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(54) **CONTINUOUS CASTING METHOD FOR SLAB CASTING PIECE**

(57) A continuous casting method by which a high quality slab can be produced is provided.

In the continuous casting method, an immersion nozzle is placed in a continuous casting mold, and casting is performed by supplying molten steel to the immersion nozzle. The immersion nozzle has a pair of discharge openings that are arranged symmetrically about a vertical axis of the immersion nozzle. An immersion depth is greater than or equal to 180 mm and less than 300 mm. A molten-steel discharge angle is in the range from 15 to 35°. The ratio A/P of a flow rate A of injected inert gas to a molten steel throughput P is in the range from 2.0 to 3.5 NL/ton. A discharge direction of the immersion nozzle is inclined with respect to a reference plane, which passes through a vertical axial center of the immersion nozzle and which is parallel to mold long side surfaces, in the range of Equation (1):

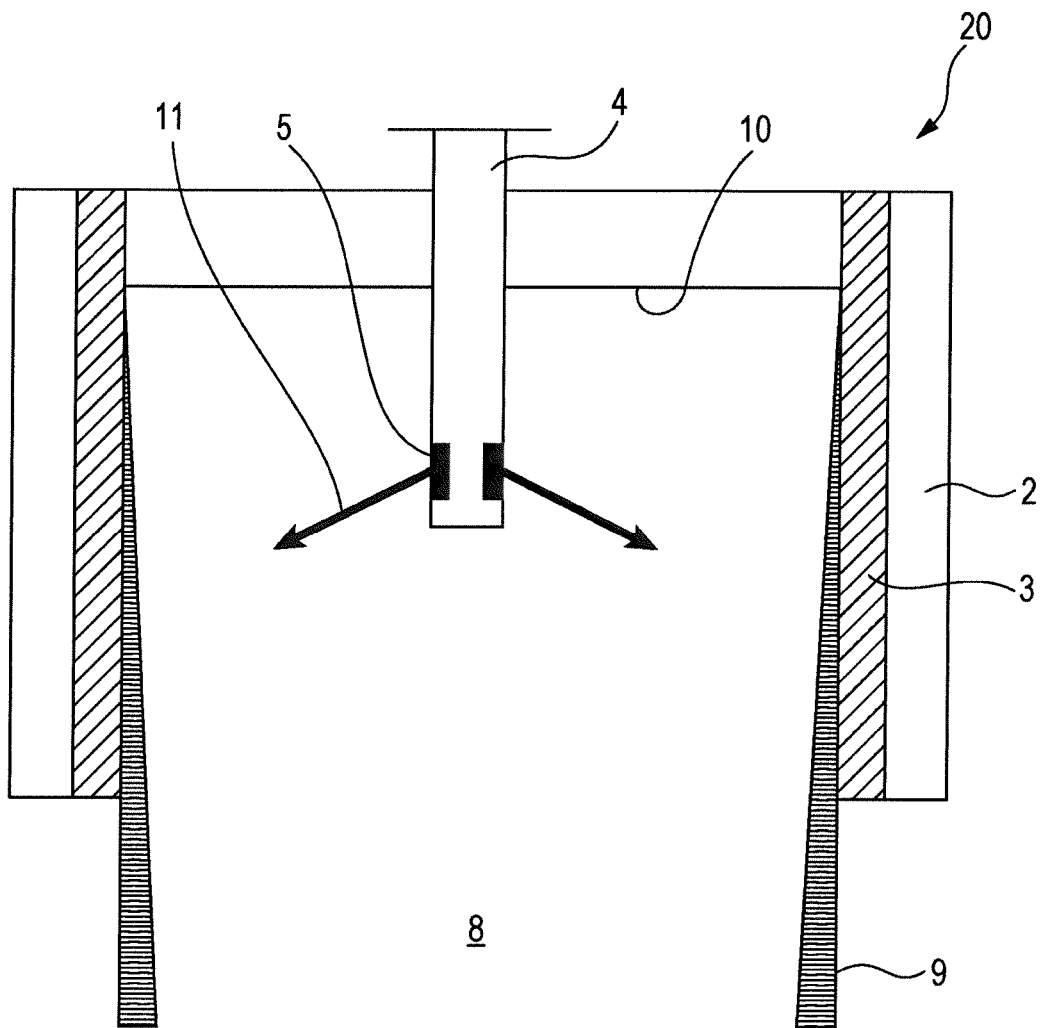
$$\theta - 6 \leq \alpha \leq \theta + 10 \quad (1)$$

In Equation (1), α is an inclination angle with respect to the reference plane and θ is an angle defined by Equation (2) :

$$\tan \theta = (D/2) / (W/2) \quad (2)$$

In Equation (2), D is a thickness of the slab and W is a width of the slab.

FIG. 1



Description

Technical Field

5 **[0001]** The present invention relates to a continuous casting method for producing a high-quality slab in which the amount of nonmetallic inclusions contained in a slab surface layer is reduced by controlling a molten steel flow in a mold.

Background Art

10 **[0002]** In recent years, quality requirements for high-quality steel products, such as steel sheets for automobile exterior panels and cans, have become stricter, and there has been a demand for higher quality from the slab stage, that is, from the continuous casting stage. One of the qualities required of a slab is that the amount of nonmetallic inclusions (hereinafter also referred to simply as "inclusions") contained in a surface layer is small.

[0003] Examples of inclusions trapped in the surface layer of the slab include:

- 15 (a) Deoxidation products generated in a process of deoxidation of molten steel by using, for example, aluminum and suspended in the molten steel;
 (b) Fine oxides contained in argon gas bubbles injected into the molten steel in a tundish or an immersion nozzle; and
 (c) Mold powder added to a molten steel surface in a mold and entrained into the molten steel as suspended matter.

20 **[0004]** Each of these inclusions causes surface defects in the steel product stage. Therefore, it is important to reduce the amount of inclusions trapped in the surface layer of the slab. In addition, when the argon gas bubbles trapped in the surface layer of the slab are open in the slab surface layer, the inner regions of the bubbles are oxidized in, for example, a furnace, and the oxidized portions serve as surface defects.

25 **[0005]** To prevent the deoxidation products, argon gas bubbles, and mold powder contained in the molten steel from becoming trapped in a solidifying shell and causing defects in steel products, methods for appropriately controlling the flow of molten steel in a continuous casting mold have been proposed.

[0006] For example, Patent Literature 1 discloses a continuous casting method using an immersion nozzle having a pair of discharge openings that are arranged symmetrically about a vertical axis of the immersion nozzle. In this method,
 30 an immersion depth of the immersion nozzle, a maximum flow velocity of discharge flows at positions corresponding to 1/4 of the width of a mold, and a discharge angle of the discharge openings are regulated, and the angle of a discharge direction of the discharge flows from the immersion nozzle with respect to mold long sides is 3 to 7° on a horizontal plane. The purpose for adjusting the angle of the discharge direction of the discharge flows with respect to the mold long sides to 3 to 7° is to bring at least portions of the discharge flows to come into contact with portions of the solidifying
 35 shell at the mold long sides, thereby reducing the flow velocity of the discharge flows.

Citation List

Patent Literature

40 **[0007]**

PTL 1: Japanese Patent No. 4285345

PTL 2: Japanese Patent No. 5742992

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Summary of Invention

Technical Problem

50 **[0008]** However, the above-described related art has the following problems.

[0009] That is, since quality requirements for steel sheets for automobile exterior panels, for example, have become stricter in recent years, defects due to entrainment of fine bubbles and mold powder that have not caused any problem are becoming problematic, and these strict quality requirements cannot be sufficiently satisfied simply by the method according to the related art. In particular, a hot-dip galvanized steel sheet is obtained by diffusing an iron component
 55 contained in a base steel sheet into a galvanized layer by applying heat after hot dipping, and the properties of the surface layer of the base steel sheet greatly affects the quality of the hot-dip galvanized layer. Namely, when the surface layer of the base steel sheet has defects due to bubbles or mold powder, even a small defect causes a variation in the thickness of the plated layer and forms a strip-shaped defect on the surface. Such a steel sheet cannot be used in an

application where quality requirements are strict, such as those for steel sheets for automobile exterior panels.

[0010] The method according to Patent Literature 1 attempts to control the molten steel flow in the mold by adjusting the immersion depth and shape of the immersion-nozzle discharge openings and the discharge direction of the immersion nozzle. In general, to reduce adhesion of inclusions (mainly Al_2O_3) to the inner wall of the immersion nozzle, inert gas, such as argon or nitrogen gas, is injected between a tundish outflow opening and the immersion-nozzle discharge openings. The injection of the gas has a very large influence on the behavior of the discharge flows, and the molten steel throughput, of course, also has a great influence on the behavior of the discharge flows. When the design items of the immersion nozzle are adjusted without controlling the amount of gas injection and molten steel throughput in appropriate ranges, sufficient flow control effect cannot be obtained. Thus, this method cannot be used to produce steel sheets required to satisfy strict requirements, such as steel sheets for automobile exterior panels.

[0011] The present invention has been made in light of the above-described problems, and its object is to provide a continuous casting method by which a high quality slab can be produced by controlling the molten steel flow in a mold by adjusting a discharge direction of an immersion nozzle to an appropriate direction in addition to controlling a position at which the molten steel is discharged from the immersion nozzle, the shape of the immersion nozzle, the molten steel throughput, and the flow rate of injected inert gas in appropriate ranges. It is also an object of the present invention to provide a continuous casting method by which a high quality slab containing a smaller amount of inclusions can be produced by proposing an appropriate discharge direction of the immersion nozzle for various technologies of electro-magnetic flow control in the mold. Solution to Problem

[0012] To solve the above-described problems, the present invention has the following features.

[1] A slab continuous casting method including steps of: placing an immersion nozzle in a continuous casting mold; and supplying molten steel to the immersion nozzle to cast the molten steel, wherein, the immersion nozzle has a pair of discharge openings that are arranged symmetrically about a vertical axis of the immersion nozzle, an immersion depth of the immersion nozzle (distance from a molten steel surface in the mold to top ends of the discharge openings) is greater than or equal to 180 mm and less than 300 mm, a downward molten-steel discharge angle of the discharge openings from a horizontal direction is in a range from 15 to 35°, a ratio A/P of a flow rate A (NL/min) of inert gas injected between a tundish outflow opening and the discharge openings to a molten steel throughput P (ton/min) is in a range from 2.0 to 3.5 NL/ton, and a discharge direction of the immersion nozzle is inclined with respect to a reference plane which passes through a vertical axial center of the immersion nozzle and which is parallel to mold long side surfaces, in a range of Equation (1):

$$\theta - 6 \leq \alpha \leq \theta + 10 \quad (1)$$

α is an inclination angle (°) of the discharge direction with respect to the reference plane when the mold is viewed from vertically above; and

θ is an angle (acute angle) between a straight line and the reference plane when the mold is viewed from vertically above, the straight line extending from the vertical axial center of the immersion nozzle toward contact points of mold long sides and mold short sides, the angle (°) being defined by Equation (2):

$$\tan \theta = (D/2) / (W/2) \quad (2)$$

D is a thickness (mm) of a continuously cast slab; and

W is a width (mm) of the slab.

[2] The slab continuous casting method according to [1], further including steps of: measuring the α during continuous casting or after completion of a change in mold width during continuous casting; and changing the discharge direction of the immersion nozzle so as to satisfy Equation (1) when the α does not satisfy the Equation (1).

[3] The slab continuous casting method according to [1], including steps of: arranging a pair of upper magnetic poles and a pair of lower magnetic poles on back surfaces of the mold long sides so as to face each other with the mold long sides disposed therebetween; positioning the discharge openings between a position at which direct-current static magnetic fields generated by the upper magnetic poles have a maximum value and a position at which direct-

current static magnetic fields generated by the lower magnetic poles have a maximum value; and applying the direct-current static magnetic fields generated by the upper magnetic poles and the lower magnetic poles to slow a molten steel flow, wherein, the discharge direction of the immersion nozzle is inclined with respect to the reference plane in a range of Equation (3) instead of Equation (1) when an intensity of the direct-current static magnetic fields generated by the upper magnetic poles is greater than or equal to 1500 Gs and less than 2500 Gs (Gauss; 1 Gs = 10^{-4} T); or

the discharge direction of the immersion nozzle is inclined in a range of Equation (4) instead of Equation (1) when the intensity of the direct-current static magnetic fields is greater than or equal to 2500 Gs and less than 3500 Gs:

$$\theta \leq \alpha \leq \theta+5 \quad (3)$$

$$\theta+6 \leq \alpha \leq \theta+10 \quad (4)$$

[4] The slab continuous casting method according to [3], including steps of: measuring the α during continuous casting or after completion of a change in mold width during continuous casting; changing discharge direction of the immersion nozzle so as to satisfy Equation (3) when the intensity of the direct-current static magnetic fields is greater than or equal to 1500 Gs and less than 2500 Gs and when α does not satisfy Equation (3); or changing the discharge direction of the immersion nozzle so as to satisfy Equation (4) when the intensity of the direct-current static magnetic fields is greater than or equal to 2500 Gs and less than 3500 Gs and when α does not satisfy Equation (4).

[5] The slab continuous casting method according to [1], further including the steps of: providing linear moving magnetic field generators on back surfaces of the mold long sides, the generators which generates magnetic fields of which moving direction is a mold width direction; and

applying moving magnetic fields in directions from the mold short sides toward the immersion nozzle to apply a slowing force to molten steel flows discharged from the immersion nozzle or applying moving magnetic fields in directions from the immersion nozzle toward the mold short sides to apply an accelerating force to the molten steel flows, to perform flow control, wherein, the discharge direction of the immersion nozzle is inclined with respect to the reference plane in a range of Equation (5) instead of Equation (1):.

$$\theta+2 \leq \alpha \leq \theta+7 \quad (5)$$

[6] The slab continuous casting method according to [5], further including steps of: measuring the α during continuous casting or after completion of a change in mold width during continuous casting; and changing the discharge direction of the immersion nozzle so as to satisfy Equation (5) when the α does not satisfy Equation (5).

[7] The slab continuous casting method according to [1], including steps of: arranging a pair of magnetic poles on back surfaces of the mold long sides so as to face each other with the mold long sides disposed therebetween; and applying alternating-current moving magnetic fields generated by the magnetic poles to swirl and stir the molten steel in a horizontal direction, wherein, an intensity of the alternating-current moving magnetic fields is set in a range from 300 to 1000 Gs, and the discharge direction of the immersion nozzle is inclined with respect to the reference plane toward upstream sides of swirling flows formed by the alternating-current moving magnetic fields, the discharge direction of the immersion nozzle being inclined with respect to the reference plane in a range of Equation (6) instead of Equation (1) when a ratio X/W (Gs/mm) of an intensity X (Gs) of the alternating-current moving magnetic fields to a width W (mm) of the continuously cast slab is greater than or equal to 0.30 and less than 0.45:

$$\theta-3 \leq \alpha \leq \theta \quad (6);$$

or

the discharge direction is inclined with respect to the reference plane toward upstream sides of the swirling flows in a range of Equation (7) instead of Equation (1) when the ratio X/W (Gs/mm) is greater than or equal to 0.45 and less than 0.55:

$$\theta - 6 \leq \alpha \leq \theta - 4 \quad (7) .$$

[8] The slab continuous casting method according to [7], including the steps of: measuring the α during continuous casting or after completion of a change in mold width during continuous casting; and changing the discharge direction of the immersion nozzle so as to satisfy Equation (6) when the ratio X/W (Gs/mm) is greater than or equal to 0.30 and less than 0.45 and when α does not satisfy Equation (6); or changing the discharge direction so as to satisfy Equation (7) when the ratio X/W (Gs/mm) is greater than or equal to 0.45 and less than 0.55 and when α does not satisfy Equation (7) .

[9] The slab continuous casting method according to [1], including steps of: arranging a pair of upper magnetic poles and a pair of lower magnetic poles on back surfaces of the mold long sides so as to face each other with the mold long sides disposed therebetween; positioning the discharge openings between a position at which direct-current static magnetic fields generated by the upper magnetic poles have a maximum value and a position at which direct-current static magnetic fields generated by the lower magnetic poles have a maximum value; and applying the direct-current static magnetic fields and alternating-current moving magnetic fields in a superposed manner from the upper magnetic poles, to slow a molten steel flow by the direct-current static magnetic fields generated by the upper magnetic poles, and to also slow the molten steel flow by the direct-current static magnetic fields generated by the lower magnetic poles, along with forming swirling flows of the molten steel that rotate in a horizontal direction along the molten steel surface in the mold by the alternating-current moving magnetic fields generated by the upper magnetic poles, wherein an intensity of the alternating-current moving magnetic fields is set in a range from 500 to 900 Gs (Gauss; 1 Gs = 10^{-4} T); and an intensity of the direct-current static magnetic fields generated by the upper magnetic poles is set in a range from 2000 to 3300 Gs; and an intensity of the direct-current static magnetic fields generated by the lower magnetic poles is set in a range from 3000 to 4500 Gs, and a ratio X/W (Gs/mm) of an intensity X (Gs) of the alternating-current moving magnetic fields to a width W (mm) of the continuously cast slab is controlled so as to be greater than or equal to 0.30 and less than 0.55; the discharge direction of the immersion nozzle is inclined with respect to the reference plane toward upstream sides of the swirling flows of the molten steel formed by the alternating-current moving magnetic fields.

[10] The slab continuous casting method according to [9], wherein, the discharge direction of the immersion nozzle is inclined with respect to the reference plane in a range of Equation (8) instead of Equation (1) when the ratio X/W (Gs/mm) is greater than or equal to 0.30 and less than 0.45:

$$\theta - 2 \leq \alpha \leq \theta + 5 \quad (8) ,$$

or

the discharge direction of the immersion nozzle is inclined with respect to the reference plane in a range of Equation (9) instead of Equation (1) when the ratio X/W (Gs/mm) is greater than or equal to 0.45 and less than 0.55:

$$\theta - 5 \leq \alpha \leq \theta + 2 \quad (9) .$$

[11] The slab continuous casting method according to [10], including steps of: measuring the α during continuous casting or after completion of a change in mold width during continuous casting; changing the discharge direction of the immersion nozzle so as to satisfy Equation (8) when the ratio X/W (Gs/mm) is greater than or equal to 0.30 and less than 0.45 and when α does not satisfy Equation (8); or, changing the discharge direction of the immersion nozzle so as to satisfy Equation (9) when the ratio X/W (Gs/mm) is greater than or equal to 0.45 and less than 0.55 and when α does not satisfy Equation (9).

Advantageous Effects of Invention

[0013] According to the present invention, a high quality slab can be produced by appropriately controlling the molten steel flow in a mold by adjusting a discharge direction of an immersion nozzle to an appropriate direction in addition to controlling the shape of the immersion nozzle, the molten steel throughput, and the flow rate of injected inert gas in appropriate ranges. In addition, a high quality slab containing a smaller amount of inclusions can be produced by adjusting the discharge direction of the immersion nozzle to an appropriate direction for various conditions for electromagnetic flow control in the mold.

Brief Description of Drawings

[0014]

[Fig. 1] Fig. 1 is a schematic sectional view of an example of a continuous casting mold viewed from a mold long side.
 [Fig. 2] Fig. 2 shows schematic sectional views of the continuous casting mold illustrating discharge flows from an immersion nozzle.

[Fig. 3] Fig. 3 is a schematic diagram illustrating the manner in which casting is performed while a discharge direction of the immersion nozzle is inclined when viewed from vertically above.

[Fig. 4] Fig. 4 is a schematic sectional view of a continuous casting mold different from that in Fig. 1.

[Fig. 5] Fig. 5 is a schematic sectional view of Fig. 4 viewed from vertically above.

[Fig. 6] Fig. 6 is a schematic sectional view of a continuous casting mold different from those in Figs. 1 and 4.

[Fig. 7] Fig. 7 shows schematic sectional views of Fig. 6 viewed from vertically above.

[Fig. 8] Fig. 8 is a schematic sectional view of a continuous casting mold different from those in Figs. 1, 4, and 6.

[Fig. 9] Fig. 9 is a schematic sectional view of Fig. 8 viewed from vertically above.

[Fig. 10] Fig. 10 is a schematic diagram illustrating the molten steel flow velocity distribution in the mold under casting conditions in which the discharge direction is perpendicular to mold short sides.

[Fig. 11] Fig. 11 is a schematic diagram illustrating the manner in which casting is performed while the discharge direction is inclined when viewed from vertically above.

[Fig. 12] Fig. 12 is a schematic sectional view of a continuous casting mold different from those in Figs. 1, 4, 6 and 8.

[Fig. 13] Fig. 13 is a schematic cross-sectional view of a part of Fig. 12 including upper magnetic poles.

[Fig. 14] Fig. 14 is a schematic cross-sectional view of a part of Fig. 12 including lower magnetic poles.

[Fig. 15] Fig. 15 is a schematic diagram illustrating the molten steel flow velocity distribution in the mold under casting conditions in which the discharge direction of the immersion nozzle is perpendicular to mold short sides.

[Fig. 16] Fig. 16 is a schematic diagram illustrating the manner in which casting is performed while the discharge direction of the immersion nozzle is inclined toward upstream sides of swirling flows when viewed from vertically above.

[Fig. 17] Fig. 17 is a flowchart of an example of a process for changing an inclination angle α of the discharge direction.

[Fig. 18] Fig. 18 is a flowchart of an example different from that in Fig. 17.

[Fig. 19] Fig. 19 is a flowchart of an example different from those in Figs. 17 and 18.

[Fig. 20] Fig. 20 is a flowchart of an example different from those in Figs. 17 to 19.

[Fig. 21] Fig. 21 is a flowchart of an example different from those in Figs. 17 to 20.

[Fig. 22] Fig. 22 is a flowchart of an example of a process in which the processes of Figs. 17 to 21 are selectively performed in response to casting conditions.

[Fig. 23] Fig. 23 is a graph showing the relationship between " α - θ " and "product defect index" of Invention Examples 19-38 divided into groups by using a static magnetic field intensity of 2500 (Gs) as a threshold.

[Fig. 24] Fig. 24 is a graph showing the relationship between " α - θ " and "product defect index" of Invention Examples 39-49.

[Fig. 25] Fig. 25 is a graph showing the relationship between " α - θ " and "product defect index" of Invention Examples 50-71 divided into groups by using a ratio X/W of 0.45 as a threshold.

[Fig. 26] Fig. 26 is a graph showing the relationship between " α - θ " and "product defect index" of Invention Examples 83-106 divided into groups by using a ratio X/W of 0.45 as a threshold.

Description of Embodiments

[0015] The present invention will be described in detail by way of embodiments of the invention. Fig. 1 illustrates an example of a continuous casting mold 20 for a slab continuous casting machine to which a continuous casting method according to the present embodiment can be applied. Fig. 1 is a sectional view of the continuous casting mold 20 viewed from a mold long side. The slab continuous casting mold 20 is formed by combining a pair of mold long sides 2 that face each other and a pair of mold short sides 3 that face each other. Continuous casting of molten steel 8 is performed by placing an immersion nozzle 4 in the inner space of the mold that is surrounded by the pair of mold long sides and the pair of mold short sides and pouring the molten steel 8 into the inner space of the mold through discharge openings 5 in the immersion nozzle 4. The discharge openings 5 are formed in a side wall of the immersion nozzle 4 so as to be vertically symmetric about the vertical axis of the immersion nozzle 4. The molten steel 8 is poured through the discharge openings 5 in the form of discharge flows toward the left and right mold short sides 3. The molten steel 8 poured into the inner space of the mold is cooled by coming into contact with the mold long sides 2 and the mold short sides 3, so that a solidifying shell 9 is formed on contact surfaces at which the molten steel 8 is in contact with the mold long sides 2 and the mold short sides 3. A slab, which includes the solidifying shell 9 as an outer shell and unsolidified molten steel

8 in the outer shell, is continuously withdrawn downward. Thus, a slab is produced. In this process, mold powder (not illustrated) that functions as a lubricant, heat insulating agent, and antioxidant is added to a molten steel surface 10 in the mold. In addition, to prevent adhesion of inclusions to the inner surface of the immersion nozzle 4, argon gas, nitrogen gas, or the like is injected between a tundish outflow opening (not illustrated) and the discharge openings 5 in the immersion nozzle 4.

[0016] The behavior of the flow in the mold under casting conditions illustrated in Fig. 1 was repeatedly studied through numerical calculations and flow velocity measurements using a water model machine whose size is equal to that of an actual machine and a test casting machine that is 1/4 the size of an actual machine and in which a low-melting-point alloy (Bi-Pb-Sn-Cd alloy having a melting point of about 70°C) is used. Quantification of conditions for making the flow in the mold appropriate was attempted by focusing attention particularly on the behavior of the discharge flows 11.

[0017] Fig. 2 shows schematic sectional views of the continuous casting mold illustrating the discharge flows from the immersion nozzle. Assume that the immersion depth of the immersion nozzle 4 (distance from the molten steel surface in the mold to the top ends of the discharge openings) is greater than or equal to 180 mm and less than 300 mm, and a downward molten-steel discharge angle of the discharge openings 5 from the horizontal direction is in the range from 15 to 35°. It has been found that, under such conditions, when the ratio A/P of a flow rate A (NL/min) of the inert gas injected between the tundish outflow opening and the discharge openings 5 in the immersion nozzle 4 to a molten steel throughput P (ton/min) is controlled to be in the range from 2.0 to 3.5 (NL/ton), the discharge flows 11 tend to flow upward toward the meniscus after reaching locations relatively close to the mold short sides, as illustrated in Fig. 2(a). In other words, it has been found that the discharge flows 11 exhibit an upward movement (lift up) when the inert gas is injected into the discharge openings 5 in the immersion nozzle 4. This shows that stable control of the behavior of the discharge flows 11 can be achieved by achieving an appropriate balance between A/P, which is the ratio of the inert gas flow rate to the molten steel throughput, the immersion depth of the immersion nozzle 4, and the discharge angle. As illustrated in Fig. 2(b), when the inert gas flow rate A is too high relative to the molten steel throughput P, the discharge flows 11 quickly flow upward due to the lift-up effect. It has been found that such a quick upward movement of the discharge flows 11 increases fluctuations of the meniscus surface and facilitates entrainment of the mold powder. It has also been found that, as illustrated in Fig. 2(c), when the inert gas flow rate A is too low relative to the molten steel throughput P, the upward movement of the discharge 11 is inhibited, and there is a risk that the discharge 11 will directly come into contact with the mold short sides 3 and cause a breakout. There is also a risk that the supply of the molten steel to the meniscus will become unstable and heat cannot be applied to the meniscus, which leads to lack of fusion of the mold powder. These findings have been confirmed under conditions in which the casting width is in the range from 1000 to 2000 (mm), the area of each discharge opening is in the range from 4000 to 10000 (mm²), and the molten steel throughput is in the range from 3.0 to 8.0 (ton/min). Therefore, the behavior of the discharge flows 11 can be stably controlled under these casting conditions.

[0018] Next, the inventors of the present invention have focused attention on the discharge direction of the discharge flows 11. As a result, it has been found that by controlling the discharge direction in an appropriate angle range toward the corners of the mold in addition to appropriately controlling the lift-up behavior of the discharge flows 11 as described above, an appropriate flow velocity can be achieved at the meniscus surface, and trapping of bubbles, fine inclusions, powder, etc., which cause surface defects, in the solidifying shell 9 can be inhibited. Thus, the surface defects can be reduced.

[0019] Fig. 3 is a schematic diagram illustrating the manner in which casting is performed while the discharge direction of the immersion nozzle is inclined when viewed from vertically above. As illustrated in Fig. 3, θ (°) is an angle (acute angle) between the straight line that passes through the vertical axial center of the immersion nozzle 4 and extends toward the contact points of the mold long sides 2 and the mold short sides 3 (corners of the mold) and a reference plane that is parallel to the mold long side surfaces and that passes through the vertical axial center of the immersion nozzle 4. Here, θ is defined by Equation (2) given below by using the thickness D (mm) of the cast slab and the width W (mm) of the cast slab (angle θ is hereinafter referred to also as "diagonal direction angle θ "). Thus, the diagonal direction angle θ varies in response to the cross-sectional dimensions of the slab.

$$\tan\theta = (D/2) / (W/2) \quad (2)$$

[0020] As illustrated in Fig. 3, when casting is performed while the discharge direction of the immersion nozzle 4 is inclined, α (°) is an inclination angle of the discharge direction of the immersion nozzle 4 with respect to the reference plane when the continuous casting mold 20 is viewed from vertically above.

[0021] The inventors of the present invention have found that a high-quality slab with less surface defects can be obtained by setting the inclination angle α with respect to the reference plane in the range of Equation (1) given below in addition to appropriately controlling the behavior of the discharge flows 11. In other words, an appropriate flow velocity

at which the causes of surface defects can be eliminated can be achieved by controlling the inclination angle α the range of Equation (1).

$$\theta - 6 \leq \alpha \leq \theta + 10 \quad (1)$$

[0022] When the inclination angle α is less than $\theta - 6$, an appropriate flow velocity cannot be achieved. When the inclination angle α is greater than $\theta + 10$, the discharge flows 11 directly come into contact with portions of the solidifying shell 9 along the long sides, and the risk of breakout increases.

[0023] Thus, by using the continuous casting method according to the present embodiment, a high-quality slab can be produced without using expensive electromagnetic flow coil equipment. In the present embodiment, it is assumed that the thickness of the slab is in the range from 220 to 300 (mm). Accordingly, the continuous casting method according to the present embodiment can be applied to slabs having a thickness in this range.

[0024] Next, the inventors of the present invention have studied optimum inclination angles α with respect to the reference plane in the cases where various methods for electromagnetic flow control in the mold are used.

[0025] Fig. 4 is a schematic sectional view of a continuous casting mold different from that described above. Fig. 5 is a schematic sectional view of Fig. 4 viewed from vertically above. A slab continuous casting mold 30 differs from the continuous casting mold 20 illustrated in Fig. 1 in that a pair of upper magnetic poles 6 and a pair of lower magnetic poles 7 are provided on back surfaces of the mold long sides 2 so as to face each other with the mold long sides 2 disposed therebetween. As illustrated in Fig. 5, the upper magnetic poles 6 and the lower magnetic poles 7 are each provided with a direct-current static magnetic field generating coil 13 that generates a direct-current static magnetic field. The direct-current static magnetic field generating coils 13 extend over a length greater than or equivalent to the width of the cast slab.

[0026] The direct-current static magnetic fields generated by the direct-current static magnetic field generating coils 13 on the upper magnetic poles 6 slow (decelerate) the molten steel flow along the molten steel surface 10 in the mold. Similarly, the direct-current static magnetic fields generated by the direct-current static magnetic field generating coils 13 on the lower magnetic poles 7 slow (decelerate) the molten steel flow of portions of the discharge flows 11 that try to flow downward beyond the position of the direct-current static magnetic field generating coils 13. The discharge openings 5 in the immersion nozzle 4 are disposed between the position at which the direct-current static magnetic fields generated by the upper magnetic poles 6 have a maximum value and the position at which the direct-current static magnetic fields generated by the lower magnetic poles 7 have a maximum value.

[0027] When electromagnetic flow control is performed as described above, entrainment of the mold powder is inhibited because the molten steel flow is slowed by the static magnetic fields. However, an appropriate flow velocity needs to be imparted to the molten steel flow to inhibit trapping of bubbles and fine inclusions in the solidifying shell 9. As a result of intensive studies, the inventors of the present invention have found that there is an appropriate inclination angle α of the discharge direction that corresponds to the intensity of the direct-current static magnetic fields generated by the upper magnetic poles 6. More specifically, it has been found that when the intensity of the direct-current static magnetic fields generated by the upper magnetic poles 6 is greater than or equal to 1500 Gs and less than 2500 Gs (Gauss; 1 Gs = 10^{-4} T), a high-quality slab can be obtained by setting the discharge direction of the immersion nozzle 4 so as to be inclined with respect to the reference plane, which passes through the vertical axial center of the immersion nozzle 4 and which is parallel to the mold long side surfaces, in the range of Equation (3). When the intensity of the direct-current static magnetic fields generated by the upper magnetic poles 6 is greater than or equal to 2500 Gs and less than 3500 Gs, a high-quality slab can be obtained by setting the discharge direction of the immersion nozzle 4 so as to be inclined in the range of Equation (4). This is because when the direct-current static magnetic fields have a relatively high intensity that is greater than or equal to 2500 Gs and less than 3500 Gs, a flow velocity that matches the slowing effect provided by the static magnetic fields can be imparted to the molten steel flow by increasing the inclination angle α as in Equation (4).

$$\theta \leq \alpha \leq \theta + 5 \quad (3)$$

$$\theta + 6 \leq \alpha \leq \theta + 10 \quad (4)$$

[0028] Fig. 6 is a schematic sectional view of a continuous casting mold different from those described above. Fig. 7 shows schematic sectional views of Fig. 6 viewed from vertically above. A slab continuous casting mold 40 differs from the continuous casting mold 20 illustrated in Fig. 1 in that a pair of linear moving magnetic field generators 42 are provided

on back surfaces of the mold long sides 2 so as to face each other with the mold long sides 2 disposed therebetween. The moving direction of the magnetic fields generated by the linear moving magnetic field generators 42 is the mold width direction. When the flow in the mold is to be controlled by applying slowing force to the discharge flows 11 discharged from the immersion nozzle 4 disposed in the mold, the moving magnetic fields are applied in directions from the mold short sides 3 toward the immersion nozzle 4, as illustrated in Fig. 7(a). When the flow in the mold is to be controlled by applying accelerating force to the discharge flows 11, the moving magnetic fields are applied in directions from the immersion nozzle 4 toward the mold short sides 3, as illustrated in Fig. 7(b). This flow control method is characterized in that the discharge flows 11 can be constantly appropriately controlled by applying a slowing force or accelerating force to the discharge flows 11. However, it has been found that, since the flow is basically vertically symmetric about the immersion nozzle 4, regions in which the flow velocity is low are generated at locations where leftward and rightward flows interfere. It has also been found that, also in this case, trapping of bubbles and fine inclusions in the solidifying shell 9 can be inhibited by setting the inclination angle α of the discharge direction of the immersion nozzle 4 with respect to the reference plane to an appropriate value. As a result of various experiments and studies, it has been found that when the method for controlling the flow in the mold is such that the moving magnetic fields are applied as described above, a high-quality slab can be obtained by setting the discharge direction of the immersion nozzle 4 so as to be inclined with respect to the reference plane, which passes through the vertical axial center of the immersion nozzle and which is parallel to the mold long side surfaces, in the range of Equation (5).

$$\theta+2 \leq \alpha \leq \theta+7 \quad (5)$$

[0029] Thus, although the flow in the mold tends to be vertically symmetric, it can be expected that an appropriate flow velocity can be imparted to the molten steel flow by setting the discharge direction of the immersion nozzle to an inclination angle that satisfies Equation (5).

[0030] Fig. 8 is a schematic sectional view of a continuous casting mold different from those described above. Fig. 9 is a schematic sectional view of Fig. 8 viewed from vertically above. A continuous casting mold 50 differs from the continuous casting mold 20 illustrated in Fig. 1 in that a pair of magnetic poles 52 are provided on back surfaces of the mold long sides 2 so as to face each other with the mold long sides 2 disposed therebetween. As illustrated in Fig. 9, the magnetic poles 52 are each provided with an alternating-current moving magnetic field generating coil 12 that generates an alternating-current moving magnetic field. The magnetic poles 52 generate alternating-current moving magnetic fields whose moving direction is the mold width direction, and the molten steel flow is controlled by causing the molten steel 8 in the mold to generate a horizontal swirling flow. Assuming that the above-described flow control method is used, an example of the flow in the mold will be described. In this example, the discharge direction of the immersion nozzle 4 is such that the molten steel is vertically symmetrically discharged toward the mold short sides 3.

[0031] Fig. 10 is a schematic diagram illustrating the molten steel flow velocity distribution in the mold under casting conditions in which the discharge direction is perpendicular to the mold short sides. In Fig. 10, reference numeral 15 denotes swirling flows that are formed by the alternating-current moving magnetic fields and rotate either clockwise or counterclockwise along or near the molten steel surface 10 in the mold; 16 denotes reverse flows that flow vertically upward after the discharge flows 11 reach portions of the solidifying shell 9 on the mold short sides 3 and then flow toward the immersion nozzle from the mold short sides along the molten steel surface 10 in the mold; 17 denotes low flow velocity regions; 18 denotes vortex flows that are generated when the swirling flows 15 and the reverse flows 16 meet; and 19 denotes downward flows that flow vertically downward after the discharge flows 11 reach the portions of the solidifying shell on the mold short sides. Although only the low flow velocity region 17 and the vortex flow 18 at one of the mold short sides are illustrated in Fig. 10, they are also generated at the other mold short side. It has been confirmed that, as illustrated in Fig. 10, the low flow velocity regions 17, in which the molten steel flow velocity is low, are generated near the mold short sides 3 in the width direction of the mold long sides 2 at the downstream sides of the swirling flows 15 formed by the alternating-current moving magnetic fields. Distributions of defects in steel products cast by a continuous casting machine under the above-described casting conditions have been studied, and it has been confirmed that the regions in which defects are formed in the steel products coincide with the locations of the low flow velocity regions 17.

[0032] As a result of various examinations, the inventors of the present invention have found that the low flow velocity regions 17 are generated when the swirling flows 15, which are formed by the alternating-current moving magnetic fields, and the reverse flows 16, which are generated when the discharge flows 11 reach the portions of the solidifying shell 9 on the short sides, meet and interfere in the regions near the mold short sides 3, and that bubbles, inclusions, etc., are trapped in the low flow velocity regions 17 and eventually form defects in the steel products. It has also been found that the vortex flows 18 are generated when the swirling flows 15 and the reverse flows 16 meet, and that the mold powder that is entrained into the vortex flows and trapped in the solidifying shell 9 may also form defects in the steel products. The inventors of the present invention have conducted intensive studies on how to solve these problems. As described

above, defects in the steel products due to trapping of inclusions, bubbles, and mold powder are caused by the low flow velocity regions 17 and the vortex flows 18, which are generated when the swirling flows 15 formed by the alternating-current moving magnetic fields and the reverse flows 16 of the discharge flows 11 meet and interfere. It has been found that also when the flow control method is such that the horizontal swirling flows 15 are formed by the alternating-current moving magnetic fields, the swirling flows 15 and the reverse flows 16 can be prevented from meeting and interfering by setting the discharge direction of the immersion nozzle 4 so as to be inclined with respect to the reference plane.

[0033] Fig. 11 is a schematic diagram illustrating the manner in which casting is performed while the discharge direction is inclined when viewed from vertically above. As a result of various flow test experiments, it has become clear that it is important to set the discharge direction of the immersion nozzle 4 so as to be inclined toward the upstream sides of the swirling flows 15 formed by the alternating-current moving magnetic fields, as illustrated in Fig. 11. The inventors of the present invention have conducted further flow test experiments and found that when the intensity of the alternating-current moving magnetic fields is in the range from 300 to 1000 Gs, a high-quality slab can be obtained by setting the discharge direction of the immersion nozzle 4 so as to be inclined with respect to the reference plane, which passes through the vertical axial center of the immersion nozzle 4 and which is parallel to the mold long side surfaces, toward the upstream sides of the swirling flows formed by the alternating-current moving magnetic fields in the range of Equation (6) when the ratio X/W (Gs/mm) of the intensity X (Gs) of the alternating-current moving magnetic fields to the width W (mm) of the continuously cast slab is greater than or equal to 0.30 and less than 0.45, and in the range of Equation (7) when the ratio X/W (Gs/mm) of the intensity X (Gs) of the alternating-current moving magnetic fields to the width W (mm) of the continuously cast slab is greater than or equal to 0.45 and less than 0.55.

$$\theta-3 \leq \alpha \leq \theta \quad (6)$$

$$\theta-6 \leq \alpha \leq \theta-4 \quad (7)$$

[0034] When direct-current static magnetic fields are applied to the molten steel 8 as illustrated in Fig. 4 or when slowing force or accelerating force is applied to the discharge flows 11 as illustrated in Fig. 6, the molten steel flow in the mold is basically vertically symmetric. Therefore, the discharge direction of the immersion nozzle 4 is preferably inclined toward the mold long sides 2 by a large amount to achieve an appropriate swirling flow velocity. In contrast, when electromagnetic flow control is performed to achieve swirling and stirring as illustrated in Fig. 8, it is sufficient to set the amount of inclination so that the reverse flows 16 and the swirling flows 15 are prevented from meeting and interfering. Therefore, the inclination angle α is preferably set to a small angle as in Equations (6) and (7). When the inclination angle α is too large, the flow velocity of the molten steel will be too high in regions near the solidifying shell 9, and there is a risk that growth of the solidifying shell 9 will be inhibited and an operation failure, such as breakout, will occur.

[0035] Fig. 12 is a schematic sectional view of a continuous casting mold 1 different from those described above. Reference numeral 1 denotes the continuous casting mold, 2 denotes mold long sides, 3 denotes mold short sides, 4 denotes an immersion nozzle, 5 denotes discharge openings in the immersion nozzle, 6 denotes upper magnetic poles, 7 denotes lower magnetic poles, 8 denotes molten steel, 9 denotes a solidifying shell, 10 denotes a molten steel surface in the mold, and 11 denotes discharge flows from the immersion nozzle.

[0036] The continuous casting mold 1 is formed by combining the pair of mold long sides 2 that face each other and the pair of mold short sides 3 that face each other. Continuous casting of the molten steel 8 is performed by placing the immersion nozzle 4 in the inner space of the mold that is surrounded by the pair of mold long sides 2 and the pair of mold short sides 3 and pouring the molten steel 8 into the inner space of the mold through the discharge openings 5 in the immersion nozzle 4. The discharge openings 5 are formed in a side wall of the immersion nozzle 4 so as to be vertically symmetric along a straight line that passes through the center of the immersion nozzle 4. The molten steel 8 is poured through the discharge openings 5 in the form of discharge flows 11 toward the left and right mold short sides 3. The molten steel 8 poured into the inner space of the mold is cooled by coming into contact with the mold long sides 2 and the mold short sides 3, so that the solidifying shell 9 is formed on contact surfaces at which the molten steel 8 is in contact with the mold long sides 2 and the mold short sides 3. A slab, which includes the solidifying shell 9 as an outer shell and unsolidified molten steel 8 in the outer shell, is continuously withdrawn downward. Thus, a slab is produced. In this process, mold powder (not illustrated) that functions as a lubricant, heat insulating agent, and antioxidant is added to the molten steel surface 10 in the mold.

[0037] Fig. 13 is a schematic cross-sectional view of a part of Fig. 12 including the upper magnetic poles. Fig. 14 is a schematic cross-sectional view of a part of Fig. 12 including the lower magnetic poles. In the continuous casting mold 1 used in the present embodiment, the pair of upper magnetic poles 6 and the pair of lower magnetic poles 7 are provided

on the back surfaces of the mold long sides 2 so as to face each other with the mold long sides 2 disposed therebetween. As illustrated in Fig. 13, the upper magnetic poles 6 are provided with alternating-current moving magnetic field generating coils 12 that generate alternating-current moving magnetic fields and direct-current static magnetic field generating coils 13 that generate direct-current static magnetic fields. As illustrated in Fig. 14, the lower magnetic poles 7 are provided with direct-current static magnetic field generating coils 14 that generate direct-current static magnetic fields. The alternating-current moving magnetic field generating coils 12, the direct-current static magnetic field generating coils 13, and the direct-current static magnetic field generating coils 14 extend over a length greater than or equivalent to the width of the cast slab.

[0038] The alternating-current moving magnetic fields generated by the alternating-current moving magnetic field generating coils 12 on the upper magnetic poles 6 generate swirling flows of the molten steel 8 that rotate in a horizontal direction in the mold. The direct-current static magnetic fields generated by the direct-current static magnetic field generating coils 13 on the upper magnetic poles 6 slow (decelerate) the molten steel flow along the molten steel surface 10 in the mold. Similarly, the direct-current static magnetic fields generated by the direct-current static magnetic field generating coils 14 on the lower magnetic poles 7 slow (decelerate) the molten steel flow of portions of the discharge flows 11 that try to flow downward beyond the position of the direct-current static magnetic field generating coils 14. The discharge openings 5 in the immersion nozzle 4 are disposed between the position at which the direct-current static magnetic fields generated by the upper magnetic poles 6 have a maximum value and the position at which the direct-current static magnetic fields generated by the lower magnetic poles 7 have a maximum value.

[0039] Fig. 15 is a schematic diagram illustrating the molten steel flow velocity distribution in the mold under casting conditions in which the discharge direction of the immersion nozzle is perpendicular to the mold short sides. By using the continuous casting mold 1 illustrated in Fig. 12, the inventors of the present invention have studied the flow in the mold under casting conditions in which direct-current static magnetic fields and alternating-current moving magnetic fields are generated in a superposed manner at the upper magnetic poles 6, direct-current static magnetic fields are generated at the lower magnetic poles 7, and the discharge direction of the discharge openings 5 in the immersion nozzle 4 is parallel to the mold long side surfaces so that the discharge flows 11 are perpendicular to the mold short sides 3.

[0040] The flow velocity distribution in the mold under the above-described casting conditions was repeatedly studied through numerical calculations and flow velocity measurements using a test casting machine that is 1/4 the size of an actual machine and in which a low-melting-point alloy (Bi-Pb-Sn-Cd alloy having a melting point of about 70°C) is used. As a result, it has been confirmed that, as illustrated in Fig. 15, low flow velocity regions 17, in which the molten steel flow velocity is low, are generated near the mold short sides 3 in the width direction of the mold long sides 2 at the downstream sides of swirling flows 15 formed by the alternating-current moving magnetic fields. In Fig. 15, reference numeral 15 denotes the swirling flows that are formed by the alternating-current moving magnetic fields and rotate either clockwise or counterclockwise along or near the molten steel surface 10 in the mold; 16 denotes reverse flows that flow vertically upward after the discharge flows 11 reach portions of the solidifying shell on the mold short sides and then flow toward the immersion nozzle from the mold short sides along the molten steel surface 10 in the mold; 17 denotes the low flow velocity regions; 18 denotes vortex flows that are generated when the swirling flows 15 and the reverse flows 16 meet; and 19 denotes downward flows that flow vertically downward after the discharge flows 11 reach the portions of the solidifying shell on the mold short sides. Although only the low flow velocity region 17 and the vortex flow 18 at one of the mold short sides are illustrated in Fig. 15, they are also generated at the other mold short side.

[0041] Distributions of defects in steel products cast by an actual continuous casting machine under the above-described casting conditions have been studied, and it has been confirmed that the regions in which defects are formed in the steel products coincide with the locations of the low flow velocity regions 17.

[0042] As a result of various examinations, the inventors of the present invention have found that the low flow velocity regions 17 are generated when the swirling flows 15, which are formed by the alternating-current moving magnetic fields, and the reverse flows 16, which are formed after the discharge flows 11 from the discharge openings 5 reach the short-side portions of the solidifying shell, meet and interfere in the regions near the mold short sides, and that bubbles, inclusions, etc., are trapped in the low flow velocity regions 17 and eventually form defects in the steel products. It has also been found that the vortex flows 18 are generated when the swirling flows 15 and the reverse flows 16 meet, and that the mold powder that is entrained into the vortex flows 18 and trapped in the solidifying shell may also form defects in the steel products.

[0043] The inventors of the present invention have conducted intensive studies on how to solve the above-described problems. As described above, defects in the steel products due to trapping of inclusions, bubbles, and mold powder are caused by the low flow velocity regions 17 and the vortex flows 18 generated when the swirling flows 15 formed by the alternating-current moving magnetic fields and the reverse flows 16 of the discharge flows 11 from the discharge openings 5 meet and interfere. Accordingly, the inventors of the present invention have studied a method for preventing the swirling flows 15 and the reverse flows 16 from meeting and interfering. As a result, it has been found that it is effective to shift the discharge direction of the discharge flows 11 from the immersion nozzle 4 from the direction perpendicular to the mold short sides 3.

[0044] The discharge openings 5 in the immersion nozzle 4 are normally arranged so as to face in a direction parallel to the mold long side surfaces so that the molten steel 8 is discharged toward the mold short side surfaces. Thus, vertical symmetry of the flow of the molten steel in the mold is maintained. However, under the conditions in which the swirling flows 15 of the molten steel 8 are generated in the mold by the alternating-current moving magnetic fields as in the present invention, it is probably preferable in terms of principle that the discharge direction of the discharge openings 5 in the immersion nozzle 4 be determined in consideration of axial symmetry about the immersion nozzle 4 rather than maintaining vertical symmetry in the mold.

[0045] Fig. 16 is a schematic diagram illustrating the manner in which casting is performed while the discharge direction of the immersion nozzle is inclined toward the upstream sides of the swirling flows when viewed from vertically above. The discharge direction of the immersion nozzle 4 has been studied under various conditions through numerical analyses and by using a test casting machine in which a low-melting-point alloy is used. As a result, it has been found that, when the intensity of the alternating-current moving magnetic fields at the upper magnetic poles 6 is in the range from 500 to 900 (Gs), the intensity of the direct-current static magnetic fields at the upper magnetic poles 6 is in the range from 2000 to 3300 (Gs), the intensity of the direct-current static magnetic fields at the lower magnetic poles 7 is in the range from 3000 to 4500 (Gs), and the ratio X/W (Gs/mm) of the intensity X (Gs) of the alternating-current moving magnetic fields at the upper magnetic poles 6 to the width W (mm) of the continuously cast slab is greater than or equal to 0.30 and less than 0.55, the swirling flows 15 and the reverse flows 16 can be prevented from meeting and interfering by setting the discharge direction of the immersion nozzle 4 so as to be inclined toward the upstream sides of the swirling flows 15 formed by the alternating-current moving magnetic fields, as illustrated in Fig. 16. Accordingly, the low flow velocity regions 17 and the vortex flows 18 are not generated, and the molten steel appropriately flows in the mold.

[0046] When the ratio X/W is less than 0.30, the flow velocity of the swirling flows 15 is too low relative to the width of the slab, and sufficient effects cannot be obtained even when the discharge direction of the immersion nozzle 4 is inclined. When the ratio X/W is greater than or equal to 0.55, the flow velocity of the swirling flows 15 is sufficiently high relative to the width of the slab, and problems such as generation of the low flow velocity regions 17 due to interference between the swirling flows 15 and the reverse flows 16 can be reduced. Accordingly, the effects of setting the discharge direction of the immersion nozzle 4 so as to be inclined are probably reduced. Also, it is not preferable to excessively increase the ratio X/W because the swirling flows 15 will be too strong and there is a risk that entrainment of the mold powder will occur and that defects will be formed due to the entrained mold powder. Furthermore, when the discharge direction is inclined while the flow velocity of the swirling flows 15 is sufficiently high, the swirling flows 15 may be too strong and the thickness of the solidifying shell 9 may be reduced. This is not preferable because there is a risk that the operational stability will be degraded due to, for example, breakout.

[0047] The inventors of the present invention have conducted intensive studies and experiments, and found the optimum discharge direction in relation to the ratio X/W of the intensity X (Gs) of the alternating-current moving magnetic fields to the width W (mm) of the cast slab.

[0048] It has been found that when the ratio X/W (Gs/mm) of the intensity X of the alternating-current moving magnetic fields to the width W of the slab is greater than or equal to 0.30 and less than 0.45, the inclination angle α of the discharge direction with respect to the reference plane, which passes through the vertical axial center of the immersion nozzle 4 and which is parallel to the mold long side surfaces, is preferably in the range of Equation (8) given below. This is probably because since the intensity X of the alternating-current moving magnetic fields is small relative to the width W of the slab, the swirling flows 15 and the reverse flows 16 need to be more positively prevented from meeting and interfering at the downstream sides of the swirling flows 15 by increasing the inclination angle α .

$$\theta-2 \leq \alpha \leq \theta+5 \quad (8)$$

[0049] It has also been found that when the ratio X/W (Gs/mm) is greater than or equal to 0.45 and less than 0.55, the inclination angle α of the discharge direction with respect to the reference plane, which passes through the vertical axial center of the immersion nozzle 4 and which is parallel to the mold long side surfaces, is preferably in the range of Equation (9) given below. This is because since the intensity X of the alternating-current moving magnetic fields is large relative to the width W of the slab, by setting the inclination angle α of the discharge direction to a small angle, the swirling flows 15 and the reverse flows 16 can be prevented from meeting and interfering at the downstream sides of the swirling flows 15 and the risk that the operational stability will be degraded due to, for example, breakout as described above can be reduced.

$$\theta-5 \leq \alpha \leq \theta+2 \quad (9)$$

[0050] The inclination angle α of the discharge direction of the immersion nozzle 4 may be set either before starting continuous casting or during continuous casting by using a device capable of changing the inclination angle α of the discharge direction. The effects can be enhanced by measuring α and θ every time the casting conditions, such as the mold width, are changed during continuous casting and changing the discharge direction of the immersion nozzle 4 by using the device so that the inclination angle α satisfy the magnitude relationship between α and θ expressed in Equations (1) and (3) to (9).

[0051] Fig. 17 is a flowchart of an example of a process for changing the inclination angle α of the discharge direction. The process for changing the inclination angle α of the discharge direction of the immersion nozzle 4 will be described with reference to Fig. 17. At predetermined time intervals, it is determined whether or not the immersion depth of the immersion nozzle 4 is greater than or equal to 180 mm and less than 300 mm, the downward molten-steel discharge angle of the discharge openings from the horizontal direction is in the range from 15 to 35°, and the ratio A/P of the flow rate A (NL/min) of the inert gas injected between the tundish outflow opening and the discharge openings to the molten steel throughput P (ton/min) is in the range from 2.0 to 3.5 NL/ton. When these conditions are met, the process illustrated in Fig. 17 is started. This process can be performed by using a device including a driving mechanism capable of changing the discharge direction (hereinafter referred to as "angle adjusting device"), such as a device disclosed in Patent Literature 2. In the present embodiment, it is assumed that the angle adjusting device is the subject that changes the inclination angle α of the discharge direction.

[0052] In the process illustrated in Fig. 17, the angle adjusting device determines whether or not steady casting is being performed by the continuous casting apparatus (Step S101). In the present embodiment, the state in which steady casting is being performed is the state in which casting is being performed without changing any of the casting speed, the mold width, the flow rate of the inert gas, and the immersion depth of the immersion nozzle 4.

[0053] The angle adjusting device ends the process illustrated in Fig. 17 when it is determined that steady casting is not being performed by the continuous casting apparatus (Step S101: No). When steady casting is being performed by the continuous casting apparatus (Step S101: Yes), the angle adjusting device measures the inclination angle α and θ , and determines whether or not the inclination angle α satisfies Equation (1) (Step S102). When it is determined that the inclination angle α satisfies Equation (1) (Step S102: Yes), the angle adjusting device ends the process illustrated in Fig. 17. When it is determined that the inclination angle α does not satisfy Equation (1) (Step S102: No), the angle adjusting device resets the inclination angle α to an angle that satisfies Equation (1) (Step S103). The angle adjusting device changes the discharge direction of the immersion nozzle 4 to the reset inclination angle α (Step S104), and ends the process illustrated in Fig. 17.

[0054] Thus, the angle adjusting device is capable of changing the discharge direction of the immersion nozzle 4 so that the inclination angle α satisfies Equation (1) at predetermined time intervals by performing the process illustrated in Fig. 17. Therefore, even when the inclination angle α is changed to an angle that does not satisfy Equation (1) for some reason, the angle adjusting device changes the discharge direction of the immersion nozzle 4 so that the inclination angle α satisfies Equation (1). Thus, continuous production of a slab containing inclusions can be prevented.

[0055] Fig. 18 is a flowchart illustrating an example different from the above-described example. Another process for changing the inclination angle α of the discharge direction of the immersion nozzle 4 will be described with reference to Fig. 18. Provided that the conditions for starting the process illustrated in Fig. 17 are met, the process illustrated in Fig. 18 is performed when the pair of upper magnetic poles 6 and the pair of lower magnetic poles 7 are provided on the back surfaces of the mold long sides 2 so as to face each other with the mold long sides disposed therebetween, when the discharge openings are disposed between the position at which the direct-current static magnetic fields generated by the upper magnetic poles 6 have a maximum value and the position at which the direct-current static magnetic fields generated by the lower magnetic poles 7 have a maximum value, and when the intensity of the static magnetic fields is greater than or equal to 1500 Gs and less than 3500 Gs.

[0056] In the process illustrated in Fig. 18, the angle adjusting device determines whether or not steady casting is being performed by the continuous casting apparatus (Step S201). The angle adjusting device ends the process illustrated in Fig. 18 when it is determined that steady casting is not being performed by the continuous casting apparatus (Step S201: No). When steady casting is being performed by the continuous casting apparatus (Step S201: Yes), the angle adjusting device determines whether or not the intensity of the direct-current static magnetic fields is in the range of 1500 ≤ Gs < 2500 (Step S202). When it is determined that the intensity of the direct-current static magnetic fields is in the range of 1500 ≤ Gs < 2500 (Step S202: Yes), the angle adjusting device measures the inclination angle α and θ , and determines whether or not the inclination angle α satisfies Equation (3) (Step S203).

[0057] When it is determined that the inclination angle α satisfies Equation (3) (Step S203: Yes), the angle adjusting device ends the process illustrated in Fig. 18. When it is determined that the inclination angle α does not satisfy Equation (3) (Step S203: No), the angle adjusting device resets the inclination angle α to an angle that satisfies Equation (3) (Step S204). The angle adjusting device changes the discharge direction of the immersion nozzle 4 to the reset inclination angle α (Step S205), and ends the process illustrated in Fig. 18.

[0058] When it is determined that the intensity of the direct-current static magnetic fields is not in the range of 1500 ≤

Gs < 2500 but in the range of $2500 \leq G_s < 3500$ (Step S202: No), the angle adjusting device measures the inclination angle α and θ , and determines whether or not the inclination angle α satisfies Equation (4) (Step S206). When it is determined that the inclination angle α satisfies Equation (4) (Step S206: Yes), the angle adjusting device ends the process illustrated in Fig. 18. When it is determined that the inclination angle α does not satisfy Equation (4) (Step S206: No), the angle adjusting device resets the inclination angle α to an angle that satisfies Equation (4) (Step S207). The angle adjusting device changes the discharge direction of the immersion nozzle 4 to the reset inclination angle α (Step S208), and ends the process illustrated in Fig. 18.

[0059] Fig. 19 is a flowchart illustrating an example different from the above-described examples. Another process for changing the inclination angle α of the discharge direction of the immersion nozzle 4 will be described with reference to Fig. 19. Provided that the conditions for starting the process illustrated in Fig. 17 are met, the process illustrated in Fig. 19 is performed when the linear moving magnetic field generators 42, which generate magnetic fields whose moving direction is the mold width direction, are provided.

[0060] In the process illustrated in Fig. 19, the angle adjusting device determines whether or not steady casting is being performed by the continuous casting apparatus (Step S301). The angle adjusting device ends the process illustrated in Fig. 19 when it is determined that steady casting is not being performed by the continuous casting apparatus (Step S301: No). When steady casting is being performed by the continuous casting apparatus (Step S301: Yes), the angle adjusting device measures the inclination angle α and θ , and determines whether or not the inclination angle α satisfies Equation (5) (Step S302). When it is determined that the inclination angle α satisfies Equation (5) (Step S302: Yes), the angle adjusting device ends the process illustrated in Fig. 19. When it is determined that the inclination angle α does not satisfy Equation (5) (Step S302: No), the angle adjusting device resets the inclination angle α to an angle that satisfies Equation (5) (Step S303). The angle adjusting device changes the discharge direction of the immersion nozzle 4 to the reset inclination angle α (Step S304), and ends the process illustrated in Fig. 19.

[0061] Fig. 20 is a flowchart illustrating an example different from the above-described examples. Another process for changing the inclination angle α of the discharge direction of the immersion nozzle 4 will be described with reference to Fig. 20. Provided that the conditions for starting the process illustrated in Fig. 17 are met, the process illustrated in Fig. 20 is performed when the pair of magnetic poles 52 are provided on the back surfaces of the mold long sides 2, when alternating-current moving magnetic fields having an intensity in the range from 300 to 1000 Gs are generated by the magnetic poles, and when the ratio X/W of the intensity of the alternating-current moving magnetic fields to the width of the slab is greater than or equal to 0.30 and less than 0.55.

[0062] In the process illustrated in Fig. 20, the angle adjusting device determines whether or not steady casting is being performed by the continuous casting apparatus (Step S401). The angle adjusting device ends the process illustrated in Fig. 20 when it is determined that steady casting is not being performed by the continuous casting apparatus (Step S401: No). When steady casting is being performed by the continuous casting apparatus (Step S401: Yes), the angle adjusting device determines whether or not the ratio X/W is greater than or equal to 0.30 and less than 0.45 (Step S402). When it is determined that the ratio X/W is greater than or equal to 0.30 and less than 0.45 (Step S402: Yes), the angle adjusting device measures the inclination angle α and θ , and determines whether or not the inclination angle α satisfies Equation (6) (Step S403).

[0063] When it is determined that the inclination angle α satisfies Equation (6) (Step S403: Yes), the angle adjusting device ends the process illustrated in Fig. 20. When it is determined that the inclination angle α does not satisfy Equation (6) (Step S403: No), the angle adjusting device resets the inclination angle α to an angle that satisfies Equation (6) (Step S404). The angle adjusting device changes the discharge direction of the immersion nozzle 4 to the reset inclination angle α (Step S405), and ends the process illustrated in Fig. 20.

[0064] When it is determined that the ratio X/W is not greater than or equal to 0.30 and less than 0.45, but is greater than or equal to 0.45 and less than 0.55 (Step S402: No), the angle adjusting device measures the inclination angle α and θ , and determines whether or not the inclination angle α satisfies Equation (7) (Step S406).

[0065] When it is determined that the inclination angle α satisfies Equation (7) (Step S406: Yes), the angle adjusting device ends the process illustrated in Fig. 20. When it is determined that the inclination angle α does not satisfy Equation (7) (Step S406: No), the angle adjusting device resets the inclination angle α to an angle that satisfies Equation (7) (Step S407). The angle adjusting device changes the discharge direction of the immersion nozzle 4 to the reset inclination angle α (Step S408), and ends the process illustrated in Fig. 20.

[0066] Fig. 21 is a flowchart illustrating an example different from the above-described examples. Another process for changing the inclination angle α of the discharge direction of the immersion nozzle 4 will be described with reference to Fig. 21. Provided that the conditions for starting the process illustrated in Fig. 17 are met, the process illustrated in Fig. 21 is performed when the pair of upper magnetic poles 6 and the pair of lower magnetic poles 7 are provided on the back surfaces of the mold long sides so as to face each other with the mold long sides disposed therebetween, when the discharge openings are disposed between the position at which the direct-current static magnetic fields generated by the upper magnetic poles 6 have a maximum value and the position at which the direct-current static magnetic fields generated by the lower magnetic poles 7 have a maximum value, when alternating-current moving magnetic fields having

an intensity in the range from 500 to 900 Gs and direct-current static magnetic fields having an intensity in the range from 2000 to 3300 Gs are generated in a superposed manner by the upper magnetic poles 6, when direct-current static magnetic fields having an intensity in the range from 3000 to 4500 Gs are generated by the lower magnetic poles 7, and when the ratio X/W of the intensity of the alternating-current moving magnetic fields to the width of the slab is greater than or equal to 0.30 and less than 0.55.

[0067] In the process illustrated in Fig. 21, the angle adjusting device determines whether or not steady casting is being performed by the continuous casting apparatus (Step S501). The angle adjusting device ends the process illustrated in Fig. 21 when it is determined that steady casting is not being performed by the continuous casting apparatus (Step S501: No). When steady casting is being performed by the continuous casting apparatus (Step S501: Yes), the angle adjusting device determines whether or not the ratio X/W is greater than or equal to 0.30 and less than 0.45 (Step S502). When it is determined that the ratio X/W is greater than or equal to 0.30 and less than 0.45 (Step S502: Yes), the angle adjusting device measures the inclination angle α and θ , and determines whether or not the inclination angle α satisfies Equation (8) (Step S503).

[0068] When it is determined that the inclination angle α satisfies Equation (8) (Step S503: Yes), the angle adjusting device ends the process illustrated in Fig. 21. When it is determined that the inclination angle α does not satisfy Equation (8) (Step S503: No), the angle adjusting device resets the inclination angle α to an angle that satisfies Equation (8) (Step S504). The angle adjusting device changes the discharge direction of the immersion nozzle 4 to the reset inclination angle α (Step S505), and ends the process illustrated in Fig. 21.

[0069] When it is determined that the ratio X/W is not greater than or equal to 0.30 and less than 0.45, but is greater than or equal to 0.45 and less than 0.55 (Step S502: No), the angle adjusting device measures the inclination angle α and θ , and determines whether or not the inclination angle α satisfies Equation (9) (Step S506).

[0070] When it is determined that the inclination angle α satisfies Equation (9) (Step S506: Yes), the angle adjusting device ends the process illustrated in Fig. 21. When it is determined that the inclination angle α does not satisfy Equation (9) (Step S506: No), the angle adjusting device resets the inclination angle α to an angle that satisfies Equation (9) (Step S507). The angle adjusting device changes the discharge direction of the immersion nozzle 4 to the reset inclination angle α (Step S508), and ends the process illustrated in Fig. 21.

[0071] Fig. 22 is a flowchart of an example of a process performed when the processes of Figs. 17 to 21 are selectively performed depending on the casting conditions. In the example illustrated in Fig. 22, the angle adjusting device checks the casting conditions at predetermined time intervals, and selectively performs the processes of Figs. 17 to 21 depending on the casting conditions. The angle adjusting device performs the process for changing the inclination angle α of the discharge direction illustrated in Fig. 17 when only condition A is satisfied. Condition A is a condition that the immersion depth of the immersion nozzle 4 is greater than or equal to 180 mm and less than 300 mm, the downward molten-steel discharge angle of the discharge openings from the horizontal direction is in the range from 15 to 35°, and the ratio A/P of the flow rate A (NL/min) of the inert gas injected between the tundish outflow opening and the discharge openings to the molten steel throughput P (ton/min) is in the range from 2.0 to 3.5 NL/ton.

[0072] The angle adjusting device performs the process for changing the inclination angle α of the discharge direction illustrated in Fig. 18 when Condition B is satisfied in addition to Condition A. Condition B is a condition that the pair of upper magnetic poles 6 and the pair of lower magnetic poles 7 are provided on the back surfaces of the mold long sides so as to face each other with the mold long sides disposed therebetween, the discharge openings are disposed between the position at which the direct-current static magnetic fields generated by the upper magnetic poles 6 have a maximum value and the position at which the direct-current static magnetic fields generated by the lower magnetic poles 7 have a maximum value, and the intensity of the static magnetic fields is greater than or equal to 1500 Gs and less than 3500 Gs.

[0073] The angle adjusting device performs the process for changing the inclination angle α of the discharge direction illustrated in Fig. 19 when Condition C is satisfied in addition to Condition A. Condition C is a condition that the linear moving magnetic field generators 42, which generate magnetic fields whose moving direction is the mold width direction, are provided.

[0074] The angle adjusting device performs the process for changing the inclination angle α of the discharge direction illustrated in Fig. 20 when Condition D is satisfied in addition to Condition A. Condition D is a condition that the pair of magnetic poles 52 are provided on the back surfaces of the long sides, alternating-current moving magnetic fields having an intensity in the range from 300 to 1000 Gs are generated by the magnetic poles 52, and the ratio X/W of the intensity of the alternating-current moving magnetic fields to the width of the slab is greater than or equal to 0.30 and less than 0.55.

[0075] The angle adjusting device performs the process for changing the inclination angle α of the discharge direction illustrated in Fig. 21 when Condition E is satisfied in addition to Condition A. Condition E is a condition that the pair of upper magnetic poles 6 and the pair of lower magnetic poles 7 are provided on the back surfaces of the mold long sides so as to face each other with the mold long sides disposed therebetween, the discharge openings are disposed between the position at which the direct-current static magnetic fields generated by the upper magnetic poles 6 have a maximum value and the position at which the direct-current static magnetic fields generated by the lower magnetic poles 7 have a maximum value, alternating-current moving magnetic fields having an intensity in the range from 500 to 900 Gs and

direct-current static magnetic fields having an intensity in the range from 2000 to 3300 Gs are generated in a superposed manner by the upper magnetic poles 6, direct-current static magnetic fields having an intensity in the range from 3000 to 4500 Gs are generated by the lower magnetic poles 7, and the ratio X/W of the intensity of the alternating-current moving magnetic fields to the width of the slab is greater than or equal to 0.30 and less than 0.55.

[0076] Thus, in the present embodiment, the angle adjusting device performs a process for changing the inclination angle α at predetermined time intervals, the process corresponding to the casting conditions. When it is determined that the inclination angle α does not satisfy one of Equations (1) and (3) to (9) that corresponds to the casting conditions, the angle adjusting device changes the discharge direction of the immersion nozzle 4 so that the corresponding equation is satisfied. Therefore, even when the inclination angle α is changed to an angle that does not satisfy the corresponding one of Equations (3) to (9) for some reason, the angle adjusting device changes the discharge direction of the immersion nozzle 4 so that the equation is satisfied. Thus, continuous production of a slab containing inclusions can be prevented.

[0077] As described above, according to the continuous casting method of the present embodiment, the intensities of the direct-current static magnetic fields generated by the upper magnetic poles and the lower magnetic poles and the intensity of the alternating-current moving magnetic fields are set so as to be in optimum ranges, and the discharge direction of the immersion nozzle is inclined toward the upstream sides of the swirling flows formed by the alternating-current moving magnetic fields. Accordingly, the occurrence of the low flow velocity regions and the vortex flows, which are generated when the swirling flows and the reverse flows meet and interfere, can be avoided and a high-quality slab in which the small amount of inclusions is reduced can be produced.

Example 1

[0078] A test of casting about 300 (ton) of molten aluminum killed steel was performed by using a slab continuous casting machine with the continuous casting mold 20 illustrated in Fig. 1. The cast slab had a thickness of 250 (mm) and a width of 1000 to 2000 (mm), and the molten steel injection flow rate was 3.0 to 8.0 (ton/min). The molten-steel discharge angle of the discharge openings in a two-opening immersion nozzle used in the test (angle of a horizontal direction is zero) was 15 (°) downward. The immersion depth of the immersion nozzle (distance from the molten steel surface in the mold to the top ends of the discharge openings) was greater than or equal to 180 (mm) and less than 300 (mm). The discharge openings in the immersion nozzle were 80 (mm) square in shape, and the inner diameter of the immersion nozzle was 80 (mm). Argon gas was used as inert gas injected through the immersion nozzle. The discharge direction of the discharge flows from the immersion nozzle was set to one of two directions: a direction parallel to the mold long sides (direction perpendicular to the mold short sides) and a direction inclined with respect to the reference plane.

[0079] The cast slab was successively subjected to hot rolling, cold rolling, and hot-dip galvanization, and surface defects on the hot-dip galvanized steel sheet were continuously measured by using an online surface inspection system. Among the defects, steelmaking defects (defects due to inclusions in the slab) were detected by observing the appearance of the defects and performing SEM analysis, ICP analysis, or the like, and evaluated based on the number of defects per 100 (m) of the hot-dip galvanized steel sheet (hereinafter referred to as "product defect index"). Table 1 shows the casting conditions and the results of the test for determining the product defect index of Invention Examples 1-18 and Comparative Examples 1-18.

[Table 1]

	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ	Molten Steel Throughput P	Argon Flow Rate A (NL/min)	A/P (NL/ton)	Discharge Opening Inclination Angle α (°)	$\alpha-\theta$ (°)	Product Defect Index (per 100 m)
Invention Example 1	250	2000	7.1	5.8	15.0	2.6	7.0	0	0.27
Invention Example 2	250	2000	7.1	6.9	15.0	2.2	12.0	5	0.28
Invention Example 3	250	2000	7.1	7.7	18.0	2.3	17.0	10	0.26
Invention Example 4	250	1800	7.9	4.9	17.0	3.5	15.0	7	0.29
Invention Example 5	250	1800	7.9	5.9	17.0	2.9	8.0	0	0.28
Invention Example 6	250	1800	7.9	8.0	17.0	2.1	2.0	-6	0.27
Invention Example 7	250	1600	8.9	3.1	10.0	3.2	3.0	-6	0.26
Invention Example 8	250	1600	8.9	4.6	13.0	2.8	12.0	3	0.28
Invention Example 9	250	1600	8.9	6.2	12.5	2.0	18.0	9	0.28
Invention Example 10	250	1400	10.1	3.0	10.5	3.5	5.0	-5	0.29
Invention Example 11	250	1400	10.1	4.6	10.0	2.2	10.0	0	0.27
Invention Example 12	250	1400	10.1	7.0	18.0	2.6	15.0	5	0.28
Invention Example 13	250	1200	11.8	3.5	12.0	3.4	20.0	8	0.27
Invention Example 14	250	1200	11.8	4.6	12.0	2.6	13.0	1	0.29

(continued)

	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ	Molten Steel Throughput P	Argon Flow Rate A (NL/min)	A/P (NL/ton)	Discharge Opening Inclination Angle α (°)	$\alpha-\theta$ (°)	Product Defect Index (per 100 m)
Invention Example 15	250	1200	11.8	5.8	11.5	2.0	6.0	-6	0.29
Invention Example 16	250	1000	14.1	3.9	13.0	3.3	9.0	-5	0.27
Invention Example 17	250	1000	14.1	4.8	13.0	2.7	13.0	-1	0.26
Invention Example 18	250	1000	14.1	5.8	13.0	2.2	18.0	4	0.28
Comparative Example 1	250	2000	7.1	6.9	15.0	2.2	0.0	-7	0.63
Comparative Example 2	250	1800	7.9	5.9	17.0	2.9	0.0	-8	0.61
Comparative Example 3	250	1600	8.9	4.6	13.0	2.8	0.0	-9	0.65
Comparative Example 4	250	1400	10.1	4.6	10.0	2.2	0.0	-10	0.68
Comparative Example 5	250	1200	11.8	4.6	12.0	2.6	0.0	-12	0.63
Comparative Example 6	250	1000	14.1	3.9	13.0	3.3	0.0	-14	0.61
Comparative Example 7	250	1400	10.1	4.6	10.0	2.2	3.0	-7	0.63
Comparative Example 8	250	1200	11.8	4.6	12.0	2.6	4.0	-8	0.65
Comparative Example 9	250	1000	14.1	3.9	13.0	3.3	7.0	-7	0.67
Comparative Example 10	250	2000	7.1	6.9	15.0	2.2	18.0	11	0.28

(continued)

	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ	Molten Steel Throughput P	Argon Flow Rate A (NL/min)	A/P (NL/ton)	Discharge Opening Inclination Angle α (°)	$\alpha-\theta$ (°)	Product Defect Index (per 100 m)
Comparative Example 11	250	1600	8.9	4.6	13.0	2.8	20.0	11	0.27
Comparative Example 12	250	1200	11.8	4.6	12.0	2.6	23.0	11	0.29
Comparative Example 13	250	1800	7.9	5.9	10.0	1.7	8.0	0	0.61
Comparative Example 14	250	1400	10.1	4.6	8.0	1.7	10.0	0	0.61
Comparative Example 15	250	1000	14.1	3.9	7.0	1.8	14.0	0	0.64
Comparative Example 16	250	1800	7.9	5.9	21.0	3.6	8.0	0	0.67
Comparative Example 17	250	1400	10.1	4.6	17.0	3.7	10.0	0	0.68
Comparative Example 18	250	1000	14.1	3.9	15.0	3.8	14.0	0	0.65

[0080] Table 1 shows the diagonal direction angle θ calculated from the thickness D of the cast slab and the width W of the slab and the inclination angle α of the discharge flows during casting. The diagonal direction angle θ is rounded off to one decimal place. The value of " $\alpha-\theta$ " is rounded off to an integer.

[0081] Invention Examples 1-18 show that the product defect index may be reduced to 0.26 to 0.29 (per 100 m) by setting " $\alpha-\theta$ " in the range from -6 to 10 ($^{\circ}$) in addition to setting the ratio A/P of the flow rate of the argon gas to the molten steel throughput in the range from 2.0 to 3.5 (NL/ton). In other words, it has been found that an appropriate flow velocity can be imparted to the molten steel flow and the product defect index can be reduced by setting the inclination angle α ($^{\circ}$) in the range of greater than or equal to " $\theta-6$ " and less than or equal to " $\theta+10$ ".

[0082] In contrast, in Comparative Examples 1-6, the product defect index is increased to 0.61 to 0.68 (per 100 m) because the discharge direction is not inclined. In Comparative Examples 7-9, the inclination angle α is smaller than those in Invention Examples 1-18. In this case, the product defect index is increased to 0.63 to 0.67 (per 100 m). This is probably because an appropriate flow velocity cannot be imparted to the molten steel flow since the inclination angle α is small.

[0083] In Comparative Examples 10-12, the inclination angle α is greater than those in Invention Examples 1-18. In this case, the product defect index is reduced to 0.27 to 0.29 (per 100 m). However, the results of cross-sectional examination of the slabs showed that there were regions in which the shell growth thickness in the mold was small. Accordingly, there was a risk that the operational stability will be degraded due to, for example, breakout.

[0084] In Comparative Examples 13-18, the ratio A/P of the argon gas flow rate A to the molten steel throughput P is outside the range from 2.0 to 3.5 (NL/ton). In this case, the product defect index is increased to 0.61 to 0.68 (per 100 m). This is probably because the effects of setting the discharge direction so as to be inclined cannot be obtained since the discharge flows cannot be controlled.

[0085] Although not illustrated in the present example, it has also been confirmed that effects similar to those described in the present example can be obtained when the thickness of the cast slab is in the range from 220 to 300 (mm). It has also been confirmed that a similar tendency can be observed when the molten-steel discharge angle of the immersion nozzle is in the range from 15 to 35 ($^{\circ}$). The shape of the discharge openings in the immersion nozzle and the inner diameter of the immersion nozzle are not limited to those described in the present example, and may be any shape and diameter as long as they are within ranges conceivable by a person skilled in the art.

Example 2

[0086] A test of casting about 300 (ton) of molten aluminum killed steel was performed by using a slab continuous casting machine with the continuous casting mold 30 including the upper magnetic poles 6 and the lower magnetic poles 7 illustrated in Fig. 4. The cast slab had a thickness of 250 (mm) and a width of 1800 (mm), and the molten steel injection flow rate was 5.0 to 8.0 (ton/min). The discharge angle of the discharge openings in a two-opening immersion nozzle used in the test was 15 ($^{\circ}$) downward. The immersion depth of the immersion nozzle (distance from the molten steel surface in the mold to the top ends of the discharge openings) was greater than or equal to 180 (mm) and less than 300 (mm). The discharge openings in the immersion nozzle were 80 (mm) square in shape, and the inner diameter of the immersion nozzle was 80 (mm). Argon gas was used as inert gas injected through the immersion nozzle. The ratio A/P of the argon gas flow rate A to the molten steel throughput P was set in the range from 2.0 to 3.5 (NL/ton).

[0087] The discharge direction of the discharge flows from the immersion nozzle was set to one of two directions: a direction parallel to the mold long sides (direction perpendicular to the mold short sides) and a direction inclined with respect to the reference plane.

[0088] The cast slab was successively subjected to hot rolling, cold rolling, and hot-dip galvanization, and surface defects on the hot-dip galvanized steel sheet were continuously measured by using an online surface inspection system. Among the defects, steelmaking defects (defects due to inclusions in the slab) were detected by observing the appearance of the defects and performing SEM analysis, ICP analysis, or the like, and evaluated based on the number of defects per 100 (m) of the hot-dip galvanized steel sheet (hereinafter referred to as "product defect index"). Table 2 shows the casting conditions and the results of the test for determining the product defect index of Invention Examples 19-38 and Comparative Examples 19-32. Also in Table 2, the diagonal direction angle θ is rounded off to one decimal place, and the value of " $\alpha-\theta$ " is rounded off to an integer. Fig. 23 is a graph showing the relationship between " $\alpha-\theta$ " and "product defect index" of Invention Examples 19-38 divided into groups by using a static magnetic field intensity of 2500 (Gs) as a threshold.

[Table 2]

	Slab Thickness D(mm)	Slab Width W (mm)	Diagonal Direction Angle θ (°)	Molten Steel Throughput P	Argon Flow Rate A (NL/min)	A/P (NL/ton)	Discharge Opening Inclination Angle α (°)	α - θ (°)	Upper Magnetic Pole Direct-Current Static Magnetic Field (Gs)	Lower Magnetic Pole Direct-Current Static Magnetic Field (Gs)	Product Defect Index (per 100 m)
Invention Example 19	250	1800	7.9	5.8	15.0	2.6	8.0	0	1500	1500	0.21
Invention Example 20	250	1800	7.9	6.9	15.0	2.2	12.0	4	1800	1800	0.22
Invention Example 21	250	1800	7.9	7.7	18.0	2.3	10.0	2	2000	2000	0.23
Invention Example 22	250	1800	7.9	5.0	17.0	3.4	11.0	3	2200	2200	0.24
Invention Example 23	250	1800	7.9	5.9	17.0	2.9	13.0	5	2400	2400	0.24
Invention Example 24	250	1800	7.9	8.0	17.0	2.1	9.0	1	1600	1600	0.22
Invention Example 25	250	1800	7.9	5.1	10.0	2.0	2.0	-6	1500	1500	0.28
Invention Example 26	250	1800	7.9	5.6	13.0	2.3	5.0	-3	2000	2000	0.29
Invention Example 27	250	1800	7.9	6.2	12.5	2.0	15.0	7	2400	2400	0.27
Invention Example 28	250	1800	7.9	5.0	10.5	2.1	18.0	10	1800	1800	0.27
Invention Example 29	250	1800	7.9	7.1	20.0	2.8	14.0	6	2500	2500	0.23
Invention Example 30	250	1800	7.9	5.3	15.0	2.8	15.0	7	2800	2800	0.21
Invention Example 31	250	1800	7.9	6.1	18.0	3.0	16.0	8	3100	3100	0.24

(continued)

	Slab Thickness D(mm)	Slab Width W (mm)	Diagonal Direction Angle θ (°)	Molten Steel Throughput P	Argon Flow Rate A (NL/min)	A/P (NL/ton)	Discharge Opening Inclination Angle α (°)	$\alpha - \theta$ (°)	Upper Magnetic Pole Direct-Current Static Magnetic Field (Gs)	Lower Magnetic Pole Direct-Current Static Magnetic Field (Gs)	Product Defect Index (per 100 m)
Invention Example 32	250	1800	7.9	5.6	15.0	2.7	17.0	9	3400	3400	0.23
Invention Example 33	250	1800	7.9	8.0	18.0	2.3	18.0	10	2700	2700	0.22
Invention Example 34	250	1800	7.9	4.6	12.0	2.6	2.0	-6	3400	3400	0.27
Invention Example 35	250	1800	7.9	5.8	11.5	2.0	5.0	-3	3000	3000	0.26
Invention Example 36	250	1800	7.9	3.9	13.0	3.3	8.0	0	2800	2800	0.28
Invention Example 37	250	1800	7.9	4.8	13.0	2.7	10.0	2	2500	2500	0.29
Invention Example 38	250	1800	7.9	5.8	13.0	2.2	13.0	5	3100	3100	0.28
Comparative Example 19	250	1800	7.9	6.9	15.0	2.2	0.0	-8	1500	1500	0.51
Comparative Example 20	250	1800	7.9	5.9	17.0	2.9	0.0	-8	1800	1800	0.53
Comparative Example 21	250	1800	7.9	5.0	13.0	2.6	0.0	-8	2000	2000	0.51
Comparative Example 22	250	1800	7.9	7.2	15.0	2.1	1.0	-7	2200	2200	0.54
Comparative Example 23	250	1800	7.9	8.0	18.0	2.3	1.0	-7	2400	2400	0.52
Comparative Example 24	250	1800	7.9	5.0	13.0	2.6	19.0	11	1800	1800	0.22

(continued)

	Slab Thickness D(mm)	Slab Width W (mm)	Diagonal Direction Angle θ (°)	Molten Steel Throughput P	Argon Flow Rate A (NL/min)	A/P (NL/ton)	Discharge Opening Inclination Angle α (°)	α - θ (°)	Upper Magnetic Pole Direct-Current Static Magnetic Field (Gs)	Lower Magnetic Pole Direct-Current Static Magnetic Field (Gs)	Product Defect Index (per 100 m)
Comparative Example 25	250	1800	7.9	6.5	18.0	2.8	20.0	12	2000	2000	0.24
Comparative Example 26	250	1800	7.9	5.6	12.0	2.1	0.0	-8	2500	2500	0.53
Comparative Example 27	250	1800	7.9	6.9	15.0	2.2	0.0	-8	3400	3400	0.51
Comparative Example 28	250	1800	7.9	8.0	18.0	2.3	0.0	-8	3000	3000	0.54
Comparative Example 29	250	1800	7.9	5.6	18.0	3.2	1.0	-7	2600	2600	0.52
Comparative Example 30	250	1800	7.9	5.9	15.0	2.5	1.0	-7	2800	2800	0.53
Comparative Example 31	250	1800	7.9	6.0	20.0	3.3	19.0	11	3100	3100	0.23
Comparative Example 32	250	1800	7.9	7.0	18.0	2.6	20.0	12	3300	3300	0.25

[0089] In Invention Examples 19-28, the direct-current static magnetic field intensity is greater than or equal to 1500 (Gs) and less than 2500 (Gs). Fig. 23 shows that, in this case, the product defect index can be reduced to 0.21 to 0.24 (per 100 m) by setting " α - θ " in the range from 0 to 5 ($^{\circ}$). In other words, when the direct-current static magnetic field intensity is greater than or equal to 1500 (Gs) and less than 2500 (Gs), the inclination angle α ($^{\circ}$) is preferably in the range of greater than or equal to " θ " and less than or equal to " θ +5".

[0090] In Invention Examples 29-38, the direct-current static magnetic field intensity is greater than or equal to 2500 (Gs) and less than 3500 (Gs). It has been found that, in this case, the product defect index can be reduced to 0.21 to 0.24 (per 100 m) by setting " α - θ " in the range from 6 to 10 ($^{\circ}$). In other words, when the direct-current static magnetic field intensity is greater than or equal to 2500 (Gs) and less than 3500 (Gs), the inclination angle α ($^{\circ}$) is preferably in the range of greater than or equal to " θ +6" and less than or equal to " θ +10".

[0091] In Comparative Examples 19-23 and Comparative Examples 26-30, the inclination angle α is smaller than " θ -6". In this case, the product defect index is increased to 0.51 to 0.54 (per 100 m). In Comparative Examples 24-25 and Comparative Examples 31-32, the inclination angle α is greater than " θ +10". In this case, the product defect index is reduced to 0.22 to 0.25 (per 100 m). However, the results of cross-sectional examination of the slabs showed that there were regions in which the shell growth thickness in the mold was small. Accordingly, there was a risk that the operational stability will be degraded due to, for example, breakout.

[0092] Although not illustrated in the present example, it has also been confirmed that effects similar to those described in the present example can be obtained when the thickness of the cast slab is in the range from 220 to 300 (mm), the casting width is in the range from 1000 to 2000 (mm), and the molten steel throughput is in the range from 3.0 to 8.0. It has also been confirmed that a similar tendency can be observed when the molten-steel discharge angle of the immersion nozzle is in the range from 15 to 35 ($^{\circ}$). The shape of the discharge openings in the immersion nozzle and the inner diameter of the immersion nozzle are not limited to those described in the present example, and may be any shape and diameter as long as they are within ranges conceivable by a person skilled in the art.

Example 3

[0093] A test of casting about 300 (ton) of molten aluminum killed steel was performed by using a slab continuous casting machine with the continuous casting mold 40 including the pair of linear moving magnetic field generators 42 illustrated in Fig. 6. The cast slab had a thickness of 250 (mm) and a width of 1600 (mm), and the molten steel injection flow rate was 5.0 to 6.0 (ton/min). The discharge angle of the discharge openings in a two-opening immersion nozzle used in the test was 25 ($^{\circ}$) downward. The immersion depth of the immersion nozzle (distance from the molten steel surface in the mold to the top ends of the discharge openings) was greater than or equal to 180 (mm) and less than 300 (mm). The discharge openings in the immersion nozzle were 70 (mm) square in shape, and the inner diameter of the immersion nozzle was 70 (mm). Argon gas was used as inert gas injected through the immersion nozzle. The ratio A/P of the argon gas flow rate A to the molten steel throughput P was set in the range from 2.0 to 3.5 (NL/ton). Casting was performed while alternating-current moving magnetic fields were generated by the magnetic poles and the molten steel discharge flows were slowed.

[0094] The cast slab was successively subjected to hot rolling, cold rolling, and hot-dip galvanization, and surface defects on the hot-dip galvanized steel sheet were continuously measured by using an online surface inspection system. Among the defects, steelmaking defects (defects due to inclusions in the slab) were detected by observing the appearance of the defects and performing SEM analysis, ICP analysis, or the like, and evaluated based on the number of defects per 100 m of the hot-dip galvanized steel sheet (hereinafter referred to as "product defect index"). Table 3 shows the casting conditions and the results of the test for determining the product defect index of Invention Examples 30-49. Also in Table 3, the diagonal direction angle θ is rounded off to one decimal place, and the value of " α - θ " is rounded off to an integer. Fig. 24 is a graph showing the relationship between " α - θ " and "product defect index" of Invention Examples 39-49.

[Table 3]

	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ (°)	Molten Steel Throughput P	Argon Flow Rate A (NL/min)	A/P (NL/ton)	Discharge Opening Inclination Angle α (°)	$\alpha - \theta$ (°)	Operation of Alternating -Current Moving Magnetic Field	Product Defect Index (per 100 m)
Invention Example 39	250	1600	8.9	5.4	13.0	2.4	11.0	2	Slow	0.22
Invention Example 40	250	1600	8.9	5.0	16.0	3.2	12.0	3	Slow	0.21
Invention Example 41	250	1600	8.9	5.7	17.0	3.0	13.0	4	Slow	0.23
Invention Example 42	250	1600	8.9	6.0	14.0	2.3	14.0	5	Slow	0.23
Invention Example 43	250	1600	8.9	5.8	16.0	2.8	15.0	6	Slow	0.22
Invention Example 44	250	1600	8.9	5.2	15.0	2.9	16.0	7	Slow	0.24
Invention Example 45	250	1600	8.9	5.1	17.0	3.3	3.0	-6	Slow	0.29
Invention Example 46	250	1600	8.9	5.6	19.0	3.4	6.0	-3	Slow	0.27
Invention Example 47	250	1600	8.9	6.0	15.0	2.5	9.0	0	Slow	0.28

(continued)

	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ (°)	Molten Steel Throughput P	Argon Flow Rate A (NL/min)	A/P (NL/ton)	Discharge Opening Inclination Angle α (°)	$\alpha - \theta$ (°)	Operation of Alternating -Current Moving Magnetic Field	Product Defect Index (per 100 m)
Invention Example 48	250	1600	8.9	5.7	13.0	2.3	17.0	8	Slow	0.27
Invention Example 49	250	1600	8.9	5.3	18.0	3.4	19.0	10	Slow	0.28

[0095] Although not shown in Table 3, it has been confirmed that when a similar flow control method is used and when the discharge openings in the immersion nozzle are not inclined but are arranged so as to face the short sides, the product defect index is increased to 0.51 to 0.56 (per 100 m).

[0096] In Invention Examples 39-44, " α - θ " is in the range from 2 to 7 ($^{\circ}$). As illustrated in Fig. 24, in this case, the product defect index is reduced to 0.22 to 0.24 (per 100 m). This shows that when the linear moving magnetic field generators are provided and flow control is performed while slowing the molten steel flow, the inclination angle α ($^{\circ}$) is preferably in the range of greater than or equal to " $\theta+2$ " and less than or equal to " $\theta+7$ ".

[0097] In Invention Examples 45-47, " α - θ " is in the range from -6 to 0 ($^{\circ}$). In this case, the product defect index is slightly increased to 0.27 to 0.29 (per 100 m). This is probably because the flow velocity imparted to the molten steel flow was slightly low. However, the quality of these slabs was sufficient. In Invention Examples 48-49, " α - θ " is in the range from 8 to 10 ($^{\circ}$). In this case, the product defect index is slightly increased to 0.27 to 0.28 (per 100 m). This is probably because the flow velocity imparted to the molten steel flow was slightly high and entrainment of the mold powder was facilitated. However, the quality of these slabs was also sufficient. The results of cross-sectional examination performed on these slabs showed that although there were regions in which the shell growth thickness in the mold was slightly small, the operational stability was not degraded.

[0098] Although not illustrated in the present example, it has also been confirmed that a similar tendency can be observed when the molten steel discharge flows from the immersion nozzle are accelerated. In addition, it has also been confirmed that effects similar to those described in the present example can be obtained when the thickness of the cast slab is in the range from 220 to 300 (mm), the casting width is in the range from 1000 to 2000 (mm), and the molten steel throughput is in the range from 3.0 to 8.0. It has also been confirmed that a similar tendency can be observed when the molten-steel discharge angle of the immersion nozzle is in the range from 15 to 35 ($^{\circ}$). The shape of the discharge openings in the immersion nozzle and the inner diameter of the immersion nozzle are not limited to those described in the present example, and may be any shape and diameter as long as they are within ranges conceivable by a person skilled in the art.

Example 4

[0099] A test of casting about 300 (ton) of molten aluminum killed steel was performed by using a slab continuous casting machine with the continuous casting mold 50 including the magnetic poles 52 illustrated in Fig. 8. The cast slab had a thickness of 260 (mm) and a width of 1600 (mm), and the molten steel injection flow rate was 5.0 to 6.0 (ton/min). The discharge angle of the discharge openings in a two-opening immersion nozzle used in the test was 25 ($^{\circ}$) downward. The immersion depth of the immersion nozzle (distance from the molten steel surface in the mold to the top ends of the discharge openings) was greater than or equal to 180 (mm) and less than 300 (mm). The discharge openings in the immersion nozzle were 70 (mm) square in shape, and the inner diameter of the immersion nozzle was 70 (mm). Argon gas was used as inert gas injected through the immersion nozzle. The ratio A/P of the argon gas flow rate A to the molten steel throughput P was set in the range from 2.0 to 3.5 (NL/ton). Casting was performed while setting the intensity of the alternating-current moving magnetic fields in the range from 300 to 1000 (Gs) and changing the ratio X/W (Gs/mm) of the intensity X of the alternating-current moving magnetic fields to the width W of the cast slab and the inclination angle α of the discharge flows from the immersion nozzle.

[0100] The cast slab was successively subjected to hot rolling, cold rolling, and hot-dip galvanization, and surface defects on the hot-dip galvanized steel sheet were continuously measured by using an online surface inspection system. Among the defects, steelmaking defects (defects due to inclusions in the slab) were detected by observing the appearance of the defects and performing SEM analysis, ICP analysis, or the like, and evaluated based on the number of defects per 100 (m) of the hot-dip galvanized steel sheet (hereinafter referred to as "product defect index"). Table 4 shows the casting conditions and the results of the test for determining the product defect index of Invention Examples 50-71. Also in Table 4, the diagonal direction angle θ is rounded off to one decimal place, and the value of " α - θ " is rounded off to an integer. Comparative Examples 33-37 show the cases where the discharge openings were arranged so as to face toward the downstream sides of the swirling flows. Fig. 25 is a graph showing the relationship between " α - θ " and "product defect index" of Invention Examples 50-71 divided into groups by using a ratio X/W of 0.45 as a threshold.

[Table 4]

	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ (°)	Discharge Opening Inclination Direction	Discharge Opening Inclination Angle α (°)	$\alpha - \theta$ (°)	Upper Magnetic Pole	Ratio X/W (Gs/mm)	Product Defect Index (per 100m)
							Alternating-Current Moving Magnetic Field (Gs)		
Invention Example 50	260	1600	9.2	Upstream Sides of Swirling Flows	6.0	-3	480	0.30	0.18
Invention Example 51	260	1600	9.2	Upstream Sides of Swirling Flows	7.0	-2	550	0.34	0.19
Invention Example 52	260	1600	9.2	Upstream Sides of Swirling Flows	8.0	-1	600	0.38	0.18
Invention Example 53	260	1600	9.2	Upstream Sides of Swirling Flows	9.0	0	700	0.44	0.20
Invention Example 54	260	1600	9.2	Upstream Sides of Swirling Flows	5.0	-4	530	0.33	0.25
Invention Example 55	260	1600	9.2	Upstream Sides of Swirling Flows	3.0	-6	480	0.30	0.23
Invention Example 56	260	1600	9.2	Upstream Sides of Swirling Flows	10.0	1	550	0.34	0.26
Invention Example 57	260	1600	9.2	Upstream Sides of Swirling Flows	12.0	3	700	0.44	0.24
Invention Example 58	260	1600	9.2	Upstream Sides of Swirling Flows	14.0	5	650	0.41	0.25
Invention Example 59	260	1600	9.2	Upstream Sides of Swirling Flows	17.0	8	600	0.38	0.23
Invention Example 60	260	1600	9.2	Upstream Sides of Swirling Flows	19.0	10	570	0.36	0.24
Invention Example 61	260	1600	9.2	Upstream Sides of Swirling Flows	3.0	-6	720	0.45	0.19
Invention Example 62	260	1600	9.2	Upstream Sides of Swirling Flows	4.0	-5	860	0.54	0.20

(continued)

	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ (°)	Discharge Opening Inclination Direction	Discharge Opening Inclination Angle α (°)	$\alpha - \theta$ (°)	Upper Magnetic Pole	Ratio X/W (Gs/mm)	Product Defect Index (per 100m)
							Alternating-Current Moving Magnetic Field (Gs)		
Invention Example 63	260	1600	9.2	Upstream Sides of Swirling Flows	5.0	-4	800	0.50	0.18
Invention Example 64	260	1600	9.2	Upstream Sides of Swirling Flows	6.0	-3	850	0.53	0.24
Invention Example 65	260	1600	9.2	Upstream Sides of Swirling Flows	8.0	-1	860	0.54	0.26
Invention Example 66	260	1600	9.2	Upstream Sides of Swirling Flows	10.0	1	720	0.45	0.25
Invention Example 67	260	1600	9.2	Upstream Sides of Swirling Flows	11.0	2	760	0.48	0.26
Invention Example 68	260	1600	9.2	Upstream Sides of Swirling Flows	13.0	4	840	0.53	0.25
Invention Example 69	260	1600	9.2	Upstream Sides of Swirling Flows	15.0	6	830	0.52	0.24
Invention Example 70	260	1600	9.2	Upstream Sides of Swirling Flows	17.0	8	750	0.47	0.25
Invention Example 71	260	1600	9.2	Upstream Sides of Swirling Flows	19.0	10	810	0.51	0.26
Comparative Example 33	260	1600	9.2	Downstream Sides of Swirling Flows	7.0	-	600	0.38	0.65
Comparative Example 34	260	1600	9.2	Downstream Sides of Swirling Flows	9.0	-	650	0.41	0.68
Comparative Example 35	260	1600	9.2	Downstream Sides of Swirling Flows	15.0	-	700	0.44	0.67
Comparative Example 36	260	1600	9.2	Downstream Sides of Swirling Flows	11.0	-	750	0.47	0.64

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	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ (°)	Discharge Opening Inclination Direction	Discharge Opening Inclination Angle α (°)	α - θ (°)	Upper Magnetic Pole Alternating-Current Moving Magnetic Field (Gs)	Ratio X/W (Gs/mm)	Product Defect Index (per 100m)
Comparative Example 37	260	1600	9.2	Downstream Sides of Swirling Flows	9.0	-	800	0.50	0.68

[0101] Although not shown in Table 4, it has been confirmed that when a similar flow control method is used and when the discharge openings in the immersion nozzle are not inclined but are arranged so as to face the short sides, the product defect index is increased to 0.45 to 0.51 (per 100 m).

[0102] In Invention Examples 50-60, the ratio X/W (Gs/mm) is greater than or equal to 0.30 and less than 0.45. Fig. 25 shows that, in this case, the product defect index can be considerably reduced to 0.18 to 0.20 (per 100 m) by setting " $\alpha-\theta$ " in the range from -3 to 0 ($^{\circ}$). In other words, when the ratio X/W (Gs/mm) is greater than or equal to 0.30 and less than 0.45, the inclination angle α ($^{\circ}$) is preferably in the range of greater than or equal to " $\theta-3$ " and less than or equal to " θ ".

[0103] In Invention Examples 61-71, the ratio X/W (Gs/mm) is greater than or equal to 0.45 and less than 0.55. It has been found that, in this case, the product defect index can be considerably reduced to 0.18 to 0.20 (per 100 m) by setting " $\alpha-\theta$ " in the range from -6 to -4 ($^{\circ}$). In other words, when the ratio X/W (Gs/mm) is greater than or equal to 0.45 and less than 0.55, the inclination angle α ($^{\circ}$) is preferably in the range of greater than or equal to " $\theta-6$ " and less than or equal to " $\theta-4$ ". This is probably because the molten steel flow can be appropriately controlled by setting an appropriate inclination angle depending on the value of X/W . The quality of the slab was also sufficient in other Invention Examples.

[0104] Comparative Examples 33-37 show that when the discharge flows are directed toward the downstream sides of the swirling flows, the product defect index is greatly increased to 0.65 to 0.68 (per 100 m). This is probably because the swirling flows and the reverse flows easily meet and interfere.

[0105] Although not illustrated in the present example, it has also been confirmed that effects similar to those described in the present example can be obtained when the thickness of the cast slab is in the range from 220 to 300 (mm), the casting width is in the range from 1000 to 2000 (mm), and the molten steel throughput is in the range from 3.0 to 8.0. It has also been confirmed that a similar tendency can be observed when the molten-steel discharge angle of the immersion nozzle is in the range from 15 to 35 ($^{\circ}$). The shape of the discharge openings in the immersion nozzle and the inner diameter of the immersion nozzle are not limited to those described in the present example, and may be any shape and diameter as long as they are within ranges conceivable by a person skilled in the art.

Example 5

[0106] A test of casting about 300 (ton) of molten aluminum killed steel was performed by using a slab continuous casting machine with the continuous casting mold 1 including the pair of upper magnetic poles 6 and the pair of lower magnetic poles 7 illustrated in Fig. 12. The cast slab had a thickness of 260 (mm) and a width of 1000 to 1900 (mm), and the molten steel injection flow rate was 4.0 to 7.5 (ton/min). The discharge angle of the discharge openings in a two-opening immersion nozzle used in the test (angle of a horizontal direction is zero) was 25° downward. The immersion depth of the immersion nozzle (distance from the molten steel surface in the mold to the top ends of the discharge openings) was greater than or equal to 180 (mm) and less than 300 (mm). The discharge openings in the immersion nozzle were 80 (mm) square in shape, and the inner diameter of the immersion nozzle was 80 (mm). Argon gas was used as inert gas injected through the immersion nozzle. The ratio A/P of the argon gas flow rate A to the molten steel throughput P was set in the range from 2.0 to 3.5 (NL/ton).

[0107] The discharge direction of the discharge flows from the immersion nozzle was set to one of three directions: direction toward the upstream sides of the swirling flows formed by the alternating-current moving magnetic fields, direction toward the downstream sides of the swirling flows, and direction parallel to the mold long sides (direction perpendicular to the mold short sides). In the cases where the discharge direction of the discharge flows was inclined toward the upstream sides of the swirling flows or the downstream sides of the swirling flows, the inclination angle α was changed. Casting was performed while changing the intensities of the alternating-current moving magnetic fields applied by the upper magnetic poles, the direct-current static magnetic fields applied by the upper magnetic poles, and the direct-current static magnetic fields applied by the lower magnetic poles.

[0108] The cast slab was successively subjected to hot rolling, cold rolling, and hot-dip galvanization, and surface defects on the hot-dip galvanized steel sheet were continuously measured by using an online surface inspection system. Among the defects, steelmaking defects (defects due to inclusions in the slab) were detected by observing the appearance of the defects and performing SEM analysis, ICP analysis, or the like, and evaluated based on the number of defects per 100 (m) of the hot-dip galvanized steel sheet (hereinafter referred to as "product defect index"). Table 5 shows the casting conditions and the results of the test for determining the product defect index of Invention Examples 72-79 and Comparative Examples 38-46. In Table 5, the diagonal direction angle θ and the inclination angle α are rounded off to one decimal place.

[Table 5]

	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ ($^{\circ}$)	Discharge Opening Inclination Direction	Discharge Opening Inclination Angle α ($^{\circ}$)	Upper Magnetic Pole		Lower Magnetic Pole	Ratio X/W (Gs/mm)	Product Defect Index (per 100 m)
						Alternating-Current Moving Magnetic Field (Gs)	Direct-Current Stationary Magnetic Field (Gs)			
Invention Example 72	260	1900	7.8	Upstream Sides of Swirling Flows	13.0	900	3000	4500	0.47	0.20
Invention Example 73	260	1900	7.8	Upstream Sides of Swirling Flows	8.0	570	2000	3700	0.30	0.12
Invention Example 74	260	1600	9.2	Upstream Sides of Swirling Flows	15.0	750	3300	3900	0.47	0.21
Invention Example 75	260	1600	9.2	Upstream Sides of Swirling Flows	7.0	650	3100	3500	0.41	0.13
Invention Example 76	260	1300	11.3	Upstream Sides of Swirling Flows	5.0	700	2700	3300	0.54	0.25
Invention Example 77	260	1300	11.3	Upstream Sides of Swirling Flows	12.0	550	2300	3000	0.42	0.15
Invention Example 78	260	1000	14.6	Upstream Sides of Swirling Flows	11.0	525	3000	4000	0.53	0.16
Invention Example 79	260	1000	14.6	Upstream Sides of Swirling Flows	9.0	500	2800	3500	0.50	0.21
Comparative Example 38	260	1900	7.8	-	0.0	750	2000	3700	0.39	0.41

(continued)

	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ (°)	Discharge Opening Inclination Direction	Discharge Opening Inclination Angle α (°)	Upper Magnetic Pole		Lower Magnetic Pole	Ratio X/W (Gs/mm)	Product Defect Index (per 100 m)
						Alternating-Current Moving Magnetic Field (Gs)	Direct-Current Stationary Magnetic Field (Gs)			
Comparative Example 39	260	1600	9.2	-	0.0	650	3100	3500	0.41	0.39
Comparative Example 40	260	1300	11.3	-	0.0	550	2300	3000	0.42	0.35
Comparative Example 41	260	1000	14.6	-	0.0	500	2800	3500	0.50	0.42
Comparative Example 42	260	1900	7.8	Downstream Sides of Swirling Flows	8.0	750	2000	3700	0.39	0.55
Comparative Example 43	260	1600	9.2	Downstream Sides of Swirling Flows	9.0	650	3100	3500	0.41	0.58
Invention Example 80	260	1000	14.6	Upstream Sides of Swirling Flows	15.0	550	2900	4000	0.55	0.32
Invention Example 81	260	1300	11.3	Upstream Sides of Swirling Flows	11.0	750	3000	3700	0.58	0.30
Invention Example 82	260	1600	9.2	Upstream Sides of Swirling Flows	9.0	900	3300	4000	0.56	0.31

[0109] As shown in Table 5, continuous casting was performed while the intensity of the alternating-current moving magnetic fields generated by the upper magnetic poles was controlled in the range from 500 to 900 (Gs), the intensity of the direct-current static magnetic fields generated by the upper magnetic poles was controlled in the range from 2000 to 3300 (Gs), and the intensity of the direct-current static magnetic fields generated by the lower magnetic poles was controlled in the range from 3000 to 4500 (Gs). Although not shown in Table 5, it has been confirmed that the product defect index generally increases when the intensities of the direct-current static magnetic fields generated by the upper magnetic poles and the lower magnetic poles are outside the above-described ranges. In addition, although not shown in Table 5, it has also been confirmed that the product defect index increases when the ratio X/W of the intensity X of the alternating-current moving magnetic fields generated by the upper magnetic poles to the width W of the slab is less than 0.30.

[0110] Table 5 shows the diagonal direction angle θ calculated from the thickness D of the cast slab and the width W of the slab and the inclination angle α of the discharge flows during casting. The diagonal direction angle θ is rounded off to one decimal place.

[0111] In Invention Examples 72-79, the discharge flows from the immersion nozzle are inclined toward the upstream sides of the swirling flows formed by the alternating-current moving magnetic fields. In this case, the product defect index is reduced to 0.12 to 0.25 (per 100 m). Thus, good results were obtained.

[0112] In contrast, in Comparative Examples 38-41, the discharge direction is not inclined. In this case, the product defect index is 0.35 to 0.42 (per 100 m), and is higher than those in Invention Examples 72-79. In addition, in Comparative Examples 42-43, the discharge direction of the immersion nozzle is inclined toward the downstream sides of the swirling flows formed by the alternating-current moving magnetic fields. In this case, the product defect index is greatly increased to 0.55 to 0.58 (per 100 m). This is probably because the swirling flows and the reverse flows easily meet and interfere at the downstream sides of the swirling flow.

[0113] In Invention Examples 80-82, the ratio X/W (Gs/mm) of the intensity X of the alternating-current moving magnetic fields generated by the upper magnetic poles to the width W of the slab is greater than or equal to 0.55. In this case, the product defect index is 0.30 to 0.32 (per 100 m), and is slightly higher than those in Invention Examples 72-79. This is probably because the intensity X of the alternating-current moving magnetic fields is too high relative to the width W , and the molten steel flow in mold is slightly unstable.

[0114] Although not illustrated in the present example, it has also been confirmed that effects similar to those described in the present example can be obtained when the thickness of the cast slab is in the range from 220 to 300 (mm). The shape of the discharge openings in the immersion nozzle and the inner diameter of the immersion nozzle are not limited to those described in the present example, and may be any shape and diameter as long as they are within ranges conceivable by a person skilled in the art.

Example 6

[0115] Similar to Example 5, a test of casting about 300 (ton) of molten aluminum killed steel was performed by using a slab continuous casting machine with the continuous casting mold 1 including upper and lower magnetic poles illustrated in Fig. 12. The cast slab had a thickness of 260 (mm) and a width of 1600 to 1700 (mm), and the molten steel injection flow rate was 6.0 to 7.0 (ton/min). The discharge angle of the discharge openings in a two-opening immersion nozzle used in the test was 25 ($^{\circ}$) downward. The immersion depth of the immersion nozzle (distance from the molten steel surface in the mold to the top ends of the discharge openings) was greater than or equal to 180 (mm) and less than 300 (mm). The discharge openings in the immersion nozzle were 80 (mm) square in shape, and the inner diameter of the immersion nozzle was 80 (mm). Argon gas was used as inert gas injected through the immersion nozzle.

[0116] In Example 6, the discharge direction of the immersion nozzle is inclined toward the upstream sides of the swirling flows formed by the alternating-current moving magnetic fields. The intensity of the alternating-current moving magnetic fields generated at the upper magnetic poles was 500 to 900 (Gs), the intensity of the direct-current static magnetic fields generated at the upper magnetic poles was 2000 to 3300 (Gs), and the intensity of the direct-current static magnetic fields generated at the lower magnetic poles was 3000 to 4500 (Gs). Casting was performed while changing the ratio X/W (Gs/mm) of the intensity X of the alternating-current moving magnetic fields to the width W of the cast slab and the inclination angle α of the discharge flows from the immersion nozzle.

[0117] The cast slab was successively subjected to hot rolling, cold rolling, and hot-dip galvanization, and surface defects on the hot-dip galvanized steel sheet were continuously measured by using an online surface inspection system. Among the defects, steelmaking defects (defects due to inclusions in the slab) were detected by observing the appearance of the defects and performing SEM analysis, ICP analysis, or the like, and evaluated based on the number of defects per 100 (m) of the hot-dip galvanized steel sheet (hereinafter referred to as "product defect index"). Table 6 shows the casting conditions and the results of the test for determining the product defect index of Invention Examples 80-103. In Table 6, the diagonal direction angle θ is rounded off to one decimal place, and the value of " $\alpha-\theta$ " is rounded off to an integer. Fig. 26 is a graph showing the relationship between " $\alpha-\theta$ " and "product defect index" of Invention Examples 83-106 divided into groups by using a ratio X/W of 0.45 as a threshold.

[Table 6]

	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ (°)	Discharge Opening Inclination Direction	Discharge Opening Inclination Angle α (°)	$\alpha - \theta$	Upper Magnetic Pole		Lower Magnetic Pole	Ratio X/W (Gs/mm)	Product Defect Index (per 100 m)
							Alternating -Current Moving Magnetic Field (Gs)	Direct-Current Stationary Magnetic Field (Gs)			
Invention Example 83	260	1700	8.7	Upstream Sides of Swirling Flows	5.0	-4	650	2300	3300	0.38	0.23
Invention Example 84	260	1600	9.2	Upstream Sides of Swirling Flows	6.0	-3	700	2800	3600	0.44	0.24
Invention Example 85	260	1600	9.2	Upstream Sides of Swirling Flows	7.0	-2	700	2500	3500	0.44	0.13
Invention Example 86	260	1700	8.7	Upstream Sides of Swirling Flows	8.0	-1	510	2200	3500	0.30	0.14
Invention Example 87	260	1600	9.2	Upstream Sides of Swirling Flows	9.0	0	570	3100	3800	0.36	0.15
Invention Example 88	260	1600	9.2	Upstream Sides of Swirling Flows	10.0	1	500	2000	3100	0.31	0.13
Invention Example 89	260	1700	8.7	Upstream Sides of Swirling Flows	11.0	2	580	2700	3900	0.34	0.14

(continued)

	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ (°)	Discharge Opening Inclination Direction	Discharge Opening Inclination Angle α (°)	$\alpha - \theta$	Upper Magnetic Pole		Lower Magnetic Pole	Ratio X/W (Gs/mm)	Product Defect Index (per 100 m)
							Alternating -Current Moving Magnetic Field (Gs)	Direct-Current Stationary Magnetic Field (Gs)			
Invention Example 90	260	1600	9.2	Upstream Sides of Swirling Flows	12.0	3	640	3000	4500	0.40	0.13
Invention Example 91	260	1700	8.7	Upstream Sides of Swirling Flows	13.0	4	750	3300	4000	0.44	0.14
Invention Example 92	260	1700	8.7	Upstream Sides of Swirling Flows	14.0	5	650	3000	3700	0.38	0.15
Invention Example 93	260	1600	9.2	Upstream Sides of Swirling Flows	15.0	6	660	2900	3800	0.41	0.22
Invention Example 94	260	1700	8.7	Upstream Sides of Swirling Flows	16.0	7	650	2800	3900	0.38	0.23
Invention Example 95	260	1700	8.7	Upstream Sides of Swirling Flows	2.0	-7	800	3000	3900	0.47	0.23
Invention Example 96	260	1600	9.2	Upstream Sides of Swirling Flows	3.0	-6	830	2000	3000	0.52	0.22

(continued)

	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ (°)	Discharge Opening Inclination Direction	Discharge Opening Inclination Angle α (°)	$\alpha - \theta$	Upper Magnetic Pole		Lower Magnetic Pole	Ratio X/W (Gs/mm)	Product Defect Index (per 100 m)
							Alternating -Current Moving Magnetic Field (Gs)	Direct-Current Stationary Magnetic Field (Gs)			
Invention Example 97	260	1600	9.2	Upstream Sides of Swirling Flows	4.0	-5	800	2500	3200	0.50	0.13
Invention Example 98	260	1700	8.7	Upstream Sides of Swirling Flows	5.0	-4	850	3100	4000	0.50	0.14
Invention Example 99	260	1600	9.2	Upstream Sides of Swirling Flows	6.0	-3	860	3300	4500	0.54	0.13
Invention Example 100	260	1700	8.7	Upstream Sides of Swirling Flows	7.0	-2	770	2700	3300	0.45	0.15
Invention Example 101	260	1600	9.2	Upstream Sides of Swirling Flows	8.0	-1	750	2800	3500	0.47	0.13
Invention Example 102	260	1700	8.7	Upstream Sides of Swirling Flows	9.0	0	770	2500	3400	0.45	0.14
Invention Example 103	260	1600	9.2	Upstream Sides of Swirling Flows	10.0	1	800	2700	3700	0.50	0.14

(continued)

	Slab Thickness D (mm)	Slab Width W (mm)	Diagonal Direction Angle θ (°)	Discharge Opening Inclination Direction	Discharge Opening Inclination Angle α (°)	α - θ	Upper Magnetic Pole		Lower Magnetic Pole	Ratio X/W (Gs/mm)	Product Defect Index (per 100 m)
							Alternating -Current Moving Magnetic Field (Gs)	Direct-Current Stationary Magnetic Field (Gs)			
Invention Example 104	260	1700	8.7	Upstream Sides of Swirling Flows	11.0	2	780	2600	3300	0.46	0.15
Invention Example 105	260	1700	8.7	Upstream Sides of Swirling Flows	12.0	3	900	3000	3900	0.53	0.22
Invention Example 106	260	1600	9.2	Upstream Sides of Swirling Flows	13.0	4	750	3200	4000	0.47	0.25

[0118] In Invention Examples 83-94, the ratio X/W (Gs/mm) is greater than or equal to 0.30 and less than 0.45. Fig. 26 shows that, in this case, the product defect index can be considerably reduced to 0.13 to 0.15 (per 100 m) by setting " α - θ " in the range from -2° to 5° . In other words, when the ratio X/W (Gs/mm) is greater than or equal to 0.30 and less than 0.45, the inclination angle α ($^\circ$) is preferably in the range of greater than or equal to " θ - 2 " and less than or equal to " θ + 5 ".

[0119] In Invention Examples 95-106, the ratio X/W (Gs/mm) is greater than or equal to 0.45 and less than 0.55. It has been found that, in this case, the product defect index can be considerably reduced to 0.13 to 0.15 (per 100 m) by setting " α - θ " in the range from -5 to 2 ($^\circ$). In other words, when the ratio X/W (Gs/mm) is greater than or equal to 0.45 and less than 0.55, the inclination angle α ($^\circ$) is preferably in the range of greater than or equal to " θ - 5 " and less than or equal to " θ + 2 ".

[0120] Although the thickness and width of the slab are in certain ranges in Table 6, it has been confirmed that similar effects can be obtained when, for example, the thickness of the slab is in the range from 220 to 300 (mm) and the width of the slab is in the range from 1000 to 2000 (mm).

Reference Signs List

[0121]

- 1 continuous casting mold
- 2 mold long side
- 3 mold short side
- 4 immersion nozzle
- 5 discharge opening
- 6 upper magnetic pole
- 7 lower magnetic pole
- 8 molten steel
- 9 solidifying shell
- 10 molten steel surface in mold
- 11 discharge flow
- 12 alternating-current moving magnetic field generating coil
- 13 direct-current static magnetic field generating coil
- 14 direct-current static magnetic field generating coil
- 15 swirling flow
- 16 reverse flow
- 17 low flow velocity region
- 18 vortex flow
- 19 downward flow
- 20 continuous casting mold
- 30 continuous casting mold
- 40 continuous casting mold
- 42 linear moving magnetic field generator
- 50 continuous casting mold
- 52 magnetic pole

Claims

1. A slab continuous casting method comprising steps of:

placing an immersion nozzle in a continuous casting mold; and
 supplying molten steel to the immersion nozzle to cast the molten steel, wherein,
 the immersion nozzle has a pair of discharge openings that are arranged symmetrically about a vertical axis of the immersion nozzle,
 an immersion depth of the immersion nozzle (distance from a molten steel surface in the mold to top ends of the discharge openings) is greater than or equal to 180 mm and less than 300 mm,
 a downward molten-steel discharge angle of the discharge openings from a horizontal direction is in a range from 15 to 35° ,
 a ratio A/P of a flow rate A (NL/min) of inert gas injected between a tundish outflow opening and the discharge openings to a molten steel throughput P (ton/min) is in a range from 2.0 to 3.5 NL/ton, and

a discharge direction of the immersion nozzle is inclined with respect to a reference plane which passes through a vertical axial center of the immersion nozzle and which is parallel to mold long side surfaces, in a range of Equation (1):

$$\theta - 6 \leq \alpha \leq \theta + 10 \quad (1)$$

α is an inclination angle (°) of the discharge direction with respect to the reference plane when the mold is viewed from vertically above; and

θ is an angle (acute angle) between a straight line and the reference plane when the mold is viewed from vertically above, the straight line extending from the vertical axial center of the immersion nozzle toward contact points of mold long sides and mold short sides, the angle (°) being defined by Equation (2):

$$\tan \theta = (D/2) / (W/2) \quad (2)$$

D is a thickness (mm) of a continuously cast slab; and
W is a width (mm) of the slab.

2. The slab continuous casting method according to Claim 1, further comprising steps of:

measuring the α during continuous casting or after completion of a change in mold width during continuous casting; and
changing the discharge direction of the immersion nozzle so as to satisfy Equation (1) when the α does not satisfy the Equation (1).

3. The slab continuous casting method according to Claim 1, comprising steps of:

arranging a pair of upper magnetic poles and a pair of lower magnetic poles on back surfaces of the mold long sides so as to face each other with the mold long sides disposed therebetween;
positioning the discharge openings between a position at which direct-current static magnetic fields generated by the upper magnetic poles have a maximum value and a position at which direct-current static magnetic fields generated by the lower magnetic poles have a maximum value; and
applying the direct-current static magnetic fields generated by the upper magnetic poles and the lower magnetic poles to slow a molten steel flow, wherein,
the discharge direction of the immersion nozzle is inclined with respect to the reference plane in a range of Equation (3) instead of Equation (1) when an intensity of the direct-current static magnetic fields generated by the upper magnetic poles is greater than or equal to 1500 Gs and less than 2500 Gs (Gauss; 1 Gs = 10^{-4} T); or
the discharge direction of the immersion nozzle is inclined in a range of Equation (4) instead of Equation (1) when the intensity of the direct-current static magnetic fields is greater than or equal to 2500 Gs and less than 3500 Gs:

$$\theta \leq \alpha \leq \theta + 5 \quad (3)$$

$$\theta + 6 \leq \alpha \leq \theta + 10 \quad (4)$$

4. The slab continuous casting method according to Claim 3, comprising steps of:

measuring the α during continuous casting or after completion of a change in mold width during continuous casting;
changing discharge direction of the immersion nozzle so as to satisfy Equation (3) when the intensity of the direct-current static magnetic fields is greater than or equal to 1500 Gs and less than 2500 Gs and when α does not satisfy Equation (3); or
changing the discharge direction of the immersion nozzle so as to satisfy Equation (4) when the intensity of the direct-current static magnetic fields is greater than or equal to 2500 Gs and less than 3500 Gs and when α does

not satisfy Equation (4).

5. The slab continuous casting method according to Claim 1, further comprising the steps of:

providing linear moving magnetic field generators on back surfaces of the mold long sides, the generators which generates magnetic fields of which moving direction is a mold width direction; and applying moving magnetic fields in directions from the mold short sides toward the immersion nozzle to apply a slowing force to molten steel flows discharged from the immersion nozzle or applying moving magnetic fields in directions from the immersion nozzle toward the mold short sides to apply an accelerating force to the molten steel flows, to perform flow control, wherein, the discharge direction of the immersion nozzle is inclined with respect to the reference plane in a range of Equation (5) instead of Equation (1):

$$\theta+2 \leq \alpha \leq \theta+7 \quad (5)$$

6. The slab continuous casting method according to Claim 5, further comprising steps of:

measuring the α during continuous casting or after completion of a change in mold width during continuous casting; and changing the discharge direction of the immersion nozzle so as to satisfy Equation (5) when the α does not satisfy Equation (5).

7. The slab continuous casting method according to Claim 1, comprising steps of:

arranging a pair of magnetic poles on back surfaces of the mold long sides so as to face each other with the mold long sides disposed therebetween; and applying alternating-current moving magnetic fields generated by the magnetic poles to swirl and stir the molten steel in a horizontal direction, wherein, an intensity of the alternating-current moving magnetic fields is set in a range from 300 to 1000 Gs, and the discharge direction of the immersion nozzle is inclined with respect to the reference plane toward upstream sides of swirling flows formed by the alternating-current moving magnetic fields, the discharge direction of the immersion nozzle being inclined with respect to the reference plane in a range of Equation (6) instead of Equation (1) when a ratio X/W (Gs/mm) of an intensity X (Gs) of the alternating-current moving magnetic fields to a width W (mm) of the continuously cast slab is greater than or equal to 0.30 and less than 0.45:

$$\theta-3 \leq \alpha \leq \theta \quad (6) ;$$

or the discharge direction is inclined with respect to the reference plane toward upstream sides of the swirling flows in a range of Equation (7) instead of Equation (1) when the ratio X/W (Gs/mm) is greater than or equal to 0.45 and less than 0.55:

$$\theta-6 \leq \alpha \leq \theta-4 \quad (7) .$$

8. The slab continuous casting method according to Claim 7, comprising the steps of:

measuring the α during continuous casting or after completion of a change in mold width during continuous casting; and changing the discharge direction of the immersion nozzle so as to satisfy Equation (6) when the ratio X/W (Gs/mm) is greater than or equal to 0.30 and less than 0.45 and when α does not satisfy Equation (6); or changing the discharge direction so as to satisfy Equation (7) when the ratio X/W (Gs/mm) is greater than or equal to 0.45 and less than 0.55 and when α does not satisfy Equation (7).

9. The slab continuous casting method according to Claim 1, comprising steps of:

arranging a pair of upper magnetic poles and a pair of lower magnetic poles on back surfaces of the mold long sides so as to face each other with the mold long sides disposed therebetween;
 positioning the discharge openings between a position at which direct-current static magnetic fields generated by the upper magnetic poles have a maximum value and a position at which direct-current static magnetic fields generated by the lower magnetic poles have a maximum value; and
 applying the direct-current static magnetic fields and alternating-current moving magnetic fields in a superposed manner from the upper magnetic poles, to slow a molten steel flow by the direct-current static magnetic fields generated by the upper magnetic poles, and to also slow the molten steel flow by the direct-current static magnetic fields generated by the lower magnetic poles, along with forming swirling flows of the molten steel that rotate in a horizontal direction along the molten steel surface in the mold by the alternating-current moving magnetic fields generated by the upper magnetic poles, wherein
 an intensity of the alternating-current moving magnetic fields is set in a range from 500 to 900 Gs (Gauss; 1 Gs = 10^{-4} T) ; and
 an intensity of the direct-current static magnetic fields generated by the upper magnetic poles is set in a range from 2000 to 3300 Gs; and
 an intensity of the direct-current static magnetic fields generated by the lower magnetic poles is set in a range from 3000 to 4500 Gs, and a ratio X/W (Gs/mm) of an intensity X (Gs) of the alternating-current moving magnetic fields to a width W (mm) of the continuously cast slab is controlled so as to be greater than or equal to 0.30 and less than 0.55;
 the discharge direction of the immersion nozzle is inclined with respect to the reference plane toward upstream sides of the swirling flows of the molten steel formed by the alternating-current moving magnetic fields.

10. The slab continuous casting method according to Claim 9, wherein,
 the discharge direction of the immersion nozzle is inclined with respect to the reference plane in a range of Equation (8) instead of Equation (1) when the ratio X/W (Gs/mm) is greater than or equal to 0.30 and less than 0.45:

$$\theta - 2 \leq \alpha \leq \theta + 5 \quad (8) ,$$

or

the discharge direction of the immersion nozzle is inclined with respect to the reference plane in a range of Equation (9) instead of Equation (1) when the ratio X/W (Gs/mm) is greater than or equal to 0.45 and less than 0.55:

$$\theta - 5 \leq \alpha \leq \theta + 2 \quad (9) .$$

11. The slab continuous casting method according to Claim 10, comprising steps of:

measuring the α during continuous casting or after completion of a change in mold width during continuous casting;

changing the discharge direction of the immersion nozzle so as to satisfy Equation (8) when the ratio X/W (Gs/mm) is greater than or equal to 0.30 and less than 0.45 and when α does not satisfy Equation (8); or,
 changing the discharge direction of the immersion nozzle so as to satisfy Equation (9) when the ratio X/W (Gs/mm) is greater than or equal to 0.45 and less than 0.55 and when α does not satisfy Equation (9).

FIG. 1

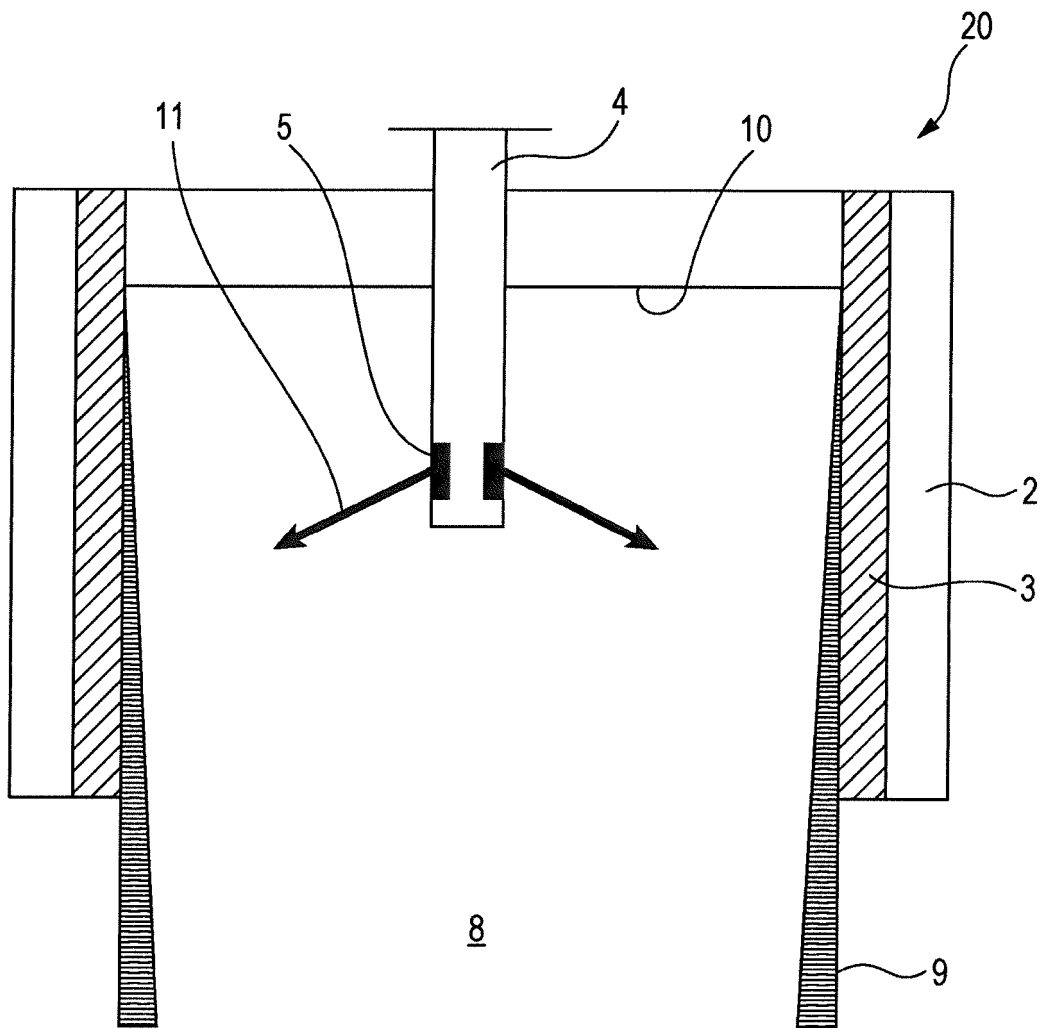


FIG. 2

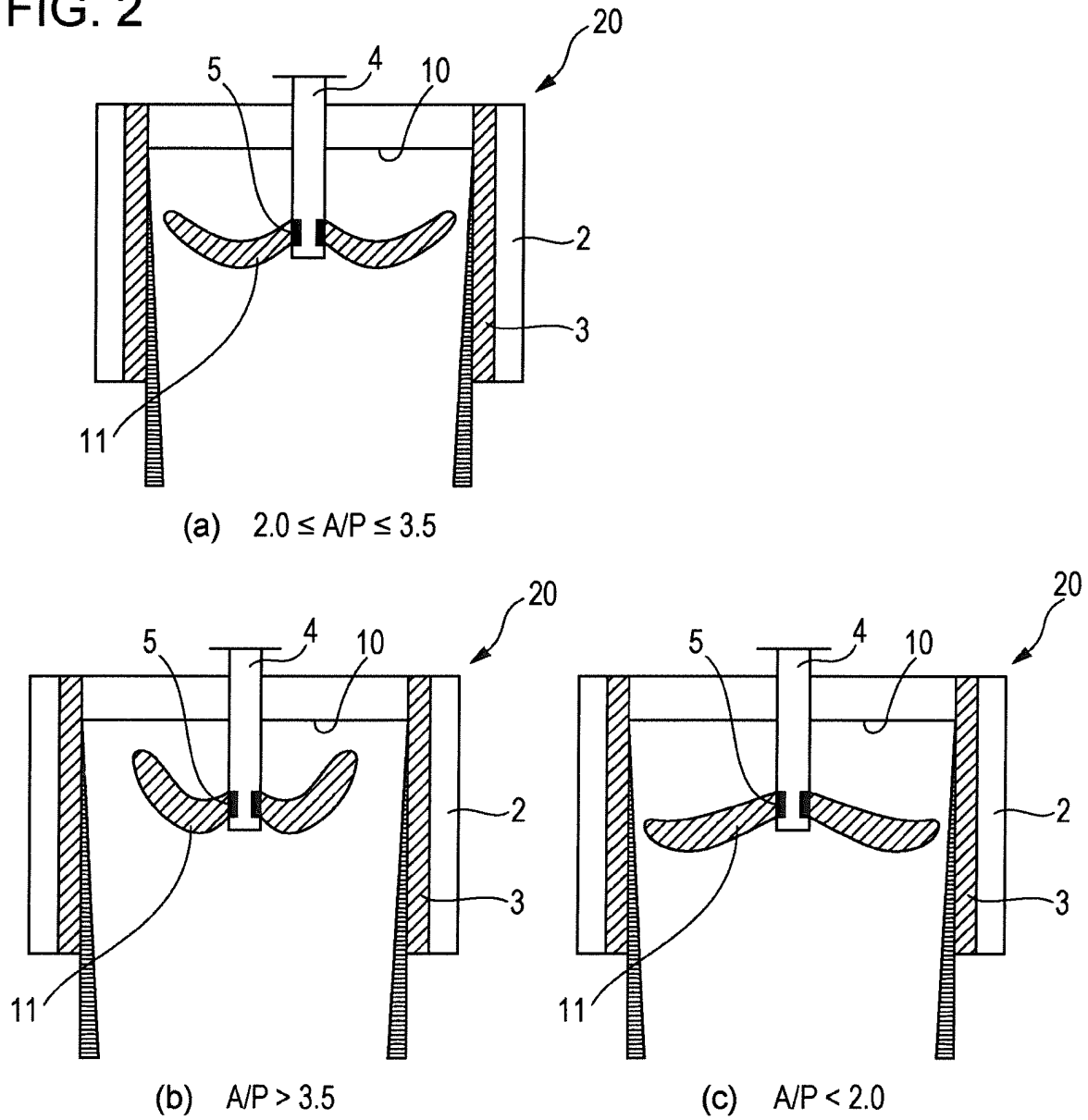


FIG. 3

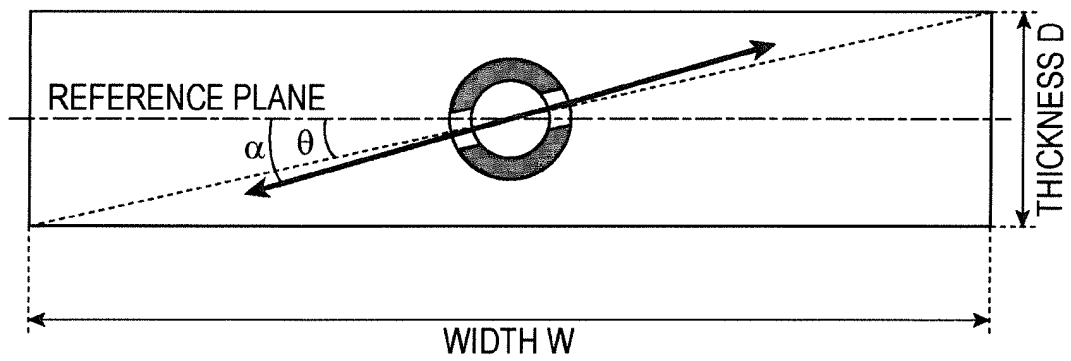


FIG. 4

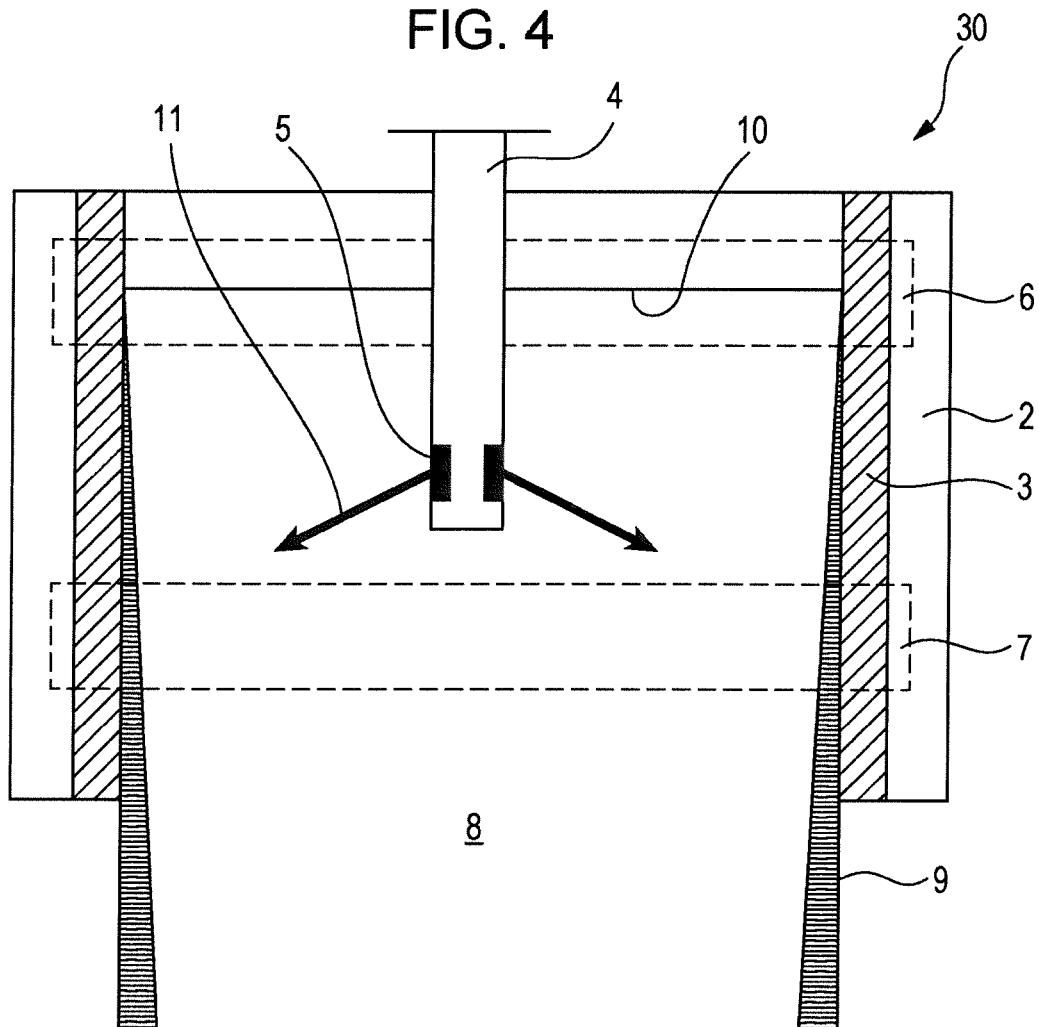


FIG. 5

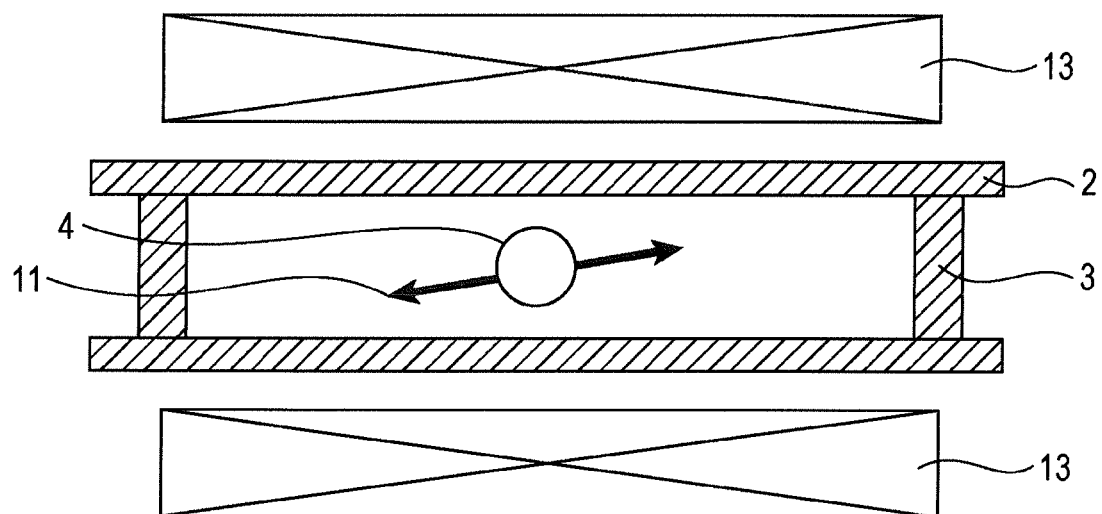


FIG. 6

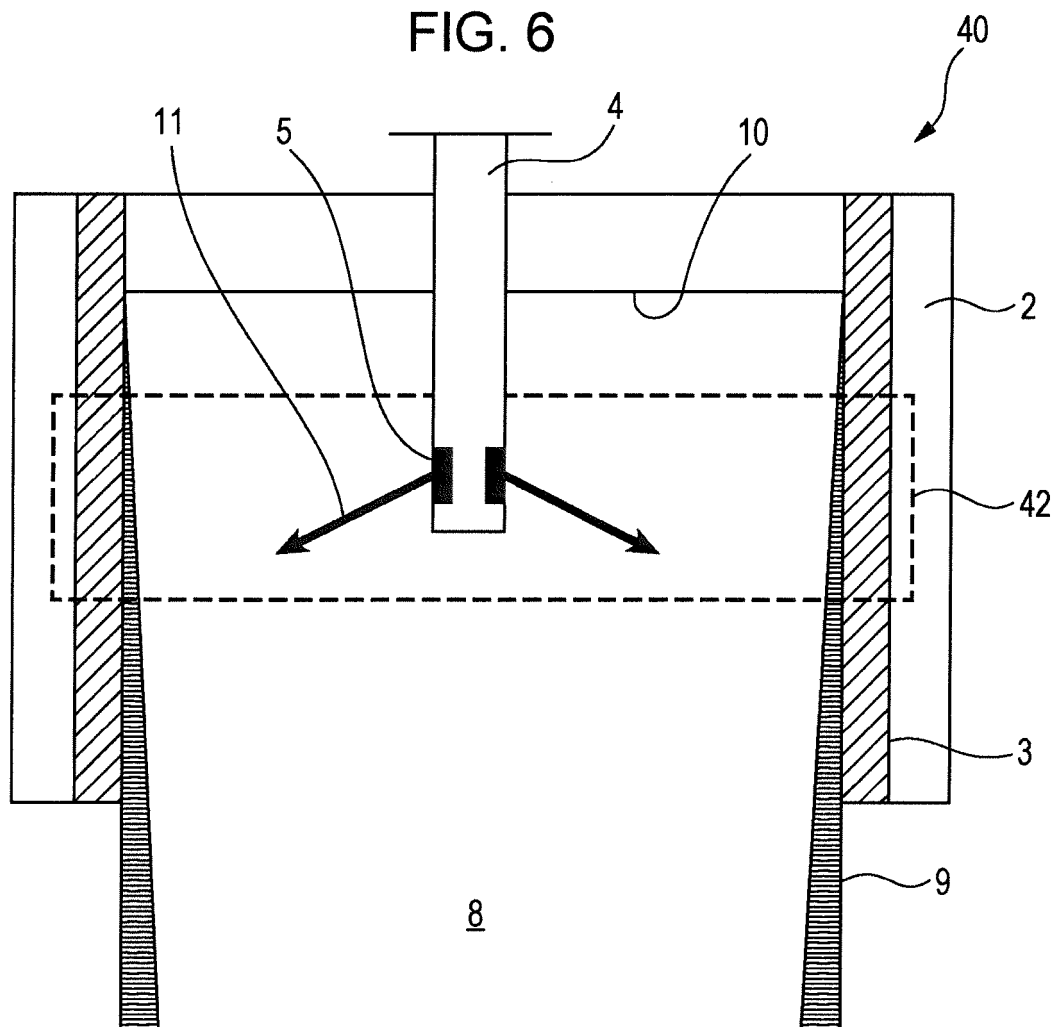


FIG. 7

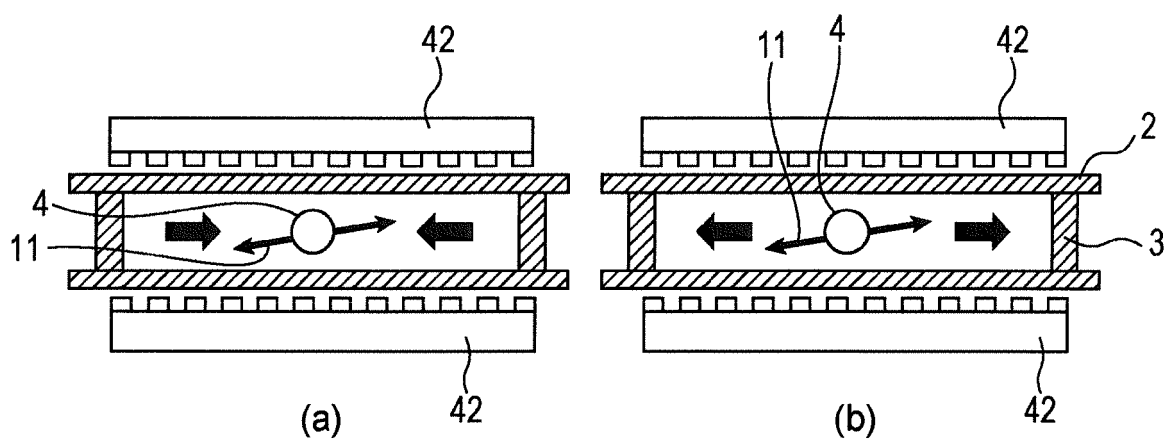


FIG. 8

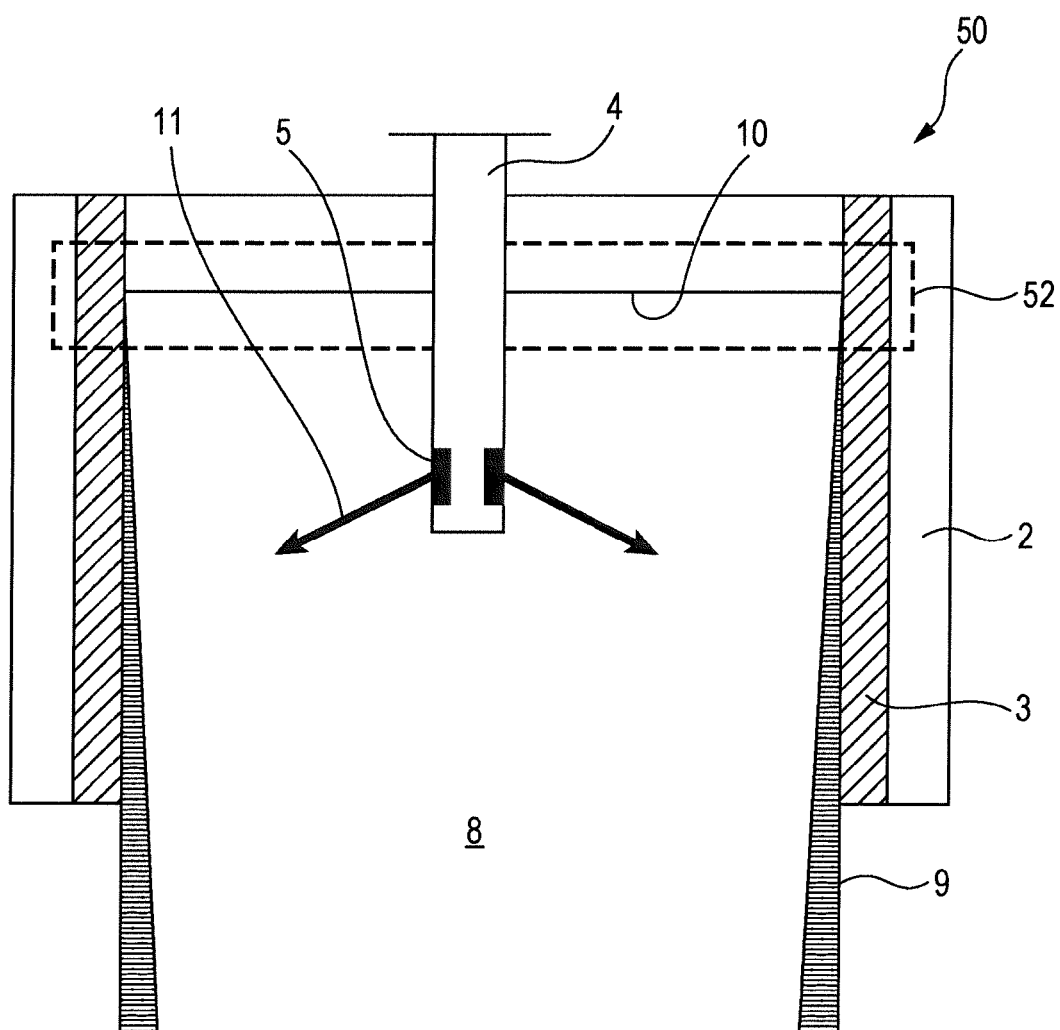


FIG. 9

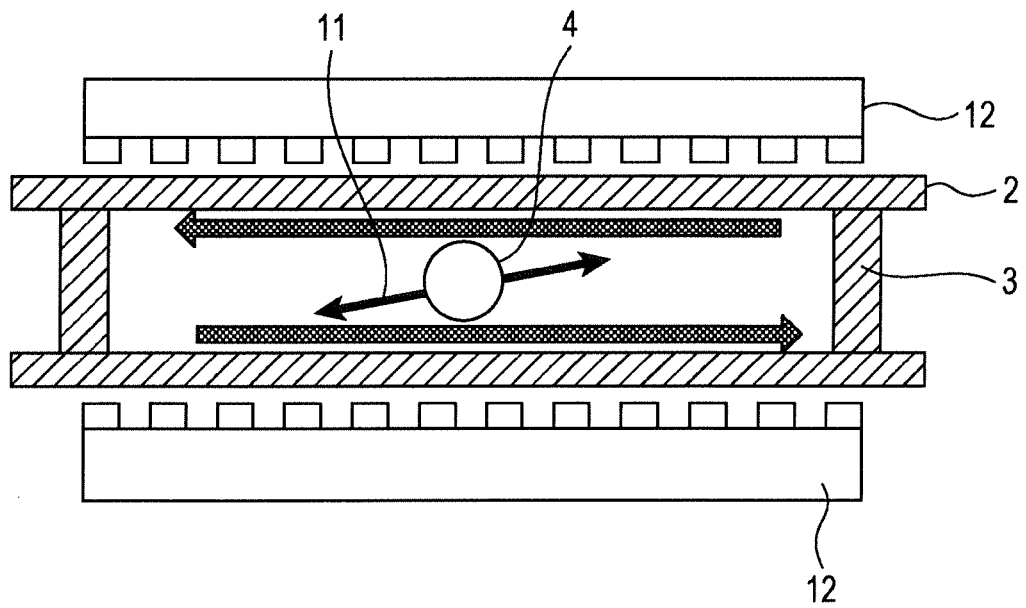


FIG. 10

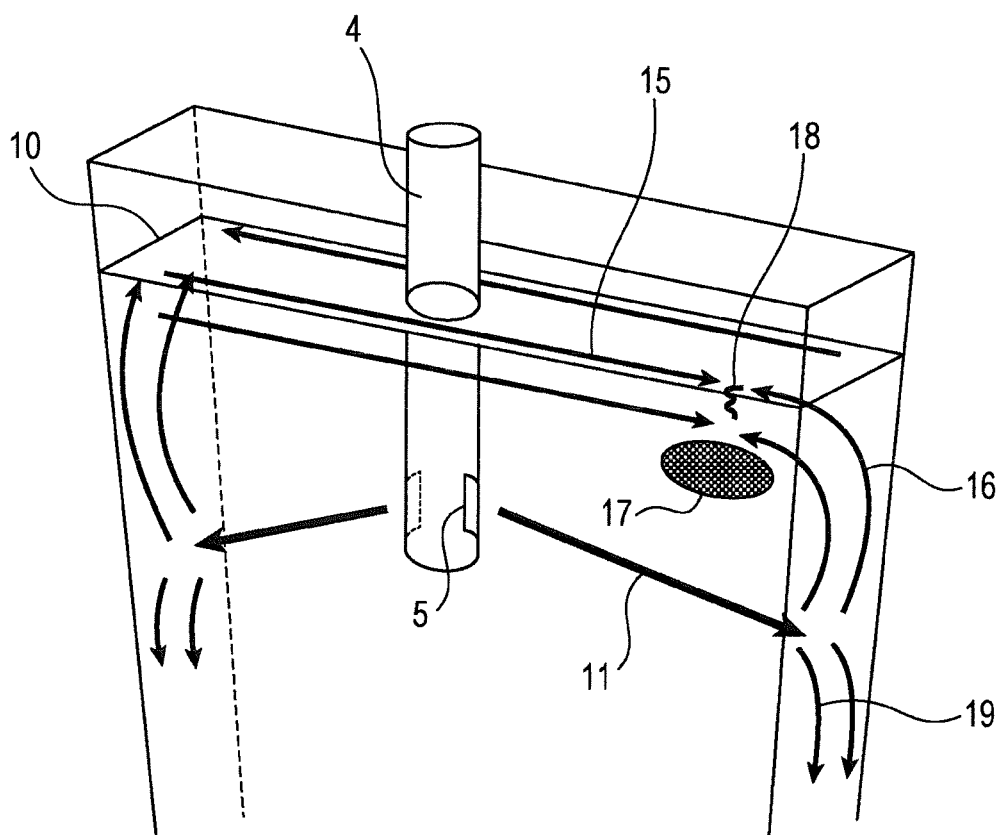


FIG. 11

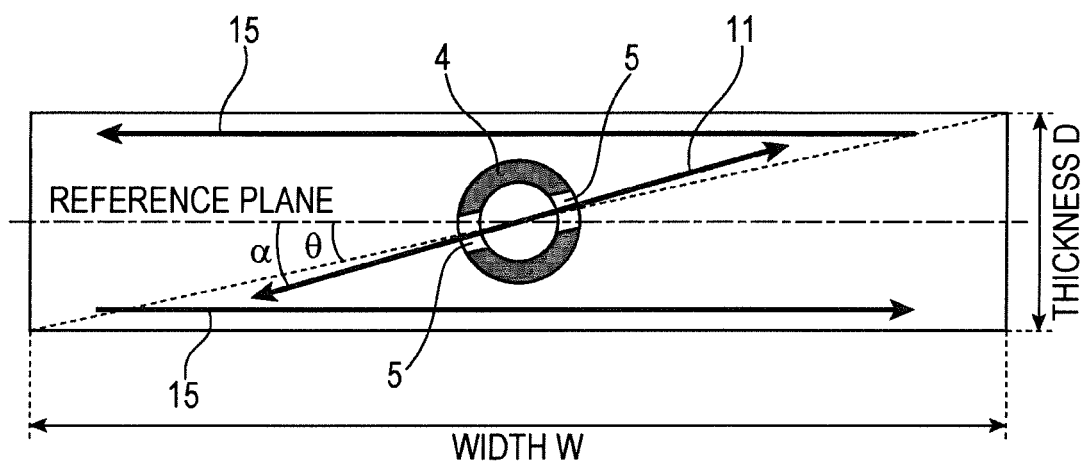


FIG. 12

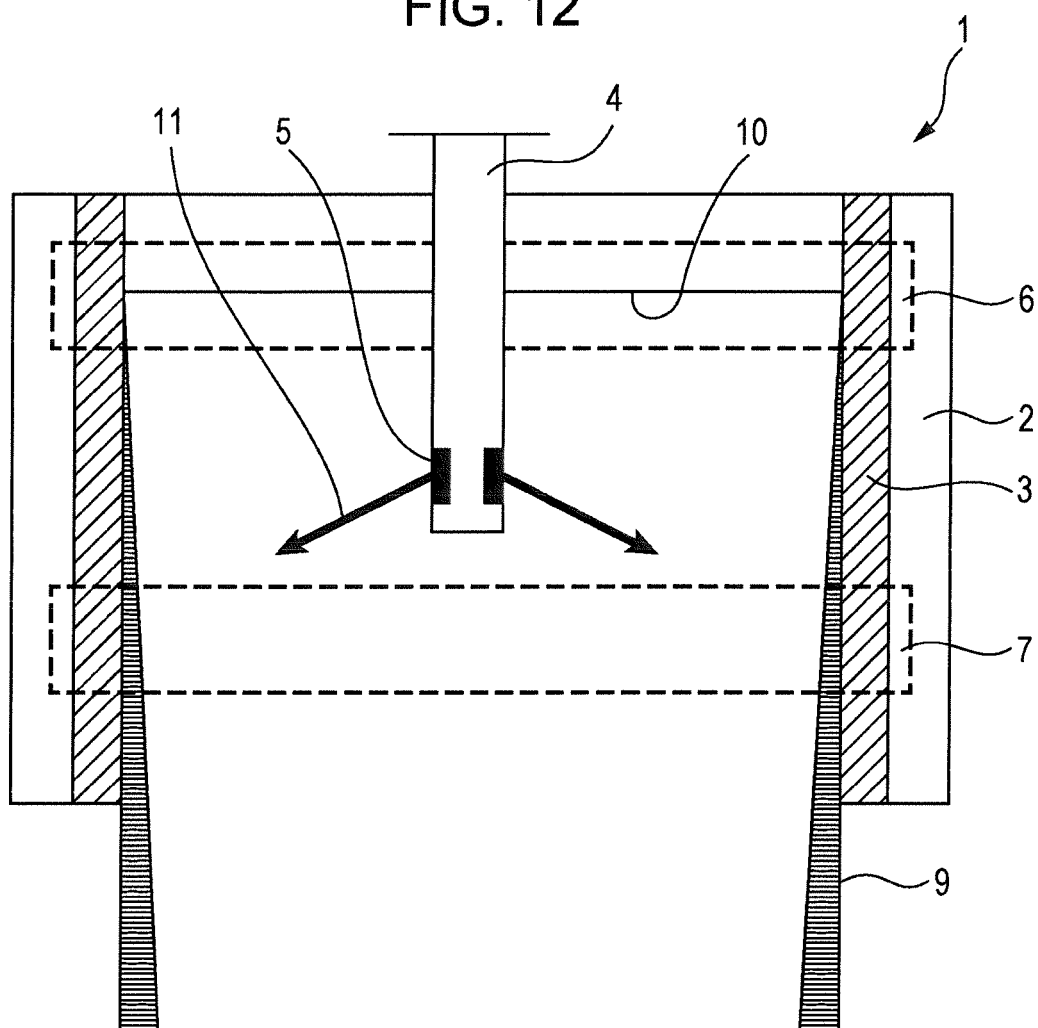


FIG. 13

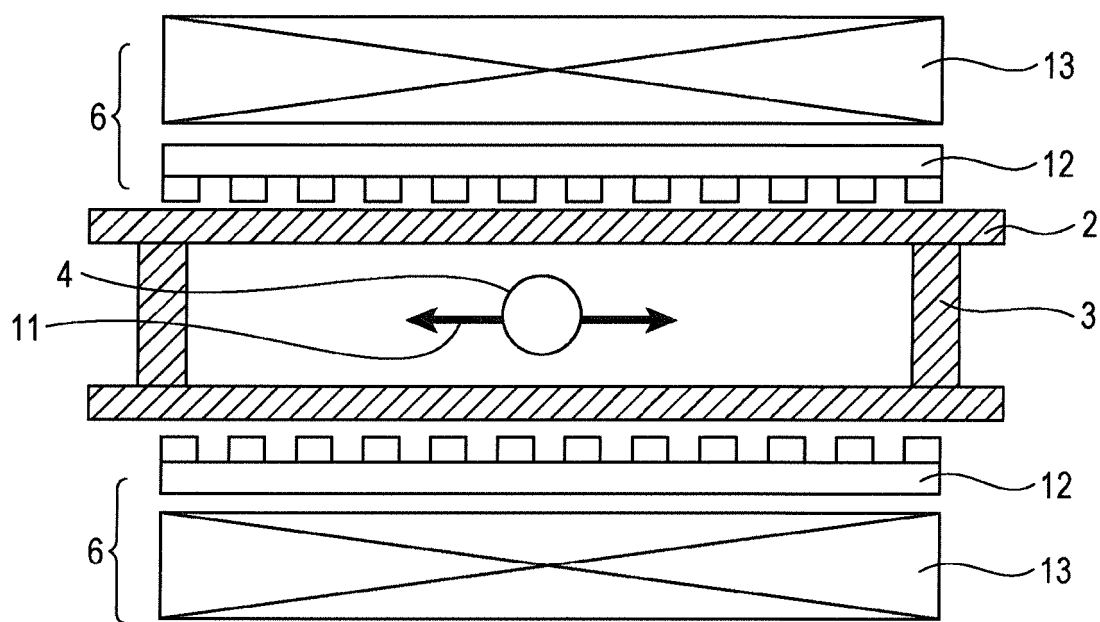


FIG. 14

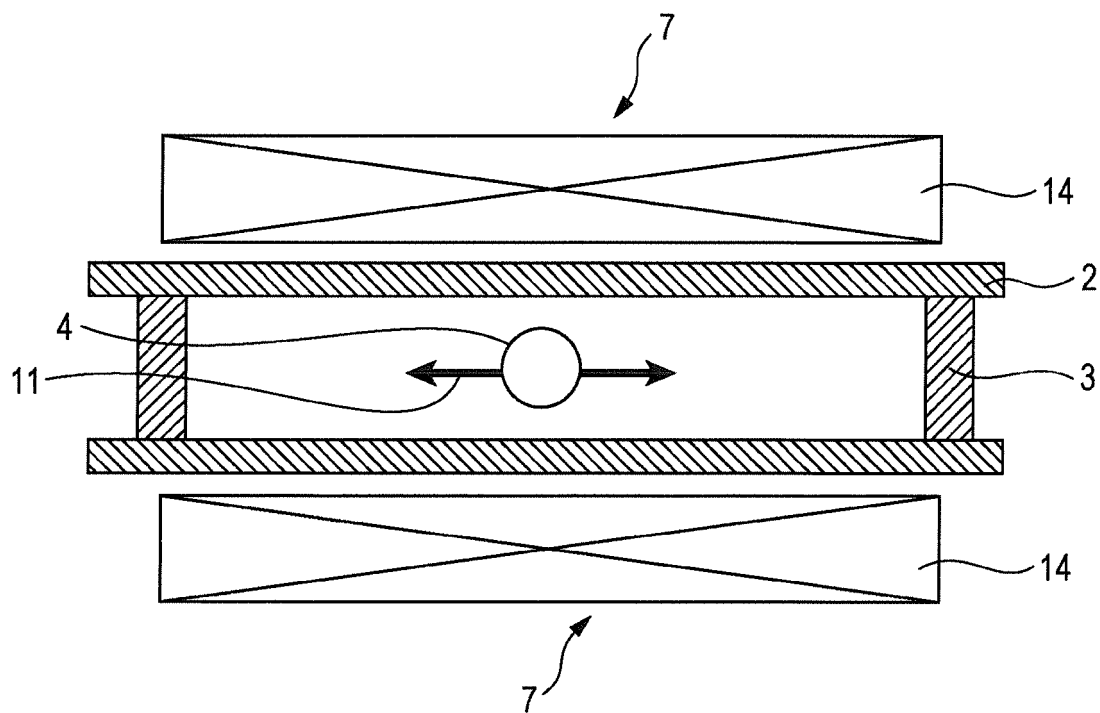


FIG. 15

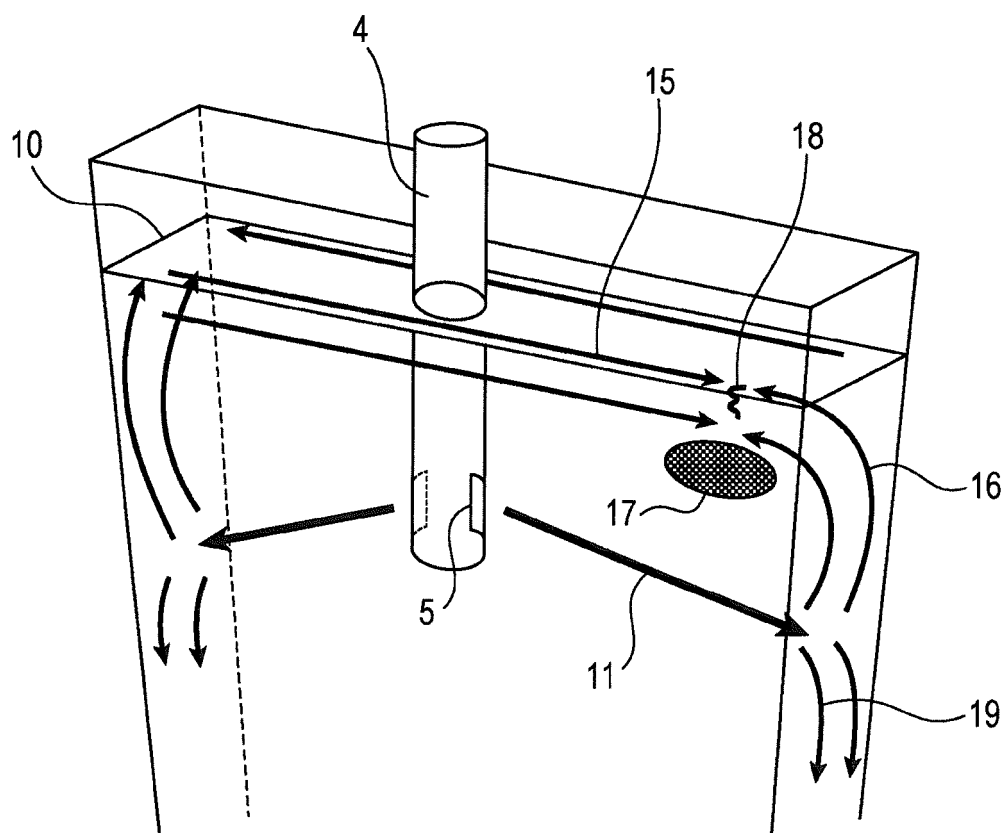


FIG. 16

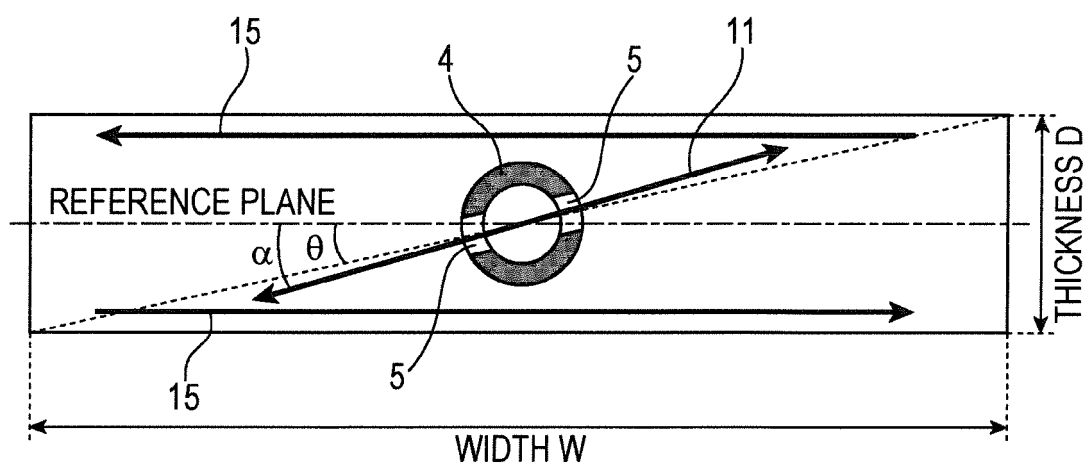


FIG. 17

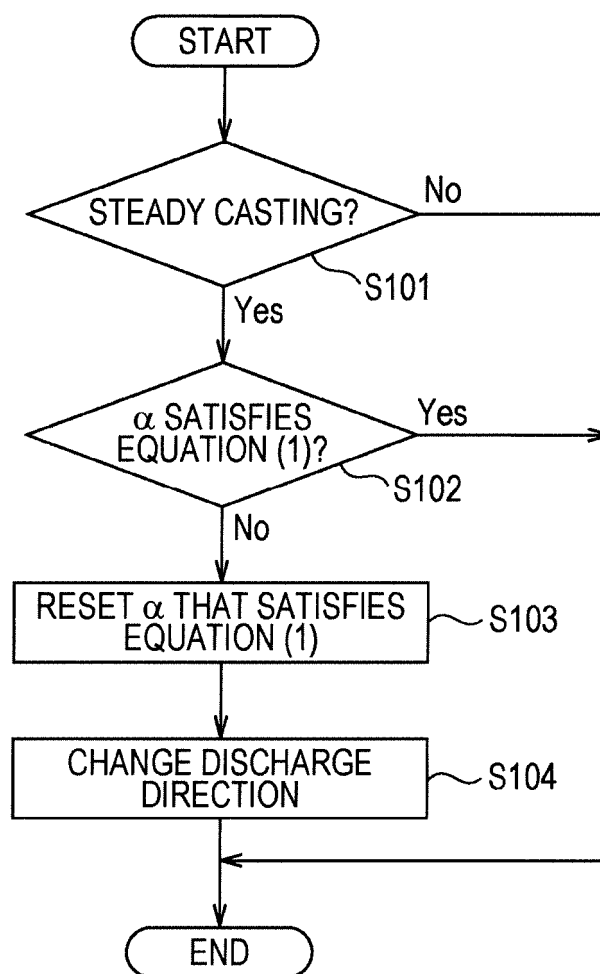


FIG. 18

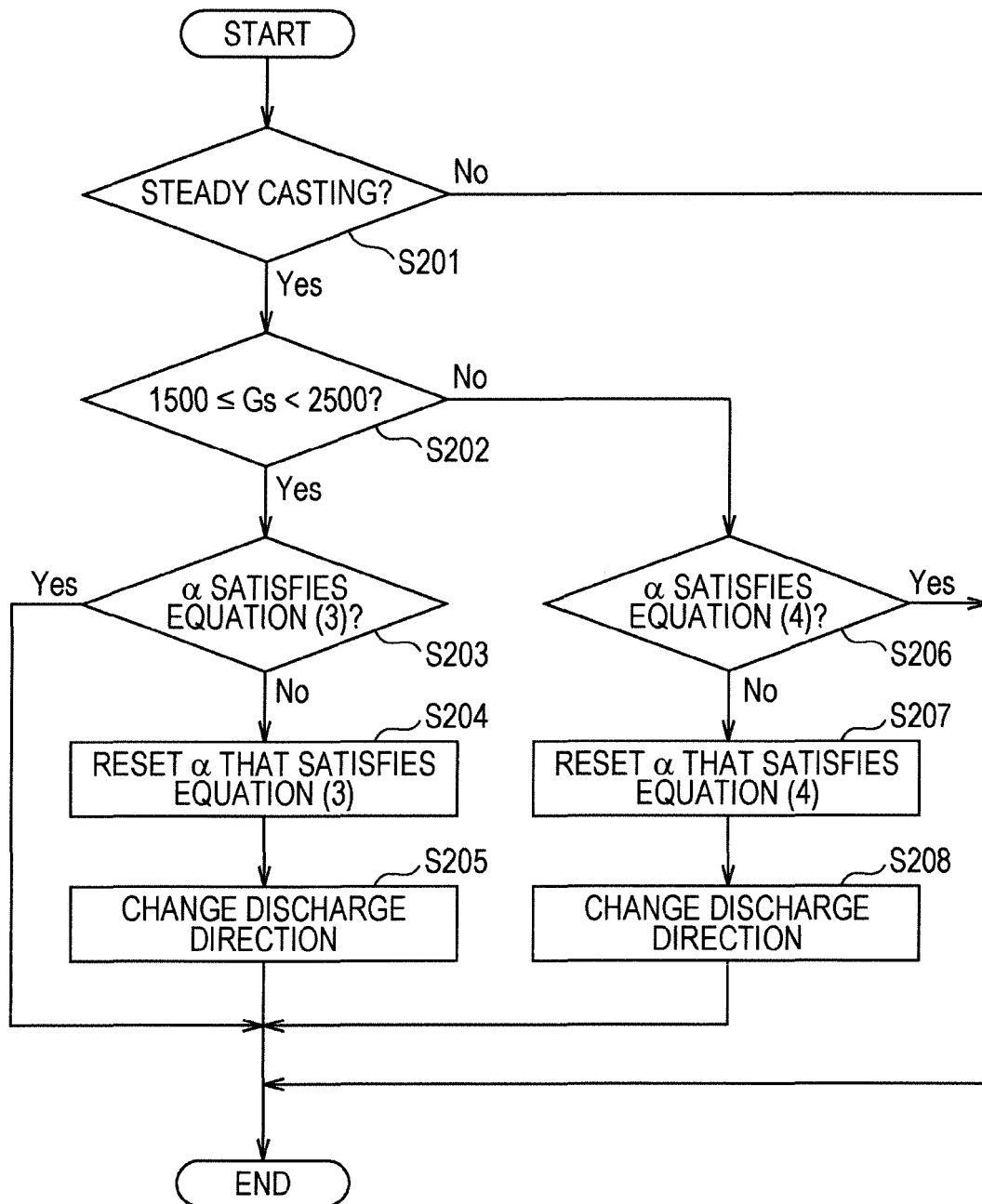


FIG. 19

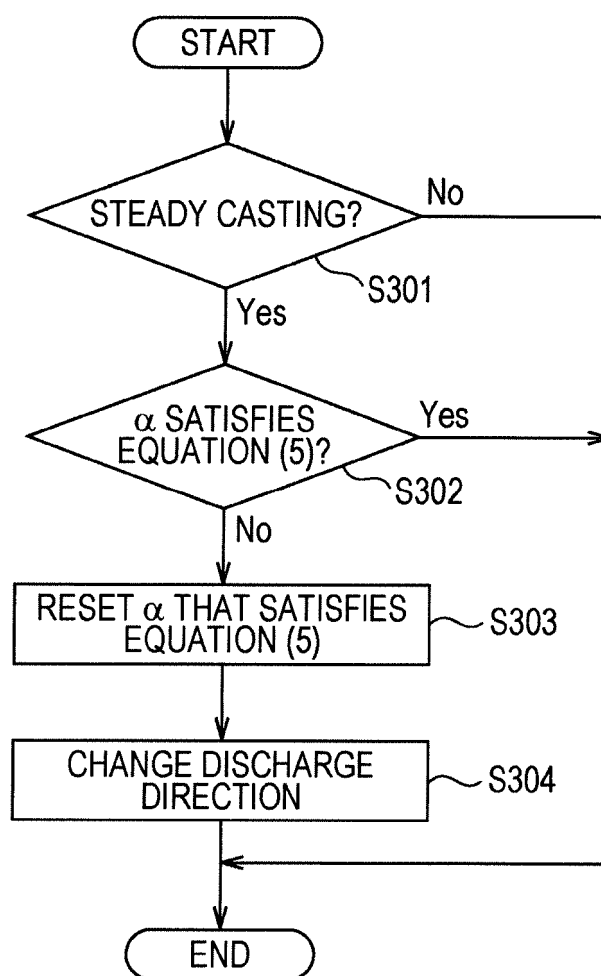


FIG. 20

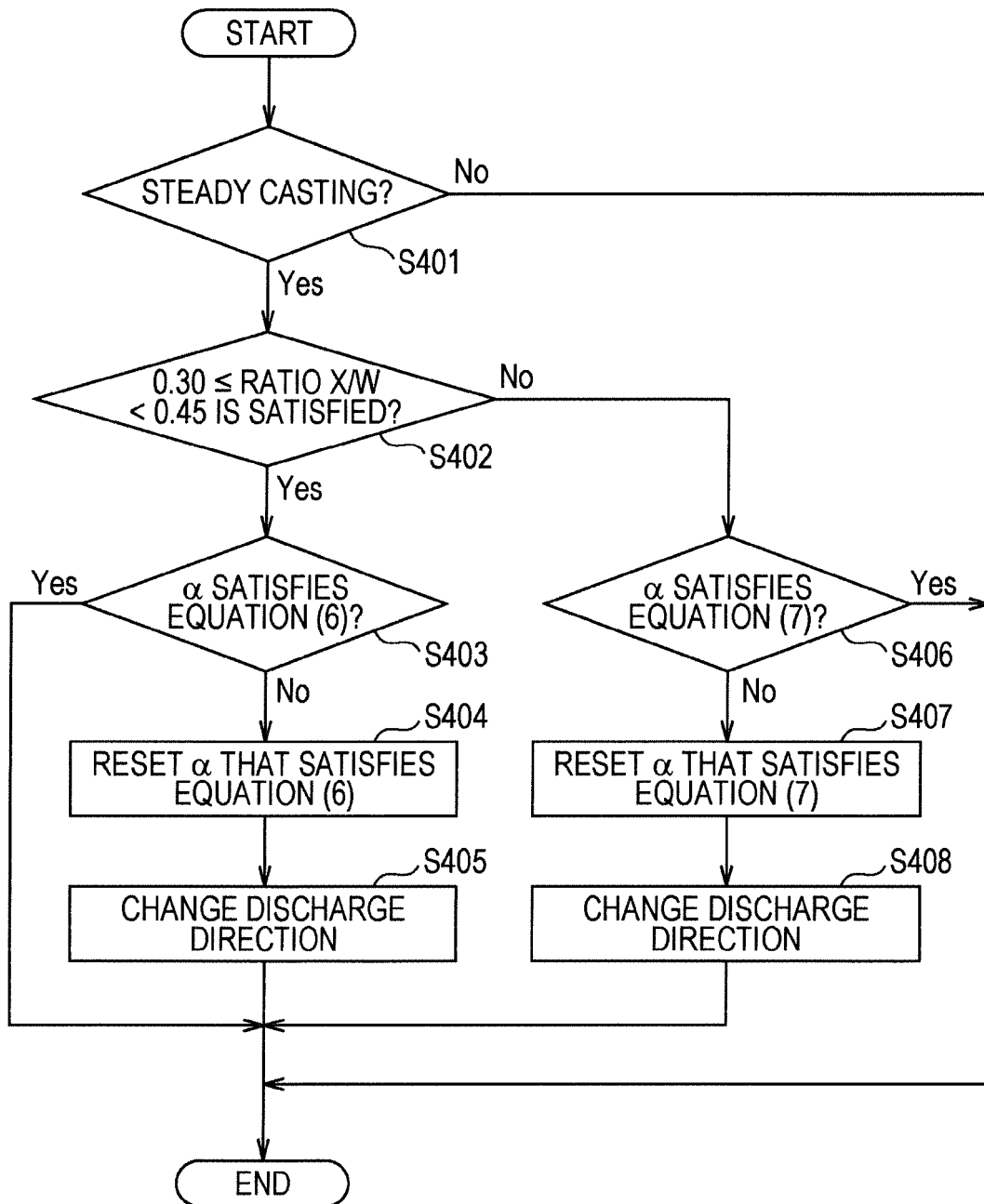


FIG. 21

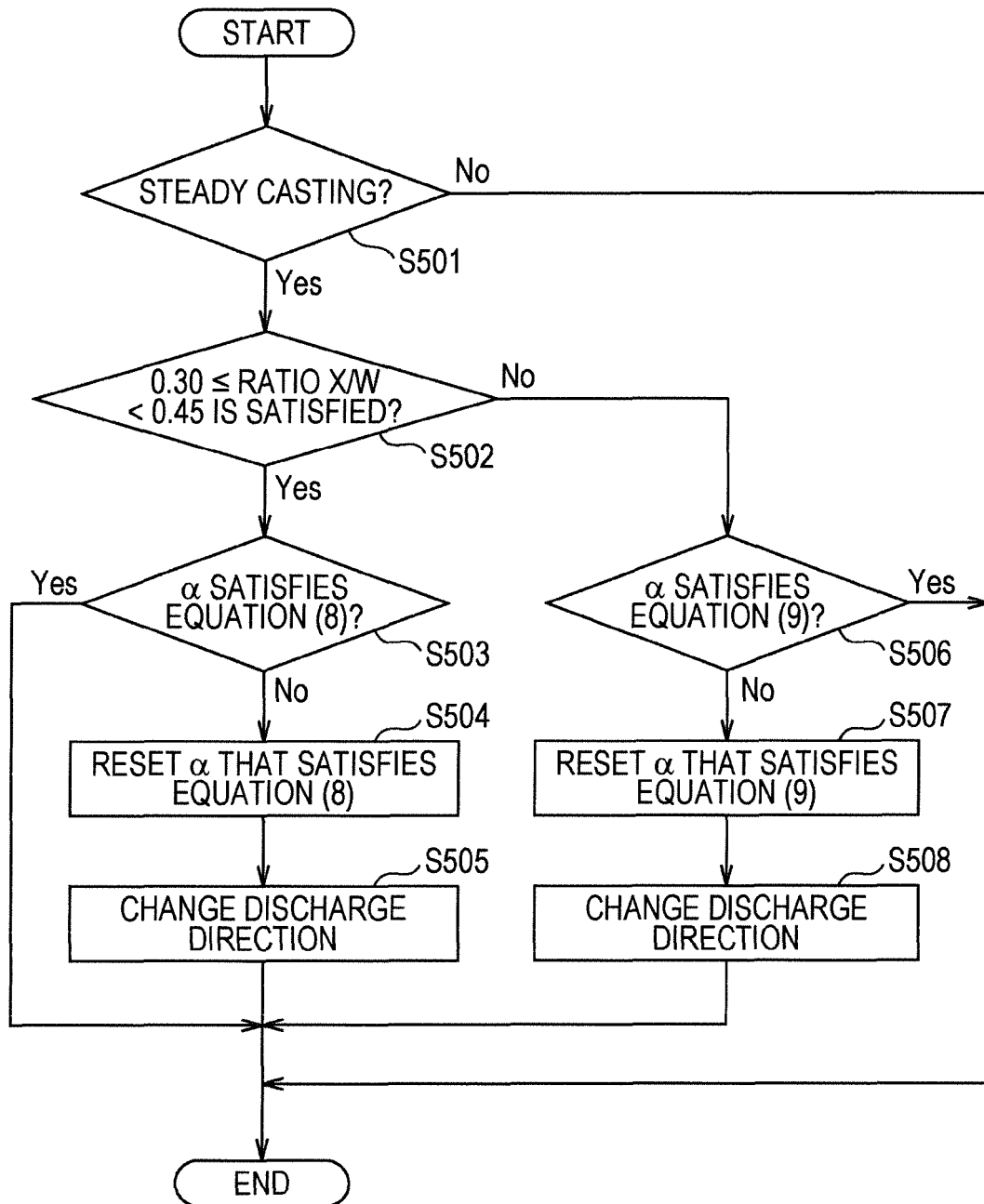


FIG. 22

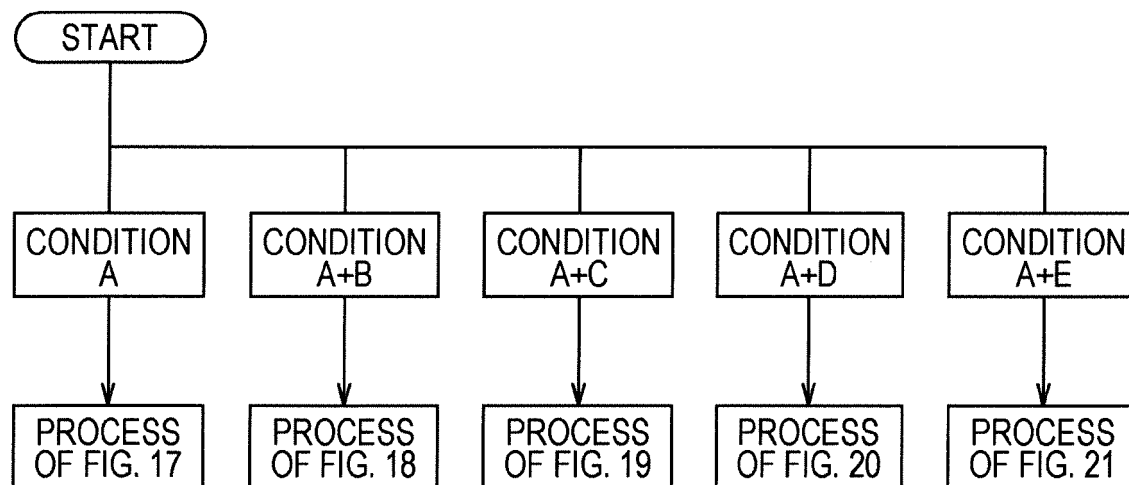


FIG. 23

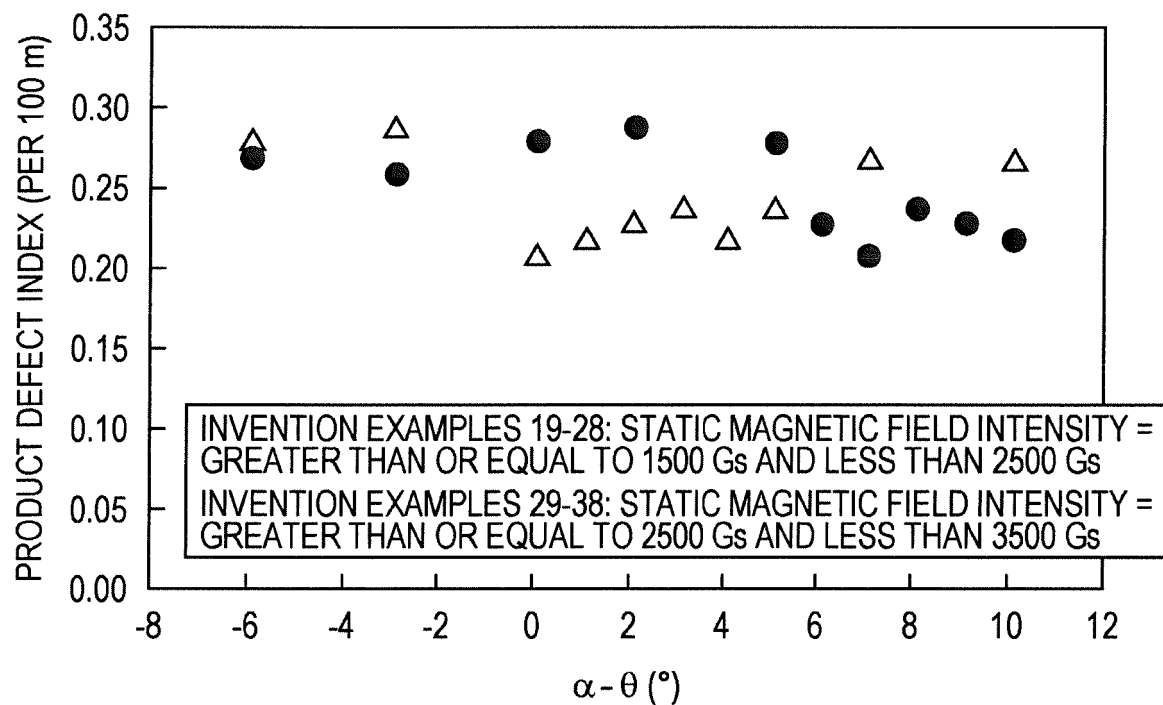


FIG. 24

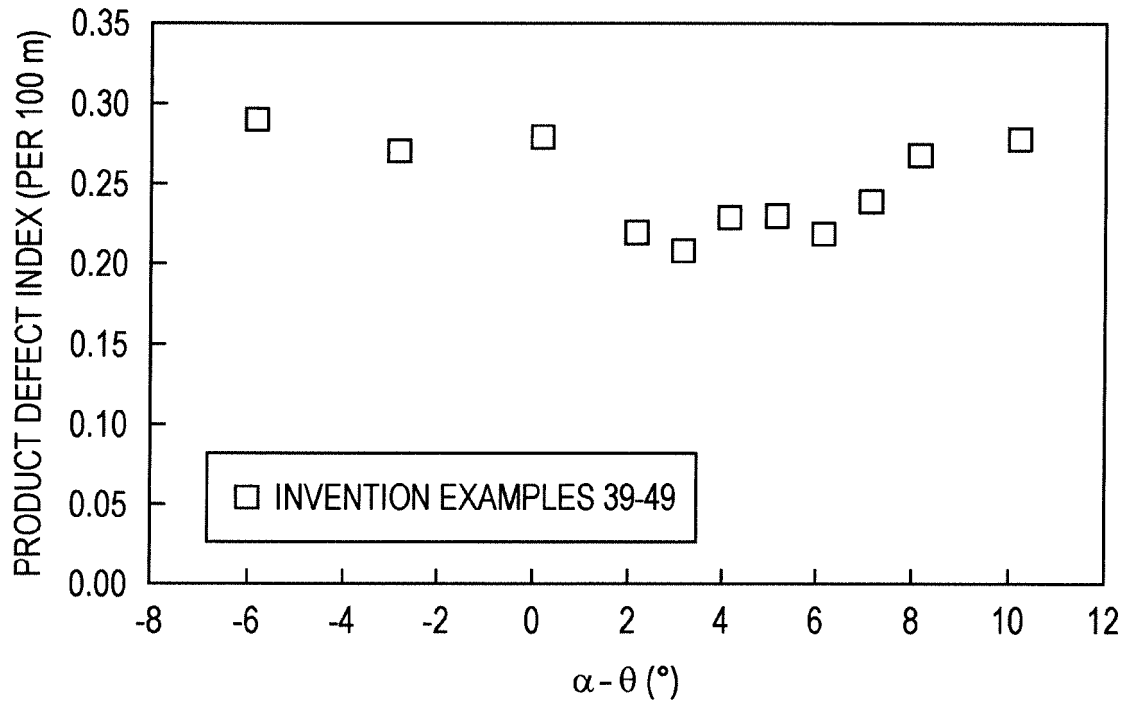


FIG. 25

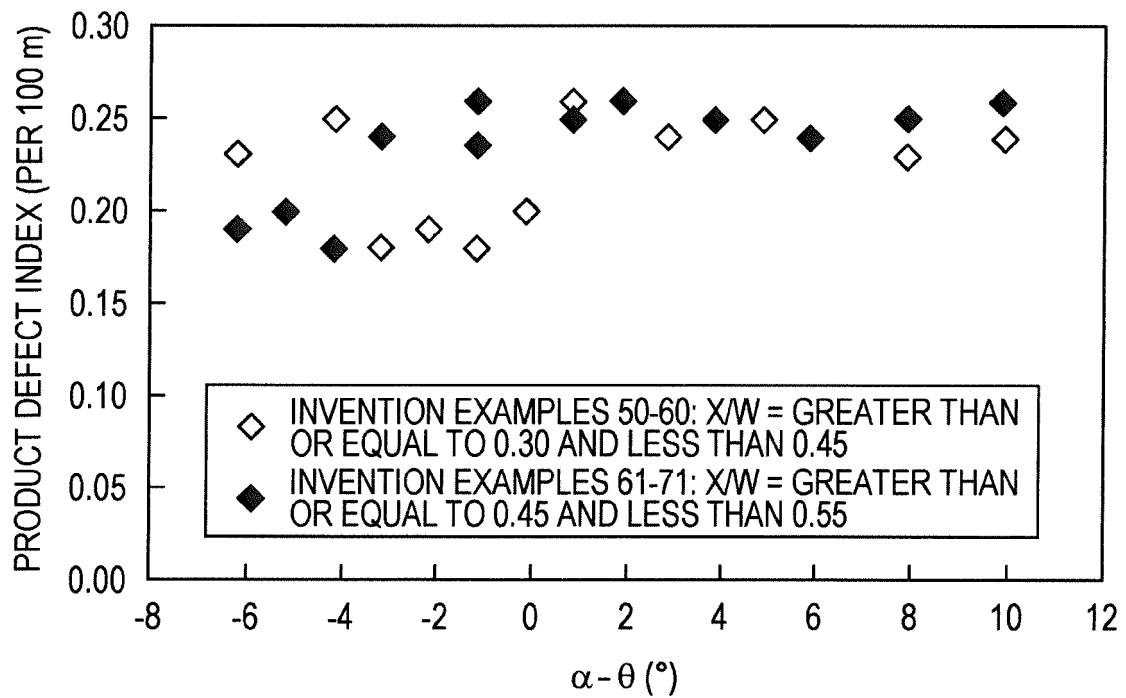
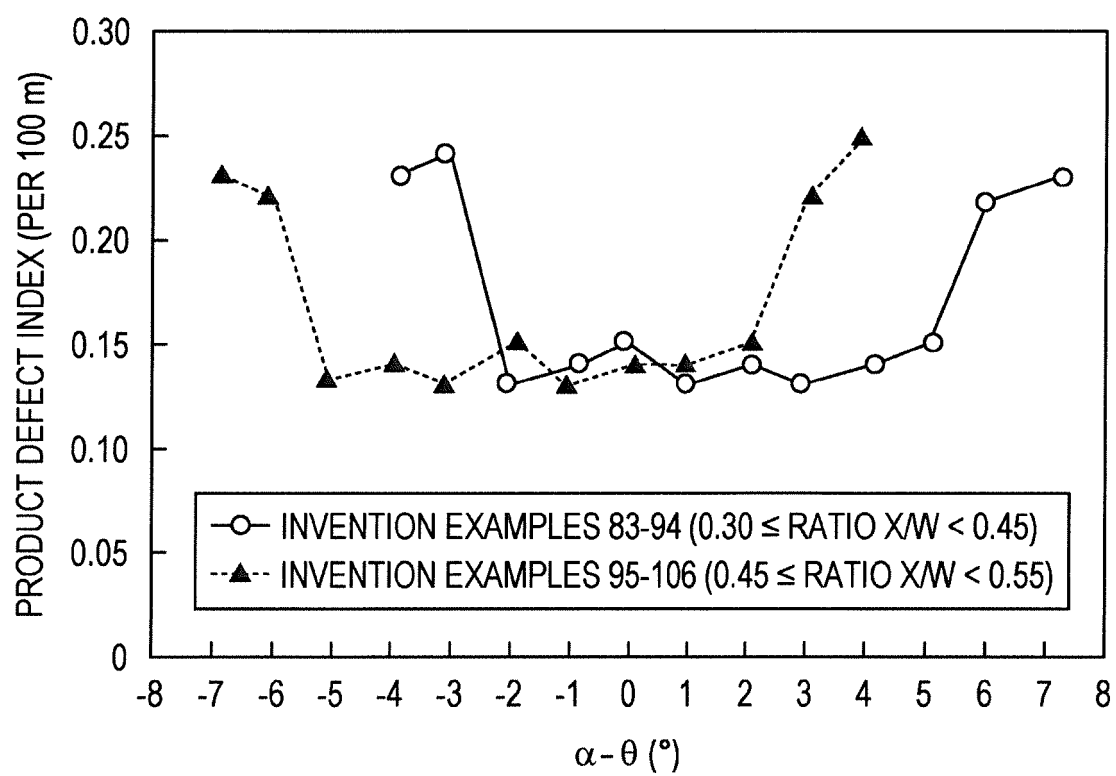


FIG. 26



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/004124

A. CLASSIFICATION OF SUBJECT MATTER

B22D11/115(2006.01)i, B22D11/10(2006.01)i, B22D11/11(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)

B22D11/115, B22D11/10, B22D11/11

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 1996-2016

Kokai Jitsuyo Shinan Koho 1971-2016 Toroku Jitsuyo Shinan Koho 1994-2016

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 2015-85370 A (JFE Steel Corp.), 07 May 2015 (07.05.2015), (Family: none)	1-11
A	JP 2006-896 A (Kobe Steel, Ltd.), 05 January 2006 (05.01.2006), (Family: none)	1-11
A	JP 2000-263199 A (Kawasaki Steel Corp.), 26 September 2000 (26.09.2000), (Family: none)	1-11



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search
21 September 2016 (21.09.16)Date of mailing of the international search report
04 October 2016 (04.10.16)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

REFERENCES CITED IN THE DESCRIPTION

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- JP 4285345 B [0007]
- JP 5742992 B [0007]