

(19)



(11)

EP 2 497 585 B1

(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention
of the grant of the patent:
29.11.2017 Bulletin 2017/48

(51) Int Cl.:
B22D 11/10 (2006.01) **B22D 41/50** (2006.01)
B22D 11/103 (2006.01) **B22D 41/08** (2006.01)

(21) Application number: **10828046.2**

(86) International application number:
PCT/JP2010/005916

(22) Date of filing: **01.10.2010**

(87) International publication number:
WO 2011/055484 (12.05.2011 Gazette 2011/19)

(54) **CONTINUOUS CASTING METHOD FOR MOLTEN METAL**

STRANGGUSSVERFAHREN FÜR GESCHMOLZENES METALL

PROCÉDÉ DE COULÉE CONTINUE POUR MÉTAL LIQUIDE

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**

(30) Priority: **06.11.2009 JP 2009255222**

(43) Date of publication of application:
12.09.2012 Bulletin 2012/37

(73) Proprietor: **Nippon Steel & Sumitomo Metal
Corporation
Tokyo 100-8071 (JP)**

(72) Inventors:
• **TSUKAGUCHI, Yuichi
Osaka-shi
Osaka 541-0041 (JP)**

• **USHIRO, Mariko
Osaka-shi
Osaka 541-0041 (JP)**

(74) Representative: **J A Kemp
14 South Square
Gray's Inn
London WC1R 5JJ (GB)**

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Description

TECHNICAL FIELD

[0001] The present invention relates to a technique for generating a swirling flow in molten metal passing through a submerged entry nozzle in continuous casting of molten metal such as molten steel. Generating a swirling flow in molten metal passing through the submerged entry nozzle is effective for stabilization of a fluid behavior of molten metal in submerged entry nozzle and in mold.

BACKGROUND ART

[0002] In continuous casting using a wide-breadth mold, such as continuous casting of slab, generally, molten metal is supplied through a single submerged entry nozzle having opposite outlet ports. On that occasion, a self-excited oscillation occurs in the flow in a mold, causing a flow velocity fluctuation or a wavy fluctuation of molten metal surface. As a result, a decrease in casting velocity is mandated for preventing the generation of defects in the surface layer of cast slab.

[0003] With the view to control the flow in a mold, an electromagnetic brake or electromagnetic stirrer using electromagnetic force or a submerged entry nozzle generating a swirling flow as disclosed in Patent Literature 1 or Patent Literature 2 are known in the past. A submerged entry nozzle provided with a twisted plate part for generating a swirling flow in molten steel is described in the Patent Literature 1. A submerged entry nozzle for continuous casting including a swirl blade with twisted plate shape is described in the Patent Literature 2, wherein the twist pitch of the swirl blade, the twist angle of the swirl blade, the diameter of the swirl blade and the plate thickness of the swirl blade are set to values in predetermined ranges respectively, the cross-sectional area after reduction of the nozzle is specified by reducing the inner diameter between the lower end of the swirl blade and an outlet port, and a necessary head prediction value between a tundish and a mold is limited in an appropriate range.

[0004] Further, a submerged entry nozzle with deep basin-shaped bottom as disclosed in Patent Literature 3 and a submerged entry nozzle with an internal annular step as disclosed in Patent Literature 4 are also known. A submerged entry nozzle for continuous casting which is described in Patent Literature 3 has a nozzle body situated inside a narrow face wall of cast slab, an outlet port formed on the sidewall of the nozzle body and opened downward toward the narrow face wall of cast slab, and a basin-shaped bottom of the submerged entry nozzle, wherein the ratio of the depth of the bottom to the inner diameter and the outlet flow angle of the outlet port are specified. In a submerged entry nozzle for continuous casting which is described in Patent Literature 4, a refractory which constitutes a part contacting with molten steel contains graphite, and a plurality of step struc-

tures having a certain length of step structure region are provided in the borehole portion of the nozzle, wherein the minimum inner diameter of the borehole portion in the nozzle, the minimum cross-sectional area, and the cross-sectional area of the outlet port are specified relative to the passing amount of molten steel.

[0005] However, the method using electromagnetic force is high in cost of equipment, and can hardly obtain a merit to the value of an investment. Since the flow of molten metal as what to be controlled is difficult to measure, controlling thereof is required to be performed without knowing the state of what to be controlled. Therefore, it is technically difficult to exhibit a sufficient effect.

[0006] On the other hand, the technique related to the above-mentioned submerged entry nozzle generating a swirling flow disclosed in Patent Literature 1 or 2 (hereinafter referred also to as "swirling flow submerged entry nozzle") is confirmed to be effective as a practical measure capable of stabilizing the flow in mold. However, since non-metallic inclusions tends to adhere to the swirl blade provided within the nozzle in casting of molten metal containing a plenty of non-metallic inclusions, it is difficult to continuously cast a large quantity of molten metal.

[0007] Although it is said that using the submerged entry nozzle disclosed in Patent Literature 3 allows effective prevention of entrapment of mold powder without an increase in velocity of surface flow in a mold even if the casting speed is increased, it is difficult to ensure a stable effect for preventing the entrapment in real operation. The submerged entry nozzle disclosed in Patent Literature 4 aims to attain improvement in cast slab quality and prevention of breakout by suppressing uneven molten steel flow in the submerged entry nozzle to homogenize the flow in a mold while preventing the clogging of the submerged entry nozzle due to adherence of alumina inclusions. However, even if such a nozzle is used, nozzle clogging is apt to occur in real casting operation, and it is also difficult to obtain a stable effect for suppressing an uneven molten steel flow.

[0008] The present inventors completed inventions shown in Patent Literature 5 and Patent Literature 6 as methods for solving the above-mentioned problems. These inventions are intended to solve the nozzle clogging that is a weak point of the above-mentioned swirling flow submerged entry nozzle with a swirl blade by providing a simple and effective swirling flow mechanism for generating a swirling flow of molten metal in a tundish. As a result, the flow of molten metal in a mold can be stabilized and should bring in expectations of stabilization of casting operation and improvement in cast slab quality.

CITATION LIST

PATENT LITERATURE

[0009]

PATENT LITERATURE 1: WO 99/15291

PATENT LITERATURE 2: Japanese Patent Application Publication No. 2002-239690

PATENT LITERATURE 3: Japanese Patent No. 3027645

PATENT LITERATURE 4: Japanese Patent No. 3207793

PATENT LITERATURE 5: Japanese Patent Application Publication No. 2007-69236

PATENT LITERATURE 6: Japanese Patent Application Publication No. 2008-030069

SUMMARY OF INVENTION

TECHNICAL PROBLEM

TECHNICAL PROBLEM

[0010] However, as the results of further addressed research and development activities, the present inventors found that concerning the elements of technology described in the Patent Literature 5 and Patent Literature 6, their effects for stabilizing the flow of molten metal in a mold are not necessarily sufficient.

[0011] In consideration of this problem, the present invention has been achieved and has an object to provide a continuous casting method capable of improving the flow stabilization effect of molten metal in a mold much more than in the inventions described in Patent Literature 5 and Patent Literature 6.

SOLUTION TO PROBLEM

[0012] To solve the above-mentioned problem, the present inventors made a great deal of examinations and studies on a casting method capable of generating a swirling flow of molten metal passing through a submerged entry nozzle without causing clogging in the submerged entry nozzle to stabilize the flow of molten metal in a mold. As a result, the present inventors obtained the following findings (a)-(g) and achieved the present invention.

(a) In the method of generating a swirling flow by installing a swirl blade with twisted plate shape in a submerged entry nozzle, stagnation and vortex of flow are caused when a downward flow of molten metal in the submerged entry nozzle collides against the swirl blade, leading to adherence of non-metallic inclusions such as Al_2O_3 . Furthermore, the installation of a swirling flow mechanism such as the swirl blade with twisted plate shape in a submerged entry nozzle with high flow velocity has problems of incurring the large flow resistance of molten metal and a low energy efficiency in generating a swirling flow. Therefore, when a required throughput is large, the intensity of a swirling flow to be generated is restricted.

(b) A swirling flow mechanism to be provided in a

tundish above a submerged entry nozzle is devised, the swirling flow mechanism having a lateral surface of hollow cylindrical, conical or truncated cone type refractory with relatively large diameter, the lateral surface including a side hole(s) for giving a circumferential component of velocity to an inflowing molten metal. This swirling flow mechanism can minimize the flow velocity of molten metal passing through the swirling flow mechanism since the side hole(s) as being a flow passage of molten metal have a large cross-sectional area.

(c) According to the above-mentioned configuration in (b), a flow passage shape which hardly causes flow stagnation or vortex disables the non-metallic inclusions such as Al_2O_3 to adhere to the inner wall of the flow passage of molten metal. The non-metallic inclusions, even if adhered, are less subject to cause clogging since the cross-sectional area of the flow passage is large. Further, since the minimized flow velocity and the less likeliness in vortex generation realizes a low flow resistance of molten metal, potential energy can be effectively utilized to generate an intensive swirling flow.

(d) To secure swirling with appropriate intensity which has a favorable effect on the flow of molten metal in a mold, the angular momentum of swirling flow of molten metal in the above-mentioned swirling flow mechanism in (b) must be optimized when the molten metal passes through side holes.

(e) As an index of the angular momentum of swirling flow of molten metal in the submerged entry nozzle, the index P expressed by the following equation (1) using the flow rate of molten metal and the shape of the swirling flow mechanism is devised. The swirling flow with appropriate intensity can be obtained by designing the swirling flow mechanism in an appropriate shape so that the value of the index P is in a predetermined appropriate range.

$$P=R \times Q/S \times \sin \theta 1 \dots (1)$$

Each sign in the above-mentioned equation (1) designates as follows:

R: mean inner radius of horizontal circular cross-section of swirling flow mechanism in opening region of side holes;

Q: flow rate of molten metal;

S: total opening area of side holes; and

$\theta 1$: angle formed by central axis of side hole relative to virtual line (radial direction) at outlet-side opening thereof.

The total opening area S of the side holes means the sum of cross-sectional areas of flow passage in all side holes, and Q/S in the above-mentioned equa-

tion (1) means the mean velocity through the side holes for the molten metal.

(f) In order for the side holes of the above-mentioned swirling flow mechanism of (b) to give a circumferential velocity to molten metal, a minimum required index T (T: the ratio of the thickness of sidewall in the side hole portion to the width of section of the side hole) exists according to the mean velocity Q/S in the side holes. Namely, T is needed to be 1.0 or more when Q/S is less than 0.05 m/s; 0.8 or more when Q/S is 0.05 m/s or more but less than 0.1 m/s; 0.6 or more when Q/S is 0.1 m/s or more but less than 0.4 m/s; 0.5 or more when Q/S is 0.4 m/s or more but less than 1.2 m/s; and 0.4 or more when Q/S is 1.2 m/s or more.

(g) If an opening should exist in an upper end portion of the above-mentioned swirling flow mechanism in (b) when the swirling flow mechanism is submerged in molten metal in the tundish, a vortex extending from the molten metal level in the tundish to the inside of the swirling flow mechanism is induced. This vortex is not preferred since it entraps slag on the molten metal level in the tundish or non-metallic inclusions. For preventing this vortex, it is required to have no opening in the upper end portion of the swirling flow mechanism or to insert a stopper rod extending from above the tundish to the opening in the upper end portion of the swirling flow mechanism.

[0013] The present invention is achieved based on the above-mentioned findings, and the summaries thereof are represented in continuous casting methods of molten metal shown in the following (1) to (4).

(1) A continuous casting method of molten metal in which a hollow cylindrical, conical or truncated cone type refractory-made structure having one or more side holes in the sidewall thereof is disposed in a tundish above a submerged entry nozzle with the central axis of the refractory-made structure aligned vertically to supply molten metal from the tundish to the submerged entry nozzle, wherein: a central axis of the side hole crosses a virtual line extending radially from the center of a horizontal circular cross-section of the refractory-made structure at an intersection thereof with an inner surface of the refractory-made structure, the central axis of the side hole being horizontally inclined at an angle θ_1 relative to the virtual line at the intersection, the molten metal in the tundish passes from inlet-side openings of side holes which are opened on an outer surface of the refractory-made structure to outlet-side openings thereof which are opened on the inner surface of the refractory-made structure, a swirling flow is generated in the molten metal supplied from the tundish to the submerged entry nozzle while giving a circumferential velocity thereto, wherein the mean inner diameter 2R of the horizontal circular cross-section of

the structure in the region having openings of side holes is 250 to 1,200 mm, the height of section of side hole is 30 to 500 mm, the angle θ_1 is 15 to 80°; and characterized in that: an index P expressed by the after-mentioned equation (1) satisfies $0.015 \text{ m}^2/\text{s} \leq P \leq 0.100 \text{ m}^2/\text{s}$, the index P being represented by the flow rate Q of the molten metal, total opening areas S of the side holes, the mean inner radius R of the horizontal circular cross-section in the region having openings of side holes, and the angle θ_1 (hereinafter also referred to as "first invention").

(2) The continuous casting method of molten metal according to the above-mentioned (1), characterized in that the relationship between an index T represented by the ratio of the thickness of sidewall in the side hole portion to the width of section of the side hole, the flow rate Q of the molten metal and total opening areas S of the side holes satisfies the following conditions (hereinafter also referred to as "second invention").

T is 1.0 or more when Q/S is less than 0.05 m/s;
T is 0.8 or more when Q/S is 0.05 m/s or more but less than 0.1 m/s;
T is 0.6 or more when Q/S is 0.1 m/s or more but less than 0.4 m/s;
T is 0.5 or more when Q/S is 0.4 m/s or more but less than 1.2 m/s; and
T is 0.4 or more when Q/S is 1.2 m/s or more.

(3) The continuous casting method of molten metal according to the above-mentioned (1) or (2), characterized in that the whole body of the refractory-made structure is submerged in the molten metal in the tundish; and an opening is provided in an upper end portion of the refractory-made structure, and a refractory-made stopper rod is inserted from above the tundish through the opening (hereinafter also referred to as "third invention").

(4) The continuous casting method of molten metal according to the above-mentioned (1) or (2), characterized in that the whole body of the refractory-made structure is submerged in the molten metal in the tundish, and no opening is provided in an upper end portion of the refractory-made structure (hereinafter also referred to as "fourth invention").

[0014] In the present invention, the "angle θ_1 formed by the central axis of the side hole relative to the virtual line (radial direction) at the outlet-side opening" is also referred to as "inclination angle (θ_1) of the side hole" in the following description.

[0015] An "inner radius of the horizontal circular cross-section" means a distance between an intersection of the central axis of side hole with the virtual line (radial direction) at the outlet-side opening of side hole (the intersection at which the angle θ_1 is formed) and the center of the horizontal circular cross-section of the refractory-

made structure, and R is determined as a mean value of a plurality of radii in the region having openings of side holes.

ADVANTAGEOUS EFFECTS OF INVENTION

[0016] The method of the present invention can ensure stable continuous casting operation and improvement in cast slab quality by forming a swirling flow with appropriate intensity in molten metal in a submerged entry nozzle while solving the nozzle clogging problem that is a weak point of conventional swirling flow submerged entry nozzles with swirl blade, and attaining flow stability of molten metal in mold or removal of non-metallic inclusions that is an excellent effect of such swirling flow submerged entry nozzles.

BRIEF DESCRIPTION OF DRAWINGS

[0017]

[Figs. 1] Figs. 1(a) and (b) are schematic views of a continuous casting machine for carrying out the method of the present invention, wherein Fig. 1(a) shows an A-A cross-section diagram in Fig. 1(b), and Fig. 1(b) shows a longitudinal section of the continuous casting machine.

[Figs. 2] Figs. 2(a) and (b) are schematic views of another continuous casting machine for carrying out the method of the present invention, wherein Fig. 2(a) shows an A-A cross-section diagram in Fig. 2(b), and Fig. 2(b) shows a longitudinal section of the continuous casting machine.

[Figs. 3] Figs. 3(a) and (b) are schematic views of the other continuous casting machine for carrying out the method of the present invention, wherein Fig. 3(a) shows an A-A cross-section diagram in Fig. 3(b), and Fig. 3(b) shows a longitudinal section of the continuous casting machine.

[Figs. 4] Figs. 4(a) and (b) are schematic views of a continuous casting machine as a comparative example to the present invention, wherein Fig. 4(a) shows an A-A cross-section diagram in Fig. 4(b), and Fig. 4(b) shows a longitudinal section of the continuous casting machine.

[Figs. 5] Figs. 5(a) and (b) are schematic views of another continuous casting machine as a comparative example to the present invention, wherein Fig. 5(a) shows an A-A cross-section diagram in Fig. 5(b), and Fig. 5(b) shows a longitudinal section of the continuous casting machine.

DESCRIPTION OF EMBODIMENTS

[0018] As described above, the present invention involves "a continuous casting method of molten metal in which a hollow cylindrical, conical or truncated cone type refractory-made structure having one or more side holes

in the sidewall thereof is disposed in a tundish above a submerged entry nozzle with the central axis of the refractory-made structure aligned vertically to supply molten metal from the tundish to the submerged entry nozzle, the method being characterized in that the central axis of the side hole crosses a virtual line extending radially from the center of a horizontal circular cross-section of the refractory-made structure at an intersection thereof with an inner surface of the refractory-made structure, the central axis of the side hole being horizontally inclined at an angle $\theta 1$ relative to the virtual line at the intersection, the molten metal in the tundish passes from inlet-side openings of side holes which are opened on an outer surface of the refractory-made structure to outlet-side openings thereof which are opened on the inner surface of the refractory-made structure, a swirling flow is generated in the molten metal supplied from the tundish to the submerged entry nozzle while giving a circumferential velocity thereto, wherein the mean inner diameter $2R$ of the horizontal circular cross-section of the structure in the region having openings of side holes is 250 to 1,200 mm, the height of section of the side hole is 30 to 500 mm, the angle $\theta 1$ is 15 to 80°; and an index P expressed by the following equation (1) satisfies $0.015 \text{ m}^2/\text{s} \leq P \leq 0.100 \text{ m}^2/\text{s}$, the index P being represented by the flow rate Q of the molten metal, total opening areas S of side holes, the mean inner radius R of the horizontal circular cross-section in the region having openings of the side holes, and the angle $\theta 1$."

$$P=R \times Q/S \times \sin \theta 1 \dots (1)$$

[0019] The content of the present invention will be described below in more detail.

[0020] Figs. 1(a) and (b) are schematic views of a continuous casting machine for carrying out the method of the present invention, wherein (a) shows an A-A cross-section diagram in (b), and (b) shows a longitudinal section of the continuous casting machine.

[0021] As shown in the above figures, a hollow cylindrical type refractory-made structure 1 having one or more side holes 2 in the sidewall thereof is disposed in a tundish 5 above a submerged entry nozzle 4, the side holes being opened respectively so that the centers of outlet-side openings lie on virtual lines X1 to X5 extending radially from the center O of a horizontal circular cross-section and the directions of central axes Y1 to Y5 of the holes each is horizontally inclined relative to the corresponding virtual line among X1 to X5. The refractory-made structure has a vertical axis 3. Molten metal 6 in the tundish 5 is given a circumferential component of velocity, when it flows into the refractory-made structure 1 through the side holes 2, to generate a swirling flow, and then supplied from the tundish 5 into the mold 11 through the submerged entry nozzle 4.

(1)A First Invention

[0022] As described above, a first invention is a continuous casting method of molten metal in which a hollow cylindrical, conical or truncated cone type refractory-made structure 1 having one or more side holes 2 in the sidewall thereof is disposed in a tundish 5 above a submerged entry nozzle 4 with the central axis of the refractory-made structure 1 aligned vertically to supply molten metal 6 from the tundish 5 to the submerged entry nozzle 4, the method being characterized in that each of the side holes 2 is configured so that the center of the outlet-side opening of the hole lies on a corresponding virtual line among X1 to XN (N represents the number of virtual lines) extending radially from the center O of a horizontal circular cross-section of the refractory-made structure 1, the direction of the central axis of the hole is horizontally inclined at an angle θ_1 relative to the virtual line X1 to XN, molten metal 6 in the tundish 5 passes from inlet-side openings of the side holes 2 which are opened on the outer surface of the refractory-made structure 1 to outlet-side openings thereof which are opened on the inner surface of the refractory-made structure 1, and a swirling flow is generated in the molten metal supplied from the tundish to the submerged entry nozzle while giving a circumferential velocity thereto, wherein the mean inner diameter 2R of the horizontal circular cross-section of the structure in the region having openings of the side holes 2 is 250 to 1,200 mm, the height of section of the side hole 2 is 30 to 500 mm; the angle θ_1 is 15 to 80°; and an index P expressed by the above-mentioned equation (1) satisfies $0.015 \text{ m}^2/\text{s} \leq P \leq 0.100 \text{ m}^2/\text{s}$, the index P being represented by the flow rate Q of the molten metal, total opening areas S of the side holes, the mean inner radius R of the horizontal circular cross-section in the region having openings of the side holes, and the angle θ_1 .

[0023] Since this refractory-made structure 1 is provided with side holes 2 each having the inclination angle θ_1 , the swirling flow can be generated in the molten metal 6 by giving the circumferential component of velocity thereto. Although the number of side holes 2 each having the inclination angle θ_1 can be one, it is preferable to provide a plurality of side holes 2 around the whole circumference of the refractory-made structure 1 with the purpose of hedging the risk of clogging by the non-metallic inclusions contained in the molten metal 6. Further, the side holes 2 may be provided in a plurality of positions around the whole circumference of, along with in a plurality of stages in a height-wise direction (along the direction of the vertical axis 3) of the refractory-made structure 1. However, when a plurality of side holes 2 are provided, each has preferably the same height of section from the viewpoint of avoiding unwanted increase in height of the refractory-made structure 1.

[0024] The inclination angle θ_1 may be constant or vary in a certain range among a plurality of side holes 2. However, it is preferred to swirl the molten metal 6 in the same

direction of rotation. Further, a number of side holes 2 may be formed in a circumferential direction of the refractory-made structure 1 with a thin fin-like partition wall each between side holes 2.

[0025] The side hole 2 preferably has a section size which allows passage of foreign substance with a maximum particle size of about 30 mm in the molten metal. The inner surfaces on the upper side and lower side of the side hole 2 may be horizontal or vertically sloped. However, the lower edge of outlet-side opening of the side hole 2 is preferably at such a low level that reduction of yield is never caused due to the residual of the molten metal 6 in the tundish 5 at the end of casting, namely, at a level within 200 mm from the bottom of the tundish.

[0026] An upper cover does not have to be provided in an upper end portion of the refractory-made structure 1. When an upper cover is provided in the upper end portion 7 of the refractory-made structure 1, the height of inner surface thereof is preferred to be at a level above 150 mm or less from the upper edge of outlet-side opening of the side hole 2 from the viewpoint of preventing attenuation of the generated swirling flow.

[0027] When the upper end portion of the refractory-made structure 1 is open without a cover, molten metal 6 in the tundish 5 (in the upper of and outside the refractory-made structure 1) is driven and rotated by the swirling flow of molten metal 6 generated inside the refractory-made structure 1. On this occasion, since the angular kinetic energy of swirling flow is consumed for this drive, the swirling flow of molten metal 6 in the refractory-made structure 1 is weakened. This consumed energy is larger as the area of opening in the upper end of the refractory-made structure 1 is larger. Therefore, when no cover is provided in the upper end portion 7 of the refractory-made structure 1, the inner diameter thereof above the level where the side hole 2 is provided is preferably reduced to 50 to 200 mm, which is smaller than the inner diameter of the portion below the level where the side hole 2 is provided, similarly from the viewpoint of preventing attenuation of the swirling flow. Further, when no upper cover is provided, it is preferred to set the level of the upper end portion 7 to be higher than the molten metal level in the tundish 5 from the viewpoint of preventing mixing of tundish slag into the refractory-made structure 1.

[0028] In the present invention, the mean inner diameter 2R of the horizontal circular cross-section of the refractory-made structure 1 in the region having openings of the side holes 2 is set in the range of 250 to 1,200 mm. This reason is that a mean inner diameter 2R of less than 250 mm is too small as the swirling flow mechanism and makes it difficult to obtain a sufficient angular momentum and, further, the smaller cross-sectional area of molten metal passage causes a problem such as an increase in clogging of the side hole 2 or increase in friction resistance of the molten metal 6. On the other hand, a mean inner diameter 2R exceeding 1,200 mm is too large as the swirling flow mechanism, and leads to not only in-

crease in cost of the refractory-made structure 1 but also increase in cost of casting equipment due to the necessity of an exclusively dedicated tundish.

[0029] Although the horizontal cross-sectional shape of the refractory-made structure 1 is preferably in the form of true circle, the same effect can be obtained even in a polygonal or elliptic shape. In that case, the mean value of the distance from the center of cross section is regarded as the mean inner diameter $2R$. However, when the cross-sectional shape is not in the form of true circle, the energy efficiency of swirling flow is deteriorated, compared with the case of the true circle.

[0030] The height of section of the side hole 2 in the refractory-made structure 1 is set in the range of 30 to 500 mm. The reason for this is that when the height of section of the side hole 2 provided in the refractory-made structure 1 is less than 30 mm, clogging tends to occur since the area of molten metal flow passage is too small. On the other hand, when the height of section of the side hole 2 exceeds 500 mm, it becomes difficult to obtain a sufficient angular momentum while securing the flow velocity of molten metal passing through the side hole 2 since the area of molten metal flow passage (the cross-sectional area of the side hole 2) is too large. In addition, the height of section of the side hole 2 exceeding 500 mm is not preferred since the whole height of the refractory-made structure 1 is unnecessarily increased. The more preferable range of the height of section of the side hole 2 is in the range of 50 to 250 mm.

[0031] The height of section of the side hole 2 is represented by the height of section of a side hole 2 itself when the side holes 2 are provided only in one stage along the vertical direction, but means the sum of heights of section of side holes 2 in a plurality of stages, one side hole in each stage, when the side holes 2 are also vertically aligned in a plurality of stages (for example, when the side hole 2 with 200 mm section height is provided in two stages, the height of section is regarded to as 400 mm calculated by $200 \text{ [mm]} \times 2$). When the cross-sectional shape of the side hole 2 is not rectangular, a maximum height of section is regarded as the height of section of the side hole 2. Furthermore, when the heights of section among a plurality of side holes 2 provided in a circumferential direction are differed to each other, the mean value of the heights of section of these side holes 2 is regarded as the height of section of the side hole 2.

[0032] The width of section of the side hole 2 is preferred to be in the range of 30 to 200 mm. When the width of section of the side hole 2 is less than 30 mm, clogging tends to occur, and when it exceeds 200 mm, the strength of the structure 1 is reduced. Further, when the width of section of the side hole 2 exceeds 200 mm, the cross-sectional area of the side hole 2 becomes too large, and makes it difficult for the value of the equation (1) to satisfy the specified range. When the cross-sectional shape of the side hole 2 is not in the form of rectangular, a maximum width of section is regarded as the width of section of the side hole 2.

[0033] The inclination angle θ_1 of the side hole 2 is set in the range of 15 to 80° . The reason is that when the inclination angle θ_1 of the side hole 2 provided in the refractory-made structure 1 is smaller than 15° , the intensity of swirling flow becomes insufficient. When the inclination angle θ_1 exceeds 80° , the thickness of the sidewall of the refractory-made structure 1 is reduced, causing a problem in strength.

[0034] The following is the reason for specifying, in the method of the present invention, an index P ($P = R \times Q/S \times \sin \theta_1$) in the range of $0.015 \text{ m}^2/\text{s}$ to $0.100 \text{ m}^2/\text{s}$, the index P being represented by the mean velocity through side holes Q/S which is determined from the flow rate Q of the molten metal and the total opening areas S of side holes, the mean inner radius R of the horizontal circular cross section in the region having openings of side holes, and the angle θ_1 .

[0035] The present inventors found that the swirling flow with appropriate intensity can be generated in the submerged entry nozzle by adopting a product P of the mean inner diameter R and a tangential component (direction vertical to the radius) of the mean velocity Q/S of molten metal passing through side holes 2 as an index of the angular momentum of swirling flow of molten metal in the refractory-made structure 1, and controlling this index P in an appropriate range.

[0036] The swirling flow generated inside the refractory-made structure 1 is throttled by a flow control device such as a stopper or sliding gate before it flows into the submerged entry nozzle. The attenuation behavior of swirling flow by this throttle is complicated, causing a phenomenon in which the swirling flow generated in the structure 1 is more markedly attenuated as the intensity of the swirling flow is higher (the angular momentum is larger). Namely, if the swirling flow generated in the structure 1 is too intensive, the attenuation of swirling flow by the flow control device becomes predominant, and the energy efficiency in generating a swirling flow is deteriorated.

[0037] As a result of the earnest examinations on the attenuation behavior of swirling flow by the flow control device, the present inventors found that when the value of the index P is in the range of $0.015 \text{ m}^2/\text{s}$ to $0.100 \text{ m}^2/\text{s}$, the attenuation of swirling flow by throttle of the flow control device (energetic loss) is not predominant, and the swirling flow generated in the submerged entry nozzle can secure sufficient intensity from the viewpoint of stably controlling the flow in mold, and achieved the present invention.

[0038] When the value of the index P exceeds the upper limit value $0.100 \text{ m}^2/\text{s}$, the attenuation of swirling flow by the throttle of the flow control device is predominantly caused, and the energy efficiency in generating a swirling flow is deteriorated by this pressure loss. Further, an excessively large circumferential velocity causes vibration of the submerged entry nozzle. On the other hand, when the value of the index P is below the lower limit value $0.015 \text{ m}^2/\text{s}$, a sufficient stabilization effect of flow in mold

cannot be exerted due to the weakened swirling flow generated in the submerged entry nozzle. The more preferable range of the index P is 0.020 m²/s to 0.085 m²/s.

[0039] The definitions for the cross-sectional areas S of side holes 2 and the angle θ_1 in a case where two side surfaces of the side hole 2 are not parallel to each other will be described below. When opposite side surfaces of the side hole 2 are parallel to each other, the angle θ_1 can be definitively determined as the angle formed by the central axis of the side hole 2 and the virtual line at the outlet-side opening thereof since the central axis of the side hole 2 is parallel to the side surfaces. The width of section of the side hole 2 is also definitively determined as the distance between the side surfaces. On the other hand, when opposite side surfaces of the side hole 2 are not parallel to each other, the angle θ_1 varies depending on how to determine the central axis of the side hole 2, and the width of section of the side hole 2 varies depending on the angle θ_1 . In such a case, the angle θ_1 and the width of section of the side hole 2 are determined as follows. Two parallel and horizontal lines which are sufficiently longer than the side surfaces in the flow direction of molten metal 6 (longer than the overall length of the side hole 2) are generated in the side hole 2 so as to contact with two side surfaces, one with each line, respectively. The center line between the parallel lines in a state where the distance between the parallel lines is the largest is taken as the central axis of the side hole 2. The angle formed by the central axis of side hole and the virtual line at the outlet-side opening of the side hole 2 is determined as the angle θ_1 . The distance between the parallel lines is regarded as the width of section of the side hole. The area of opening of each side hole 2 is the area in the portion where the cross-section vertical to the central axis of the side hole 2 is minimized.

(2) A Second Invention

[0040] A second invention of the present invention will be described using the above-mentioned Figs. 1 similarly to the first invention.

[0041] A second invention is the continuous casting method of molten metal according to the first invention, characterized in that the relationship between the mean velocity Q/S in the side hole 2 of the refractory-made structure 1 and the index T (T: the ratio of the thickness of sidewall in the side hole portion to the width of section of the side hole 2) satisfies the following conditions.

Namely, T is 1.0 or more when Q/S is less than 0.05 m/s;

T is 0.8 or more when Q/S is 0.05 m/s or more but less than 0.1 m/s;

T is 0.6 or more when Q/S is 0.1 m/s or more but less than 0.4 m/s;

T is 0.5 or more when Q/S is 0.4 m/s or more but less than 1.2 m/s; and

T is 0.4 or more when Q/S is 1.2 m/s or more.

[0042] When the mean velocity Q/S in the side hole 2 is small, the function of giving the circumferential velocity to molten metal is deteriorated unless the length of the sidewall is increased relative to the width of section of side hole. The minimum value of the index T (T: the ratio of the thickness of sidewall in the side hole portion to the width of section of the side hole 2), representing the ratio of the side hole length to the side hole section width, is the above-mentioned value. Although the upper limit of the index T is not particularly specified, a substantial upper limit of T is 2.0 since an excessively large T unnecessarily increases the thickness of the sidewall, leading to gigantic enlargement of the scale of the refractory-made structure 1. The thickness of sidewall in the side hole portion is a value obtained by dividing the difference between the outer diameter and inner diameter of the refractory-made structure 1 in the region having openings of side holes by two.

(3) A Third Invention

[0043] Figs. 2(a) and (b) are schematic views of another continuous casting machine for carrying out the method of the present invention. In the same figures, (a) shows an A-A cross-section diagram in (b), and (b) shows a longitudinal section of the continuous casting machine. In the continuous casting machine shown in Figs. 2, the same reference signs are assigned to the parts substantially identical to those in the above-mentioned continuous casting machine shown in Figs. 1(a) and (b).

[0044] A third invention is the continuous casting method of molten metal according to the first invention or second invention, characterized in that an opening is provided in an upper end portion of the refractory-made structure 1 which is entirely submerged in molten metal, and a refractory-made stopper rod 14 is inserted through the opening from above the tundish, as shown in Figs. 2(a) and (b).

[0045] Since a swirling flow of molten metal is generated inside the refractory-made structure 1 when the whole body of the refractory-made structure 1 is submerged in the molten metal, a phenomenon in which a vortex extending from the molten metal level to the inside of the submerged entry nozzle 4 is generated to suck and mix slag on the molten metal level in the tundish 5 into the mold 11 is caused if the opening be provided in the upper end portion of the refractory-made structure 1. To avoid this phenomenon, it is effective to insert the refractory-made stopper rod 14 to the central portion of circular cross section of the refractory-made structure 1 from above the tundish.

[0046] In this case, the refractory-made structure 1 provided with the opening in the upper end portion may have any of a cylindrical, conical or truncated cone shape. The level of an inner surface of upper end portion of the refractory-made structure 1 is preferably set to the same level of or at most 150 mm above the upper edge of outlet-side opening of the side holes 2 in order to make the

refractory-made structure 1 compact. The diameter of the opening provided in the upper cover of the refractory-made structure 1 is preferably set to be larger by 1 to 20 mm than the diameter of the stopper rod 14.

[0047] Since the stopper rod 14 generally performs the opening and closing of the molten metal passage extending from the inside of the tundish 5 to the submerged entry nozzle 4, the lower end of the stopper rod 14 is positioned at several mm to more than a dozen mm high above the bottom of the tundish 5 during casting, and the upper end portion thereof is connected to a lifting mechanism installed above an upper portion of the tundish 5.

[0048] In the present invention, the stopper rod 14 is used for the purpose of preventing generation of the vortex associated with a swirling flow. However, the stopper rod 14, if it has a lifting function, may be used for molten metal level control in the mold 11. Otherwise, it may be used only to open and close the molten metal passage at the start of casting and at the end thereof. When the stopper rod 14 is used only to open and close the molten metal passage at the start and end of casting, the molten metal level control in the mold 11 during casting is preferably performed using a sliding gate 9 provided between the submerged entry nozzle 4 and an upper nozzle 8.

(4) A Fourth Invention

[0049] Figs. 3(a) and (b) are schematic views of the other continuous casting machine for carrying out the method of the present invention. In the same figures, (a) shows an A-A cross-sectional diagram in (b), and (b) shows a longitudinal section of the continuous casting machine. In the continuous casting machine shown in Figs. 3(a) and (b), the same reference signs are assigned to the parts substantially identical to those in the above-mentioned continuous casting machine shown in Figs. 1(a) and (b).

[0050] A fourth invention is the continuous casting method of molten metal according to the first invention or second invention, characterized in that no opening is provided in an upper end portion of the refractory-made structure 1 which is entirely submerged in molten metal in a tundish, as shown in Figs. 3(a) and (b).

[0051] Since a swirling flow of molten metal is generated inside the refractory-made structure 1 when the whole body of the refractory-made structure 1 is submerged in the molten metal, a vortex extending from the molten metal level to the inside of the submerged entry nozzle 4 can be generated, if an opening be provided in the upper end portion of the refractory-made structure 1, to suck and mix slag on the molten metal level in the tundish 5 into the mold 11. To avoid this phenomenon, it is effective to provide no opening in the upper end portion of the refractory-made structure 1.

EXAMPLES

[0052] The effects of the continuous casting method

of molten metal of the present invention will be then described in detail based on examples. In the following examples, molten steel is taken as the molten metal.

5 (Inventive Example 1)

[0053] Figs. 1 (a) and (b) are schematic views of a continuous casting machine for carrying out the method of the present invention as described above, wherein (a) shows an A-A cross-section diagram in (b), and (b) shows a longitudinal section of the continuous casting machine. The example shown in the same figures satisfies the conditions specified in the above-mentioned first invention and second invention.

[0054] As shown in the same figures, a hollow cylindrical type refractory-made structure 1 has an inner diameter of 400 mm, an outer diameter of 550 mm and an overall height of 1,200 mm, including a region having openings of side holes, and is made of alumina-silica type refractory. Namely, the mean inner radius R in the region having openings of side holes 2 is 200 mm. The molten metal level in the tundish 5 during steady state of casting is 200 mm below the upper end portion 7 of the refractory-made structure 1.

[0055] On the sidewall of the refractory-made structure 1, as shown in (a) of the same figures, five side holes 2 each having a cross section of 180 mm high and 80 mm wide are provided in a circumferential direction so that central axes Y1 to Y5 thereof each forms an inclination angle $\theta 1=40^\circ$ relative to a corresponding virtual radial line among X1 to X5 on the inner surface of the refractory-made structure. Namely, total opening areas S of side holes 2 is 72,000 mm² calculated by $S=180 \text{ [mm]} \times 80 \text{ [mm]} \times 5 \text{ [counts]}$. The flow rate Q of molten steel during steady state of casting is 60 m³/hr. Accordingly, the value of the index P expressed by the above-mentioned equation (1) is 0.030 m²/s calculated by $P=R \times Q/S \times \sin \theta 1=200 \text{ [mm]} \times 60 \text{ [m}^3/\text{hr}]/72,000 \text{ [mm}^2] \times 0.643$.

[0056] The value of the index T (T: the ratio of the thickness of sidewall in the side hole portion to the width of section of the side hole) is 75 [mm]/80 [mm]=0.938, which corresponds to the appropriate value (T: 0.6 or more) to the mean velocity through side holes of molten steel $Q/S=0.231 \text{ m/s}$.

[0057] In Inventive Example 1 shown in Figs. 1(a) and (b), molten steel 6 is given a circumferential velocity by passing through the side holes 2, increases the circumferential velocity according to the law of conservation of angular momentum when it passes through the upper nozzle 8 with a reduced inner diameter and the sliding gate 9, and generates an intensive swirling flow in the submerged entry nozzle 4. The swirling flow generated in the submerged entry nozzle 4 is uniformly and equally discharged through two outlet ports in the vicinity of the lower end of the submerged entry nozzle 4 by the effect of centrifugal force to generate a stable flow in the mold 11.

[0058] Further, when argon gas is injected from the inner periphery of an upper fixed plate of the sliding gate 9 with dual plates, the argon gas forms an inverted cone shaped bubbles curtain by the centrifugal force acting on the molten steel 6. In that case, an effect such that non-metallic inclusions in the molten steel 6 flowing down across the bubbles curtain is effectively captured by bubbles, and floated and removed together with the bubbles in the mold 11 is also provided. The same effect can be obtained also when the argon gas is injected from the upper nozzle 8. Regardless of the injection site, the effect can be enhanced by injecting the gas from entire inner periphery, not from part thereof.

[0059] Since the above-mentioned stabilization effect of flow in a mold facilitates the control of the flow velocity of molten steel in a mold to an appropriate range, a clean steel can be suitably obtained. In addition, the above-mentioned capturing and floating effect of inclusions by bubbles also promotes the cleaning of steel. Since the swirling flow stabilizes flow of molten metal in the vicinity of the inner wall of the submerged entry nozzle 4, the clogging of the submerged entry nozzle due to adherence of non-metallic inclusions is very unlikely.

[0060] The refractory-made structure 1 shown in Figs. 1(a) and (b) is configured to prevent the slag in the tundish 5 from entering to the inside thereof by positioning the upper end portion 7 at a level higher than the molten metal level in the tundish 5. Therefore, even if the vortex is generated inside the refractory-made structure 1, the slag in the tundish 5 is never entrapped into the mold 11.

(Inventive Example 2)

[0061] Figs. 2 (a) and (b) are schematic views of another continuous casting machine for carrying out the method of the present invention as described above, wherein (a) shows an A-A cross-section diagram in (b), and (b) shows a longitudinal section of the continuous casting machine. The example shown in the same figures satisfies all conditions specified in the above-mentioned first to third inventions.

[0062] As shown in the same figures, in a hollow truncated cone type refractory-made structure 1, the inner diameter in the region having openings of the side holes 2 is 550 mm at the lower edge of outlet-side opening of the side hole 2 and is 400 mm at the upper edge of outlet-side opening of the side hole 2. The outer diameter in the region having openings of the side holes 2 is 700 mm at the lower edge of inlet-side opening of the side hole 2 and is 550 mm at the upper edge of inlet-side opening of the side hole 2. The structure is 140 mm high to the inner surface of the upper cover and 180 mm high in all. The material of the refractory-made structure 1 is alumina-magnesia type refractory. The mean inner diameter $2R$ in the region having openings of the side holes 2 is 475 mm calculated by $(550 \text{ [mm]} + 400 \text{ [mm]})/2$, and the mean inner radius R is 237.5 mm.

[0063] On the sidewall of the refractory-made structure

1, as shown in (a) of the same figures, four side holes 2 each having a cross section of 100 mm high and 100 mm wide are provided in a circumferential direction so that central axes $Y1$ to $Y4$ thereof each forms an inclination angle $\theta1=55^\circ$ relative to a corresponding virtual line among $X1$ to $X4$ on the inner surface of the refractory-made structure. Namely, total opening areas S of the side holes 2 is 40,000 mm^2 calculated by $S=100 \text{ [mm]} \times 100 \text{ [mm]} \times 4 \text{ [counts]}$. The flow rate Q of molten steel during steady state of casting is 50 m^3/hr . Accordingly, the value of the index P expressed by the above-mentioned equation (1) is 0.068 m^2/s calculated by $P=R \times Q/S \times \sin \theta1 = 237.5 \text{ [mm]} \times 50 \text{ [m}^3/\text{hr}] / 40,000 \text{ [mm}^2] \times 0.819$.

[0064] The value of the index T (T : the ratio of the thickness of sidewall in the side hole portion to the width of section of the side hole) is $75 \text{ [mm]} / 100 \text{ [mm]} = 0.75$, which corresponds to the appropriate value (T : 0.6 or more) to the mean velocity through side holes of molten steel $Q/S = 0.347 \text{ m/s}$.

[0065] An opening with 110 mm in diameter is provided in an upper end portion 7 of the hollow truncated cone, and a stopper rod 14 with 100 mm in diameter is inserted to the vicinity of the upper nozzle 8 from above the tundish 5 through the opening. The molten metal level in the tundish 5 during steady state of casting is such that the refractory-made structure 1 is completely submerged.

[0066] In Inventive Example 2 shown in Figs. 2(a) and (b), also, molten steel 6 passing through the side holes 2 is given a circumferential velocity, similarly to the case of the above-mentioned Inventive Example 1, increases the circumferential velocity according to the law of conservation of angular momentum when it passes through the upper nozzle 8 with a reduced inner diameter and the sliding gate 9, and generates an intensive swirling flow in the submerged entry nozzle 4. The swirling flow generated in the submerged entry nozzle 4 is uniformly and equally discharged through two outlet ports in the vicinity of the lower end of the submerged entry nozzle 4 by the effect of centrifugal force to generate a stable flow in mold.

[0067] When argon gas is injected from the inner periphery of the upper nozzle 8, this argon gas forms an inverted cone shaped bubbles curtain by the centrifugal force acting on the molten steel 6. Therefore, an effect such that non-metallic inclusions in the molten steel 6 flowing down across this bubbles curtain is effectively captured by bubbles, and floated and removed together with the bubbles in the mold 11 is also produced. The same effect can be obtained when the argon gas is injected from the sliding gate 9. Regardless of the injection site, this effect can be enhanced by injecting the gas from entire inner periphery, not from part thereof.

[0068] Since the above-mentioned stabilization effect of flow in a mold facilitates the control of the flow velocity of molten steel in a mold to an appropriate range, a clean steel can be suitably obtained. In addition, the above-mentioned capturing and floating effect of inclusions by

bubbles also promotes the cleaning of steel. Further, since the swirling flow stabilizes the flow of molten metal in the vicinity of the inner wall of the submerged entry nozzle 4, the clogging of the submerged entry nozzle due to adherence of non-metallic inclusions is very unlikely.

[0069] In Inventive Example 2, the existence of the stopper rod 14 prevents generation of the vortex resulting from swirling flow, and the possibility that the slag in the tundish 5 is carried into the mold 11 is extremely low. Further, during steady state of casting, the flow rate of molten steel to the mold can be controlled by fully opening the sliding gate 9 so as to make the flow passage cross-section to a true circle shape, and adjusting the level of the stopper rod 14. In that case, a circumferentially equalized swirling flow can be generated in the submerged entry nozzle 4. Such a circumferentially equalized swirling flow leads to further uniformed and stabilized flow of molten steel in a mold, compared with Inventive Example 1.

(Inventive Example 3)

[0070] Figs. 3(a) and (b) are schematic views of the other continuous casting machine for carrying out the method of the present invention as described above, wherein (a) is an A-A cross-section diagram in (b), and (b) is a longitudinal section of the continuous casting machine. The example shown in the same figures satisfies all conditions regulated in the above-mentioned first, second and fourth inventions.

[0071] As shown in the same figures, in a hollow truncated cone type refractory-made structure 1, the inner diameter in the region having openings of the side holes 2 is 550 mm at the lower edge of outlet-side opening of the side hole 2 and is 400 mm at the upper edge thereof. The outer diameter in the region having openings of the side holes 2 is 700 mm at the lower edge of inlet-side opening of the side hole 2 and is 550 mm at the upper edge thereof. The structure is 140 mm high to the inner surface of the upper cover and 180 mm high in all. The material of the refractory-made structure 1 is alumina-magnesia type refractory. The mean inner diameter $2R$ in the region having openings of the side holes 2 is 475 mm calculated by $(550 \text{ [mm]} + 400 \text{ [mm]})/2$, and the mean inner radius R is 237.5 mm.

[0072] On the sidewall of the refractory-made structure 1, as shown in (a) of the same figures, four side holes 2 each having a cross section of 100 mm high and 100 mm wide are provided in a circumferential direction so that central axes $Y1$ to $Y4$ thereof each forms an inclination angle $\theta1=55^\circ$ relative to a corresponding virtual line among $X1$ to $X4$ on the inner surface of the refractory-made structure. Namely, total opening areas S of the side holes 2 is $40,000 \text{ mm}^2$ calculated by $S=100 \text{ [mm]} \times 100 \text{ [mm]} \times 4 \text{ [counts]}$. The flow rate Q of molten steel during steady state of casting is $60 \text{ m}^3/\text{hr}$. Accordingly, the value of the index P expressed by the above-mentioned equation (1) is $0.081 \text{ m}^2/\text{s}$ calculated by

$$P=R \times Q/S \times \sin \theta1 = 237.5 \text{ [mm]} \times 60 \text{ [m}^3/\text{hr]} / 40,000 \text{ [mm}^2] \times 0.819.$$

[0073] The value of the index T (T : the ratio of the thickness of sidewall in the side hole portion to the width of section of the side hole) is $75 \text{ [mm]} / 100 \text{ [mm]} = 0.75$, which corresponds to the appropriate value (T : 0.5 or more) to the mean velocity through side hole of molten steel $Q/S = 0.417 \text{ m/s}$.

[0074] No opening is provided in an upper end portion 7 of the hollow truncated cone. The molten metal level in the tundish 5 during steady state of operation is such that the refractory-made structure 1 is completely submerged.

[0075] In Inventive Example 3 shown in Figs. 3(a) and (b), also, molten steel 6 passing through the side holes 2 is given a circumferential velocity, similarly to the case of the above-mentioned Inventive Example 1, increases the circumferential velocity according to the law of conservation of angular momentum when it passes through the upper nozzle 8 with reduced inner diameter and the sliding gate 9, and generates an intensive swirling flow in the submerged entry nozzle 4. The swirling flow generated in the submerged entry nozzle 4 is uniformly and equally discharged through two outlet ports in the vicinity of the lower end of the submerged entry nozzle 4 by the effect of centrifugal force to generate a stable flow in mold.

[0076] When argon gas is injected from the inner periphery of the upper nozzle 8, the argon gas forms an inverted cone shaped bubbles curtain by the centrifugal force acting on the molten steel 6. Therefore, an effect such that the non-metallic inclusions in the molten steel 6 flowing down across the bubbles curtain is effectively captured by bubbles, and floated and removed together with the bubbles in the mold 11 is also produced. The same effect can be obtained when the argon gas is injected from the sliding gate 9. Regardless of the injection site, this effect can be enhanced by injecting the gas from entire inner periphery, not from part thereof.

[0077] Since the above-mentioned stabilization effect of flow in a mold facilitates the control of the flow velocity of molten steel in a mold to an appropriate range, a clean steel can be suitably obtained. In addition, the above-mentioned capturing and floating effect of inclusions by bubbles also promotes the cleaning of steel. Further, since the swirling flow stabilizes the flow of molten metal in the vicinity of the inner wall of the submerged entry nozzle 4, the clogging of the submerged entry nozzle due to adherence of non-metallic inclusions is very unlikely.

[0078] In Inventive Example 3, since no opening is provided in the upper end portion 7 of the hollow truncated cone, generation of the vortex resulting from swirling flow is prevented, and the possibility that the slag in the tundish 5 is entrapped into the mold 11 is extremely low. Inventive Example 3 is low in cost since the refractory-made structure 1 is small, compared with Inventive Example 1. Further, Inventive Example 3 is also superior in cost to Inventive Example 2 since the stopper rod 14 is

not used.

[0079] Since the continuous casting method of molten metal of the present invention shown in the above-mentioned Inventive Examples 1 to 3 can stabilize the flow in the vicinity of the inner wall of the submerged entry nozzle 4 to suppress the adherence of non-metallic inclusions to the inner wall since the swirling flow can be generated in the submerged entry nozzle 4, compared with an ordinary continuous casting method without installation of the refractory-made structure 1. Consequently, the method of the present invention exerts a high effect on improvement in cast slab quality and productivity of continuous casting through the stabilization of the flow in a mold.

(Comparative Example 1)

[0080] Figs. 4(a) and (b) are schematic views of a continuous casting machine as a comparative example to the present invention, wherein (a) shows an A-A cross-section diagram in (b), and (b) shows a longitudinal section of the continuous casting machine. In the continuous casting machine shown in the same figures, the same reference signs are assigned to the parts substantially identical to the above-mentioned continuous casting machine shown in Figs. 2(a) and (b). The example shown in the same figures does not satisfy the conditions specified in the first invention.

[0081] As shown in the same figures, in a hollow truncated cone type refractory-made structure 1, the inner diameter in the region having openings of the side holes 2 is 600 mm at the lower edge of outlet-side opening of the side hole 2 and is 400 mm at the upper edge thereof. The outer diameter in the region having openings of the side holes 2 is 700 mm at the lower edge of inlet-side opening of the side hole 2 and is 500 mm at the upper edge thereof. Further, the structure is 350 mm high to the inner surface of the upper cover and 400 mm high in all, being formed of alumina-magnesia type refractory. The mean inner diameter $2R$ in the region having openings of the side holes 2 is 500 mm calculated by $(600 \text{ [mm]} + 400 \text{ [mm]})/2$, and the mean inner radius R is 250 mm.

[0082] On the sidewall of the refractory-made structure 1, as shown in (a) of the same figures, eight side holes 2 each having a cross section of 250 mm high and 100 mm wide are provided in a circumferential direction so that central axes Y_1 to Y_8 thereof each forms an inclination angle $\theta_1 = 55^\circ$ relative to a corresponding virtual line among X_1 to X_8 on the inner surface of the refractory-made structure. Namely, total opening areas S of the side holes 2 is 200,000 mm² calculated by $S = 250 \text{ [mm]} \times 100 \text{ [mm]} \times 8 \text{ [counts]}$. The flow rate Q of molten steel during steady state of casting is 32 m³/hr. Accordingly, the value of the index P expressed by the above-mentioned equation (1) is 0.009 m²/s calculated by $P = R \times Q/S \times \sin \theta_1 = 250 \text{ [mm]} \times 32 \text{ [m}^3/\text{hr}] / 200,000 \text{ [mm}^2] \times 0.819$, which is smaller than the range specified

by the present invention.

[0083] The value of the index T (T : the ratio of the thickness of sidewall in the side hole portion to the width of section of the side hole) is 50 [mm]/100 [mm] = 0.5, which is too small, compared with the appropriate value (T : 1.0 or more) to the mean velocity through side holes of molten steel $Q/S = 0.044 \text{ m/s}$.

[0084] An opening with 110 mm in diameter is provided in an upper end portion 7 of the hollow truncated cone, and a stopper rod 14 with 100 mm in diameter is inserted to the vicinity of the upper nozzle 8 from above the tundish 5 through the opening. The molten metal level in the tundish 5 during steady state of operation is such that the refractory-made structure 1 is completely submerged.

[0085] In Comparative Example shown in Figs. 4(a) and (b), molten steel 6 passing through the side holes 2 is given a circumferential velocity, increases the circumferential velocity according to the law of conservation of angular momentum when it passes through an upper nozzle 8 with reduced inner diameter and a sliding gate 9, and generates a swirling flow in the submerged entry nozzle 4. However, since the value of the index P or the value of the index T is small, being out of the specified range of the present invention as described above, a swirling flow with sufficient intensity cannot be generated.

(Comparative Example 2)

[0086] Figs. 5(a) and (b) are schematic views of another continuous casting machine as a comparative example to the present invention, wherein (a) shows an A-A cross-section diagram in (b), and (b) shows a longitudinal section of the continuous casting machine. In the continuous casting machine shown in Figs. 5(a) and (b), the same reference signs are assigned to the parts substantially identical to the above-mentioned continuous casting machine shown in Figs. 1(a) and (b). The example shown in the same figures does not satisfy the conditions specified in the above-mentioned first to third inventions.

[0087] A hollow cylindrical type refractory-made structure 1 has an inner diameter of 400 mm, an outer diameter of 550 mm, and an overall height of 1250 mm, including a region having openings of side holes, and is formed of alumina-silica type refractory. Namely, the mean inner radius R in the region having openings of the side holes 2 is 200 mm. The molten metal level in the tundish 5 during steady state of continuous casting is 100 mm below an upper end portion 7 of the refractory-made structure 1.

[0088] On the sidewall of the refractory-made structure 1, as shown in (a) of the same figures, three side holes 2 each having a cross section of 80 mm high and 80 mm wide are provided in a circumferential direction so that central axes Y_1 to Y_3 thereof each forms an inclination angle $\theta_1 = 40^\circ$ relative to a corresponding virtual line among X_1 to X_3 on the inner surface of the refractory-

made structure. Namely, total opening areas S of the side holes 2 is 19,200 mm² calculated by $S=80\text{ [mm]}\times 80\text{ [mm]}\times 3\text{ [counts]}$. The flow rate Q of molten steel during steady state of casting is 65 m³/hr. Accordingly, the value of the index P expressed by the above-mentioned equation (1) is 0.121 m²/s calculated by $P=R\times Q/S\times \sin\theta_1=200\text{ [mm]}\times 65\text{ [m}^3\text{/hr]}/19,200\text{ [mm}^2\text{]}\times 0.643$, which is larger than the range specified by the present invention.

[0089] The value of the index T (T : the ratio of the thickness of sidewall in the side hole portion to the width of section of the side hole) is $75\text{ [mm]}/80\text{ [mm]}=0.938$, which is sufficiently large, compared with the appropriate value (T : 0.5 or more) to the mean velocity through side holes of molten steel $Q/S=0.940\text{ m/s}$.

[0090] In Comparative Example 2 shown in Figs. 5(a) and (b), molten steel 6 passing through the side holes 2 is given a circumferential velocity, increases the circumferential velocity according to the law of conservation of angular momentum when it passes through an upper nozzle 8 with reduced inner diameter and a sliding gate 9, and generates a swirling flow in a submerged entry nozzle 4. However, since the value of the index P is excessively large as described above, excessively high intensity of swirling flow causes deterioration of the energy efficiency. Further, the problem of vibration of the submerged entry nozzle 4 is also caused.

INDUSTRIAL APPLICABILITY

[0091] According to the method of the present invention, stable continuous casting operation and improvement in cast slab quality can be attained by generating a swirling flow in molten metal in a submerged entry nozzle without causing nozzle clogging that is a weak point of a conventional swirling flow submerged entry nozzle provided with a swirl blade with twisted plate shape, and exerting effects possessed by the swirling flow submerged entry nozzle, such as excellent flow stability of molten metal in a mold or removal of non-metallic inclusions. Therefore, the continuous casting method of molten metal of the present invention is a technique extensively applicable in the field of casting, where stabilization of continuous casting and achieving high-level cleanliness of cast slab are sought after, by an inexpensive device and a simple method.

REFERENCE SIGNS LIST

[0092]

1: Refractory-made structure, 2: Side hole, 3: Axis of refractory-made structure, 4: Submerged entry nozzle, 5: Tundish, 51: Tundish refractory, 52: Tundish casing, 6: Molten metal (molten steel), 7: Upper end portion of refractory-made structure, 8: Upper nozzle, 9: Sliding gate, 10: Inert gas, 11: Mold, 12: Solidified shell, 13: Mold powder, 14: Stopper

rod, O: Center of horizontal circular cross-section, X1 to X8: Radially extending virtual lines, Y1 to Y8: Central axes of side holes, θ_1 : Inclination angle of side hole

Claims

1. A continuous casting method of molten metal in which a hollow cylindrical, conical or truncated cone type refractory-made structure having one or more side holes in a sidewall thereof is disposed in a tundish above a submerged entry nozzle with an central axis of the refractory-made structure aligned vertically to supply molten metal from the tundish to the submerged entry nozzle, wherein:

a central axis of the side hole crosses a virtual line extending radially from the center of a horizontal circular cross-section of the refractory-made structure at an intersection thereof with an inner surface of the refractory-made structure, the central axis of side hole being horizontally inclined at an angle θ_1 relative to the virtual line at the intersection;

the molten metal in the tundish passes from inlet-side openings of side holes which are opened on an outer surface of the refractory-made structure to outlet-side openings thereof which are opened on the inner surface of the refractory-made structure, whereby a swirling flow is generated in the molten metal supplied from the tundish to the submerged entry nozzle while giving a circumferential velocity thereto; and

a mean inner diameter $2R$ of the horizontal circular cross-section of the structure in the region having openings of side holes is 250 to 1,200 mm, the height of section of side hole is 30 to 500 mm, and the angle θ_1 is 15 to 80°; and **characterized in that:**

an index P expressed by the following equation (1) satisfies $0.015\text{ m}^2/\text{s}\leq P\leq 0.100\text{ m}^2/\text{s}$, the index P being represented by a flow rate Q of the molten metal, total opening areas S of the side holes, a mean inner radius R of horizontal circular cross-section in a region having openings of side holes, and the angle θ_1 .

$$P=R\times Q/S\times \sin\theta_1 \dots (1)$$

2. The continuous casting method of molten metal according to claim 1, **characterized in that** a relationship between an index T represented by the ratio of the thickness of sidewall in the side hole portion to

the width of section of side hole, the flow rate Q of the molten metal, and total opening areas S of the side holes satisfies the following conditions.

T is 1.0 or more when Q/S is less than 0.05 m/s;

T is 0.8 or more when Q/S is 0.05 m/s or more but less than 0.1 m/s; 5

T is 0.6 or more when Q/S is 0.1 m/s or more but less than 0.4 m/s;

T is 0.5 or more when Q/S is 0.4 m/s or more but less than 1.2 m/s; and 10

T is 0.4 or more when Q/S is 1.2 m/s or more.

3. The continuous casting method of molten metal according to claim 1 or 2, **characterized in that** a whole body of the refractory-made structure is submerged in the molten metal in the tundish; and an opening is provided in an upper end portion of the refractory-made structure, and a refractory-made stopper rod is inserted from above the tundish through the opening. 15 20
4. The continuous casting method of molten metal according to claim 1 or 2, **characterized in that** a whole body of the refractory-made structure is submerged in the molten metal in the tundish; and no opening is provided in an upper end portion of the refractory-made structure. 25

Patentansprüche 30

1. Stranggussverfahren für geschmolzenes Metall, bei dem eine hohle zylindrische, konische oder kegelförmige feuerfeste Struktur, die ein oder mehrere Seitenlöcher in einer Seitenwand davon aufweist, in einer Verteilerrinne über einer eingetauchten Eintrittsdüse angeordnet ist, wobei eine Mittelachse der feuerfesten Struktur vertikal ausgerichtet ist, um geschmolzenes Metall von der Verteilerrinne zur eingetauchten Eintrittsdüse zu leiten, wobei: 35 40

eine Mittellinie des Seitenloches eine virtuelle Linie, die sich radial von der Mitte eines horizontalen kreisförmigen Querschnitts der feuerfesten Struktur erstreckt an einem Schnittpunkt davon mit einer Innenfläche der feuerfesten Struktur kreuzt, wobei die Mittelachse des Seitenloches am Schnittpunkt um einen Winkel θ_1 relativ zur virtuellen Linie geneigt ist; 45
das geschmolzene Metall in der Verteilerrinne von einlassseitigen Öffnungen der Seitenlöcher, die auf einer Außenfläche der feuerfesten Struktur geöffnet sind, zu auslassseitigen Öffnungen davon gelangt, die auf der Innenfläche der feuerfesten Struktur geöffnet sind, wobei im geschmolzenen Metall, das von der Verteilerrinne zur eingetauchten Eintrittsdüse geleitet wird, ein wirbelnder Fluss erzeugt wird, während die-

sem eine Umfangsgeschwindigkeit verliehen wird; und

ein mittlerer Innendurchmesser 2R des horizontalen kreisförmigen Querschnitts der Struktur in der Region, die Öffnungen von Seitenlöchern aufweist, 250 bis 1.200 mm, die Schnitthöhe des Seitenloches 30 bis 500 mm und der Winkel θ_1 15 bis 80° beträgt; und **dadurch gekennzeichnet, dass:**

ein Index P, der durch die folgende Gleichung (1) ausgedrückt ist, $0,015 \text{ m}^2/\text{s} \leq P \leq 0,100 \text{ m}^2/\text{s}$ erfüllt, wobei der Index P durch eine Durchflussrate Q des geschmolzenen Metalls, Gesamtöffnungsgebiete S der Seitenlöcher, einen mittleren Innenradius R des horizontalen kreisförmigen Querschnitts in einer Region, die Öffnungen von Seitenlöchern aufweist, und den Winkel θ_1 repräsentiert wird.

$$P = R \times Q / S \times \sin \theta_1 \dots (1)$$

2. Stranggussverfahren für geschmolzenes Metall nach Anspruch 1, **dadurch gekennzeichnet, dass** eine Beziehung zwischen einem Index T, der vom Verhältnis der Dicke einer Seitenwand im Seitenlochabschnitt zur Schnittbreite des Seitenloches, die Durchflussrate Q des geschmolzenen Metalls und Gesamtöffnungsgebiete S der Seitenlöcher repräsentiert wird, die folgenden Bedingungen erfüllt. 30 35
T ist 1,0 oder mehr, wenn Q/S kleiner ist als 0,05 m/s;
T ist 0,8 oder mehr, wenn Q/S 0,05 m/s oder mehr, aber kleiner als 0,1 m/s;
T ist 0,6 oder mehr, wenn Q/S 0,1 m/s oder mehr, aber kleiner als 0,4 m/s;
T ist 0,5 oder mehr, wenn Q/S 0,4 m/s oder mehr, aber kleiner als 1,2 m/s; und
T ist 0,4 oder mehr, wenn Q/S 1,2 m/s oder mehr ist. 40
3. Stranggussverfahren für geschmolzenes Metall nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** ein ganzer Körper der feuerfesten Struktur in das geschmolzene Metall in der Verteilerrinne eingetaucht ist; und in einem oberen Endabschnitt der feuerfesten Struktur eine Öffnung bereitgestellt und eine feuerfeste Anschlagstange von oberhalb der Verteilerrinne durch die Öffnung eingeführt ist. 45 50
4. Stranggussverfahren für geschmolzenes Metall nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** ein ganzer Körper der feuerfesten Struktur in das geschmolzenen Metall in der Verteilerrinne eingetaucht ist; und in einem oberen Endabschnitt der feuerfesten Struktur 55

tur keine Öffnung bereitgestellt ist.

Revendications

1. Procédé de coulée continu de métal en fusion, dans lequel une structure faite de réfractaire de type creux cylindrique, conique ou tronconique possédant un ou plusieurs trous latéraux dans une paroi latérale de celle-ci est disposée dans un panier de coulée au-dessus d'une buse d'entrée immergée avec un axe central de la structure faite de réfractaire aligné verticalement pour fournir du métal en fusion du panier de coulée à la buse d'entrée immergée, dans lequel :

un axe central du trou latéral croise une ligne virtuelle s'étendant radialement à partir du centre d'une section transversale circulaire horizontale de la structure faite de réfractaire à une intersection de celle-ci avec une surface intérieure de la structure faite de réfractaire, l'axe central de trou latéral étant horizontalement incliné à un angle $\theta 1$ par rapport à la ligne virtuelle à l'intersection ;

le métal en fusion dans le panier de coulée passe d'ouvertures côté entrée de trous latéraux, qui sont ouvertes sur une surface extérieure de la structure faite de réfractaire, à des ouvertures côté sortie de ceux-ci, qui sont ouvertes sur la surface intérieure de la structure faite de réfractaire, moyennant quoi un écoulement tourbillonnant est généré dans le métal en fusion fourni du panier de coulée à la buse d'entrée immergée tout en donnant une vitesse circonférentielle à celui-ci ; et

un diamètre intérieur moyen $2R$ de la section transversale circulaire horizontale de la structure dans la région possédant des ouvertures de trous latéraux est 250 à 1200 mm, la hauteur de section de trou latéral est 30 à 500 mm, et l'angle $\theta 1$ est 15 à 80° ; et **caractérisé en ce que** :

un indice P exprimé par l'équation suivante (1) satisfait à $0,015 \text{ m}^2/\text{s} \leq P \leq 0,100 \text{ m}^2/\text{s}$, l'indice P étant représenté par un débit Q du métal en fusion, des superficies d'ouvertures totales S des trous latéraux, un rayon intérieur moyen R de section transversale circulaire horizontale dans une région possédant ouvertures de trous latéraux, et l'angle $\theta 1$.

$$P=R \times Q/S \times \sin \theta 1 \dots (1)$$

2. Procédé de coulée continu de métal en fusion selon

la revendication 1, **caractérisé en ce qu'**une relation entre un indice T représenté par le rapport de l'épaisseur de paroi latérale dans le trou latéral portion par rapport à la largeur de section de trou latéral, le débit Q du métal en fusion, et des superficies d'ouvertures totales S des trous latéraux satisfait aux conditions suivantes :

T est 1,0 ou plus lorsque Q/S est inférieur à 0,05 m/s ;

T est 0,8 ou plus lorsque Q/S est 0,05 m/s ou plus mais inférieur à 0,1 m/s ;

T est 0,6 ou plus lorsque Q/S est 0,1 m/s ou plus mais inférieur à 0,4 m/s ;

T est 0,5 ou plus lorsque Q/S est 0,4 m/s ou plus mais inférieur à 1,2 m/s ; et

T est 0,4 ou plus lorsque Q/S est 1,2 m/s ou plus.

3. Procédé de coulée continu de métal en fusion selon la revendication 1 ou 2, **caractérisé en ce qu'**un corps entier de la structure faite de réfractaire est immergé dans le métal en fusion dans le panier de coulée ; et

une ouverture est prévue dans une portion d'extrémité supérieure de la structure faite de réfractaire, et une quenouille faite de réfractaire est insérée à partir d'au-dessus du panier de coulée à travers l'ouverture.

4. Procédé de coulée continu de métal en fusion selon la revendication 1 ou 2, **caractérisé en ce qu'**un corps entier de la structure faite de réfractaire est immergé dans le métal en fusion dans le panier de coulée ; et

aucune ouverture n'est prévue dans une portion d'extrémité supérieure de la structure faite de réfractaire.

FIG. 1

A-A cross-section

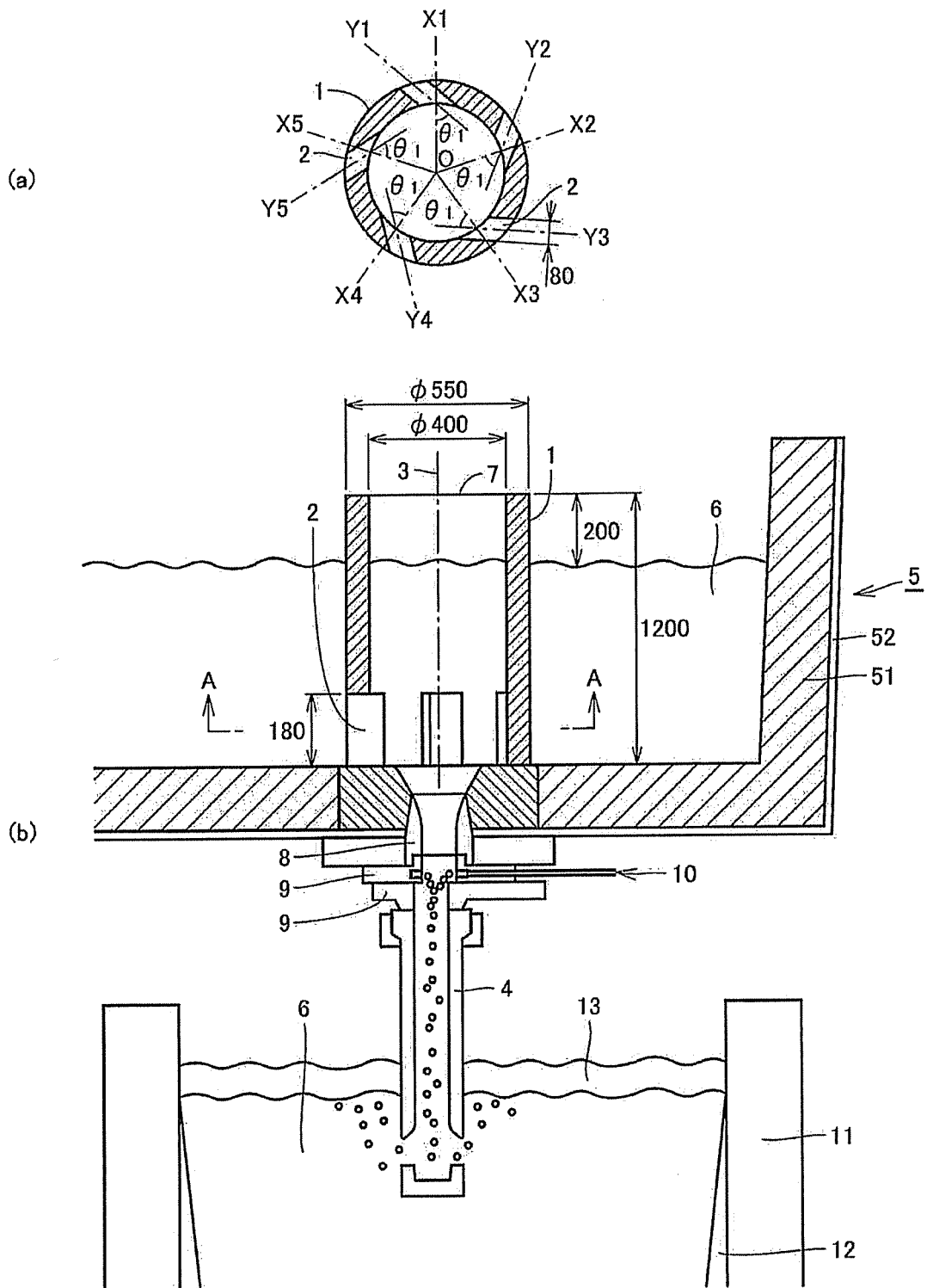


FIG. 2

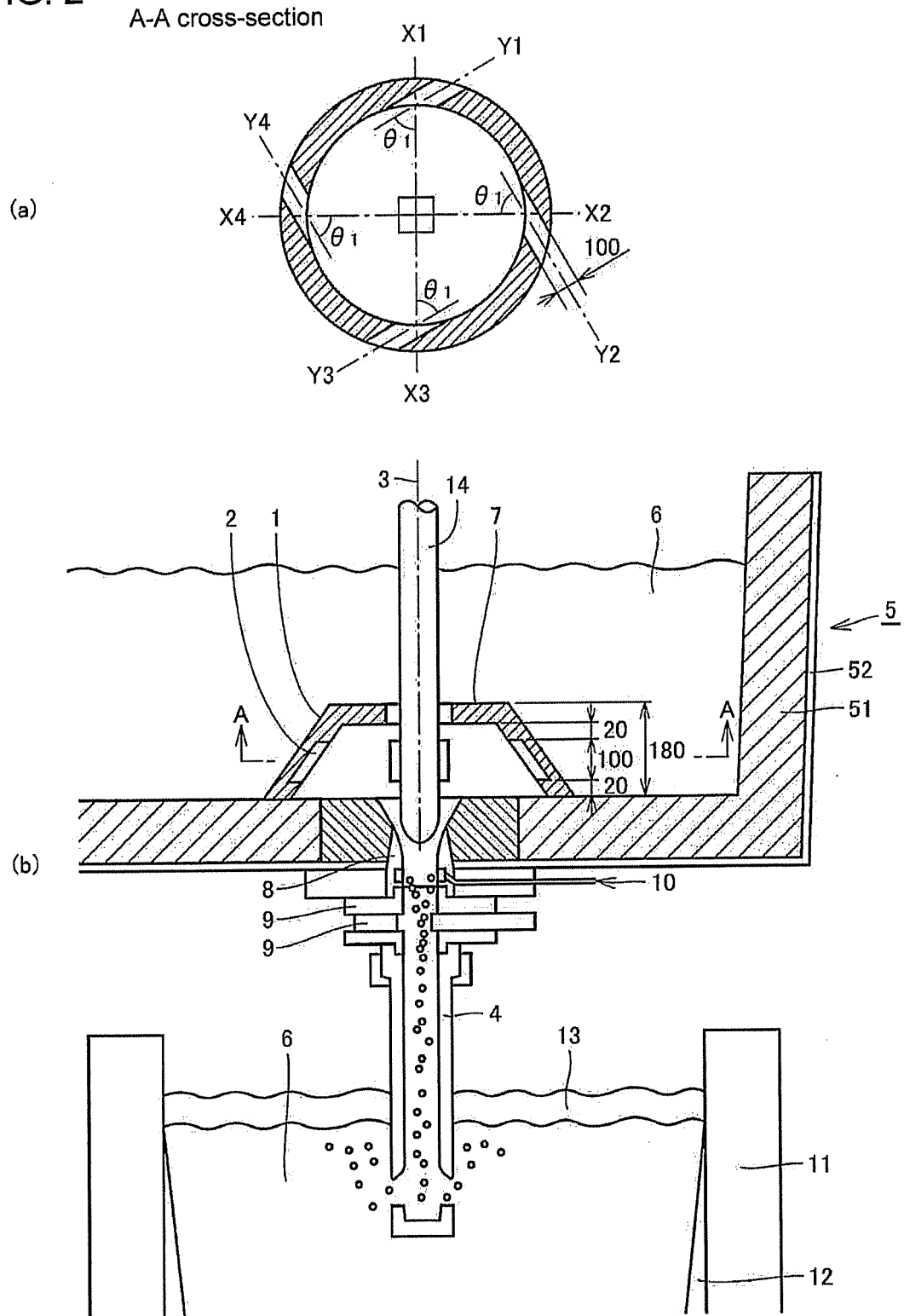


FIG. 3

A-A cross-section

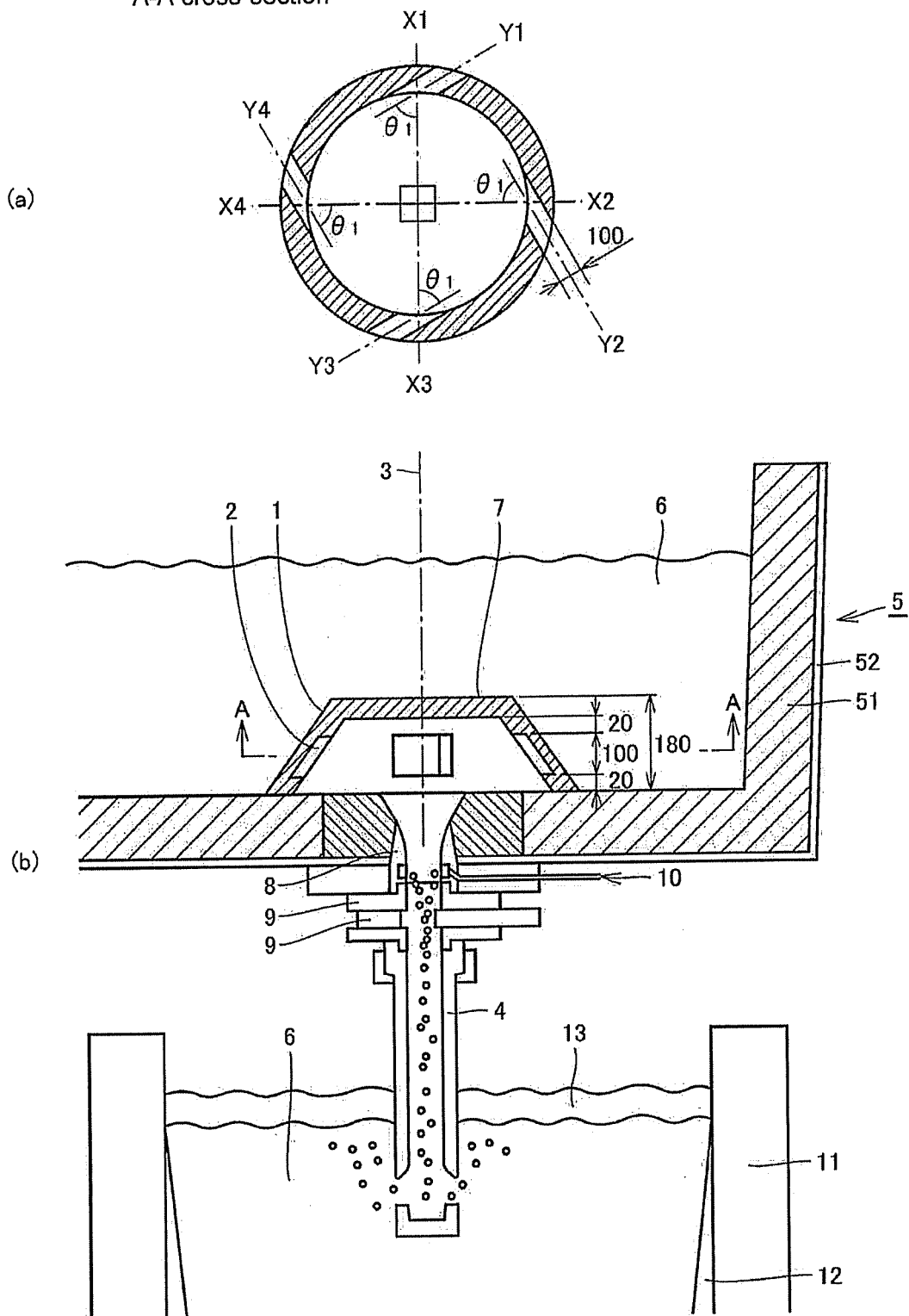


FIG. 4

A-A cross-section

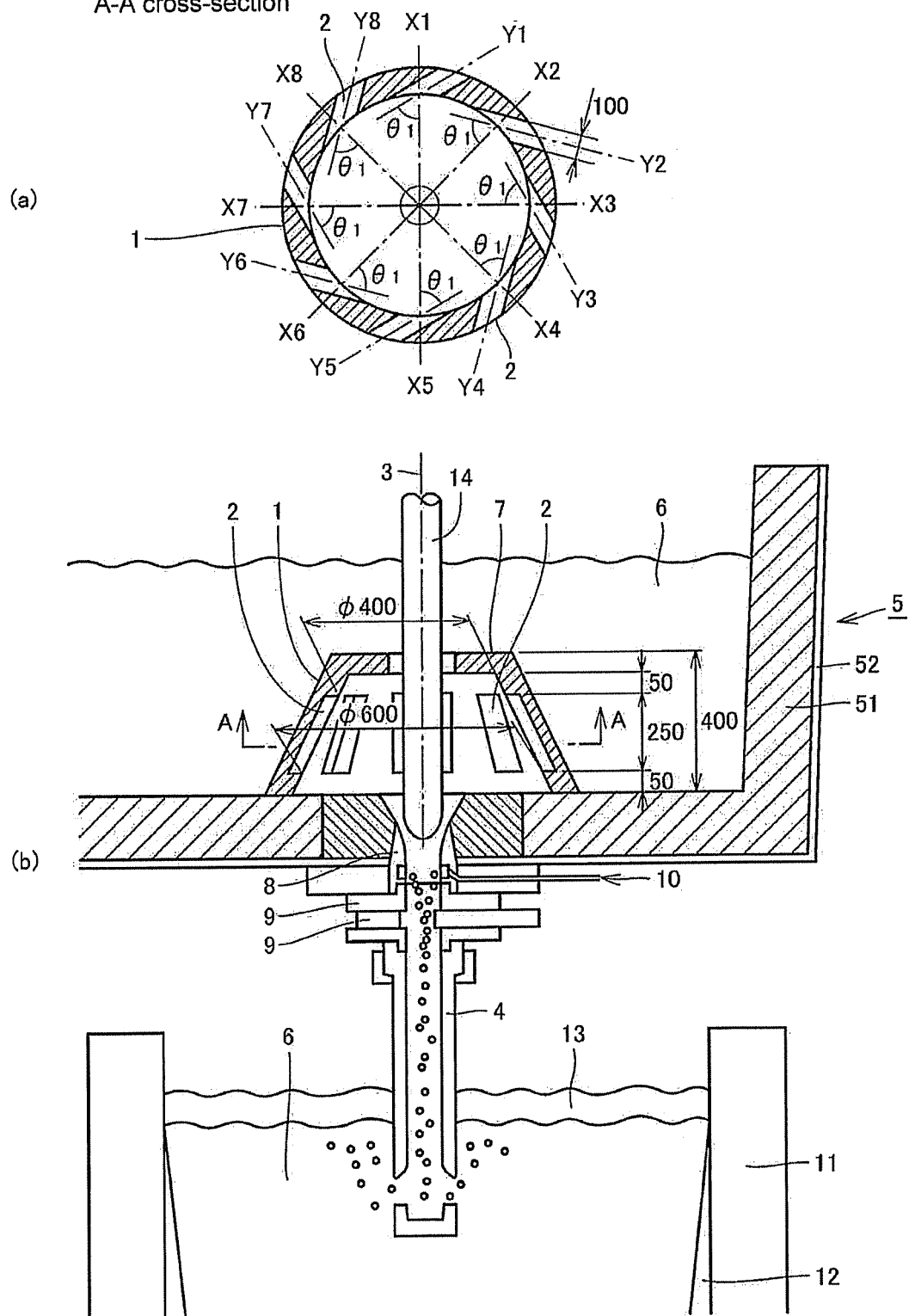
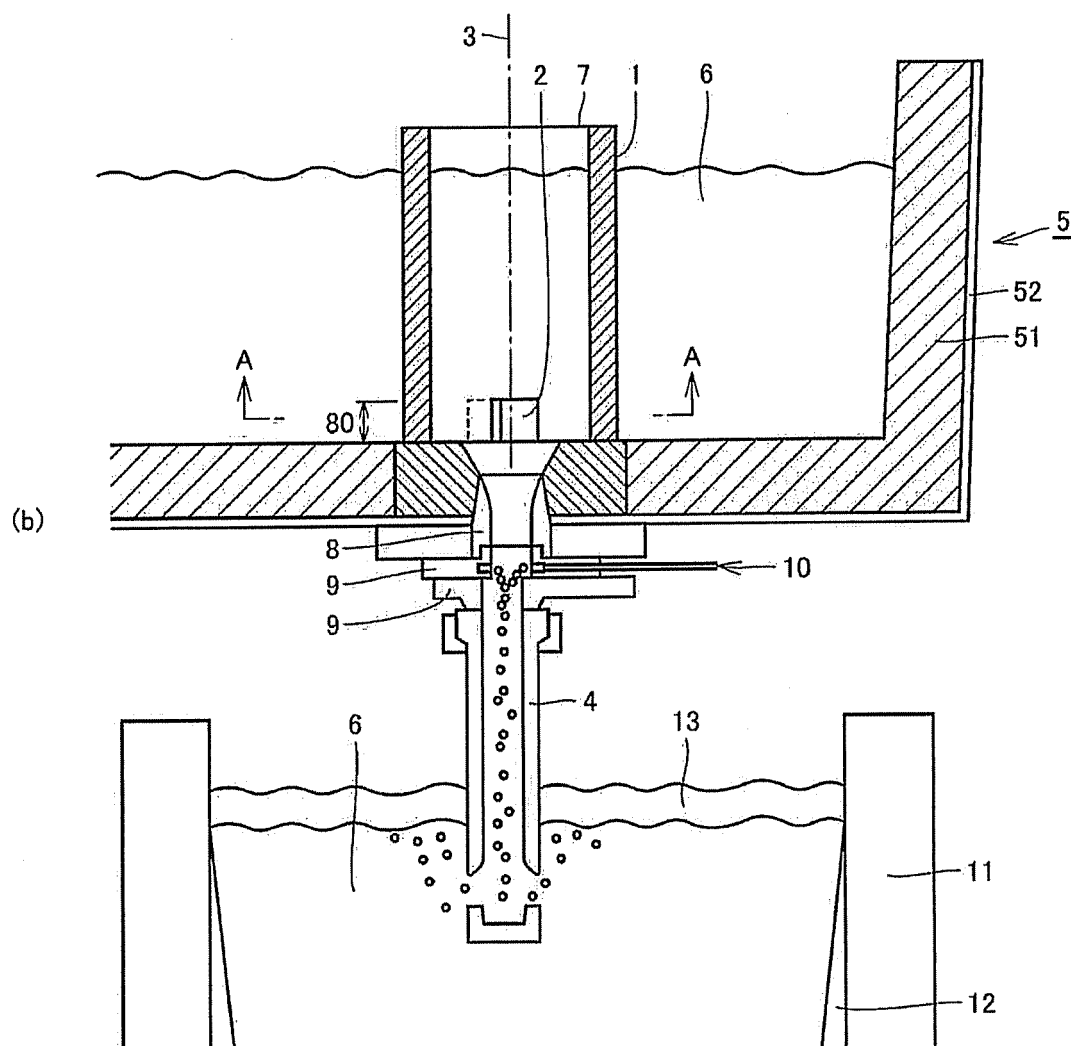
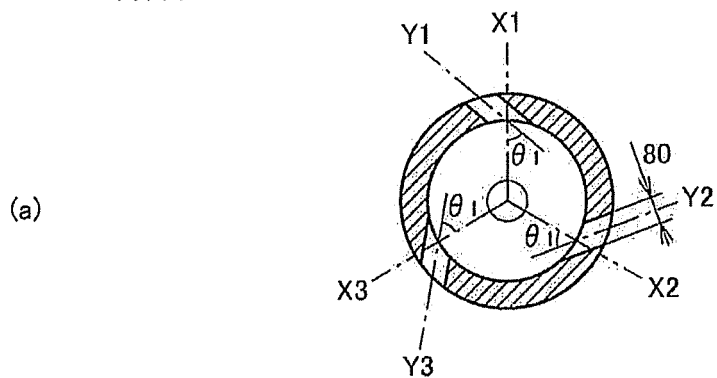


FIG. 5

A-A cross-section



REFERENCES CITED IN THE DESCRIPTION

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