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(54) **CONTINUOUS CASTING APPARATUS FOR STEEL**

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(57) **ABSTRACT**

A continuous casting apparatus for steel includes: a casting mold for casting a molten steel with a pair of long side walls and a pair of short side walls; a submerged entry nozzle which discharges the molten steel into the casting mold; and an electromagnetic stirring device which is disposed along each external surface of each of the long side walls and stirs an upper portion of the molten steel within the casting mold. A curved portion which is convexly curved toward the electromagnetic stirring device in plan view is formed at least at a position where the curved portion faces the submerged entry nozzle on each of the long side walls, and each of the long side walls including the curved portion has a uniform thickness. The shortest horizontal distance between a top which is a most depressed position when an internal surface of the curved portion is seen in plan view and an outer peripheral surface of the submerged entry nozzle is 30 mm to 80 mm in a range from a lower end portion of the electromagnetic stirring device to a position higher than an upper end portion thereof by 50 mm when viewed along a vertical direction.

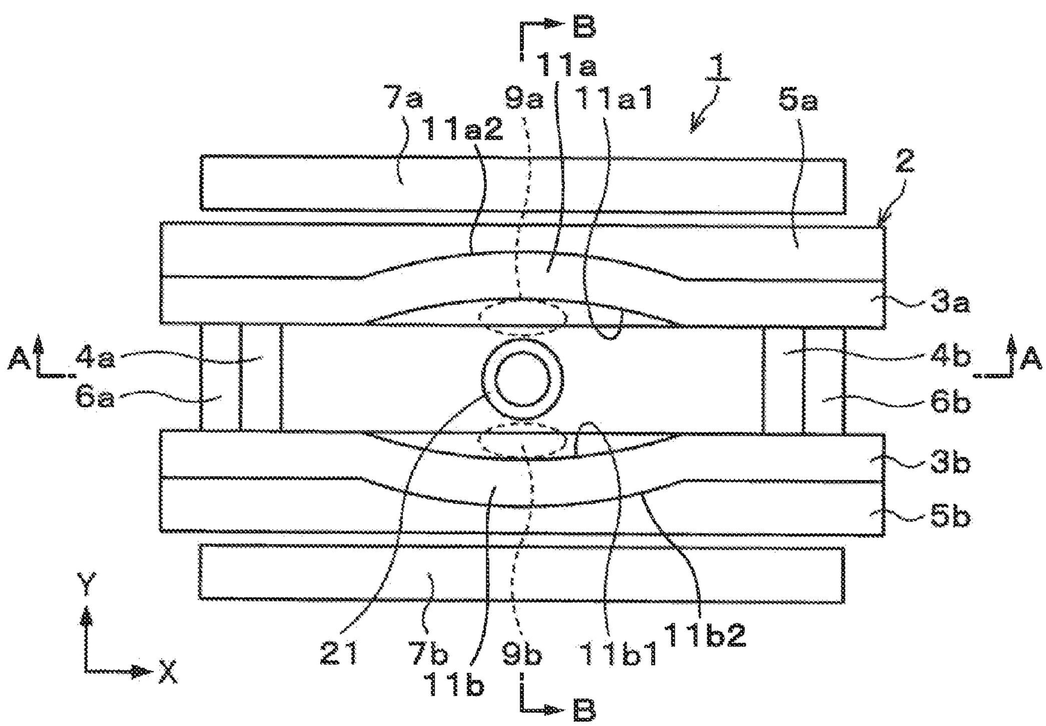
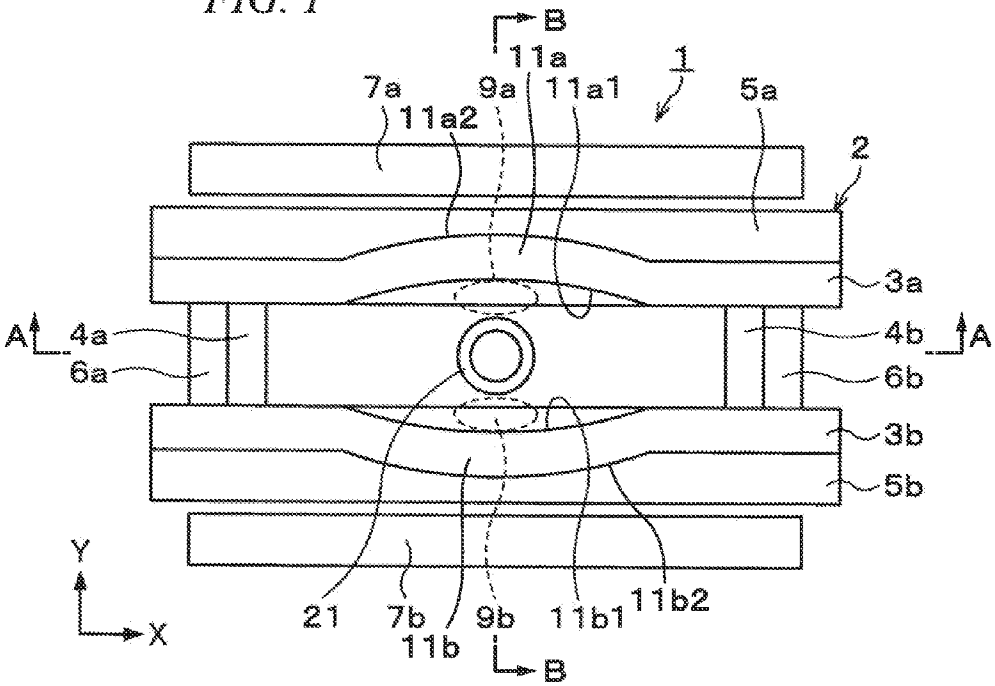


FIG. 1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11a
7a
9a
11a1
1
5a
11a2
2
3a
A
4a
4b
A
6a
6b
3b
5b
Y
X
21
7b
9b
11b1
11b2
11b
B

FIG. 2

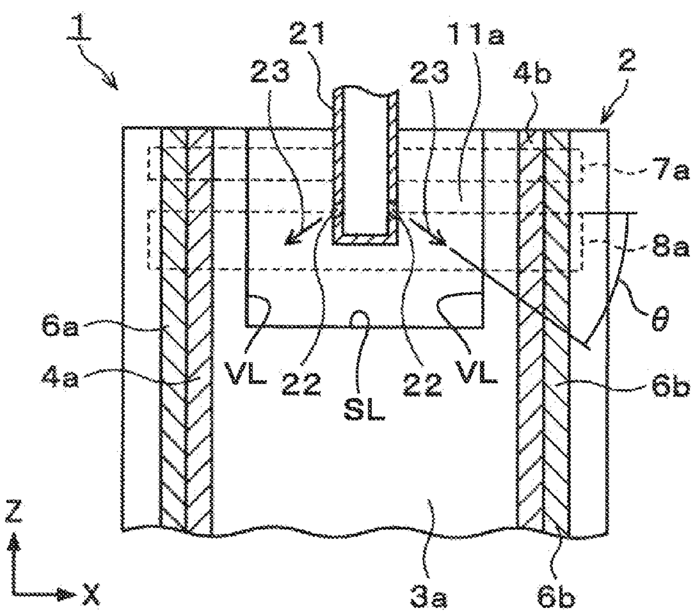
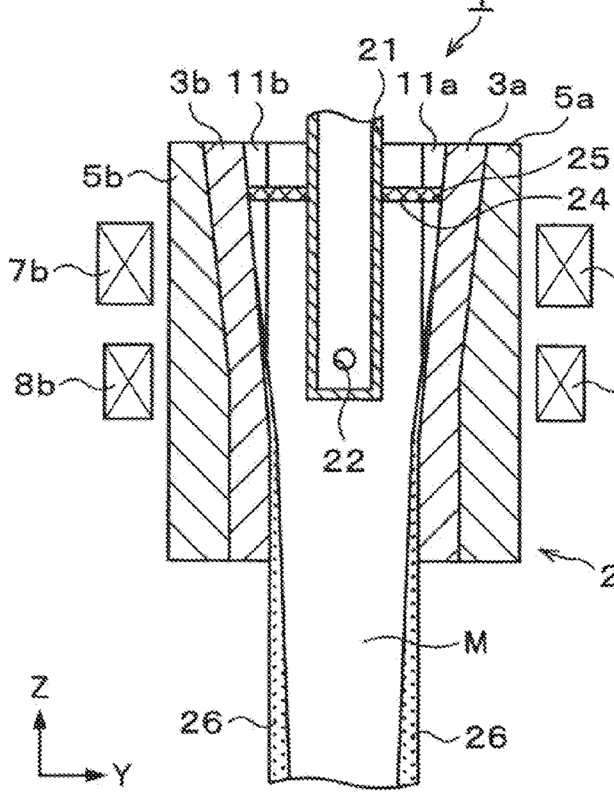

1
21
11a
2
23
23
4b
7a
8a
θ
6a
4a
VL
22
SL
22
VL
6b
Z
X
3a
6b

FIG. 3


1
21
3b
11b
11a
3a
5a
25
5b
24
7b
7a
8b
8a
22
2
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Z
Y
26
26

FIG. 4

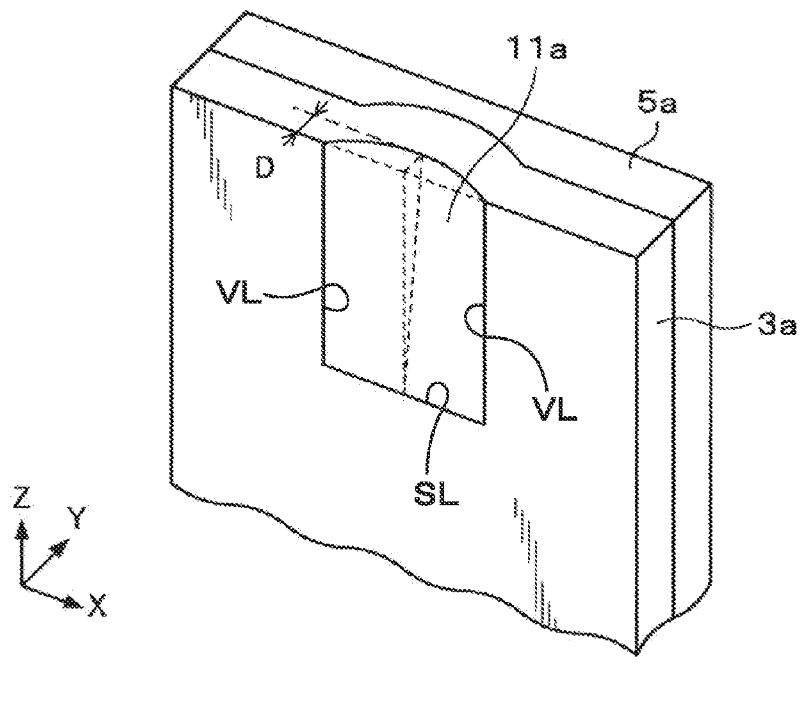
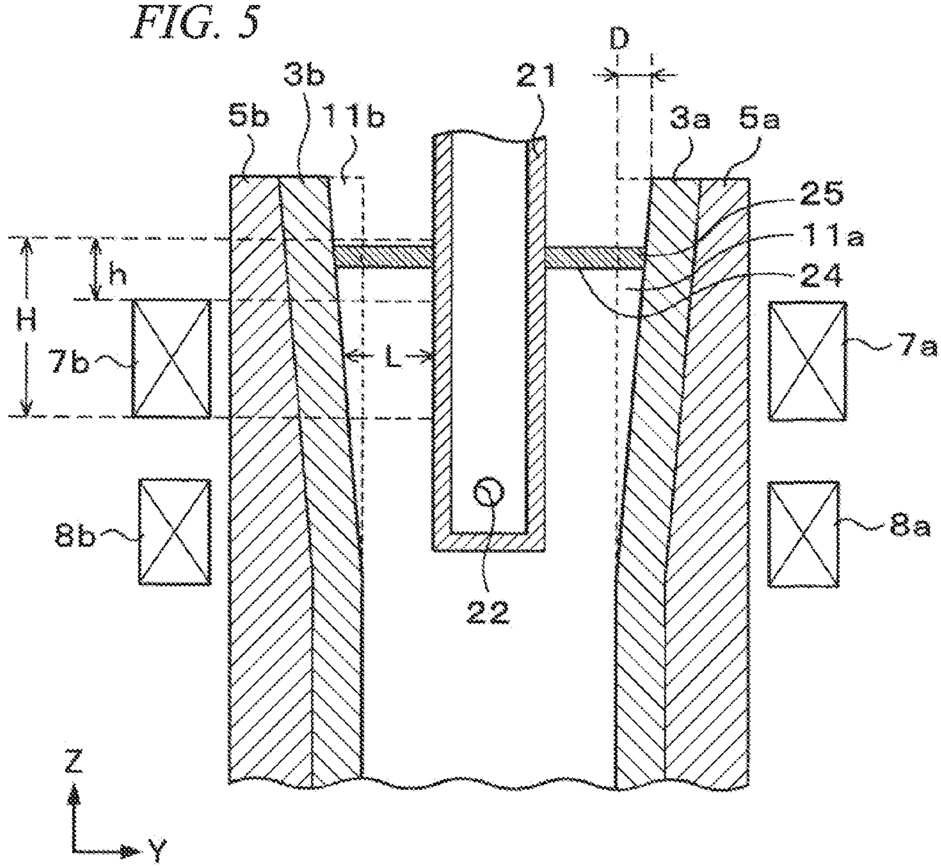
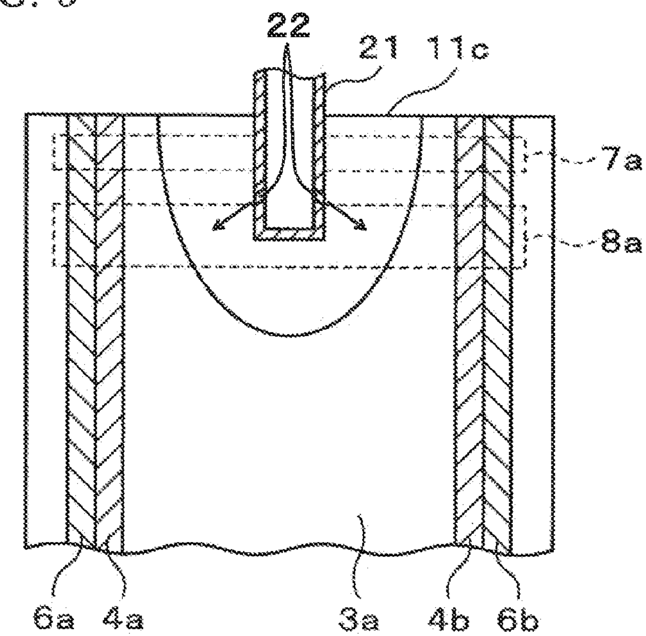

11a
5a
D
VL
3a
VL
SL
Z
Y
X

FIG. 5



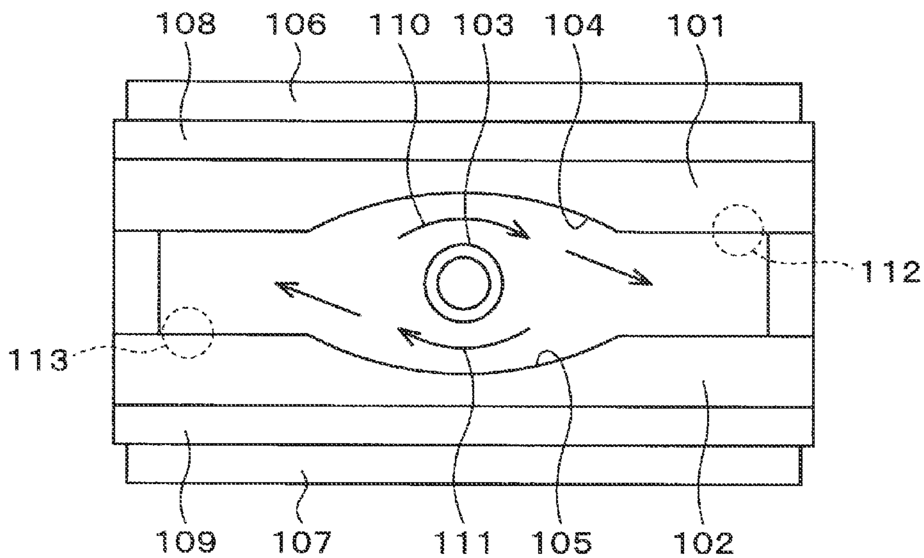
D
3b
21
5b
11b
3a
5a
25
11a
h
24
H
7b
L
7a
8b
22
8a
Z
Y

FIG. 6



22
21
11c
7a
8a
6a
4a
3a
4b
6b

FIG. 7



CONTINUOUS CASTING APPARATUS FOR STEEL

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates to a continuous casting apparatus for steel, which supplies molten steel into a casting mold to manufacture a cast piece.

BACKGROUND ART

[0002] In continuous casting for steel, in order to improve surface properties of a cast piece, hitherto, an electromagnetic stirring device having an electromagnetic coil provided in the vicinity of the upper portion of a casting mold is used to electromagnetically stir molten steel within the casting mold.

[0003] For the electromagnetic stirring, for example, the electromagnetic stirring devices are disposed along a pair of long side walls included in the casting mold. In addition, when the molten steel is discharged from a submerged entry nozzle into the casting mold, current is supplied to the electromagnetic stirring devices to apply a thrust to the upper part of the molten steel within the casting mold. The molten steel is stirred in a horizontal plane by the thrust such that a swirling flow of the molten steel is formed. By the swirling flow, trapping of inclusions, bubbles, and the like in the vicinity of a meniscus at the upper portion in the casting mold by a solidified shell formed on the side surfaces of the casting mold is suppressed.

[0004] However, since the submerged entry nozzle is submerged in the casting mold, regions between the long side walls and the submerged entry nozzle are narrower than the other regions. Therefore, in the regions between the long side walls and the submerged entry nozzle, compared to the other regions, it is difficult for the molten steel to flow.

[0005] In addition, inclusions and the like are likely to adhere to and deposit on the periphery of the submerged entry nozzle in the casting mold. There may be cases where the adhered matter deposited as such has a thickness of several tens of millimeters. Therefore, the regions between the long side walls and the submerged entry nozzle are narrower than the other regions. In this case, the flow channel for the swirling flow is partially narrowed, and thus it is difficult for the molten steel to flow in the regions between the long side walls and the submerged entry nozzle.

[0006] Here, simultaneously with the use of electromagnetic stirring devices described above, instead of a flat shaped casting mold having a flat internal surface in a furnace, using a so-called irregular shaped casting mold in which, as illustrated in FIG. **7**, surfaces **104** and **105** in long side walls **101** and **102**, which face a submerged entry nozzle **103** are convexly curved toward electromagnetic stirring devices **106** and **107**, respectively, is proposed (Patent Document 1). In addition, in FIG. **7**, back plates **108** and **109** made of stainless steel, in which flow channels of cooling water (not illustrated) used to cool the long side walls **101** and **102** are provided are disposed between the long side walls **101** and **102** and the electromagnetic stirring devices **106** and **107**.

[0007] According to the irregular shaped casting mold, since the surfaces **104** and **105** in the long side walls **101** and **102**, which face the submerged entry nozzle **103** are convexly curved toward the electromagnetic stirring devices **106** and **107**, respectively, the shortest horizontal distances between the submerged entry nozzle **103** and the long side walls **101** and **102** are longer than those of the parallel casting mold according to the related art. Therefore, the flow channels of swirling flows **110** and **111** can be widely ensured to that extent, and thus the molten steel easily flows.

RELATED ART DOCUMENT

Patent Document

[0008] [Patent Document 1] Japanese Unexamined Patent Application, First Publication No. 2008-183597

SUMMARY OF THE INVENTION

Problem to be Solved by the Invention

[0009] However, in the above-described technique according to the related art, in order to convexly curve the surfaces **104** and **105** in the long side walls **101** and **102**, which face the submerged entry nozzle **103**, the center portions of the long side walls **101** and **102** made of copper are cut. Therefore, the thicknesses of the long side walls **101** and **102** are extremely small in the parts of the curved surfaces **104** and **105**. In general, the electromagnetic field made by the electromagnetic stirring devices **106** and **107** is an alternate current magnetic field, and thus the magnetic field is attenuated in conductors. Therefore, in the parts of the curved surfaces **104** and **105**, the magnetic field is less attenuated than the other linear parts, and thus the electromagnetic force increases. Accordingly, the flow velocity of the stirring flow in the regions between the curved surfaces **104** and **105** and the submerged entry nozzle **103** becomes faster than that in the other regions. As a result, the flow velocity of stirring flows **110** and **111** becomes partially non-uniform, a flow disturbance or a stagnant zone is generated in regions **112** and **113** on the downstream sides of the stirring flows **110** and **111** in the long side walls **101** and **102**, and there is a problem in that inclusions, bubbles, and the like are likely to be trapped by a solidified shell. Therefore, enhancement of steel quality to an expected degree cannot be obtained.

[0010] The inventors had further performed examinations, and found that trapping of inclusions by the solidified shell of the long side walls **101** and **102** could not be suppressed by only forming the curved surfaces **104** and **105** which allow the stirring flows **110** and **111** to easily flow. That is, it was proved that when the horizontal distance between the curved surfaces **104** and **105** and the submerged entry nozzle **103** is increased, trapping of bubbles can be suppressed. However, in the parts of the curved surfaces **104** and **105**, the electromagnetic force is also strengthened, and the flow velocities of the stirring flows that flow in the regions between the curved surfaces **104** and **105** and the submerged entry nozzle **103** become faster than those of the stirring flows that flow in the other regions. Therefore, a flow disturbance or a stagnant zone is generated in the regions **112** and **113** on the downstream sides of the stirring flows **110** and **111**, and thus a problem in which inclusions are likely to be trapped by the solidified shell is not solved.

[0011] The present invention has been made taking the foregoing points into consideration, and an object thereof, even in an irregular shaped casting mold in a continuous casting apparatus for steel, is to allow the flow velocity of molten steel at the upper portion in the casting mold to be uniform and to allow a horizontal distance between a surface concavely curved in the casting mold and a submerged entry nozzle to be appropriate, thereby enhancing the quality of a cast piece obtained by casting.

Means for Solving the Problem

[0012] In order to accomplish the object, the present invention employed the following measures.

[0013] (1) That is, according to an aspect of the present invention, a continuous casting apparatus for steel includes: a casting mold for casting a molten steel, which includes a pair of long side walls and a pair of short side walls; a submerged entry nozzle which discharges the molten steel into the casting mold; and an electromagnetic stirring device which is disposed along an external surface of each of the long side walls and stirs an upper part of the molten steel within the casting mold. A curved portion which is convexly curved toward the electromagnetic stirring device in plan view is formed at least at a position where the curved portion faces the submerged entry nozzle on each of the long side walls, and each of the long side walls including the curved portion has a uniform thickness. The shortest horizontal distance between a top which is a most depressed position when an internal surface of the curved portion is seen in plan view and an outer peripheral surface of the submerged entry nozzle is 30 mm to 80 mm in a range from a lower end portion of the electromagnetic stirring device to a position higher than an upper end portion of the electromagnetic stirring device by 50 mm when viewed along a vertical direction.

[0014] (2) In the aspect according to the above (1), an electromagnetic brake device disposed below the electromagnetic stirring device may be further included, and the electromagnetic brake device applies a direct current magnetic field having a magnetic flux density distribution which is uniform in a casting mold width direction along each of the long side walls in plan view, in a casting mold thickness direction along each of the short side walls.

[0015] In addition, in the aspect of the above (1), it is more preferable that the shortest horizontal distance be 50 mm to 75 mm in the range from the lower end portion of the electromagnetic stirring device to a position higher than the upper end portion of the electromagnetic stirring device by 50 mm when viewed along the vertical direction.

Effects of the Invention

[0016] According to the aspect described in the above (1), each of the long side walls has the curved portion which is convexly curved toward the electromagnetic stirring device at least at a position that faces the submerged entry nozzle, and each of the long side walls including the curved portion has a uniform thickness. Therefore, the electromagnetic force generated by the electromagnetic stirring device is uniform over the curved portion and the other parts. As a result, the flow velocity of the stirring flow becomes uniform. That is, the intensity distribution of the electromagnetic force when each of the long side walls is seen in plan view is the same in the curved portion and the parts other than the curved portion. Therefore, unlike the related art, the electromagnetic force can be prevented from becoming partially stronger at a point corresponding to the curved portion.

[0017] Therefore, the generation of a flow disturbance or a stagnant zone as in the related art can be suppressed, and easy trapping of bubbles by the solidified shell can be suppressed.

[0018] In addition, since the shortest horizontal distance between the top of the curved portion and the submerged entry nozzle is set to be 30 mm to 80 mm in a range from the position of the lower end portion of the electromagnetic stirring device to a position higher than the upper end portion of the electromagnetic stirring device by 50 mm when viewed in the height direction of the continuous casting apparatus, a smooth and uniform flow of the molten steel can be ensured even in the region between the top of the curved portion and the submerged entry nozzle.

[0019] That is, according to the knowledge newly obtained by the inventors, when the shortest horizontal distance between the top of the curved portion and the submerged entry nozzle is smaller than 30 mm, it is difficult for the molten steel to flow in the curved regions, and bubbles and the like in the molten steel are likely to be trapped by the solidified shell. In contrast, when the shortest horizontal distance exceeds 80 mm, it is difficult to ensure a uniform flow of the molten steel in the curved region, and in a region where the flow velocity of the molten steel is slow, inclusions in the molten steel are likely to be trapped by the solidified shell.

[0020] In the present invention, based on the knowledge, the shortest horizontal distance between the top of the curved portion and the submerged entry nozzle is set to 30 mm to 80 mm. Therefore, in the curved region between the top of the curved portion and the submerged entry nozzle, a smooth and uniform flow of the stirring flow of the molten steel is ensured, and bubbles in the molten steel can be prevented from being trapped by the solidified shell.

[0021] In addition, the range in the height direction in which the shortest horizontal distance between the top of the curved portion and the submerged entry nozzle is set to 30 mm to 80 mm, as such is a range from the lower end portion of the electromagnetic stirring device to a position higher than the upper end portion of the electromagnetic stirring device by 50 mm. This is because although a part of the molten steel that is directly stirred by the electromagnetic force generated by the electromagnetic stirring device is a part from the lower end portion to the upper end portion of the electromagnetic stirring device, in a practical operation, the surface of a meniscus is positioned at a position higher than the upper end portion of the electromagnetic stiffing device. In addition, typically, in the case where the surface of the meniscus is positioned at a position higher than the upper end portion of the electromagnetic stirring device, the height is at a position higher than the upper end portion of the electromagnetic stirring device by about 50 mm. Therefore, the range in the height direction in which the shortest horizontal distance between the top of the curved portion and the submerged entry nozzle is set to be 30 mm to 80 mm is from the lower end portion of the electromagnetic stirring device to the position higher than the upper end portion of the electromagnetic stirring device by 50 mm.

[0022] In addition, a uniform thickness of the long side wall is referred to as a thickness in which a change in a penetration degree of an electromagnetic field in the molten steel due to a change in thickness excluding parts where bolt holes, cooling water grooves, and the like are formed is less than 10% which is an error in an acceptable range. This will be described hereinafter. In a case where a magnetic field having a predetermined magnetic flux density is applied to the inside of the casting mold from the outside of the long side wall, the magnetic field intensity induced inside the casting mold has a loss depending on the value of the thickness of the long side wall. That is, when the thickness of the long side wall is changed, the penetration depth of the magnetic field into the casting mold is changed. When the long side wall is thick, it is difficult for the magnetic field to penetrate. Therefore, the magnetic field intensity in the casting mold is changed with the magnitude of the loss. However, the thickness of the long side wall is caused to be uniform so that the change is less than 10% when viewed in the horizontal direction along the wall surface of the long side wall.

[0023] In addition, the range in the height direction of the uniform thickness of the long side wall may be a range from the lower end portion of the electromagnetic stirring device to a position higher than the upper end portion of the electromagnetic stirring device by 50 mm as described in the effect of the electromagnetic stirring device.

[0024] In addition, "the uniform thickness of the long side wall" will be further supplementarily described. When the long side wall disposed along the vertical direction is seen in plan view, the relative relationship between the thickness of the part of the curved portion and the thickness of the adjacent part excluding the curved portion is particularly important. That is, "each of the long side walls including the curved portion has a uniform thickness" described in the above (1) means that, in a case where the thickness of the part of the curved portion is t**1** and the thickness of the adjacent part excluding the curved portion is t**2**, t**1** is within ±10% of t**2** ($0.9\times t2 \le t1 \le 1.1\times t2$). In addition, it is most preferable that t**1**=t**2**.

[0025] In addition, as described in the above (2), in the continuous casting apparatus for steel, the so-called electromagnetic brake device may also be used together with the electromagnetic stirring device. That is, an electromagnetic brake device which is disposed below the electromagnetic stirring device and which applies the direct current magnetic field having a magnetic flux density distribution which is uniform in the casting mold width direction along the long side walls of the casting mold, in the casting mold thickness direction along the short side walls of the casting mold may further be included.

[0026] In this case, rising of bubbles and inclusions in the molten steel discharged from the submerged entry nozzle is accelerated, and bubbles and inclusions in the molten steel are suspended and can be impeded from remaining in a cast piece which is casted and causing a degradation in quality. Therefore, the quality of the cast piece can be further enhanced.

[0027] In addition, the "uniform magnetic flux density" described in the above (2) will be supplementarily described. In a case where the casting mold is seen in plan view and the magnetic flux density distribution is then seen in the casting mold width direction along the long side walls, the uniform magnetic flux density means that a variation in the magnetic flux density in the length dimensions of the coil parts of the electromagnetic brake devices is within ±30% of the average thereof

[0028] As described above, according to the present invention, the amount of bubbles and the like included in the cast piece which is casted can be reduced and thus the quality of the cast piece can be enhanced.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] FIG. **1** is a schematic plan view illustrating a schematic configuration of a part in the vicinity of a casting mold of a continuous casting apparatus according to an embodiment of the present invention.

[0030] FIG. **2** is a longitudinal sectional view when the continuous casting apparatus is seen in a cross-section taken along the line A-A in FIG. **1**.

[0031] FIG. **3** is a longitudinal sectional view when the continuous casting apparatus is seen in a cross-section taken along the line B-B in FIG. **1**.

[0032] FIG. **4** is a perspective view of a long side wall of the continuous casting apparatus.

[0033] FIG. **5** is a diagram corresponding to FIG. **3** and is a longitudinal sectional view for showing sizes in the periphery of the casting mold of the continuous casting apparatus.

[0034] FIG. **6** is a diagram illustrating a modified example of the continuous casting apparatus and is a longitudinal sectional view corresponding to FIG. **2** in a case where a curved portion having a different shape is included.

[0035] FIG. **7** is a schematic plan view for illustrating a schematic configuration of parts in the vicinity of a casting mold of a continuous casting apparatus according to the related art.

EMBODIMENTS OF THE INVENTION

[0036] Hereinafter, an embodiment of the present invention will be described. FIG. **1** is an explanatory view schematically showing the configuration of the vicinity of a casting mold of a continuous casting apparatus **1** for steel according to this embodiment in plan view, FIG. **2** is an explanatory view schematically showing the cross-section of the same in front view, and FIG. **3** is an explanatory view schematically showing a cross-section of the same in side view.

[0037] The continuous casting apparatus **1** includes a casting mold **2** which is, for example, substantially rectangular in plan view as illustrated in FIG. **1**. The casting mold **2** includes a pair of long side walls **3***a* and **3***b* and a pair of short side walls **4***a* and **4***b*. All of the long side walls **3***a* and **3***b* and the short side walls **4***a* and **4***b* are configured of copper sheets, and on the outsides thereof, back plates **5***a*, **5***b*, **6***a*, and **6***b* made of austenitic stainless steel, which are non-magnetic bodies and reinforce the long side walls **3***a* and **3***b* and the short side walls **4***a* and **4***b* are disposed. That is, the back plate **5***a* is disposed on the outside of the long side wall **3***a*, the back plate **5***b* is disposed on the outside of the long side wall **3***b*, the back plate **6***a* is disposed on the outside of the short side wall **4***a*, and the back plate **6***b* is disposed on the outside of the short side wall **4***b*.

[0038] In addition, on the outsides of the back plates **5***a* and **5***b*, electromagnetic stirring devices **7***a* and **7***b* which respectively include electromagnetic coils are disposed. In addition, immediately below the electromagnetic stirring devices **7***a* and **7***b*, electromagnetic brake devices **8***a* and **8***b* are disposed. That is, the electromagnetic stirring device **7***a* and the electromagnetic brake device **8***a* are disposed on the outside of the back plate **5***a*, and the electromagnetic brake device **8***a* is disposed immediately below the electromagnetic stirring device **7***a*. In addition, the electromagnetic stirring device **7***b* and the electromagnetic brake device **8***b* are disposed on the outside of the back plate **5***b*, and the electromagnetic brake device **8***b* is disposed immediately below the electromagnetic stirring device **7***b*.

[0039] In this embodiment, the length (casting thickness) when the short side walls **4***a* and **4***b* are seen in plan view is, for example, about 50 mm to 300 mm. This length is determined depending on a desired cast piece width, and is about 50 mm to 80 mm in a case of a thin width cast piece, is about 80 mm to 150 mm in the case of an intermediate width cast piece, and is about 150 mm to 300 mm in the case of a typical width cast piece. In addition, a horizontal direction (the X direction in FIGS. **1** to **3**) along the long side walls **3***a* and **3***b* is referred to as a casting mold width direction, and a horizontal direction (the Y direction in FIGS. **1** and **3**) along the short side walls **4***a* and **4***b* is referred to as a casting mold thickness direction.

[0040] At the center portions of the internal surfaces when the long side walls **3***a* and **3***b* are seen in plan view, curved portions **11***a* and **11***b* which are convexly curved toward the electromagnetic stirring devices **7***a* and **7***b* are respectively formed. The curved portions **11***a* and **11***b* are formed at positions facing a submerged entry nozzle **21** provided in the casting mold **2** which will be described later. Regarding the thickness distribution of the long side walls **3***a* and **3***b* along the extension direction thereof when the long side walls **3***a* and **3***b* are seen in plan view, the parts corresponding to the curved portions **11***a* and **11***b* are molded so as not to be different from the straight parts on both adjacent sides thereof but to have a uniform thickness in the horizontal direction. Specifically, the curved portions **11***a* and **11***b* are formed in the long side walls **3***a* and **3***b* by, for example, press forming.

[0041] More specifically, the curved portion **11***a* is formed to include an internal surface **11***a***1** which is curved so that the internal wall surface of the long side wall **3***a* is separated from the submerged entry nozzle **21**, and an external surface **11***a***2** which is curved so that the external wall surface of the long side wall **3***a* is separated from the submerged entry nozzle **21**. Similarly, the curved portion **11***b* is formed to include an internal surface **11***b***1** which is curved so that the internal wall surface of the long side wall **3***b* is separated from the submerged entry nozzle **21**, and an external surface **11***b***2** which is curved so that the external wall surface of the long side wall **3***b* is separated from the submerged entry nozzle **21**.

[0042] Since the long side walls **3***a* and **3***b* have a uniform thickness at all the positions including the curved portions **11***a* and **11***b*, each of external surfaces of the long side walls **3***a* and **3***b* is convexly curved toward the electromagnetic stirring devices **7***a* and **7***b* in the external surfaces **11***a***2** and **11***b***2** included in the curved portions **11***a* and **11***b*.

[0043] In addition, the uniform thickness of the long side walls **3***a* and **3***b* will be supplementarily described. When the long side walls **3***a* and **3***b* are seen in plan view, in a case where the thickness at the curved portions **11***a* and **11***b* is t**1** and the thickness at both adjacent parts to the curved portions **11***a* and **11***b* is t**2**, the uniform thickness means that t**1** is within ±10% of t**2** ($0.9\times t2 \leq t1 \leq 1.1\times t2$). In addition, it is most preferable that t**1**=t**2**.

[0044] The back plates **5***a* and **5***b* have parts in which the center internal surfaces thereof have shapes that are convexly curved toward the electromagnetic stirring devices **7***a* and **7***b* so as to fit the curved shapes of the external surfaces **11***a***2** and **11***b***2** of the curved portions **11***a* and **11***b* of the long side walls **3***a* and **3***b*. However, the external surfaces of the back plates **5***a* and **5***b*, that is, the surfaces thereof that face the electromagnetic stirring devices **7***a* and **7***b* are molded to be flat (flat surfaces).

[0045] Typically, in this type of back plate, a cooling water flow channel used to cool the long side wall made of copper is formed therein. However, in order to form the flow channels in the back plates **5***a* and **5***b*, for example, groove-like flow channels are formed on the surfaces (the internal surfaces) of the back plates **5***a* and **5***b* on the sides that come into contact with the long side walls **3***a* and **3***b*, thereby easily forming the cooling water flow channel. That is, by assembling the back plates **5***a* and **5***b* having the groove-like flow channels formed on the internal surfaces so that the internal surfaces come into close contact with and overlap the external surfaces of the long side walls **3***a* and **3***b*, the groove-like flow channels can be easily formed.

[0046] The curved portions **11***a* and **11***b* are formed to face the submerged entry nozzle **21** from the upper end positions of the long side walls **3***a* and **3***b* in a downward direction as illustrated in FIGS. **2** and **3**. Each of the lower end positions of the curved portions **11***a* and **11***b* may be formed to be at the same height as the lower end position of the submerged entry nozzle **21** or to be lower than the lower end position of the submerged entry nozzle **21**. In spaces (gaps) between the curved portions **11***a* and **11***b* and the submerged entry nozzle **21**, curved regions **9***a* and **9***b* are respectively formed as illustrated in FIG. **1**.

[0047] The curved portions **11***a* and **11***b* have shapes in which the curved parts gradually disappear toward their lower ends (that is, depressions that form the curved portions **11***a* and **11***b* gradually become shallow and disappear). In this embodiment, as illustrated in FIG. **4**, for example, in the internal surface of the long side wall **3***a*, the boundary line between the curved portion **11***a* and the other flat part is a straight line (a straight line SL horizontal along the X direction in FIG. **4**) parallel to the length direction of the long side wall **3***a* at the lower end part of the curved portion **11***a* and is a straight line (a straight line VL in the extension direction along the Z direction in FIG. **4**) parallel to the height direction of the long side wall **3***a* at both side edge parts of the curved portion **11***a*.

[0048] As illustrated in FIG. **5**, in a case where the curved portions **11***a* and **11***b* are seen in a cross-section along the sheet thickness direction thereof, the shortest horizontal distances L between the tops of the curves (the most depressed points) and the peripheral surfaces of the submerged entry nozzle **21** have tapered shapes in which the depressions gradually become shallow and disappear toward the lower ends of the curved portions **11***a* and **11***b*, and thus the lengths thereof in the height direction vary. In this embodiment, in a range from the position of the lower end portion of each of the electromagnetic stirring devices **7***a* and **7***b* to a position higher than the upper end portion of each of the electromagnetic stirring devices **7***a* and **7***b* by 50 mm, the shortest horizontal distance L is set to be 30 mm to 80 mm. In addition, the shortest horizontal distance L is preferably 30 mm to 80 mm as specified here, but is more preferably 50 mm to 75 mm.

[0049] That is, this will be described with reference to FIG. **5**. The shortest horizontal distances L between the tops of the curves of the curved portions **11***a* and **11***b* and the peripheral surfaces of the submerged entry nozzle **21** are set to be 30 mm to 80 mm in a range H from the positions of the lower end portions of the electromagnetic stirring devices **7***a* and **7***b* to heights higher than the upper end portions of the electromagnetic stirring devices **7***a* and **7***b* by 50 mm. The length of h in FIG. **5** is 50 mm.

[0050] Depths D of the depressions that form the curved portions **11***a* and **11***b* for ensuring 30 mm to 80 mm as the shortest horizontal distances L between the tops of the curves of the curved portions **11***a* and **11***b* and the peripheral surfaces of the submerged entry nozzle **21** depend on the thicknesses of the long side walls **3***a* and **3***b*. However, in consideration of the strengths of the back plates **5***a* and **5***b* and reducing the total thickness due to the electromagnetic force which is weakened as the electromagnetic stirring devices **7***a* and **7***b* become distant in position from the molten steel, the depths D of the depressions may be appropriately set. As the upper limit of the depth D of the depression, 50 mm or less, and preferably 40 mm or less, are exemplary examples. As the lower limit of the depth D of the depression, 5 mm or greater and preferably 10 mm or greater are exemplary examples. That is, the depth D is preferably 5 mm to 50 mm, and more preferably 10 mm to 40 mm.

[0051] Regarding the above-mentioned submerged entry nozzle **21**, as illustrated in FIG. **3**, during casting, the lower portion thereof is submerged in the molten steel M within the casting mold **2**. In addition, in FIG. **3**, in order to clearly show the structure inside the continuous casting apparatus **1**, hatching of the molten steel M is omitted. In the vicinity of the lower end of the side surface of the submerged entry nozzle **21**, discharge holes **22** that discharge the molten steel obliquely downward in the casting mold **2** are formed at two points. The discharge holes **22** are formed at positions that respectively face the short side walls **4***a* and **4***b* of the casting mold **2**. A discharge flow **23** discharged from each of the discharge holes **22** includes Ar gas bubbles blown to clean nozzles, alumina or slag-based inclusions, and the like. The bubbles and inclusions rise to the vicinity of a meniscus **24**. In addition, on the meniscus **24**, a molten powder **25** having molten oxides is supplied by a supply mechanism (not illustrated).

[0052] On the internal surface of the casting mold **2**, as illustrated in FIG. **3**, a solidified shell **26** in which the molten steel M cools and solidifies is formed.

[0053] Each of the electromagnetic stirring devices **7***a* and **7***b* has the electromagnetic coil, and receives an alternate current power supplied from a power supply (not illustrated) and generates an electromagnetic force, thereby applying a thrust to the molten steel M at the upper portion of the casting mold **2**. In addition, the molten steel M to which the thrust is applied horizontally swirls around the submerged entry nozzle **21** in the casting mold **2** and generates a stirring flow that stirs the molten steel M. By the stirring flow, the inclusions, the bubbles, and the like in the vicinity of the meniscus **24** at the upper portion of the casting mold **2** are prevented from being trapped by the solidified shell **26** formed on the side surfaces of the casting mold **2**.

[0054] The electromagnetic brake devices **8***a* and **8***b* which are respectively disposed below the electromagnetic stirring devices **7***a* and **7***b* and include electromagnets and the like may apply a direct current magnetic field having a substantially uniform magnetic flux density distribution in the casting mold width direction (the X direction in FIGS. **1** and **2**) along the long side walls **3***a* and **3***b* of the casting mold **2** to the discharge flows **23** of the molten steel M immediately after being respectively discharged from the discharge holes **22** in the casting mold thickness direction (the Y direction in FIGS. **1** and **2**) along the short side walls **4***a* and **4***b* of the casting mold **2**. By the direct current magnetic field and the discharge flows **23** of the molten steel M respectively discharged from the discharge holes **22**, an induced current is generated in the casting mold width direction (the X direction in FIGS. **1** and **2**), and by the induced current and the direct current magnetic field, counter flows that flow in the opposite directions to the discharge flows **23** are formed in the vicinity of the discharge flows **23**. By the counter flows, deep infiltration of the bubbles and included portions into the molten steel M in the discharge flows **23** are suppressed, and rising of the bubbles and included portions is accelerated, thereby suppressing trapping of the bubbles and included portions by the solidified shell **26**.

[0055] In addition, the "uniform magnetic flux density" will be supplementarily described. In a case where the casting mold **2** is seen in plan view and the magnetic flux density distribution is then seen in the casting mold width direction along the long side walls **3***a* and **3***b*, the uniform magnetic flux density means that a variation in the magnetic flux density in the length dimensions of the coil parts of the electromagnetic brake devices **8***a* and **8***b* is within ±30% from the average thereof

[0056] The continuous casting apparatus **1** according to this embodiment is configured as described above. Next, a continuous casting method of the molten steel M using the continuous casting apparatus **1** will be described.

[0057] First, while Ar gas is blown into the submerged entry nozzle **21**, the molten steel M is discharged into the casting mold **2** from each of the discharge holes **22** of the submerged entry nozzle **21**. The molten steel M is discharged obliquely downward such that the discharge flows **23** directed from the discharge holes **22** toward the short side walls **4***a* and **4***b* of the casting mold **2** are formed. The discharge flows **23** include the Ar gas bubbles and the other inclusions, and they are suspended in the molten steel M within the casting mold **2** and rise by the buoyancy due to a difference in the specific gravity between the bubbles and inclusions, and the molten steel M.

[0058] In addition, the electromagnetic brake devices **8***a* and **8***b* may be operated at the same time as when the molten steel M is discharged from the submerged entry nozzle **21**. In the case of using the electromagnetic brake devices **8***a* and **8***b*, counter flows in the opposite direction to the flows of the discharge flows **23** are formed in the molten steel M. As a result, as described above, deep infiltration of the bubbles and the other inclusions into the molten steel M in the discharge flows **23** is suppressed and diffusing towards the periphery of the submerged entry nozzle **21** is suppressed. In addition, the bubbles and the other inclusions in the discharge flows **23** rise to the vicinity of the meniscus **24** from the vicinity of the submerged entry nozzle **21** by the counter flows.

[0059] In addition, at the same time during the operation of the electromagnetic brake devices **8***a* and **8***b*, the electromagnetic stirring devices **7***a* and **7***b* are operated. Therefore, as described above, the stirring flow is formed in the molten steel M in the vicinity of the meniscus **24** within the casting mold **2** due to the electromagnetic stirring by the electromagnetic force. In addition, the Ar gas bubbles and the like that rise to the vicinity of the meniscus **24** by riding on the counter flows described above are swirled by the stirring flow and are incorporated into, for example, the molten powder **25** having the molten oxides without being trapped by the solidified shell **26** of the casting mold **2** so as to be removed.

[0060] Since the curved portions **11***a* and **11***b* are respectively formed at the center positions of the upper portions of the long side walls **3***a* and **3***b* of the casting mold **2**, the curved regions **9***a* and **9***b* are formed between the curved portions **11***a* and **11***b* and the submerged entry nozzle **21**. At this time, since the long side walls **3***a* and **3***b* also include the curved portions **11***a* and **11***b* and have the uniform thickness, the magnetic flux density of the electromagnetic force applied to the molten steel M by the electromagnetic stirring devices **7***a* and **7***b* is at the same degree in both (1) the molten steel M that flows in the curved regions **9***a* and **9***b* and (2) the molten steel M that linearly flows at positions other than the curved regions **9***a* and **9***b*. Therefore, the stirring flow having a uniform flow velocity can be formed along the flow direction of the molten steel M. Accordingly, a flow disturbance or a stagnant zone is prevented from occurring in regions (the regions **112** and **113** in the related art described with reference to FIG. **7**) on the downstream sides of the stirring flow in the long side walls **3***a* and **3***b*. Therefore, it is possible to suppress trapping of bubbles and the like by the solidified shell due to the occurrence of the stagnant zone.

[0061] In addition, although the long side walls **3***a* and **3***b* including the curved portions **11***a* and **11***b* have a uniform thickness at each position, the thicknesses of the back plates **5***a* and **5***b* at the parts corresponding to the curved portions **11***a* and **11***b* are thin, and thus the magnetic flux density becomes non-uniform to that extent. However, since the electromagnetic field during the electromagnetic stirring is generally an alternate current magnetic field, the electromagnetic field is attenuated in conductors, and the attenuation particularly becomes intensive as the electrical conductivity is increased. In addition, since this type of the back plates **5***a* and **5***b* is made of non-magnetic austenitic stainless steel, the electrical conductivity thereof is much smaller than that of the long side walls **3***a* and **3***b* made of copper. Therefore, even though the thicknesses of the back plates **5***a* and **5***b* are partially thin, the effect thereof is rarely present, and the uniform magnetic flux density can be obtained even in the molten steel M that flows in the curved regions **9***a* and **9***b*.

[0062] The inventors had actually measured and examined the magnetic flux density using a gaussmeter and found the following. That is, in a case where the continuous casting apparatus **1** was viewed along the height direction, the magnetic flux density at the center position of the height of the electromagnetic stirring device **7***a* and at a point of 10 mm toward the submerged entry nozzle **21** from the top of the curve of the curved portion **11***a* of which the depression depth D was 30 mm was measured using the gaussmeter, and it was confirmed that the magnetic flux density varied by 10% or less even when compared to the magnetic flux density of the linear parts other than the curved portion **11***a* of the long side wall **3***a*. That is, the magnetic flux density at the same height of the continuous casting apparatus **1** was measured at a plurality of points, and the values were compared to each other. It was confirmed that the measurement value at the point corresponding to the curved portion **11***a* and the measurement values at the flat parts on both sides of the curved portion **11***a* had a difference of only about 10%.

[0063] For reference, in a case where the curved portion having a depression depth D of 30 mm was formed by cutting only a curved concave surface from the long side wall as in the related art and the thickness of the curved portion was thinned, it was confirmed that the magnetic flux density thereof was increased by about 40% from the magnetic flux density of the linear part of the long side wall. That is, similarly to the structure of the related art illustrated in FIG. **7**, the curved concave surface similar to that of the above-described example was formed only on the internal surface while the external surface of the long side wall was flat, and the magnetic flux density was measured to perform the same evaluation. As a result, it was confirmed that the measurement value at the point corresponding to the curved portion was higher than the measurement values at the flat parts on both sides of the curved portion by about 40%. Therefore, the effect of this embodiment could be confirmed by the foregoing point.

[0064] This will be described with reference to FIG. **5**. In this embodiment, the shortest horizontal distances L between the tops of the curves of the curved portions **11***a* and **11** and the submerged entry nozzle **21** are set to 30 mm to 80 mm in the range H from the lower end portions of the electromagnetic stirring devices **7***a* and **7***b* to the positions higher than the upper end portions of the electromagnetic stirring devices **7***a* and **7***b* by 50 mm. In this configuration, the flow velocity of the stirring flow that flows in the curved regions **9***a* and **9***b* is uniform, and a smooth and steady flow of the molten steel M can be ensured. Therefore, it is possible to sufficiently stir the molten steel M in the casting mold **2**, and trapping of the bubbles and the like by the solidified shell **26** can be suppressed by the foregoing point.

[0065] Moreover, in this embodiment, since the electromagnetic brake devices **8***a* and **8***b* are also used, the rising of the inclusions such as bubbles in the molten steel M is accelerated and the diffusion to the periphery thereof is suppressed. Therefore, trapping of the bubbles and the like by the solidified shell **26** can be further suppressed.

[0066] In addition, in this embodiment, as illustrated in FIGS. **2** and **4**, the shapes of the curved portions **11***a* and **11***b* are shapes in which the boundary between the curved portion **11***a* and the flat part of the periphery thereof is a straight line (the straight line SL along the X direction in FIGS. **2** and **4**) parallel to the length direction of the long side wall **3***a* at the lower end part of the curved portion **11***a* and is a straight line (the straight line VL along the Z direction in FIGS. **2** and **4**) parallel to the height direction of the long side wall **3***a* at both side parts of the curved portion **11***a*. However, other shapes may also be employed as the shapes of the curved portions **11***a* and **11***b*. For example, as illustrated in FIG. **6**, curved portion **11***c* having a so-called inverted bell shape in which the boundary line between the curved portion and the other flat parts is converged on a single point at the lowermost end as it goes to the lower end and disappears may be employed. That is, as illustrated in FIG. **6**, the curved portion **11***c* having a boundary line in a semi-elliptical shape that tapers to the lower portion in an opposed view of the long side wall **3***a* may be employed.

EXAMPLE 1

[0067] Hereinafter, an effect of removing Ar gas bubbles and inclusions included in molten steel in a case where a continuous casting apparatus for steel according to Examples of the present invention is used will be described. When the Examples were performed, the continuous casting apparatus **1** illustrated in FIGS. **1** to **3** was used as a continuous casting apparatus for steel.

[0068] At the formation position of the meniscus **24** in the casting mold **2** having a width of 1200 mm, a height of 900 mm, and a thickness of 250 mm, the electromagnetic stirring devices **7***a* and **7***b* having a height of 200 mm and a thrust of 100 mmFe were set so that the upper end positions thereof had the same height as the position of the meniscus, and the electromagnetic brake devices **8***a* and **8***b* which were disposed to apply the maximum magnetic flux density at a position having a depth of 500 mm down from the meniscus **24** were used. In addition, the submerged entry nozzle **21** having a maximum outside diameter of 190 mm and an inside diameter of 100 mm was inserted into a molten steel submerged portion at a position having a depth of 400 mm down from the meniscus **24** along the vertical direction to perform casting.

[0069] The continuous casting machine **1** of this example included vertical portions having bend radiuses of 7.5 m and 2.5 m. By using the continuous casting machine **1**, a low carbon aluminium-killed steel was casted at a casting rate of 2 m/min. The discharge holes **22** of the submerged entry nozzle **21** faced the internal surfaces of the short side walls **4***a* and **4***b* in the space of the casting mold **2** and had a discharge angle θ (see FIG. **2**) of **30** degrees in the downward direction, and a two-hole nozzle having a hole diameter of 70 mm was used as the submerged entry nozzle **21**.

[0070] The thicknesses of the long side walls **3***a* and **3***b* were constant at 30 mm, and a typical casting mold having parallel long side copper sheets and the center parts of the long side copper sheets were subjected to press forming, and the back plates **5***a* and **5***b* were cut to have depression depths D of 0, 5, 10, 20, 30, 40, 50, and 55 mm at the position of the meniscus **24**. That is, when the long side walls **3***a* and **3***b* were produced, rectangular copper sheets having a uniform thickness of 30 mm were prepared, press forming was performed on the center portions of the upper ends of the copper sheets, and accordingly, seven types of long side walls **3***a* and **3***b* having depression depths D of 0, 5, 10, 20, 30, 40, 50, and 55 mm at the height position of the meniscus **24** were produced. In addition, a depression depth D of 0 mm means a casting mold having a long side wall without depressions.

[0071] On the other hand, seven types of back plates **5***a* and **5***b* in which the shapes of the curved concave portions (the depths of the curves) were different were produced so as to fit the shapes (the depths of the curves) of the curved portions **11***a* and **11***b* of the seven types of long side walls **3***a* and **3***b*. In addition, the thickness of each of the back plates **5***a* and **5***b* was 80 mm, but the part where the curved concave portion was formed was thinner.

[0072] The curved portions **11***a* and **11***b* in the long side walls **3***a* and **3***b* were formed to have a length of 400 mm from the center of the casting mold width in the casting width direction to each of both sides, and as illustrated in FIG. **2**, the boundary between the curved portion **11***a* (**11***b*) and the other flat part was, as the curved portion **11***a* (**11***b*) goes to the lower end, a straight line parallel to the length direction (the X direction in FIG. **2**) of the long side wall **3***a* at the lower end part of the curved portion **11***a* (**11***b*) and was a straight line parallel to the height direction (the Z direction in FIG. **2**) of the long side wall **3***a* at both side parts of the curved portion **11***a*, thereby forming a rectangular shape. The long side walls **3***a* and **3***b* having the curved portions **11***a* and **11***b* were used as a part of the casting mold.

[0073] Bubbles and inclusion defects of a cast piece were evaluated by observing a part having a depth of 50 mm from the cast piece surface layer of the cast piece and counting the number of bubbles and inclusions having a diameter of 100 μm or greater as indexes. The index of the number of Ar gas bubbles in Table 1 represents the ratio of the number of Ar gas bubbles in each condition with respect to the number of Ar gas bubbles which was set to 1 in a case where the distances L (see FIG. **5**) between the curved portions **11***a* and **11***b* and the submerged entry nozzle **21** were 25 mm and the depression depth D was 0 mm, that is, the curved portions **11***a* and **11***b* were not formed on the long side walls **3***a* and **3***b*.

[0074] In addition, similarly, the index of the number of inclusions represents the ratio of the number of inclusions in each condition with respect to the number of inclusions which was set to 1 in a case where the distances L between the curved portions **11***a* and **11***b* and the submerged entry nozzle **21** were 25 mm and the depression depth D was 0 mm, that is, the curved portions **11***a* and **11***b* were not formed on the long side walls **3***a* and **3***b*. In addition, the distances L between the curved portions and the submerged entry nozzle in Table 1 show dimensions at the lower end positions of the electromagnetic stirring devices **7***a* and **7***b*. In addition, the depression depth D shows dimensions at the height position where the meniscus **24** is present.

[0075] In addition, in order to check the effects of the Examples of the present invention, first, a result of operating only the electromagnetic stirring devices **7***a* and **7***b* without operating the electromagnetic brake devices **8***a* and **8***b* is shown in Table 1.

TABLE 1

Distance between curved portion and submerged entry nozzle L (mm)	Depression depth of curved portion D (mm)	Index of number of Ar gas bubbles	Index of number of inclusions of casting mold parallel portion
25	0	1	1
25	5	1	1
30	5	0.6	1
40	10	0.4	1
50	20	0.2	1
60	30	0.2	1.1
70	40	0.2	1.2
80	50	0.2	1.3
85	55	0.2	2.0

[0076] According to the result shown in Table 1, in a case where the distance L was 25 mm, even when the curved portions **11***a* and **11***b* having a depression depth D of 5 mm were formed, similarly to the case where the depression depth D was 0 mm, both the index of the number of Ar gas bubbles and the index of the number of inclusions were 1, and it was found that the number of Ar gas bubbles and inclusions could not be reduced.

[0077] However, at a distance L of 30 mm, even though the depression depth D was 5 mm and small, the index of the number of Ar gas bubbles was reduced to 0.6.

[0078] In addition, at a distance L of 80 mm, the index of the number of Ar gas bubbles was 0.2 which is a low level. Moreover, the index of the number of inclusions was 1.3 which is also a low level. However, it was seen that at a distance L of 85 mm, the index of the number of inclusions was rapidly increased to 2.0.

EXAMPLE 2

[0079] Next, under the same conditions as those of Example 1, the electromagnetic stirring devices **7***a* and **7***b* were also used while operating the electromagnetic brake devices **8***a* and **8***b*, and the result is shown in Table 2.

TABLE 2

Distance between curved portion and submerged entry nozzle L (mm)	Depression depth of curved portion D (mm)	Index of number of Ar gas bubbles	Index of number of inclusions of casting mold parallel portion
25	0	1	1
25	5	1	1
30	5	0.5	1
40	10	0.3	1
50	20	0.1	1
60	30	0.1	1
70	40	0.1	1.1
80	50	0.1	1.2
85	55	0.1	1.8

[0080] According to the result shown in Table 2, the same tendency as in the case where the electromagnetic brakes **8***a* and **8***b* were not operated was shown. That is, in a case where the distance L was 25 mm, even when the curved portions **11***a* and **11***b* having a depression depth D of 5 mm were formed, both the index of the number of Ar gas bubbles and the index of the number of inclusions were 1, and there was no change from the case where the depression depth D was 0 mm. Therefore, the number of Ar gas bubbles and inclusions could not be reduced.

[0081] On the other hand, at a distance L of 30 mm, even when the depression depth D was 5 mm, the index of the number of Ar gas bubbles was halved to 0.5.

[0082] In addition, at a distance L of 80 mm, the index of the number of Ar gas bubbles was 0.1 and was further reduced compared to 0.2 shown in Table 1. Therefore, it could be confirmed that in the case where the electromagnetic brake devices **8***a* and **8***b* were also used, there was an effect in removing Ar gas bubbles. However, at a distance L of 85 mm, it was seen that the effect of removing Ar gas bubbles was still high, and the index of the number of inclusions was rapidly increased to 1.8.

INDUSTRIAL APPLICABILITY

[0083] The present invention is effective in supplying molten steel into a casting mold and producing a cast piece.

BRIEF DESCRIPTION OF THE REFERENCE SYMBOLS

[0084] **1**: CONTINUOUS CASTING APPARATUS
[0085] **2**: CASTING MOLD
[0086] **3***a*, **3***b*: LONG SIDE WALL
[0087] **4***a*, **4***b*: SHORT SIDE WALL
[0088] **5***a*, **5***b*, **6***a*, **6***b*: BACK PLATE
[0089] **7***a*, **7***b*: ELECTROMAGNETIC STIRRING DEVICE
[0090] **8***a*, **8***b*: ELECTROMAGNETIC BRAKE DEVICE
[0091] **9***a*, **9***b*: CURVED REGION
[0092] **11***a*, **11***b*, **11***c*: CURVED PORTION
[0093] **21**: SUBMERGED ENTRY NOZZLE
[0094] **22**: DISCHARGE HOLE
[0095] **23**: DISCHARGE FLOW
[0096] **24**: MENISCUS
[0097] **25**: MOLTEN POWDER
[0098] **26**: SOLIDIFIED SHELL
[0099] M: MOLTEN STEEL

1. A continuous casting apparatus for steel comprising:
a casting mold for casting a molten steel, which includes a pair of long side walls and a pair of short side walls;
a submerged entry nozzle which discharges the molten steel into the casting mold; and
an electromagnetic stirring device which is disposed along an external surface of each of the long side walls and stirs an upper part of the molten steel within the casting mold,
wherein a curved portion which is convexly curved toward the electromagnetic stirring device in plan view is formed at least at a position where the curved portion faces the submerged entry nozzle on each of the long side walls, and each of the long side walls including the curved portion has a uniform thickness, and
a shortest horizontal distance between a top which is a most depressed position when an internal surface of the curved portion is seen in plan view and an outer peripheral surface of the submerged entry nozzle is 30 mm to 80 mm in a range from a lower end portion of the electromagnetic stirring device to a position higher than an upper end portion of the electromagnetic stirring device by 50 mm when viewed along a vertical direction.

2. The continuous casting apparatus for steel according to claim **1**, further comprising:
an electromagnetic brake device disposed below the electromagnetic stirring device,
wherein the electromagnetic brake device applies a direct current magnetic field having a magnetic flux density distribution which is uniform in a casting mold width direction along each of the long side walls in plan view, in a casting mold thickness direction along each of the short side walls.

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