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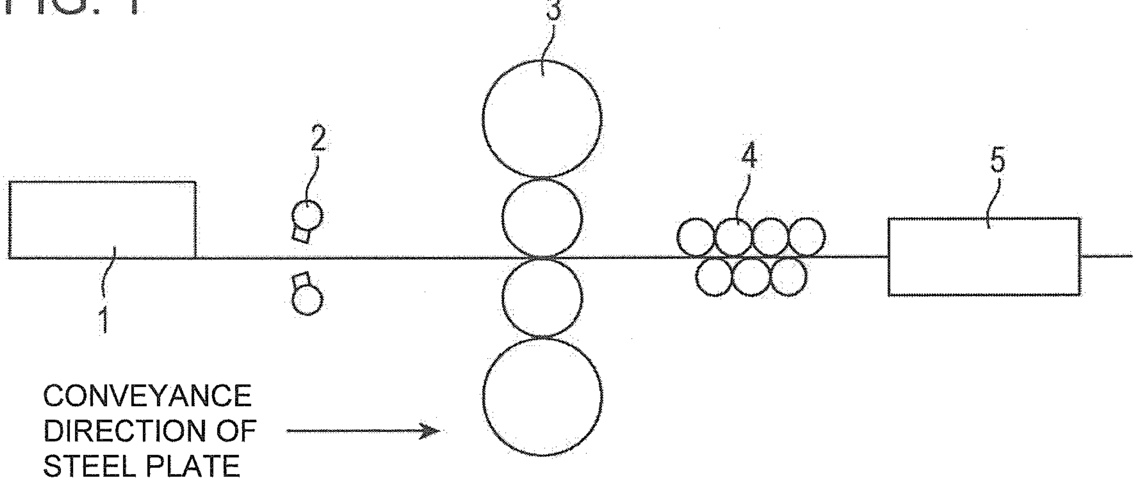
(54) **THICK STEEL PLATE MANUFACTURING METHOD AND MANUFACTURING DEVICE**

(57) An object of the present invention is to provide a method and a facility for manufacturing a steel plate by which a high-quality steel plate having less variation in quality can be ensured.

A method for manufacturing a steel plate, including a hot-rolling step, a shape correction step and an accelerated cooling step in this order, the method further includes a temperature adjustment step of performing air cooling such that a surface temperature of the steel plate is lowered below the $Ar_3$ transformation point or performing water cooling by supplying cooling water to upper and lower surfaces of the steel plate at a water amount density of 0.3 to 2.2 $m^3/m^2 \cdot min$ between the shape correction step and the accelerated cooling step, to transform the surface of the steel plate and, a descaling step of jetting high pressure water having an energy density of 0.05 $J/mm^2$ or more to the surfaces of the steel plate after the temperature adjustment step and before the accelerated cooling step.

FIG. 1

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**Description**

Technical Field

**[0001]** The present invention relates to a method and a facility for manufacturing a steel plate.

Background Art

**[0002]** In the process of manufacturing a steel plate by hot rolling, the application of cooling control has become prevalent. For example, as shown in Fig. 1, after a steel plate (not shown) is reheated in a heating furnace 1, the steel plate is descaled in a descaling apparatus 2. The steel plate is rolled by a rolling mill 3, is corrected by a shape correction apparatus 4, and is then subjected to controlled cooling by water cooling or air cooling in an accelerated cooling apparatus 5. The arrow in the figure indicates the direction of movement of the steel plate.
**[0003]** It is known that as shown in Fig. 2, the thicker scale on the surface of the steel plate becomes, the shorter cooling time becomes, and therefore, the higher cooling rate in water-cooling the steel plate becomes in the accelerated cooling apparatus. However, there is a problem that if there is a variation in scale thickness, since the cooling rate is non-uniform, qualities of the steel plate such as strength and hardness vary.
**[0004]** If the scale thickness is non-uniform, the cooling rate is non-uniform as described above. It is known that in such a case, distribution of the steel plate surface temperature when accelerated cooling is stopped (hereinafter referred to as "cooling stop temperature") in the width direction of the steel plate varies, for example, as shown in Fig. 3. There is a problem that since the cooling stop temperature of the steel plate varies, uniform qualities cannot be obtained. To illustrate, if portions in which the scale thickness is 40 $\mu$m and portions in which the scale thickness is 20 $\mu$m are mixed in the width direction of the steel plate, the cooling stop temperature when cooling the steel plate having a thickness of 25 mm from 800°C to a target temperature of 500°C is 460°C in the portions of 40 $\mu$m, and 500°C in the portions of 20 $\mu$m. In the portions of 40 $\mu$m, the cooling stop temperature is lower than the target temperature by 40°C. As a result, uniform quality cannot be obtained.
**[0005]** Thus, Patent Literature 1 discloses a method for achieving uniformization of cooling stop temperature by controlling the scale thickness to uniformize the cooling rate. In Patent Literature 1, using descaling apparatuses provided in front of and behind a rolling mill during rolling, when the cooling stop temperature of a tail end of the steel plate is lower than that of a front end thereof, the amount of jetted water in descaling on the tail end side is controlled so as to be larger than the amount of jetted water on the front end side and the scale removal rate and the residual thickness are controlled in the longitudinal direction of the steel plate. Thereby changing the heat transfer coefficient of the steel plate surface during the controlled cooling, the cooling stop temperature in the longitudinal direction of the steel plate is uniformized.

Citation List

Patent Literature

**[0006]** Patent Literature 1: Japanese Unexamined Patent Application Publication No. 6-330155

Summary of Invention

Technical Problem

**[0007]** In conventional arts, it has been attempted to uniformize the cooling stop temperature by adjusting the amount of cooling water or the conveyance velocity. However, in this method, since the cooling rate varies owing to the variation in the scale thickness, not only the uniformization of the cooling rate but also the uniformization of the cooling stop temperature is difficult.
**[0008]** In the method of Patent Literature 1, if the scale removal rate and the residual thickness cannot be controlled online, since the heat transfer coefficient cannot be controlled, high-precision uniformization of the cooling rate cannot be achieved. When changing the scale removal rate, portions in which scale remains and portions in which scale is removed mutually differ in cooling stop temperature, and therefore, the quality varies.
**[0009]** An object of the present invention is to solve the above problems and to provide a method and a facility for manufacturing a steel plate, which can ensure a high-quality steel plate having less variation in quality. Solution to Problem
**[0010]** The present invention has been made to solve the conventional problems described above. The gist of the present invention is as follows:

[1] A method for manufacturing a steel plate, comprising a hot-rolling step, a shape correction step and an accelerated cooling step in this order, the method further includes a temperature adjustment step of performing air cooling such that a surface temperature of the steel plate is lowered below the $Ar_3$ transformation point or performing water cooling by supplying cooling water to upper and lower surfaces of the steel plate at a water amount density of 0.3 to 2.2 $m^3/m^2 \cdot min$ between the shape correction step and the accelerated cooling step, to transform the surface of the steel plate and, a descaling step of jetting high pressure water having an energy density of 0.05 $J/mm^2$ or more to the surfaces of the steel plate after the temperature adjustment step and before the accelerated cooling step.

[2] The method for manufacturing a steel plate according to [1], wherein jet pressure of the high pressure water is set to 10 MPa or more in the descaling step.

[3] A facility for manufacturing a steel plate, comprising a hot-rolling apparatus, a shape correction apparatus, a temperature adjustment apparatus, a descaling apparatus and an accelerated cooling apparatus arranged in this order from a upstream side in a conveyance direction, wherein, in the temperature adjustment apparatus, air cooling is performed such that surface temperature of the steel plate is lowered below the $Ar_3$ transformation point or water cooling is performed by supplying cooling water to upper and lower surfaces of the steel plate at a water amount density of 0.3 to 2.2 $m^3/m^2 \cdot min$ to transform the steel plate surface, and, in the descaling apparatus, high pressure water having an energy density of 0.05 $J/mm^2$ or more is jetted to the surfaces of the steel plate.

[4] The facility for manufacturing a steel plate according to [3], wherein jet pressure of the high pressure water is set to 10 MPa or more in the descaling apparatus. Advantageous Effects of Invention

**[0011]** Since the present invention includes a temperature adjustment step of lowering the steel plate surface temperature below the $Ar_3$ transformation point to transform the steel plate surface between the shape correction step and the accelerated cooling step, and a descaling step of jetting high pressure water at an energy density of 0.05 $J/mm^2$ or more is jetted to the surfaces of the steel plate after the temperature adjustment step, thereby making it possible to uniformize the cooling rate and the cooling stop temperature. As a result, it is possible to manufacture a high-quality steel plate having less variation in quality.

Brief Description of Drawings

**[0012]**

[Fig. 1] Fig. 1 is a schematic diagram showing a conventional facility for manufacturing a steel plate.

[Fig. 2] Fig. 2 is a diagram showing the relationship between the scale thickness, the cooling time, and the steel plate surface temperature at the time of accelerated cooling.

[Fig. 3] Fig. 3 is a diagram showing the relationship between the position in the width direction of the steel plate and the cooling stop temperature after the accelerated cooling.

[Fig. 4] Fig. 4 is a schematic diagram showing a facility for manufacturing a steel plate that is an embodiment of the present invention.

[Fig. 5] Fig. 5 is a diagram showing the relationship between the energy density of high pressure water and the scale removal rate in case of the presence or absence of transformation of the steel plate surface.

[Fig. 6] Fig. 6 is a diagram showing the relationship between the temperature of the steel plate surface after the completion of rolling and the jet pressure required for destruction of scale.

[Fig. 7] Fig. 7 is a diagram that defines the temperature difference of the steel plate surface from the temperature adjustment step before the start of the descaling step.

[Fig. 8] Fig. 8 is a diagram showing the relationship between the amount of temperature drop of the steel plate surface and the variation in the cooling stop temperature.

[Fig. 9] Fig. 9 is a side view of a cooling apparatus according to an embodiment of the present invention.

[Fig. 10] Fig. 10 is a side view of another cooling apparatus according to an another embodiment of the present invention.

[Fig. 11] Fig. 11 is a diagram illustrating an example of nozzle arrangement of a partition wall according to an embodiment of the present invention.

[Fig. 12] Fig. 12 is a diagram illustrating a flow of drainage cooling water on the partition wall.

[Fig. 13] Fig. 13 is a diagram illustrating another flow of drainage cooling water on the partition wall.

[Fig. 14] Fig. 14 is a diagram illustrating temperature distribution in the width direction of a steel plate of a conventional example.

[Fig. 15] Fig. 15 is a diagram illustrating the flow of cooling water in an accelerated cooling apparatus.

[Fig. 16] Fig. 16 is a diagram illustrating the non-interference with drainage cooling water on the partition wall in the accelerated cooling apparatus.

Description of Embodiments

**[0013]** Embodiments of the present invention will be described with reference to the drawings below.

**[0014]** Fig. 4 is a schematic diagram showing a facility for manufacturing a steel plate that is an embodiment of the present invention. In Fig. 4, the arrow indicates a conveyance direction of the steel plate. A heating furnace 1, a descaling apparatus 2, a rolling mill 3, a shape correction apparatus 4, a temperature adjustment apparatus 6, a descaling apparatus 7, and an accelerated cooling apparatus 5 are arranged in this order from the upstream side in the conveyance direction of the steel plate. After the steel plate (not shown) is reheated in the heating furnace 1, the steel plate is descaled for primary scale removal in the descaling apparatus 2. Then, the steel plate is hot rolled by the rolling mill 3, and is corrected by the shape correction apparatus 4. After the steel plate surface temperature is lowered in the temperature adjustment apparatus 6, descaling in which scale is completely removed is performed in the descaling apparatus 7. Then, controlled cooling by water cooling or air cooling is performed in the accelerated cooling apparatus 5.

**[0015]** In the present invention, the temperature adjustment apparatus 6 and the descaling apparatus 7 are disposed between the shape correction apparatus 4 and the accelerated cooling apparatus 5. In the temperature adjustment apparatus 6, the steel plate surface temperature is lowered below the $Ar_3$ transformation point to transform the steel plate surface. This embodiment is characterized in that thereafter descaling in which high pressure water having an energy density of 0.05 J/mm$^2$ or more is jetted to the steel plate is performed in the descaling apparatus 7.

**[0016]** The temperature adjustment apparatus 6 is disposed between the shape correction apparatus 4 and the descaling apparatus 7. In the temperature adjustment step in the temperature adjustment apparatus 6, the steel plate surface temperature is lowered below the $Ar_3$ transformation point to transform the steel plate surface, thereby making it easier to remove scale in the subsequent descaling step.

**[0017]** In the temperature adjustment step, the steel plate surface temperature is lowered below the $Ar_3$ transformation point to transform the steel plate surface, transformation of base iron occurs. The transformation of base iron causes displacement at the interface between scale and base iron, and the adhesion of scale decreases. This is owing to the following mechanism. When the surface of the steel plate is cooled below the $Ar_3$ transformation point, base iron is transformed from austenite to ferrite. At this time, base iron expands, therefore force is applied to the interface between scale and base iron, and cracks are generated at the interface. As a result, the adhesion of scale decreases. Therefore, by lowering the steel plate surface temperature below the $Ar_3$ transformation point to transform the steel plate surface, scale removal is facilitated during the descaling step in the descaling apparatus 7. The $Ar_3$ transformation point can be calculated by the following equation (*) :

$$Ar_3 = 910 - 310C - 80Mn - 20Cu - 15Cr - 55Ni - 80Mo \quad \ldots (*),$$

where the element symbols denote the content (mass%) in steel of each element.

**[0018]** Next, the steel plate of which surface is transformed by lowering the steel plate surface temperature below the $Ar_3$ transformation point is subjected to descaling in which scale is removed in the descaling apparatus 7. At this time, by jetting high pressure water having an energy density of 0.05 J/mm$^2$ or more (in the present invention, high pressure water means a case where the jet pressure is 5 MPa or more) to the steel plate, scale can be completely removed. By completely removing scale in this descaling step, cooling control is made possible in the subsequent accelerated cooling step in the heating and cooling apparatus 5. As a result, the cooling rate and the cooling stop temperature can be precisely uniformized. High pressure water may be jetted over the entire length of the steel plate.

**[0019]** The present inventors examined, using a certain type of steel, the relationship between the energy density of high pressure water and the scale removal rate (the proportion of the area where scale is removed to the area of the steel plate), in case of the presence or absence of transformation of the steel plate surface before the descaling step. As a result, findings shown in Fig. 5 were obtained. From Fig. 5, it was found that when the energy density is high, the scale removal rate is high and that by transforming the steel plate surface, scale removal is made possible even when the energy density is low. Also, from Fig. 5, it is possible to say that when performing descaling after transformation, and when the energy density is lower than 0.05 J/mm$^2$, the scale removal rate is low, therefore scale remains in parts of the steel plate, the cooling stop temperature varies, and the quality is non-uniform. Therefore, the energy density of high pressure water is set to 0.05 J/mm$^2$ or more. Preferably, 0.10 J/mm$^2$ or more. In view of energy consumption of the pump for supplying high pressure water, the energy density of high pressure water is preferably 0.60 J/mm$^2$ or less.

**[0020]** In the present invention, in the descaling step, it is preferable to jet high pressure water at a jet pressure of 10 MPa or more. By setting the jet pressure to 10 MPa or more, scale can be completely removed. Therefore, the uniformization of the cooling rate and the cooling stop temperature in the accelerated cooling step can be achieved. To destroy scale, the pressure when droplets of high pressure water collide with the steel plate needs to exceed the hardness of scale. The present inventors examined the relationship between the temperature of the steel plate surface after the completion of rolling and the jet pressure of high pressure water required for the destruction of scale, and obtained the findings of Fig. 6. When manufacturing a steel plate requiring controlled cooling as in the present invention, the temperature of the steel plate surface after the completion of rolling is generally at the highest about 900°C. Therefore, in the present invention, in order to destroy scale, it is preferable that the jet pressure of high pressure water be set to 10 MPa or more.

**[0021]** Here, the energy density E (J/$mm^2$) of cooling water jetted to the steel plate is an indicator of the capacity to remove scale by descaling, and is defined as the following equation (1):

$$E = Q / (d \times W) \times \rho v^2 / 2 \times t \ldots (1),$$

where Q: jet flow rate of descaling water [$m^3$/s], d: spray jet thickness [mm] of flat nozzle, W: spray jet width [mm] of flat nozzle, fluid density ρ [kg/$m^3$], fluid velocity v [m/s] at the time of collision with steel plate, and collision time t [s] (t = d / 1000 / V, conveyance velocity V [m/s]).

**[0022]** However, the measurement of the fluid velocity v at the time of collision with steel plate is not always easy, and exactly finding the energy density E defined by equation (1) requires a great deal of labor.

**[0023]** Thus, the present inventors have further studied, and as a result have found that water amount density × jet pressure × collision time may be used as a simple definition of the energy density E (J/$mm^2$) of cooling water jetted to the steel plate. Here, water amount density ($m^3/m^2 \cdot$min) is a value calculated by "jet flow rate of cooling water ÷ cooling water collision area". Jet pressure (MPa) is defined as discharge pressure of cooling water. Collision time (s) is a value calculated by "the collision thickness of cooling water ÷ the conveyance velocity of the steel plate." The relationship between energy density of high pressure water and scale removal rate of the present invention calculated by this simple definition is also the same as Fig. 5.

**[0024]** In the temperature adjustment step, the steel plate surface temperature is lowered below the $Ar_3$ transformation point by air cooling or water cooling. In the case of air cooling, air cooling may be appropriately performed below the $Ar_3$ transformation point on a table roller for conveying the steel plate.

**[0025]** In the present invention, when performing water cooling in the temperature adjustment step, cooling water is supplied to the upper and lower surfaces of the steel plate at a water amount density of 0.3 to 2.2 $m^3/m^2 \cdot$min. If the water amount density is less than 0.3 $m^3/m^2 \cdot$min, the steel plate surface temperature cannot be lowered below the $Ar_3$ transformation point, and the steel plate surface cannot be transformed. As a result, scale remains on the steel plate. Even if cooling control is performed in the subsequent accelerated cooling step, the cooling stop temperature varies and the quality is non-uniform. If the water amount density is more than 2.2 $m^3/m^2 \cdot$min, the amount of temperature drop ΔT in the temperature adjustment step to be described later exceeds 200°C, the cooling stop temperature varies and the quality is non-uniform.

**[0026]** When transforming the steel plate surface in the temperature adjustment apparatus 6, the steel plate surface is cooled in a state in which scale is adhering to the steel plate. The present inventors obtained findings that when the amount of temperature drop in the cooling in the temperature adjustment apparatus 6 is large, the adhesion state of scale affects the uniformization of the cooling stop temperature, and the variation in the cooling stop temperature (the difference between the target steel plate surface temperature after the accelerated cooling step and the actual steel plate surface temperature after the accelerated cooling) is large. Here, the amount of temperature drop ΔT of the steel plate surface in the temperature adjustment apparatus 6 is defined, as shown in Fig. 7, as the difference between the steel plate surface temperature at the start of cooling and the lowest reached temperature of the steel plate surface.

**[0027]** The present inventors manufactured a steel plate, using a steel plate after the rolling in the rolling mill having a surface temperature of 800°C and a thickness of 25 mm, in the order of the temperature adjustment step, the descaling step and the accelerated cooling step. Here, the energy density at the time of descaling was set to 0.2 J/$mm^2$ as a condition under which scale can be completely removed regardless whether the steel plate surface at the time of descaling is untransformed or transformed. In the accelerated cooling step, cooling was performed such that the steel plate surface temperature becomes 500°C. As a result, the relationship between the amount of temperature drop ΔT in the temperature adjustment step and the variation in the cooling stop temperature was found to be as shown in Fig. 8. From Fig. 8, in order to obtain uniform quality, it is preferable that the variation in the cooling stop temperature be 25°C or less, and the amount of temperature drop ΔT in the temperature adjustment step be 200°C or less.

**[0028]** As shown in Fig. 9, the accelerated cooling apparatus 5 of the present invention preferably includes an upper header 11 for supplying cooling water to the upper surface of the steel plate 10, cooling water jetting nozzles 13 that are suspended from the upper header 11 and that jet rod-like cooling water, and a partition wall 15 placed between the steel plate 10 and the upper header 11. Further, the partition wall 15 is preferably provided with many water supply ports 16 into which the lower ends of the cooling water jetting nozzles 13 are inserted, and many drainage ports 17 for draining the cooling water supplied to the upper surface of the steel plate 10 to above the partition wall 15.

**[0029]** Specifically, the upper surface cooling equipment includes an upper header 11 for supplying cooling water to the upper surface of the steel plate 10, cooling water jetting nozzles 13 that are suspended from the upper header 11, and a partition wall 15 that is placed horizontally between the upper header 11 and the steel plate 10 across the width direction of the steel plate and that has many through-holes (water supply ports 16 and drainage ports 17). The cooling water jetting nozzles 13 are circular tube nozzles 13 that jet rod-shaped cooling water, and the tips thereof are inserted into the through-holes (water supply ports 16) provided in the partition wall 15 and are placed so as to be above the lower end of the partition wall 15. In order to prevent the cooling water jetting nozzles 13 from sucking the foreign matter in the bottom of the upper header 11 and clogging, the cooling water jetting nozzles 13 preferably penetrate into the upper header 11 so that the upper ends thereof protrude into the inside of the upper header 11.

**[0030]** Here, the rod-like cooling water in the present invention means cooling water that is jetted in a state of being pressurized to certain degree from nozzle jetting ports having a circular shape (including an elliptical shape and a polygonal shape), and cooling water of such continuous and linear water flows that the jet velocity of cooling water from the nozzle jetting ports is 6 m/s or more and preferably 8 m/s or more and the cross-section of water flows jetted from the nozzle jetting ports is kept substantially circular. That is, it differs from free fall flows from circular tube laminar nozzles and one that is jetted in a liquid droplet state, such as a spray.

**[0031]** The reason why the tips of the cooling water jetting nozzles 13 are inserted into the through-holes and are placed so as to be above the lower end of the partition wall 15 is that if the steel plate whose front end is warped upward enters, the cooling water jetting nozzles 13 are prevented from being damaged by the partition wall 15. Therefore, since cooling can be performed in a state where the cooling water jetting nozzles 13 are in good condition over a long period of time, it is possible to prevent the occurrence of temperature unevenness of the steel plate without performing equipment maintenance or the like.

**[0032]** Since the tips of the circular tube nozzles 13 are inserted into the through-holes, as shown in Fig. 16, they does not interfere with the flow of drainage water 19 in the width direction indicated by the dotted arrow and flowing on the upper surface of the partition wall 15. Therefore, the cooling water jetted from the cooling water jetting nozzles 13 can reach the upper surface of the steel plate equally regardless of the position in the width direction, and cooling that is uniform in the width direction can be performed.

**[0033]** To give an example of the partition wall 15, as shown in Fig. 11, many through-holes having a diameter of 10 mm are formed in the partition wall 15 in a grid at a pitch of 80 mm in the width direction of the steel plate and 80 mm in the conveyance direction. Cooling water jetting nozzles 13 having an outer diameter of 8 mm, an inner diameter of 3 mm, and a length of 140 mm are inserted into the water supply ports 16. The cooling water jetting nozzles 13 are arranged in a staggered manner, and through-holes through which the cooling water jetting nozzles 13 are not passed serve as drainage ports 17 for cooling water. Thus, the many through-holes provided in the partition wall 15 of the accelerated cooling apparatus of the present invention consist of approximately the same number of water supply ports 16 and drainage ports 17, which share roles and functions.

**[0034]** In this case, the total cross-sectional area of the drainage ports 17 is sufficiently larger than the total cross-sectional area of the inner diameters of the circular tube nozzles 13 of the cooling water jetting nozzles 13, and about 11 times the total cross-sectional area of the inner diameters of the circular tube nozzle 13 is ensured. As shown in Fig. 9, cooling water supplied to the upper surface of the steel plate fills the space between the steel plate surface and the partition wall 15, is guided to above the partition wall 15 through the drainage ports 17, and is rapidly discharged. Fig. 12 is a front view illustrating the flow of drainage cooling water on the partition wall and in the vicinity of an end in the width direction of the steel plate. The drainage direction of the drainage ports 17 is an upward direction which is opposite the cooling water jetting direction. After passing through the partition wall 15 to above the partition wall 15, drainage cooling water turns to the outer side in the width direction of the steel plate, flows through a drainage passage between the upper header 11 and the partition wall 15, and is drained.

**[0035]** On the other hand, in the example shown in Fig. 13, the drainage ports 17 are inclined in the width direction of steel plate and in an oblique direction toward the outer side in the width direction so that the drainage direction is directed to the outer side in the width direction of the steel plate. This is preferable because the flow of drainage water 19 on the partition wall 15 is smooth and the water discharge is facilitated.

**[0036]** Here, if a drainage port and a water supply port are provided in the same through-hole as shown in Fig. 14, cooling water, after colliding with the steel plate, is not apt to pass through the partition wall 15 to above the partition wall 15, and flows through the space between the steel plate 10 and the partition wall 15 toward an end in the width direction of the steel plate. The flow rate of the drainage cooling water between the steel plate 10 and the partition wall 15 increases toward the ends in the plate width direction. Therefore, the nearer the ends in the plate width direction, the more the force with which jetted cooling water 18 penetrates the film of stagnant water to reach the steel plate is inhibited.

**[0037]** In the case of a steel sheet, a width thereof is at most about 2 m, and therefore the effect is limited. However, particularly in the case of a steel plate having a plate width of 3 m or more, the effect cannot be ignored. Therefore, the cooling of the ends in the width direction of the steel plate weakens, and the temperature distribution in the width direction of the steel plate in this case is a non-uniform.

**[0038]** In contrast, in the accelerated cooling apparatus 5 of the present invention, the water supply ports 16 and the drainage ports 17 are separately provided as shown in Fig. 15, and share the roles of water supply and drainage, and therefore, drainage cooling water passes through the drainage ports 17 of the partition wall 15 and smoothly flows to above the partition wall 15. Therefore, the drainage water after cooling is removed rapidly from the upper surface of the steel plate, therefore cooling water supplied subsequently can penetrate the film of stagnant water easily, and a sufficient cooling capacity can be obtained. The temperature distribution in the width direction of the steel plate in this case is a uniform temperature distribution, and a temperature distribution that is uniform in the width direction can be obtained.

**[0039]** If the total cross-sectional area of the drainage ports 17 is more than or equal to 1.5 times as large as the total cross-sectional area of the inner diameters of the circular tube nozzles 13, the discharge of cooling water is performed rapidly. This can be achieved, for example, by forming holes larger than the outer diameter of the circular tube nozzles 13 in the partition wall 15, and making the number of drainage ports equal to or greater than the number of the water supply ports.

**[0040]** It is undesirable that the total cross-sectional area of the drainage ports 17 is less than 1.5 times the total cross-sectional area of the inner diameters of the circular tube nozzles 13 because the flow resistance of the drainage ports is increased, stagnant water is difficult to drain, and as a result, the amount of cooling water that can reach the steel plate surface through the film of stagnant water is greatly reduced, and the cooling capacity is reduced. More preferably, four times or more. On the other hand, if the number of drainage ports is too large, or the cross-sectional diameter of the drainage ports is too large, the rigidity of the partition wall 15 is reduced, and the partition wall 15 is easily damaged when the steel plate collides with it. Therefore, the ratio of the total cross-sectional area of the drainage ports to the total cross-sectional area of the inner diameters of the circular tube nozzle 13 is preferably within the range of 1.5 to 20.

**[0041]** The clearance between the outer peripheral surface of circular tube nozzle 13 inserted into water supply port 16 of the partition wall 15 and the inner surface of water supply port 16 is preferably 3 mm or less. If this clearance is large, owing to the accompanying flow of cooling water jetted from circular tube nozzle 13, the cooling drainage water discharged to the upper surface of the partition wall 15 is drawn into the clearance between water supply port 16 and the outer peripheral surface of circular tube nozzle 13, and is supplied onto the steel plate again, and therefore the cooling efficiency is deteriorated. To prevent this deterioration, it is more preferable to make the outer diameter of the circular tube nozzles 13 substantially the same as the size of the water supply ports 16. However, in consideration of working accuracy and mounting error, a clearance of up to 3 mm having a substantially low impact is acceptable. More preferably, 2 mm or less.

**[0042]** Further, in order for cooling water to be able to reach the steel plate through the film of stagnant water, the inner diameter and length of the circular tube nozzles 13, the jet velocity of cooling water, and the nozzle distance must also be optimized.

**[0043]** The nozzle inner diameter is preferably 3 to 8 mm. If the nozzle inner diameter is less than 3 mm, the bundle of water jetted from nozzle becomes thin and the momentum becomes weak. On the other hand, if the nozzle diameter is more than 8 mm, the flow rate becomes low, and the force to penetrate the film of stagnant water becomes weak.

**[0044]** The length of circular tube nozzle 13 is preferably 120 to 240 mm. The length of circular tube nozzle 13 herein means the length from the inlet port at the nozzle upper end penetrated into the header to some extent to the lower end of nozzle inserted into water supply port of the partition wall. If the circular tube nozzles 13 are shorter than 120 mm, the distance between the lower surface of the header and the upper surface of the partition wall is too short (for example, when the header thickness is 20 mm, the amount of protrusion of the nozzle upper end into the header is 20 mm, and the amount of insertion of the nozzle lower end into the partition wall is 10 mm, this distance is less than 70 mm). Therefore, the drainage space above the partition wall is small, and the drainage cooling water cannot be discharged smoothly. On the other hand, if the circular tube nozzles 13 are longer than 240 mm, pressure loss of the circular tube nozzles 13 is increased, and the force to penetrate the film of stagnant water becomes weak.

**[0045]** The jet velocity of cooling water from the nozzles needs to be 6 m/s or more, and preferably 8 m/s or more. The reason is that, if the jet velocity is less than 6 m/s, the force with which cooling water penetrates the film of stagnant water is extremely weak. The jet velocity is preferably 8 m/s or more because a larger cooling capacity can be ensured. In addition, the distance from the lower end of cooling water jetting nozzle 13 for upper surface cooling to the surface of the steel plate 10 is preferably set to 30 to 120 mm. If this distance is less than 30 mm, the frequency at which the steel plate 10 collides with the partition wall 15 is extremely increased, and equipment maintenance is difficult. If this distance exceeds 120 mm, the force with which cooling water penetrates the film of stagnant water is extremely weak.

**[0046]** In the cooling of the upper surface of the steel plate, draining rolls 20 is preferably placed in front of and behind the upper header 11 so that cooling water does not spread in the longitudinal direction of the steel plate. Owing to this, the cooling zone length becomes constant, and the temperature control is facilitated. Here, the flow of cooling water in the steel plate conveyance direction is dammed by the draining rolls 20, and therefore drainage cooling water flows to the outer side in the width direction of the steel plate. However, in the vicinities of the draining rolls 20, cooling water tends to stagnate.

**[0047]** Thus, it is preferable that, as shown in Fig. 10, of the rows of circular tube nozzles 13 arranged in the width direction of the steel plate, the cooling water jetting nozzles of the row on the most upstream side in the steel plate conveyance direction be inclined at 15 to 60 degrees toward the upstream direction in the steel plate conveyance direction, and the cooling water jetting nozzles of the row on the most downstream side in the steel plate conveyance direction be inclined at 15 to 60 degrees toward the downstream direction in the steel plate conveyance direction. This is preferable because positions close to the draining rolls 20 can also be supplied with cooling water, cooling water does not stagnate in the vicinities of the draining rolls 20, and the cooling efficiency is improved.

**[0048]** The distance between the lower surface of the upper header 11 and the upper surface of the partition wall 15 is provided such that the cross-sectional area of flow passage in the width direction of the steel plate in the space surrounded by the lower surface of the upper header and the upper surface of the partition wall is 1.5 or more times as large as the total cross-sectional area of the inner diameters of the cooling water jetting nozzles, for example, about 100 mm or more. If the cross-sectional area of flow passage in the width direction of the steel plate is less than 1.5 times as large as the total cross-sectional area of the inner diameters of the cooling water jetting nozzles, the drainage cooling water discharged through the drainage ports 17 provided in the partition wall to the upper surface of the partition wall 15 cannot be discharged smoothly in the width direction of the steel plate.

**[0049]** In the accelerated cooling apparatus of the present invention, the range of water amount density that is most effective is 1.5 $m^3/m^2 \cdot min$ or more. If the water amount density is lower than this, the film of stagnant water is not so thick. There may be a case where even when a known technique in which rod-like cooling water is allowed to fall freely to cool a steel plate is applied, the temperature unevenness in the width direction is not so large. On the other hand, even when the water amount density is more than 4.0 $m^3/m^2 \cdot min$, the use of the technique of the present invention is effective, but there are practical problems such as an increase in equipment cost, and therefore the water amount density of 1.5 to 4.0 $m^3/m^2 \cdot min$ is the most practical.

**[0050]** The application of the cooling technique of the present invention is effective particularly for a case where draining rolls are disposed in front of and behind the cooling header. However, the cooling technique of the present invention can also be applied to a case where there is no draining rolls. For example, the cooling technique of the present invention can also be applied to cooling equipment in which a header is relatively long in the longitudinal direction (in a case where the header is about 2 to 4 m long), and water spray for purging is jetted in front of and behind the header to prevent water leakage to the non-water cooling zones.

**[0051]** In the present invention, the cooling apparatus on the lower surface side of the steel plate is not particularly limited. In the embodiment shown in Figs. 9 and 10, an example of lower cooling header 12 having the same circular tube nozzles 14 as those of the cooling apparatus on the upper surface side. However, in the cooling of the lower surface side of the steel plate, jetted cooling water falls freely after colliding with the steel plate, and therefore, a partition wall 15 for discharging cooling water in the width direction of the steel plate as in the cooling of the upper surface side is not necessary. Known techniques that supply film-like cooling water, atomized spray cooling water, or the like may be used.

**[0052]** The heating furnace 1 and the descaling apparatus 2 of the present invention are not particularly limited, and conventional apparatuses may be used. The descaling apparatus 2 need not have the same configuration as that of the descaling apparatus 7 of the present invention.

EXAMPLE 1

**[0053]** Examples of the present invention will be described below. In the following description, the steel plate temperature is the temperature of surface thereof.

**[0054]** A steel plate of the present invention was manufactured using the facility for manufacturing a steel plate shown in Fig. 4. After reheating a slab in the heating furnace 1, primary scale was removed in the descaling apparatus 2, hot rolling was performed in the rolling mill 3, and shape correction was performed in the shape correction apparatus 4. After the shape correction, the temperature of the steel plate surface was adjusted in the temperature adjustment apparatus 6, and then descaling was performed in the descaling apparatus 7. In the descaling apparatus 7, the jet distance (the distance between jet nozzle of the descaling apparatus 7 and the surface of the steel plate) was set to 130 mm, the nozzle jet angle was set to 32°, and the nozzle angle of attack was set to 15°. After the descaling in the descaling apparatus 7, cooling was performed to 500°C in the accelerated cooling apparatus 5. Here, the temperature adjustment step and the descaling step after the temperature adjustment were performed under the conditions shown in Table 1. The cooling length of the temperature adjustment apparatus 6 was set to 1 m. The $Ar_3$ transformation point of the steel plate used was 780°C. After the completion of rolling in the rolling mill 3, the plate thickness was 25 mm, and the steel plate temperature was 830°C. The amount of temperature drop $\Delta T$ in the temperature adjustment step was measured only in the case where water cooling was used in the temperature adjustment step. This is because when temperature adjustment is performed by air cooling, the problem due to excessive temperature drop does not arise.

**[0055]** For the obtained steel plate, in order to obtain a steel plate having less variation in quality, on the basis of the relationship of Fig. 8, a steel plate having a variation in cooling stop temperature within 25°C was determined as "passing standard".

**[0056]** The manufacturing conditions and the results are shown in Table 1.

**[0057]**

[Table 1]

| Item | Temperature adjustment step | | Descaling conditions | | | | |
|---|---|---|---|---|---|---|---|
| | Water amount density ($m^3/m^2 \cdot min$) | Amount of temperature drop $\Delta T$ (°C) | Steel plate surface temperature at the time of descaling (°C) | Conveyance velocity (m/s) | Energy density ($J/mm^2$) | Jetpressure (MPa) | Variation in cooling stop temperature (°C) |
| Invention Example 1 | [Air cooling] | - | 770 | 1.6 | 0.08 | 15 | 10 |
| Invention Example 2 | 1.0 | 120 | 750 | 1.6 | 0.08 | 15 | 19 |
| Invention Example 3 | [Air cooling] | - | 770 | 1.0 | 0.13 | 15 | 10 |
| Invention Example 4 | [Air cooling] | - | 770 | 0.4 | 0.13 | 8 | 23 |
| Comparative Example 1 | [Air cooling] | - | 770 | 2.2 | 0.04 | 12 | 36 |
| Comparative Example 2 | [Air cooling] | - | 800 | 1.6 | 0.08 | 15 | 40 |
| Comparative Example 3 | 0.2 | 35 | 785 | 1.6 | 0.08 | 15 | 41 |
| Comparative Example 4 | 2.4 | 220 | 720 | 1.6 | 0.08 | 15 | 27 |

**[0058]** In Invention Example 1, after the completion of rolling, the steel plate surface temperature was lowered to 770°C by air cooling in the temperature adjustment apparatus 6. Then, in the descaling apparatus 7, high pressure water was jetted over the entire length of the steel plate at an energy density of 0.08 $J/mm^2$, a jet pressure of 15 MPa, and a jet flow rate per nozzle of 40 L/min (= $6.7 \times 10^{-4}$ $m^3/s$), and then cooling is performed in the accelerated cooling apparatus 5 to manufacture. Since descaling was performed after the steel plate surface had been transformed from austenite to ferrite, scale was able to be completely removed, and the variation in the cooling stop temperature (hereinafter simply referred to as temperature unevenness) was 10°C.

**[0059]** In Invention Example 2, after the completion of rolling, cooling water was supplied to the upper and lower surfaces of a steel plate at a water amount density of 1.0 $m^3/m^2 \cdot min$ to lower the steel plate surface temperature to 750°C in the temperature adjustment apparatus 6. After that, in the descaling apparatus 7, high pressure water was jetted over the entire length of the steel plate at an energy density of 0.08 $J/mm^2$, and then cooling is performed in the accelerated cooling apparatus 5 to manufacture. Since the water amount density for water cooling in the temperature adjustment apparatus 6 was 1.0 $m^3/m^2 \cdot min$, the steel plate temperature at the time of descaling was 750°C, and descaling was able to be performed after the steel plate surface had been transformed from austenite to ferrite. Since the amount of temperature drop $\Delta T$ during the temperature adjustment step was 120°C, the temperature unevenness was 19°C.

**[0060]** In Invention Example 3, after the completion of rolling, the steel plate surface temperature was lowered to 770°C by air cooling. Then, in the descaling apparatus 7, high pressure water was jetted over the entire length of the steel plate at a jet pressure of 15 MPa, a jet flow rate per nozzle of 40 L/min (= $6.7 \times 10^{-4}$ $m^3/s$), and an energy density of 0.13 $J/mm^2$, and then cooling is performed in the accelerated cooling apparatus 5 to manufacture. Descaling was performed after the steel plate surface had been transformed from austenite to ferrite. Therefore, scale was able to be completely removed, and the temperature unevenness was 10°C.

**[0061]** In Invention Example 4, after the completion of rolling, the steel plate surface temperature was lowered to 770°C in the temperature adjustment apparatus 6. Then, in the descaling apparatus 7, high pressure water was jetted over the entire length of the steel plate at an energy density of 0.13 $J/mm^2$, and a jet pressure of 8 MPa, and then cooling is performed in the accelerated cooling apparatus to manufacture. Since the jet pressure was 8 MPa, and was of a value outside a range that is preferable in the present invention, it is thought that scale was not able be destroyed and slightly remained, and the temperature unevenness was 23°C. Although the jet pressure in Invention Example 4 was higher than in the case of Invention Example 3, which was within the preferable range of the present invention, the other conditions that were essential in the present invention were satisfied, and therefore the target, within 25°C, was achieved.

**[0062]** In Comparative Example 1, after the completion of rolling, the steel plate surface temperature was lowered to 770°C by air cooling in the temperature adjustment apparatus 6. Then, in the descaling apparatus 7, high pressure water was jetted over the entire length of the steel plate at an energy density of 0.04 $J/mm^2$, and a jet pressure of 12 MPa, and then cooling is performed in the accelerated cooling apparatus 5 to manufacture. Since the energy density was 0.04 $J/mm^2$, it is thought that scale remained in parts of the steel plate, and the temperature unevenness was 36°C. The surface of the steel plate of Comparative Example 1 that was cooled to room temperature was observed visually, and color tone unevenness was found on the surface. Therefore, the cause of the temperature unevenness is presumed to be caused by the fact that scale remained in parts of the steel plate.

**[0063]** In Comparative Example 2, after the completion of rolling, the steel plate surface temperature was not lowered in the temperature adjustment apparatus 6. In the descaling apparatus 7, high pressure water was jetted to a steel plate having a steel plate surface temperature of 800°C over the entire length of the steel plate at an energy density of 0.08 $J/mm^2$, and a jet pressure of 15 MPa, and then cooling is performed in the accelerated cooling apparatus 5 to manufacture. The energy density was within the range of the present invention. However, since descaling was performed in a state where the surface of the steel plate is not transformed, it is thought that scale remained in parts of the steel plate, and the temperature unevenness was 40°C. The surface of the steel plate of Comparative Example 2 that was cooled to room temperature was observed visually, and color tone unevenness was found on the surface. Therefore, the cause of the temperature unevenness is presumed to be caused by the fact that scale remained in parts of the steel plate.

**[0064]** In Comparative Example 3, after the completion of rolling, cooling water was supplied to the upper and lower surfaces of a steel plate at a water amount density of 0.2 $m^3/m^2 \cdot min$ in the temperature adjustment apparatus 6. Then, in the descaling apparatus 7, high pressure water was jetted over the entire length of the steel plate at an energy density of 0.08 $J/mm^2$, and then cooling is performed in the accelerated cooling apparatus 5 to manufacture. Since the water amount density was as low as 0.2 $m^3/m^2 \cdot min$, the steel plate temperature was only lowered to 785°C, and descaling was performed in a state where the surface of the steel plate is not transformed. Therefore, it is thought that scale remained in parts of the steel plate, and the temperature unevenness was 41°C. The surface of the steel plate of Comparative Example 3 that was cooled to room temperature was observed visually, and color tone unevenness was found on the surface. Therefore, the cause of the temperature unevenness is presumed to be caused by the fact that scale remained in parts of the steel plate.

**[0065]** In Comparative Example 4, after the completion of rolling, cooling water was supplied to the upper and lower surfaces of a steel plate at a water amount density of 2.4 $m^3/m^2 \cdot min$ in the temperature adjustment apparatus 6. After that, in the descaling apparatus 7, high pressure water was jetted over the entire length of the steel plate at an energy density of 0.08 J/mm$^2$, and then cooling is performed in the accelerated cooling apparatus 5 to manufacture. Since the water amount density was as high as 2.4 m$^3$/m$^2$·min, $\Delta$T at the time of cooling before descaling was 220°C, and the temperature unevenness was 27°C. The surface of the steel plate of Comparative Example 4 that was cooled to room temperature was observed visually, and color tone unevenness was found on the surface. Therefore, the cause of the temperature unevenness is presumed to be caused by the fact that scale remained in parts of the steel plate. Reference Signs List

**[0066]**

1 heating furnace
2 descaling apparatus
3 rolling mill
4 shape correction apparatus
5 accelerated cooling apparatus
6 temperature adjustment apparatus
7 descaling apparatus
10 steel plate
11 upper header
12 lower header
13 upper cooling water jetting nozzle (circular tube nozzle)
14 lower cooling water jetting nozzle (circular tube nozzle)
15 partition wall
16 water supply port
17 drainage port
18 jetted cooling water
19 drainage water
20 draining roll
21 draining roll

## Claims

**1.** A method for manufacturing a steel plate, comprising a hot-rolling step, a shape correction step and an accelerated cooling step in this order, the method further comprising:

a temperature adjustment step of performing air cooling such that a surface temperature of the steel plate is lowered below the $Ar_3$ transformation point or performing water cooling by supplying cooling water to upper and lower surfaces of the steel plate at a water amount density of 0.3 to 2.2 m$^3$/m$^2$·min between the shape correction step and the accelerated cooling step, to transform the surface of the steel plate and,
a descaling step of jetting high pressure water having an energy density of 0.05 J/mm$^2$ or more to the surfaces of the steel plate after the temperature adjustment step and before the accelerated cooling step.

**2.** The method for manufacturing a steel plate according to Claim 1, wherein jet pressure of the high pressure water is set to 10 MPa or more in the descaling step.

**3.** A facility for manufacturing a steel plate, comprising a hot-rolling apparatus, a shape correction apparatus, a temperature adjustment apparatus, a descaling apparatus and an accelerated cooling apparatus arranged in this order from a upstream side in a conveyance direction, wherein,
in the temperature adjustment apparatus, air cooling is performed such that surface temperature of the steel plate is lowered below the $Ar_3$ transformation point or water cooling is performed by supplying cooling water to upper and lower surfaces of the steel plate at a water amount density of 0.3 to 2.2 m$^3$/m$^2$·min to transform the steel plate surface, and,
in the descaling apparatus, high pressure water having an energy density of 0.05 J/mm$^2$ or more is jetted to the surfaces of the steel plate.

**4.** The facility for manufacturing a steel plate according to Claim 3, wherein jet pressure of the high pressure water is set to 10 MPa or more in the descaling apparatus.

FIG. 1

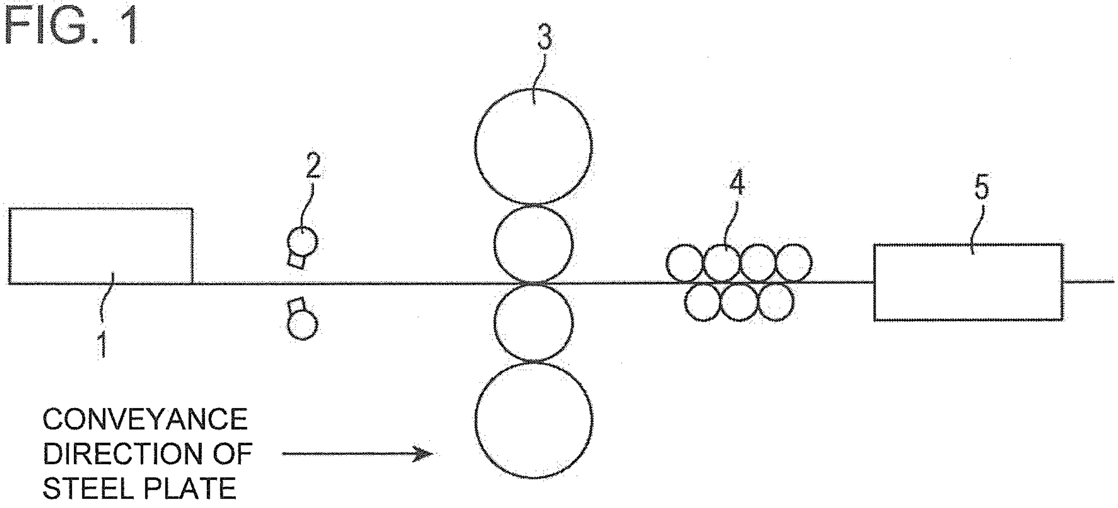



FIG. 2

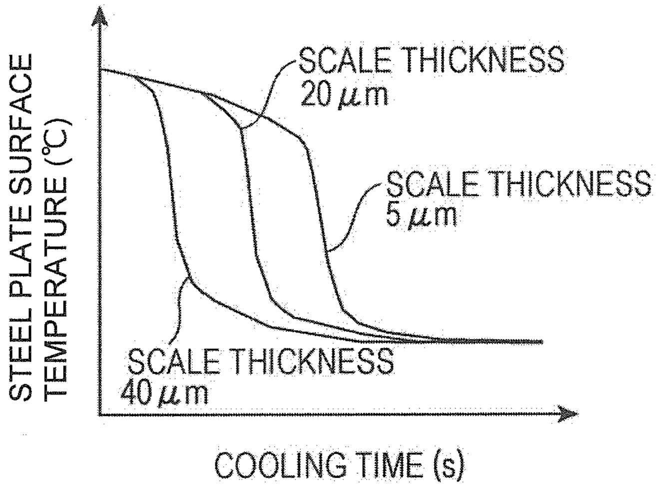



FIG. 3

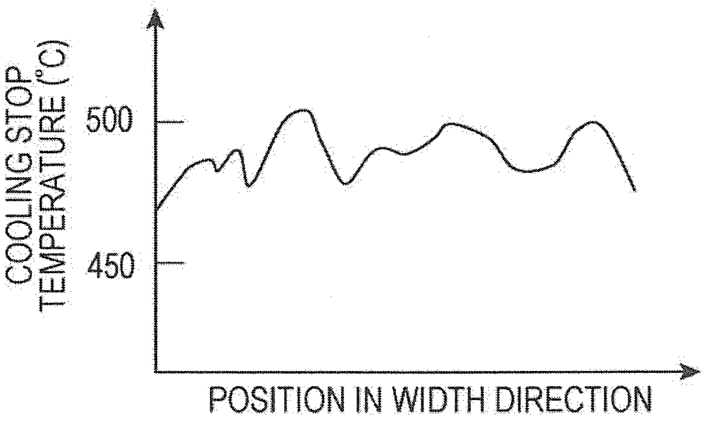


FIG. 4

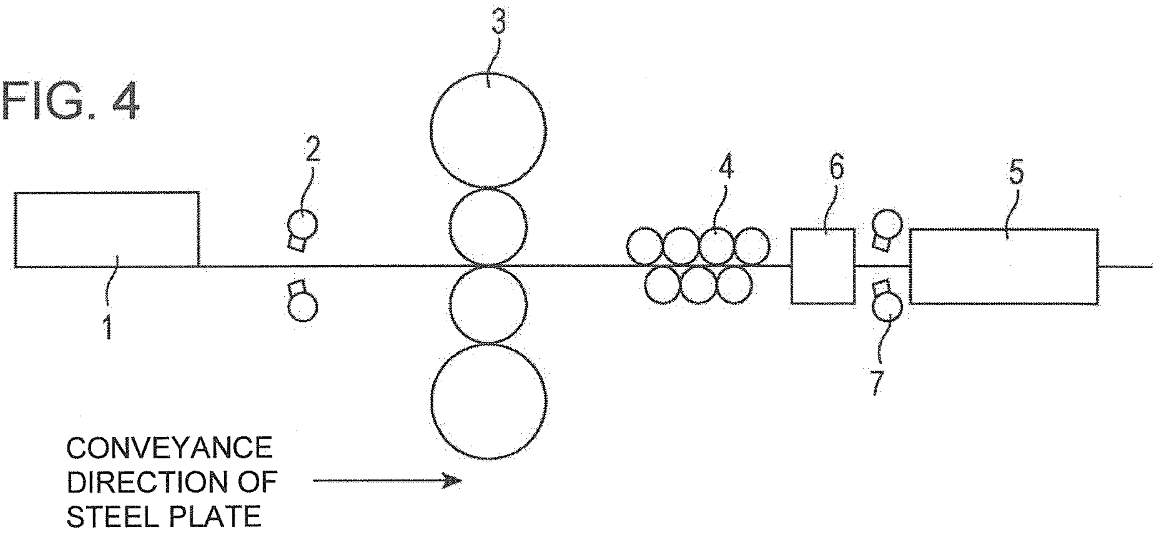



FIG. 5

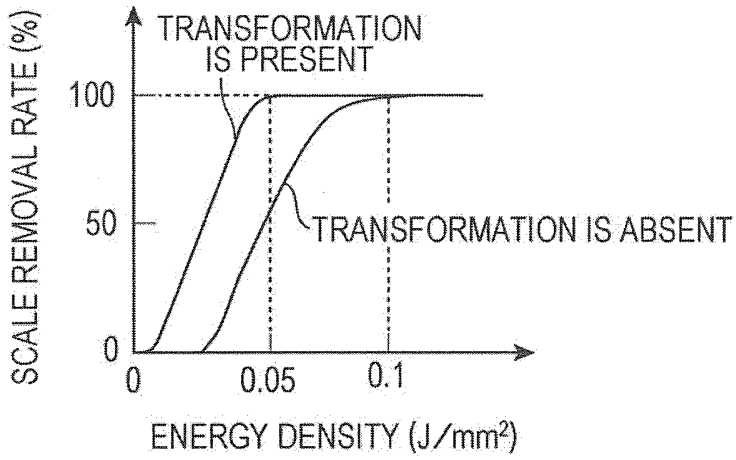



FIG. 6

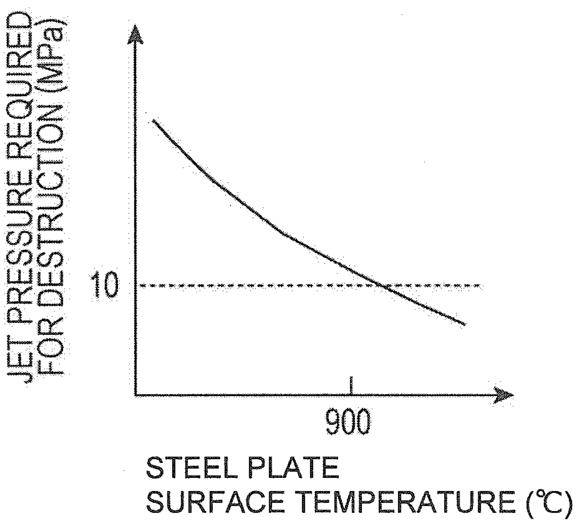


FIG. 7

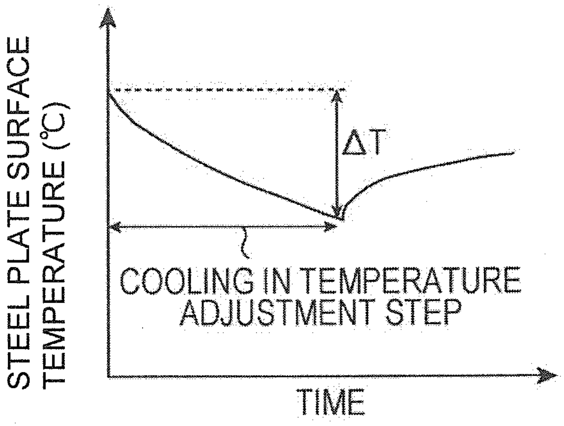

STEEL PLATE SURFACE
TEMPERATURE (℃)
ΔT
COOLING IN TEMPERATURE
ADJUSTMENT STEP
TIME

FIG. 8

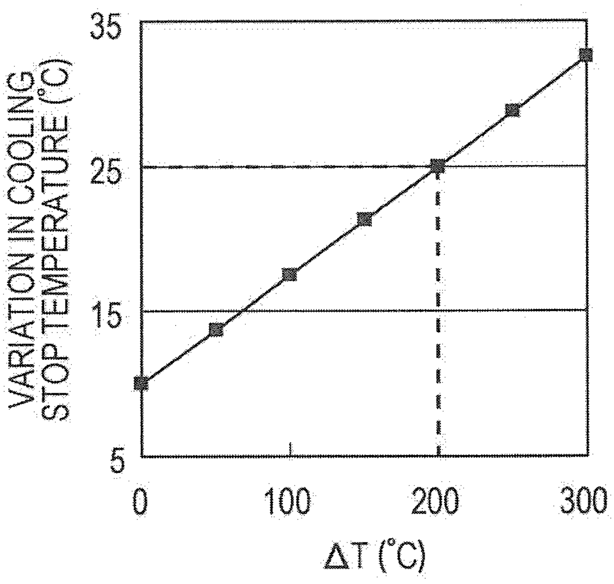

35
25
15
5
VARIATION IN COOLING
STOP TEMPERATURE (℃)
0
100
200
300
ΔT (℃)

FIG. 9

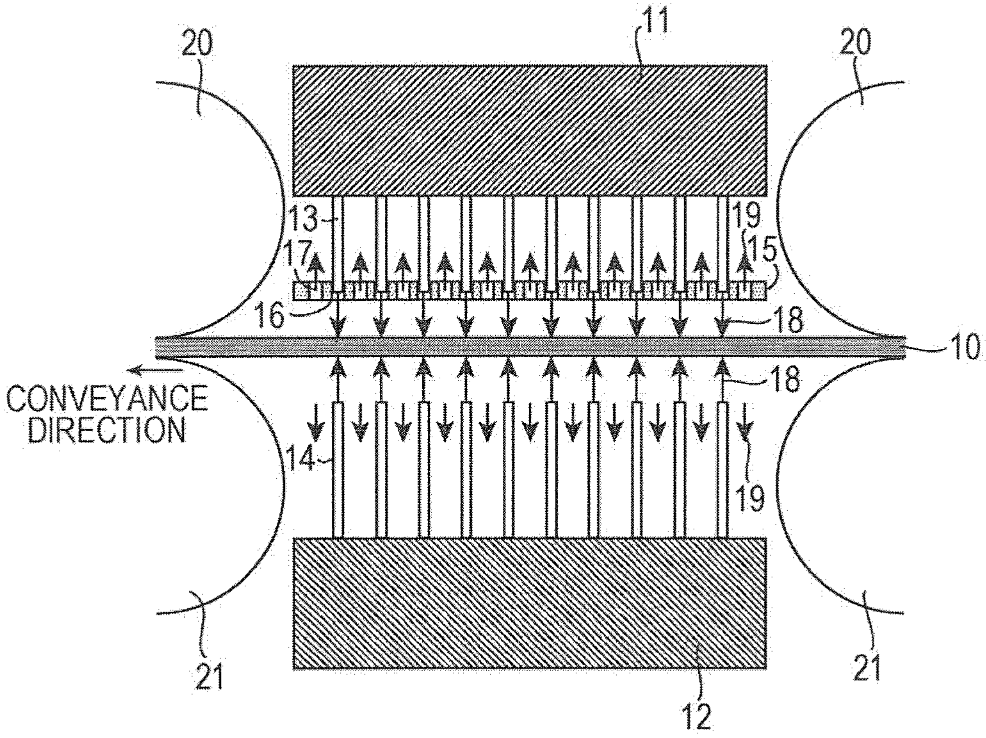

11
20
20
13
19
17
15
16
18
10
CONVEYANCE
DIRECTION
18
14
19
21
21
12

FIG. 10

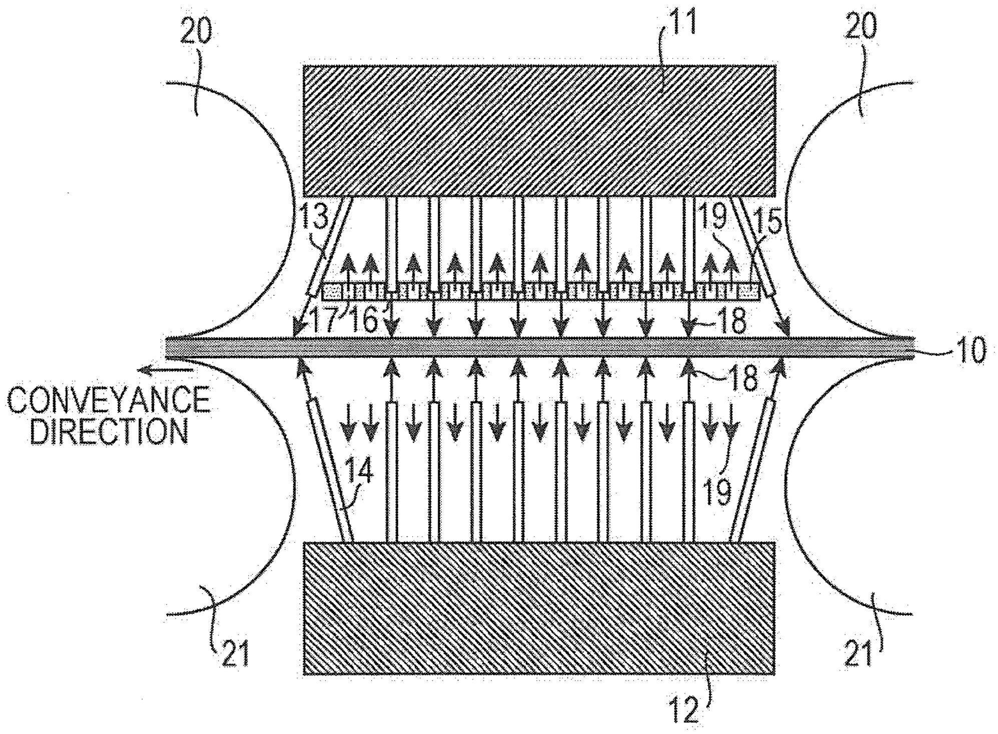

11
20
20
13
19
15
17
16
18
10
CONVEYANCE
DIRECTION
18
14
19
21
21
12

FIG. 11

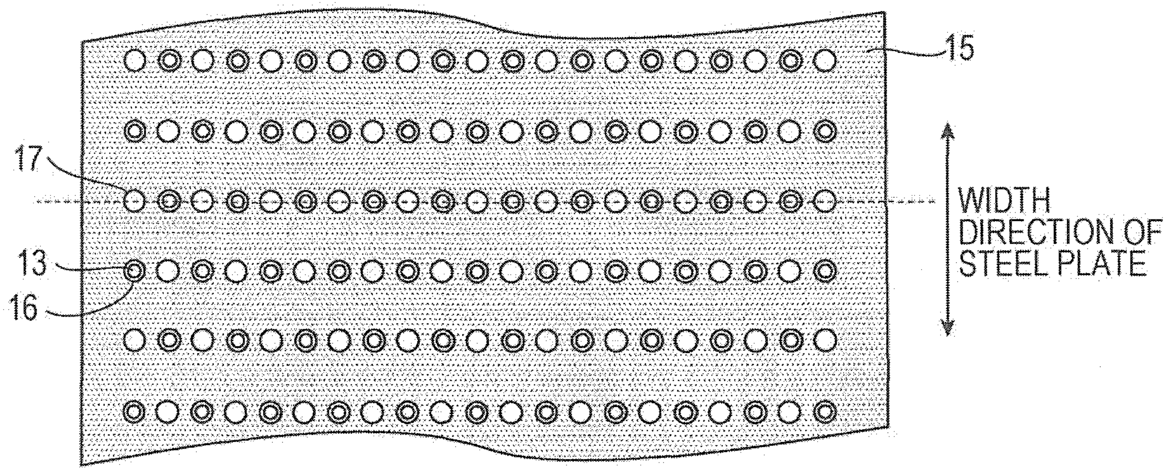



FIG. 12

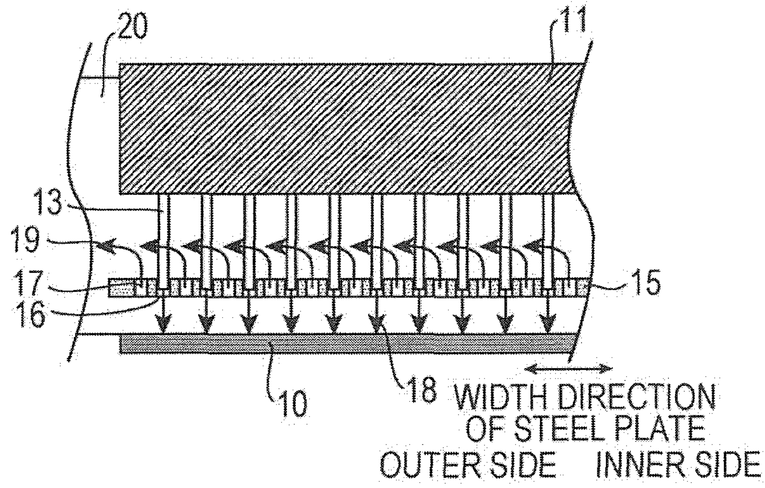



FIG. 13

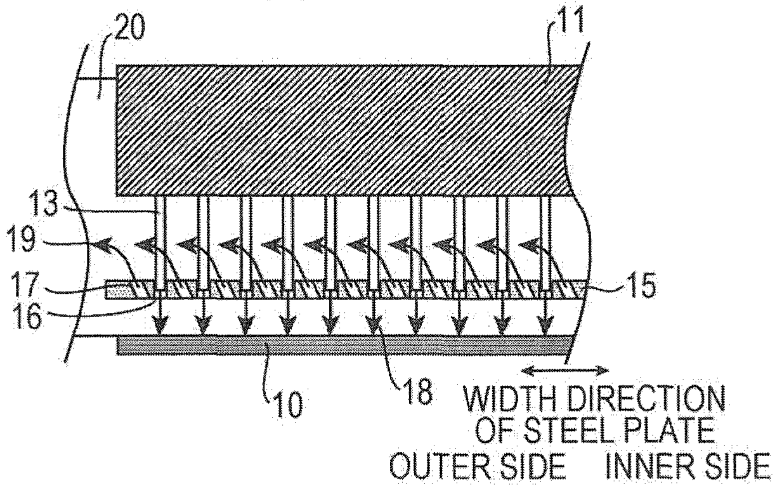


FIG. 14

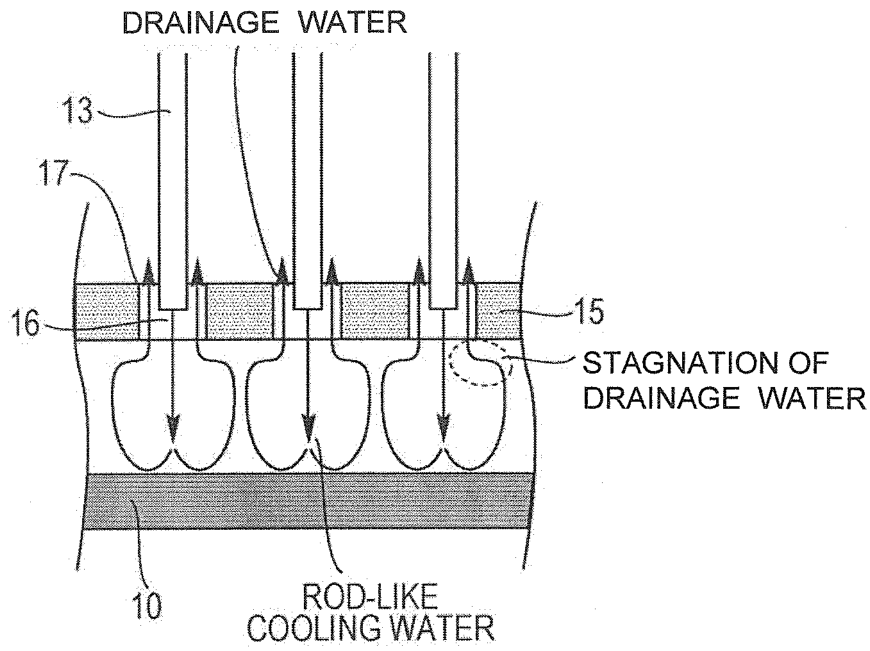

DRAINAGE WATER
13
17
16
15
STAGNATION OF
DRAINAGE WATER
10
ROD-LIKE
COOLING WATER

FIG. 15

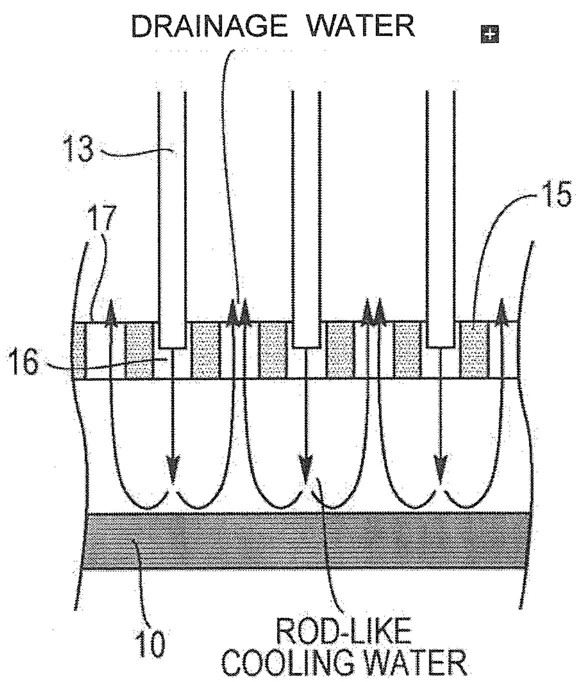
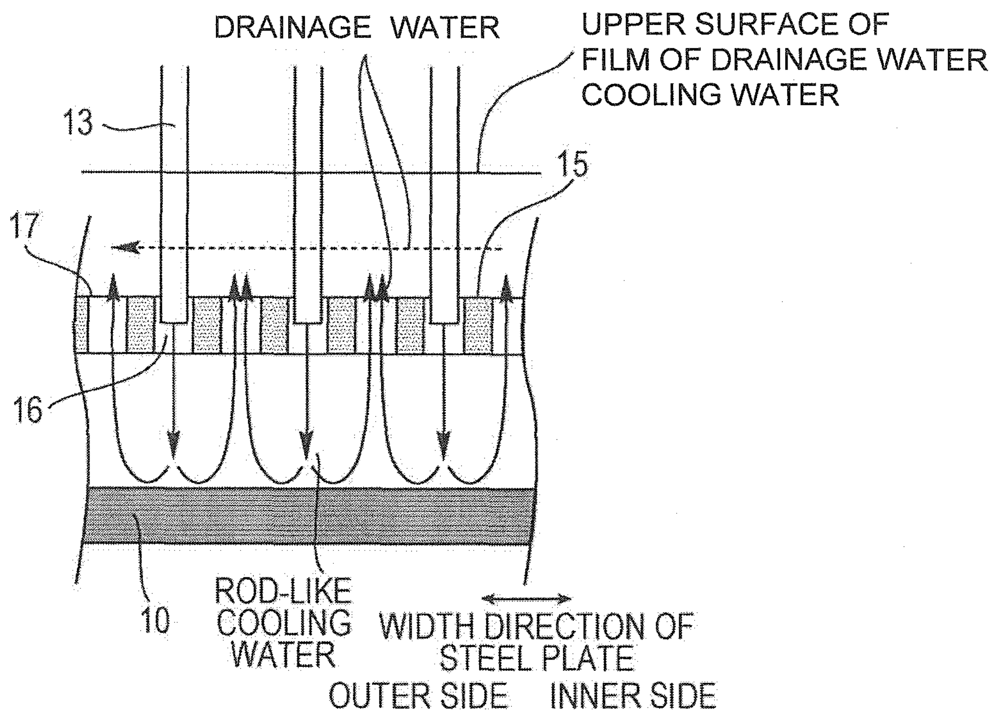

DRAINAGE WATER
13
17
15
16
10
ROD-LIKE
COOLING WATER

FIG. 16


DRAINAGE WATER
UPPER SURFACE OF FILM OF DRAINAGE WATER COOLING WATER
13
15
17
16
10
ROD-LIKE COOLING WATER
WIDTH DIRECTION OF STEEL PLATE
OUTER SIDE
INNER SIDE

**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/JP2014/001613

A. CLASSIFICATION OF SUBJECT MATTER
*B21B45/08*(2006.01)i, *B21B45/02*(2006.01)i

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)
B21B45/08, B21B45/02

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

| | | | |
|---|---|---|---|
| Jitsuyo Shinan Koho | 1922-1996 | Jitsuyo Shinan Toroku Koho | 1996-2014 |
| Kokai Jitsuyo Shinan Koho | 1971-2014 | Toroku Jitsuyo Shinan Koho | 1994-2014 |

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 2001-300627 A (Nippon Steel Corp.), 30 October 2001 (30.10.2001), paragraphs [0014], [0020] (Family: none) | 1-4 |
| A | WO 2010/110473 A1 (JFE Steel Corp.), 30 September 2010 (30.09.2010), paragraph [0036] & US 2012/0017660 A1 & EP 2412455 A1 & WO 2010/110473 A1 & CN 102361704 A & KR 10-2011-0115163 A | 1-4 |

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

* Special categories of cited documents:
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"P" document published prior to the international filing date but later than the priority date claimed
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"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 |
|---|---|
| 07 April, 2014 (07.04.14) | 15 April, 2014 (15.04.14) |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| Japanese Patent Office | |
| Facsimile No. | Telephone No. |

Form PCT/ISA/210 (second sheet) (July 2009)

## REFERENCES CITED IN THE DESCRIPTION

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### Patent documents cited in the description


- JP 6330155 A **[0006]**