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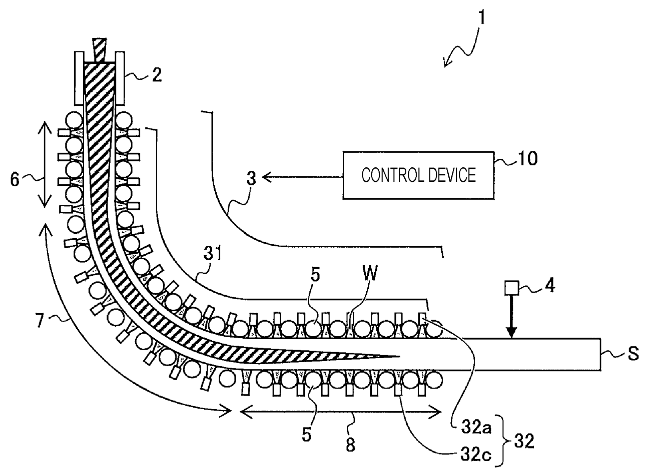
(54) CAST SLAB CONTINUOUS CASTING EQUIPMENT AND CAST SLAB CONTINUOUS CASTING METHOD

(57) A steel continuous-casting machine capable of suppressing the collision of sprays of cooling water discharged from spray nozzles adjacent to each other in a width direction of cast steel and the disruption of a film boiling state is provided.

A steel continuous-casting machine 1 includes a cooling apparatus 3 that cools cast steel S with water. The cooling apparatus 3 includes two or more cooling-water-discharging nozzles 32 arranged in a width direction of the cast steel S. The two or more cooling-water-discharging nozzles 32 are arranged such that spray discharge surfaces of cooling-water-discharging nozzles 32 adjacent to each other in the width direction of the cast steel S do not overlap.

FIG. 2



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Description

Technical Field

[0001] The present invention relates to a steel continuous-casting machine and a steel continuous-casting method.

Background Art

[0002] In a steel continuous-casting process, molten steel poured into a mold is cooled, and cast steel extracted from the mold is transported while being cooled at the exit side of the mold. Thus, cast steel is continuously produced. Then, the cast steel is cut into predetermined lengths to produce slabs, blooms, and billets as rolling materials.

[0003] The cast steel extracted from the mold has unsolidified molten steel therein. The unsolidified molten steel is solidified to the center by being cooled at the exit side of the mold. The properties and quality of the cast steel vary depending on the solidification rate. Therefore, cooling at the exit side of the mold (hereinafter referred to as secondary cooling) is a process that determines the properties and quality of the cast steel.

[0004] In recent years, the properties and uniformity required of steel materials have become increasingly stringent. Accordingly, the quality requirements for slabs, blooms, and billets have been increasing year by year, and cast steel of high quality over the entire length and width is required. Therefore, in the continuous-casting process, particularly in secondary cooling, uniform cooling over the entire width of the cast steel has become more important than ever.

[0005] Fig. 1 is a graph showing the relationship between the surface temperature of cast steel and the boiling state in a water cooling process for the cast steel. As illustrated in Fig. 1, in the initial stage of water cooling, the cast steel is cooled in a film boiling state in which a vapor film is present between the cast steel and water. In the film boiling state, the water and the cast steel do not come into direct contact with each other, so that the heat transfer coefficient, which is an index of cooling capacity, is low and the surface temperature of the cast steel decreases slowly. However, when the surface temperature of the cast steel is reduced to about 700°C, it becomes difficult to maintain the vapor film between the water and the cast steel, and the cast steel is cooled in a transition boiling state in which the water and the cast steel are partially in contact with each other. When the water and the cast steel come into contact, the flow of the water near the cast steel intensifies due to the evaporation of the water that has come into contact with the cast steel. Therefore, the heat transfer coefficient rapidly increases, and the surface temperature of the cast steel rapidly drops. After that, the boiling state changes to a nucleate boiling state in which the cast steel and the water are steadily in contact with each other while the high heat transfer coefficient is maintained, and the surface temperature of the cast steel rapidly drops to a temperature close to the water temperature.

[0006] In general, as the temperature of the object to be cooled is high, transition to the nucleate boiling state is less likely to occur, and a larger amount of cooling water is required to induce the transition. This leads to a higher production cost. In addition, when a high-temperature object is cooled in the nucleate boiling state in which the cooling capacity is high, the surface and interior of the object receive a high thermal stress, and the risk of defects, such as cracks, increases. Therefore, in secondary cooling of the continuous-casting process, in which the cast steel has a high surface temperature, the cast steel is generally cooled in the film boiling state in which the vapor film is provided between the cast steel and the water.

[0007] In light of the above discussion, the film boiling state is preferably maintained over the entire width during the secondary cooling in the continuous-casting process. When the vapor film is disrupted locally or entirely, the transition to the nucleate boiling state, in which the cooling capacity is high, occurs. This leads to an increase in the temperature deviation between a region in the film boiling state and a region in the nucleate boiling state or an excessive cooling rate. As a result, cast steel having high and uniform quality over the entire width cannot be produced.

[0008] The disruption of the film boiling state may be caused by, for example, a local increase in the water flow density, stagnation of the cooling water on the upper surface of the cast steel, or collision of sprays of cooling water discharged from adjacent sprays. To produce cast steel with uniform quality over the entire width, efforts have been made to avoid the above-described causes and maintain the film boiling state.

[0009] The local increase in the water flow density may be suppressed by improving tip portions of nozzles that discharge the cooling water and making the distribution of the cooling water discharged toward the cast steel uniform. It is also effective to use nozzles having spray discharge surfaces with a low aspect ratio and a large discharge area to reduce the local concentration of the cooling water. When the spray discharge surfaces are rectangular, the aspect ratio is the ratio of the short-side length to the long-side length. When the spray discharge surfaces are elliptical, the aspect ratio is the ratio of the minor axis to the major axis. When the spray discharge surfaces are square or circular, the aspect ratio is 1.

[0010] Patent Literature 1 describes a technique for suppressing the stagnation of the cooling water on the cast steel. In this technique, the cooling water is discharged as sprays having central axes at an angle relative to the central axes of the nozzles, so that the cooling water present between roll pairs that support and convey the cast steel is efficiently removed to the outside of the zones, and that the film boiling state can be maintained. Patent Literature 2 describes a technique for suppressing the collision of the sprays of cooling water. In this technique, the cooling water is discharged such that the major axes of the spray discharge surfaces are at an angle θ or 5° of more and less than 45° relative to the width direction of the cast steel, so that the collision of the sprays of cooling water discharged from the adjacent sprays is avoided, and that the film boiling state can be maintained.

Citation List

Patent Literature

[0011]

PTL 1: International Publication No. 2018/101287
PTL 2: Japanese Unexamined Patent Application Publication No. 2009-255127

Summary of Invention

Technical Problem

[0012] An object of the technology disclosed in Patent Literature 1 is to prevent stagnant water from flowing to a region downstream of a vertical section and a curved section in a continuous-casting machine having the vertical section and the curved section. The technology disclosed in Patent Literature 1 is not sufficient to remove the stagnant cooling water on the cast steel in a horizontal section in which the cast steel surface layer temperature is reduced and the film boiling state is easily disrupted. In addition, also in the vertical section and the curved section, when the cooling water is simply discharged upward to prevent the cooling water from flowing downstream, stagnation of the water occurs between the roll pairs, and the temperature deviation in the width direction increases. Therefore, also in the vertical section and the curved section, a technique for smoothly removing the cooling water discharged toward the cast steel to the outside of the cast steel in the width direction is required.

[0013] Also, when the technology disclosed in Patent Literature 2 is used, the collision of the sprays of cooling water discharged from the adjacent nozzles may occur if low-aspect-ratio sprays effective in spreading the water flow distribution and maintaining the film boiling state are used. In addition, even when high-aspect-ratio spray nozzles are used, the collision of the sprays of cooling water occurs if the distances between the spray nozzles are small. As a result, the disruption of the film boiling state may be accelerated.

[0014] The present invention has been made in light of the above-described problems, and an object of the present invention is to provide a steel continuous-casting machine and a steel continuous-casting method capable of suppressing the collision of sprays of cooling water discharged from spray nozzles adjacent to each other in a width direction of cast steel and the disruption of a film boiling state.

Solution to Problem

[0015] Means for solving the above-described problems are as follows:

[1] A steel continuous-casting machine including a cooling apparatus that cools cast steel with water, wherein the cooling apparatus includes two or more cooling-water-discharging nozzles arranged in a width direction of the cast steel, and wherein the two or more cooling-water-discharging nozzles are arranged such that spray discharge surfaces of cooling-water-discharging nozzles adjacent to each other in the width direction of the cast steel do not overlap.

[2] The steel continuous-casting machine according to [1], wherein the spray discharge surfaces of the cooling-water-discharging nozzles are rectangular or elliptical, and wherein each of the two or more cooling-water-discharging nozzles is disposed to satisfy Inequality (1) below:

[Math. 1]

$$\frac{L}{\sqrt{2}} > L \times \sin\theta_1 > t_1 \cdots (1)$$

where L is an arrangement interval (m) of the cooling-water-discharging nozzles, θ_1 is an angle (°) of a long-side direction or a major-axis direction of the spray discharge surface relative to the width direction, and t_1 is a length (m) of a short side or a minor axis of the spray discharge surface.

[3] The steel continuous-casting machine according to [1], wherein the spray discharge surfaces of the cooling-water-

discharging nozzles are square, and wherein each of the two or more cooling-water-discharging nozzles is disposed to satisfy Inequality (2) below:

$$L \times \sin\theta_2 > t \qquad (2)$$

where L is an arrangement interval (m) of the cooling-water-discharging nozzles, θ_2 is an angle (°) of a direction of one side of the spray discharge surface relative to the width direction, the one side of the spray discharge surface being one of sides of the spray discharge surface that is closest to an adjacent spray discharge surface, and t is a length (m) of the one side.

[4] The steel continuous-casting machine according to [1], wherein the spray discharge surfaces of the cooling-water-discharging nozzles are circular, and wherein each of the two or more cooling-water-discharging nozzles is disposed to satisfy Inequality (3) below:

$$L > D \qquad (3)$$

wherein L is an arrangement interval (m) of the cooling-water-discharging nozzles and D is a diameter (m) of the spray discharge surface.

[5] The steel continuous-casting machine according to [2], wherein an aspect ratio of the spray discharge surface is 100 or less.

[6] The steel continuous-casting machine according to any one of [1] to [5], wherein a surface-layer cooling rate of the cast steel in the cooling apparatus is in a range of 0.3°C/sec or more and 100°C/sec or less.

[7] The steel continuous-casting machine according to any one of [1] to [6], further including a control device that controls an amount of cooling water discharged from the cooling-water-discharging nozzles and a transportation speed of the cast steel.

[8] A steel continuous-casting method including a cooling step of cooling cast steel with water, wherein, in the cooling step, the cast steel is cooled by discharging cooling water from two or more cooling-water-discharging nozzles arranged in a width direction of the cast steel, and wherein the two or more cooling-water-discharging nozzles are arranged such that spray discharge surfaces of cooling-water-discharging nozzles adjacent to each other in the width direction of the cast steel do not overlap.

[9] The steel continuous-casting method according to [8], wherein the spray discharge surfaces of the cooling-water-discharging nozzles are rectangular or elliptical, and wherein each of the two or more cooling-water-discharging nozzles is disposed to satisfy Inequality (1) below:

[Math. 2]

$$\frac{L}{\sqrt{2}} > L \times \sin\theta_1 > t_1 \cdots (1)$$

where L is an arrangement interval (m) of the cooling-water-discharging nozzles, θ_1 is an angle (°) of a long-side direction or a major-axis direction of the spray discharge surface relative to the width direction, and t_1 is a length (m) of a short side or a minor axis of the spray discharge surface.

[10] The steel continuous-casting method according to [8], wherein the spray discharge surfaces of the cooling-water-discharging nozzles are square, and wherein each of the two or more cooling-water-discharging nozzles is disposed to satisfy Inequality (2) below:

$$L \times \sin\theta_2 > t \qquad (2)$$

where L is an arrangement interval (m) of the cooling-water-discharging nozzles, θ_2 is an angle (°) of a direction of one side of the spray discharge surface relative to the width direction, the one side of the spray discharge surface being one of sides of the spray discharge surface that is closest to an adjacent spray discharge surface, and t is a length (m) of the one side.

[11] The steel continuous-casting method according to [8], wherein the spray discharge surfaces of the cooling-water-discharging nozzles are circular, and wherein each of the two or more cooling-water-discharging nozzles is disposed to satisfy Inequality (3) below:

$$L > D \qquad (3)$$

wherein L is an arrangement interval (m) of the cooling-water-discharging nozzles and D is a diameter (m) of the spray discharge surface.

[12] The steel continuous-casting method according to [9], wherein an aspect ratio of the spray discharge surface is 100 or less.

[13] The steel continuous-casting method according to any one of [8] to [12], wherein a surface-layer cooling rate of the cast steel in the cooling step is in a range of 0.3°C/sec or more and 100°C/sec or less.

[14] The steel continuous-casting method according to any one of [8] to [13], wherein, in the cooling step, at least one of a surface-layer cooling rate of the cast steel and a temperature drop of the cast steel is controlled by controlling an amount of cooling water discharged from the cooling-water-discharging nozzles and a transportation speed of the cast steel.

Advantageous Effects of Invention

[0016] According to the present invention, the collision of sprays of cooling water discharged from spray nozzles that are adjacent to each other in the width direction of the cast steel can be suppressed. Therefore, the disruption of the film boiling state is suppressed when the cast steel is subjected to secondary cooling, and the temperature deviation on the surface of the cast steel being cooled can be reduced, so that cast steel with fewer defects can be produced by continuous casting.

Brief Description of Drawings

[0017]

[Fig. 1] Fig. 1 is a graph showing the relationship between the surface temperature of cast steel and the boiling state in a water cooling process for the cast steel.

[Fig. 2] Fig. 2 is a schematic sectional view of a steel continuous-casting machine according to an embodiment of the present invention.

[Fig. 3] Fig. 3 illustrates spray discharge surfaces of cooling water discharged from cooling-water-discharging nozzles on cast steel S.

[Fig. 4] Fig. 4 is a schematic diagram illustrating an example of the structure of a control device 10.

[Fig. 5] Fig. 5 is a schematic partial sectional view of a steel continuous-casting machine including a water purging roll.

[Fig. 6] Fig. 6 is a schematic partial sectional view of a steel continuous-casting machine including a purge nozzle.

[Fig. 7] Fig. 7 is a schematic partial sectional view of a steel continuous-casting machine including a water purging roll and a purge nozzle.

[Fig. 8] Fig. 8 is a schematic sectional view illustrating another example of a steel continuous-casting machine according to the present embodiment.

[Fig. 9] Fig. 9 is a schematic sectional view illustrating another example of a steel continuous-casting machine according to the present embodiment.

[Fig. 10] Fig. 10 is a schematic sectional view illustrating another example of a steel continuous-casting machine according to the present embodiment.

Description of Embodiments

[0018] The present invention will now be described by means of embodiments of the present invention. The embodiments described below illustrate devices and methods for embodying the technical idea of the present invention. In the technical idea of the present invention, materials, shapes, structures, arrangements, and the like of constituent parts are not limited to those in the embodiments described below. The drawings are schematic, and therefore it is to be noted that the relationships, ratios, and the like between the thicknesses and the planar dimensions are different from the actual ones. The drawings may also differ from each other in dimensional relationships and ratios.

[0019] Fig. 2 is a schematic sectional view of a steel continuous-casting machine according to an embodiment of the present invention. The main components of a steel continuous-casting machine 1 according to the embodiment of the present invention include a mold 2 that cools molten steel poured from a tundish (not illustrated) and form an outer shell shape of cast steel; a cooling apparatus 3 that cools the cast steel extracted from the mold; a thermometer 4 that measures a temperature of the cast steel at the exit side of the cooling apparatus 3; and a control device 10 that controls the operation of the cooling apparatus 3. In the following description, a long-side surface of the cast steel at the upper right in Fig. 2 is referred to as a first surface, a short-side surface at the near side as a second surface, a long-side surface at the lower left side as a third surface, and a short-side surface at the far side as a fourth surface.

[Mold 2]

[0020] The molten steel is produced in a refining apparatus at a location separate from the steel continuous-casting machine 1, and is poured into the mold 2. The molten steel poured into the mold 2 is cooled by the mold 2 so that the molten steel solidifies from the contact surface between the molten steel and the mold 2 toward an inner layer and that the outer shell shape is formed. In the following description, the molten steel whose outer shell shape is formed, including completely solidified steel, is referred to as cast steel S. The cast steel S extracted from the mold 2 is cooled by the cooling apparatus 3 while being supported and transported by cast-steel support rolls 5 provided at the exit side of the mold 2. A commonly known mold may be used as the mold 2.

[Cooling Apparatus 3]

[0021] The cooling apparatus 3 includes a water cooling device 31 that cools the cast steel S with water under predetermined cooling conditions. The water cooling device 31 includes the cast-steel support rolls 5 that support and transport the cast steel S, and cooling-water-discharging nozzles 32. The cast-steel support rolls 5 on the first-surface side and the third-surface side of the cast steel S form pairs and are arranged with equal intervals in the casting direction. At positions between the cast-steel support rolls 5 adjacent to each other in the casting direction, two or more cooling-water-discharging nozzles 32a on the first-surface side and two or more cooling-water-discharging nozzles 32c on the third-surface side form pairs across the cast steel S and are arranged at a predetermined interval in the casting direction. The cooling-water-discharging nozzles 32 discharge cooling water W toward the cast steel S. The cast steel S is fed into the cooling apparatus 3, so that the cast steel S is transported in the casting direction while being cooled by the cooling water W discharged from the cooling-water-discharging nozzles 32 in the secondary cooling process. In the following description, a cooling section in which one pair of cast-steel support rolls 5 in the casting direction serves as a unit is referred to as a cooling zone, and cooling sections will be counted in units of "zones". Although a total of 19 zones are provided as the cooling zones in Fig. 2, the number of zones is not limited to this, and may be greater or smaller than 19.

[0022] The steel continuous-casting machine 1 illustrated in Fig. 2 is a vertical-bending continuous-casting machine, and is characterized in that the cooling apparatus 3 is constituted by a vertical section 6 in which the cast steel S extracted from the mold 2 and orientated vertically is cooled with water; a curved section 7 in which the cast steel S is cooled with water while being curved by the cast-steel support rolls 5; and a horizontal section 8 in which the cast steel S is cooled with water after being curved to extend horizontally by the cast-steel support rolls 5. Although the vertical-bending continuous-casting machine will be described as an example in the present embodiment, the continuous-casting machine is not limited to a vertical-bending continuous-casting machine, and may be a vertical continuous-casting machine including only the vertical section 6 in the cooling apparatus 3, a curved continuous-casting machine including only the curved section 7 and the horizontal section 8, or a horizontal continuous-casting machine including only the horizontal section 8.

[0023] Operation parameters of the water cooling device 31 include the amount of cooling water W (amount of cooling water) and the amount of compressed air discharged from the cooling-water-discharging nozzles 32 and the transportation speed at which the cast steel S is transported. As the amount of cooling water increases, the cooling rate and the temperature drop of the cast steel S increase. As the transportation speed of the cast steel S decreases, the temperature drop of the cast steel S increases. Therefore, at least one of the surface-layer cooling rate and the temperature drop of the cast steel S can be controlled by controlling at least one of the transportation speed of the cast steel S and the amount of cooling water, and the cast steel S having the desired material quality can be produced. In addition, the cooling capacity and the surface distribution of the cooling water W can be adjusted by adding the compressed air to the cooling water W discharged from the cooling-water-discharging nozzles 32. The desired properties, deterioration of the machine over time, and small changes in the nozzle arrangement may also be controlled under appropriate conditions by adjusting the amount of compressed air.

[0024] The balance between the amounts of cooling water in the cooling zones may be changed as an operation parameter of the water cooling device 31 (for example, the amount of cooling water may be increased in upstream cooling zones and reduced in downstream cooling zones). Thus, the cooling rate can be controlled for each temperature range of the cast steel S. In addition, the number of cooling zones in which the cooling water is discharged may be changed. The temperature drop of the cast steel S can be controlled while the cooling rate is maintained constant by changing the number of cooling zones that are used.

[0025] Furthermore, the ratio between the amount of cooling water W discharged from the cooling-water-discharging nozzles 32a on the first-surface side and the amount of cooling water W discharged from the cooling-water-discharging nozzles 32c on the third-surface side can be changed. Accordingly, shape defects due to the difference in the temperature drop between the first surface and the third surface of the cast steel S can be controlled. In addition, the amount of cooling water can be changed in accordance with the composition of the cast steel S. This is because the thermal conductivity of the cast steel S changes in accordance with the composition of the cast steel S, and the cooling state changes accordingly. When the amount of cooling water is changed, the amount of compressed air and the transportation speed of the cast steel

S may also be changed. The cooling capacity and the surface distribution of the cooling water W may be controlled by changing the amount of compressed air, and the temperature history of the cast steel S may be controlled by changing the transportation speed of the cast steel S. Thus, the cooling conditions can be finely adjusted, thereby improving the quality of the cast steel.

[0026] The operation parameters of the water cooling device 31 may be changed as the casting proceeds. In particular, the leading and trailing end portions of the cast steel S are additionally cooled from the leading and trailing end faces and therefore tend to become nonstationary portions. Therefore, the operation parameters of the water cooling device 31 may be finely adjusted for these portions, so that high quality can be ensured over the entire length and width and the yield in the nonstationary portions can be increased.

[0027] The operation parameters of the water cooling device 31 may also be finely adjusted for the stationary portion excluding the leading and trailing end portions as the casting proceeds. When, for example, the properties of the stationary portion vary in the longitudinal direction due to the composition segregation of the cast steel S, the cast steel having a uniform quality over the entire length can be obtained by finely adjusting the operation parameters of the water cooling device 31.

[0028] The cooling rate is preferably variable in accordance with the material, operating conditions, and the machine status. When the surface-layer cooling rate exceeds 100°C/sec, the surface layer is often transformed into martensite, causing defects, such as cracks, on the surface of the cast steel. Therefore, the surface-layer cooling rate is preferably less than or equal to 100°C/sec. When the surface-layer cooling rate is less than 0.3°C/sec, the cooling rate is substantially equal to that in the case where the cast steel is allowed to be naturally cooled, and the production efficiency is reduced. In addition, as the cooling rate decreases, the segregation in the cast steel is increased, and the quality of the cast steel is degraded. Therefore, the surface-layer cooling rate is preferably greater than or equal to 0.3°C/sec.

[0029] As is clear from the graph illustrated in Fig. 1, the film boiling state eventually transitions to the nucleate boiling state. Therefore, discharging of the cooling water W toward the cast steel S is to be stopped while the temperatures of the front and back surfaces of the cast steel S are 500°C or higher, preferably 600°C or higher. When the temperatures of the front and back surfaces of the cast steel S are sufficiently increased due to internal recuperation after the cooling water W is discharged, the cooling water W may be discharged again. When the cooling rate is increased by discharging the cooling water W again, the production efficiency can be increased and the quality of the cast steel can be improved.

[0030] Nozzles capable of uniformly discharging cooling water at a predetermined flow rate are preferably used as the cooling-water-discharging nozzles 32. Although spray nozzles are used as the cooling-water-discharging nozzles 32 in the present embodiment, the cooling-water-discharging nozzles 32 are not limited to spray nozzles, and may be slit-type nozzles, multi-hole jet nozzles, mist nozzles, or fog nozzles. The cooling-water-discharging nozzles 32 may be either one-fluid nozzles that discharge only liquid (generally water) or two-fluid nozzles that discharge mixed fluid containing liquid (generally water) and gas (generally air) .

[0031] Nozzles that discharge only air does not cause a transition of the boiling state, but may be disposed at positions near or slightly displaced from the cooling-water-discharging nozzles 32. These nozzles may discharge air to improve drainage or for water purging. In addition, the cooling-water-discharging nozzles 32 are preferably capable of varying the amount of cooling water and the amount of compressed air in accordance with the desired cooling rate.

[0032] When the cooling water W discharged from the cooling-water-discharging nozzles 32 comes into contact with the cast steel S such that collision of the sprays of the cooling water W discharged from the adjacent cooling-water-discharging nozzles 32 occurs on the cast steel S, horizontal momentum changes to vertical momentum at the collision point, and the downward component of the vertical flow breaks the vapor film and causes a local disruption of the film boiling state. When the spray has a rectangular spray discharge surface, the horizontal component of the moment of the cooling water W discharged in the long-side direction is greater than that of the cooling water W discharged in the short-side direction. Therefore, collision of the sprays of the cooling water W discharged from the adjacent cooling-water-discharging nozzles 32 in the long-side direction needs to be avoided.

[0033] Fig. 3 illustrates spray discharge surfaces on the cast steel S toward which the cooling water is discharged from the cooling-water-discharging nozzles. Fig. 3(a) illustrates rectangular spray discharge surfaces. Assume that the cooling-water-discharging nozzles 32 are such that the spray discharge surfaces on the cast steel S have a rectangular shape with short sides having a length of t_1 (m) and long sides having a length of t_2 (m). Due to the geometric relationship, to avoid the collision of the spray discharge surfaces in the long-side direction, the cooling-water-discharging nozzles 32 need to be placed such that the spray discharge surfaces of the cooling-water-discharging nozzles 32 adjacent to each other in the width direction of the cast steel S do not overlap. More specifically, the cooling-water-discharging nozzles 32 are arranged such that the arrangement interval of the cooling-water-discharging nozzles 32 adjacent to each other in the width direction of the cast steel S, the angle of the long-side direction relative to the width direction of the cast steel, and the length of the short sides of the spray discharge surfaces are in the ranges that satisfy Inequality (1) below. When the cooling-water-discharging nozzles 32 are arranged such that Inequality (1) below is satisfied, collision in the long-side direction of the sprays of the cooling water W discharged from the cooling-water-discharging nozzles 32 adjacent to each other in the width direction of the cast steel S can be suppressed, so that the disruption of the film boiling state can be suppressed. This also applies to the cooling-water-discharging nozzles whose spray discharge surfaces on the cast steel S are elliptical. In such a case, in Inequality (1) below, the long-side direction may be changed to the major-axis direction, and the length of the short sides may be changed to the length of the minor axis.

[Math. 3]

$$\frac{L}{\sqrt{2}} > L \times \sin\theta_1 > t_1 \cdots (1)$$

[0034] In Inequality (1) above, L is the arrangement interval (m) of the cooling-water-discharging nozzles, θ_1 is the angle (°) of the long-side direction of the spray discharge surface relative to the width direction of the cast steel, and t_1 is the length (m) of the short sides of the spray discharge surfaces.

[0035] When the spray discharge surfaces on the cast steel S are rectangular or elliptical, the aspect ratio of the discharge surfaces is preferably 100 or less. When sprays having the spray discharge surfaces with a low aspect ratio are used, the spray discharge surfaces can be broadened, and the local concentration of the cooling water can be suppressed, so that the film boiling state can be maintained longer. The aspect ratio of the spray discharge surfaces is more preferably 50 or less, and still more preferably 30 or less.

[0036] When nozzles having the long sides of the same length are used to discharge the same amount of water, the nozzles preferably have a low aspect ratio and a long minor-axis dimension. When the nozzles have a low aspect ratio and short sides that are long, the area of the spray discharge surfaces is increased. Therefore, the water flow density is reduced and the local concentration of the cooling water can be suppressed. When the aspect ratio is too low, the amount of water that flows in the major-axis direction of the sprays is reduced, and the cooling water W easily remains on the cast steel S. Therefore, the aspect ratio is preferably two or more, more preferably 5 or more, and still more preferably 10 or more.

[0037] The angle θ_1 of the long-side direction is preferably less than 45° so that the cooling water W discharged toward the cast steel S can be quickly removed to the outside of the cast steel. The angle θ_1 of the long-side direction of 45° or more is not preferable because when the velocity of the cooling water W in the long-side direction is resolved into the transport direction of the cast steel and the width direction of the cast steel, the component in the transport direction is greater than the component in the width direction of the cast steel. More preferably, the angle θ_1 of the long-side direction is 30° or less.

[0038] Fig. 3(b) illustrates square spray discharge surfaces. When the spray discharge surfaces on the cast steel S are square, collision of the sprays of cooling water can be suppressed by arranging the cooling-water-discharging nozzles 32 such that the arrangement interval of the cooling-water-discharging nozzles 32 adjacent to each other in the width direction of the cast steel S, the angle of the direction of one side of each spray discharge surface relative to the width direction of the cast steel, and the length of one side of each spray discharge surface are in the ranges that satisfy Inequality (2) below.

$$L \times \sin\theta_2 > t \cdots (2)$$

[0039] In Inequality (2) above, L is the arrangement interval (m) of the cooling-water-discharging nozzles 32, θ_2 is the angle (°) of the direction of one side of each spray discharge surface relative to the width direction of the cast steel, and t is the length (m) of one side of each spray discharge surface. Here, one side of each spray discharge surface is one of the sides of the spray discharge surface that is closest to an adjacent spray discharge surface. More specifically, in a spray discharge surface 20 illustrated in Fig. 3(b), the direction of one side is the direction of a side 21 that is closest to an adjacent spray discharge surface 22. In the spray discharge surface 22, the direction of one side is the direction of one of sides 23 and 24 that are closest to adjacent spray discharge surfaces 20 and 25, respectively.

[0040] Fig. 3(c) illustrates circular spray discharge surfaces. When the spray discharge surfaces on the cast steel S are circular, collision of the sprays of cooling water can be suppressed by arranging the cooling-water-discharging nozzles 32 such that the arrangement interval of the cooling-water-discharging nozzles 32 adjacent to each other in the width direction of the cast steel S and the diameter of the spray discharge surfaces are in the ranges that satisfy Inequality (3) below.

$$L > D \cdots (3)$$

[0041] In Inequality (3) above, L is the arrangement interval (m) of the cooling-water-discharging nozzles 32, and D is the diameter (m) of the spray discharge surfaces.

[0042] The level of local concentration of the cooling water can be evaluated by the water flow density defined as flow rate/discharge area. Since the water flow density of the discharged cooling water and the boiling transition temperature are positively correlated, the film boiling state can be maintained longer by reducing the water flow density. With regard to the local water flow density of the cooling water in the steel continuous-casting machine 1, to stabilize the film boiling state, the water flow density of the cooling water is preferably 1000 L/($m^2 \times$min) or less, more preferably 800 L/($m^2 \times$min) or less, and still more preferably 600 L/($m^2 \times$min) or less.

[Thermometer 4]

[0043] The thermometer 4 may be a device that scans the cast steel S in the width direction to measure the surface temperature of the cast steel S, or be one or more devices arranged in the width direction of the cast steel S to measure the surface temperature of the cast steel S. It can be checked whether the cast steel S is cooled as expected by measuring the surface temperature of the cast steel S cooled by the cooling apparatus 3 by using the thermometer 4.

[0044] Referring to Fig. 2 again, although the thermometer 4 is disposed at the exit side of the cooling apparatus 3 in Fig. 2, the thermometer 4 may be disposed in the cooling apparatus 3 when the temperature of the steel sheet that has been cooled by the water cooling device 31 can be measured. In such a case, multiple thermometers 4 may be arranged next to each other in the transport direction of the cast steel S to measure the temperature of the cast steel S in each cooling zone.

[0045] In addition, the thermometer 4 may be disposed at the entry side of the cooling apparatus 3 and the entry side of the mold 2 to measure the initial temperature of the cast steel S and the temperature of the molten steel that is poured. This is because the accuracy of the calculation of the cooling rate can be increased by additionally taking into account the result of the temperature measurement at the entry side of the cooling apparatus 3. One or more thermometers 4 may be disposed in the cooling apparatus 3 to measure the temperature of the cast steel S during water cooling. When the result of the temperature measurement in the cooling apparatus 3 is additionally taken into account, the accuracy of the calculation of the cooling rate can be increased and the time history of the cooling rate can be obtained.

[0046] The temperature information of the molten steel and the result of the temperature measurement of the cast steel S may be used in heat transfer calculation or heat transfer simulation to calculate the cooling rate during water cooling and check whether the cast steel S is being cooled as expected. In addition, the temperature distribution along the surfaces of the cast steel S during or after water cooling may be measured to check whether the cast steel S is uniformly cooled. Furthermore, the temperature distribution along the surfaces of the cast steel S before water cooling may be measured to check whether the temperature distribution along the surfaces of the cast steel S that enters the cooling apparatus 3 is uniform. The operation parameters of the cooling apparatus 3 and the operating conditions of the steel continuous-casting machine 1 may be changed based on the above-described calculation results.

[Control Device 10]

[0047] The control device 10 will now be described. Fig. 4 is a schematic diagram illustrating an example of the structure of the control device 10. The control device 10 is an information processing device, such as a personal computer. The control device 10 receives, from the host computer 11, the molten steel temperature, the size information, such as the thickness, of the cast steel S, and information regarding the desired range of the amount of cooling required to achieve the desired material quality and the desired range of the cooling rate. The control device 10 calculates operating conditions of the steel continuous-casting machine 1 for achieving the desired amount of cooling and the desired cooling rate, and determines the operation parameters of the devices.

[0048] The control device 10 includes the control unit 12 and the storage unit 13. The control unit 12 is, for example, a CPU that executes programs read from the storage unit 13 to cause the control unit 12 to function as the computing unit 14 and the output unit 15. The storage unit 13 is, for example, an information recording medium, such as a re-recordable flash memory, a hard disk that is built-in or connected with a data communication terminal, or a memory card, and a read/write device for the information recording medium. The storage unit 13 stores programs for causing the control unit 12 to execute the functions and data used by the programs.

[0049] The computing unit 14 performs a heat transfer calculation based on an internal model to determine the number of cooling zones to be used, the amount of cooling water, the amount of compressed air, and the transportation speed of the cast steel S for achieving the desired amount of cooling and the desired cooling rate set as the cooling conditions. The thus determined command values of the amount of cooling water, the amount of compressed air, and the transportation speed of the cast steel S are output from the output unit 15 to the water cooling device 31. Based on the command values of the amount of cooling water, the amount of compressed air, and the transportation speed of the cast steel S, the water cooling device 31 generates commands regarding the number of cooling water pumps to be operated and operating pressures thereof, the number of air compressors to be operated and operating pressures thereof, the number of headers disposed upstream of the cooling-water-discharging nozzles 32, the opening degree of the flow control valve, and the rotational speeds of the cast-steel support rolls 5, and determines the operating conditions of the water cooling device 31.

[0050] One or more of the number of cooling zones to be used, the amount of cooling water, the amount of compressed air, and the transportation speed of the cast steel S may be determined in advance by using a table based on information such as the composition and size information of the cast steel S and the desired material quality, and transmitted to the water cooling device 31 as the commands. Preferably, adjustment parameters are provided to allow the number of cooling zones to be used, the amount of cooling water, the amount of compressed air, and the transportation speed of the cast steel S to be varied in accordance with changes in conditions during the operation.

[Steel Continuous-Casting Method]

[0051] A steel continuous-casting method using the steel continuous-casting machine 1 illustrated in Fig. 2 will now be described. First, molten steel produced in a refining apparatus at a location separate from the steel continuous-casting machine 1 is poured into the mold 2 through a tundish (not illustrated). The poured molten steel is cooled by the mold 2 and solidifies from the contact surface between the molten steel and the mold 2 toward the inner layer, so that the outer shell shape of the cast steel S is formed.

[0052] The cast steel S extracted from the mold 2 is cooled by the cooling apparatus 3 while being supported and transported by the cast-steel support rolls 5 disposed at the exit side of the mold 2. In a cooling step, the number of zones to be used, the amount of cooling water, the amount of compressed air, and the transportation speed are calculated and set by the control device 10 in accordance with the size of the cast steel S and the desired properties of the cast steel S. In the present embodiment, it is assumed that the cast steel S is cooled by discharging water and air in all the zones illustrated in Fig. 2.

[0053] A predetermined amount of cooling water W and a predetermined amount of compressed air A are discharged from 19 pairs of cooling-water-discharging nozzles 32, and the cast-steel support rolls 5 are rotated at a predetermined speed. These parameters are set by the control device 10 so that desired cast steel properties can be obtained, and are transmitted to the cooling-water-discharging nozzles 32 and the cast-steel support rolls 5. The cast steel S having the desired properties can be produced by cooling the cast steel S with the cooling apparatus 3. After the cooling step, the cast steel S is subjected to a subsequent process.

[0054] Although an embodiment of the present invention is described above, the present invention is not limited to this, and various alterations and modifications are possible. Fig. 5 is a schematic partial sectional view of a steel continuous-casting machine including a water purging roll. As illustrated in Fig. 5, a water purging roll 33 may be disposed at the exit side of the water cooling device 31 of the steel continuous-casting machine 1 to purge the cooling water W remaining on the cast steel S. Thus, the cast steel S can be prevented from being cooled in a partial or entire area by the cooling water W remaining on the cast steel S such that the desired amount of cooling cannot be obtained and that the desired properties cannot be obtained as a result in a partial or entire area.

[0055] To achieve good purging performance, the pressing force that presses the water purging roll 33 against the cast steel S is preferably 4 tons or more. The pressing force that presses the water purging roll 33 against the cast steel S is more preferably 6 tons or more, and still more preferably 8 tons or more. When the pressing force that presses the water purging roll 33 against the cast steel S is excessively increased, the water purging roll 33 is bent by elastic deformation, and a gap is formed between the cast steel S and the water purging roll 33, resulting in degradation of the purging performance. Therefore, the pressing force that presses the water purging roll 33 against the cast steel S is preferably 20 tons or less.

[0056] A mechanism that applies the pressing force to the water purging roll 33 may be a spring-type mechanism, such as a spring, or a pneumatic or hydraulic mechanism capable of applying a constant pressing force. To adjust the bending of the water purging roll 33, the mechanism is preferably capable of maintaining the pressing force constant, and is more preferably capable of changing the pressing force in the longitudinal direction of the cast steel S.

[0057] The cast-steel support rolls 5 may serve as water purging rolls. In such a case, the pressing force applied by the cast-steel support rolls 5 is not limited to the above-described ranges. This is because the quality of the cast steel may be improved by subjecting the cast steel S to rolling reduction by the cast-steel support rolls 5.

[0058] Fig. 6 is a schematic partial sectional view of a steel continuous-casting machine including a purge nozzle. As illustrated in Fig. 6, a purge nozzle 34 may be disposed instead of the water purging roll 33, and a water purging jet 35 is emitted to purge the cooling water W remaining on the cast steel S. The water purging jet 35 may be liquid, gas, or fluid of gas-liquid mixture. When liquid is used as the water purging jet 35, the portion receiving the liquid may be cooled and the temperature deviation along the surface of the cast steel S may be increased. Therefore, gas is preferably used as the water purging jet 35. To reduce production costs, more preferably, air is used as the water purging jet 35.

[0059] Fig. 7 is a schematic partial sectional view of a steel continuous-casting machine including a water purging roll and a purge nozzle. As illustrated in Fig. 7, the water purging roll 33 and the purge nozzle 34 may both be used. In addition, one or both of the water purging roll 33 and the purge nozzle 34 may be disposed at the entry side of the water cooling device 31 to purge the cooling water W that leaks from the water cooling device 31. In this case, a reduction in the temperature of the cast steel S that enters the cooling apparatus 3 can be suppressed, and the cooling water W can be prevented from entering another device (for example, the mold 2) disposed upstream of or around the cooling apparatus 3.

[0060] In addition, one or both of the water purging roll 33 and the purge nozzle 34 may be disposed not only at the entry and exit sides of the water cooling device 31 but also at the entry and exit sides of each cooling zone to divide the cooling zones from each other. When the amount of water discharged differs between the cooling zones, the temperature history of the steel sheet can be determined by dividing the zones with different amounts of cooling water from each other.

[0061] It is not necessary that all of the cooling-water-discharging nozzles 32 included in the cooling apparatus 3 satisfy Inequality (1), (2), or (3) above as long as two or more cooling-water-discharging nozzles 32 adjacent to each other in the width direction of the cast steel satisfy Inequality (1), (2), or (3) above. In such a case, compared to a steel continuous-casting machine in which none of the cooling-water-discharging nozzles 32 satisfy Inequality (1), (2), or (3) above, the collision of the sprays of cooling water can be further suppressed, so that the disruption of the film boiling state can be further suppressed.

[0062] Fig. 8 is a schematic sectional view illustrating another example of a steel continuous-casting machine according to the present embodiment. Referring to Fig. 8, a steel continuous-casting machine 40 includes cooling-water-discharging nozzles 36 capable of discharging an amount of cooling water that changes the boiling state to the nucleate boiling state at both the entry and exit sides of the water cooling device 31. The cooling-water-discharging nozzles 36 are used to cool the cast steel S depending on the desired properties of the cast steel S. Thus, the cooling-water-discharging nozzles 36 that discharge an amount of cooling water that changes the boiling state to the nucleate boiling state may be disposed at the entry and exit sides of the water cooling device 31. Although the cooling-water-discharging nozzles 36 are disposed at both the entry and exit sides of the water cooling device 31 in Fig. 8, the cooling-water-discharging nozzles 36 are not limited to this, and may be provided at one of the entry and exit sides. In addition, although the cooling-water-discharging nozzles 36 are provided for three zones at the entry side and three zones at the exit side of the water cooling device 31 in Fig. 8, the number of cooling zones for which the cooling-water-discharging nozzles 36 are provided is not limited to this, and may be other than three.

[0063] Fig. 9 is a schematic sectional view illustrating another example of a steel continuous-casting machine according to the present embodiment. Referring to Fig. 9, a steel continuous-casting machine 50 includes the cooling-water-discharging nozzles 32 and cooling-water-discharging nozzles 36 capable of discharging an amount of cooling water that changes the boiling state to the nucleate boiling state in the same cooling zones. Thus, the cooling-water-discharging nozzles 32 and the cooling-water-discharging nozzles 36 may be disposed in the same cooling zones. When cooling by the cooling-water-discharging nozzles 32 and cooling by the cooling-water-discharging nozzles 36 are combined, cooling with various temperature histories can be achieved. Although the cooling-water-discharging nozzles 32 and the cooling-water-discharging nozzles 36 are disposed in two zones in Fig. 9, the number of zones is not limited to this, and may be other than 2.

[0064] Fig. 10 is a schematic sectional view illustrating another example of a steel continuous-casting machine according to the present embodiment. Referring to Fig. 10, a steel continuous-casting machine 60 includes cooling-water-discharging nozzles 37 that discharges only an amount of water that changes the boiling state to the nucleate boiling state in place of some of the cooling-water-discharging nozzles of the water cooling device 31. Thus, the cooling-water-discharging nozzles 37 may be provided in place of some of the cooling-water-discharging nozzles of the water cooling device 31. This is because when a portion excluding the cooling-water-discharging nozzles 37 is regarded as the water cooling device 31 and collision of the sprays of cooling water is suppressed in this portion, the effect that the disruption of the film boiling state is suppressed can be obtained. The cooling-water-discharging nozzles 36 capable of discharging an amount of water that changes the boiling state to the nucleate boiling state may be one-fluid nozzles that discharge only air, one-fluid nozzles that discharge only water, or two-fluid nozzles that discharge mixed fluid containing water and air.

[0065] The cast steel S extracted from the mold 2 is generally transported while being subjected not only to cooling but also to rolling reduction by the cast-steel support rolls 5. This is because the internal segregation can be reduced and the quality of the cast steel can be improved by performing rolling reduction on the cast steel S. Therefore, the steel continuous-casting method according to the present embodiment and a commonly known cast-steel rolling reduction technology may both be applied. In such a case, the quality of the cast steel that is produced can be further improved. Preferably, the operation parameters of the water cooling device 31 and the operation parameters regarding the commonly known cast-steel rolling reduction technology are both satisfied.

[0066] In the steel continuous-casting machine 1 according to the present embodiment, the cast-steel support rolls 5 are disposed on the first and third surfaces of the cast steel S. However, the cast-steel support rolls 5 are not limited to this, and may be disposed on the second and fourth surfaces. When the second and fourth surfaces are supported and subjected to rolling reduction by the rolls, the expansion in the width direction resulting from the rolling reduction by the cast-steel support rolls 5 on the first and third surfaces can be suppressed.

Examples

[0067] An example in which the steel continuous-casting machine 1 illustrated in Fig. 2 was used to cool the continuously cast steel S with the cooling apparatus 3 and manufacture a slab as a rolling material will now be described. In the steel continuous-casting machine 1, the cooling apparatus 3 was disposed downstream of the mold 2. The cooling apparatus 3 included 19 pairs of cooling-water-discharging nozzles 32 constituting the water cooling device 31 and 20 pairs of cast-steel support rolls 5. The cooling-water-discharging nozzles 32 were structured such that rectangular spray nozzles, square spray nozzles, and circular spray nozzles were removably attachable and replaced in accordance with the casting conditions.

[0068] The thermometer 4 was disposed at a position 5 m downstream from the exit of the cooling apparatus 3 to measure the surface-layer temperature distribution of the cast steel S in the width direction after the cast steel S passed through the cooling apparatus 3. In the temperature distribution of the cast steel S in the width direction measured by the thermometer 4, a value obtained by subtracting the minimum value from the maximum value was evaluated as the temperature deviation in the cast steel S. The temperature deviation of less than 50°C was evaluated as acceptable. In addition, a slab produced by cutting the cast steel S was subjected to a subsequent process of follow-up inspection for small cracks on the surface of the slab. In addition, the number of segregated grains at the center of the cast steel in the thickness direction was counted. In addition, the slab was subjected to hot rolling and cold rolling, and the resulting steel strip was subjected to a subsequent process of follow-up inspection for checking whether or not defects were found on the steel strip after cold rolling. In addition, a heat transfer simulation was performed based on the result of the temperature measurement by the thermometer 4, and the surface-layer cooling rate of the cast steel S was calculated. Table 1 shows the casting conditions and the evaluation results of the cast steel S according to Example. In Table 1, the angle is θ_1 for a rectangular shape and θ_2 for a square shape. In addition, the length is t_1 for a rectangular shape, t for a square shape, and the diameter D for a circular shape.

[Table 1]

	Nozzle Discharge Surface	Aspect Ratio	Angle	Interval L	Length	Water Flow Density	Surface Cooling Rate	Temperature Deviation	Defects After Rolling
		[-]	[°]	[mm]	[mm]	[L/(m^2·min)]	[°C/sec]	[°C]	-
Invention Example 1	Rectangular	2	30	350	150	120	4.0	37	No
Invention Example 2	Rectangular	30	30	350	30			12	No
Invention Example 3	Rectangular	120	30	350	10			25	No
Invention Example 4	Rectangular	30	40	350	30			39	No
Invention Example 5	Square	1	30	350	150			40	No
Invention Example 6	Circular	1	30	350	150			42	No
Invention Example 7	Rectangular	30	30	350	30	500	179.0	18	No
Invention Example 8	Square	1	30	350	150			45	No
Invention Example 9	Circular	1	30	350	150			43	No
Invention Example 10	Rectangular	30	30	350	30	10	0.2	8	No
Invention Example 11	Square	1	30	350	150			32	No
Invention Example 12	Circular	1	30	350	150			34	No
Comparative Example 1	Rectangular	30	5	200	30	120	4.0	90	Yes
Comparative Example 2	Rectangular	30	60	200	30			218	Yes
Comparative Example 3	Square	1	30	200	250			86	Yes
Comparative Example 4	Circular	1	30	200	250			92	Yes

[0069] For each of Invention Examples 1 to 6, the cast steel was evaluated as acceptable. A slab with high quality over the entire width and length was obtained, and no defects were found on the steel strip after cold rolling; the resulting product was shippable. In Invention Example 4, no defects were found on the steel strip after cold rolling, and the temperature deviation was less than 50°C. However, the temperature deviation was greater than that for Invention Example 2. This may be because since the discharge angle θ_1 was increased, the velocity component of the spray water in the transport direction was increased, and the cooling water discharged toward the cast steel was not quickly removed to the outside of the cast steel, resulting in the occurrence of local subcooling portions. In addition, under the same conditions, the temperature deviation in the width direction was smaller when the rectangular spray nozzles were used than when the circular or square spray nozzles were used. This may be because when the rectangular spray nozzles were used, the cooling water W discharged in the major-axis direction at a high flow rate was quickly removed to the outside of the cast steel S in the width direction.

[0070] When rectangular spray nozzles were used, the temperature deviation was smallest when the spray nozzles having the spray discharge surfaces with an aspect ratio of 30 were used. When the aspect ratio is low, the effect of removing the cooling water W is reduced. When the aspect ratio is high, the local concentration of the cooling water W occurs, and the temperature deviation increases. This result shows that the aspect ratio of the spray discharge surfaces has an optimum value.

[0071] Invention Examples 7 to 9 are examples in which casting was performed using rectangular, square, and circular spray nozzles and in which the water flow density was increased. In Invention Examples 7 to 9, the temperature deviation was less than 50°C and was acceptable, but several small cracks were found on the surface of the slab. The formation of small cracks may be because the cooling rate was excessively high and the surface layer of the cast steel S transformed into martensite. However, since the temperature deviation was acceptable for Invention Examples 7 to 9, no defects were found on the steel strip after cold rolling, and the resulting product was shippable.

[0072] Invention Examples 10 to 12 are examples in which casting was performed using rectangular, square, and circular spray nozzles and in which the water flow density was reduced. In Invention Examples 10 to 12, the temperature deviation was less than 50°C and was acceptable, but the number of segregated grains at the center of the cast steel in the thickness direction increased. The increase in the number of segregated grains at the center of the cast steel in the thickness direction may be because the cooling rate was excessively low and the temperature gradient in the cast steel S was reduced. However, since the temperature deviation was acceptable for Invention Examples 10 to 12, no defects were found on the steel strip after cold rolling, and the resulting product was shippable.

[0073] Comparative Example 1 is an example in which casting was performed using flat spray nozzles, and the discharge angle was reduced such that Inequality (1) above was not satisfied. In Comparative Example 1, the temperature deviation was 90°C. The quality of the produced slab was not uniform over the entire width, and defects were found on the steel strip after rolling. Therefore, the steel strip produced from this slab was not shippable. This may be because the sprays of the cooling water W discharged from adjacent nozzles interfered with each other, causing a disruption of the film boiling state and an increase in the cooling capacity in that region.

[0074] Comparative Example 2 is an example in which casting was performed using rectangular spray nozzles, and the discharge angle was increased such that Inequality (1) above was not satisfied. In Comparative Example 2, the temperature deviation was 218°C. The quality of the produced slab was not uniform over the entire width, and defects were found on the steel strip after rolling. Therefore, the steel strip produced from this slab was not shippable. This may be because the cooling water W on the cast steel S was not removed to the outside of the cast steel S in the width direction and remained on the cast steel S, causing a local transition from the film boiling state to the nucleate boiling state.

[0075] Comparative Examples 3 and 4 are examples in which square or circular spray nozzles were used and in which the nozzle arrangement interval was reduced such that Inequality (2) or (3) above was not satisfied. In Comparative Examples 3 and 4, the temperature deviation was 86°C and 92°C, respectively. The quality of the produced slab was not uniform over the entire width, and defects were found on the steel strip after cold rolling. Therefore, the steel strip produced from this slab was not shippable. This may be because the sprays of the cooling water W discharged from adjacent spray nozzles interfered with each other, causing an increase in the cooling capacity in that region.

Reference Signs List

[0076]

1	steel continuous-casting machine
2	mold
3	cooling apparatus
4	thermometer
5	cast-steel support roll
6	vertical section

7	curved section
8	horizontal section
10	control device
11	host computer
12	control unit
13	storage unit
14	computing unit
15	output unit
20	spray discharge surface
21	side
22	spray discharge surface
23	side
24	side
25	spray discharge surface
31	water cooling device
32	cooling-water-discharging nozzle
32a	cooling-water-discharging nozzle
32c	cooling-water-discharging nozzle
33	water purging roll
34	purge nozzle
35	water purging jet
36	cooling-water-discharging nozzle
37	cooling-water-discharging nozzle
40	steel continuous-casting machine
50	steel continuous-casting machine
60	steel continuous-casting machine
S	cast steel
W	cooling water

Claims

1. A steel continuous-casting machine comprising a cooling apparatus that cools cast steel with water,

wherein the cooling apparatus includes two or more cooling-water-discharging nozzles arranged in a width direction of the cast steel, and
wherein the two or more cooling-water-discharging nozzles are arranged such that spray discharge surfaces of cooling-water-discharging nozzles adjacent to each other in the width direction of the cast steel do not overlap.

2. The steel continuous-casting machine according to Claim 1, wherein the spray discharge surfaces of the cooling-water-discharging nozzles are rectangular or elliptical, and

wherein each of the two or more cooling-water-discharging nozzles is disposed to satisfy Inequality (1) below:
[Math. 1]

$$\frac{L}{\sqrt{2}} > L \times \sin\theta_1 > t_1 \cdots \quad (1)$$

where L is an arrangement interval (m) of the cooling-water-discharging nozzles, θ_1 is an angle (°) of a long-side direction or a major-axis direction of the spray discharge surface relative to the width direction, and ti is a length (m) of a short side or a minor axis of the spray discharge surface.

3. The steel continuous-casting machine according to Claim 1, wherein the spray discharge surfaces of the cooling-water-discharging nozzles are square, and

wherein each of the two or more cooling-water-discharging nozzles is disposed to satisfy Inequality (2) below:

$$L \times \sin\theta_2 > t \qquad (2)$$

where L is an arrangement interval (m) of the cooling-water-discharging nozzles, θ_2 is an angle (°) of a direction of one side of the spray discharge surface relative to the width direction, the one side of the spray discharge surface being one of sides of the spray discharge surface that is closest to an adjacent spray discharge surface, and t is a length (m) of the one side.

4. The steel continuous-casting machine according to Claim 1, wherein the spray discharge surfaces of the cooling-water-discharging nozzles are circular, and

wherein each of the two or more cooling-water-discharging nozzles is disposed to satisfy Inequality (3) below:

$$L > D \qquad (3)$$

wherein L is an arrangement interval (m) of the cooling-water-discharging nozzles and D is a diameter (m) of the spray discharge surface.

5. The steel continuous-casting machine according to Claim 2, wherein an aspect ratio of the spray discharge surface is 100 or less.

6. The steel continuous-casting machine according to any one of Claims 1 to 5, wherein a surface-layer cooling rate of the cast steel in the cooling apparatus is in a range of 0.3°C/sec or more and 100°C/sec or less.

7. The steel continuous-casting machine according to any one of Claims 1 to 5, further comprising a control device that controls an amount of cooling water discharged from the cooling-water-discharging nozzles and a transportation speed of the cast steel.

8. The steel continuous-casting machine according to Claim 6, further comprising a control device that controls an amount of cooling water discharged from the cooling-water-discharging nozzles and a transportation speed of the cast steel.

9. A steel continuous-casting method comprising a cooling step of cooling cast steel with water,

wherein, in the cooling step, the cast steel is cooled by discharging cooling water from two or more cooling-water-discharging nozzles arranged in a width direction of the cast steel, and
wherein the two or more cooling-water-discharging nozzles are arranged such that spray discharge surfaces of cooling-water-discharging nozzles adjacent to each other in the width direction of the cast steel do not overlap.

10. The steel continuous-casting method according to Claim 9, wherein the spray discharge surfaces of the cooling-water-discharging nozzles are rectangular or elliptical, and

wherein each of the two or more cooling-water-discharging nozzles is disposed to satisfy Inequality (1) below:
[Math. 2]

$$\frac{L}{\sqrt{2}} > L\times \sin\theta_1 > t_1 \quad \cdots \quad (1)$$

where L is an arrangement interval (m) of the cooling-water-discharging nozzles, θ_1 is an angle (°) of a long-side direction or a major-axis direction of the spray discharge surface relative to the width direction, and ti is a length (m) of a short side or a minor axis of the spray discharge surface.

11. The steel continuous-casting method according to Claim 9, wherein the spray discharge surfaces of the cooling-water-discharging nozzles are square, and

wherein each of the two or more cooling-water-discharging nozzles is disposed to satisfy Inequality (2) below:

$$L\times\sin\theta_2 > t \qquad (2)$$

where L is an arrangement interval (m) of the cooling-water-discharging nozzles, θ_2 is an angle (°) of a direction of one side of the spray discharge surface relative to the width direction, the one side of the spray discharge surface being one of sides of the spray discharge surface that is closest to an adjacent spray discharge surface, and t is a length (m) of the one side.

12. The steel continuous-casting method according to Claim 9, wherein the spray discharge surfaces of the cooling-water-discharging nozzles are circular, and

wherein each of the two or more cooling-water-discharging nozzles is disposed to satisfy Inequality (3) below:

$$L > D \qquad (3)$$

wherein L is an arrangement interval (m) of the cooling-water-discharging nozzles and D is a diameter (m) of the spray discharge surface.

13. The steel continuous-casting method according to Claim 10, wherein an aspect ratio of the spray discharge surface is 100 or less.

14. The steel continuous-casting method according to any one of Claims 9 to 13, wherein a surface-layer cooling rate of the cast steel in the cooling step is in a range of 0.3°C/sec or more and 100°C/sec or less.

15. The steel continuous-casting method according to any one of Claims 9 to 13, wherein, in the cooling step, at least one of a surface-layer cooling rate of the cast steel and a temperature drop of the cast steel is controlled by controlling an amount of cooling water discharged from the cooling-water-discharging nozzles and a transportation speed of the cast steel.

16. The steel continuous-casting method according to Claim 14, wherein, in the cooling step, at least one of a surface-layer cooling rate of the cast steel and a temperature drop of the cast steel is controlled by controlling an amount of cooling water discharged from the cooling-water-discharging nozzles and a transportation speed of the cast steel.

FIG. 1

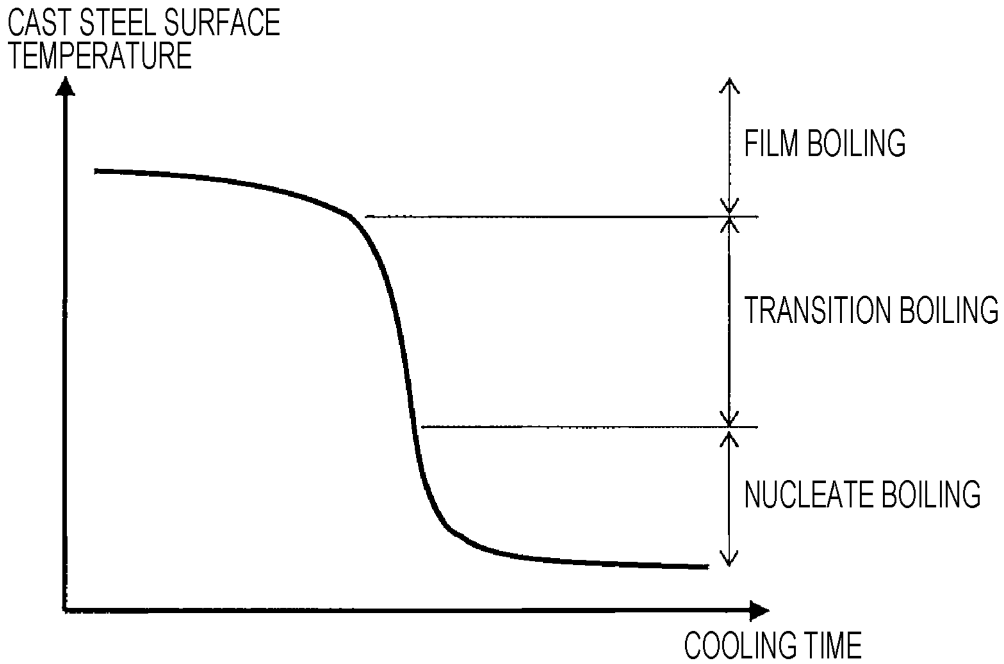

CAST STEEL SURFACE TEMPERATURE
FILM BOILING
TRANSITION BOILING
NUCLEATE BOILING
COOLING TIME

FIG. 2

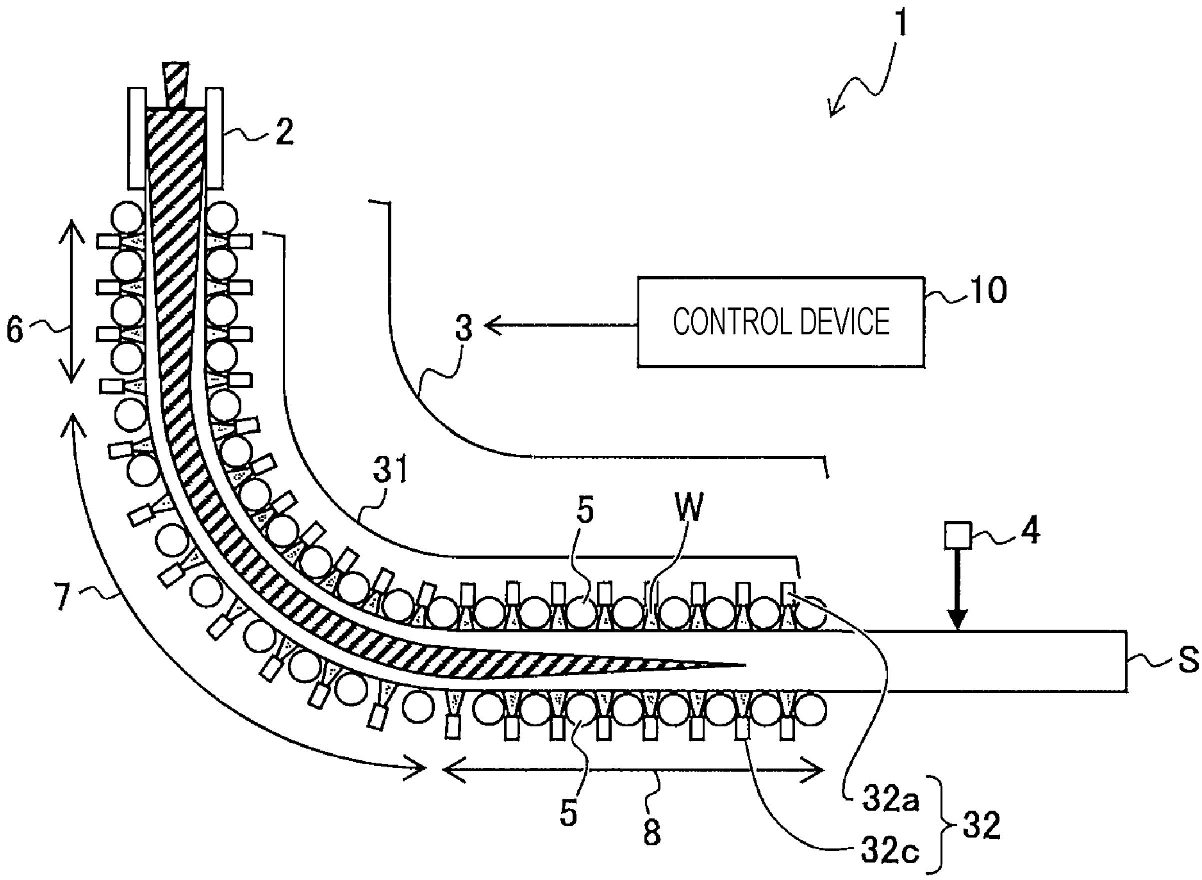

1
2
6
3
CONTROL DEVICE
10
31
5
W
4
7
S
5
8
32a
32c
32

FIG. 3

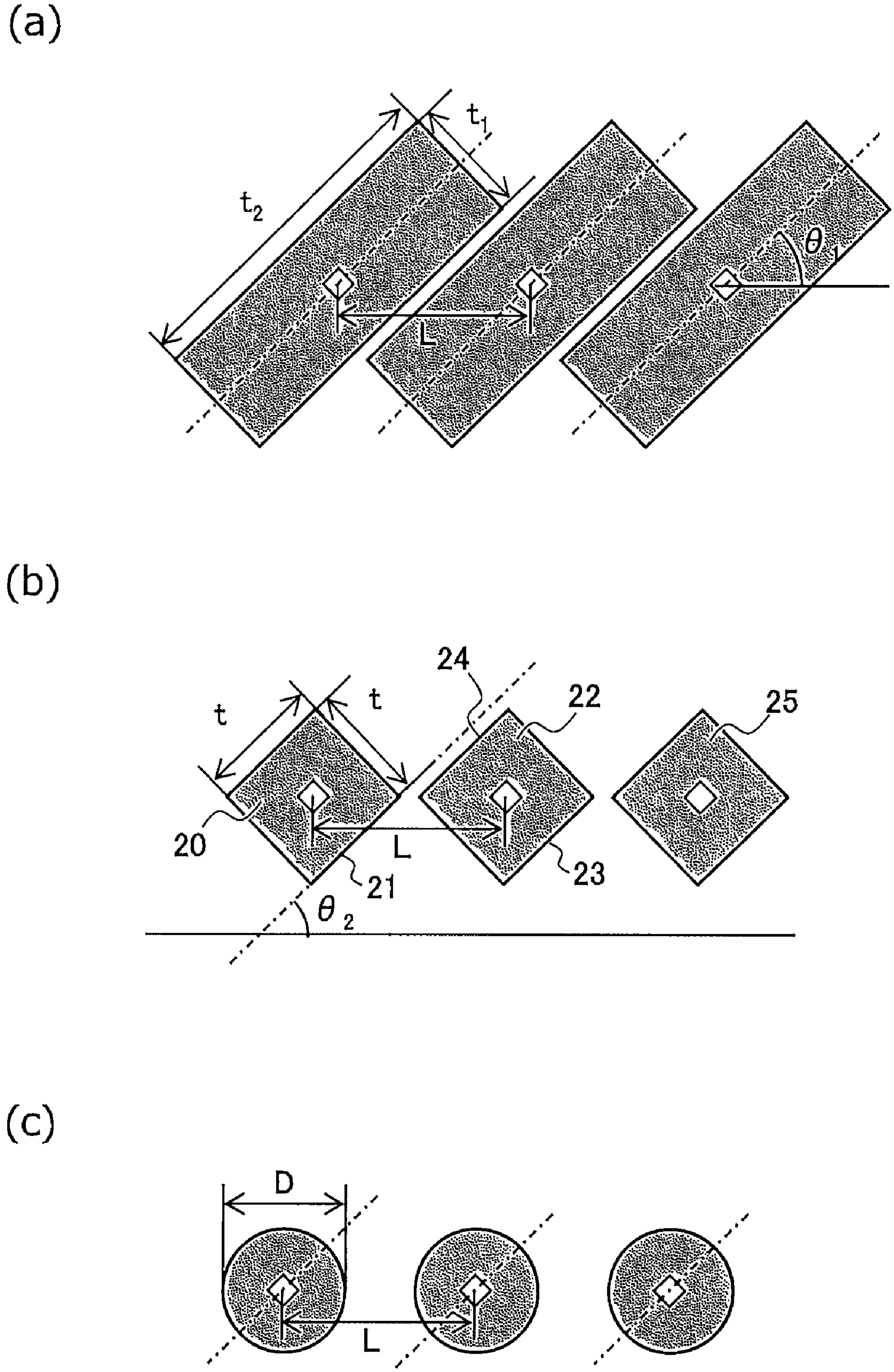


FIG. 4

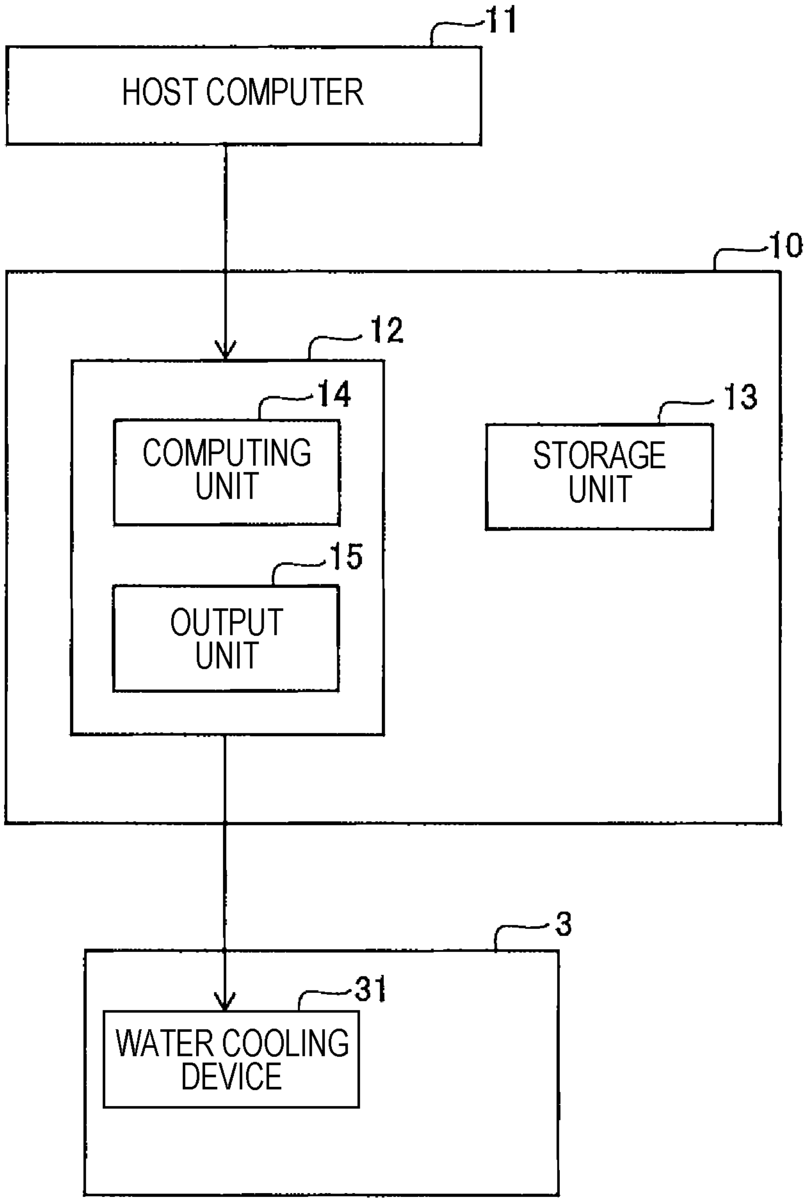

11
HOST COMPUTER
10
12
14
COMPUTING UNIT
13
STORAGE UNIT
15
OUTPUT UNIT
3
31
WATER COOLING DEVICE

FIG. 5

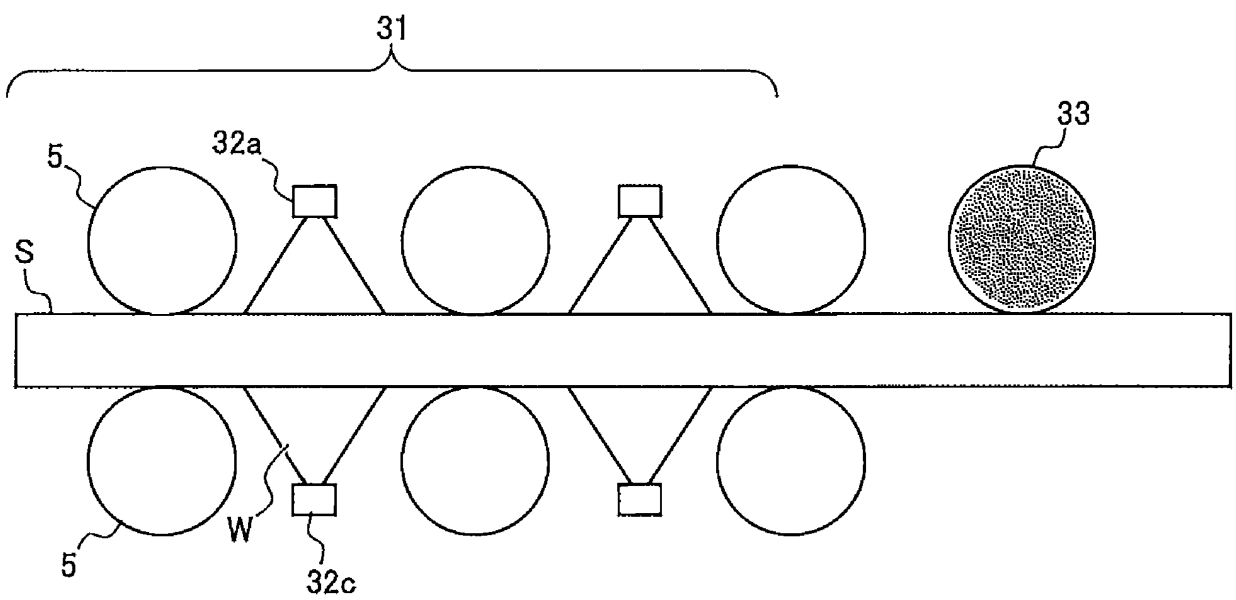


FIG. 6

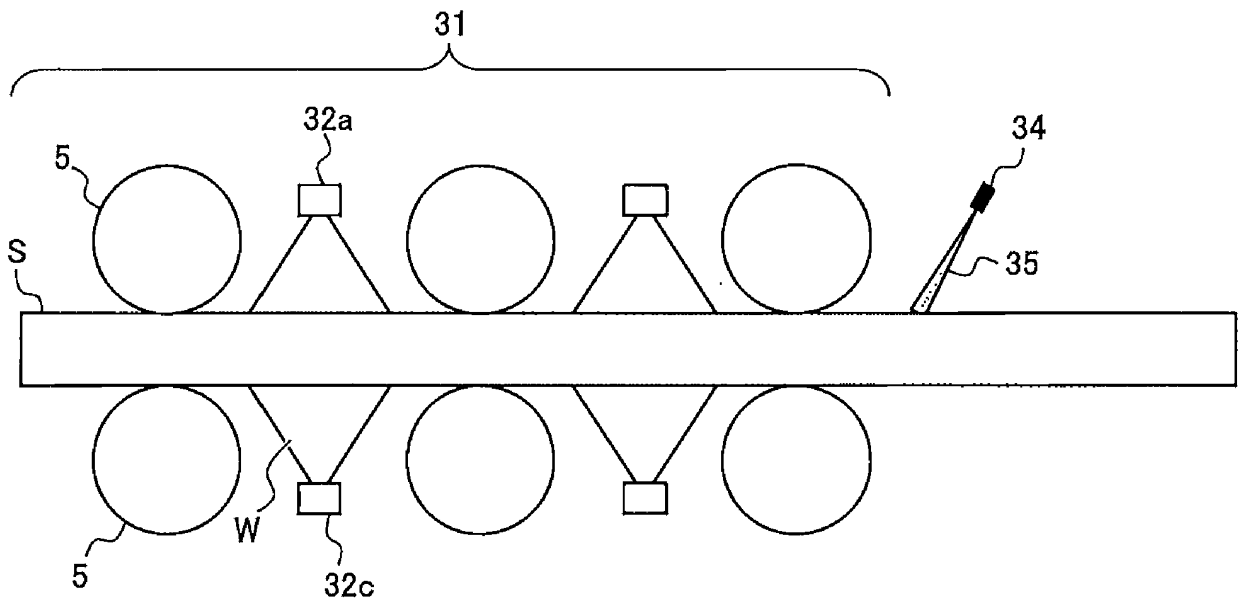


FIG. 7

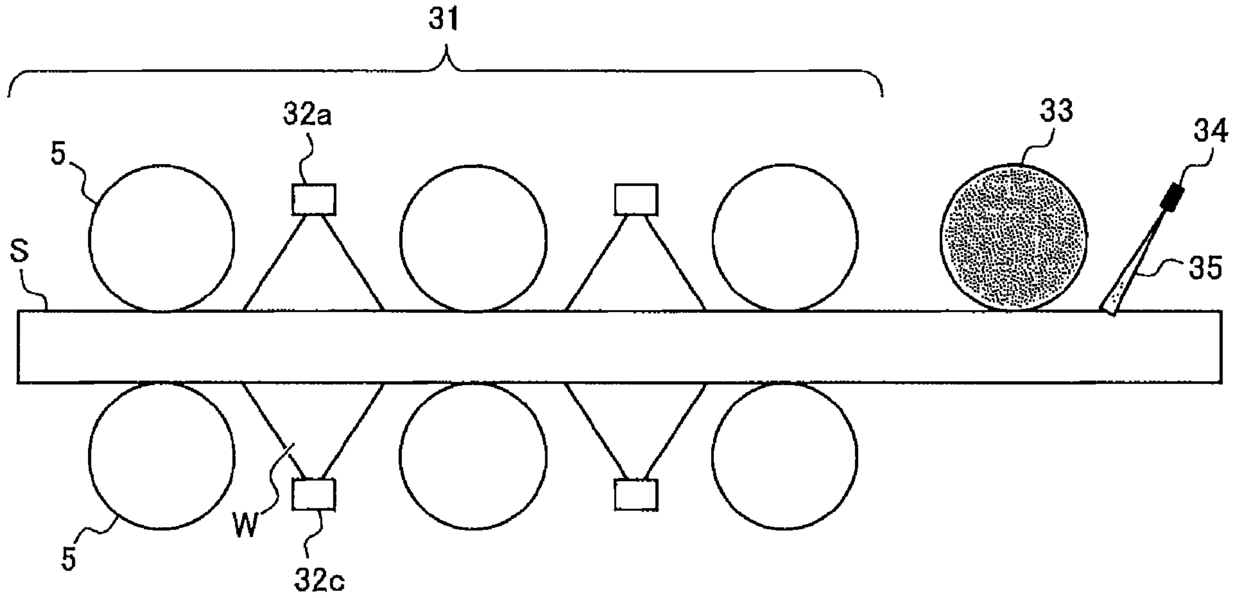
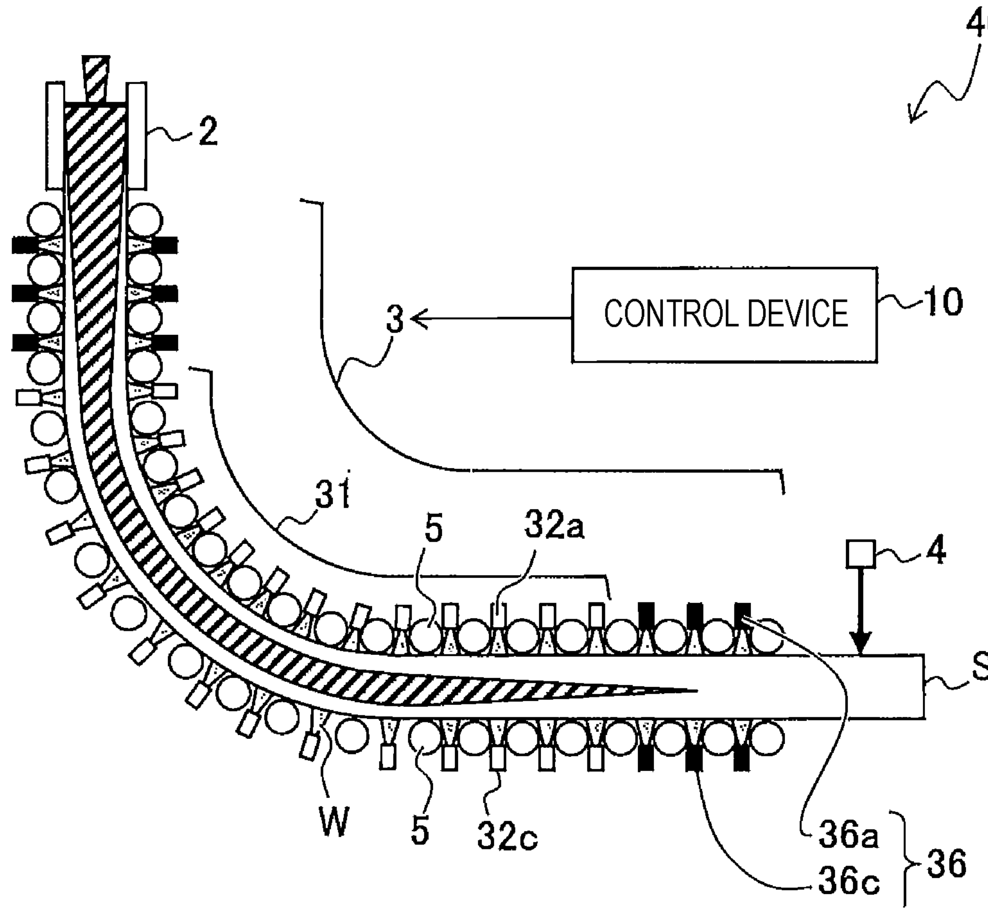

31
32a
5
33
34
S
35
W
5
32c

FIG. 8


40
2
CONTROL DEVICE
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3
31
5
32a
4
S
W
5
32c
36a
36c
36

FIG. 9

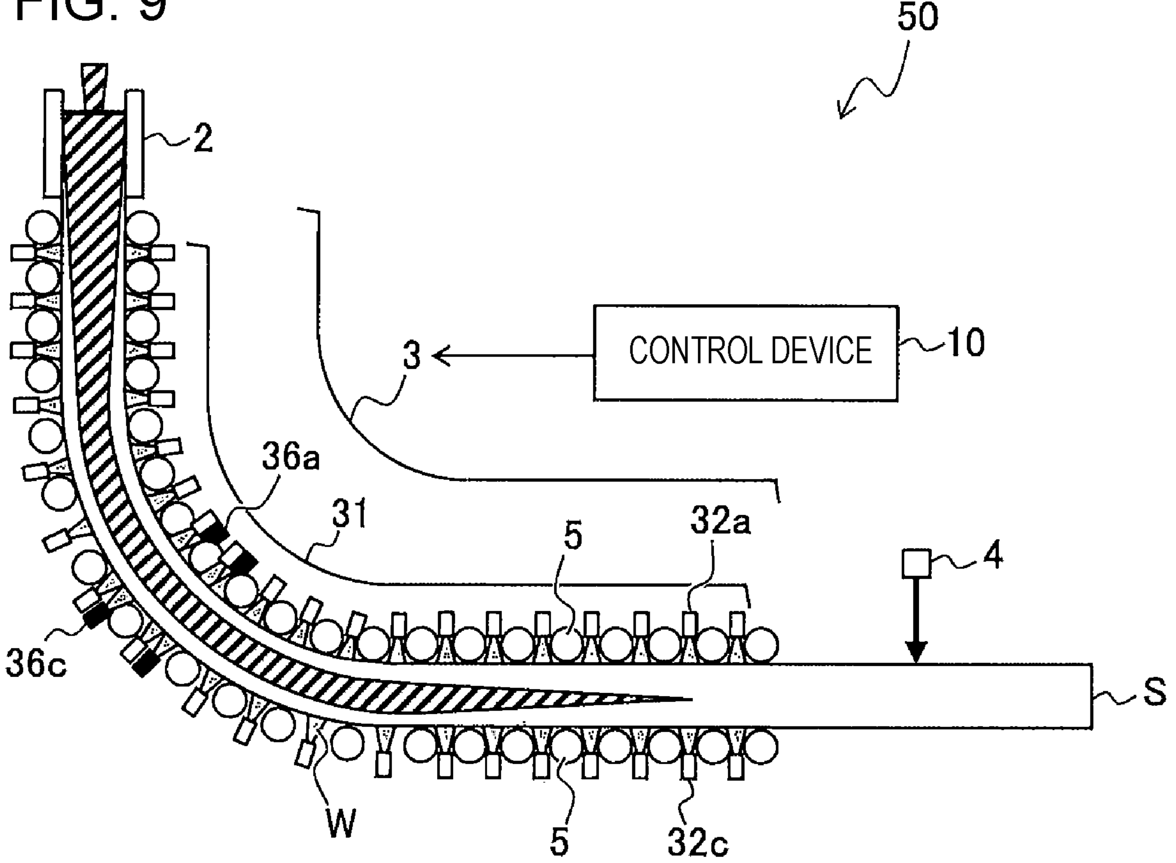
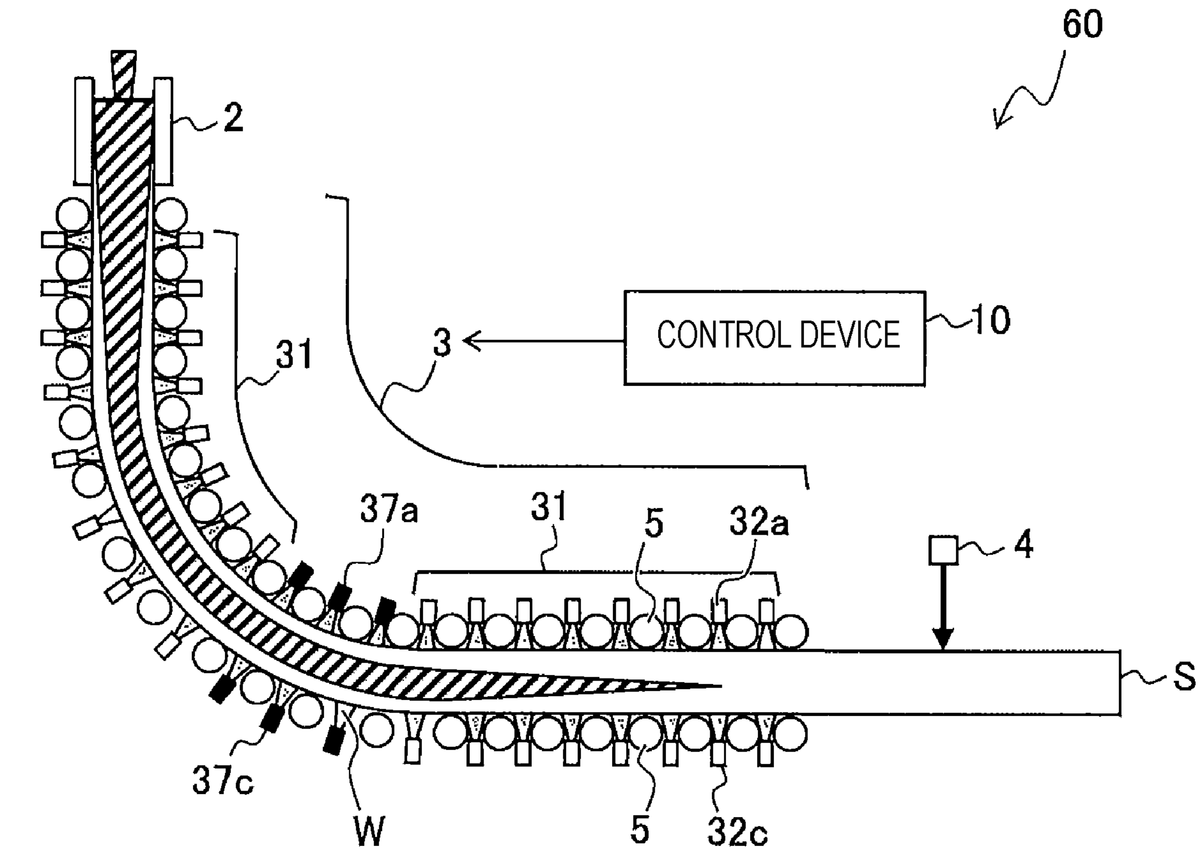

50
2
CONTROL DEVICE
10
3
36a
31
5
32a
4
36c
S
W
5
32c

FIG. 10


60
2
CONTROL DEVICE
10
3
31
37a
31
5
32a
4
S
37c
W
5
32c

INTERNATIONAL SEARCH REPORT

International application No. **PCT/JP2023/017363**

A. CLASSIFICATION OF SUBJECT MATTER

B22D 11/124(2006.01)i; ***B22D 11/22***(2006.01)i
FI: B22D11/124 G; B22D11/124 N; B22D11/22 B

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)

B22D11/124; B22D11/22

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 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 2014-050874 A (NIPPON STEEL & SUMITOMO METAL CORP.) 20 March 2014 (2014-03-20) paragraphs [0001]-[0029], fig. 1-7, 10	1-2, 4-10, 12-13
Y		2-3, 5-8, 10-11, 13-16
X	JP 2007-118043 A (JFE STEEL KK) 17 May 2007 (2007-05-17) paragraphs [0001]-[0037], fig. 1-3	1-2, 4-10, 12-13
Y		2-3, 5-8, 10-11, 13-16
Y	JP 2020-131193 A (KOBE STEEL, LTD.) 31 August 2020 (2020-08-31) paragraphs [0017], [0073]-[0076], fig. 9-10	2-3, 5-8, 10-11, 13-16
Y	JP 2020-069483 A (NIPPON STEEL CORP.) 07 May 2020 (2020-05-07) paragraphs [0037]-[0040], fig. 1	2-3, 5-8, 10-11, 13-16
Y	JP 2015-217435 A (NIPPON STEEL & SUMITOMO METAL CORP.) 07 December 2015 (2015-12-07) paragraphs [0062]-[0067]	2-3, 5-8, 10-11, 13-16

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

* Special categories of cited documents:
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"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
03 July 2023	**18 July 2023**

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

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/017363

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2014-050874 A	20 March 2014	(Family: none)	
JP 2007-118043 A	17 May 2007	(Family: none)	
JP 2020-131193 A	31 August 2020	US 2020/0254514 A1 paragraphs [0021], [0130]-[0136], fig. 9-10 CN 111545715 A	
JP 2020-069483 A	07 May 2020	(Family: none)	
JP 2015-217435 A	07 December 2015	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

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- JP 2018101287 A **[0011]**
- JP 2009255127 A **[0011]**