to respective different ones of the cooling water supply systems. The flow rate densities of cooling water injected from adjacent ones of the cooling spray nozzles that are adjacent to each other in the width direction of the steel plate differ from each other. At a given injection pressure, some of the cooling spray nozzles that inject the cooling water at a maximum flow rate density can inject the cooling water at a flow rate density equal to or higher than three times the flow rate density of the cooling water injected from some of the cooling spray nozzles that inject the cooling water at a minimum flow rate density. The cooling device further includes a control mechanism that selects each of the cooling water supply systems individually and controls the each of the cooling water supply systems using a corresponding one of the regulating valves such that corresponding ones of the cooling spray nozzles inject the cooling water.

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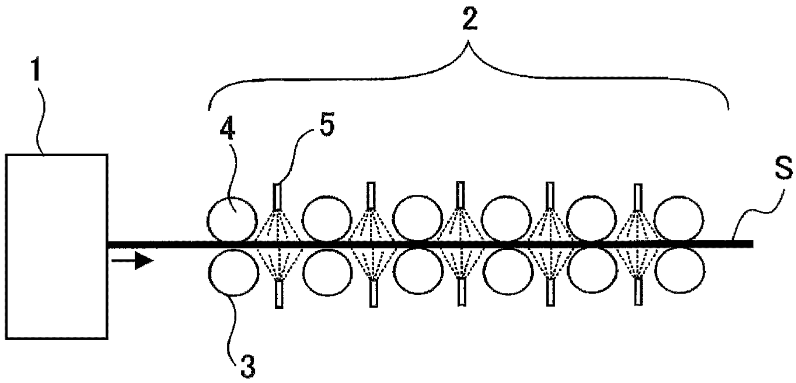
FIG. 1



Description

Technical Field

[0001] The present invention relates to a cooling device and to a cooling method which are used in a steel plate production line and which, when a steel plate is subjected to controlled cooling after hot rolling or when a steel plate cooled to room temperature after hot rolling is reheated and cooled by quenching, can adjust the cooling rate in a wider range than that in conventional devices and methods while the shape of the steel plate is controlled. The present invention also relates to a steel plate production facility using the cooling device and to a steel plate production method using the cooling method.

Background Art

[0002] In the production of, in particular, a thick steel plate (which may be referred to simply as a steel plate), it is necessary to ensure mechanical properties, in particular, strength and toughness, required for the steel plate. In an operation performed to achieve this, a high-temperature steel plate subjected to rolling is cooled directly or air-cooled to room temperature and then subjected to off-line re-reheating/quenching. In the cooling operation, the steel plate is often cooled at a high cooling rate in order to obtain the characteristics required for the steel plate, in particular, high strength.

[0003] Recent sophistication of material quality control has led to not only a need for higher strength but also an increasing need for a combination of a soft transformation structure and a hard transformation structure. For example, in a technique for obtaining a dual-phase structure such as a ferrite + bainite structure or a ferrite + martensite structure, a relatively low cooling rate condition is used at the initial or late stage of cooling. The formation of the dual-phase structure can reduce, for example, the yield ratio that is the ratio of the yield strength to the tensile strength and may allow the production of a steel plate excellent in earthquake resistant.

[0004] To form the dual-phase structure in a steel plate, multi-stage heat treatment in which re-heating and quenching are performed a plurality of times has been conventionally used. However, to reduce the number of steps, there is a need for a cooling technique that allows the cooling rate to be changed at any timing during a single quenching operation. In particular, to facilitate the formation of ferrite, it is necessary to perform cooling at a very low cooling rate (e.g., about 2 to about 20°C/s) over a long time. Therefore, it is necessary to adjust the cooling rate to a value extremely lower than the cooling rate of a general on-line controlled cooling device or a quenching device for heat treatment (about 30 to about 60°C/s for a plate thickness of 20mm).

[0005] Examples of the technique that allows the cooling rate to be changed at any timing during cooling of a steel plate includes techniques in the following Patent Literatures.

[0006] Patent Literature 1 discloses a technique in which a water tank and spray nozzles disposed in the water tank are provided for a cooling header for a lower surface to change the water level of the water tank to thereby change the cooling ability over a wide range. In Patent Literature 1, to increase the cooling ability, the water level of the water tank is increased to immerse the tips of the nozzles in the water. In this case, the water in the water tank is entrained with the spray water, and the steel plate is exposed to a larger amount of water than the amount of water injected from the spray nozzles. To decrease the cooling ability, the water level of the water tank is reduced such that the tips of the spray nozzles are not immersed in the water to prevent the occurrence of the entrained water flow described above, and therefore the steel plate is exposed to a smaller amount of water. However, with the above-described technique, since it is necessary to dispose the water tank between table rolls, only the lower surface of the steel plate can be cooled, and the technique cannot be used to cool the upper surface. In a facility, such as a quenching device for steel plates, in which the distance between the table rolls is small, the water tank cannot be disposed between the rolls in the first place.

[0007] Patent Literature 2 is a technique in which water is supplied to a plurality of nozzles attached in a width direction such that the water is supplied to adjacent nozzles from their respective independent systems. To reduce the flow rate, only one of the systems is used for injection to thereby adjust the flow rate. Even with this technique, the adjustable amount of the flow rate is only about 50% of the maximum cooling rate.

[0008] To improve the above issue, Patent Literature 3 discloses a technique in which a rapid cooling device and a gradual cooling device that include respective rod-shaped cooling water nozzles having different flow rate characteristics are arranged in a back-and-forth direction in one cooling area to adjust the cooling rate in the cooling area over a wide range by switching injecting water between the rapid cooling device and the gradual cooling device.

Citation List

Patent Literature

[0009]

PTL 1: Japanese Unexamined Patent Application Publication No. 59-47010
PTL 2: Japanese Unexamined Patent Application Publication No. 2014-124634
PTL 3: Japanese Unexamined Patent Application Publication No. 2011-167759

Summary of Invention

Technical Problem

[0010] To cool a steel plate, in particular, to perform off-line heat treatment, so-called roller quenching is often used, in which the steel plate restrained by rolls is caused to pass through to thereby cool the steel plate. In this method, since the steel plate is cooled while restrained by the rolls, the flatness of the steel plate after cooling is good, and the degree of shape correction treatment performed thereafter can be reduced, so that this method is widely used. To obtain a good cooled shape by roller quenching, relatively large-diameter rolls are used, and the steel plate is restrained at a small roll pitch, so that a large space cannot be provided for a cooling means disposed between the rolls. It is therefore difficult to apply the technique in Patent Literature 3 to a roller quenching type cooling device.

[0011] The present invention has been made in view of the above circumstances, and it is an object to provide a cooling device and a cooling method which are used to cool a steel plate, in which the cooling rate can be adjusted over a wide range by adjusting the amount of cooling water over a wide range while the shape of the steel plate is controlled, and which, when the cooling device is used in particular for a roller quenching type cooling apparatus in which a cooling means is disposed between steel plate restraining rolls, is effective in the case of a narrow cooling space. It is another object of the present invention to provide a steel plate production facility using the above cooling device and a steel plate production method using the above cooling method.

Solution to Problem

[0012] The present inventors have conducted extensive studies and found that the cooling rate can be adjusted over a wide range by setting the ratio P/D of a restraining roll pitch P to a restraining roll diameter D within a prescribed range to thereby control the shape of a steel plate and using cooling spray nozzles with different flow rate densities.

[0013] The present invention is summarized as follows.

[1] A cooling device for a steel plate, the cooling device including: a plurality of restraining rolls arranged in a steel plate conveying direction; and a plurality of cooling headers each disposed between corresponding ones of the restraining rolls,
wherein the ratio P/D of a restraining roll pitch P and a restraining roll diameter D is 2.5 or less,
wherein each of the cooling headers is connected to one of at least two cooling water supply systems,
wherein a regulating valve is attached to each of the cooling water supply systems so that ON/OFF control of water supply and flow rate control in the each of the cooling water supply systems can be performed independently of those in the rest of the cooling water supply systems,
wherein a plurality of cooling spray nozzles arranged in a width direction of the steel plate are attached to each of the cooling headers,
wherein adjacent ones of the cooling spray nozzles that are adjacent to each other in the width direction of the steel plate are connected to respective ones of the cooling headers belonging to respective different ones of the cooling water supply systems,
wherein the flow rate densities of cooling water injected from adjacent ones of the cooling spray nozzles that are adjacent to each other in the width direction of the steel plate differ from each other, wherein, at a given injection pressure, some of the cooling spray nozzles that inject the cooling water at a maximum flow rate density can inject the cooling water at a flow rate density equal to or higher than three times the flow rate density of the cooling water injected from some of the cooling spray nozzles that inject the cooling water at a minimum flow rate density, and
wherein the cooling device further includes a control mechanism that selects each of the cooling water supply systems individually and controls the each of the cooling water supply systems using a corresponding one of the regulating valves such that corresponding ones of the cooling spray nozzles inject the cooling water.
[2] The cooling device for a steel plate according to [1], wherein the cooling spray nozzles are installed such that

the distance from a tip of each of the cooling spray nozzles to the steel plate is equal to or less than the height of center axes of the restraining rolls ±50 mm.

[3] The cooling device for a steel plate according to [1] or [2], wherein each of the cooling spray nozzles is at least one of a flat spray nozzle, a full cone spray nozzle, a square spray nozzle, and an elliptical spray nozzle, and wherein the injection angle of the cooling water when the cooling water is injected from each of the cooling spray nozzles is within the range of 60 to 120°.

[4] A method for cooling a steel plate using a cooling device including a plurality of restraining rolls arranged in a steel plate conveying direction and a plurality of cooling headers each disposed between corresponding ones of the restraining rolls,

wherein the ratio P/D of a restraining roll pitch P and a restraining roll diameter D is 2.5 or less,

wherein each of the cooling headers is connected to one of at least two cooling water supply systems,

wherein a regulating valve is attached to each of the cooling water supply systems so that ON/OFF control of water supply and flow rate control in the each of the cooling water supply systems can be performed independently of those in the rest of the cooling water supply systems,

wherein a plurality of cooling spray nozzles arranged in a width direction of the steel plate are attached to each of the cooling headers,

wherein adjacent ones of the cooling spray nozzles that are adjacent to each other in the width direction of the steel plate are connected to respective ones of the cooling headers belonging to respective different ones of the cooling water supply systems,

wherein the flow rate densities of cooling water injected from adjacent ones of the cooling spray nozzles that are adjacent to each other in the width direction of the steel plate differ from each other, wherein, at a given injection pressure, some of the cooling spray nozzles that inject the cooling water at a maximum flow rate density can inject the cooling water at a flow rate density equal to or higher than three times the flow rate density of the cooling water injected from some of the cooling spray nozzles that inject the cooling water at a minimum flow rate density, and

wherein each of the cooling water supply systems is selected individually and controlled using a corresponding one of the regulating valves such that corresponding ones of the cooling spray nozzles inject the cooling water.

[5] The method for cooling a steel plate according to [4], wherein the cooling spray nozzles are installed such that the distance from a tip of each of the cooling spray nozzles to the steel plate is equal to or less than the height of center axes of the restraining rolls ±50 mm.

[6] The method for cooling a steel plate according to [4] or [5], wherein each of the cooling spray nozzles is at least one of a flat spray nozzle, a full cone spray nozzle, a square spray nozzle, and an elliptical spray nozzle, and wherein the injection angle of the cooling water when the cooling water is injected from each of the cooling spray nozzles is within the range of 60 to 120°.

[7] A steel plate production facility including the cooling device according to any of [1] to [3].

[8] A method for producing a steel plate, the method including a cooling step using the method for cooling according to any of [4] to [6].

Advantageous Effects of Invention

[0014] According to the present invention, during cooling of a steel plate, the cooling rate can be adjusted over a wide range while the shape of the steel plate is controlled, and steel plates having different strengths can be produced. In particular, the present invention is a technique effective in the case of a narrow cooling space allowed such as a cooling space formed when the cooling means is disposed between restraining rolls arranged at a small pitch in a conveying direction.

Brief Description of Drawings

[0015]

[Fig. 1] Fig. 1 is a schematic illustration of an off-line heat treatment facility for a steel plate that uses the cooling device of the present invention.

[Fig. 2] Fig. 2 is a schematic illustration showing an embodiment of the cooling device of the present invention.

[Fig. 3] Fig. 3 is an illustration showing the positional relation between a cooling spray nozzle and restraining rolls in the present invention.

[Fig. 4] Fig. 4 is an illustration showing the injection angle of cooling water (spray water) injected from a cooling spray nozzle.

[Fig. 5] Fig. 5 shows schematic illustrations when the cooling device of the present invention is viewed from above, Fig. 5(a) being an illustration showing the structure of cooling headers, Figs. 5(b) and 5(c) being illustrations showing spray water sprayed from cooling spray nozzles.

[Fig. 6] Fig. 6 shows the arrangement of cooling headers and cooling spray nozzles when multiple systems (4 systems) are used for the cooling headers.

[Fig. 7] Fig. 7 shows illustrations when spray water injected from low-flow rate cooling spray nozzles and impinging on a steel plate is viewed from above in the case where the cooling water is injected from cooling headers belonging to two different systems, Fig. 7(a) being an illustration when a flat spray nozzle is used, Fig. 7(b) being an illustration when an oval spray nozzle is used, Fig. 7(c) being an illustration when a full cone spray nozzle is used, Fig. 7(d) being an illustration when a square spray nozzle is used.

[Fig. 8] Fig. 8 shows schematic illustrations when the nozzle pitch of high-flow rate cooling spray nozzles differs from the nozzle pitch of low-flow rate cooling spray nozzles, Fig. 8(a) being an illustration showing the structure of cooling headers, Fig. 8(b) being an illustration showing the spray water from the high-flow rate cooling spray nozzles, Fig. 8(c) being an illustration showing the spray water from the low-flow rate cooling spray nozzles.

[Fig. 9] Fig. 9 is a schematic illustration of a steel plate cooling treatment facility using the cooling device of the present invention.

[Fig. 10] Fig. 10 is a graph showing the relation between injection pressure and flow rate density in high-flow rate cooling spray nozzles and low-flow rate cooling spray nozzles.

[Fig. 11] Fig. 11 is a graph showing the relation between a cooling rate and the flow rate density when a steel plate is cooled until the center in its thickness direction reaches from 800°C to 400°C.

Description of Embodiments

[0016] Embodiments of the present invention will be described with reference to the drawings.

[0017] Fig. 1 is an illustration when the cooling device of the present invention is used for off-line heat treatment of a steel plate. The steel plate S has been rolled to a prescribed thickness (e.g., 40 mm) and a prescribed width (e.g., 2500 mm) in a rolling facility. The steel plate S is conveyed to the heat treatment line, heated to a prescribed temperature (e.g., 920°C) in a heating furnace 1, and then cooled in the cooling device 2 disposed on the exit side of the heating furnace 1. The cooling device 2 includes table rolls 3 that convey the steel plate S, restraining rolls 4 that restrain the steel plate S, and cooling headers 5 disposed above and below the surfaces of the steel plate S.

[0018] The details of the cooling device 2, which is an embodiment of the present invention, are shown in Fig. 2. As shown in Fig. 2, a plurality of the table rolls 3 that convey the steel plate S and a plurality of the restraining rolls 4 that restrain the steel plate S are provided, and a plurality of high-flow rate cooling headers 51 and a plurality of low-flow rate cooling headers 52 are disposed above the surface of the steel plate, each located between corresponding ones of the restraining rolls 4, and below the surface of the steel plate (between corresponding ones of the table rolls 3). In each of the cooling headers, the flow rate of cooling water to be supplied to the cooling header is measured by a flowmeter 6, and a flow regulating valve 7 is provided such that the flow rate can be adjusted to a prescribed value according to the measurement results. The flow regulating valves 7 are connected to a control mechanism (not shown) and can be individually controlled to perform ON/OFF control of the cooling water (switch between supply of water and suspension of the supply). A plurality of cooling spray nozzles 53(54) are attached to each of the cooling headers. The cooling spray nozzles 53(54) will be described later in detail.

[0019] The positional relation between cooling headers (cooling spray nozzles) and the restraining rolls 4 above the upper surface of the steel plate will be described. The pitch of the table rolls 3 and the pitch of the restraining rolls 4 are the same. Therefore, the positional relation between cooling headers (cooling spray nozzles) and the table rolls 3 below the lower surface of the steel plate is the same as the positional relation between cooling headers (cooling spray nozzles) and the restraining rolls 4 above the upper surface of the steel plate.

[0020] Fig. 3 is an illustration showing the positional relation between a cooling spray nozzle and restraining rolls in the present invention. The present invention is aimed to be used mainly for a steel plate, and an important issue is to prevent out-of-plane deformation that occurs during cooling of the steel plate. From the viewpoint of preventing the out-of-plane deformation, a method in which the steel plate S is cooled while restrained by the restraining rolls 4 and the table rolls 3 is used. In this case, it is advantageous in terms of preventing the out-of-plane deformation of the steel plate that the installation pitch of the restraining rolls 4 (the restraining roll pitch P) in the conveying direction is as small as possible. Moreover, from the viewpoint of preventing the out-of-plane deformation appropriately, it is preferable that the restraining roll diameter D of the restraining rolls 4 is as large as possible in order to reduce deflection of the restraining rolls 4 even under a large load. However, as the restraining roll pitch P of the restraining rolls 4 arranged decreases, the roll gap G decreases, and therefore the space for installing the cooling device 2 decreases. In particular, the nozzles described in Patent Literature 3 require a large cooling header, and the cooling device of the present invention cannot be installed in the case of using such nozzles. From the viewpoint of achieving uniform cooling, it is preferable that, in order to cool also the vicinities of the contact points between the steel plate S and the restraining rolls 4, a spray length L when the cooling spray nozzle 53 (or the cooling spray nozzle 54) is viewed from one side is larger than the roll gap

G so that regions of the steel plate S that are located below the restraining rolls 4 are sprayed with the cooling water. From the above point of view also, it is preferable to use a method such as spray cooling in which the cooling water can be sprayed over a wide area.

[0021] Based on the above, the inventors have conducted extensive studies and found that, from the viewpoint of controlling the shape of the steel plate, the ratio P/D of the restraining roll pitch P of the restraining rolls 4 to the restraining roll diameter D thereof is set to 2.5 or less. When P/D is 1.0, the restraining roll pitch is the same as the restraining roll diameter, and no gap is formed between restraining rolls arranged in a back-and-forth direction, so that no cooling spray nozzles can be installed. Therefore, P/D is preferably more than 1.0, and the gap (P-D) formed between restraining rolls arranged in the back-and-forth direction is at least 50 mm. Therefore, from the operational point of view, P/D is more preferably 1.17 or more. From the viewpoint of shape control, P/D is preferably as small as possible. Therefore, P/D is preferably 2.0 or less.

[0022] The roll diameter of the table rolls 3 is not necessarily the same as the restraining roll diameter D. It is only necessary that, even when the restraining roll diameter D and the roll diameter of the table rolls 3on the upper and lower surfaces of the steel plate respectively, are the same or different, the ratio P/D be 2.5 or less as described above. Moreover, it is only necessary that the ratio of the roll pitch of the table rolls 3 and the roll diameter of table rolls on the lower surface of the steel plate be 2.5 or less.

[0023] It is preferable that the spray length L, in the conveying direction, of each cooling spray nozzle 53(54) between corresponding restraining rolls 4 is as close as possible to the restraining roll pitch P because the area of non-cooled portions between the restraining rolls 4 is reduced and efficient cooling can be performed. Therefore, it is preferable that the spray length L is larger than at least the roll gap G. To increase the spray length L, it is necessary to increase the injection angle θ of the cooling spray nozzle 53(54) shown in Fig. 4. In this case, if the injection angle θ of the cooling spray nozzle 53(54) is excessively large or if the cooling spray nozzle 53(54) is installed with the nozzle center axis of the cooling spray nozzle 53(54) displaced from the center position between the restraining rolls 4 in the conveying direction (the left-right direction in the figure), the spray water 55(56) from the cooling spray nozzle 53(54) may impinge on the restraining rolls 4 before it impinges on the steel plate S, so that the steel plate S may not be cooled efficiently. Therefore, it is preferable to select an appropriate injection angle θ. It is also preferable that the nozzle center axis of the cooling spray nozzle 53(54) is disposed at a position within ± 10 mm from the center position between the restraining rolls 4 in the conveying direction (the left-right direction in the figure). Most preferably, the nozzle center axis is located at substantially the center position between the restraining rolls 4.

[0024] Next, the cooling headers of the cooling device 2 will be described. Fig. 5(a) is a schematic illustration of the cooling device 2 of the present invention when it is viewed from above and describes the structure of the cooling headers. A plurality of high-flow rate cooling spray nozzles 53 arranged in the width direction of the steel plate are attached to a high-flow rate cooling header 51. A plurality of low-flow rate cooling spray nozzles 54 arranged in the width direction of the steel plate are attached to a low-flow rate cooling header 52.

[0025] In the present invention, the cooling spray nozzles disposed include cooling spray nozzles with different flow rates per unit area and unit time. The phrase "per unit area and unit time" is used for the flow rate of the cooling water sprayed within an area corresponding to the distance P' between adjacent cooling spray nozzles. The flow rate per unit area and unit time is hereinafter referred to as flow rate density (unit: $L/(min \cdot m^2)$).

[0026] Specifically, as shown in Fig. 5(a), cooling spray nozzles with a large flow rate density are attached to the high-flow rate cooling header 51, and cooling spray nozzles with a small flow rate density are attached to the low-flow rate cooling header 52. In this case, cooling spray nozzles adjacent to each other in the width direction are connected to respective cooling headers belonging to different systems.

[0027] In the present invention, cooling spray nozzles with different flow rate densities are arranged so as to be adjacent to each other in the width direction. The high-flow rate cooling spray nozzles 53 and the low-flow rate cooling spray nozzles 54 are aligned at a prescribed pitch in the width direction of the steel plate S.

[0028] In the present invention, to increase the cooling rate of the steel plate, the flow regulating valves 7 are used to suspend water supply to the low-flow rate cooling headers 52 so that the cooling water is not injected from the low-flow rate cooling spray nozzles 54, while the cooling water is injected from the high-flow rate cooling spray nozzles 53. To reduce the cooling rate, the flow regulating valves 7 are used to suspend water supply to the high-flow rate cooling headers 51 so that the cooling water is not injected from the high-flow rate cooling spray nozzles 53, while the cooling water is injected from the low-flow rate cooling spray nozzles 54. In short, in the present invention, the cooling water is injected by individually selecting the cooling water supply systems. In this case, the flow rate can be adjusted over a wide range, and the cooling rate can be adjusted over a wide range.

[0029] Generally, when a nozzle having certain characteristics is selected and used to inject cooling water, the flow rate of the cooling water is proportional to the 0.5 power of the injection pressure. Therefore, even when the injection pressure is reduced, the change in flow rate is small, so that it is very difficult to change the cooling rate largely. Generally, the cooling rate is said to be proportional to about the 0.7 power of the flow rate density. Therefore, the cooling rate is proportional to about the 0.35 power of the injection pressure.

[0030] For this reason, to reduce the cooling rate to, for example, about one-half, it is necessary to reduce the injection pressure to about 1/7. In a general flow regulating valve, the injection pressure can be adjusted within the range of about 10 to 100% of the rated value, so that the adjustment of the cooling ability is substantially limited within the range of about 50 to about 100%. The injection flow rate is proportional to the 0.5 power of the injection pressure. Therefore, in consideration of the fact that the injection pressure can be adjusted within the range of about 10 to about 100% as described above, the adjustment of the injection flow rate is limited within the range of 31.6 to 100%. Accordingly, in the present invention, cooling spray nozzles with different flow rate densities are disposed between restraining rolls 4 to allow the cooling rate to be adjusted over a wide range.

[0031] In the present invention, the flow rate densities of the cooling water injected from cooling spray nozzles adjacent to each other in the width direction of the steel plate differ from each other. Moreover, at a given injection pressure, cooling spray nozzles that inject the cooling water at a maximum flow rate density can inject the cooling water at a flow rate density equal to or higher than three times the flow rate density of the cooling water injected from cooling spray nozzles that inject the cooling water at a minimum flow rate density. In Fig. 5(a), at a given injection pressure, the flow rate density of the high-flow rate cooling spray nozzles 53 arranged at a pitch P' is at least three times that from the low-flow rate cooling spray nozzles 54.

[0032] Next, a description will be given of a specific method for selecting a cooling spray nozzle. Specifically, injection of the cooling water from cooling headers belonging to two different systems will be described as an example.

[0033] Suppose that the nozzle pitch of the high-flow rate cooling spray nozzles 53 in the width direction of the steel plate and the nozzle pitch of the low-flow rate cooling spray nozzles 54 in the width direction are the same. Then, when the cooling water is injected at a pressure of 0.4 MPa, the flow rate density of the high-flow rate cooling spray nozzles 53 is selected to 1500 L/(min·m^2), and the flow rate density of the low-flow rate cooling spray nozzles 54 is selected to 500 L/(min·m^2). In this configuration, by using the flow regulating valves 7 to control the flow rates, the flow rate density of the high-flow rate cooling spray nozzles 53 can be adjusted down to 500 L/(min·m^2) (1/3 of the rated value), and the flow rate density of the low-flow rate cooling spray nozzles 54 can be adjusted down to 167 L/(min·m^2) (1/3 of the rated value). Therefore, the flow rate control and switching between the cooling spray nozzles allow the flow rate to be adjusted continuously from the maximum flow rate density 1500 L/(min·m^2) from the high-flow rate cooling spray nozzles to the minimum flow rate density 167 L/(min·m^2) from the low-flow rate cooling spray nozzles. In the production of the steel plate, if it is unnecessary that the flow rate density of the high-flow rate cooling spray and the low-flow rate cooling spray nozzles 54 be adjusted such that the flow rate density changes continuously as described above, it is unnecessary that the maximum flow rate density of the low-flow rate cooling spray nozzles 54 be the same as the minimum flow rate density of the high-flow rate cooling spray nozzles 53. For example, the maximum flow rate density of the high-flow rate cooling spray nozzles 53 may be selected to 1500 L/(min·m^2), and the maximum flow rate density of the low-flow rate cooling spray nozzles 54 may be selected to 50 L/(min·m^2).

[0034] As described above, the flow regulating valves 7 are used to select cooling headers belonging to one system to inject cooling water from corresponding cooling spray nozzles, and the amount of the spray water can thereby be adjusted continuously over a wide range.

[0035] In the present invention, cooling spray nozzles with different flow rate densities are disposed so as to be adjacent to each other, and only one type of cooling spray nozzles is used for injection. This will be described using an exemplary arrangement in which the spray water is sprayed in a fan shape, i.e., a flat spray shape, as shown in Figs. 5(b) and 5(c). In Fig. 5(b), the injection angle θ (see Fig. 4) and a twist angle α (see Fig. 5(c)) are set such that the widthwise positions of edges of adjacent flows of the spray water 55 injected from the high-flow rate cooling spray nozzles 53 are substantially the same. In this manner, when the steel plate passes through and is cooled, the steel plate can be cooled uniformly without formation of portions that do not collide with the cooling water and extend in the width direction when viewed from the steel plate side.

[0036] In the case of Fig. 5(c) also, the injection angle θ (see Fig. 4) and the twist angle α (see Fig. 5(c)) are set such that the widthwise positions of edges of adjacent flows of spray water 56 injected from the low-flow rate cooling spray nozzles 54 are substantially the same. In this manner, when the steel plate passes through and is cooled, the steel plate can be cooled uniformly without formation of portions that do not collide with the cooling water and extend in the width direction when viewed from the steel plate side.

[0037] It is preferable that the cooling spray nozzles (the high-flow rate cooling spray nozzles 53 or the low-flow rate cooling spray nozzles 54) are installed in narrow portions between the restraining rolls 4 and that the sprayed cooling water does not impinge on the restraining rolls 4 and reaches the steel plate, and therefore the injection angle θ of the cooling spray nozzles is set such that the sprayed cooling water spreads over as wide an angle as possible. In the present invention, the injection angle θ of the cooling spray nozzles (see Fig. 4) is preferably at least 60 to 120°. This is because of the following reasons. If the injection angle θ is less than 60°, the cooling water is not sprayed over a large area, and it is feared that portions on which no cooling water impinges cause temperature unevenness. If the injection angle is larger than 120°, the flying distance of the spray water to a position of the steel plate directly below the nozzle differs largely from the flying distances to other positions, so that it is difficult to maintain uniformity of cooling.

[0038] The distance from the tip of a cooling spray nozzle to the steel plate (the nozzle height H) will be described using Fig. 3. The distance between the cooling spray nozzle (a high-flow rate cooling spray nozzle 53 or a low-flow rate cooling spray nozzle 54) and the steel plate S will be described in terms of impingement of the spray water on the restraining rolls 4. As the tip of the cooling spray nozzle approaches the steel plate, the cooling water is less likely to impinge on the restraining rolls 4 even when the cooling water is injected with a large injection angle θ. At a height at which the distance between the cooling spray nozzle and the steel plate S is equal to one half of the restraining roll diameter D, the gap between the restraining rolls 4 is smallest. In particular, when the distance between the cooling spray nozzle and the steel plate S is equal to or larger than one half of the restraining roll diameter D, the spray water from the cooling spray nozzle is likely to impinge on the restraining rolls 4 in the smallest gap portion between the restraining rolls 4. Therefore, as for the distance between the cooling spray nozzle and the steel plate S, it is preferable that the cooling spray nozzle is positioned at a height lower than about one-half of the restraining roll diameter D (i.e., the radius). If the distance between the tip of the cooling spray nozzle and the steel plate S is small, the spray water must be sprayed with a large angle, so that there is a risk that the injection angle θ will exceed 120°. There is also a risk that a tip portion of the steel plate passing through will impinge on the tip of the cooling spray nozzle. In practice, as for the distance H between the steel plate and the tip of each cooling spray nozzle during cooling of the steel plate, it is preferable in consideration of the above both issues that the tip of the spray nozzle is disposed within ± 50 mm of the restraining roll center axis height, which is the distance between the steel plate and the center axes of restraining rolls disposed upstream and downstream of the spray nozzle in the steel plate conveying direction.

[0039] In the example described above, the cooling rate is adjusted using the flow rate densities of the high-flow rate cooling spray nozzles 53 and the low-flow rate cooling spray nozzles 54 that belong to two different systems. However, the present invention is applicable to cooling rate adjustment using two or more systems. For example, as shown in Fig. 6, multiple systems (4 systems) may be used for the cooling headers to adjust the cooling rate over a wider range.

[0040] In Fig. 6, medium-flow rate cooling headers 57 and 58 are disposed in addition to the high-flow rate cooling headers 51 including the plurality of high-flow rate cooling spray nozzles 53 arranged in the width direction of the steel plate and the low-flow rate cooling headers 52 including the plurality of low-flow rate cooling spray nozzles 54 arranged in the width direction of the steel plate. A plurality of medium-flow rate cooling spray nozzles 59 and 60 arranged in the width direction of the steel plate are attached to the medium-flow rate cooling headers 57 and 58, respectively.

[0041] A specific cooling spray nozzle selection method in the case of Fig. 6 is as follows. Suppose that the nozzle pitches of the cooling spray nozzles in the width direction are the same and spraying is performed at a pressure of 0.4 MPa. Then the flow rate density of the high-flow rate cooling spray nozzles 53 is selected to 1500 L/(min·m^2), and the flow rate density of the medium-flow rate cooling spray nozzles 59 is selected to 150 L/(min·m^2) The flow rate density of the medium-flow rate cooling spray nozzles 60 is selected to 40 L/(min·m^2), and the flow rate density of the low-flow rate cooling spray nozzles 54 is selected to 10 L/(min·m^2). In this case, as for the cooling spray nozzles with the largest flow rate density and the cooling spray nozzles with the smallest flow rate density, the difference in flow rate density at the same injection pressure can be at least three times the smallest flow rate density. In this structure, by adjusting the flow rates using the flow regulating valves 7, the cooling rate can be adjusted continuously over a wide range.

[0042] In the present invention, each of the cooling spray nozzles is preferably at least one of a flat spray nozzle, a full cone spray nozzle, a square spray nozzle, or an elliptical spray nozzle.

[0043] The injection angle of each of the cooling spray nozzles means a largest injection angle when the injected spray water is viewed from a side. Fig. 7 shows illustrations when the spray water 55(56) injected from a cooling spray nozzle 53(54) and impinging on a steel plate is viewed from above. Fig. 7(a) shows an example of a flat spray nozzle that injects the spray water in a substantially fan shape and forms an impingement surface with a small thickness (about 20 mm) and a large width, and Fig. 7(b) is an example of an oval spray nozzle that forms an elliptical impingement surface. When the impingement surface of the cooling water has an elliptical shape as in the flat spray nozzle and the oval spray nozzle, an angle subtended by the major axis of the impingement surface is the largest angle as shown in Figs. 7(a) and (b) and is used as the injection angle. In a full cone spray nozzle forming a circular impingement surface as shown in Fig. 7(c), the injection angle in a side view is constant even when the spray water is viewed from any direction. In a square spray nozzle etc. forming a rectangular (square or oblong) impingement surface as shown in Fig. 7(d), an angle subtended by a diagonal line of the impingement surface is the largest angle and is used as the injection angle.

[0044] As shown in Fig. 8, the nozzle installation pitch of the high-flow rate cooling spray nozzles 53 in the width direction may differ from the nozzle installation pitch of the low-flow rate cooling spray nozzles 54 in the width direction. Fig. 8(a) is an illustration showing the structures of cooling headers when the installation pitch of the low-flow rate cooling spray nozzles 54 in the width direction is two times the installation pitch of the high-flow rate cooling spray nozzles 53. Fig. 8(b) is an illustration showing the spray water from high-flow rate spray nozzles 53, and Fig. 8(c) is an illustration showing the spray water from the low-flow rate cooling spray nozzles 54. In Figs. 8(b) and 8(c), all the spray nozzles used are flat spray nozzles. An example of the case in which the flow rate density of the high-flow rate cooling spray nozzles 53 is more than three times that of the low-flow rate cooling spray nozzles 54 will be shown. When the flow rate density of the high-flow rate cooling spray nozzles 53 is four times the flow rate density of the low-flow rate cooling spray nozzles 54 and a pressure of 0.4 MPa is used for spraying, the maximum flow rate density of the high-flow rate cooling spray nozzles 53 is 1500 L/(min·m^2), and the minimum flow rate density of the low-flow rate cooling spray nozzles 54 is 375 L/(min·m^2).

[0045] The spraying mode of the high-flow rate cooling spray nozzles 53 may differ from the spraying mode of the low-flow rate cooling spray nozzles 54.

[0046] The example of the off-line heat treatment process for the steel plate has been described above. Of course, as shown in Fig. 9, after a slab is heated in the heating furnace 1 and rolled to a prescribed size in a rolling mill 8, the resulting product may be cooled in the cooling device 2 including the cooling headers 5 disposed between the restraining rolls 4 as in the present invention. To smoothly convey the steel plate S immediately after rolling to the cooling device 2, it is preferable that the steel plate is levelled in advance by a hot leveler 9 and then conveyed to the cooling device 2.

[0047] The cooling device of the present invention can be suitably used for a steel plate having a thickness of 4.0 mm or more and a width of 100 mm or more.

[0048] Therefore, with a steel plate production facility including the cooling device of the present invention, the cooling rate can be adjusted over a wide range while the shape of the steel plate is controlled, so that steel plates having various strengths can be produced. With the cooling method of the present invention, a steel plate can be cooled over a wide cooling rate range while the shape of the steel plate is controlled. Therefore, with a production method including the step of cooling a steel plate using the cooling method of the present invention, steel plates having various strengths can be produced.

Example 1

[0049] In a first Example of the present invention, a steel plate was produced using the off-line steel plate heat treatment facility shown in Fig. 1. A steel plate (thickness: 25 mm, width 3500 mm, steel plate length: 7 m) in a room temperature state was heated to 920°C in the heating furnace 1 and cooled in the cooling device 2 located 2.5 m behind the heating furnace 1 while the traveling speed of the plate was controlled such that the temperature of the steel plate reached 100°C. The structure of the cooling device 2 was the same as that in Fig. 2. The diameters of the table rolls 3 and the restraining rolls 4 were 300 mm, and the roll pitches P of the table rolls 3 and the restraining rolls 4 were 600 mm. The cooling spray nozzles 53 and 54 were disposed between the restraining rolls 4 (P/D = 2.0). 15 cooling spray nozzles 53, 15 cooling spray nozzles 54, and 15 restraining rolls 4 were arranged in the steel plate conveying direction (the length of the cooling device 2: 9.0m).

[0050] The arrangement of the cooling spray nozzles 53 and 54 was the same as that in Fig. 3, and the distance between the steel plate and the cooling spray nozzles was 200 mm. The high-flow rate cooling spray nozzles 53 were flat spray nozzles that inject water at 150 L/min at an injection pressure of 0.4 MPa. The injection angle θ of the high-flow rate cooling spray nozzles 53 was 100°. The widthwise pitch P' of adjacent high-flow rate cooling spray nozzles 53 was 160 mm, and the twist angle α was 48° in the traveling direction of the steel plate. In this case, the flow rate density of the high-flow rate cooling spray nozzles 53 when the injection pressure was 0.4 MPa was 1563 L/(min·m^2) The low-flow rate cooling spray nozzles 54 were flat spray nozzles that inject water at 40 L/min at an injection pressure of 0.4 MPa. The injection angle θ of the low-flow rate cooling spray nozzles 54 was 100°. The widthwise pitch P' of adjacent low-flow rate cooling spray nozzles 54 was 160 mm, and the twist angle α was 48° in the traveling direction of the steel plate. In this case, the flow rate density of the low-flow rate cooling spray nozzles 54 when the injection pressure was 0.4 MPa was 417 L/(min·m^2).

[0051] Fig. 10 was a graph showing the relation between the injection pressure and the flow rate density in the high-flow rate cooling spray nozzles 53 and the low-flow rate cooling spray nozzles 54.

[0052] First, water was supplied to the high-flow rate cooling headers 51, and the injection pressure for the high-flow rate cooling spray nozzles 53 was reduced gradually from 0.4 MPa. The injection pressure could be adjusted using the flow regulating valves 7 until the injection pressure was about 0.04 MPa. However, when the pressure was further reduced, a slight difference in the degree of opening of the flow regulating valves 7 caused the pressure to fluctuate largely, so that the pressure could not be adjusted stably. The flow rate density of the high-flow rate cooling spray nozzles 53 was 1563 L/(min·m^2) when the injection pressure was 0.4 MPa and was 494 L/(min·m^2) when the injection pressure was 0.04 MPa.

[0053] Then the water supply to the high-flow rate cooling headers 51 was stopped, and water was supplied to the low-flow rate cooling headers 52. The flow rate density of the low-flow rate cooling spray nozzles 54 at an injection pressure of 0.4 MPa was 417 L/(min·m^2), and the low-flow rate cooling spray nozzles 54 were found to be capable of injecting the cooling water at approximately the same flow rate density as the lower limit of the water amount of the high-flow rate cooling spray nozzles 53. When the injection pressure for the low-flow rate cooling spray nozzles 54 was gradually reduced from 0.4 MPa, the injection pressure could be adjusted using the flow regulating valves 7 until the injection pressure was about 0.04 MPa. However, when the pressure was further reduced, a slight difference in the degree of opening of the flow regulating valves 7 caused the pressure to fluctuate largely, so that the pressure could not be adjusted stably. The flow rate density of the low-flow rate cooling spray nozzles 54 was 132 L/(min·m^2) when the injection pressure was 0.04 MPa.

[0054] As can be seen from the results in Fig. 10, by using the cooling spray nozzles with different flow rate densities, the amount of the spray water could be changed over a wide range.

[0055] Next, the relation between the flow rate density and the cooling rate when a steel plate was actually cooled until the center of the steel plate in its thickness direction reached from 800°C to 400° was shown in Fig. 11. The structures of the cooling spray nozzles were the same as those in Fig. 10. Scanning radiation thermometers (not shown) were disposed on the entrance and exit sides of the cooling device, and the surface temperature of the steel plate was measured in the width and lengthwise directions. The average temperature of the steel plate in the thickness direction was computed by a thermal transfer computation based on the information about the temperatures on the entrance and exit sides to thereby compute the cooling rate during water cooling. The results of the measurement at a portion located at the center in the width and length directions of the steel plate were used as the cooling rate at the center of the steel plate.

[0056] As shown in Fig. 11, the cooling rate could be adjusted in the range of about 20 to about 30°C/s when the high-flow rate cooling spray nozzles 53 were used for cooling, and the cooling rate could be adjusted in the range of about 7 to about 20°C/s when the low-flow rate cooling spray nozzles 54 were used for cooling. It was found that the cooling rate could be adjusted over a wider range than when only the low-flow rate cooling spray nozzles or the high-flow rate cooling spray nozzles were used.

Example 2

[0057] In a second Example of the present invention, as in the first Example, a steel plate (thickness: 25 mm, width 3500 mm, steel plate length: 7 m) in a room temperature state was heated to 920°C in the heating furnace 1 and cooled in the cooling device 2 located 2.5 m behind the heating furnace 1 while the traveling speed of the plate was controlled such that the temperature of the steel plate reached 100°C. Then the cooling rate until the center in the thickness direction reached from 800°C to 400°C and the temperature deviation of the steel plate in the width direction after cooling were examined. The temperature deviation in the width direction was determined as follows. The temperature was measured at a widthwise pitch of 20 mm and a lengthwise pitch of 100 mm using a scanning radiation thermometer, and the value at the center of the steel plate in the lengthwise direction of the steel plate was used as the temperature deviation in the width direction.

[0058] The structure of the cooling device 2 was the same as that in Fig. 2, and the diameters of the table rolls 3 and the restraining rolls 4 were as shown in Table 1. The high-flow rate spray nozzles 53 used and the low-flow rate spray nozzles 54 used were flat spray nozzles, and the injection angle θ, the widthwise pitch P', and the twist angle α were as shown in Table 1. The length of the cooling device 2 was 9.0 m, and the number of restraining rolls 4 installed and the number of cooling spray nozzles 53(54) installed were as shown in Table 1.

[Table 1]

Item	Restraining roll conditions			Number of restraining rolls and cooling spray nozzles installed	Type of nozzles used	Injection pressure (MPa)	Flow rate (L/min)	Flow rate density (L/(min·m²))	Injection angle θ (°)	Widthwise pitch P' of adjacent spray nozzles (mm)	Twist angle (°)	Conveying speed (mpm)	Cooling rate at thicknesswise center of plate at from 800 to 400°C (°C/s)	Temperature deviation in width direction (°C)
	Restraining roll pitch P (mm)	Restraining roll diameter D (mm)	P/D											
Example 1	600	300	2.0	15	High-flow rate cooling spray nozzle	0.4	150	1563	100	160	48	15	31.3	12
Example 2	600	300	2.0	15		0.2	106	1105	100	160	48	14	29.6	14
Example 3	600	300	2.0	15		0.1	75	781	100	160	48	13	27.1	12
Example 4	600	300	2.0	15		0.04	47	494	100	160	48	11	21.9	5
Example 5	600	300	2.0	15	Low-flow rate cooling spray nozzle	0.4	40	417	100	160	48	10	19.6	10
Example 6	600	300	2.0	15		0.2	28	295	100	160	48	8	15	7
Example 7	600	300	2.0	15		0.1	20	208	100	160	48	7	11	9
Example 8	600	300	2.0	15		0.04	13	132	100	160	48	5	7.3	5
Example 9	750	300	2.5	12	High-flow rate cooling spray nozzle	0.4	190	1583	100	160	48	15	31.6	15
Example 10	750	300	2.5	12		0.2	134	1120	100	160	48	14	28.9	18
Example 11	750	300	2.5	12		0.1	95	792	100	160	48	13	26.5	19
Example 12	750	300	2.5	12		0.04	60	501	100	160	48	11	22	10
Example 13	750	300	2.5	12	Low-flow rate cooling spray nozzle	0.4	50	417	100	160	48	10	20.3	15
Example 14	750	300	2.5	12		0.2	35	295	100	160	48	8	15.1	12
Example 15	750	300	2.5	12		0.1	25	208	100	160	48	7	11.1	10
Example 16	750	300	2.5	12		0.04	16	132	100	160	48	5	7.6	7

(continued)

Item	Restraining roll conditions			Number of restraining rolls and cooling spray nozzles installed	Type of nozzles used	Injection pressure (MPa)	Flow rate (L/min)	Flow rate density (L/(min·m^2))	Injection angle θ (°)	Widthwise pitch P' of adjacent spray nozzles (mm)	Twist angle (°)	Conveying speed (mpm)	Cooling rate at thicknesswise center of plate at from 800 to 400°C (°C/s)	Temperature deviation in width direction (°C)
	Restraining roll pitch P (mm)	Restraining roll diameter D (mm)	P/D											
Comparative Example 1	900	300	3.0	10	High-flow rate cooling spray nozzle	0.4	230	1597	100	160	48	15	32.2	40
Comparative Example 2	900	300	3.0	10		0.2	163	1129	100	160	48	14	28.3	35
Comparative Example 3	900	300	3.0	10		0.1	115	799	100	160	48	13	26.3	50
Comparative Example 4	900	300	3.0	10		0.04	73	505	100	160	48	11	21.4	60
Comparative Example 5	900	300	3.0	10	Low-flow rate cooling spray nozzle	0.4	60	417	100	160	48	10	20.1	30
Comparative Example 6	900	300	3.0	10		0.2	42	295	100	160	48	8	15.6	27
Comparative Example 7	900	300	3.0	10		0.1	30	208	100	160	48	7	10.7	30
Comparative Example 8	900	300	3.0	10		0.04	19	132	100	160	48	5	8.1	38
Comparative Example 9	600	220	2.7	15	High-flow rate cooling spray nozzle	0.4	150	1563	100	160	26	15	31.5	60
Comparative Example 10	600	220	2.7	15		0.2	106	1105	100	160	26	14	28.2	55
Comparative Example 11	600	220	2.7	15		0.1	75	781	100	160	26	13	27.1	40
Comparative Example 12	600	220	2.7	15		0.04	47	494	100	160	26	11	20.7	45

(continued)

Item	Restraining roll conditions			Number of restraining rolls and cooling spray nozzles installed	Type of nozzles used	Injection pressure (MPa)	Flow rate (L/min)	Flow rate density (L/(min·m^2))	Injection angle θ (°)	Widthwise pitch P' of adjacent spray nozzles (mm)	Twist angle (°)	Conveying speed (mpm)	Cooling rate at thicknesswise center of plate at from 800 to 400°C (°C/s)	Temperature deviation in width direction (°C)
	Restraining roll pitch P (mm)	Restraining roll diameter D (mm)	P/D											
Comparative Example 13	600	220	2.7	15	Low-flow rate cooling spray nozzle	0.4	40	417	100	160	26	10	19.8	35
Comparative Example 14	600	220	2.7	15		0.2	28	295	100	160	26	8	15.6	48
Comparative Example 15	600	220	2.7	15		0.1	20	208	100	160	26	7	11.4	50
Comparative Example 16	600	220	2.7	15		0.04	13	132	100	160	26	5	7.5	40

[0059] In Examples 1 to 8, when the high-flow rate cooling spray nozzles 53 were used for cooling, the cooling rate could be adjusted in the range of about 20 to about 30°C/s. When the low-flow rate cooling spray nozzles 54 were used for cooling, the cooling rate could be adjusted in the range of about 7 to about 20°C/s. In this case, the temperature deviation in the width direction was less than 15°C. The strength etc. of the cooled materials were later measured and found to be at a level not causing a particular quality problem.

[0060] In Examples 9 to 16, when the high-flow rate cooling spray nozzles 53 were used for cooling, the cooling rate could be adjusted in the range of about 20 to about 30°C/s. When the low-flow rate cooling spray nozzles 54 were used for cooling, the cooling rate could be adjusted in the range of about 7 to about 20°C/s. In this case, the temperature deviation in the width direction was less than 20°C. The temperature deviation was slightly higher than that when P/D was 2.0. The strength etc. of the cooled materials were later measured and found to be at a level not causing a particular quality problem.

[0061] Comparative Examples 1 to 8 are examples in which the restraining roll pitch P was larger than that in Examples 1 to 8. P/D is 3.0 and is outside the range of the present invention. When the high-flow rate cooling spray nozzles 53 were used for cooling, the cooling rate could be adjusted in the range of about 20 to about 30°C/s. When the low-flow rate cooling spray nozzles 54 were used for cooling, the cooling rate could be adjusted in the range of about 7 to about 20°C/s. However, under all the conditions, the steel plate was deformed into a wavy shape. Restraining rolls 4 on the entrance side of the cooling device 2 were visually inspected during the cooling operation, and a gap was found to be present between the steel plate and the restraining rolls 4. The reason for the deformation may be because the cooling water leaking through the gap into a portion in the width direction cooled the steel plate locally. The temperature deviation in the width direction after cooling varied in the range of 27 to 60°C. The strength etc. of the cooled materials were later measured. The hardness of a portion of the steel plate on which the leakage water was present was high, and this caused a quality problem.

[0062] Comparative Examples 9 to 16 were examples in which the roll diameter D is smaller than that in Examples 1 to 8 of the present invention. P/D was 2.7 and was outside the range of the present invention. When the high-flow rate cooling spray nozzles 53 were used for cooling, the cooling rate could be adjusted in the range of about 20 to about 30°C/s. When the low-flow rate cooling spray nozzles 54 were used for cooling, the cooling rate could be adjusted in the range of about 7 to about 20°C/s. However, under all the conditions, the steel plate was deformed into a wavy shape. The restraining rolls on the entrance side of the cooling device were visually inspected during the cooling operation, and a gap was found to be present between the steel plate and the restraining rolls. The reason for the deformation may be because the cooling water leaking through the gap into a portion in the width direction cooled the steel plate locally. The temperature deviation in the width direction after cooling varied in the range of 35 to 60°C. The strength etc. of the cooled materials were later measured. The hardness of a portion of the steel plate on which the leakage water was present was high, and this caused a quality problem.

Reference Signs List

[0063]

1	heating furnace
2	cooling device
3	table roll
4	restraining roll
5	cooling header
51	high-flow rate cooling header
52	low-flow rate cooling header
53	high-flow rate cooling spray nozzle
54	low-flow rate cooling spray nozzle
55	spray water
56	spray water
57	medium-flow rate cooling header
58	medium-flow rate cooling header
59	medium-flow rate cooling spray nozzle
60	medium-flow rate cooling spray nozzle
6	flowmeter
7	flow regulating valve
8	rolling mill
9	hot leveler
S	steel plate

P restraining roll pitch
D restraining roll diameter
G roll gap
L spray length
H nozzle height
P' (widthwise) pitch
θ injection angle
α twist angle

Claims

1. A cooling device for a steel plate, the cooling device comprising: a plurality of restraining rolls arranged in a steel plate conveying direction; and a plurality of cooling headers each disposed between corresponding ones of the restraining rolls,
wherein the ratio P/D of a restraining roll pitch P and a restraining roll diameter D is 2.5 or less,
wherein each of the cooling headers is connected to one of at least two cooling water supply systems,
wherein a regulating valve is attached to each of the cooling water supply systems so that ON/OFF control of water supply and flow rate control in the each of the cooling water supply systems can be performed independently of those in the rest of the cooling water supply systems,
wherein a plurality of cooling spray nozzles arranged in a width direction of the steel plate are attached to each of the cooling headers,
wherein adjacent ones of the cooling spray nozzles that are adjacent to each other in the width direction of the steel plate are connected to respective ones of the cooling headers belonging to respective different ones of the cooling water supply systems,
wherein the flow rate densities of cooling water injected from adjacent ones of the cooling spray nozzles that are adjacent to each other in the width direction of the steel plate differ from each other, wherein, at a given injection pressure, some of the cooling spray nozzles that inject the cooling water at a maximum flow rate density can inject the cooling water at a flow rate density equal to or higher than three times the flow rate density of the cooling water injected from some of the cooling spray nozzles that inject the cooling water at a minimum flow rate density, and
wherein the cooling device further comprises a control mechanism that selects each of the cooling water supply systems individually and controls the each of the cooling water supply systems using a corresponding one of the regulating valves such that corresponding ones of the cooling spray nozzles inject the cooling water.

2. The cooling device for a steel plate according to claim 1, wherein the cooling spray nozzles are installed such that the distance from a tip of each of the cooling spray nozzles to the steel plate is equal to or less than the height of center axes of the restraining rolls $\pm$50 mm.

3. The cooling device for a steel plate according to claim 1 or 2, wherein each of the cooling spray nozzles is at least one of a flat spray nozzle, a full cone spray nozzle, a square spray nozzle, and an elliptical spray nozzle, and wherein the injection angle of the cooling water when the cooling water is injected from each of the cooling spray nozzles is within the range of 60 to 120°.

4. A method for cooling a steel plate using a cooling device including a plurality of restraining rolls arranged in a steel plate conveying direction and a plurality of cooling headers each disposed between corresponding ones of the restraining rolls,
wherein the ratio P/D of a restraining roll pitch P and a restraining roll diameter D is 2.5 or less,
wherein each of the cooling headers is connected to one of at least two cooling water supply systems,
wherein a regulating valve is attached to each of the cooling water supply systems so that ON/OFF control of water supply and flow rate control in the each of the cooling water supply systems can be performed independently of those in the rest of the cooling water supply systems,
wherein a plurality of cooling spray nozzles arranged in a width direction of the steel plate are attached to each of the cooling headers,
wherein adjacent ones of the cooling spray nozzles that are adjacent to each other in the width direction of the steel plate are connected to respective ones of the cooling headers belonging to respective different ones of the cooling water supply systems,
wherein the flow rate densities of cooling water injected from adjacent ones of the cooling spray nozzles that are adjacent to each other in the width direction of the steel plate differ from each other, wherein, at a given injection

pressure, some of the cooling spray nozzles that inject the cooling water at a maximum flow rate density can inject the cooling water at a flow rate density equal to or higher than three times the flow rate density of the cooling water injected from some of the cooling spray nozzles that inject the cooling water at a minimum flow rate density, and wherein each of the cooling water supply systems is selected individually and controlled using a corresponding one of the regulating valves such that corresponding ones of the cooling spray nozzles inject the cooling water.

5. The method for cooling a steel plate according to claim 4, wherein the cooling spray nozzles are installed such that the distance from a tip of each of the cooling spray nozzles to the steel plate is equal to or less than the height of center axes of the restraining rolls ±50 mm.

6. The method for cooling a steel plate according to claim 4 or 5, wherein each of the cooling spray nozzles is at least one of a flat spray nozzle, a full cone spray nozzle, a square spray nozzle, and an elliptical spray nozzle, and wherein the injection angle of the cooling water when the cooling water is injected from each of the cooling spray nozzles is within the range of 60 to 120°.

7. A steel plate production facility comprising the cooling device according to any of claims 1 to 3.

8. A method for producing a steel plate, the method comprising a cooling step using the method for cooling according to any of claims 4 to 6.

FIG. 1

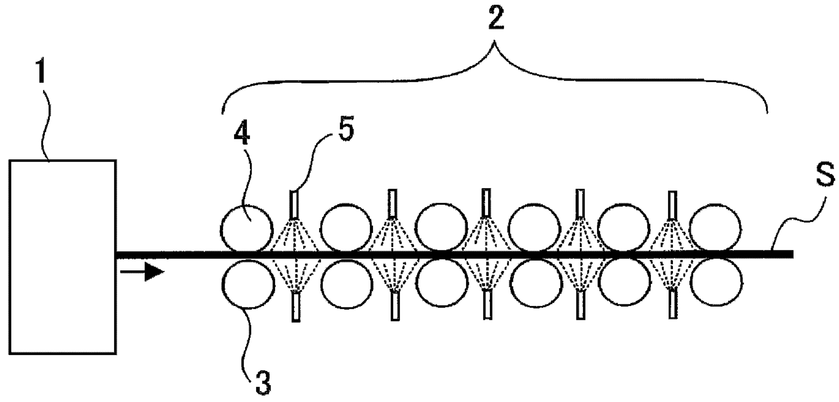


FIG. 2

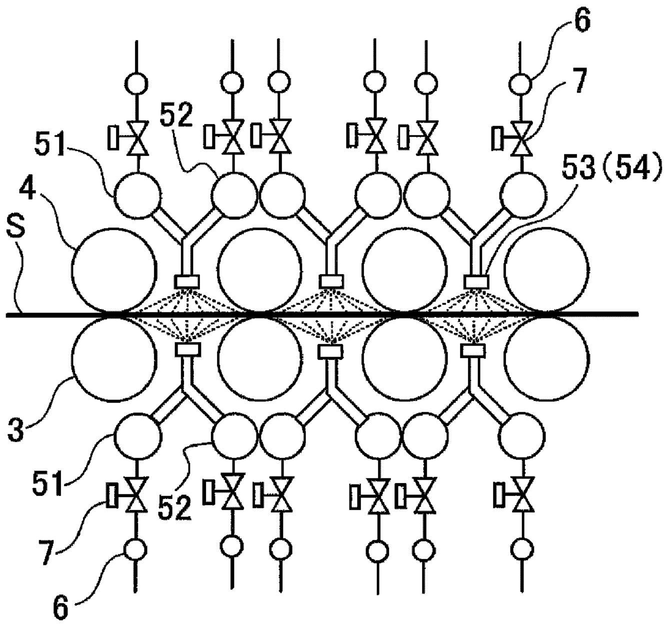


FIG. 3

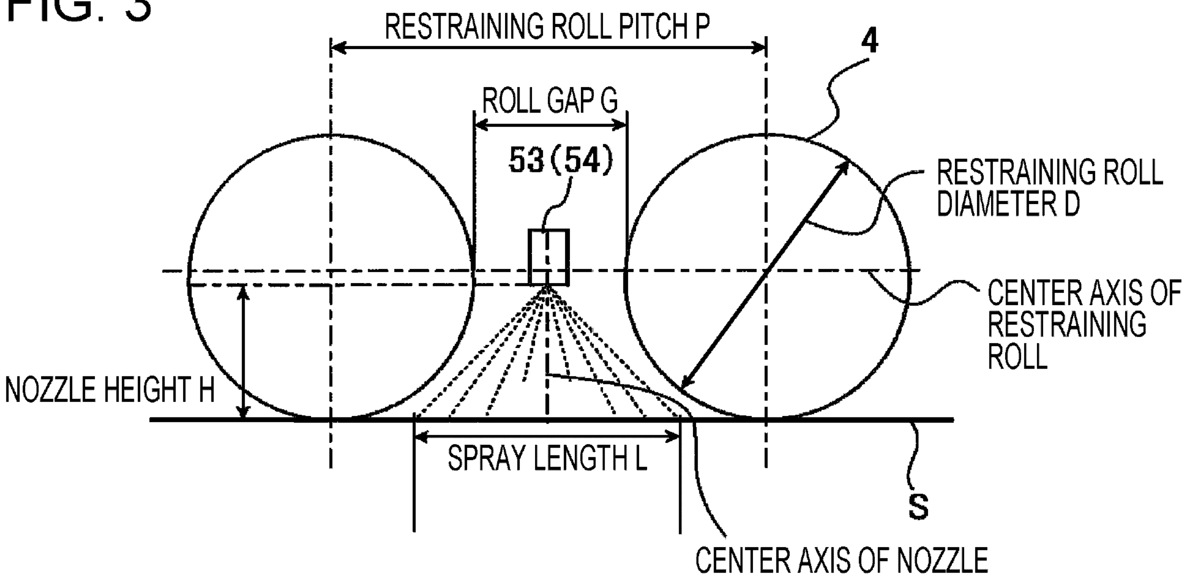


FIG. 4

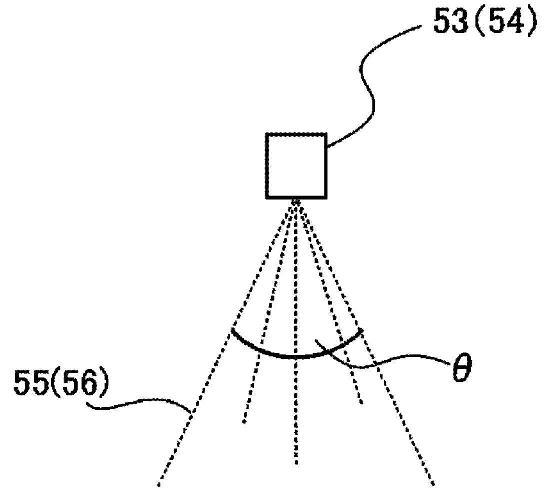

53(54)
55(56)
θ

FIG. 5

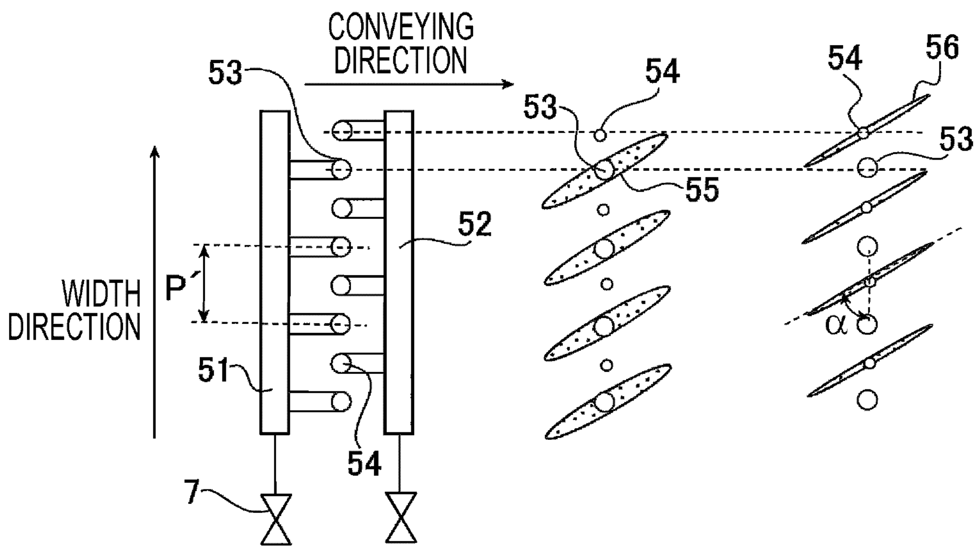

CONVEYING DIRECTION
WIDTH DIRECTION
53
54
55
56
51
52
7
P´
α
(a)
(b)
(c)

FIG. 6

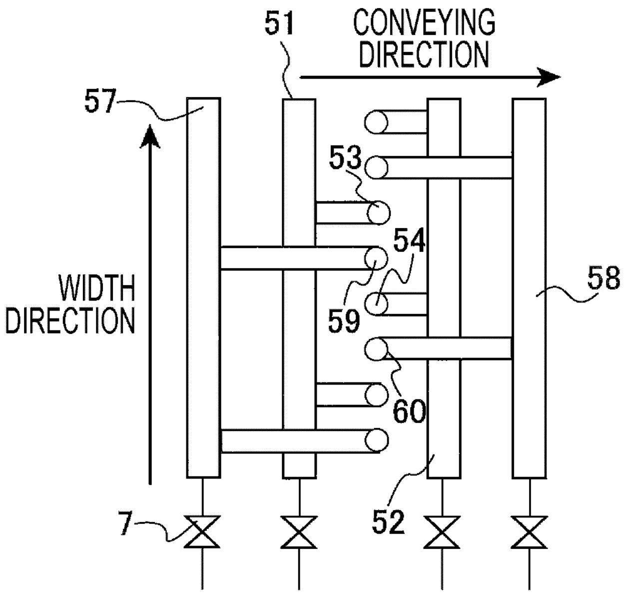

51
CONVEYING DIRECTION
57
53
54
WIDTH DIRECTION
58
59
60
7
52

FIG. 7

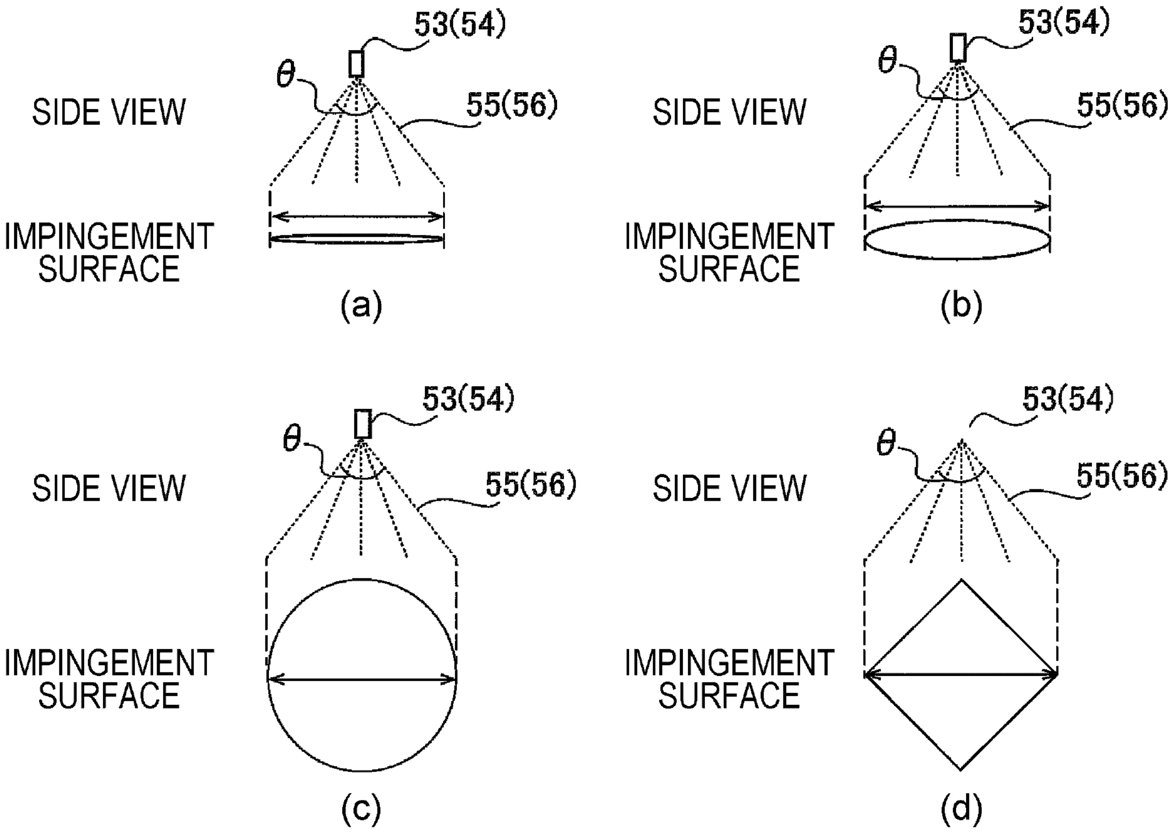

SIDE VIEW
53(54)
θ
55(56)
IMPINGEMENT SURFACE
(a)
SIDE VIEW
53(54)
θ
55(56)
IMPINGEMENT SURFACE
(b)
SIDE VIEW
53(54)
θ
55(56)
IMPINGEMENT SURFACE
(c)
SIDE VIEW
53(54)
θ
55(56)
IMPINGEMENT SURFACE
(d)

FIG. 8

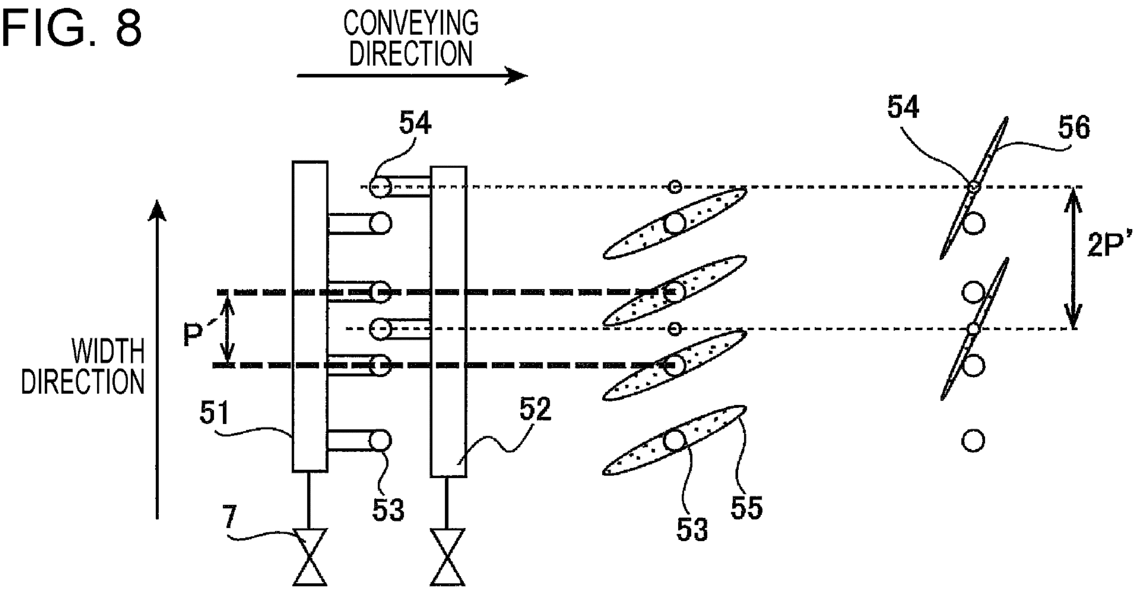


FIG. 9

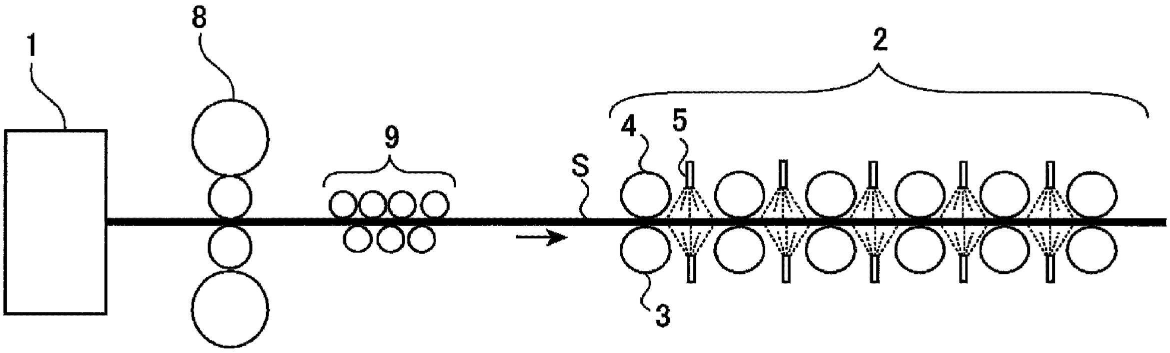


FIG. 10

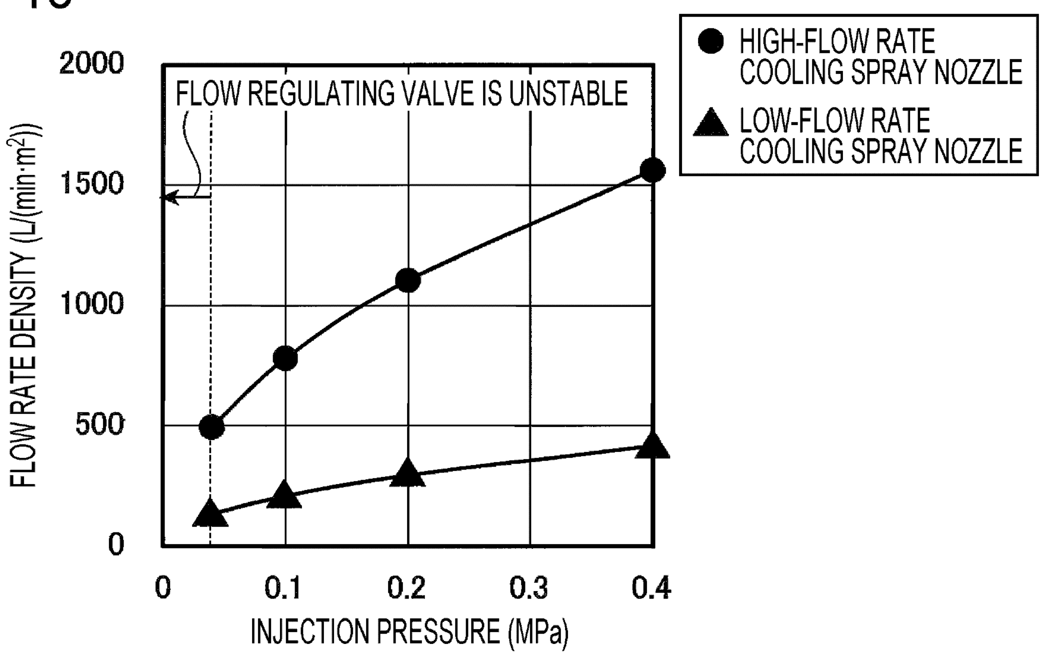
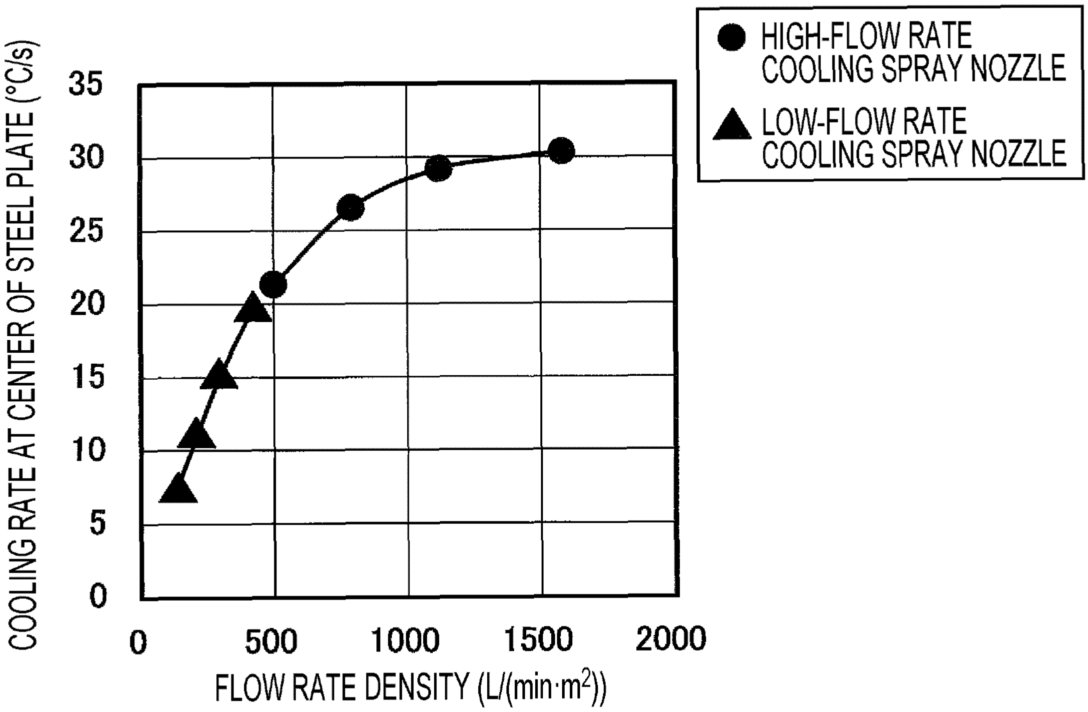


FIG. 11


HIGH-FLOW RATE COOLING SPRAY NOZZLE
LOW-FLOW RATE COOLING SPRAY NOZZLE
COOLING RATE AT CENTER OF STEEL PLATE (°C/s)
35
30
25
20
15
10
5
0
0
500
1000
1500
2000
FLOW RATE DENSITY (L/(min·m2))

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/046067

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. C21D1/00(2006.01)i, B21B1/38(2006.01)i, C21D1/18(2006.01)i, B21B45/02(2006.01)n

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. C21D1/00, B21B1/38, C21D1/18, B21B45/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2019
Registered utility model specifications of Japan	1996-2019
Published registered utility model applications of Japan	1994-2019

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.
A	JP 62-130222 A (NIPPON STEEL CORP.) 12 June 1987 (Family: none)	1-8
A	JP 53-37510 A (ISHIKAWAJIMA-HARIMA HEAVY INDUSTRIES CO., LTD.) 06 April 1978 (Family: none)	1-8
A	JP 64-2718 A (NIPPON STEEL CORP.) 06 January 1989 (Family: none)	1-8

☒ 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
"T" 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	Date of mailing of the international search report
26 February 2019 (26.02.2019)	19 March 2019 (19.03.2019)

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/046067

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2007-301568 A (NIPPON STEEL CORP.) 22 November 2007 & TW 200904559 A	1-8
A	JP 2005-118838 A (NIPPON STEEL CORP.) 12 May 2005 (Family: none)	1-8
A	US 4148673 A (UNITED STATES STEEL CORPORATION) 10 April 1979 (Family: none)	1-8
A	KR 10-2006-0090944 A (JIN SUNG HEAVY INDUSTRIES CO., LTD.) 17 August 2006 (Family: none)	1-8

Form PCT/ISA/210 (continuation of second sheet) (January 2015)

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- JP 59047010 A **[0009]**
- JP 2014124634 A **[0009]**
- JP 2011167759 A **[0009]**