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(54) SUBMERGED ENTRY NOZZLE FOR CONTINUOUS CASTING, AND CONTINUOUS CASTING METHOD FOR STEEL

(57) An immersion nozzle and a steel manufacturing method that improve the quality of a cast piece are provided. The immersion nozzle for continuous casting having a shape of a cylinder with a bottom has, at a portion to be immersed in molten steel inside a mold for continuous casting, two or more pairs of discharge ports that are axially symmetrical with respect to an axial center of the immersion nozzle. In a molten steel flow passage inside a straight body part, an inside diameter at a lower part is equal to or smaller than an inside diameter at an upper part. When an opening part area of an upper discharge port is S3 and an opening part area of a lower discharge port is S4, a ratio of a straight-body-part internal cross-sectional area S1 at the upper part to a total one-side opening part area of the discharge ports is within a range of 0.30 to 0.50; a ratio of a straight-body-part internal cross-sectional area S2 at the lower part to the total one-side opening part area of the discharge ports is within a range of 0.10 to 0.40; and a relationship $0.20 \leq (S2/S4) \leq (S1/S3) \leq 1.0$ is met. A discharge angle of each discharge port is within a range of +20° to -50°, with an upward direction based on a horizontal direction being positive, and the discharge angle of the lower discharge port is downward within a range of 20° to 55° based on the discharge angle of the upper discharge port.

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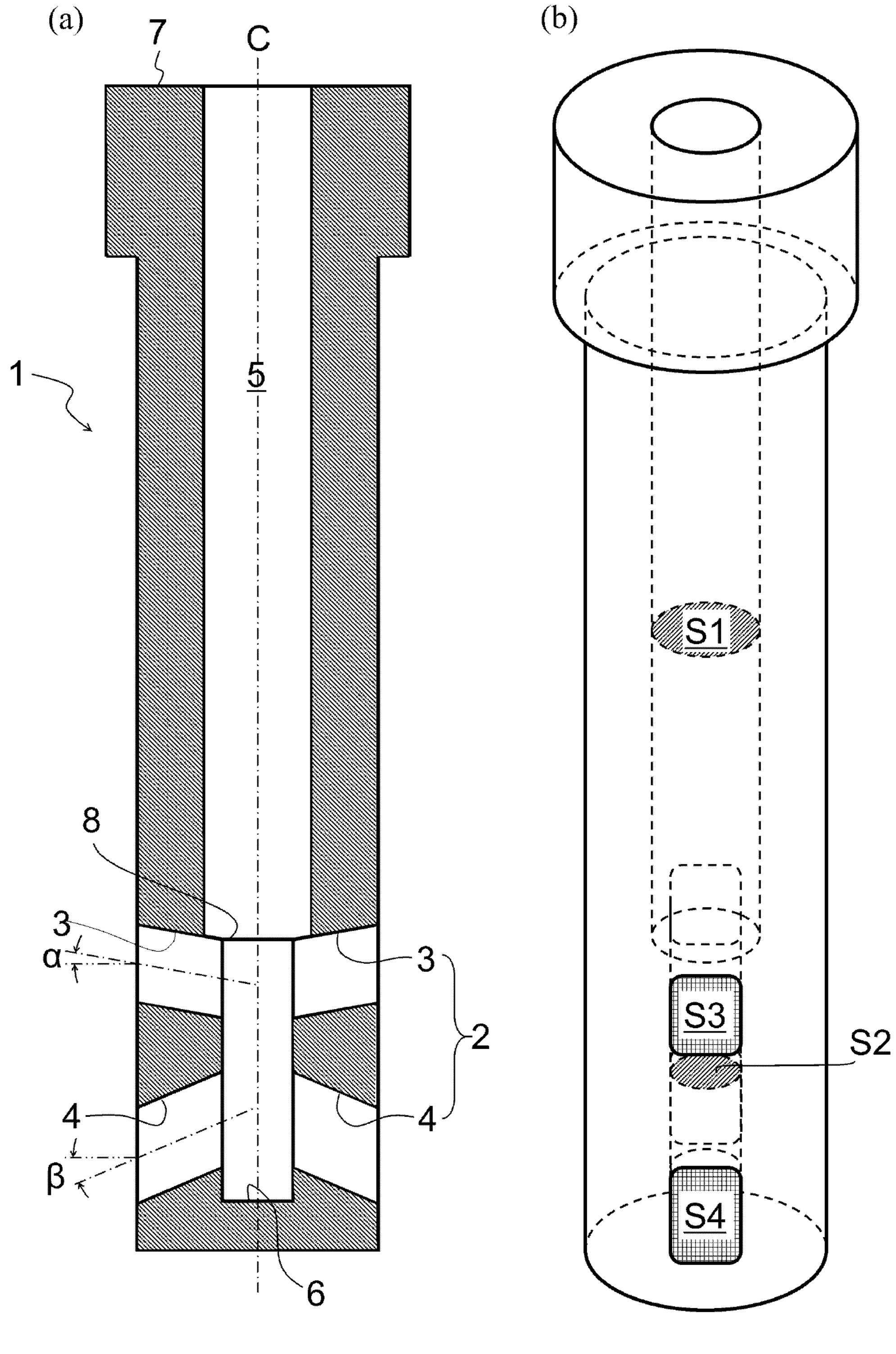
Fig. 1



Description

Technical Field

[0001] The present invention relates to an immersion nozzle for pouring molten steel into a mold when continuously casting the molten steel, and to a continuous casting method for steel using this immersion nozzle. Specifically, the present invention relates to an immersion nozzle for continuous casting and a continuous casting method for steel that can inhibit both capture, in a solidified shell, of bubbles of an inert gas blown into the immersion nozzle and entrapment of a mold powder in the solidified shell.

Background Art

[0002] Criteria for determining the quality of a cast piece of steel produced by a continuous casting machine include the following two. The first one is that the amount of bubbles of an inert gas, such as an argon gas, captured in the cast piece after being blown into molten steel flowing down inside an immersion nozzle is small. The second one is that the amount of a mold powder captured in the cast piece after being added to a meniscus (the bath surface of the molten steel inside the mold) is small. As the bubbles of the inert gas and the mold powder that have been captured in the cast piece constitute surface defects of the steel product, reducing these amounts is important.

[0003] When casting a slab cast piece using a continuous casting machine, an immersion nozzle having discharge ports facing the left and right short sides of the mold is generally used. Therefore, a discharge flow of molten steel discharged through each discharge port of the immersion nozzle collides with a solidified shell on the side of the short side of the mold (cast piece short-side solidified shell) and diverges upward and downward after the collision. One of the divergent flows forms a flow heading toward the lower side of the mold (hereinafter referred to as a "descending divergent flow"), while the other forms a flow heading toward the meniscus at an upper part (hereinafter referred to as an "ascending divergent flow").

[0004] Of these flows, the ascending divergent flow heading toward the meniscus forms an ascending flow along the short-side solidified shell of the slab cast piece (hereinafter referred to as an "ascending short-side flow"). This ascending short-side flow significantly influences the flow velocity of the molten steel in the meniscus. Specifically, the faster the ascending divergent flow becomes, the faster the ascending short-side flow becomes, and as the flow velocity of the ascending short-side flow increases, the flow velocity of the molten steel in the meniscus becomes higher. As a result, the frequency of entrapment of the mold powder present on the meniscus in the solidified shell increases. Thus, one problem in reducing defects due to the mold powder is how to decelerate the ascending divergent flow after the collision with the cast piece short-side solidified shell.

[0005] On the other hand, the descending divergent flow heading toward the lower side of the mold forms a descending flow along the short-side solidified shell of the slab cast piece (hereinafter referred to as a "descending short-side flow"). This descending short-side flow reaches deep inside an unsolidified layer. In this case, the faster the descending divergent flow becomes, the faster the descending short-side flow becomes, leading to an increase in the depth of penetration of the descending short-side flow into the unsolidified layer.

[0006] An inert gas, such as an argon gas, that has been blown into the molten steel flowing down inside the immersion nozzle to prevent adhesion of alumina to an inner wall of the immersion nozzle turns into bubbles and is discharged through the discharge ports of the immersion nozzle into the molten steel inside the mold. Part of the bubbles of the inert gas discharged into the molten steel inside the mold penetrates to the lower side of the mold along with the descending divergent flow. The faster the descending divergent flow becomes, the faster the descending short-side flow becomes, which results in an increase in the depth of penetration of the bubbles of the inert gas into the unsolidified layer and an increase in the amount of bubbles of the inert gas captured in the cast piece. Thus, one problem in reducing the amount of bubbles of the inert gas captured in the cast piece is how to decelerate the descending divergent flow after the collision with the cast piece short-side solidified shell.

[0007] Some measures have been proposed for these challenges, and as one such measure, a technology has been proposed that performs continuous casting using an immersion nozzle having a plurality of discharge ports at upper and lower positions on left and right sides of a part of the immersion nozzle to be immersed in molten steel.

[0008] For example, Patent Literature 1 discloses an immersion nozzle for continuous casting which has, at a portion of the immersion nozzle to be immersed in molten steel, a plurality of upper and lower discharge ports formed such that the opening part area of the discharge port provided on the lower side becomes smaller than the opening part area of the discharge port provided on the upper side, and in which the inside diameter of a molten steel flow passage inside the immersion nozzle is smaller in a range where the discharge ports are provided than in an upper part where discharge ports are not provided.

[0009] Patent Literature 1 alleges that discharge flows from the discharge ports can be made into slow uniform flows, and that thereby the descending short-side flow can be weakened to reduce the amounts of bubbles of an inert gas and non-metallic inclusions entrapped in a cast piece.

[0010] Patent Literature 2 discloses an immersion nozzle for continuous casting that has, at a portion of the immersion nozzle to be immersed in molten steel, four discharge ports consisting of a left-row, upper-tier port, a left-row, lower-tier port, a right-row, upper-tier port, and a right-row, lower-tier port. The opening part area of each lower-tier discharge port is smaller than the opening part area of each upper-tier discharge port. A ratio of the opening part area of each lower-tier discharge port to a total of the opening part areas of the upper-tier and lower-tier discharge ports is between 0.2 and 0.4 inclusive. The discharge angles of the lower-tier discharge ports are 10° or more downward based on the discharge angles of the upper-tier discharge ports.

[0011] Patent Literature 2 alleges that the flow velocity of the molten steel near an inner wall on the side of a cast piece short-side solidified shell can be sufficiently controlled, and that thereby bubbles of an inert gas and non-metallic inclusions can be inhibited from penetrating to a deep part of the cast piece through the descending short-side flow to obtain a cast piece with few internal defects.

[0012] Patent Literature 3 discloses an immersion nozzle having, at a portion to be immersed into molten steel inside a mold, two or more pairs of discharge ports that are bilaterally symmetrical with respect to an axial center of the immersion nozzle. For two discharge ports with the vertical positional relationship, the opening part area of the discharge port located on the lower side is equal to or larger than the opening part area of the discharge port located on the upper side. The discharge angle of each discharge port is limited to a maximum of 15° upward relative to the horizontal direction and a maximum of 50° downward relative to the horizontal direction. Of the two discharge ports with a vertical positional relationship, the discharge port located on the lower side has a discharge angle that is a downward angle larger than the discharge angle of the discharge port located on the upper side, and the difference between the discharge angle of the discharge port located on the lower side and the discharge angle of the discharge port located on the upper side is between 20° and 55° inclusive.

Citation List

Patent Literature

[0013]

Patent Literature 1: JP-2006-198655A
Patent Literature 2: International Publication No. WO 2010/109887
Patent Literature 3: JP-2019-63851A

Summary of Invention

Technical Problem

[0014] However, the above-described related art has the following problems.

[0015] In the technology described in Patent Literature 1, the discharge angle of each discharge port is preferably within a range of 10° upward to 45° downward. In an example of implementation of Patent Literature 1, however, the discharge angle of the discharge port provided on the lower side and the discharge angle of the discharge port provided on the upper side are the same. Thus, no difference is provided between the discharge angle of the discharge port provided on the lower side and the discharge angle of the discharge port provided on the upper side. Therefore, discharge flows discharged through the upper and lower discharge ports merge, so that an ideal damping effect on the discharge flows can hardly be achieved.

[0016] In the technology described in Patent Literature 2, the opening part area of the lower discharge port is smaller than the opening part area of the upper discharge port, and the difference between the discharge angle of the lower discharge port and the discharge angle of the upper discharge port is small. For these reasons, the flow velocity of the molten steel in the meniscus becomes high, leading to a high chance of the occurrence of the entrapment of the mold powder.

[0017] While the technology described in Patent Literature 3 mentions angles of the discharge ports, there is no specific description of the relationship between the straight-body-part internal cross-sectional area of the immersion nozzle and the areas of the discharge ports. Thus, specific conditions are unknown, and it is doubtful that an improving effect can be actually achieved.

[0018] The present invention has been developed in view of these circumstances, and an object thereof is to provide an immersion nozzle for continuous casting that improves the quality of a cast piece when pouring molten steel into a mold for continuous casting in continuous casting of steel. Specifically, the object is to stably inhibit the capture, in the cast piece, of bubbles of an inert gas, such as an argon gas, having been blown into the molten steel flowing down inside the immersion nozzle, as well as to stably inhibit the capture, in the cast piece, of a mold powder having been added to the meniscus.

Another object is to provide a steel continuous casting method that uses the immersion nozzle.

Solution to Problem

[0019] An immersion nozzle for continuous casting according to the present invention for solving the above-described problems is an immersion nozzle for continuous casting which has a shape of a cylinder with a bottom and through which molten steel is poured into a mold for continuous casting. This immersion nozzle has the following characteristics. The immersion nozzle has, at a portion to be immersed in the molten steel inside the mold for continuous casting, two or more pairs of discharge ports that are axially symmetrical with respect to an axial center of the immersion nozzle. In a molten steel flow passage inside a straight body part of the immersion nozzle, an inside diameter in a range from an upper end of an upper discharge port to a bottom of the immersion nozzle is equal to or smaller than that at other portions. When a one-side opening part area of the upper discharge port is S3 and a one-side opening part area of the lower discharge port is S4, a ratio of a straight-body-part internal cross-sectional area (S1) in a range from an upper end of the immersion nozzle to the upper end of the upper discharge port to a total one-side opening part area (S3 + S4) of the discharge ports is within a range of 0.30 to 0.50; a ratio of a straight-body-part internal cross-sectional area (S2) in a range from the upper end of the upper discharge port to the bottom of the immersion nozzle to the total one-side opening part area (S3 + S4) of the discharge ports is within a range of 0.10 to 0.40; and the straight-body-part internal cross-sectional areas (S1, S2) of the immersion nozzle and the one-side opening areas (S3, S4) of the discharge ports meet a relationship $0.20 \leq (S2/S4) \leq (S1/S3) \leq 1.0$. A discharge angle of each of the discharge ports is within a range of +20° to -50°, with an upward direction based on a horizontal plane being positive. The discharge angle of the discharge port on a vertically lower side is vertically downward within a range of 20° to 55° based on the discharge angle of the discharge port on a vertically upper side.

[0020] The immersion nozzle for continuous casting according to the present invention could be a more preferable solution when two of the discharge ports with a vertical positional relationship face different directions in the horizontal plane, and at least one pair of the discharge ports faces a direction parallel to a long-side surface of the mold.

[0021] A steel continuous casting method according to the present invention is characterized in that: the above-described immersion nozzle is used; a mold powder is added to a surface of molten steel inside a mold for continuous casting; and molten steel inside a tundish is poured into the mold through the immersion nozzle, while an inert gas is blown into molten steel flowing down the molten steel flow passage of the immersion nozzle.

[0022] The steel continuous casting method according to the present invention could be a more preferable solution when, for example:

(a) the molten steel inside the tundish is poured into the mold through the immersion nozzle, while a direct-current static magnetic field is applied to the molten steel inside the mold, on an upper side of a discharge port located at a vertically uppermost part and on a lower side of a discharge port located at a vertically lowermost part of the immersion nozzle, from a direct-current magnetic field generation device installed on a back surface of the mold for continuous casting; and

(b) the molten steel inside the tundish is poured into the mold through the immersion nozzle, while an alternating-current moving magnetic field is applied to the molten steel inside the mold from an alternating-current magnetic field generation device installed on the back surface of the mold for continuous casting.

Advantageous Effects of Invention

[0023] When the immersion nozzle according to the present invention is used, molten steel discharged through the upper and lower discharge ports of the immersion nozzle is kept at an appropriate discharge flow rate, and moreover, the discharge flows discharged through the upper and lower discharge ports collide with the cast piece short-side solidified shell without merging. Thus, a descending divergent flow, after the collision with the cast piece short-side solidified shell, of the discharge flow from the discharge port located on the upper side and an ascending divergent flow, after the collision with the cast piece short-side solidified shell, of the discharge flow from the discharge port located on the lower side collide with each other, thereby each dampening the other's flow velocity. As a result, the descending short-side flow that influences the capture of bubbles of an inert gas in the cast piece is mainly formed by the descending divergent flow, after the collision with the cast piece short-side solidified shell, of the discharge flow discharged through the discharge port on the vertically lowermost side. On the other hand, the ascending short-side flow that influences the flow velocity of the molten steel in the meniscus that is a determining factor in the entrapment of the mold powder is mainly formed by the ascending divergent flow, after the collision with the cast piece short-side solidified shell, of the discharge flow discharged through the discharge port on the vertically uppermost side. Thus, both the ascending short-side flow and the descending short-side flow can be decelerated, which makes it possible to stably inhibit both the entrapment of the mold powder and capture of bubbles of the inert gas in the cast piece. Therefore, the quality of the cast piece can be improved when pouring molten steel into a mold for continuous casting using the immersion nozzle according to the present invention in continuous casting of steel.

Brief Description of Drawings

[0024]

[Fig. 1] (a) is a longitudinal sectional view of an immersion nozzle according to one embodiment of the present invention, and (b) is a perspective view as seen from above discharge directions.
[Fig. 2] is a view schematically showing a result of a study on a flow inside a mold in a water model experiment simulating a flow of molten steel inside a mold using the immersion nozzle according to the embodiment.

Description of Embodiments

[0025] An embodiment of the present invention will be specifically described below. The drawings are schematic and may differ from the reality. The following embodiment presents examples of a device and a method for embodying the technical idea of the present invention, and is not intended to restrict the configuration to the one described below. That is, various changes can be made to the technical idea of the present invention within the technical scope described in the claims.

[0026] In the following, the present invention will be specifically described.

[0027] In a lateral cross-section of a slab cast piece, the cast piece width is far larger than the cast piece thickness, and slab cast pieces with various cast piece widths are needed. In general, the cast piece width/cast piece thickness ratio is often within a range of about 4 to 12. In a continuous casting machine that produces a slab cast piece, therefore, a mold for continuous casting commensurate with the dimensions of the lateral cross-section of the slab cast piece to be cast is used. To adjust the internal space of the rectangular mold, the mold for continuous casting has one pair of mold long sides facing each other and one pair of mold short sides facing each other, and is configured such that the mold short sides are movable on the inner side of the mold long sides.

[0028] As an immersion nozzle for pouring molten steel into this mold for continuous casting, an immersion nozzle having one or more pairs of discharge ports that face one pair of mold short sides facing each other is used. The molten steel is poured through each discharge port toward each mold short side. Therefore, the discharge flow of the molten steel discharged through each discharge port collides with a solidified shell on the side of the mold short side, i.e., a cast piece short-side solidified shell, and diverges upward and downward after the collision. One of the divergent flows forms a flow heading toward the lower side of the mold, i.e., a descending divergent flow. The other divergent flow forms a flow heading toward the meniscus at an upper part, i.e., an ascending divergent flow. The ascending divergent flow heading toward the meniscus forms an ascending flow along the short-side solidified shell of the slab cast piece, i.e., an ascending short-side flow. The descending divergent flow heading toward the lower side of the mold forms a descending flow along the short-side solidified shell of the slab cast piece, i.e., a descending short-side flow.

[0029] The present inventors considered an immersion nozzle that could decelerate both the descending short-side flow and the ascending short-side flow in such a slab continuous casting machine. As a result, we found that an immersion nozzle having the following shape was optimal.

[0030] Specifically, the immersion nozzle according to this embodiment is a refractory having a shape of a cylinder with a bottom through which molten steel is poured into a mold for continuous casting. The immersion nozzle has, at a portion to be immersed in the molten steel inside the mold for continuous casting, two or more pairs of discharge ports that are bilaterally symmetrical with respect to an axial center of the immersion nozzle. In a molten steel flow passage inside a straight body part of the immersion nozzle, an inside diameter in a range from an upper end of an upper discharge port to a bottom of the immersion nozzle is equal to or smaller than that at other portions. A cross-sectional area S1 of the straight body part at the upper part in the inner diameter of the immersion nozzle, a cross-sectional area S2 of the straight body part where the discharge ports are disposed, an opening part area S3 of the discharge port disposed on the upper side, and an opening part area S4 of the discharge port disposed on the lower side meet relationships $S1/(S3+S4) = 0.30$ to 0.50 and $S2/(S3+S4) = 0.10$ to 0.40. In addition, they meet a relationship $0.20 \leq (S2/S4) \leq (S1/S3) \leq 1.0$. Further, as for discharge angles of the discharge ports, the discharge ports disposed one above the other are within a range of +20° to -50°. The discharge angle of the discharge port on the vertically lower side is vertically downward within a range of 20° to 55° based on the discharge angle of the discharge port on the vertically upper side. Here, "the discharge angle of the discharge port" refers to an angle formed between a central axis of the discharge port and a horizontal plane, and being upward means being positive.

[0031] The immersion nozzle according to this embodiment has, at the portion to be immersed in the molten steel inside the mold for continuous casting, two or more pairs of discharge ports that are axially symmetrical with respect to the axial center of the immersion nozzle. This is because when the immersion nozzle has two or more pairs of axially symmetrical discharge ports, discharge flows discharged through the discharge ports are dispersed and the flow velocities of the discharge flows decrease. Thus, both the descending divergent flow and the ascending divergent flow that are formed after the discharge flows collide with the cast piece short-side solidified shell decelerate.

[0032] In the molten steel flow passage inside the straight body part of the immersion nozzle, the inside diameter in the range from the upper end of the upper discharge port to the bottom of the immersion nozzle is equal to or smaller than that at other portions. The cross-sectional area S1 of the straight body part at the upper part in the inner diameter of the immersion nozzle, the cross-sectional area S2 of the straight body part where the discharge ports are disposed, the opening part area S3 of the discharge port disposed on the upper side, and the opening part area S4 of the discharge port disposed on the lower side meet the relationships $S1/(S3+S4) = 0.30$ to 0.50 and $S2/(S3+S4) = 0.10$ to 0.40. In addition, they meet the relationship $0.20 \leq (S2/S4) \leq (S1/S3) \leq 1.0$. Thus, a phenomenon that the flow rate of the discharge flow discharged through the discharge port on the vertically lower side becomes high due to a pressure difference can be mitigated. In addition, the descending short-side flow can be further reduced by the discharge flows distributed through the discharge ports provided one above the other. When these conditions are not met, the flow rate balance between the discharge ports changes, so that the molten steel flow passage may become clogged with a substance such as alumina adhering to an inner wall etc., of the immersion nozzle.

[0033] As for the discharge angles of the discharge ports, the discharge ports disposed one above the other are within the range of +20° to -50°. This is because if the discharge angles of the discharge ports are set to be upward beyond 20° upward relative to the horizontal direction, the discharge flow from the discharge port provided on the vertically uppermost side may fail to collide with the cast piece short-side solidified shell and directly head for the meniscus without being decelerated. On the other hand, if the discharge angles of the discharge ports are set to be downward beyond 50° downward relative to the horizontal direction, the position at which the discharge flow from the discharge port provided on the vertically lowermost side collides with the cast piece short-side solidified shell becomes a position deeper than the lower end of the mold, so that the descending short-side flow may fail to be decelerated. Therefore, the discharge angles of the discharge ports should be within the range of +20° to -50°.

[0034] For the two discharge ports with a vertical positional relationship, the discharge angle of the discharge port located on the lower side should have a downward angle larger than the discharge angle of the discharge port located on the upper side, and the difference between the discharge angle of the discharge port located on the lower side and the discharge angle of the discharge port located on the upper side should be between 20° and 55° inclusive. These specifications are to prevent the discharge flow from the discharge port located on the upper side and the discharge flow from the discharge port located on the lower side from merging before colliding with the cast piece short-side solidified shell. If the difference in the discharge angle is smaller than 20°, the discharge flows from the two discharge ports may merge. On the other hand, if the difference in the discharge angle exceeds 55°, the discharge flow from the discharge port located on the lower side may collide with the cast piece short-side solidified shell below the lower end of the mold, and the depth of penetration of the descending short-side flow may increase. Or the discharge flow from the discharge port located on the upper side may collide with the cast piece short-side solidified shell immediately below the meniscus, and the ascending short-side flow may become faster.

[0035] Further, in the immersion nozzle according to this embodiment, it is preferable that the two discharge ports with a vertical positional relationship face different directions in the horizontal plane, and that at least one pair of the discharge ports faces a direction parallel to a long-side surface of the mold. That the discharge flow from the upper discharge port and the discharge flow from the lower discharge port are oriented in different directions in the horizontal plane is preferable, because then the likelihood that the discharge flows may interfere with each other and merge decreases and the dispersing effect on the discharge flows is enhanced. The different directions in the horizontal plane should be less than 90° apart at a maximum. This is because when the discharge flows collide with the solidified shell on the side of the mold long-side surface, the balance of the thickness of the solidified shell is lost, which may adversely affect the quality of the cast piece. In particular, when a discharge port with a higher discharge flow rate of the two discharge ports with a vertical positional relationship is oriented in a direction parallel to the long-side surface of the mold, the flow of the molten steel inside the mold can be appropriately controlled.

[0036] Fig. 1 shows the immersion nozzle for continuous casting according to one embodiment of the present invention. Fig. 1 (a) is a longitudinal sectional view as cut along a plane including a central axis C of an immersion nozzle 1 and a central axes of discharge ports 2, and Fig. 1 (b) is a perspective view as seen from an obliquely upper side facing the discharge ports 2. The immersion nozzle 1 of the embodiment shown in Fig. 1 is the immersion nozzle 1 having two pairs of discharge ports 2 that are axially symmetrical with respect to the axial center C of the immersion nozzle 1, one vertically above the other at a portion to be immersed in molten steel.

[0037] Reference signs in Fig. 1 denote as follows: 1 is the immersion nozzle; 2 is the discharge ports; 3 is discharge ports located on the vertically upper side (hereinafter referred to as "upper discharge ports"); 4 is discharge ports located on the vertically lower side (hereinafter referred to as "lower discharge ports"); 5 is a molten steel flow passage provided inside the immersion nozzle 1; 6 is a bottom of the immersion nozzle 1; 7 is an upper end position of the immersion nozzle 1; 8 is an upper end position of the upper discharge ports 3; α is a discharge angle of the upper discharge ports 3; β is a discharge angle of the lower discharge ports 4; S 1 is an area of the molten steel flow passage in a range from the upper end position 7 of the immersion nozzle 1 to the upper end position 8 of the upper discharge ports 3 (straight-body-part internal cross-sectional area); S2 is an area of the molten steel flow passage in a range from the upper end position 8 of the upper discharge ports 3 to the bottom 6 of the immersion nozzle 1 (straight-body-part internal cross-sectional area); S3 is a one-side opening part area of the upper discharge ports 3; and S4 is a one-side opening part area of the lower discharge ports 4. In the immersion nozzle 1 shown in Fig. 1, since two pairs of discharge ports 2 are each vertically arranged, the upper discharge ports 3 correspond to the discharge ports 2 provided on the vertically uppermost side, and the lower discharge ports 4 correspond to the discharge ports 2 provided on the vertically lowermost side. In the example of Fig. 1, the upper discharge ports 3 and the lower discharge ports 4 are oriented in the same direction in a horizontal plane.

[0038] The immersion nozzle 1 of this embodiment is configured as described above. In the following, a steel continuous casting method using the immersion nozzle 1 according to this embodiment thus configured will be described.

[0039] The immersion nozzle 1 is installed at the bottom of a tundish, and the tundish is installed above a mold for continuous casting such that the immersion nozzle 1 is located nearly at the center of the space inside the mold. While molten steel produced in a refining furnace, such as a converter, is poured into the tundish from a ladle containing the molten steel, the molten steel is poured from the tundish into the mold for continuous casting through the immersion nozzle 1. A mold powder is added to a meniscus, i.e., the bath surface of the molten steel inside the mold so as to cover the surface of the molten steel inside the mold. An inert gas, such as an argon gas or a nitrogen gas, is blown into the molten steel flowing down the molten steel flow passage 5 of the immersion nozzle 1 through a sliding nozzle or a tundish upper nozzle.

[0040] Fig. 2 is a view schematically showing a result of a study on a flow inside a mold in a water model experiment simulating a flow of molten steel inside a mold that was performed using the immersion nozzle 1 of this embodiment in which two pairs of discharge ports 2 were each vertically arranged. In the following, the flow of the molten steel inside the mold will be described based on Fig. 2. While Fig. 2 shows only half of the mold for continuous casting on one side, half thereof on the other side has the same form, with the central axis C being an axis of symmetry.

[0041] Reference signs in Fig. 2 denote as follows: 9 is a mold short side; 10 is the bath surface inside the mold (corresponding to the meniscus); 11 is a discharge flow from the upper discharge port 3; 12 is a discharge flow from the lower discharge port 4; 13 is an ascending divergent flow formed as the discharge flow 11 from the upper discharge port 3 diverges; 14 is a descending divergent flow formed as the discharge flow 11 from the upper discharge port 3 diverges; 15 is an ascending divergent flow formed as the discharge flow 12 from the lower discharge port 4 diverges; 16 is a descending divergent flow formed as the discharge flow 12 from the lower discharge port 4 diverges; 17 is an ascending short-side flow flowing along the mold short side 9; 18 is a descending short-side flow flowing along the mold short side 9; and 19 is a meniscus flow. In Fig. 2, the same parts as in Fig. 1 are denoted by the same reference signs while description thereof will be omitted. In Fig. 2, reference signs 20 and 21 are a flow velocity meter-sensor that measures the flow velocity of the meniscus flow 19 and a flow velocity meter-sensor that measures the flow velocity of the descending short-side flow 18, respectively, in the water model experiment. In Fig. 2, the discharge flow 11 and the discharge flow 12 are represented by straight lines, but the discharge flow 11 and the discharge flow 12 in reality flow toward the mold short side 9 while moving up and down as time passes.

[0042] As shown in Fig. 2, the discharge flow 11 discharged through the upper discharge port 3 and the discharge flow 12 discharged through the lower discharge port 4 collide with the mold short side 9 without merging in a range before colliding with the mold short side 9. After colliding with the mold short side 9, the discharge flow 11 diverges into the ascending divergent flow 13 and the descending divergent flow 14, and the discharge flow 12 diverges into the ascending divergent flow 15 and the descending divergent flow 16. In the immersion nozzle 1 of this embodiment, the discharge flow is dispersed into the two of the discharge flow 11 and the discharge flow 12. When the amount of molten steel poured into the mold is the same, i.e., when a cast piece pulling speed is the same, in this embodiment, the flow velocity of each of the ascending divergent flow 13, the descending divergent flow 14, the ascending divergent flow 15, and the descending divergent flow 16 is reduced compared with an ascending divergent flow and a descending divergent flow in the case where there is one pair of discharge ports 2 (only one discharge port on one side). Further, the descending divergent flow 14 and the ascending divergent flow 15 are flows facing opposite directions, and the descending divergent flow 14 and the ascending divergent flow 15 collide and interfere with each other and thereby decelerate.

[0043] As a result, the ascending short-side flow 17 that influences the meniscus flow 19 that is a determining factor in the entrapment of the mold powder is mainly determined by the flow velocity of the ascending divergent flow 13 while being little influenced by the ascending divergent flow 15. Since the ascending divergent flow 13 is decelerated compared with the velocity of the ascending divergent flow in the case of one pair of discharge ports 2, the ascending short-side flow 17 is decelerated, and thereby the flow velocity of the meniscus flow 19 is reduced.

[0044] Similarly, the descending short-side flow 18 that influences the capture of gas bubbles in the cast piece is mainly determined by the flow velocity of the descending divergent flow 16 while being little influenced by the descending divergent flow 14. Since the descending divergent flow 16 is decelerated compared with the velocity of the descending divergent flow in the case of one pair of discharge ports 2, the flow velocity of the descending short-side flow 18 decreases.

[0045] Thus, when molten steel is continuously cast using the immersion nozzle 1 according to this embodiment, both the meniscus flow 19 that influences the entrapment of the mold powder and the descending short-side flow 18 that influences the capture of gas bubbles in the cast piece are decelerated. As a result, both the entrapment of the mold powder and capture of bubbles of the inert gas in the cast piece can be stably inhibited.

[0046] In the above-described embodiment, one pair of discharge ports 2 on the upper side and another pair of discharge ports 2 on the lower side are used. This may be changed so as to use two or more pairs of discharge ports 2 that discharge in different directions relative to the horizontal direction, at the same vertical position on either the upper side or the lower side. In this case, the opening cross-sectional areas of the discharge ports 2 should be the total opening area on one side relative to the central axis.

[0047] As has been described above, according to this embodiment, both the ascending short-side flow 17 that influences the flow velocity of the molten steel in the meniscus that is a determining factor in the entrapment of the mold powder and the descending short-side flow 18 that influences the capture of bubbles of the inert gas in the cast piece can be decelerated. Thus, it is possible to stably inhibit both the entrapment of the mold powder and capture of bubbles of the inert gas in the cast piece.

Examples

[0048] The present invention is configured as has been described above. In the following, the implementability and effects of the present invention will be further described using examples of implementation.

[0049] Continuous casting operation was performed in an actual slab continuous casting machine using the immersion nozzle 1 according to the embodiment (Invention Example). The lateral cross-section of a slab cast piece that was continuously cast had dimensions with a thickness of 220 to 260 mm and a width of 1000 to 2200 mm. An argon gas was used as an inert gas blown into the immersion nozzle 1, and an optimal mold powder according to the cast piece pulling speed and the type of steel was added to the surface of the molten steel inside the mold. For comparison, an immersion nozzle having one pair of discharge ports on the left and right sides of the immersion nozzle, an immersion nozzle having two pairs of discharge ports on the left and right sides of the immersion nozzle, and an immersion nozzle in which conditions for providing two pairs of discharge ports were outside the range of the present invention were also used.

[0050] The following three types of molds for continuous casting were used: a mold in which no magnetic field generation device was installed; a mold in which direct-current magnetic field generation devices were installed on back surfaces of the mold for continuous casting so as to face each other across the long sides of the mold, in a total of two levels, one on each of the upper side of the upper discharge port and the lower side of the lower discharge port; and a mold in which alternating-current magnetic field generation devices were installed on the back surfaces of the mold for continuous casting so as to face each other across the long sides of the mold.

[0051] In the continuous casting operation using the mold for continuous casting in which the direct-current magnetic field generation devices were installed, a direct-current static magnetic field was applied from the direct-current magnetic field generation devices in the two upper and lower levels to the molten steel inside the mold, on the upper side of the upper discharge port and the lower side of the lower discharge port. In the continuous casting operation using the mold for continuous casting in which the alternating-current magnetic field generation devices were installed, an alternating-current moving magnetic field was applied from the alternating-current magnetic field generation devices to the molten steel inside the mold for continuous casting, and continuous casting was performed while the molten steel inside the mold was swirled in a horizontal direction in the meniscus.

[0052] Slab cast pieces produced by the slab continuous casting machine were hot-rolled into hot-rolled steel sheets, and these hot-rolled steel sheets were inspected for surface defects caused by argon gas bubbles and mold powder. From these surface defects, argon gas bubbles and mold powder remaining in the cast piece were evaluated. Specifically, a steel product with a lower defect index was evaluated as having fewer argon gas bubbles and less mold powder remaining in the cast piece.

[0053] Table 1 shows the conditions of the immersion nozzle, and Table 2 shows the operation conditions and the operation results. Designing the immersion nozzle within the range of the present invention resulted in lower ratios of inclusion of defects in the steel product.

Table 1

No.	Discharge Angle		Area Ratio				Remarks
	α	β	S1/(S3+S4)	S2/(S3+S4)	S1/S3	S2/S4	
	○	○	-	-	-	-	
1	+10	-25	0.3	0.1	0.1	0.1	Invention Example
2	+5	-30	0.3	0.1	0.1	0.1	Invention Example
3	0	-35	0.3	0.1	0.1	0.1	Invention Example

(continued)

No.	Discharge Angle		Area Ratio				Remarks
	α	β	S1/(S3+S4)	S2/(S3+S4)	S1/S3	S2/S4	
	○	○	-	-	-	-	
4	+10	-25	0.4	0.2	0.3	0.2	Invention Example
5	+5	-30	0.4	0.2	0.3	0.2	Invention Example
6	0	-35	0.4	0.2	0.3	0.2	Invention Example
7	+10	-25	0.5	0.3	0.5	0.4	Invention Example
8	+5	-30	0.5	0.3	0.5	0.4	Invention Example
9	0	-35	0.5	0.3	0.5	0.4	Invention Example
10	+10	-25	0.5	0.1	0.7	0.5	Invention Example
11	+5	-30	0.5	0.1	0.7	0.5	Invention Example
12	0	-35	0.5	0.1	0.7	0.5	Invention Example
13	+10	-25	0.3	0.2	1.0	0.8	Invention Example
14	+5	-30	0.3	0.2	1.0	0.8	Invention Example
15	0	-35	0.3	0.2	1.0	0.8	Invention Example
16	+10	-25	0.4	0.3	0.3	0.1	Invention Example
17	+5	-30	0.4	0.3	0.3	0.1	Invention Example
18	0	-35	0.4	0.3	0.3	0.1	Invention Example
19	0	-15	0.3	0.2	0.1	0.1	Comparative Example
20	0	-5	0.3	0.2	0.1	0.1	Comparative Example
21	+10	-50	0.3	0.2	0.1	0.1	Comparative Example
22	+10	-50	0.4	0.3	0.3	0.2	Comparative Example
23	-	-15	-	0.4	-	0.4	Comparative Example
24	-	-25	-	0.4	-	0.4	Comparative Example
25	-	-45	-	0.5	-	0.4	Comparative Example
26	+10	-25	0.5	0.5	1	0.9	Comparative Example
27	+5	-30	0.6	0.4	1.1	0.9	Comparative Example
28	+10	-25	0.4	0.07	0.8	0.2	Comparative Example
29	+5	-30	1.6	1.1	3.2	2.2	Comparative Example
30	0	-35	0.4	0.5	0.8	1	Comparative Example

Table 2

No.	Amount of Molten Steel Passed	Direct-current Magnetic field	Alternating-current Moving Magnetic Field	Steel product Defect Index	Remarks
	ton/min	Applied/Not applied	Applied/Not applied	-	
1	4.2	Applied	Not Applied	0.25	Invention Example
2	4.2	Applied	Not Applied	0.23	Invention Example
3	4.2	Applied	Not Applied	0.21	Invention Example
4	5.4	Applied	Not Applied	0.18	Invention Example
5	5.4	Applied	Not Applied	0.15	Invention Example

(continued)

No.	Amount of Molten Steel Passed	Direct-current Magnetic field	Alternating-current Moving Magnetic Field	Steel product Defect Index	Remarks
	ton/min	Applied/Not applied	Applied/Not applied	-	
6	5.4	Applied	Not Applied	0.16	Invention Example
7	5.0	Applied	Not Applied	0.19	Invention Example
8	5.0	Applied	Not Applied	0.18	Invention Example
9	5.0	Applied	Not Applied	0.13	Invention Example
10	4.2	Not Applied	Applied	0.17	Invention Example
11	4.2	Not Applied	Applied	0.12	Invention Example
12	4.2	Not Applied	Applied	0.15	Invention Example
13	5.4	Not Applied	Applied	0.14	Invention Example
14	5.4	Not Applied	Applied	0.19	Invention Example
15	5.4	Not Applied	Applied	0.20	Invention Example
16	5.0	Not Applied	Applied	0.21	Invention Example
17	5.0	Not Applied	Applied	0.23	Invention Example
18	5.0	Not Applied	Applied	0.22	Invention Example
19	4.2	Not Applied	Not Applied	0.32	Comparative Example
20	4.2	Not Applied	Not Applied	0.35	Comparative Example
21	4.2	Not Applied	Not Applied	0.37	Comparative Example
22	4.2	Not Applied	Not Applied	0.33	Comparative Example
23	4.2	Not Applied	Not Applied	0.35	Comparative Example
24	4.2	Not Applied	Not Applied	0.38	Comparative Example
25	4.2	Not Applied	Not Applied	0.40	Comparative Example
26	5.0	Not Applied	Not Applied	0.40	Comparative Example
27	5.0	Not Applied	Not Applied	0.40	Comparative Example
28	4.2	Not Applied	Not Applied	0.32	Comparative Example
29	4.2	Not Applied	Not Applied	0.37	Comparative Example
30	4.2	Not Applied	Not Applied	0.39	Comparative Example

Reference Signs List

[0054]

1 Immersion nozzle
2 Discharge port
3 Upper discharge port
4 Lower discharge port
5 Molten steel flow passage
6 Bottom of immersion nozzle
7 Upper end position of immersion nozzle
8 Upper end position of upper discharge port
9 Mold short side
10 Bath surface inside mold
11 Discharge flow from upper discharge port

12 Discharge flow from lower discharge port
13 Ascending divergent flow
14 Descending divergent flow
15 Ascending divergent flow
16 Descending divergent flow
17 Ascending short-side flow
18 Descending short-side flow
19 Meniscus flow
20 Flow velocity meter-sensor
21 Flow velocity meter-sensor
α, β Discharge angle
S1 Straight-body-part internal cross-sectional area (in a range from upper end position of immersion nozzle to upper end position of upper discharge port)
S2 Straight-body-part internal cross-sectional area (in a range from upper end position of upper discharge port to bottom of immersion nozzle)
S3 Opening part area (on one side of upper discharge port)
S4 Opening part area (on one side of lower discharge port)
C Central axis (axial center)

Claims

1. An immersion nozzle for continuous casting which has a shape of a cylinder with a bottom and through which molten steel is poured into a mold for continuous casting, **characterized in that**:

    the immersion nozzle has, at a portion to be immersed in the molten steel inside the mold for continuous casting, two or more pairs of discharge ports that are axially symmetrical with respect to an axial center of the immersion nozzle;
    in a molten steel flow passage inside a straight body part of the immersion nozzle, an inside diameter in a range from an upper end of an upper discharge port to a bottom of the immersion nozzle is equal to or smaller than that at other portions;
    when a one-side opening part area of the upper discharge port is S3 and a one-side opening part area of the lower discharge port is S4,

        a ratio of a straight-body-part internal cross-sectional area (51) in a range from an upper end of the immersion nozzle to the upper end of the upper discharge port to a total one-side opening part area (S3 + S4) of the discharge ports is within a range of 0.30 to 0.50,
        a ratio of a straight-body-part internal cross-sectional area (S2) in a range from the upper end of the upper discharge port to the bottom of the immersion nozzle to the total one-side opening part area (S3 + S4) of the discharge ports is within a range of 0.10 to 0.40, and
        the straight-body-part internal cross-sectional areas (S1, S2) of the immersion nozzle and the one-side opening areas (S3, S4) of the discharge ports meet a relationship $0.20 \leq (S2/S4) \leq (S1/S3) \leq 1.0$;

    a discharge angle of each of the discharge ports is within a range of +20° to -50°, with an upward direction based on a horizontal plane being positive; and
    the discharge angle of the discharge port on a vertically lower side is vertically downward within a range of 20° to 55° based on the discharge angle of the discharge port on a vertically upper side.

2. The immersion nozzle for continuous casting according to claim 1, wherein two of the discharge ports with a vertical positional relationship face different directions in the horizontal plane, and at least one pair of the discharge ports faces a direction parallel to a long-side surface of the mold.

3. A steel continuous casting method, **characterized in that**:

    the immersion nozzle for continuous casting according to claim 1 or 2 is used;
    a mold powder is added to a surface of molten steel inside a mold for continuous casting; and
    molten steel inside a tundish is poured into the mold through the immersion nozzle, while an inert gas is blown into molten steel flowing down the molten steel flow passage of the immersion nozzle.

4. The steel continuous casting method according to claim 3, wherein the molten steel inside the tundish is poured into the mold through the immersion nozzle, while a direct-current static magnetic field is applied to the molten steel inside the mold, on an upper side of a discharge port located at a vertically uppermost part and on a lower side of a discharge port located at a vertically lowermost part of the immersion nozzle, from a direct-current magnetic field generation device installed on a back surface of the mold for continuous casting.

5. The steel continuous casting method according to claim 3, wherein the molten steel inside the tundish is poured into the mold through the immersion nozzle, while an alternating-current moving magnetic field is applied to the molten steel inside the mold from an alternating-current magnetic field generation device installed on a back surface of the mold for continuous casting.

6. The steel continuous casting method according to claim 4, wherein the molten steel inside the tundish is poured into the mold through the immersion nozzle, while an alternating-current moving magnetic field is applied to the molten steel inside the mold from an alternating-current magnetic field generation device installed on the back surface of the mold for continuous casting.

Fig. 1

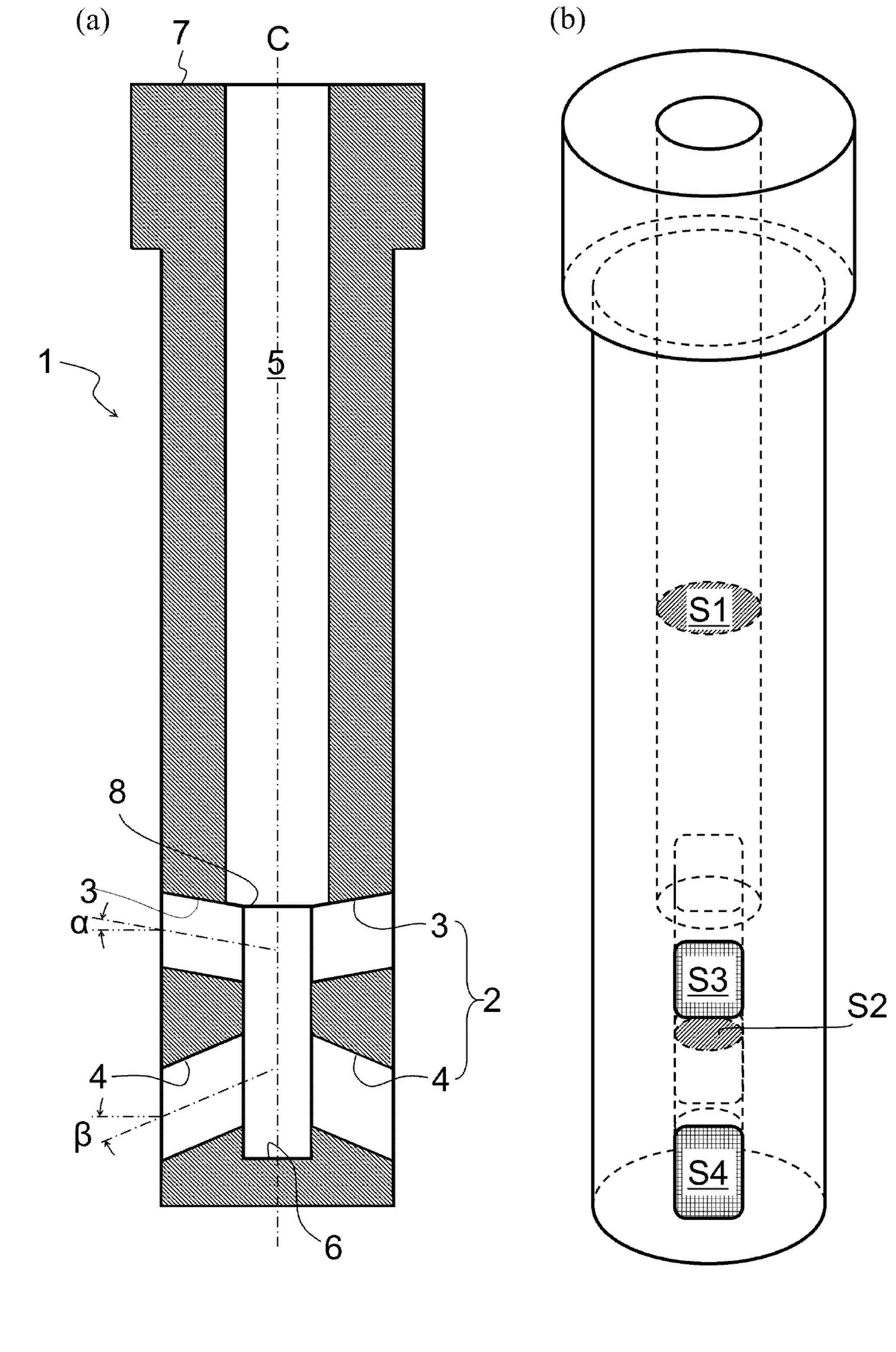
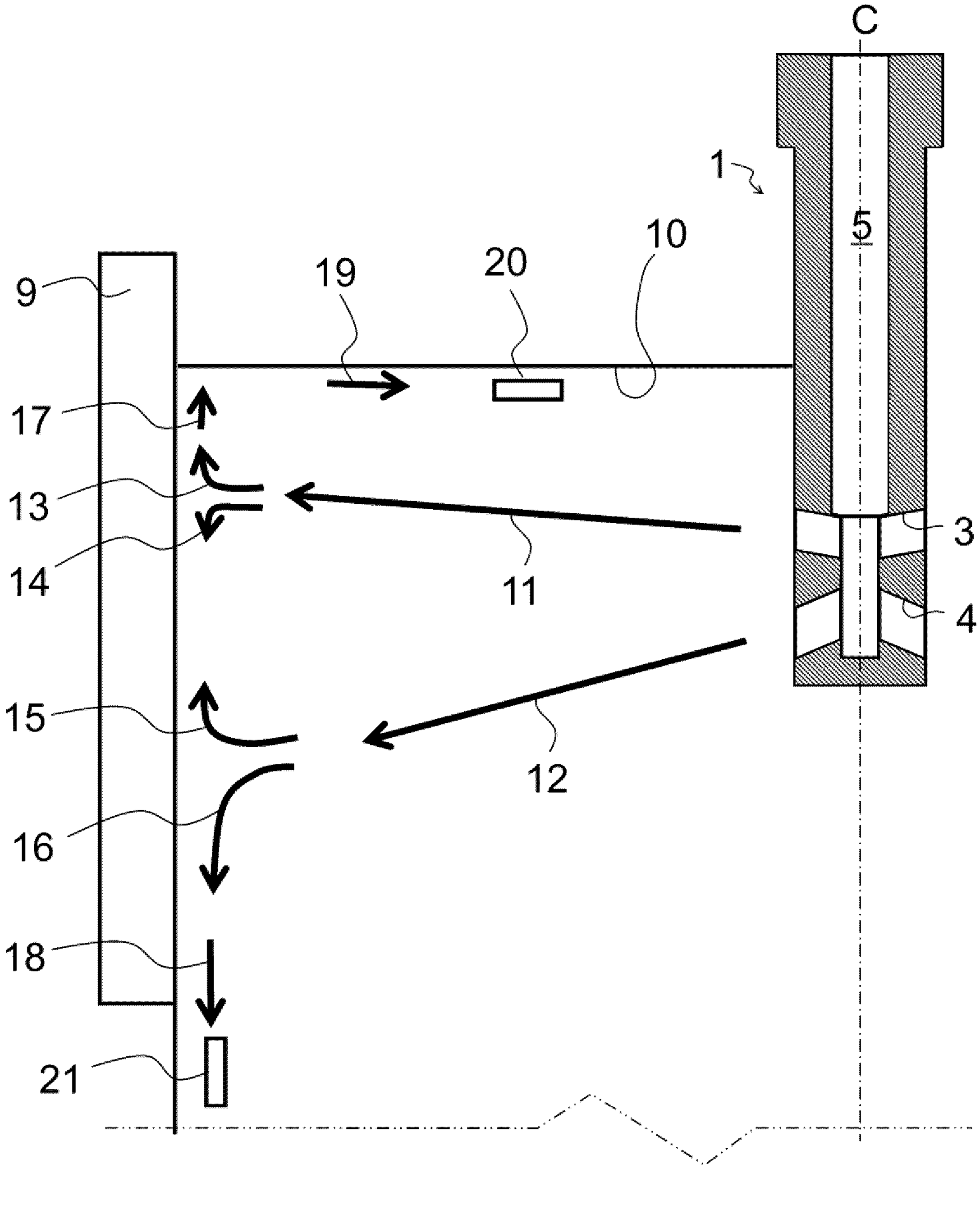


Fig. 2



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2023/003993

A. CLASSIFICATION OF SUBJECT MATTER

B22D 11/10(2006.01)i; ***B22D 11/04***(2006.01)i; ***B22D 11/11***(2006.01)i; ***B22D 11/115***(2006.01)i; ***B22D 41/50***(2006.01)i; ***B22D 41/58***(2006.01)i
FI: B22D11/10 330G; B22D11/10 330E; B22D11/10 330F; B22D11/10 330C; B22D11/10 360B; B22D11/11 D; B22D11/115 B; B22D11/04 311J; B22D41/50 520; B22D41/58

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)

B22D11/10; B22D11/04; B22D11/11; B22D11/115; B22D41/50; B22D41/58

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2019-63851 A (JFE STEEL CORP.) 25 April 2019 (2019-04-25) claims, paragraphs [0021]-[0044], fig. 1, 2	1-6
A	WO 2010/109887 A1 (NIPPON STEEL CORP.) 30 September 2010 (2010-09-30) paragraphs [0011]-[0015], [0017]-[0042], fig. 1	1-6
A	JP 2007-319923 A (NIPPON STEEL CORP.) 13 December 2007 (2007-12-13) claims, paragraphs [0048]-[0064], fig. 2	1-6
A	JP 2015-85370 A (JFE STEEL CORP.) 07 May 2015 (2015-05-07) claims, paragraphs [0014]-[0036], fig. 1-3	1-6
A	JP 2001-1115 A (NIPPON STEEL CORP.) 09 January 2001 (2001-01-09) claims, paragraphs [0022]-[0023], fig. 6	1-6

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

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Date of the actual completion of the international search	Date of mailing of the international search report
12 April 2023	**25 April 2023**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2023/003993

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 2019-63851 A	25 April 2019	(Family: none)	
WO 2010/109887 A1	30 September 2010	CN 102361712 A	
		BR PI1011869 A	
JP 2007-319923 A	13 December 2007	(Family: none)	
JP 2015-85370 A	07 May 2015	(Family: none)	
JP 2001-1115 A	09 January 2001	(Family: none)	

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REFERENCES CITED IN THE DESCRIPTION

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- WO 2010109887 A **[0013]**
- JP 2019063851 A **[0013]**