(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 347 840 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
27.07.2011 Bulletin 2011/30

(51) Int Cl.:
B22D 17/30 ***(2006.01)*** ***B22D 25/00*** ***(2006.01)***

(21) Application number: **11151616.7**

(22) Date of filing: **21.01.2011**

(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
Designated Extension States:
BA ME

(30) Priority: **22.01.2010 JP 2010011751**
18.03.2010 JP 2010063237
18.03.2010 JP 2010063241
18.03.2010 JP 2010063246

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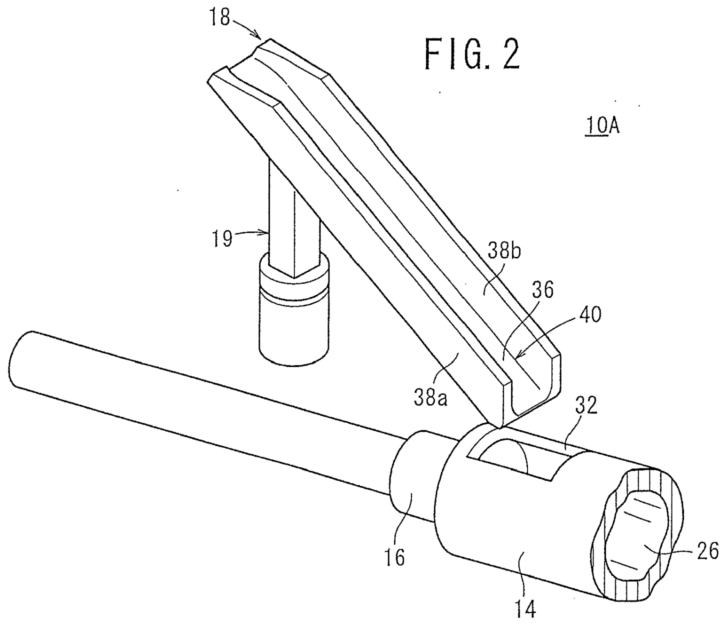
(54) **Casting method and casting apparatus**

(57) A casting apparatus (10A) has a long cooling jig (18) inclined with respect to a vertical direction. A melt (34) is supplied to and flowed on a bottom surface (36a) of the cooling jig (18), whereby a solid phase is generated in the melt (34) to obtain a semi-solid slurry (48), and the semi-solid slurry (48) is transferred into and solidified in a cavity (24) of a mold (12) to obtain a casting. The casting apparatus (10A) further has a release agent application unit (42), and a release agent (44) is applied by the application unit (42) to the bottom surface (36a) of the cooling jig (18) in a direction toward a supply of the melt (34) at an angle of less than 90° to the bottom surface (36a) before supplying the melt (34) to the cooling jig (18).

FIG. 2



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Description

BACKGROUND OF THE INVENTION

Field of the Invention:

[0001] The present invention relates to a casting method using a cooling jig for generating a solid phase in a melt flow to prepare a semi-solid slurry and a casting apparatus containing the cooling jig.

Description of the Related Art:

[0002] In common casting, a cavity formed in a mold is filled with a high-temperature liquid-phase melt. Recently, a semi-solid slurry containing both of solid and liquid phases is occasionally used instead of the melt. For example, as described in Japanese Patent Nos. 3920378 and 3339333, the semi-solid slurry can be prepared by flowing a melt on a cooling jig, so as to cooling the melt to generate a solid phase therein.

[0003] Thus obtained semi-solid slurry is poured from the cooling jig into a plunger sleeve of a casting apparatus, and is then transferred from the plunger sleeve to the cavity of the mold.

[0004] After the melt is flowed on the cooling jig, a residual solid generated by the solidification of the melt remains on the cooling jig. When another melt for the next casting is flowed on the cooling jig without removing the residual solid, the melt cannot be sufficiently cooled and the solid phase content of the semi-solid slurry cannot be easily increased to a desired level.

[0005] Furthermore, when the residual solid is poured together with the melt into the plunger sleeve, it may cause clogging. In addition, even if the clogging can be avoided, in case the residual solid is transferred together with the melt to the cavity, the quality of the resultant casting is deteriorated.

[0006] To avoid the above malfunctions, the residual solid should be removed from the cooling jig before the next casting. A release agent is desirably used for readily performing the removal.

[0007] For example, a technology proposed in Japanese Laid-Open Patent Publication No. 2006-305618 contains applying a release agent having a heat insulation function to the cooling jig within a predetermined thickness range to crystallize a fine solid phase. In this technology, the release agent may be boron nitride (BN).

[0008] In a case where the release agent is applied to the cooling jig in this manner, the following problems are generally caused.

[Problem 1: Release agent application direction]

[0009] When the release agent applied to the cooling jig is splashed or flowed in the melt flow direction, the agent may be introduced into the plunger sleeve placed in the vicinity of the lower end of the cooling jig. In this case, the release agent may be undesirably incorporated into the generated semi-solid metal to increase gas defects in the product.

[Problem 2: Continuous operation (type of release agent)]

[0010] A wide variety of release agents have been known. When the release agent is water-soluble or heat-insulating, the following problems are caused.

(a) Problem with water-soluble release agent

[0011] In the case of using the water-soluble release agent, water often remains on the cooling jig. When the water is brought into contact with the melt, a water vapor may be generated and splash the melt. Furthermore, the water may be incorporated into the melt and gasified therein, causing a gas defect. As a result, the quality of the resultant product may be significantly deteriorated. To avoid the problem, for example, the cooling jig may be heated to 100°C or higher to evaporate the water. However, the cooling jig having such a high temperature exhibits a deteriorated melt cooling performance disadvantageously.

[0012] In addition, immediately after the water-soluble release agent reaches the cooling jig in the early stage of the application, the release agent may be partially evaporated due to the heat of the cooling jig, generating a vapor around the cooling jig. When the cooling jig is covered with the generated vapor, the vapor may interfere with the release agent application in the later stage of the continuous application.

[0013] This trouble can be solved by increasing the application pressure or amount of the release agent. However, disadvantageously, the excess release agent may be splashed and introduced into the plunger sleeve placed in the vicinity of the lower end of the cooling jig, and the cooling jig may be excessively cooled by the excess release agent. Obviously, the application of the excess release agent results in casting cost increase.

(b) Problem with heat-insulating release agent

[0014] In above described Japanese Laid-Open Patent Publication No. 2006-305618, the thickness of the heat-insulating release agent such as the boron nitride (BN) applied to the cooling jig is limited. This technology has the following disadvantage in the continuous operation.

[0015] That is, it is difficult to uniformly apply a powder of the BN or the like to the cooling jig. When the predetermined thickness is not realized, the desired semi-solid metal cannot be obtained, and the resultant product cannot have excellent quality.

[0016] When the release agent such as the BN powder is applied in every casting process in the continuous operation, the agent is accumulated on the cooling jig.

Therefore, the BN thickness should be automatically controlled every time the metal melt is supplied. In addition, it is remarkably difficult to control the thickness of the coating per se in the continuous operation.

[0017] The above trouble can be solved by cleaning the accumulated release agent. However, in this case, a complicated apparatus is disadvantageously required. Further, when the cleaning takes a long time, the cycle time and the casting cost are increased.

[Problem 3: Space saving]

[0018] The cooling jig has to be compact when placed in a small installation space. However, in the case of applying the heat-insulating release agent to the cooling jig as described in Japanese Laid-Open Patent Publication No. 2006-305618, the melt cooling efficiency of the cooling jig is lowered, whereby the size of the cooling jig is inevitably increased to obtain the semi-solid metal with a desired solid phase content. Thus, this technology is disadvantageous also in space saving.

[Problem 4: Semi-solid metal structure]

[0019] As described in Japanese Laid-Open Patent Publication No. 2006-305618, when the heat-insulating release agent is applied to the cooling jig, because the heat transfer between the metal melt and the cooling jig is reduced, the metal melt cooling rate is deteriorated. The crystal nucleus generation frequency in the semi-solidification of the metal melt is reduced due to the deterioration of the cooling rate. Thus, the resultant semi-solid metal has a coarse structure, and the desired solid phase content cannot be achieved.

[0020] The cooling jig may be used without the release agent. However, in this case, the cooling jig is readily interacted with the melt, causing erosion. Also, the residual solid cannot be easily removed from the cooling jig as described above.

[0021] The cooling jig described in Japanese Patent No. 3920378 has a shape of a flat plate, trough, pipe, etc.

[0022] When the melt is flowed on the cooling jig having a simple flat plate shape, the melt leaks from a side of the cooling jig. As described in Japanese Patent No. 3920378, the cooling jig having a trough or pipe shape is used to prevent the leakage. However, in this case, it is difficult to remove the residual solid from the cooling jig disadvantageously.

[0023] In the case of using the cooling jig having a trough shape, the semi-solid slurry may be attached to and solidified on the melt outlet end of the cooling jig and generate a relatively large solid aggregate. In this case, it is difficult to remove the residual solid due to the aggregate.

[0024] On the other hand, in the case of using the cooling jig having a pipe shape, only the melt inlet and outlet are opened. Therefore, it is naturally difficult to remove the residual solid.

[0025] Thus, a method described in Japanese Laid-Open Patent Publication No. 10-034307 may be efficiently used. In this method, a plurality of the cooling jigs are radially arranged on a rotary shaft, and the rotary shaft is rotated to replace a used cooling jig with another one after each casting process. This Japanese Laid-Open Patent Publication No. 10-034307 describes that the residual solid on the used cooling jig falls during the rotation of the cooling jig on the rotary shaft.

[0026] In the method disclosed in Japanese Laid-Open Patent Publication No. 10-034307, a large space is required in order that the plural cooling jigs are prepared, connected to one rotary shaft, and rotated. In general, the casting apparatus is practically placed in a small space. Therefore, it is difficult to put the rotary shaft and the plural cooling jigs into practical use.

[0027] In addition, due to the plural cooling jigs, an equipment containing the casting apparatus has a complicated structure and increased control and regulation items. Therefore, this method is disadvantageous in that the casting process cannot be continuously repeated with ease.

SUMMARY OF THE INVENTION

[0028] A general object of the present invention is to provide a casting method capable of continuously producing a casting with stable quality at reduced production cost in a small equipment without adverse affects on the cycle time.

[0029] A principal object of the present invention is to provide a casting method capable of easily removing an attached residual solid from a cooling member.

[0030] Another object of the present invention is to provide a cooling jig capable of preventing heat crack due to contact with a high-temperature melt and being easy to remove an attached residual solid therefrom.

[0031] A further object of the present invention is to provide a casting apparatus having a removal mechanism capable of easily removing an attached residual solid from a cooling member, and making it possible to continuously repeating a casting process with ease.

[0032] According to an aspect of the present invention, there is provided a casting apparatus comprising a long cooling jig inclined with respect to a vertical direction, wherein a melt is supplied to and flowed on a predetermined surface of the cooling jig, whereby a solid phase is generated in the melt to obtain a semi-solid slurry, and the semi-solid slurry is transferred into and solidified in a cavity of a mold to obtain a casting, and

[0033] the casting apparatus further comprises a release agent application unit for applying a release agent to the predetermined surface of the cooling jig in a direction toward a supply of the melt at an angle of less than 90° to the predetermined surface before supplying the melt to the cooling jig.

[0034] Since the release agent is applied at an angle of less than 90° to the predetermined surface of the cooling jig, the release agent can be prevented from splashing. In addition, since the release agent is applied in a direction toward the melt supply opposite to an injection sleeve or a vessel, it can be prevented from being introduced into the injection sleeve or vessel.

[0035] The release agent application unit preferably contains one or more release agent application nozzles for spraying the release agent along with an air onto the predetermined surface of the cooling jig in a direction toward the melt supply at an angle of less than 90° to the predetermined surface. In this case, the release agent can be uniformly applied in a small thickness.

[0036] The release agent application unit preferably contains, in addition to the release agent application nozzle, an air nozzle for spraying an air toward a lower end of the cooling jig, from which the melt is discharged as the semi-solid slurry. In this case, even when the lower end of the cooling jig faces the injection sleeve or vessel in the step of applying the release agent, the air sprayed from the air nozzle can act as a so-called air curtain to prevent the release agent from being introduced into the injection sleeve or vessel.

[0037] The casting apparatus preferably comprises a jig transfer unit for moving the cooling jig, and at least the position of the cooling jig in the step of supplying the melt is preferably changed by the jig transfer unit from that in the step of applying the release agent. In this case, the lower end of the cooling jig can be moved away from the injection sleeve or vessel in the step of applying the release agent to reliably prevent the release agent from being introduced into the injection sleeve or vessel.

[0038] The release agent application unit preferably contains two or more of the release agent application nozzles, and the inclination angle of a line connecting the application nozzles is preferably approximately equal to that of the predetermined surface of the cooling jig. In this case, the release agent can be uniformly applied in a small thickness on the predetermined surface of the cooling jig efficiently.

[0039] According to another aspect of the present invention, there is provided a casting method, wherein a melt is supplied to and flowed on a predetermined surface of a long cooling jig inclined with respect to a vertical direction, whereby a solid phase is generated in the melt to obtain a semi-solid slurry, and the semi-solid slurry is transferred into and solidified in a cavity of a mold to obtain a casting, and

[0040] the casting method comprises the steps of

[0041] applying a release agent to the predetermined surface of the cooling jig in a direction toward a supply of the melt at an angle of less than 90° to the predetermined surface, and

[0042] supplying the melt to the predetermined surface of the cooling jig after the application of the release agent.

[0043] In the step of applying the release agent, the release agent along with an air are preferably sprayed onto the predetermined surface of the cooling jig in a direction toward the supply of the melt at an angle of less than 90° to the predetermined surface.

[0044] Furthermore, in the step of applying the release agent, at the same time as the spraying of the release agent and the air, an air is preferably sprayed toward a lower end of the cooling jig, from which the melt is discharged as the semi-solid slurry.

[0045] By performing the above steps, a solidified metal piece can be more easily removed from the cooling jig, and the casting can be continuously produced with stable quality.

[0046] As compared with the technology using the heat-insulating release agent, this method is capable of reducing the deterioration of the heat transfer between the cooling jig and the melt, thereby more efficiently cooling the melt. Therefore, the cooling jig can have a compact size in the method. In addition, the semi-solid slurry can have a fine structure due to the reduction of the heat transfer deterioration, resulting in improved product quality.

[0047] In this method, the release agent can be readily applied in continuous operation. Furthermore, it is not necessary to apply an excess amount of the release agent, so that the release agent can be prevented from being introduced into the injection sleeve or vessel. Therefore, the method is capable of producing the casting with stable quality at reduced production cost while preventing gas defect generation.

[0048] According to a further aspect of the present invention, there is provided a cooling jig for cooling a melt flowing thereon, thereby generating a solid phase in the melt to obtain a semi-solid slurry, comprising a bottom, a first side, and a second side, wherein

[0049] the first and second sides bend and extend from the bottom and are arranged facing each other,

[0050] a flow channel for the semi-solid slurry is formed by inner walls of the bottom and the first and second sides, and

[0051] curved portions are formed between the inner walls of the bottom and the first side and between the inner walls of the bottom and the second side, respectively.

[0052] In this cooling jig, the first and second sides are connected only to the bottom. Therefore, the flow channel is exposed, so that a residual solid on the cooling jig can be remarkably easily removed.

[0053] In a case where the cooling jig has a sharply bent portion to be brought into contact with the melt or the semi-solid slurry, a heat stress may be concentrated, generating a heat crack in this portion. Since the cooling jig of the present invention has the curved portions between the inner walls of the bottom and the first and second sides without the sharply bent portion, it can be prevented from heat cracking.

[0054] Thus, the cooling jig of the present invention is excellent in durability and capable of being significantly easy to remove the residual solid thereon.

[0055] The first and second sides extending from the bottom are preferably inclined at an angle of 0.25° to 10°

to a vertical line so that the distance between the sides is increased with increasing distance from the bottom. Thus, the first and second sides are preferably at an obtuse inclination angle to the bottom.

[0056] In this case, the residual solid can be prevented from being fixed and remaining between the bottom and the first side and between the bottom and the second side. As a result, the residual solid cannot cause clogging or casting quality deterioration in the successive casting process.

[0057] In addition, an excessively or insufficiently cooled portion is not generated in the melt.

[0058] In this case, the curved portions preferably have a curvature radius of 1 to 40 mm. When the curvature radius is less than 1 mm, the above advantageous effect may be unachievable, and it may be difficult to prevent the heat cracking of the curved portions. On the other hand, when the curvature radius is more than 40 mm, the contact area between the cooling jig and the melt may be reduced, thereby failing to sufficiently cool the melt.

[0059] It is more preferred that the cooling jig having such a structure is capable of rotating on a rotation axis parallel to an axis direction thereof, and an inclined surface is formed at an end of a melt outlet in the bottom so that the length of the bottom decreases in the direction from the inner wall to the outer wall.

[0060] In this case, when the cooling jig is rotated, a surface of the cooling jig, on which the melt flows mainly, can face vertically downward. Since the residual solid is attached to the cooling jig by a relatively small adhesion force, it can be dropped off by this rotation. Thus, the residual solid can be easily removed from the cooling jig.

[0061] Since the inclined surface is formed at the end of the melt outlet, the semi-solid slurry can be prevented from wrapping around from the inner wall (the bottom surface of the flow channel) to the outer wall of the bottom. Therefore, the residual solid does not extend from the inner wall to the outer wall of the bottom, whereby the residual solid is not engaged with and blocked by the melt outlet.

[0062] Thus, an aggregate of the residual solid is not formed on the melt outlet, and the residual solid can be easily removed.

[0063] The inner wall of the bottom and the curved portions preferably have a ten-point average roughness Rz of 6.3 μm or less (see JIS B 0601-1994). In this case, the contact area between the melt and the cooling jig is increased, and the heat of the melt can be rapidly transferred to the cooling jig. Thus, the efficiency of the heat transfer from the melt to the cooling jig is increased, and the semi-solid slurry can be easily prepared with a desired solid phase content.

[0064] The cooling jig may contain an Fe-based alloy such as a steel. In this case, a hardened layer is preferably formed on a surface of the cooling jig by a nitridation treatment to increase the surface hardness. The cooling jig having the hardened layer is further hardly heat-cracked, and thus has a further improved durability. In addition, the erosion resistance of the cooling jig can be improved by forming the hardened layer in the nitridation treatment.

[0065] The cooling jig may contain a Cu-based alloy. In this case, a film of a nitride such as CrN is preferably formed on a surface of the cooling jig to improve the erosion resistance of the cooling jig.

[0066] In addition, a refrigerant is preferably circulated in the cooling jig to improve the erosion resistance.

[0067] According to a further aspect of the present invention, there is provided a method for removing a residual solid, which is generated on a long cooling jig inclined with respect to a vertical direction when a melt is flowed on a predetermined surface of the cooling jig, whereby a solid phase is generated in the melt to obtain a semi-solid slurry, and the semi-solid slurry is transferred into and solidified in a cavity to obtain a casting, wherein the cooling jig is circularly moved on an axis to drop the residual solid.

[0068] For example, the circular movement may be a rotation movement on a parallel axis extending parallel to an axis direction of the cooling jig. The residual solid can be dropped off by rotating the cooling jig such that the predetermined surface faces vertically downward.

[0069] Thus, in this case, when the cooling jig is rotated, a surface of the cooling jig, on which the melt flows mainly, faces vertically downward. The residual solid is attached to the cooling jig by a relatively small adhesion force, and thereby can be dropped off by this rotation. Thus, the residual solid can be easily removed from the cooling jig.

[0070] The parallel axis may be equal to or different from an axis of a rotary shaft in a rotation mechanism for rotating the cooling jig.

[0071] In each case, in the rotation of the cooling jig, the rotation center of the parallel axis is preferably at an offset distance from a width-direction center axis of the surface of the cooling jig, on which the melt flows mainly. As a result, a relatively large centrifugal force acts on the surface and thus the residual solid. Therefore, the rotation makes the peeling and removal of the residual solid easier.

[0072] In another specific example, the circular movement may be a turning movement on a vertical axis extending in a vertical direction. The residual solid can be dropped off by turning the cooling jig to apply an external force to the residual solid.

[0073] Thus, in this case, when the cooling jig is turned, the external force (mainly a centrifugal force) is applied to the residual solid on the cooling jig. The residual solid is attached to the cooling jig by a relatively small adhesion force and thereby can be readily dropped off (i.e. removed) by external force.

[0074] The vertical axis may be equal to or different from an axis of a rotary shaft in a turning mechanism for turning the cooling jig.

[0075] In each case, in the turning of the cooling jig, the turning center of the vertical axis is preferably at an offset distance from an axis-direction center axis of the surface of the cooling jig, on which the melt flows mainly. As a result, a relatively large external force (such as a centrifugal force) acts on the surface and thus the residual solid. Therefore, the turning makes the peeling and removal of the residual solid easier.

[0076] As described above, the residual solid can be removed from the cooling jig by circularly moving (e.g. rotating or turning) the cooling jig after the transfer of the semi-solid slurry to the injection sleeve. The removal can be carried out while the semi-solid slurry is transferred to the cavity and then cooled and solidified. Therefore, a casting process can be continuously repeated by using only one cooling jig. This is because the residual solid can be removed from the cooling jig before the melt is poured into the injection sleeve in the second casting process, and the residual solid does not cause clogging or casting quality deterioration.

[0077] In addition, in this case, the structure of an equipment containing the casting apparatus is not complicated, and the control and regulation items are not increased. This is because a plurality of cooling jigs are not needed as described above. Thus, the regulation and control (such as a cooling jig temperature control) of the casting apparatus can be easily carried out in operation.

[0078] According to a further aspect of the present invention, there is provided a casting apparatus comprising

[0079] a long cooling jig for cooling a melt flowing thereon, thereby generating a solid phase in the melt to obtain a semi-solid slurry,

[0080] an injection sleeve into which the semi-solid slurry is poured from the cooling jig,

[0081] an injection mechanism for injecting the semi-solid slurry contained in the injection sleeve, and

[0082] a mold having a cavity into which the semi-solid slurry is introduced by pressure of the injection mechanism, wherein

[0083] the casting apparatus further comprises a circular movement mechanism for circularly moving the cooling jig, and

[0084] the cooling jig is circularly moved by the circular movement mechanism.

[0085] For example, the circular movement mechanism may be a rotation mechanism having a rotary shaft extending parallel to an axis direction of the cooling jig inclined with respect to a vertical direction.

[0086] In such a structure, when the rotation mechanism is energized, the cooling jig is rotated so that a surface of the cooling jig, on which the melt flows mainly, faces vertically downward. As described above, the residual solid can be easily removed from the cooling jig by the rotation.

[0087] As described above, the rotation center (the parallel axis) of the cooling jig may be an axis of the rotary shaft of the rotation mechanism or an axis of another shaft extending in the vertical direction.

[0088] In each case, the rotation center of the cooling jig is preferably at an offset distance from a width-direction center axis of the surface of the cooling jig, on which the melt flows mainly. As a result, as described above, a relatively large centrifugal force acts on the residual solid. Therefore, the rotation makes the removal of the residual solid easier.

[0089] It is preferred that the casting apparatus further comprises a stopper movable in response to the rotation of the cooling jig and a blocking member for blocking the stopper in contact therewith, and the rotation of the cooling jig is stopped when the stopper is brought into contact with the blocking member.

[0090] In this case, when the stopper is brought into contact with the blocking member, an impact load is generated. The impact load is transmitted from the cooling jig to the residual solid. Therefore, the impact load makes the removal of the residual solid easier.

[0091] It is preferred that the cooling jig has a flow channel for the melt, and the width of the flow channel increases in a vertically upward direction. In this case, when the cooling jig is rotated, the width of the flow channel increases in a vertically downward direction. Therefore, the residual solid can be easily dropped off from the cooling jig.

[0092] In another specific example, the circular movement mechanism may be a turning mechanism having a rotary shaft extending in a vertical direction.

[0093] In such a structure, when the turning mechanism is energized, the cooling jig is turned so that an external force such as a centrifugal force is applied to the residual solid remaining on the cooling jig. As described above, the residual solid can be easily removed from the cooling jig by the external force.

[0094] As described above, the turning center (the vertical axis) of the cooling jig may be an axis of the rotary shaft of the turning mechanism or an axis of another shaft extending in the vertical direction.

[0095] In each case, the turning center of the cooling jig is preferably at an offset distance from an axis-direction center axis of the surface of the cooling jig, on which the melt flows mainly. As a result, as described above, a relatively large centrifugal force acts on the residual solid. Therefore, the turning makes the removal of the residual solid from the cooling jig easier.

[0096] It is preferred that the casting apparatus further comprises a stopper movable in response to the turning of the cooling jig and a blocking member for blocking the stopper in contact therewith, and the turning of the cooling jig is stopped when the stopper is brought into contact with the blocking member.

[0097] In this case, when the stopper is brought into contact with the blocking member, an impact load is generated. The impact load is transmitted from the cooling jig to the residual solid. Therefore, the impact load makes the removal of the residual solid from the cooling jig easier.

[0098] In a case where the width of the cooling jig is decreased in the upstream-to-downstream direction of the melt, when the residual solid is dropped off along the cooling jig inclined vertically downward, the residual solid may be blocked by the narrow lower portion of the cooling jig. To solve the problem, the width of the cooling jig preferably increases in the upstream-to-downstream direction of the melt.

[0099] Thus, in this case, the residual solid can be easily slid advantageously.

[0100] In each case of using the rotation or turning, one cooling jig is appropriately subjected to the above removal process, and a plurality of cooling jigs are not needed. Thus, it is not necessary to increase the size of an equipment containing the casting apparatus.

[0101] The casting apparatus requires only one cooling jig to satisfactorily perform the casting process, and therefore has a simple overall structure. Thus, the casting apparatus does not need a large installation space.

[0102] The above and other objects features and advantages of the present invention will become more apparent from the following description when taken in conjunction with the accompanying drawings in which a preferred embodiment of the present invention is shown by way of illustrative example.

BRIEF DESCRIPTION OF THE DRAWINGS

[0103]

FIG. 1 is a structural view showing a first casting apparatus;
FIG. 2 is an enlarged perspective view showing a cooling jig and vicinity thereof in the first casting apparatus;
FIG. 3 is a structural view showing an example of a release agent application unit;
FIG. 4 is a flow chart of a first casting method;
FIG. 5 is an enlarged perspective view showing a cooling jig and vicinity thereof in a second casting apparatus;
FIG. 6 is a flow chart of a second casting method;
FIG. 7 is an enlarged perspective view showing a cooling jig and vicinity thereof in a third casting apparatus;
FIG. 8 is a flow chart of a third casting method;
FIG. 9 is a characteristic chart showing the change with time in the temperature of a supplied melt in a cooling jig outlet (the outlet melt temperature) in each of Example and Comparative Example;
FIG. 10 is a characteristic chart showing the average outlet melt temperature in each of Example and Comparative Example;
FIG. 11 is a characteristic chart showing the change with time in the difference from the initial cooling jig temperature in each of Example and Comparative Example;
FIG. 12 is an overall, schematic, side view showing a casting apparatus according to a second embodiment;
FIG. 13 is an enlarged perspective view showing a cooling jig and vicinity thereof in the casting apparatus;
FIG. 14 is a cross-sectional view taken along the line XIV-XIV in the direction of the arrows in FIG. 13;
FIG. 15 is a cross-sectional view taken along the line XV-XV in the direction of the arrows in FIG. 13;
FIG. 16 is a schematic side view showing a principal part of the casting apparatus;
FIG. 17 is a schematic front view observed in the direction of the arrow A in FIG. 16;
FIG. 18 is an enlarged side view showing a principal part of FIG. 16;
FIG. 19 is a cross-sectional view taken along the line XIX-XIX in the direction of the arrows in FIG 18;
FIG. 20 is a width-direction cross-sectional view showing an insufficiently cooled portion generated in the vicinity of the width-direction center surface of a melt on a flow channel of the cooling jig;
FIG. 21 is a width-direction cross-sectional view showing an excessively cooled portion generated in a contact area between the melt and a bottom inner wall and an insufficiently cooled portion generated in the vicinity of the width-direction center surface of the melt on the cooling jig;
FIG. 22 is a cross-sectional view showing a stopper turned 180° from the position shown in FIG. 19;
FIG. 23 is an enlarged perspective view showing the cooling jig inverted from the position shown in FIG. 13;
FIG. 24 is an overall, schematic, perspective view showing a casting apparatus according to a modified example of the second embodiment;
FIG. 25 is an overall, schematic, side view showing a casting apparatus according to an embodiment of the present invention;
FIG. 26 is an enlarged perspective view showing a cooling jig and vicinity thereof in the casting apparatus;
FIG. 27 is a schematic side view showing a principal part of the casting apparatus;
FIG 28 is a schematic front view observed in the direction of the arrow A in FIG. 27;
FIG. 29 is an enlarged side view showing a principal part of FIG. 27;
FIG. 30 is a cross-sectional view taken along the line XXX-XXX in the direction of the arrows in FIG. 29;
FIG. 31 is a cross-sectional view showing a stopper turned 180° from the position shown in FIG. 30;
FIG. 32 is an enlarged perspective view showing the cooling jig inverted from the position shown in FIG. 26;
FIG. 33 is an overall, schematic, side view showing a casting apparatus according to an embodiment of the present invention;
FIG. 34 is an enlarged perspective view showing a cooling jig and vicinity thereof in the casting apparatus;

FIG. 35 is a schematic side view showing a principal part of the casting apparatus;

FIG. 36 is a schematic front view observed in the direction of the arrow A in FIG. 35;

FIG. 37 is a partially cutaway plan view showing the cooling jig of FIG. 34 before turning;

FIG. 38 is an enlarged side view showing a principal part of FIG. 37;

FIG. 39 is a cross-sectional view showing a stopper turned 90° from the position shown in FIG. 38; and

FIG 40 is a partially cutaway plan view showing the cooling jig turned 90° from the position shown in FIG. 37.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0104] Several preferred embodiments of the casting method and the related casting apparatus used therein of the present invention will be described in detail below with reference to the accompanying drawings.

[0105] First, a technology according to a first embodiment for applying a release agent will be described below using the examples of a first casting apparatus 10A (see FIG. 1), a second casting apparatus 10B (see FIG. 5), and a third casting apparatus 10C (see FIG. 7).

[0106] As shown in FIG. 1, the first casting apparatus 10A has a mold 12, a plunger sleeve 14, a plunger tip 16, and a cooling jig 18.

[0107] The mold 12 contains a movable mold portion 20 and a stationary mold portion 22. The movable mold portion 20 can be moved in the direction toward and away from the stationary mold portion 22. When the movable mold portion 20 is combined with the stationary mold portion 22 into the closed state, a cavity 24 is divided and formed as a casting space therebetween.

[0108] The plunger sleeve 14 has a cylindrical shape containing a hollow portion 26. The end of the plunger sleeve 14 is inserted and connected to the stationary mold portion 22 by a connecting portion 28, whereby the hollow portion 26 is connected to the cavity 24 of the mold 12 by a distributor 30 in the movable mold portion 20 and a runner 31 in the stationary mold portion 22. The posterior end of the plunger sleeve 14 has an opening, into which the plunger tip 16 is inserted. A melt inlet 32 is formed on an upper side of the plunger sleeve 14 in the vicinity of the posterior end.

[0109] The plunger tip 16 can be moved in the hollow portion 26 of the plunger sleeve 14 in the direction toward and away from the mold 12.

[0110] The cooling jig 18 is formed as a long object and inclined at a predetermined angle to the vertical direction on a supporting member 19, so that a melt 34 is transferred from a ladle 33 to the plunger sleeve 14 at a predetermined flow rate. The lower end of the cooling jig 18 is arranged facing the melt inlet 32 of the plunger sleeve 14.

[0111] In this case, as shown in FIG. 2, the cooling jig 18 has a curved shape, which contains a bottom 36 with a first side 38a and a second side 38b extending from the side edges of the bottom 36. The space surrounded by the bottom 36, the first side 38a, and the second side 38b acts as a flow channel 40. The first and second sides 38a, 38b function to prevent the melt 34 (or a semi-solid slurry 48) from leaking and falling from the side edges of the cooling jig 18.

[0112] As shown in FIG. 3, the first casting apparatus 10A further has a release agent application unit 42, which functions to apply a release agent to the flow channel of the cooling jig 18 before supplying the melt 34 to the cooling jig 18. The release agent is applied in a direction toward the supply of the melt 34 (the upper end of the cooling jig 18) at an angle θ of less than 90° to a bottom surface 36a (a predetermined surface) of the flow channel.

[0113] The release agent application unit 42 contains two release agent application nozzles (a first release agent application nozzle 46a and a second release agent application nozzle 46b) for spraying a release agent 44 and an air toward the upper end of the cooling jig 18 at the angle θ of less than 90° to the bottom surface 36a of the cooling jig 18, an air nozzle 52 (shown by a two-dot chain line) for spraying an air 50 toward the lower end of the cooling jig 18 (from which the melt 34 is discharged as the semi-solid slurry 48 (see FIG. 1)), and a support 54 for fixing the first release agent application nozzle 46a, the second release agent application nozzle 46b, and the air nozzle 52 at the same angle θ to the bottom surface 36a of the cooling jig 18. The inclination angle ϕa of a line connecting the first and second release agent application nozzles 46a, 46b on the support 54 to the vertical direction is approximately equal to the inclination angle ϕb of the bottom surface 36a of the cooling jig 18 to the vertical direction.

[0114] A casting method using the first casting apparatus 10A (hereinafter referred to as the first casting method) will be described with reference to the flow chart of FIG. 4.

[0115] In the step S1 of FIG. 4, the movable mold portion 20 is moved and combined with the stationary mold portion 22 (mold closing). In this step, the isolated cavity 24 is formed in the mold 12.

[0116] In the step S2, as shown in FIG. 3, the release agent 44 and the air are sprayed from the first and second release agent application nozzles 46a, 46b to apply the release agent 44 onto the bottom surface 36a of the cooling jig 18. In addition, in the step S2, the air 50 is sprayed from the air nozzle 52 toward the lower end of the cooling jig 18.

[0117] In the step S3, the application of the release agent 44 from the first and second release agent application nozzles 46a, 46b and the spray of the air 50 from the air nozzle 52 are stopped.

[0118] In the step S4, the melt 34 is supplied (poured) to the upper end of the cooling jig 18. The supplied melt 34 flows toward the lower end of the inclined cooling jig 18 along the flow channel 40 (see FIG. 2). In this step, the cooling jig 18 draws heat from the melt 34, so that a part of the melt 34 is converted to a solid phase. Thus, the melt 34 is gradually converted to the semi-solid slurry 48 containing both of solid and liquid phases during the flowing on the cooling jig 18. Most of the semi-solid slurry 48 is transferred from the flow channel 40 through the melt inlet 32 into the plunger sleeve 14.

[0119] In the step S5, when a predetermined amount of the semi-solid slurry 48 is put in the plunger sleeve 14, the plunger tip 16 is moved frontward (toward the mold 12). Thus, the semi-solid slurry 48 in the plunger sleeve 14 is transferred through the distributor 30 and the runner 31 into the cavity 24 of the mold 12.

[0120] Then, the semi-solid slurry 48 is cooled and solidified in the cavity 24 to obtain a casting. In the step S6, a so-called mold opening is performed to take out the casting from the cavity 24.

[0121] In the first casting apparatus 10A and the first casting method, since the release agent 44 is sprayed toward the upper end of the cooling jig 18 (the supply of the melt 34) at the angle θ of less than 90° to the bottom surface 36a before supplying the melt 34 in this manner, the release agent 44 is applied at the angle θ of less than 90° to the bottom surface 36a and thereby can be prevented from splashing. In addition, since the release agent 44 is applied in a direction toward the supply of the melt 34 opposite to the plunger sleeve 14 or a vessel, the release agent 44 can be prevented from being introduced into the plunger sleeve 14 or vessel.

[0122] Particularly in the first casting apparatus 10A, since the two release agent application nozzles (the first and second release agent application nozzles 46a, 46b) are used for spraying the release agent 44 and the air, the release agent 44 can be uniformly applied in a small thickness.

[0123] Since the air nozzle 52 for spraying the air 50 toward the lower end of the cooling jig 18 is used in addition to the first and second release agent application nozzles 46a, 46b, even when the lower end of the cooling jig 18 faces the plunger sleeve 14 or vessel in the step of applying the release agent 44, the air 50 sprayed from the air nozzle 52 can act as a so-called air curtain to prevent the release agent 44 from being introduced into the plunger sleeve 14 or vessel. Furthermore, since the spraying of the air 50 from the air nozzle 52 toward the lower end of the cooling jig 18 is carried out at the same time as the application of the release agent 44 using the first and second release agent application nozzles 46a, 46b, even when the release agent 44 is splashed on the cooling jig 18 in the application step, the splashed release agent 44 can be efficiently prevented by the air 50 from being introduced into the plunger sleeve 14 or vessel.

[0124] Since the inclination angle ϕa of the line connecting the first and second release agent application nozzles 46a, 46b is approximately equal to the inclination angle ϕb of the bottom surface 36a of the cooling jig 18, the release agent 44 can be uniformly applied in a small thickness on the bottom surface 36a efficiently.

[0125] Several preferred conditions for the application of the release agent 44 will be described below.

[Preferred condition 1: application method]

[0126] The release agent 44 has to be uniformly applied in a small thickness to the bottom surface 36a of the cooling jig 18 (the flow channel 40) so that the melt 34 is prevented from being baked and attached onto the cooling jig 18 while not inhibiting the heat transfer between the melt 34 and the cooling jig 18. Therefore, it is preferred that the release agent 44 is sprayed from the first and second release agent application nozzles 46a, 46b as described above under the following conditions.

[0127] (1-1) The first and second release agent application nozzles 46a, 46b are capable of spraying both the two fluids of the release agent 44 and the air.

[0128] (1-2) The first and second release agent application nozzles 46a, 46b have a nozzle diameter of 0.1 to 10 mm.

[0129] (1-3) The first and second release agent application nozzles 46a, 46b have a spraying air pressure of 0.01 to 10 MPa.

[0130] (1-4) The spray pattern of the release agent 44 formed by the first and second release agent application nozzles 46a, 46b (the shape of the release agent 44 applied onto the bottom surface 36a of the cooling jig 18) is a circular shape, an ellipsoidal shape, a multiround shape (a shape containing a plurality of circular islands arranged in a circle), a flat shape (a shape containing end curved portions and a rectangle therebetween) so that the release agent 44 can be uniformly applied in a small thickness to the bottom surface 36a of the cooling jig 18 while reducing undesired application to a portion other than the cooling jig 18.

[0131] (1-5) The first and second release agent application nozzles 46a, 46b are placed in positions, in which they are not interacted with the cooling jig 18. And they are each at a minimum distance of 10 to 2000 mm to the bottom surface 36a of the cooling jig 18 so that the release agent 44 can be uniformly applied in a small thickness to the bottom surface 36a while reducing undesired application to a portion other than the cooling jig 18.

[0132] (1-6) Though the two release agent application nozzles (the first and second release agent application nozzles 46a, 46b) are used in this example, only one release agent application nozzle (e.g. the first release agent application nozzle 46a) may be moved toward the lower or upper end of the cooling jig 18 while maintaining the angle θ to apply the release agent 44.

[Preferred condition 2: continuous operation (application amount control)]

[0133] (2-1) The application amount of the release agent 44 is 0.1 to 5 cc per 1 cycle so that the heat transfer between the melt 34 and the cooling jig 18 is not inhibited by the release agent 44 and the gasified release agent

44 is prevented from being introduced into the melt 34. This number range is preferred when the cooling jig 18 has an entire length of 1000 mm and a width of 120 mm.

[0134] (2-2) The application amount of the release agent 44 is controlled by selecting the application time or the application flow rate to reduce the variation in each cycle of the continuous operation.

[Preferred condition 3: heat transfer coefficient of release agent 44]

[0135] It is preferred that the heat transfer between the cooling jig 18 and the melt 34 is not inhibited by the release agent 44 to efficiently cool the melt 34. Therefore, the release agent 44 is preferably a water-insoluble agent having a heat transfer coefficient of 6 kW/m^2K or more, further preferably an oil-based agent having a heat transfer coefficient of 8 kW/m^2K or more.

[0136] Next, the second casting apparatus 10B having a jig transfer unit will be described below with reference to FIGS. 5 and 6.

[0137] Though the structure of the second casting apparatus 10B is approximately equal to that of the above first casting apparatus 10A, the second casting apparatus 10B is different from the first casting apparatus 10A in that a jig transfer unit 56 is disposed. The cooling jig 18 is moved by the jig transfer unit 56 at least such that the position of the cooling jig 18 in the step of supplying the melt 34 is different from that in the step of applying the release agent 44. Particularly, the jig transfer unit 56 of the second casting apparatus 10B contains a turning device 58 for turning the cooling jig 18 on a rotation axis extending in the vertical direction.

[0138] The turning device 58 contains a turning motor 60 in the supporting member 19. A rotary shaft 62 of the turning motor 60 extends upward in the vertical direction, and the end thereof is connected to an outer wall of the upper end in the cooling jig 18.

[0139] In FIG. 5, L1 represents a width-direction center line of the bottom 36 of the cooling jig 18. Thus, the bottom 36 is divided into two by the center line L1 along the axis. As shown in FIG. 5, the rotary shaft 62 is connected to the vicinity of the upper end of the cooling jig 18, whereby the cooling jig 18 is turned on a rotation axis L2. As is clear from FIG. 5, the rotation axis L2 of the cooling jig 18 is at an offset distance from the center line L1.

[0140] When the melt 34 is supplied to the cooling jig 18, as shown by a solid line in FIG. 5, the cooling jig 18 is turned to a position in which the lower end of the cooling jig 18 faces the melt inlet 32 of the plunger sleeve 14. On the other hand, when the release agent 44 is applied to the cooling jig 18 by the first and second release agent application nozzles 46a, 46b (see FIG. 3), as shown by a two-dot chain line in FIG. 5, the cooling jig 18 is turned to a position in which the lower end of the cooling jig 18 is distant from the melt inlet 32 of the plunger sleeve 14 (an initial position). In the second casting apparatus 10B, the release agent 44 is not introduced into the plunger sleeve 14 or vessel in the application step, and thus the air nozzle 52 shown in FIG. 3 is not needed.

[0141] A casting method using the second casting apparatus 10B (hereinafter referred to as the second casting method) will be described with reference to the flow chart of FIG. 6. It should be noted that the lower end of the cooling jig 18 is in the initial position.

[0142] In the step S101 of FIG. 6, the movable mold portion 20 is moved and combined with the stationary mold portion 22 (mold closing). In this step, the isolated cavity 24 is formed in the mold 12.

[0143] In the step S102, when the lower end of the cooling jig 18 is in the initial position, the release agent 44 and the air are sprayed from the first and second release agent application nozzles 46a, 46b to apply the release agent 44 onto the bottom surface 36a of the cooling jig 18.

[0144] In the step S 103, the application of the release agent 44 from the first and second release agent application nozzles 46a, 46b is stopped.

[0145] In the step S104, the cooling jig 18 is turned to a position in which the lower end faces the melt inlet 32 of the plunger sleeve 14.

[0146] In the step S105, the melt 34 is supplied (poured) to the upper end of the cooling jig 18. The supplied melt 34 flows toward the lower end of the inclined cooling jig 18 along the flow channel 40 (see FIG. 2), and the resultant semi-solid slurry 48 is transferred into the plunger sleeve 14.

[0147] In the step S106, when a predetermined amount of the semi-solid slurry 48 is put in the plunger sleeve 14, the plunger tip 16 is moved frontward (toward the mold 12). Thus, the semi-solid slurry 48 in the plunger sleeve 14 is transferred into the cavity 24 of the mold 12.

[0148] Then, the semi-solid slurry 48 is cooled and solidified in the cavity 24 to obtain a casting. In the step S107, a so-called mold opening is performed to take out the casting from the cavity 24.

[0149] In the second casting apparatus 10B and second casting method, since the cooling jig 18 is turned by the turning device 58 such that the lower end thereof is placed in the position distant from the melt inlet 32 of the plunger sleeve 14 or vessel (the initial position) before supplying the melt 34, the release agent 44 is not introduced into the plunger sleeve 14 or vessel in the application step. In addition, since the air nozzle 52 is not needed, the casting space can be saved and the air supply system can be simplified.

[0150] Next, the third casting apparatus 10C having another jig transfer unit will be described below with reference to FIGS. 7 and 8.

[0151] Though the structure of the third casting apparatus 10C is approximately equal to that of the above second casting apparatus 10B, the third casting apparatus 10C is different from the second casting apparatus 10B in that the jig transfer unit 56 contains a horizontally moving device 64 for moving the cooling jig 18 in the horizontal direction while maintaining the inclination angle ϕb. The horizontally moving device 64 may contain a common oil hydraulic cylinder, a robot, etc.

[0152] When the melt 34 is supplied to the cooling jig 18, as shown by a two-dot chain line in FIG. 7, the cooling jig 18 is moved in the horizontal direction to a position in which the lower end of the cooling jig 18 faces the melt inlet 32 of the plunger sleeve 14 while maintaining the inclination angle ϕb. On the other hand, when the release agent 44 is applied to the cooling jig 18 by the first and second release agent application nozzles 46a, 46b (see FIG. 3), as shown by a solid line in FIG. 7, the cooling jig 18 is moved in the horizontal direction to a position in which the lower end of the cooling jig 18 is distant from the melt inlet 32 of the plunger sleeve 14 (an initial position) while maintaining the inclination angle ϕb. In the third casting apparatus 10C, the release agent 44 is not introduced into the plunger sleeve 14 or vessel in the application step, and thus the air nozzle 52 shown in FIG. 3 is not needed.

[0153] A casting method using the third casting apparatus 10C (hereinafter referred to as the third casting method) will be described with reference to the flow chart of FIG. 8. It should be noted that the lower end of the cooling jig 18 is in the initial position.

[0154] In the step S201 of FIG. 8, the movable mold portion 20 is moved and combined with the stationary mold portion 22 (mold closing). In this step, the isolated cavity 24 is formed in the mold 12.

[0155] In the step S202, when the lower end of the cooling jig 18 is in the initial position, the release agent 44 and the air are sprayed from the first and second release agent application nozzles 46a, 46b to apply the release agent 44 onto the bottom surface 36a of the cooling jig 18.

[0156] In the step S203, the application of the release agent 44 from the first and second release agent application nozzles 46a, 46b is stopped.

[0157] In the step S204, the cooling jig 18 is moved in the horizontal direction to a position in which the lower end faces the melt inlet 32 of the plunger sleeve 14 while maintaining the inclination angle ϕb.

[0158] In the step S205, the melt 34 is supplied (poured) to the upper end of the cooling jig 18. The supplied melt 34 flows toward the lower end of the inclined cooling jig 18 along the flow channel 40 (see FIG. 2), and the resultant semi-solid slurry 48 is transferred into the plunger sleeve 14.

[0159] In the step S206, when a predetermined amount of the semi-solid slurry 48 is put in the plunger sleeve 14, the plunger tip 16 is moved frontward (toward the mold 12). Thus, the semi-solid slurry 48 in the plunger sleeve 14 is transferred into the cavity 24 of the mold 12.

[0160] Then, the semi-solid slurry 48 is cooled and solidified in the cavity 24 to obtain a casting. In the step S207, a so-called mold opening is performed to take out the casting from the cavity 24.

[0161] In the third casting apparatus 10C and third casting method, since the cooling jig 18 is moved in the horizontal direction by the horizontally moving device 64 while maintaining the inclination angle ϕb such that the lower end thereof is placed in the position distant from the melt inlet 32 of the plunger sleeve 14 or vessel (the initial position) before supplying the melt 34, the release agent 44 is not introduced into the plunger sleeve 14 or vessel in the application step. In addition, since the air nozzle 52 is not needed, the casting space can be saved and the air supply system can be simplified.

Examples

[0162] In a specific example of the first embodiment and a comparative example, several affects of the release agent 44 (the affects on the semi-solid slurry, the semi-solid slurry structure, and the return to the initial temperature of the cooling jig 18) were examined.

[Example]

[0163] In Example, the first casting apparatus 10A had the release agent application unit 42 containing the two release agent application nozzles (the first and second release agent application nozzles 46a, 46b) and the air nozzle 52. Each nozzle had a nozzle diameter of 0.5 mm and was used at an application air pressure of 0.3 MPa. The spray pattern was an ellipsoidal shape, and the minimum distance between each nozzle and the bottom surface 36a of the cooling jig 18 was 600 mm. An oil-based release agent WFR-5AL (trade name, available from Aoki Science Institute Co., Ltd.) was used as the release agent 44.

[Comparative Example]

[0164] A heat-insulating release agent BORON COAT (trade name, available from Okitsumo Incorporated) was used as the release agent 44 under the same conditions as Example.

[Experiment]

[0165] In each of Example and Comparative Example, the release agent 44 was applied to the cooling jig 18, and then the melt 34 was supplied to the upper end of the cooling jig 18.

[Experiment result]

<Affect of release agent on semi-solid slurry>

[0166] The temperature of the supplied melt 34 in the outlet of the cooling jig 18 (the outlet melt temperature) was monitored, and the outlet melt temperature change with time was measured. The measurement results are shown in FIG. 9. In FIG. 9, a solid line A represents the characteristic of Example, and a solid line B represents the characteristic of Comparative Example. Further, the difference of the average outlet melt temperatures is shown in FIG. 10.

[0167] As shown in FIGS. 9 and 10, in Example using the oil-based release agent, the average outlet melt temperature was 601.9°C, and the melt 34 could be satisfactorily semi-solidified. In contrast, in Comparative Example using the heat-insulating release agent, the melt 34 was hardly semi-solidified. Thus, in the case of using the heat-insulating release agent, the size of the cooling jig 18 has to be increased so that the melt 34 is sufficiently cooled and semi-solidified by the cooling jig 18. Accordingly, the oil-based release agent is preferred from the viewpoint of space saving.

<Affect of release agent on semi-solid slurry structure>

[0168] As a result of observing the obtained semi-solid slurry structures, the crystal particles of Example had an average diameter of 46.7 μm, and those of Comparative Example had an average diameter of 57.7 μm.

[0169] As compared with the heat-insulating release agent, the oil-based release agent was more excellent in the heat transfer between the cooling jig 18 and the melt 34 and thereby exhibited a higher melt cooling rate. Therefore, in the case of using the oil-based release agent, the nucleus generation frequency was increased in the semi-solidification of the melt 34, and the resultant semi-solid slurry had a finer structure.

<Affect of release agent on return to initial temperature of the cooling jig>

[0170] After the supply of the melt 34 to the cooling jig 18 was started, the change in the temperature of the cooling jig 18 was measured with time. The temporal change of the difference between the temperature of the cooling jig 18 and the initial temperature in each example is shown in FIG. 11. In FIG. 11, a solid line C represents the characteristic of Example, and a solid line D represents the characteristic of Comparative Example.

[0171] As shown in FIG. 11, in Example using the oil-based release agent, the temperature of the cooling jig 18 was more rapidly lowered, and the oil-based release agent was more excellent in the return to the initial temperature, as compared with Comparative Example.

[0172] A technology according to a second embodiment relating to a cooling jig structure will be described below with reference to a circularly movable structure according to a third embodiment. It is to be understood that the structure to be described below may be used in the above first embodiment.

[0173] FIG. 12 is an overall, schematic, side view of a casting apparatus 110 according to the second embodiment. The casting apparatus 110 has a cooling jig 118 for guiding a melt 114 from a ladle 112 to a plunger sleeve 116, a plunger tip 120 capable of reciprocating in the plunger sleeve 116, a stationary mold 122 having the plunger sleeve 116, and a movable mold 124 capable of moving toward and away from the stationary mold 122 by using a drive mechanism (not shown).

[0174] As shown in FIG. 12 as well as FIG. 13 (an enlarged perspective view showing a principal part of FIG. 12), the cooling jig 118 is formed as a long object and inclined at 10° to 80°, preferably about 20° to 40°, to the vertical direction, so that the melt 114 is transferred to the plunger sleeve 116 at a predetermined flow rate. Of course, the upper end of the cooling jig 118 is positioned as a start point in the vicinity of the ladle 112 (see FIG. 12), and the lower end is positioned as a terminal facing a melt inlet 126 formed on the upper surface of the plunger sleeve 116 (see FIGS. 12 and 13).

[0175] In this case, the cooling jig 118 has a curved shape, which contains a bottom 128 with a first side 130 and a second side 132 extending from the side edges of the bottom 128 (see FIG. 13). A flow channel 134 is formed on inner walls of the bottom 128, the first side 130, and the second side 132.

[0176] As shown in FIG. 14, which is a cross-sectional view taken along the line XIV-XIV in the direction of the arrows in FIG. 13, the inner wall of the bottom 128 is connected to the inner walls of the first and second sides 130, 132 by R portions (curved portions) 136, 138. In other words, the curved R portions 136, 138 are formed between the inner walls of the bottom 128 and the first side 130 and between the inner walls of the bottom 128 and the second side 132, respectively.

[0177] The R portions 136, 138 preferably have a curvature radius of 1 to 40 mm. When the curvature radius is less than 1 mm, the R portions 136, 138 tend to be easily heat-cracked. On the other hand, when the curvature radius is more than 40 mm, the contact area between the cooling jig 118 and the melt 114 is reduced to deteriorate the cooling efficiency. The R portions 136, 138 more preferably have a curvature radius of 3 to 20 mm.

[0178] As shown in FIG. 15, which is a cross-sectional view taken along the line XV-XV in the direction of the arrows in FIG. 13, an upper portion of the flow channel 134 has a larger width. In other words, the first and second sides 130, 132 arranged facing each other are inclined such that the distance therebetween is increased with increasing distance from the bottom 128.

[0179] The first and second sides 130, 132 are preferably at an angle θ1 of 0.25° to 10° to a vertical line M. When the angle θ1 is less than 0.25°, a residual solid cannot be easily removed from the cooling jig 118 in the rotation step to be hereinafter described. On the other hand, when the angle θ1 is more than 10°, an insufficiently or excessively cooled portion may be generated in the flow of the melt 114 or semi-solid slurry on the flow channel 134, and the residual solid may be removed and scattered from the cooling jig 118 before the completion of the rotation step.

[0180] As shown in FIG. 14, the lower end of the bottom 128 acts as a melt outlet, and the length of the bottom 128 decreases in the direction from the inner wall to the outer wall in the lower end. Thus, an inclined surface 140 is formed in the lower end (the melt outlet) of the bottom 128 to increase the distance between the lower end and the melt inlet 126. For example, the inclined surface 140 may be at an inclination angle θ2 of 60° to the vertical line M.

[0181] In the cooling jig 118 having such a structure, at least the inner wall of the bottom 128 (the bottom surface of the flow channel 134) and the R portions 136, 138 have an ten-point average roughness Rz of 6.3 μm or less. In this case, the contact area between the wall surfaces of the flow channel 134 and the melt 114 or semi-solid slurry is increased. Therefore, the efficiency of the heat transfer from the melt 114 to the cooling jig 118 is increased, and the size of the cooling jig 118 can be reduced.

[0182] Furthermore, since the heat transfer from the melt 114 to the cooling jig 118 can be carried out with high efficiency as described above, the inner wall of the bottom 128 and the R portions 136, 138 are prevented from being heat-cracked.

[0183] The ten-point average roughness Rz is preferably kept as low as possible. However, in the case of excessively reducing the roughness Rz, a precision surface finishing process is required, whereby the cooling jig 118 cannot be efficiently prepared, and the process cost is increased. Thus, the ten-point average roughness Rz may be approximately 1.6 μm or more.

[0184] The contact area between the inner walls of the first and second sides 130, 132 and the melt 114 or semi-solid slurry is relatively small, whereby the heat stress is hardly concentrated in the inner walls. Therefore, the wall surfaces of the first and second sides 130, 132 may have a ten-point average roughness Rz larger than those of the inner wall of the bottom 128 and the R portions 136, 138. Specifically, the wall surfaces may have a ten-point average roughness Rz of approximately 25 μm. Of course, the ten-point average roughness Rz of the wall surfaces may be equal to those of the inner wall of the bottom 128 and the R portions 136, 138, i.e. within a range of 1.6 to 6.3 μm.

[0185] When the cooling jig 118 is composed of an Fe-based alloy such as a steel, the entire cooling jig 118 may be subjected to a nitridation treatment. In this case, a hardened layer containing a nitride is formed on the surface of the cooling jig 118 to increase the surface hardness. Therefore, even when the heat stress is concentrated, the cooling jig 118 is hardly heat-cracked. Furthermore, the erosion resistance of the cooling jig 118 is improved due to the hardened layer containing the nitride.

[0186] When the cooling jig 118 is composed of a Cu-based alloy, a treatment for forming a nitride film on the entire cooling jig 118 is preferably carried out instead of the nitridation treatment. For example, the nitride is preferably CrN or the like. In this case, the erosion resistance of the cooling jig 118 can be improved.

[0187] A frame (not shown) is disposed in the vicinity of the cooling jig 118 having above structure. As shown in FIGS. 13 and 16 to 18, a supporting plate 144 is fixed to the frame, and a rotation mechanism of a rotating motor 142 is attached to the supporting plate 144. In other words, the rotating motor 142 is fixed to the frame by the supporting plate 144. Incidentally, FIG. 17 is a front view observed in the direction of the arrow A in FIG. 16.

[0188] A rotary shaft 146 extending from the center of the rotating motor 142 is inserted into a through-hole formed in the supporting plate 144 (see FIG. 13). A space is formed between the inner wall of the through-hole and the side surface of the rotary shaft 146. Therefore, the supporting plate 144 is not rotated when the rotary shaft 146 is rotated.

[0189] As is clear from FIG 18, the rotary shaft 146 extends from the through-hole parallel to the axis direction of the cooling jig 118. As shown in FIG. 19, which is a cross-sectional view taken along the line XIX-XIX in the direction of the arrows in FIG 18, a first gear 148 and a stopper holder 150 are fitted onto the rotary shaft 146. The first gear 148 and the stopper holder 150 are rotated when the rotary shaft 146 is rotated.

[0190] The first gear 148 is engaged with a second gear 154 fitted onto a rotating shaft 152. Therefore, the rotating shaft 152 is rotated by the second gear 154 in response to the rotation of the rotary shaft 146. As is clear from FIGS. 13 and 19, the center of the rotating shaft 152 is at an offset distance from the center of the rotary shaft 146.

[0191] A first bracket 156 and a second bracket 158 having a flat plate shape are fitted at a distance onto the rotating shaft 152. The rotating shaft 152 is inserted into a through-hole of each of the first and second brackets 156, 158, so that it is disposed around one side of the first and second brackets 156, 158.

[0192] The cooling jig 118 is firmly press-fitted into and connected to a holder 160 having an approximately C-shaped cross section. Thus, the first side 130, the bottom 128, and the second side 132 of the cooling jig 118 are firmly fitted into a concave portion 162 of the holder 160. As shown in FIGS. 13, 14, and 16, the sides of the holder 160 corresponding to the first and second sides 130, 132 are firmly connected by bolts 164 to the outer walls of the first and second sides 130, 132.

[0193] In FIG. 13, L3 represents the width-direction center axis of the bottom 128 of the cooling jig 118. Thus, the bottom 128 is divided into two by the center axis L3 along the width direction.

[0194] In FIG. 13, L4 represents the rotation center axis of the cooling jig 118. The cooling jig 118 is rotated on the rotating shaft 152 as described below.

[0195] As is clear from the comparison between the rotation center axis L4 and the center axis L3, the rotation center axis L4 of the cooling jig 118 is at an offset distance from the center axis L3 dividing the cooling jig 118 into two along the width direction.

[0196] As shown in FIG. 19, the stopper holder 150 has a ring-shaped portion 166 and a holding portion 168 extending linearly therefrom. A fitting through-hole 170 is formed in the holding portion 168. A stopper 172 is firmly fitted into the fitting hole 170, and extends from either side of the fitting hole 170.

[0197] On the supporting plate 144, a first blocking member 174 is positioned and fixed in the vicinity of the rotating shaft 152, and a second blocking member 176 is positioned and fixed at an angle of 180° to the first blocking member 174. When the flow channel 134 of the cooling jig 118 faces vertically upward, the stopper 172 is in contact with the first blocking member 174. On the other hand, when the cooling jig 118 is rotated 180° and the flow channel 134 faces vertically downward, the stopper 172 is in contact with the second blocking member 176 (see FIG. 22).

[0198] As shown in FIG. 12, the plunger sleeve 116 has an approximately cylindrical shape and has the melt inlet 126 on the upper surface as described above. The plunger tip 120 inserted into the plunger sleeve 116 is connected by a rod 178 to an oil hydraulic cylinder (not shown) and thereby can be reciprocated by the oil hydraulic cylinder.

[0199] A connecting board 180 is disposed between the plunger sleeve 116 and the stationary mold 122. A runner 184 for guiding the semi-solid slurry extends in the vertical direction in the stationary mold 122.

[0200] In the stationary mold 122, a concave portion 186 is caved and formed on the surface facing the movable mold 124. On the other hand, in the movable mold 124, a convex portion 188 is projected and formed on the surface facing the stationary mold 122 in a position corresponding to the concave portion 186. The height of the convex portion 188 is slightly smaller than the depth of the concave portion 186, so that a clearance is formed between the bottom surface of the concave portion 186 and the top surface of the convex portion 188. The clearance acts as a cavity 190.

[0201] The runner 184 extends toward the cavity 190 in an approximately vertical direction in the vicinity of the contact surface between the stationary mold 122 and the movable mold 124. Thus, the semi-solid slurry is introduced through the runner 184 to the cavity 190.

[0202] The casting apparatus 110 of the second embodiment has the above described basic structure containing the cooling jig 118. The advantageous function effects of the cooling jig 118 in operation of the casting apparatus 110 will be described below.

[0203] Prior to casting, a release agent is applied to the inner walls of the bottom 128 and the first and second sides 130, 132 of the flow channel 134 in the cooling jig 118 (see FIG. 13). For example, the application may be carried out in accordance with the above first embodiment.

[0204] Then, as shown in FIG. 12, the ladle 112 is inclined, whereby the melt 114 of a metal such as an aluminum alloy contained in the ladle 112 is poured into the flow channel 134 in the vicinity of the upper end of the cooling jig 118.

[0205] In this case, the cooling jig 118 is inclined preferably at 10° to 80°, more preferably at 20° to 40°, to the vertical direction. At such an inclination angle, the melt 114 can be flowed at an appropriate flow rate on the flow channel 134, so that the flow of the melt 114 can be satisfactorily brought into contact with the cooling jig 118 without gas incorporation.

[0206] Furthermore, in this embodiment, since the inner wall of the bottom 128 (the bottom surface of the flow channel 134) and the R portions 136, 138 have a ten-point average roughness Rz of 6.3 μm or less in the cooling jig 118, the contact area between the melt 114 and the cooling jig 118 can be increased to improve the heat transfer from the melt 114 to the cooling jig 118.

[0207] As a result of intense research, the inventors have found that when the angle $\theta 1$ is 15°, as shown in FIG. 20, an insufficiently cooled portion may be generated in the vicinity of the width-direction center surface of the melt 114 on the flow channel 134. Furthermore, when the angle $\theta 1$ is 30°, as shown in FIG. 21, a potion in the melt 114 in contact with the inner wall of the bottom 128 may be excessively cooled to generate an excessively cooled portion on the flow channel 134, and an insufficiently cooled portion may be generated in the vicinity of the width-direction center surface of the melt 114 in the same manner as FIG. 20.

[0208] In contrast, in this embodiment, since the angle $\theta 1$ is preferably 0.25° to 10° (see FIG. 15), an insufficiently or excessively cooled portion is not generated in the melt 114.

[0209] For these reasons, the heat of the melt 114 is satisfactorily transferred at an appropriate rate to the cooling jig 118, and the temperature of the melt 114 is lowered during the flowage toward the lower end of the cooling jig 118. A solid phase is gradually crystallized in the melt 114 during the temperature decrease, to provide the semi-solid slurry.

[0210] In fact, in the step of flowing the melt 114 toward the lower end of the inclined cooling jig 118, the cooling jig 118 draws heat from the melt 114, so that a part of the melt 114 is converted to a solid phase. Thus, the melt 114 is gradually converted to the semi-solid slurry containing both of solid and liquid phases.

[0211] Since the flow of the melt 114 (or the semi-solid slurry) has a high temperature, when the cooling jig 118 has a sharply bent portion to be brought into contact with the melt 114 (or the semi-solid slurry), a heat stress may be concentrated in this portion to generate a heat crack. In this embodiment, the R portions 136, 138 are formed between the inner walls of the bottom 128 and the first and second sides 130, 132, and the curvature radii of the R portions 136, 138 are preferably 1 to 40 mm, more preferably 3 to 20 mm. Therefore, in this embodiment, the cooling jig 118 does not have a sharply bent portion, whereby the R portions 136, 138 and thus the cooling jig 118 can be prevented from heat cracking due to the contact of the melt 114 (or the semi-solid slurry).

[0212] When the cooling jig 118 is subjected to the nitridation treatment (in other words, the hardened layer is formed on the surface of the cooling jig 118), the prevention effect is further improved. This is because the surface hardness of the cooling jig 118 is increased by the nitridation treatment, whereby the heat crack is more effectively prevented even under a concentrated heat stress.

[0213] The flow of the melt 114 (or the semi-solid slurry) is blocked by the first and second sides 130, 132. Thus, the first and second sides 130, 132 function to prevent the melt 114 (or the semi-solid slurry) from leaking and falling from the side edges of the cooling jig 118.

[0214] The inclined surface 140 is formed in the lower end (the melt outlet) of the bottom 128 to increase the distance between the lower end and the melt inlet 126. Therefore, the lower end of the bottom 128 is excellent in the discharge of the semi-solid slurry (a so-called liquid cutoff). In other words, the semi-solid slurry is prevented from spreading to the outer wall of the bottom 128.

[0215] Most of the semi-solid slurry is transferred from the flow channel 134 through the melt inlet 126 into the plunger sleeve 116. Obviously the plunger tip 120 is placed in the backmost position at this stage.

[0216] When a predetermined amount of the semi-solid slurry is put in the plunger sleeve 116, the plunger tip 120 is moved frontward by the oil hydraulic cylinder. Thus, the semi-solid slurry in the plunger sleeve 116 is pressed and transferred through the runner 184 into the cavity 190.

[0217] Then, the melt 114 is cooled and solidified in the cavity 190 to obtain a casting. A so-called mold opening is performed to take out the casting from the cavity 190.

[0218] When the semi-solid slurry is flowed on the cooling jig 118, a part of the slurry may remain on the cooling jig 118 in the form of a liquid droplet or the like on the flow path. When the supply of the melt 114 is stopped, the remaining part of the slurry is exposed to air and solidified to generate a solid phase. Thus, the part remains as a residual solid (a metal piece) mainly on the bottom 128 of the cooling jig 118.

[0219] When the next casting process is carried out without removing the residual solid, the melt 114 flowing on the cooling jig 118 cannot be sufficiently cooled as described above. Furthermore, the residual solid may cause clogging in the plunger sleeve 116, the runner 184, etc. or quality deterioration of the resultant casting.

[0220] To avoid the failure, in this embodiment, the residual solid remaining on the cooling jig 118 is removed while the semi-solid slurry is transferred to the cavity 190 and then cooled and solidified.

[0221] Specifically, after the melt 114 is completely supplied and most of the semi-solid slurry is poured into the plunger sleeve 116, the rotating motor 142 (see FIGS. 13 and 16 to 18) is energized. The rotary shaft 146 is rotated by the energization in the arrow direction shown in FIGS. 13, 16, and 17. It is not particularly necessary to completely solidify the residual solid before the start of the rotation.

[0222] As described above, the first gear 148 and the stopper holder 150 are rotated in response to the rotation of the rotary shaft 146. Then, the rotary drive force of the rotary shaft 146 is transmitted to the rotating shaft 152 by the second gear 154 engaged with the first gear 148, whereby the rotating shaft 152 is rotated on the rotation center axis L4.

[0223] When the rotating shaft 152 is rotated, the first and second brackets 156, 158 attached thereto are rotated on the rotation center axis L4. Furthermore, also the holder 160 connected to the first and second brackets 156, 158 is rotated.

[0224] As described above, the holder 160 is firmly connected to the cooling jig 118. Thus, eventually, the cooling jig 118 is rotated in response to the rotation of the first and second brackets 156, 158 and the holder 160.

[0225] Also the stopper holder 150 is rotated in response to the rotation of the rotary shaft 146. Then, the stopper 172 supported by the stopper holder 150 is moved in the arrow direction shown in FIG. 22. Thus, the stopper 172 is moved away from the first blocking member 174 toward the second blocking member 176.

[0226] When the stopper holder 150 makes a half turn (i.e., it is turned 180°), the stopper 172 is brought into contact with the second blocking member 176. The stopper 172 is blocked by the contact, whereby the stopper holder 150 and thus the rotary shaft 146 are prevented from further rotating.

[0227] As a result, as shown by imaginary lines in FIGS. 16 and 17 and a solid line in FIG. 23, the cooling jig 118 is stopped when turned 180°, the bottom 128 facing vertically downward.

[0228] The rotation center axis L4 of the cooling jig 118 is at an offset distance from the center axis L3 of the bottom 128 (see FIGS. 13, 17, and 18). As a result, a relatively large centrifugal force acts on the cooling jig 118, whereby an inertial force is applied to the residual solid. Therefore, the residual solid can be easily removed from the cooling jig 118.

[0229] The residual solid can be more easily removed from the cooling jig 118 as it is further cooled and solidified. In other words, the residual solid is not firmly attached to the cooling jig 118. Furthermore, the release agent applied to the cooling jig 118 makes the removal of the residual solid easier.

[0230] In addition, when the stopper 172 is brought into contact with the second blocking member 176, an impact load is applied to the residual solid by the cooling jig 118. Also the impact load makes the removal of the residual solid easier.

[0231] The residual solid can be naturally removed from the cooling jig 118 due to the combination of the above effects. Since the width of the flow channel 134 is increased with increasing distance from the bottom 128 as described above, the first and second sides 130, 132 are inclined at an obtuse angle to the bottom 128. Therefore, the residual solid is not fixed between the bottom

128 and the first side 130 and between the bottom 128 and the second side 132, and is not blocked by the first and second sides 130, 132.

[0232] The semi-solid slurry is prevented from spreading to the outer wall of the bottom 128 in the melt outlet. Therefore, the residual solid does not extend from the inner wall to the outer wall of the bottom 128, whereby the residual solid is not engaged with and blocked by the melt outlet.

[0233] For these reasons, the residual solid can be easily dropped off from the cooling jig 118. Since the first and second sides 130, 132 are at a preferred angle θ1 of 10° or less to the vertical line M, the residual solid is not removed from the cooling jig 118 during the rotation of the cooling jig 118 as described above.

[0234] The dropped residual solid may be introduced to a shooter (not shown) or the like by a guide plate 192 shown in FIGS. 16 and 17, and then collected and discharged.

[0235] After the residual solid is removed, the rotary shaft 146 of the rotating motor 142 is rotated in the direction opposite to the above direction. Thus, the cooling jig 118 is returned to the initial position as shown by the solid lines in FIGS. 12, 13, 16, and 17. In this step, as shown in FIG. 19, the stopper 172 is brought into contact with the first blocking member 174. The cooling jig 118 is prevented by the contact from further rotating from the initial position.

[0236] In the second embodiment, the melt 114 can be cooled at an appropriate rate while preventing the heat crack of the cooling jig 118, and the residual solid can be easily removed.

[0237] Furthermore, since the residual solid remaining on the cooling jig 118 is removed while the semi-solid slurry is transferred to the cavity 190 and then cooled and solidified, the casting apparatus 110 of the second embodiment can be satisfactorily used in continuous casting operation using only one cooling jig 118.

[0238] Since the casting apparatus 110 requires only one cooling jig 118 and does not need a large space for placing the rotating motor 142, the casting apparatus 110 can be placed in a small installation space. Thus, there are no particular restrictions on the layout of the structure capable of removing the residual solid from the cooling jig 118.

[0239] Furthermore, in this case, since a plurality of cooling jigs 118 are not needed, advantageously the structure of an equipment containing the casting apparatus 110 is not complicated, and the control and regulation items are not increased. The casting apparatus 110 having the only one cooling jig 118 can be more easily controlled in operation as compared with an apparatus having plural cooling jigs. For example, the temperature control of the casting apparatus 110 can be remarkably simply carried out. Also the regulation of the casting apparatus 110 can be simply carried out with ease in operation.

[0240] Though the cooling jig 118 is rotated by the rotating motor 142 in the second embodiment, as shown by solid and imaginary lines in FIG. 24, a turning motor 200 corresponding to the turning motor 60 of the first embodiment may be used instead of the rotating motor 142, and the cooling jig 118 may be turned by the turning motor 200. Also in this case, since the cooling jig 118 has the above described shape, the residual solid can be easily removed from the cooling jig 118.

[0241] In this case, a rotation center axis L5 is at an offset distance from a longitudinal center axis L6 of the cooling jig 118. Thus, a large force can be applied to the residual solid, whereby the residual solid can be easily removed in the same manner as above.

[0242] Between the ladle 112 and the plunger sleeve 116, the width of the cooling jig 118 may be increased with increasing distance from the ladle 112. This makes the removal or drop of the residual solid from the cooling jig 118 easier.

[0243] Furthermore, also in this case, the first and second gears 148, 154, the rotating shaft 152, the stopper 172, the first and second blocking members 174, 176, and the holder 160 may be disposed between the turning motor 200 and the cooling jig 118 as in the structure of FIG. 18, and the rotating shaft 152 may be rotated by the turning motor 200 to turn the cooling jig 118. Such a structure will be described in detail in a second example of the third embodiment.

[0244] Though excessive rotation of the cooling jig 118 is prevented by the contact of the stopper 172 with the second blocking member 176 in the above example, the stopper 172 is not always necessary. The circular movement (the rotation or turning) of the cooling jig 118 may be blocked by stopping the rotating motor 142 or the turning motor 200.

[0245] A technology according to the third embodiment relating to a casting apparatus containing a cooling jig, which is circularly movable and thereby capable of easily removing a residual solid, will be described below.

[0246] A structure according to a first example of the third embodiment contains a rotation mechanism for rotating (circularly moving) a cooling jig. Such a structure, in which a rotation axis of the rotation mechanism is at an offset distance from an axis of the cooling jig, is illustrated below.

[0247] Though the rotation mechanism according to the third embodiment described below is similar to the rotation mechanism according to the second embodiment, even the same components are represented by the different numerals in the third embodiment.

[0248] FIG. 25 is an overall, schematic, side view showing a casting apparatus 210 according to this embodiment. The casting apparatus 210 has a cooling jig 218 for guiding a melt 214 from a ladle 212 to a plunger sleeve 216 (an injection sleeve), a plunger tip 220 (an injection mechanism) capable of reciprocating in the plunger sleeve 216, a stationary mold 222 having the plunger sleeve 216, and a movable mold 224 capable of moving toward and away from the stationary mold 222 by using a drive mechanism (not shown).

[0249] As shown in FIG. 25 as well as FIG. 26 (an enlarged perspective view showing a principal part of FIG. 25), the cooling jig 218 is formed as a long object and inclined at a predetermined angle to the vertical direction, so that the melt 214 is introduced into the plunger sleeve 216 at a predetermined flow rate. Of course, the upper end of the cooling jig 218 is positioned as a start point in the vicinity of the ladle 212 (see FIG. 25), and the lower end is positioned as a terminal facing a melt inlet 226 formed on the upper surface of the plunger sleeve 216 (see FIGS. 25 and 26).

[0250] In this case, the cooling jig 218 has a curved shape, which contains a bottom 228 with a first side 230 and a second side 232 extending from the side edges of the bottom 228 (see FIG. 26). The space surrounded by the bottom 228, the first side 230, and the second side 232 acts as a flow channel 234. The first and second sides 230, 232 function to prevent the melt 214 (or a semi-solid slurry) from leaking and falling from the side edges of the cooling jig 218.

[0251] The distance between the first and second sides 230, 232 arranged facing each other is increased with increasing distance from the bottom 228. In other words, a vertically upper portion of the flow channel 234 has a larger width.

[0252] A frame (not shown) is disposed in the vicinity of the cooling jig 218. As shown in FIGS. 26 to 29, a supporting plate 238 is fixed to the frame, and a rotation mechanism of a rotating motor 236 is attached to the supporting plate 238. In other words, the rotating motor 236 is fixed to the frame by the supporting plate 238. Incidentally, FIG. 28 is a front view observed in the direction of the arrow A in FIG. 27.

[0253] A rotary shaft 240 extending from the center of the rotating motor 236 is inserted into a through-hole formed in the supporting plate 238 (see FIG. 26). A space is formed between the inner wall of the through-hole and the side surface of the rotary shaft 240. Therefore, the supporting plate 238 is not rotated when the rotary shaft 240 is rotated.

[0254] As is clear from FIG. 29, the rotary shaft 240 extends from the through-hole parallel to the longitudinal direction (the axis direction) of the cooling jig 218. As shown in FIG. 30, which is a cross-sectional view taken along the line XXX-XXX in the direction of the arrows in FIG. 29, a first gear 242 and a stopper holder 244 are fitted onto the rotary shaft 240. The first gear 242 and the stopper holder 244 are rotated when the rotary shaft 240 is rotated.

[0255] The first gear 242 is engaged with a second gear 248 fitted onto a rotating shaft 246 (a parallel shaft). Therefore, the rotating shaft 246 is rotated by the second gear 248 in response to the rotation of the rotary shaft 240. As is clear from FIGS. 26 and 30, the center of the rotating shaft 246 is at an offset distance from the center of the rotary shaft 240.

[0256] A first bracket 250 and a second bracket 252 having a flat plate shape are fitted at a distance onto the rotating shaft 246. The rotating shaft 246 is inserted into a through-hole of each of the first and second brackets 250, 252, so that it is disposed around one side of the first and second brackets 250, 252.

[0257] The cooling jig 218 is firmly press-fitted into and connected to a holder 254 having an approximately C-shaped cross section. Thus, the first side 230, the bottom 228, and the second side 232 of the cooling jig 218 are firmly fitted into a concave portion 256 of the holder 254. As shown in FIGS. 26, 27, and 29, the sides of the holder 254 corresponding to the first and second sides 230, 232 are firmly connected by bolts 257 to the outer walls of the first and second sides 230, 232.

[0258] In FIG. 26, L7 represents the width-direction center axis of the bottom 228 of the cooling jig 218. Thus, the bottom 228 is divided into two by the center axis L7 along the width direction.

[0259] In FIG. 26, L8 represents the rotation center axis of the cooling jig 218. The cooling jig 218 is rotated on the rotating shaft 246 as described below.

[0260] As is clear from the comparison between the rotation center axis L8 and the center axis L7, the rotation center axis L8 of the cooling jig 218 is at an offset distance from the center axis L7 dividing the cooling jig 218 into two along the width direction.

[0261] As shown in FIG. 30, the stopper holder 244 has a ring-shaped portion 258 and a holding portion 260 extending linearly therefrom. A fitting through-hole 262 is formed in the holding portion 260. A stopper 264 is firmly fitted into the fitting hole 262, and extends from either side of the fitting hole 262.

[0262] On the supporting plate 238, a first blocking member 266 is positioned and fixed in the vicinity of the rotating shaft 246, and a second blocking member 268 is positioned and fixed at an angle of 180° to the first blocking member 266. When the flow channel 234 of the cooling jig 218 faces vertically upward, the stopper 264 is in contact with the first blocking member 266. On the other hand, when the cooling jig 218 is rotated 180° and the flow channel 234 faces vertically downward, the stopper 264 is in contact with the second blocking member 268 (see FIG. 31).

[0263] As shown in FIG. 25, the plunger sleeve 216 has an approximately cylindrical shape and has the melt inlet 226 on the upper surface as described above. The plunger tip 220 inserted into the plunger sleeve 216 is connected by a rod 270 to an oil hydraulic cylinder (not shown) and thereby can be reciprocated by the oil hydraulic cylinder.

[0264] A connecting board 272 is disposed between the plunger sleeve 216 and the stationary mold 222. A runner 276 for guiding the semi-solid slurry extends in the vertical direction in the stationary mold 222.

[0265] In the stationary mold 222, a concave portion 278 is caved and formed on the surface facing the movable mold 224. On the other hand, in the movable mold 224, a convex portion 280 is projected and formed on the surface facing the stationary mold 222 in a position corresponding to the concave portion 278. The height of the convex portion 280 is slightly smaller than the depth of the concave portion 278, so that a clearance is formed between the bottom surface of the concave portion 278 and the top surface of the convex portion 280. The clearance acts as a cavity 282.

[0266] The runner 276 extends toward the cavity 282 in an approximately vertical direction in the vicinity of the contact surface between the stationary mold 222 and the movable mold 224. Thus, the semi-solid slurry is introduced through the runner 276 to the cavity 282.

[0267] The casting apparatus 210 of the first example of the third embodiment has the above described basic structure. The operation and advantageous function effects of the casting apparatus 210 will be described below with respect to a residual solid removal method.

[0268] Prior to casting, a release agent is applied to the inner walls of the bottom 228 and the first and second sides 230, 232 of the flow channel 234 in the cooling jig 218 (see FIG. 26). Then, as shown in FIG. 25, the ladle 212 is inclined, whereby the melt 214 of a metal such as an aluminum alloy contained in the ladle 212 is poured into the flow channel 234 in the vicinity of the upper end of the cooling jig 218.

[0269] The poured melt 214 flows along the flow channel 234 toward the lower end of the inclined cooling jig 218. In this step, the cooling jig 218 draws heat from the melt 214, so that a part of the melt 214 is converted to a solid phase. Thus, the melt 214 is gradually converted to the semi-solid slurry containing both of solid and liquid phases while flowing on the cooling jig 218.

[0270] Most of the semi-solid slurry is transferred from the flow channel 234 through the melt inlet 226 into the plunger sleeve 216. Obviously the plunger tip 220 is placed in the backmost position at this stage.

[0271] When a predetermined amount of the semi-solid slurry is put in the plunger sleeve 216, the plunger tip 220 is moved frontward by the oil hydraulic cylinder. Thus, the semi-solid slurry in the plunger sleeve 216 is pressed and transferred through the runner 276 into the cavity 282.

[0272] Then, the melt 214 is cooled and solidified in the cavity 282 to obtain a casting. A so-called mold opening is performed to take out the casting from the cavity 282.

[0273] When the semi-solid slurry is flowed on the cooling jig 218, a small part of the slurry may remain on the cooling jig 218. When the supply of the melt 214 is stopped, the remaining part of the slurry is exposed to air and solidified to generate a solid phase. Thus, the part remains as a residual solid (a metal piece) mainly on the bottom 228 of the cooling jig 218.

[0274] When the next casting process is carried out without removing the residual solid, the melt 214 flowing on the cooling jig 218 cannot be sufficiently cooled as described above. Furthermore, the residual solid may cause clogging in the plunger sleeve 216, the runner 276, etc. or quality deterioration of the resultant casting.

[0275] To avoid the failure, in the first example of the third embodiment, the residual solid remaining on the cooling jig 218 is removed while the semi-solid slurry is transferred to the cavity 282 and then cooled and solidified.

[0276] Specifically, after the melt 214 is completely supplied and most of the semi-solid slurry is poured into the plunger sleeve 216, the rotating motor 236 (see FIGS. 26 to 29) is energized. The rotary shaft 240 is rotated by the energization in the arrow direction shown in FIGS. 26 to 28. It is not particularly necessary to completely solidify the residual solid before the start of the rotation.

[0277] As described above, the first gear 242 and the stopper holder 244 are rotated in response to the rotation of the rotary shaft 240. Then, the rotary drive force of the rotary shaft 240 is transmitted to the rotating shaft 246 by the second gear 248 engaged with the first gear 242, whereby the rotating shaft 246 is rotated on the rotation center axis L8.

[0278] When the rotating shaft 246 is rotated, the first and second brackets 250, 252 attached thereto are rotated on the rotation center axis L8. Furthermore, also the holder 254 connected to the first and second brackets 250, 252 is rotated.

[0279] As described above, the holder 254 is firmly connected to the cooling jig 218. Thus, eventually, the cooling jig 218 is rotated in response to the rotation of the first and second brackets 250, 252 and the holder 254.

[0280] Also the stopper holder 244 is rotated in response to the rotation of the rotary shaft 240. Then, the stopper 264 supported by the stopper holder 244 is moved in the arrow direction shown in FIG. 31. Thus, the stopper 264 is moved away from the first blocking member 266 toward the second blocking member 268.

[0281] When the stopper holder 244 makes a half turn (i.e., it is turned 180°), the stopper 264 is brought into contact with the second blocking member 268. The stopper 264 is blocked by the contact, whereby the stopper holder 244 and thus the rotary shaft 240 are prevented from further rotating.

[0282] As a result, as shown by imaginary lines in FIGS. 27 and 28 and a solid line in FIG. 32, the cooling jig 218 is stopped when turned 180°, the bottom 228 facing vertically downward.

[0283] The rotation center axis L8 of the cooling jig 218 is at an offset distance from the center axis L7 of the bottom 228 (see FIGS. 26 and 28). As a result, a relatively large centrifugal force acts on the cooling jig 218, whereby an inertial force is applied to the residual solid. Therefore, the residual solid can be easily removed from the cooling jig 218.

[0284] The residual solid can be more easily removed from the cooling jig 218 as it is further cooled and solidified. In other words, the residual solid is not firmly attached to the cooling jig 218. Furthermore, in the first example of the third embodiment, the release agent applied to the cooling jig 218 makes the removal of the residual solid easier.

[0285] In addition, when the stopper 264 is brought into contact with the second blocking member 268, an impact load is applied to the residual solid by the cooling jig 218. Also the impact load makes the removal of the residual solid easier.

[0286] The residual solid can be naturally removed from the cooling jig 218 due to the combination of the above effects. Since the width of the flow channel 234 is increased with increasing distance from the bottom 228 as described above, the first and second sides 230, 232 are inclined at an obtuse angle to the bottom 228. Therefore, the residual solid is not fixed between the bottom 228 and the first side 230 and between the bottom 228 and the second side 232, and is easily dropped off.

[0287] The dropped residual solid may be introduced to a shooter (not shown) or the like by a guide plate 284 shown in FIGS. 27 and 28, and then collected and discharged.

[0288] After the residual solid is removed, the rotary shaft 240 of the rotating motor 236 is rotated in the direction opposite to the above direction. Thus, the cooling jig 218 is returned to the initial position as shown by the solid lines in FIGS. 25 to 28. In this step, as shown in FIG. 30, the stopper 264 is brought into contact with the first blocking member 266. The cooling jig 218 is prevented by the contact from further rotating from the initial position.

[0289] In the first example of the third embodiment, the residual solid remaining on the cooling jig 218 is removed while the semi-solid slurry is transferred to the cavity 282 and then cooled and solidified. Therefore, the casting apparatus 210 of the first example can be satisfactorily used in continuous casting operation using only one cooling jig 218.

[0290] The casting apparatus 210 requires only one cooling jig 218 and does not need a large space for placing the rotating motor 236. Therefore, the casting apparatus 210 can be placed in a small installation space. Thus, there are no particular restrictions on the layout of the structure capable of removing the residual solid from the cooling jig 218.

[0291] Furthermore, in this case, since a plurality of cooling jigs 218 are not needed, the structure of an equipment containing the casting apparatus 210 is not complicated, and the control and regulation items are not increased. The casting apparatus 210 having the only one cooling jig 218 can be more easily controlled in operation as compared with an apparatus having plural cooling jigs. For example, the temperature control of the casting apparatus 210 can be remarkably simply carried out. Also the regulation of the casting apparatus 210 can be simply carried out with ease in operation.

[0292] The rotation angle of the cooling jig 218 is not particularly limited to 180°, and may be optionally selected from 170°, 200°, etc. In this case, the angle between the first and second blocking member 266, 268 may be controlled at 170°, 200°, etc.

[0293] Though excessive rotation of the cooling jig 218 is prevented by the contact of the stopper 264 with the second blocking member 268 in the first example, the stopper 264 is not always necessary. The rotation of the cooling jig 218 may be blocked by stopping the rotating motor 236.

[0294] The cooling jig 218 may be rotated not on the rotating shaft 246 but on the rotary shaft 240 of the rotating motor 236. In this case, the rotary shaft 240 may be positioned such that the center thereof is at an offset distance from the center axis L7.

[0295] The rotation center axis L8 of the cooling jig 218 (the center of the rotary shaft 240 or the rotating shaft 246) may correspond to the center axis L7 in each case.

[0296] A second example of the third embodiment will be described below.

[0297] A structure according to the second example of the third embodiment contains a turning mechanism for turning (circularly moving) a cooling jig. Such a structure, in which a rotation axis of the turning mechanism is at an offset distance from an axis of the cooling jig, is illustrated below. It is to be understood that also in this example, the cooling jig is circularly movable and thereby capable of easily removing a residual solid.

[0298] Though the turning mechanism described below according to the third embodiment contains the same components as those according to the first embodiment (see FIG. 5) and the second embodiment (see FIG. 33), the same components are represented by the different numerals in the third embodiment.

[0299] FIG. 33 is an overall, schematic, side view showing a casting apparatus 310 according to the second example of the third embodiment. The casting apparatus 310 has a cooling jig 318 for guiding a melt 314 from a ladle 312 to a plunger sleeve 316 (an injection sleeve), a plunger tip 320 (an injection mechanism) capable of reciprocating in the plunger sleeve 316, a stationary mold 322 having the plunger sleeve 316, and a movable mold 324 capable of moving toward and away from the stationary mold 322 by using a drive mechanism (not shown).

[0300] As shown in FIG. 33 as well as FIG. 34 (an enlarged perspective view showing a principal part of FIG. 33), the cooling jig 318 is formed as a long object and inclined at a predetermined angle to the vertical direction, so that the melt 314 is introduced into the plunger sleeve 316 at a predetermined flow rate. Of course, the upper end of the cooling jig 318 is positioned as a start point in the vicinity of the ladle 312 (see FIG. 33), and the lower end is positioned as a terminal facing a melt inlet 326 formed on the upper surface of the plunger sleeve 316 (see FIGS. 33 and 34).

[0301] In this case, the cooling jig 318 has a curved shape, which contains a bottom 328 with a first side 330 and a second side 332 extending from the side edges of the bottom 328 (see FIG. 34). The space surrounded by the bottom 328, the first side 330, and the second side

332 acts as a flow channel 334. The first and second sides 330, 332 function to prevent the melt 314 (or a semi-solid slurry) from leaking and falling from the side edges of the cooling jig 318.

[0302] The distance between the first and second sides 330, 332 arranged facing each other (i.e., the width of the flow channel 334) may be constant in the axis direction of the bottom 328. Thus, in FIG. 34, a width W1 may be equal to a width W2. However, it is preferred that the distance is smaller in the vicinity of the ladle 312 and larger in the vicinity of the melt inlet 326. In the second example, such a structure, the width of the flow channel 334 is increased in the upstream-to-downstream direction of the melt 314 (i.e., the widths W1 and W2 in FIG. 34 satisfy the relation of W1<W2), is illustrated below.

[0303] A frame (not shown) is disposed in the vicinity of the cooling jig 318. As shown in FIGS. 34 to 37, a supporting plate 338 is fixed to the frame, and a turning mechanism of a turning motor 336 is attached to the supporting plate 338. In other words, the turning motor 336 is fixed to the frame by the supporting plate 338. Incidentally, FIG. 36 is a front view observed in the direction of the arrow A in FIG. 35. A space is formed between the inner wall of a through-hole and the side surface of a rotary shaft 340. Therefore, the supporting plate 338 is not rotated when the rotary shaft 340 is rotated.

[0304] As is clear from FIGS. 34 to 37, the rotary shaft 340 extends vertically upward from the through-hole. As shown in FIG. 38, which is an enlarged view showing a principal part of FIG. 37, a first gear 342 and a stopper holder 344 are fitted onto the rotary shaft 340. The first gear 342 and the stopper holder 344 are rotated when the rotary shaft 340 is rotated.

[0305] The first gear 342 is engaged with a second gear 348 fitted onto a turning shaft 346 (a vertical shaft). Therefore, the turning shaft 346 is rotated by the second gear 348 in response to the rotation of the rotary shaft 340. As is clear from FIGS. 34 and 38, the center of the turning shaft 346 is at an offset distance from the center of the rotary shaft 340.

[0306] A first bracket 350 and a second bracket 352 are fitted at a distance onto the turning shaft 346 (see FIG. 35). The first and second brackets 350, 352 have a flat plate shape, and an end of the shape is cut and inclined at an angle corresponding to the inclination angle of the cooling jig 318. As shown in FIG. 38, the turning shaft 346 is inserted into a through-hole of each of the first and second brackets 350, 352, so that it is disposed around one side of the first and second brackets 350, 352.

[0307] The cooling jig 318 is firmly press-fitted into and connected to a holder 354 having an approximately C-shaped cross section. Thus, the first side 330, the bottom 328, and the second side 332 of the cooling jig 318 are firmly fitted into a concave portion 356 of the holder 354. As shown in FIGS. 34 and 35, the sides of the holder 354 corresponding to the first and second sides 330, 332 are firmly connected by bolts 357 to the outer walls of the first and second sides 330, 332.

[0308] In FIGS. 34 to 37, L9 represents the axis-direction center axis of the bottom 328 of the cooling jig 318. Thus, the bottom 328 is divided into two by the center axis L9 along the axis direction.

[0309] In FIGS. 34 to 37, L10 represents the turning center axis of the cooling jig 318. The cooling jig 318 is turned on the turning shaft 346 as described below.

[0310] As is clear from the comparison between the turning center axis L10 and the center axis L9, the turning center axis L10 of the cooling jig 318 is at an offset distance from the center axis L9 dividing the cooling jig 318 into two along the axis direction.

[0311] As shown in FIG. 38, the stopper holder 344 has a ring-shaped portion 358 and a holding portion 360 extending linearly therefrom. A fitting through-hole 362 is formed in the holding portion 360. A stopper 364 is firmly fitted into the fitting hole 362, and extends from either side of the fitting hole 362.

[0312] On the supporting plate 338, a first blocking member 366 is positioned and fixed in the vicinity of the turning shaft 346, and a second blocking member 368 is positioned and fixed at an angle of approximately 180° to the first blocking member 366. The flow channel 334 of the cooling jig 318 faces vertically upward, and the stopper 364 is in contact with the first blocking member 366. When the cooling jig 318 is turned 90°, the stopper 364 is in contact with the second blocking member 368 (see FIG. 39).

[0313] As shown in FIG. 33, the plunger sleeve 316 has an approximately cylindrical shape and has the melt inlet 326 on the upper surface as described above. The plunger tip 320 inserted into the plunger sleeve 316 is connected by a rod 370 to an oil hydraulic cylinder (not shown) and thereby can be reciprocated by the oil hydraulic cylinder.

[0314] A connecting board 372 is disposed between the plunger sleeve 316 and the stationary mold 322. A runner 376 for guiding the semi-solid slurry extends in the vertical direction in the stationary mold 322.

[0315] In the stationary mold 322, a concave portion 378 is caved and formed on the surface facing the movable mold 324. On the other hand, in the movable mold 324, a convex portion 380 is projected and formed on the surface facing the stationary mold 322 in a position corresponding to the concave portion 378. The height of the convex portion 380 is slightly smaller than the depth of the concave portion 378, so that a clearance is formed between the bottom surface of the concave portion 378 and the top surface of the convex portion 380. The clearance acts as a cavity 382.

[0316] The runner 376 extends toward the cavity 382 in an approximately vertical direction in the vicinity of the contact surface between the stationary mold 322 and the movable mold 324. Thus, the semi-solid slurry is introduced through the runner 376 to the cavity 382.

[0317] The casting apparatus 310 of the second example of the third embodiment has the above described basic structure. The operation and advantageous function effects of the casting apparatus 310 will be described below with respect to a residual solid removal method.

[0318] Prior to casting, a release agent is applied to the inner walls of the bottom 328 and the first and second sides 330, 332 of the flow channel 334 in the cooling jig 318 (see FIG. 34). Then, as shown in FIG. 33, the ladle 312 is inclined, whereby the melt 314 of a metal such as an aluminum alloy contained in the ladle 312 is poured into the flow channel 334 in the vicinity of the upper end of the cooling jig 318.

[0319] The poured melt 314 flows along the flow channel 334 toward the lower end of the inclined cooling jig 318. In this step, the cooling jig 318 draws heat from the melt 314, so that a part of the melt 314 is converted to a solid phase. Thus, the melt 314 is gradually converted to the semi-solid slurry containing both of solid and liquid phases while flowing on the cooling jig 318.

[0320] Most of the semi-solid slurry is transferred from the flow channel 334 through the melt inlet 326 into the plunger sleeve 316. Obviously the plunger tip 320 is placed in the backmost position at this stage.

[0321] When a predetermined amount of the semi-solid slurry is put in the plunger sleeve 316, the plunger tip 320 is moved frontward by the oil hydraulic cylinder. Thus, the semi-solid slurry in the plunger sleeve 316 is pressed and transferred through the runner 376 into the cavity 382.

[0322] Then, the melt 314 is cooled and solidified in the cavity 382 to obtain a casting. A so-called mold opening is performed to take out the casting from the cavity 382.

[0323] When the semi-solid slurry is flowed on the cooling jig 318, a small part of the slurry may remain on the cooling jig 318. When the supply of the melt 314 is stopped, the remaining part of the slurry is exposed to air and solidified to generate a solid phase. Thus, the part remains as a residual solid (a metal piece) mainly on the bottom 328 of the cooling jig 318.

[0324] When the next casting process is carried out without removing the residual solid, the melt 314 flowing on the cooling jig 318 cannot be sufficiently cooled as described above. Furthermore, the residual solid may cause clogging in the plunger sleeve 316, the runner 376, etc. or quality deterioration of the resultant casting.

[0325] To avoid the failure, in the second example of the third embodiment, the residual solid remaining on the cooling jig 318 is removed while the semi-solid slurry is transferred to the cavity 382 and then cooled and solidified.

[0326] Specifically, after the melt 314 is completely supplied and most of the semi-solid slurry is poured into the plunger sleeve 316, the turning motor 336 (see FIGS. 34 to 37) is energized. The rotary shaft 340 is rotated by the energization in the arrow direction shown in FIGS. 34 to 36. It is not particularly necessary to completely solidify the residual solid before the start of the rotation.

[0327] As described above, the first gear 342 and the stopper holder 344 are rotated in response to the rotation of the rotary shaft 340. Then, the rotary drive force of the rotary shaft 340 is transmitted to the turning shaft 346 by the second gear 348 engaged with the first gear 342, whereby the turning shaft 346 is turned on the turning center axis L10.

[0328] When the turning shaft 346 is turned, the first and second brackets 350, 352 attached thereto are turned on the turning center axis L10. Furthermore, also the holder 354 connected to the first and second brackets 350, 352 is turned.

[0329] As described above, the holder 354 is firmly connected to the cooling jig 318. Thus, eventually, the cooling jig 318 is turned in response to the turning of the first and second brackets 350, 352 and the holder 354.

[0330] Also the stopper holder 344 is rotated in response to the rotation of the rotary shaft 340. Then, the stopper 364 supported by the stopper holder 344 is moved in the arrow direction shown in FIG. 39. Thus, the stopper 364 is moved away from the first blocking member 366 toward the second blocking member 368.

[0331] When the stopper holder 344 makes a quarter turn (i.e., it is turned 90°), the stopper 364 is brought into contact with the second blocking member 368. The stopper 364 is blocked by the contact, whereby the stopper holder 344 and thus the rotary shaft 340 are prevented from further rotating.

[0332] As a result, as shown by an imaginary line in FIG. 34 and a solid line in FIG. 40, the lower end of the cooling jig 318 is moved away from the melt inlet 326, the cooling jig 318 is turned 90° and then stopped, and the bottom 328 extends downward.

[0333] The turning center axis L10 of the cooling jig 318 is at an offset distance from the center axis L9 of the bottom 328 (see FIGS. 34 and 37). As a result, a relatively large centrifugal force acts on the cooling jig 318, whereby an inertial force is applied to the residual solid. Therefore, the residual solid can be easily removed from the cooling jig 318.

[0334] The residual solid can be more easily removed from the cooling jig 318 as it is further cooled and solidified. In other words, the residual solid is not firmly attached to the cooling jig 318. Furthermore, also in the second example, the release agent applied to the cooling jig 318 makes the removal of the residual solid easier.

[0335] In addition, when the stopper 364 is brought into contact with the second blocking member 368, an impact load is applied to the residual solid by the cooling jig 318. Also the impact load makes the removal of the residual solid easier.

[0336] The residual solid can be naturally removed from the cooling jig 318 due to the combination of the above effects. In the second example of the third embodiment, the width of the flow channel 334 in the cooling jig 318 is increased in the upstream-to-downstream direction of the melt 314 as described above. In a case where the width of the flow channel 334 is increased in the opposite direction (i.e., the distance between the first and second sides 330, 332 is decreased in the upstream-to-downstream direction), when the residual solid is dropped off along the cooling jig 318 inclined downward, the residual solid may be blocked by the first and second sides 330, 332. This problem is not caused in the second example using the above structure.

[0337] The dropped residual solid may be introduced to a shooter (not shown) or the like by a guide plate 384 shown in FIGS. 35 and 36, and then collected and discharged.

[0338] After the residual solid is removed, the rotary shaft 340 of the turning motor 336 is rotated in the direction opposite to the above direction. Thus, the cooling jig 318 is returned to the initial position as shown by the solid lines in FIGS. 33 to 36. In this step, as shown in FIG. 38, the stopper 364 is brought into contact with the first blocking member 366. The cooling jig 318 is prevented by the contact from further turning from the initial position.

[0339] In the second example of the third embodiment, the residual solid remaining on the cooling jig 318 is removed while the semi-solid slurry is transferred to the cavity 382 and then cooled and solidified. Therefore, the casting apparatus 310 of the second example can be satisfactorily used in continuous casting operation using only one cooling jig 318.

[0340] The casting apparatus 310 requires only one cooling jig 318 and does not need a large space for placing the turning motor 336. Therefore, the casting apparatus 310 can be placed in a small installation space. Thus, there are no particular restrictions on the layout of the structure capable of removing the residual solid from the cooling jig 318.

[0341] Furthermore, in this case, since a plurality of cooling jigs 318 are not needed, the structure of an equipment containing the casting apparatus 310 is not complicated, and the control and regulation items are not increased. The casting apparatus 310 having the only one cooling jig 318 can be more easily controlled in operation as compared with an apparatus having plural cooling jigs. For example, the temperature control of the casting apparatus 310 can be remarkably simply carried out. Also the regulation of the casting apparatus 310 can be simply carried out with ease in operation.

[0342] The turning angle of the cooling jig 318 is not particularly limited to 90°, and may be optionally selected from 100°, 180°, etc. In this case, the angle between the first and second blocking member 366, 368 may be appropriately controlled.

[0343] Though excessive turning of the cooling jig 318 is prevented by the contact of the stopper 364 with the second blocking member 368 in the second example, the stopper 364 is not always necessary. The turning of the cooling jig 318 may be blocked by stopping the turning motor 336.

[0344] The cooling jig 318 may be turned not on the turning shaft 346 but on the rotary shaft 340 of the turning motor 336. In this case, the rotary shaft 340 may be positioned such that the center thereof is at an offset distance from the center axis L9.

[0345] The turning center axis L10 of the cooling jig 18 (the center of the rotary shaft 340 or the turning shaft 346) may correspond to the center axis L9 in each case.

[0346] Though the rotating motor 236 and the turning motor 336 are of electrically driven type in the first and second examples, of course a hydraulic rotation or turning mechanism or the like may be used instead thereof.

[0347] The cooling jig 118 of the second embodiment may be used as the cooling jig 218 or 318 of the third embodiment. Furthermore, the release agent application method used in the first embodiment may be used in the second and third embodiments.

[0348] A casting apparatus (10A) has a long cooling jig (18) inclined with respect to a vertical direction. A melt (34) is supplied to and flowed on a bottom surface (36a) of the cooling jig (18), whereby a solid phase is generated in the melt (34) to obtain a semi-solid slurry (48), and the semi-solid slurry (48) is transferred into and solidified in a cavity (24) of a mold (12) to obtain a casting. The casting apparatus (10A) further has a release agent application unit (42), and a release agent (44) is applied by the application unit (42) to the bottom surface (36a) of the cooling jig (18) in a direction toward a supply of the melt (34) at an angle of less than 90° to the bottom surface (36a) before supplying the melt (34) to the cooling jig (18).

Claims

1. A casting apparatus (10A) comprising a long cooling jig (18) inclined with respect to a vertical direction, wherein a melt (34) is supplied to and flowed on a predetermined surface (36a) of the cooling jig (18), whereby a solid phase is generated in the melt (34) to obtain a semi-solid slurry (48), and the semi-solid slurry (48) is transferred into and solidified in a cavity (24) of a mold (12) to obtain a casting, and
the casting apparatus (10A) further comprises a release agent application unit (42) for applying a release agent (44) to the predetermined surface (36a) of the cooling jig (18) in a direction toward a supply of the melt (34) at an angle of less than 90° to the predetermined surface (36a).

2. The casting apparatus (10A) according to claim 1, wherein the release agent application unit (42) contains one or more release agent application nozzles (46a, 46b) for spraying the release agent (44) along with an air onto the predetermined surface (36a) of the cooling jig (18) in a direction toward the supply of the melt (34) at an angle of less than 90° to the predetermined surface (36a).

3. The casting apparatus (10A) according to claim 2, wherein the release agent application unit (42) contains, in addition to the release agent application nozzle (46a, 46b), an air nozzle (52) for spraying an air (50) toward a lower end of the cooling jig (18), from

which the melt (34) is discharged as the semi-solid slurry (48).

4. The casting apparatus (10A) according to claim 1, wherein the casting apparatus (10A) further comprises a jig transfer unit (56) for moving the cooling jig (18), thereby changing at least the position of the cooling jig (18) in the step of supplying the melt (34) from that in the step of applying the release agent (44).

5. The casting apparatus (10A) according to claim 2, wherein the release agent application unit (42) contains two or more of the release agent application nozzles (46a, 46b), and the inclination angle of a line connecting the release agent application nozzles (46a, 46b) is approximately equal to that of the predetermined surface (36a) of the cooling jig (18).

6. A casting method, wherein a melt (34) is supplied to and flowed on a predetermined surface (36a) of a long cooling jig (18) inclined with respect to a vertical direction, whereby a solid phase is generated in the melt (34) to obtain a semi-solid slurry (48), and the semi-solid slurry (48) is transferred into and solidified in a cavity (24) of a mold (12) to obtain a casting, and the casting method comprises the steps of
applying a release agent (44) to the predetermined surface (36a) of the cooling jig (18) in a direction toward a supply of the melt (34) at an angle of less than 90° to the predetermined surface (36a), and
supplying the melt (34) to the predetermined surface (36a) of the cooling jig (18) after the application of the release agent (44).

7. The casting method according to claim 6, wherein in the step of applying the release agent (44), the release agent (44) and an air (50) are sprayed onto the predetermined surface (36a) of the cooling jig (18) in a direction toward the supply of the melt (34) at an angle of less than 90° to the predetermined surface (36a).

8. The casting method according to claim 7, wherein in the step of applying the release agent (44), at the same time as the spraying of the release agent (44) and the air (50), an air (50) is sprayed toward a lower end of the cooling jig (18), from which the melt (34) is discharged as the semi-solid slurry (48).

9. A cooling jig (118) for cooling a melt (114) flowing thereon, thereby generating a solid phase in the melt (114) to obtain a semi-solid slurry, comprising a bottom (128), a first side (130), and a second side (132), wherein
the first side (130) and the second side (132) bend and extend from the bottom (128) and are arranged facing each other,
a flow channel (134) for the semi-solid slurry is formed by inner walls of the bottom (128), the first side (130), and the second side (132), and
curved portions (136, 138) are formed between the inner walls of the bottom (128) and the first side (130) and between the inner walls of the bottom (128) and the second side (132) respectively.

10. The cooling jig (118) according to claim 9, wherein the first side (130) and the second side (132) extending from the bottom (128) are inclined at an angle of 0.25° to 10° to a vertical line so that the distance between the first side (130) and the second side (132) is increased with increasing distance from the bottom (128), and the curved portions (136, 138) have a curvature radius of 1 to 40 mm.

11. The cooling jig (118) according to claim 9, wherein the cooling jig (118) is capable of rotating on a rotation axis parallel to an axis direction thereof, and an inclined surface (140) is formed on an end of a melt outlet in the bottom (128) so that the length of the bottom (128) decreases in the direction from the inner wall to the outer wall.

12. The cooling jig (118) according to claim 9, wherein the inner wall of the bottom (128) and the curved portions (136, 138) have a ten-point average roughness Rz of 6.3 μm or less.

13. The cooling jig (118) according to claim 9, wherein the cooling jig (118) contains an Fe-based alloy, and a hardened layer is formed on a surface of the cooling jig (118) by a nitridation treatment.

14. The cooling jig (118) according to claim 9, wherein the cooling jig (118) contains a Cu-based alloy, and a film of a nitride is formed on a surface of the cooling jig (118).

15. A method for removing a residual solid, which is generated on a long cooling jig (218) inclined with respect to a vertical direction when a melt (214) is flowed on a predetermined surface of the cooling jig (218), whereby a solid phase is generated in the melt (214) to obtain a semi-solid slurry, and the semi-solid slurry is transferred into and solidified in a cavity (282) to obtain a casting, wherein
the cooling jig (218) is circularly moved on an axis to drop the residual solid.

16. The removing method according to claim 15, wherein the cooling jig (218) is rotated on a parallel axis extending parallel to an axis direction of the cooling jig (218) so that the predetermined surface faces vertically downward to drop the residual solid.

17. The removing method according to claim 16, wherein the parallel axis is different from an axis of a rotary shaft (240) in a rotation mechanism (236) for rotating the cooling jig (218).

18. The removing method according to claim 16, wherein the parallel axis is at an offset distance from a width-direction center of the predetermined surface of the cooling jig (218).

19. The removing method according to claim 15, wherein the cooling jig (218) is turned on a vertical axis extending in a vertical direction so that an external force is applied to the residual solid to drop the residual solid.

20. The removing method according to claim 19, wherein the vertical axis is different from an axis of a rotary shaft (340) in a turning mechanism (336) for turning the cooling jig (218).

21. The removing method according to claim 19, wherein the vertical axis is at an offset distance from an axis-direction center of the predetermined surface of the cooling jig (218).

22. A casting apparatus (210) comprising
a long cooling jig (218) for cooling a melt (214) flowing thereon, thereby generating a solid phase in the melt (214) to obtain a semi-solid slurry,
an injection sleeve (216) into which the semi-solid slurry is poured from the cooling jig (218),
an injection mechanism (220) for injecting the semi-solid slurry contained in the injection sleeve (216), and
a mold (222, 224) having a cavity (282) into which the semi-solid slurry is introduced by pressure of the injection mechanism (220), wherein
the casting apparatus (210) further comprises a circular movement mechanism for circularly moving the cooling j ig (218), and
the cooling jig (218) is circularly moved by the circular movement mechanism.

23. The casting apparatus (210) according to claim 22, wherein
the circular movement mechanism is a rotation mechanism (236) having a rotary shaft (240) extending parallel to an axis direction of the cooling jig (218) inclined with respect to a vertical direction, and
when the rotary shaft (240) in the rotation mechanism (236) is rotated, the cooling jig (218) is rotated so that a predetermined surface of the cooling jig (218), on which the melt (214) flows, faces vertically downward.

24. The casting apparatus (210) according to claim 23, wherein the casting apparatus (210) further comprises another shaft (246) extending parallel to the axis direction of the cooling jig (218) between the rotary shaft (240) and the cooling jig (218), and the cooling jig (218) is rotated on the another shaft (246).

25. The casting apparatus (210) according to claim 23, wherein the rotation center of the cooling jig (218) is at an offset distance from a width-direction center of the predetermined surface of the cooling jig (218).

26. The casting apparatus (210) according to claim 23, wherein the casting apparatus (210) further comprises a stopper (264) movable in response to the rotation of the cooling jig (218) and a blocking member (266, 268) for blocking the stopper (264) in contact therewith, and the rotation of the cooling jig (218) is stopped when the stopper (264) is brought into contact with the blocking member (266, 268).

27. The casting apparatus (210) according to claim 23, wherein the cooling jig (218) has a flow channel (234) for the melt (214), and the width of the flow channel (234) increases in a vertically upward direction.

28. The casting apparatus (310) according to claim 22, wherein
the circular movement mechanism is a turning mechanism (336) having a rotary shaft (340) extending in a vertical direction, and
when the rotary shaft (340) in the turning mechanism (336) is rotated, the cooling jig (318) is turned.

29. The casting apparatus (310) according to claim 28, wherein the casting apparatus (310) further comprises another shaft extending in the vertical direction between the rotary shaft (340) and the cooling jig (318), and the cooling jig (318) is turned on the another shaft.

30. The casting apparatus (310) according to claim 28, wherein the turning center of the cooling jig (318) is at an offset distance from an axis-direction center of a predetermined surface of the cooling jig (318).

31. The casting apparatus (310) according to claim 28, wherein the casting apparatus (310) further comprises a stopper (364) movable in response to the turning of the cooling jig (318) and a blocking member (366, 368) for blocking the stopper (364) in contact therewith, and the turning of the cooling jig (318) is stopped when the stopper (364) is brought into contact with the blocking member (366, 368).

32. The casting apparatus (310) according to claim 28, wherein the width of the cooling jig (318) increases in the upstream-to-downstream direction of the melt (214).

FIG. 1

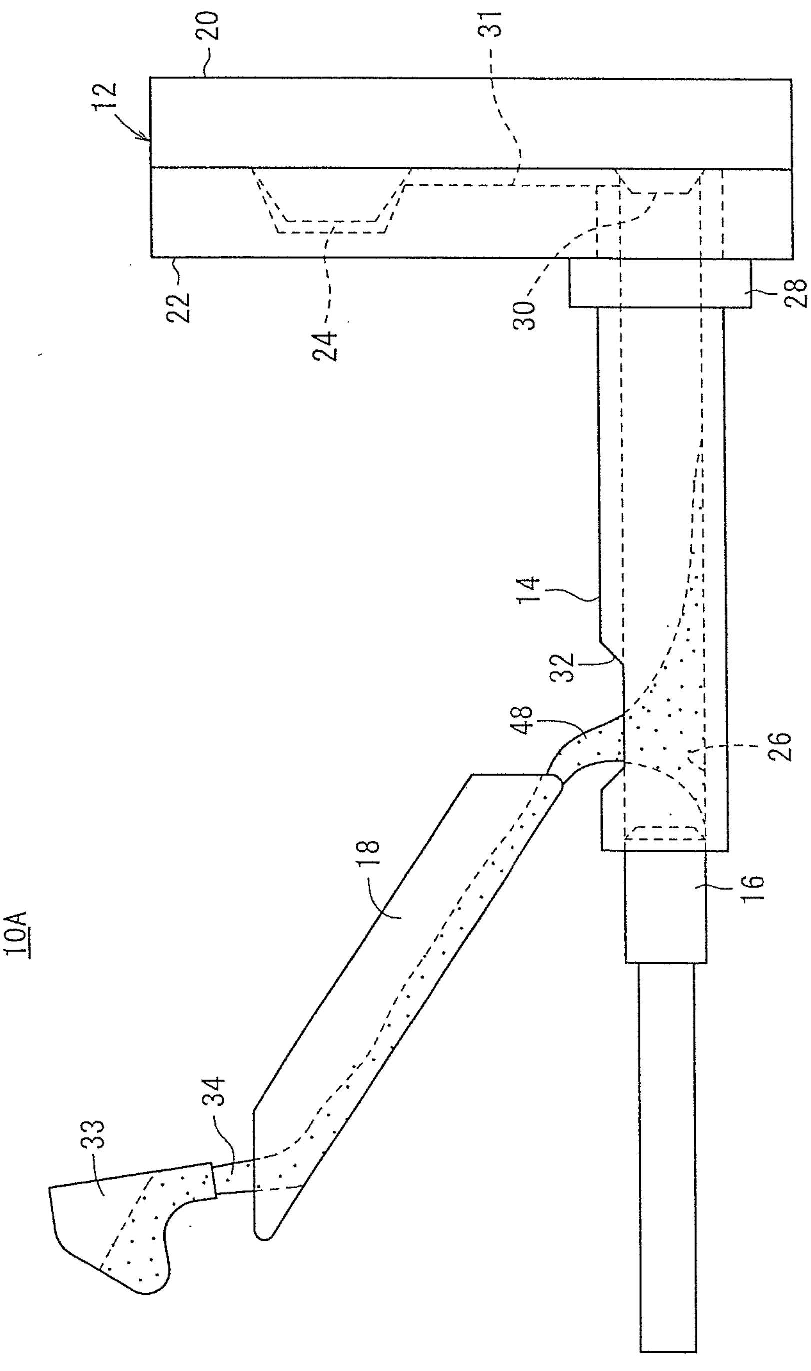


FIG. 2

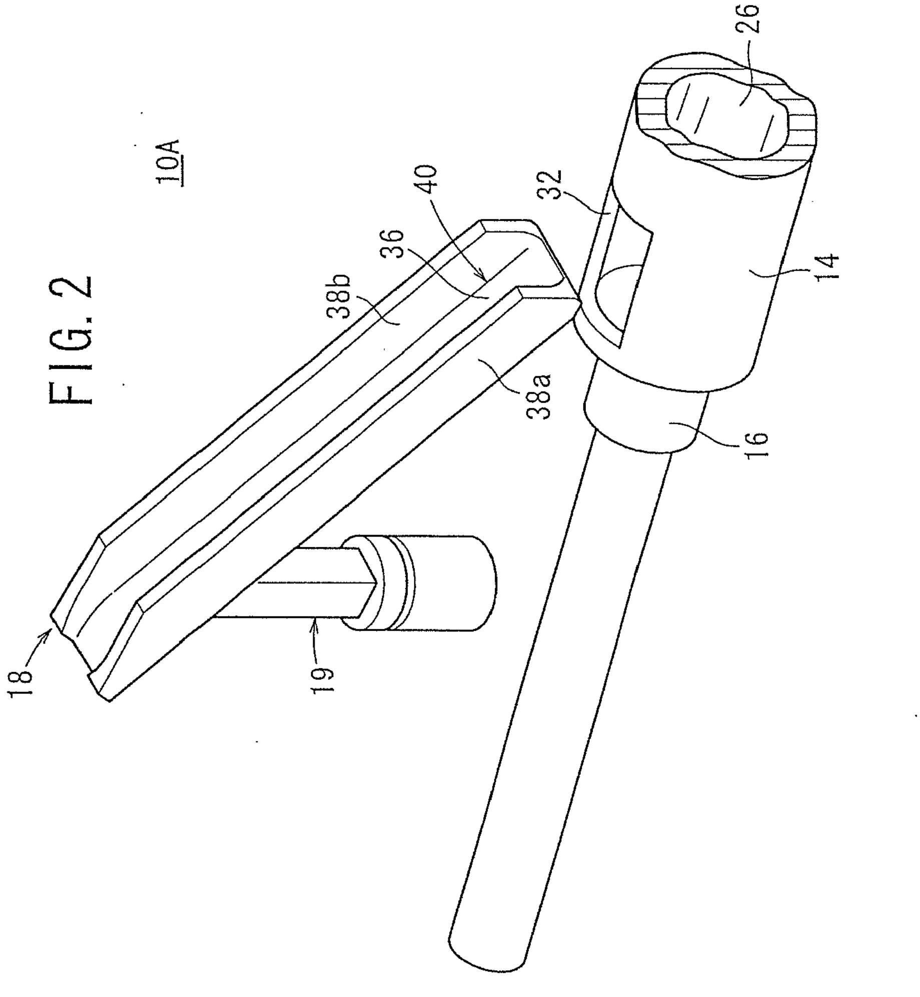


FIG. 3

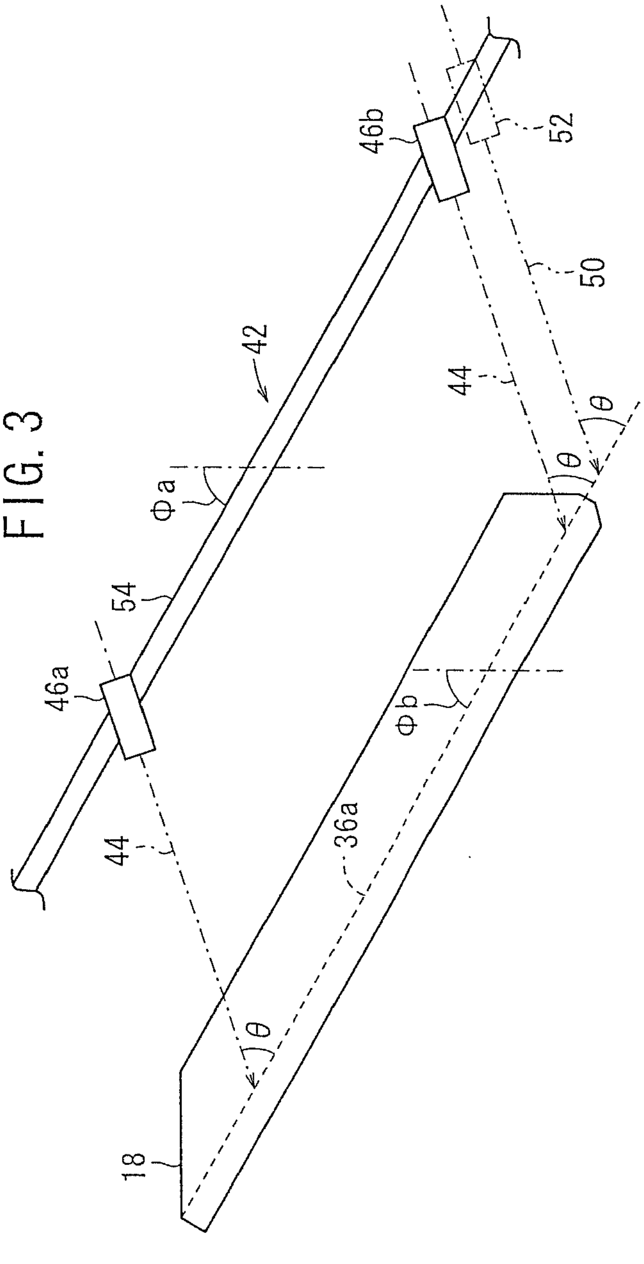


FIG. 4

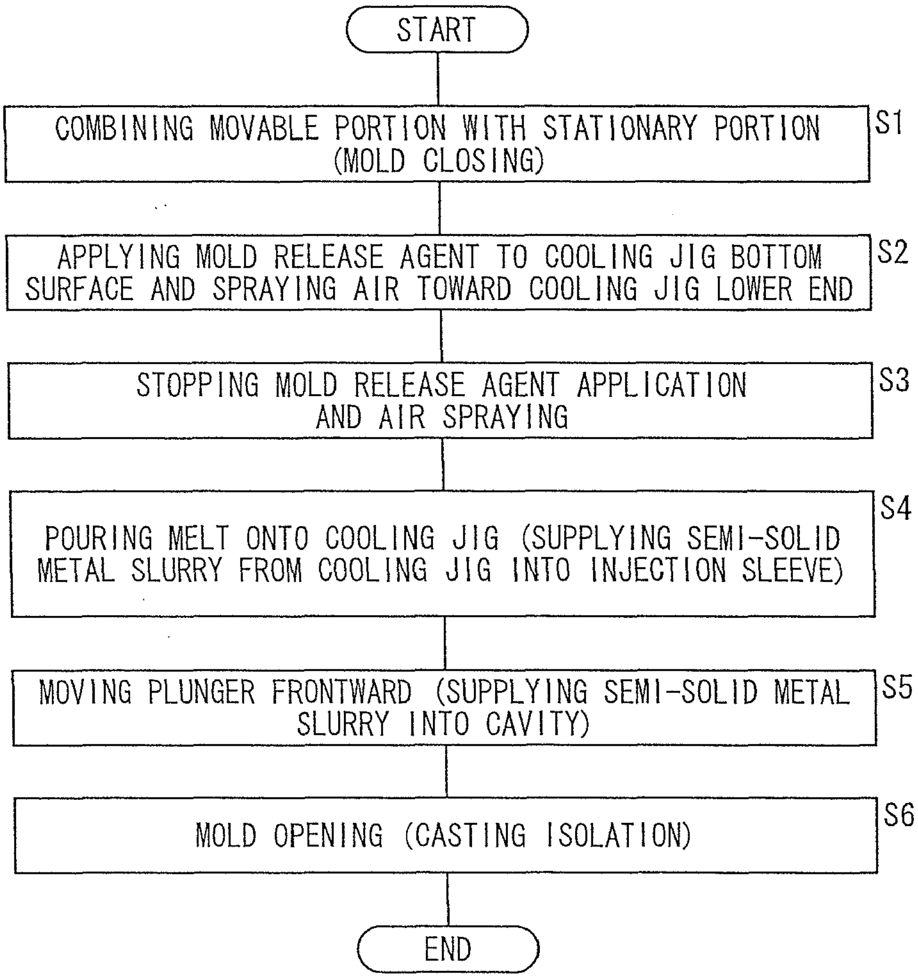

START
COMBINING MOVABLE PORTION WITH STATIONARY PORTION (MOLD CLOSING)
S1
APPLYING MOLD RELEASE AGENT TO COOLING JIG BOTTOM SURFACE AND SPRAYING AIR TOWARD COOLING JIG LOWER END
S2
STOPPING MOLD RELEASE AGENT APPLICATION AND AIR SPRAYING
S3
POURING MELT ONTO COOLING JIG (SUPPLYING SEMI-SOLID METAL SLURRY FROM COOLING JIG INTO INJECTION SLEEVE)
S4
MOVING PLUNGER FRONTWARD (SUPPLYING SEMI-SOLID METAL SLURRY INTO CAVITY)
S5
MOLD OPENING (CASTING ISOLATION)
S6
END

FIG. 5

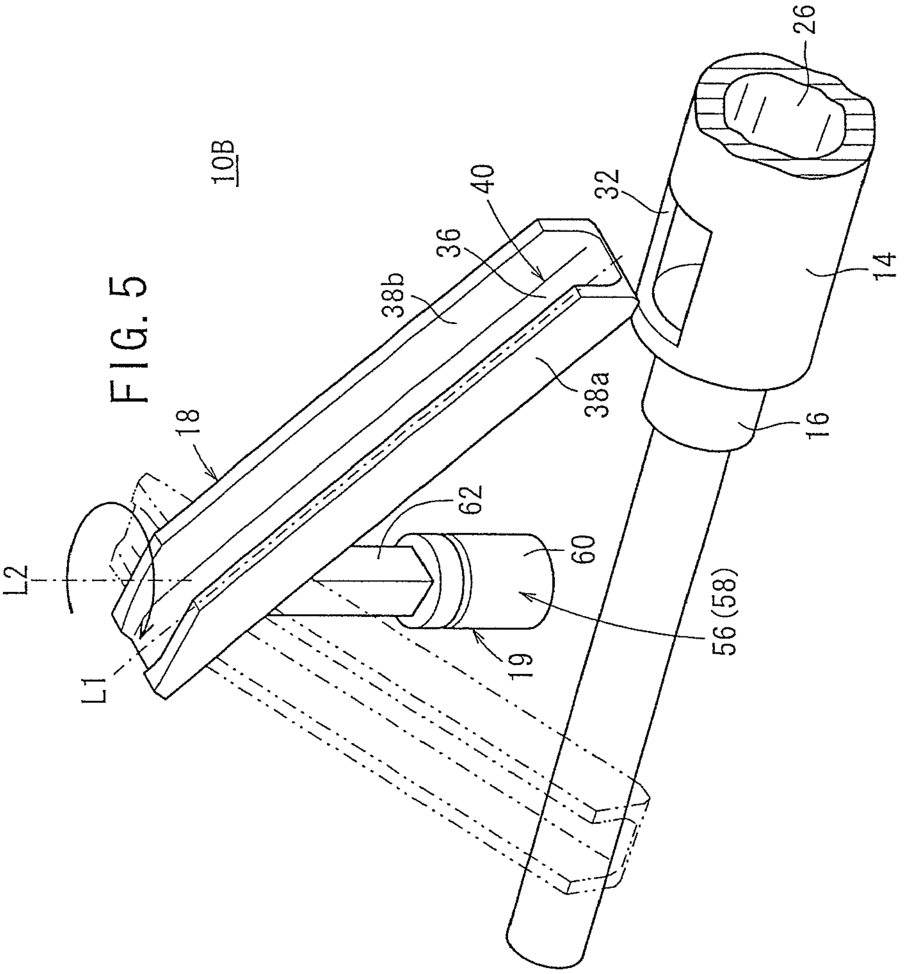


FIG. 6

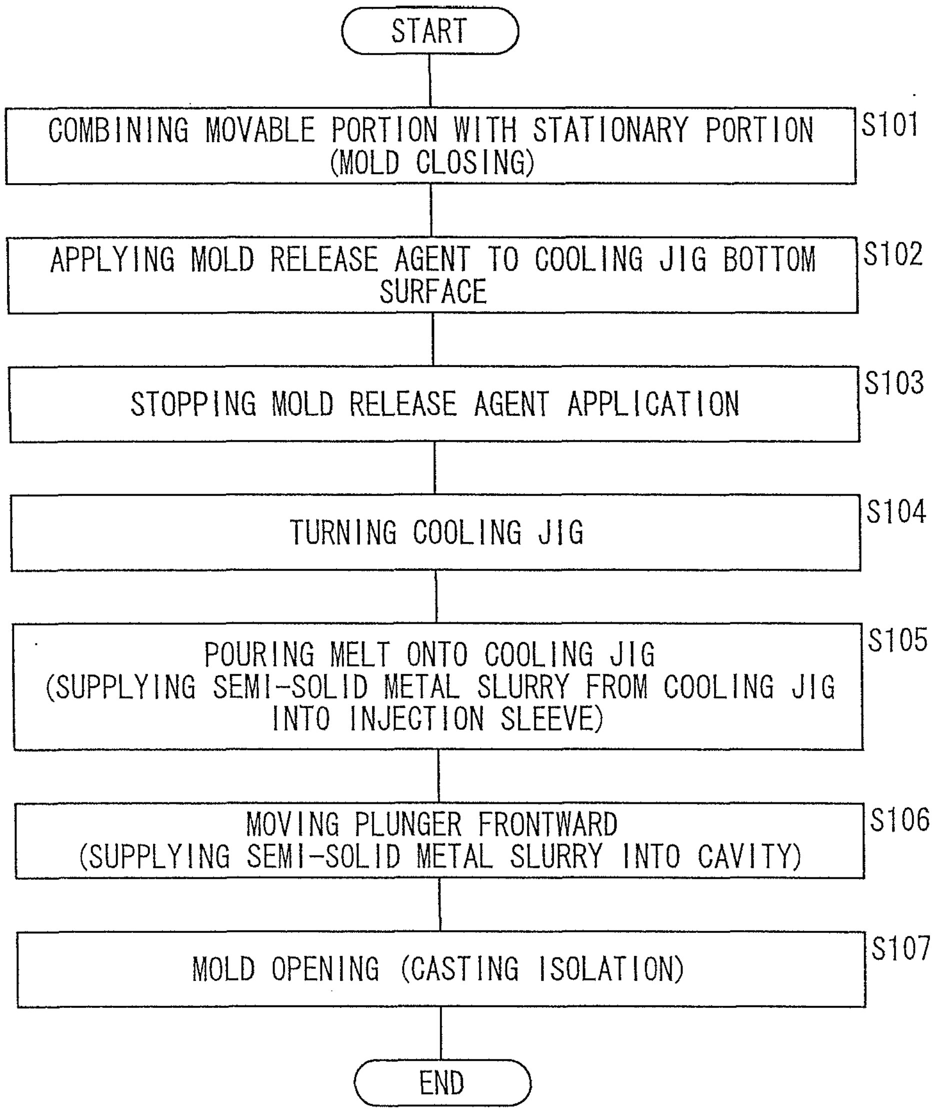

START
COMBINING MOVABLE PORTION WITH STATIONARY PORTION (MOLD CLOSING)
S101
APPLYING MOLD RELEASE AGENT TO COOLING JIG BOTTOM SURFACE
S102
STOPPING MOLD RELEASE AGENT APPLICATION
S103
TURNING COOLING JIG
S104
POURING MELT ONTO COOLING JIG (SUPPLYING SEMI-SOLID METAL SLURRY FROM COOLING JIG INTO INJECTION SLEEVE)
S105
MOVING PLUNGER FRONTWARD (SUPPLYING SEMI-SOLID METAL SLURRY INTO CAVITY)
S106
MOLD OPENING (CASTING ISOLATION)
S107
END

FIG. 7

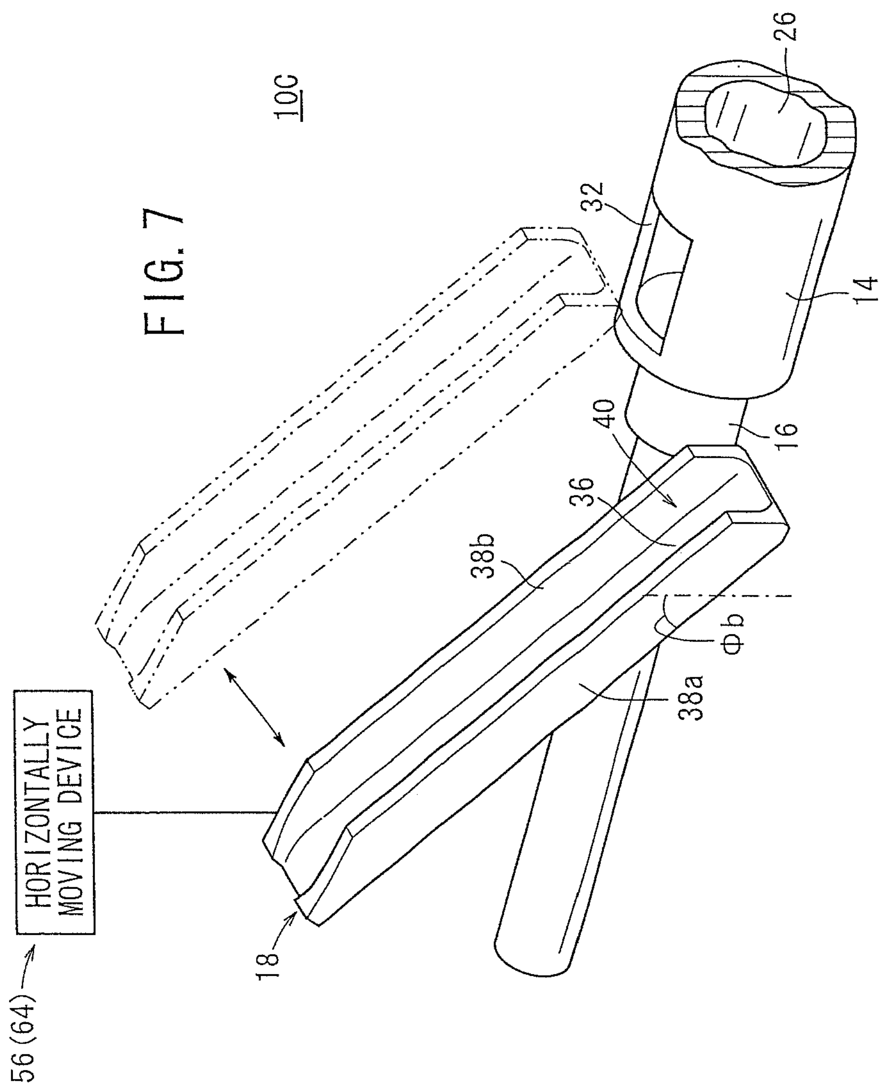

10C
26
32
14
16
40
36
38b
Φb
38a
18
HORIZONTALLY
MOVING DEVICE
56(64)

FIG. 8

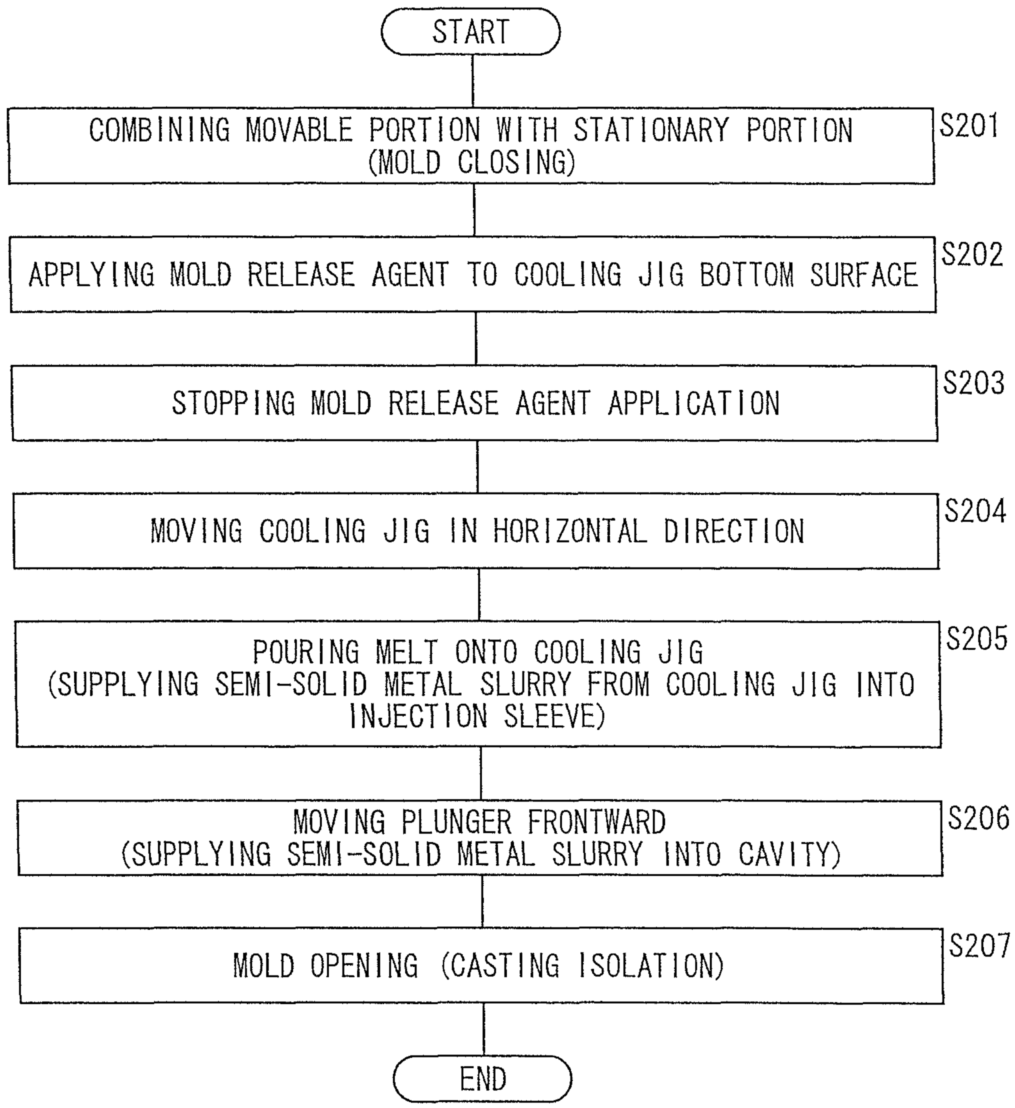

START
COMBINING MOVABLE PORTION WITH STATIONARY PORTION (MOLD CLOSING)
S201
APPLYING MOLD RELEASE AGENT TO COOLING JIG BOTTOM SURFACE
S202
STOPPING MOLD RELEASE AGENT APPLICATION
S203
MOVING COOLING JIG IN HORIZONTAL DIRECTION
S204
POURING MELT ONTO COOLING JIG (SUPPLYING SEMI-SOLID METAL SLURRY FROM COOLING JIG INTO INJECTION SLEEVE)
S205
MOVING PLUNGER FRONTWARD (SUPPLYING SEMI-SOLID METAL SLURRY INTO CAVITY)
S206
MOLD OPENING (CASTING ISOLATION)
S207
END

FIG. 9

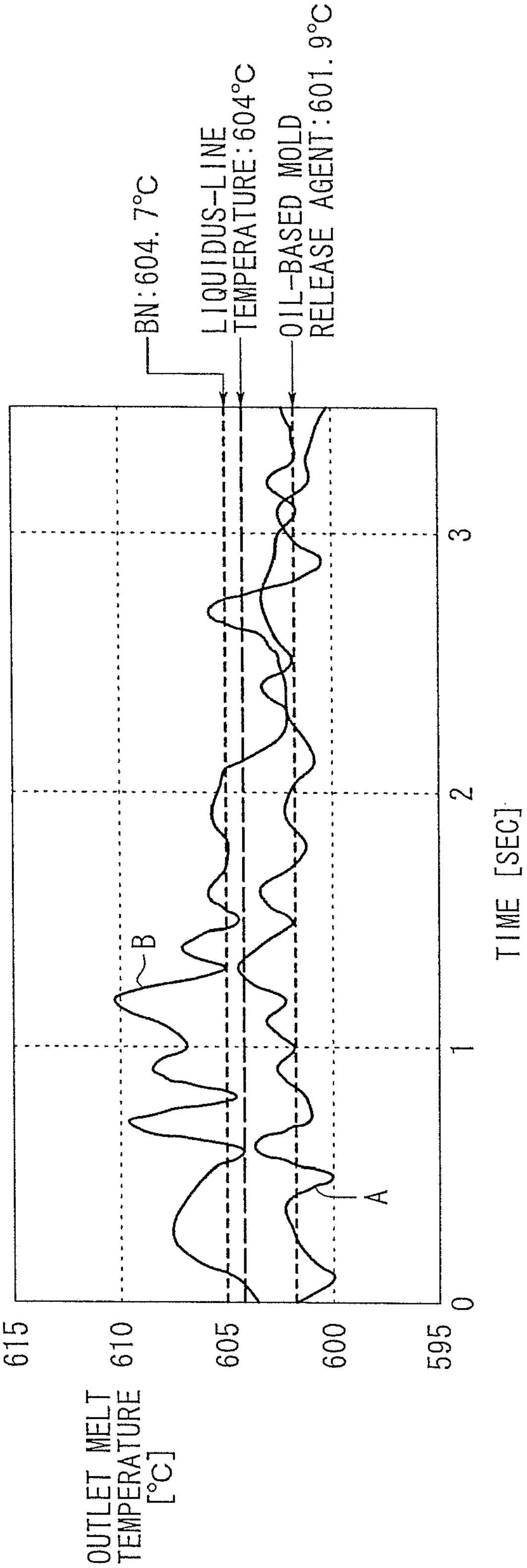

OUTLET MELT TEMPERATURE [°C]
615
610
605
600
595
0
1
2
3
TIME [SEC]
A
B
BN:604. 7°C
LIQUIDUS-LINE TEMPERATURE:604°C
OIL-BASED MOLD RELEASE AGENT:601. 9°C

FIG. 10

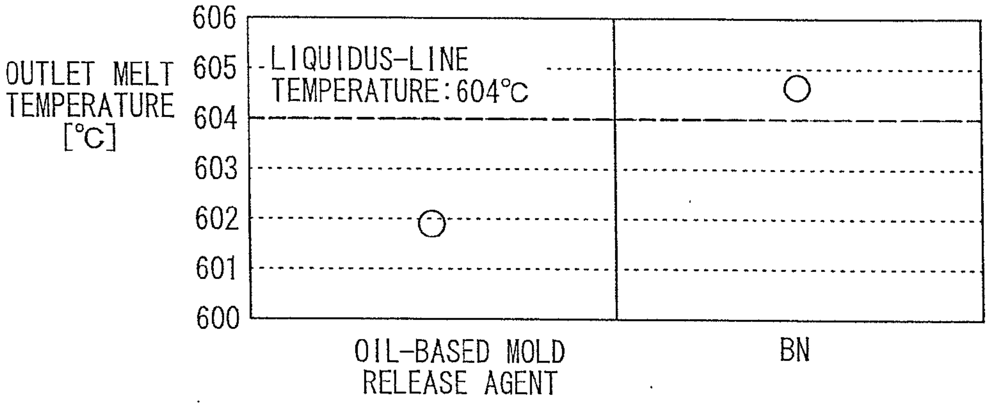
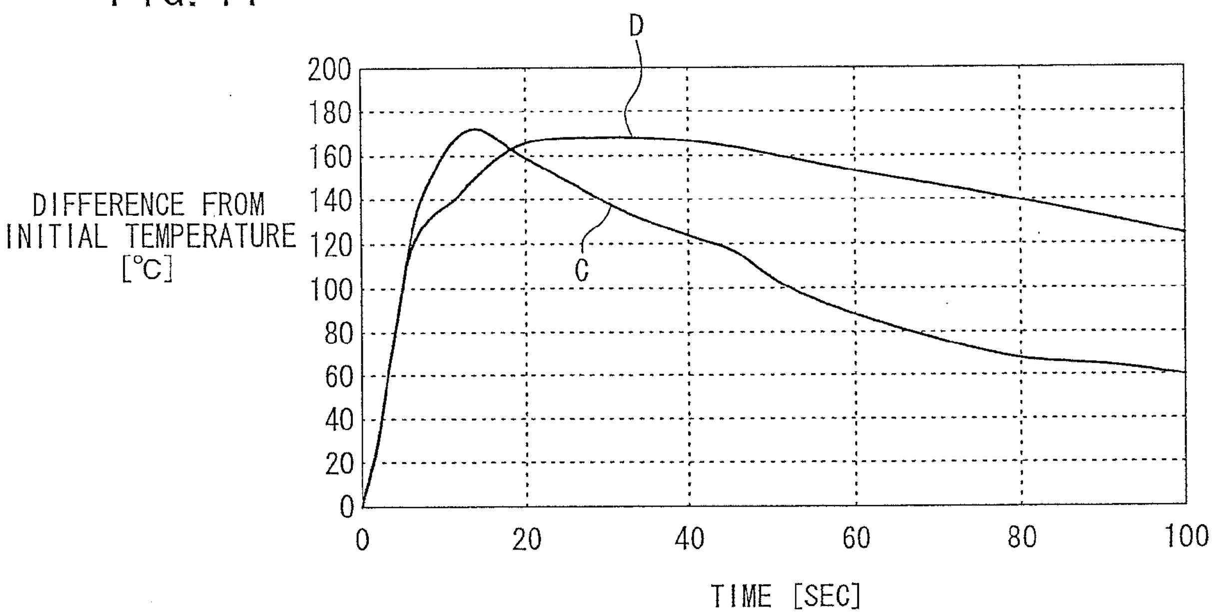

606
605
604
603
602
601
600
OUTLET MELT TEMPERATURE [°C]
LIQUIDUS-LINE TEMPERATURE: 604°C
OIL-BASED MOLD RELEASE AGENT
BN

FIG. 11


D
C
200
180
160
140
120
100
80
60
40
20
0
DIFFERENCE FROM INITIAL TEMPERATURE [°C]
0
20
40
60
80
100
TIME [SEC]

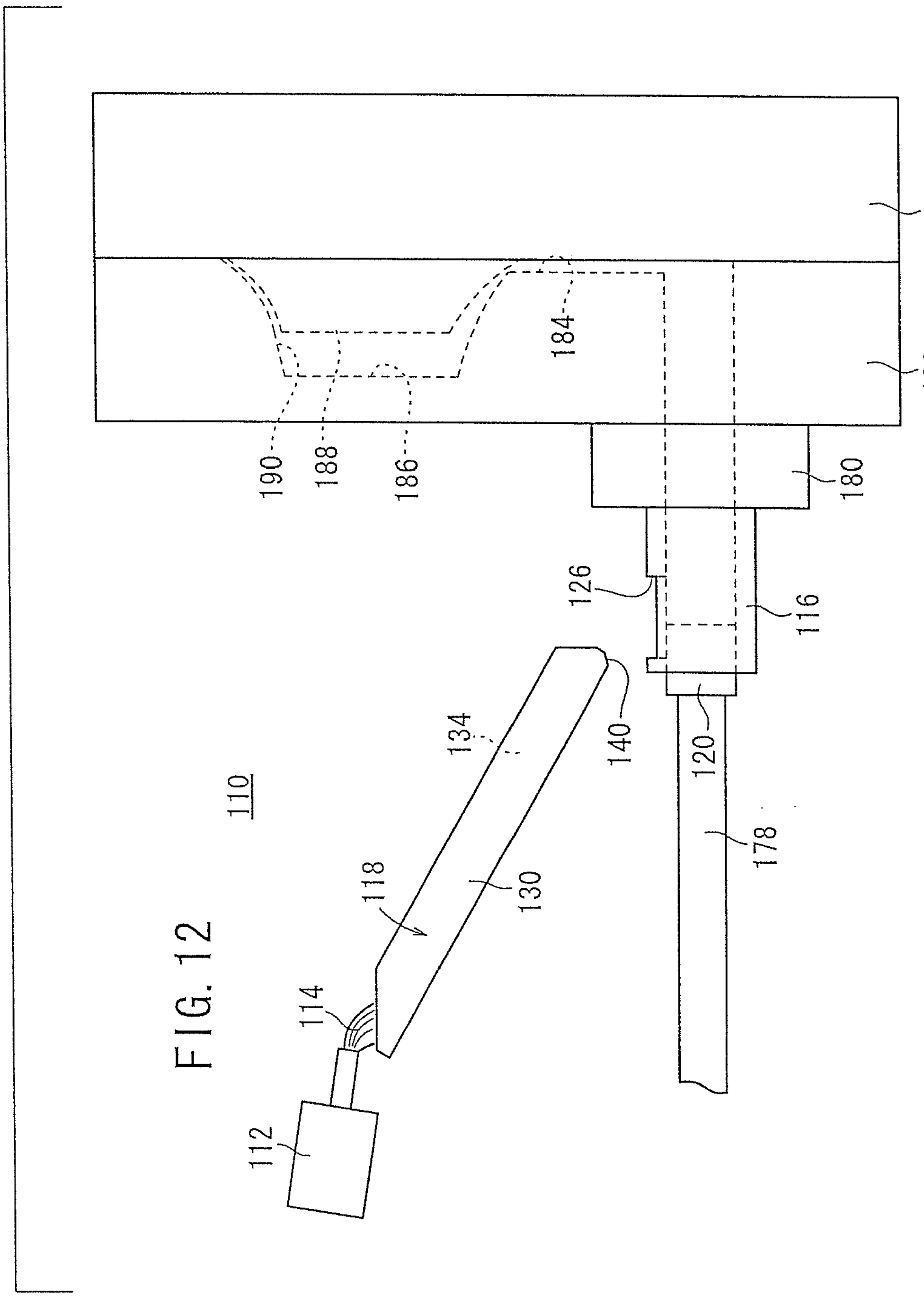
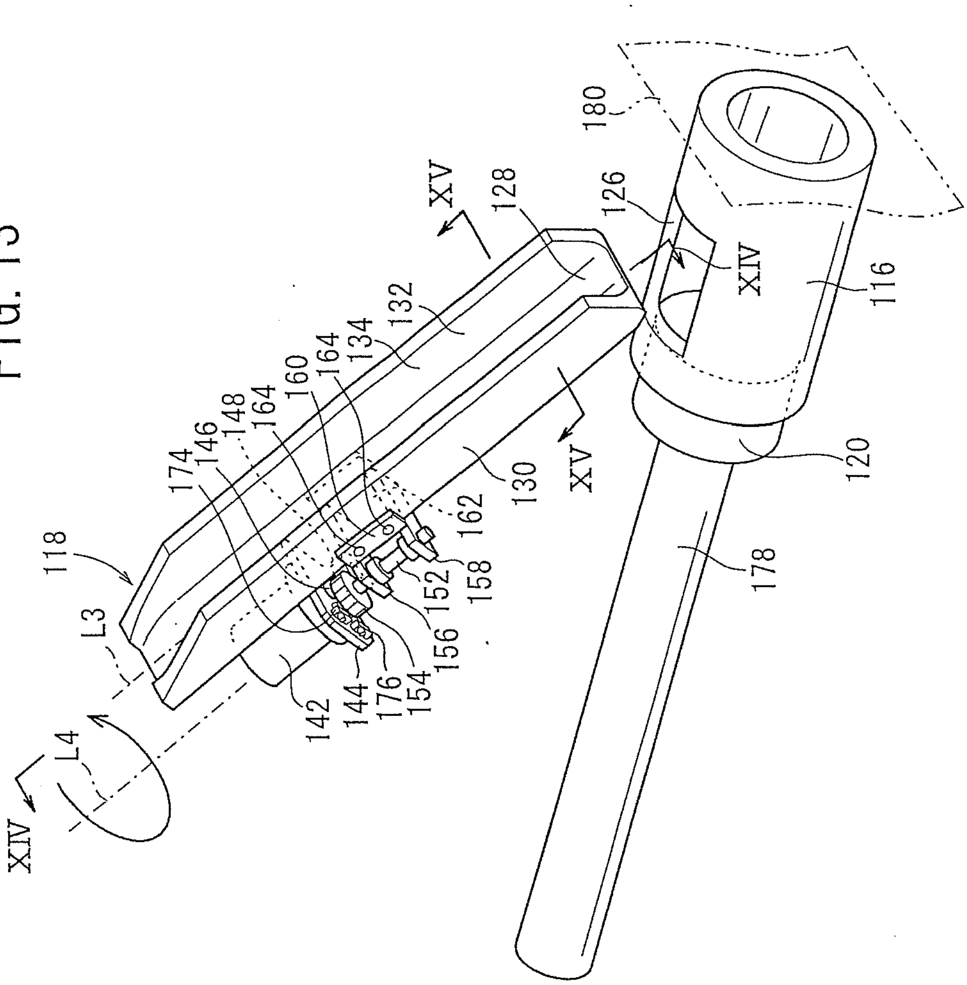

110
112
114
116
118
120
122
124
126
130
134
140
178
180
184
186
188
190

FIG. 12

FIG. 13


116
118
120
126
128
130
132
134
142
144
146
148
152
154
156
158
160
162
164
174
176
178
180
L3
L4
XIV
XV

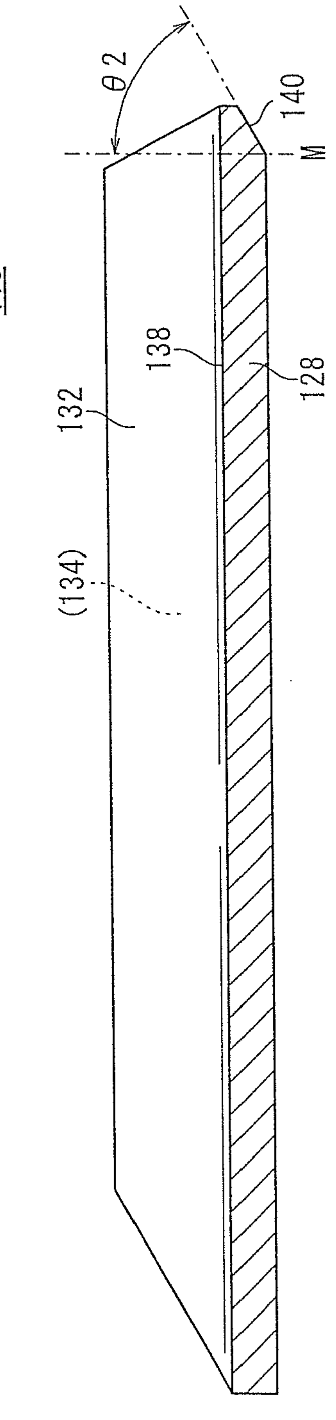
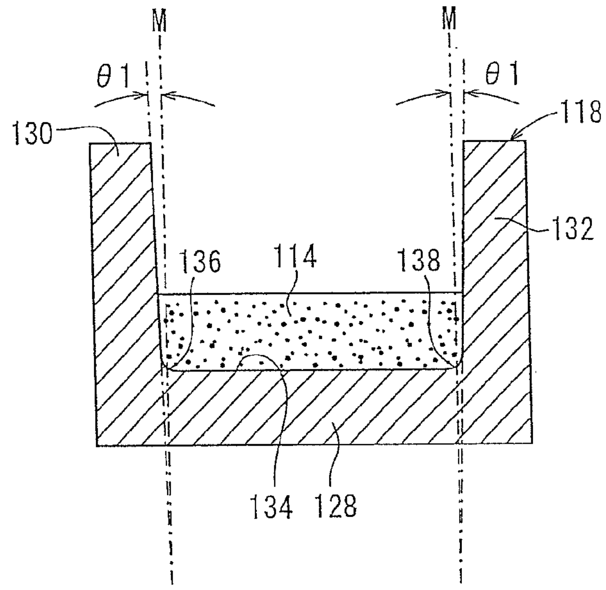


FIG. 14

FIG. 15



(θ1=0.25° ~10°)

FIG. 16

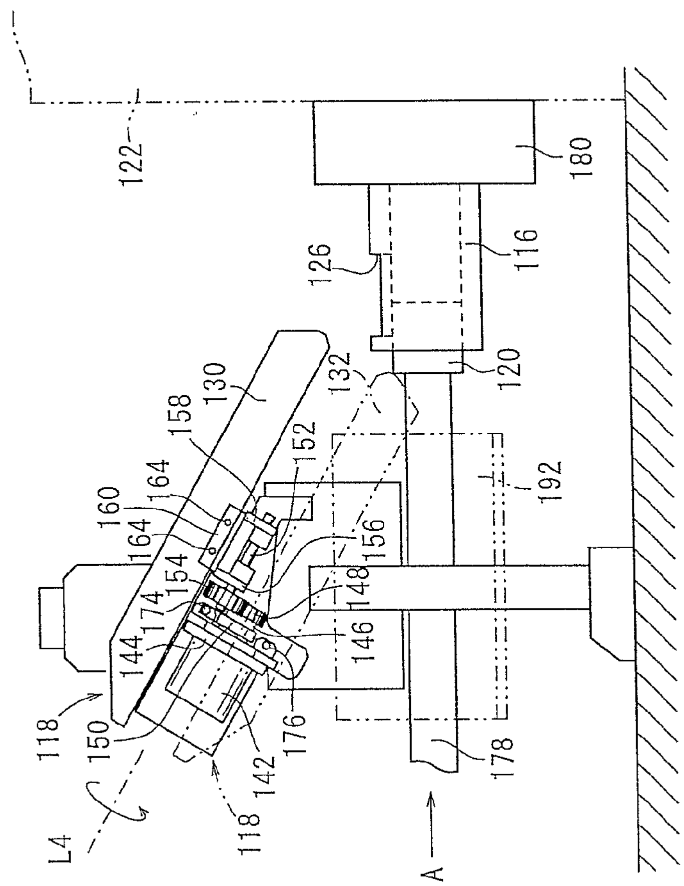


FIG. 17

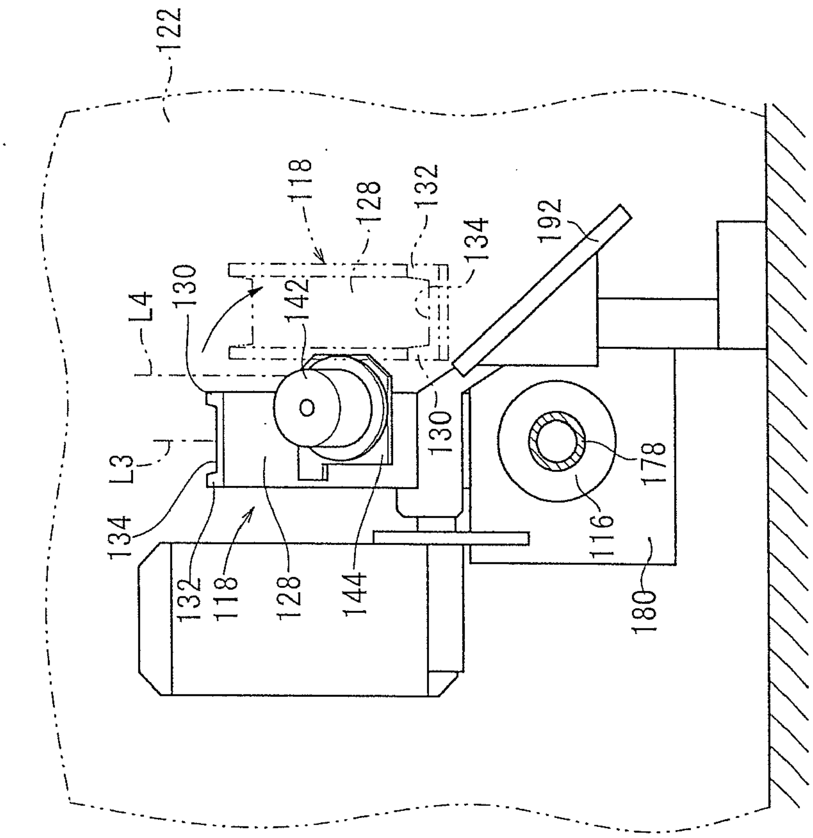

122
118
128
132
134
192
130
L4
142
L3
134
132
118
128
144
130
116
178
180

FIG. 18

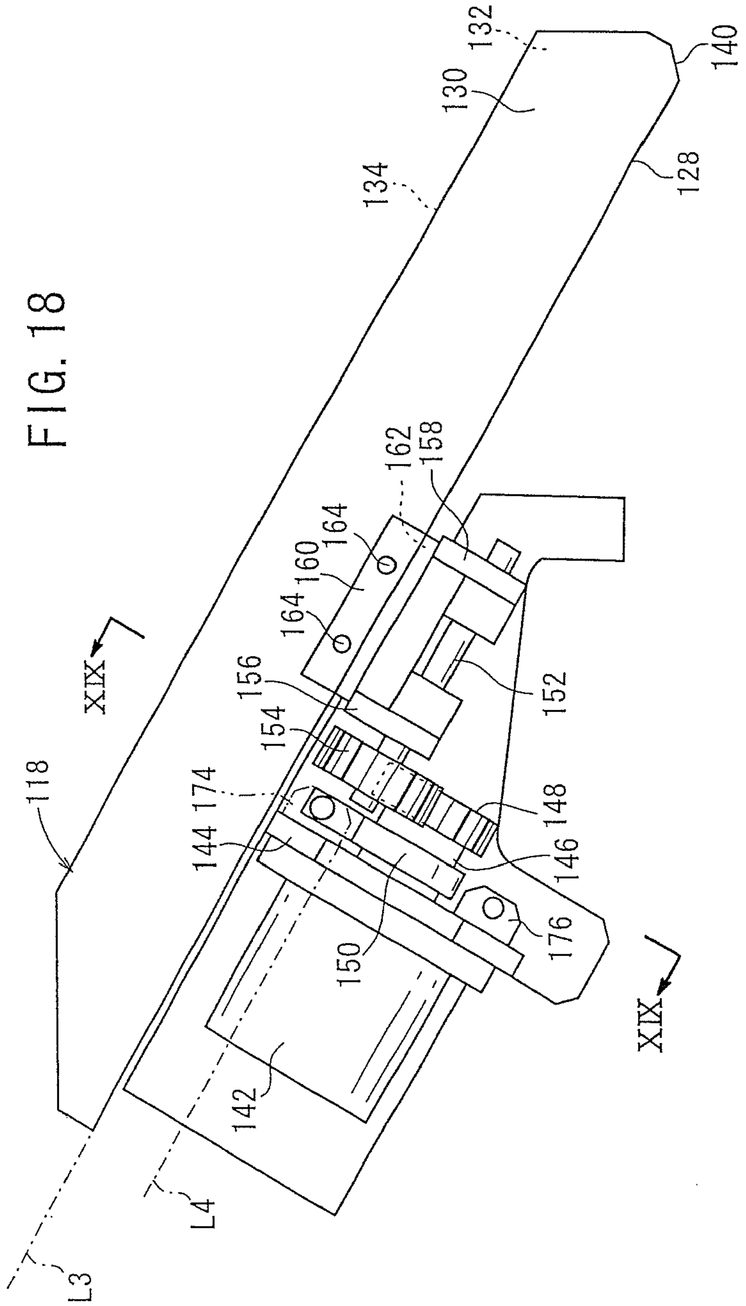

132
140
130
134
128
162
158
164
160
164
XIX
156
152
154
118
174
148
144
146
150
176
XIX
142
L4
L3

FIG. 19

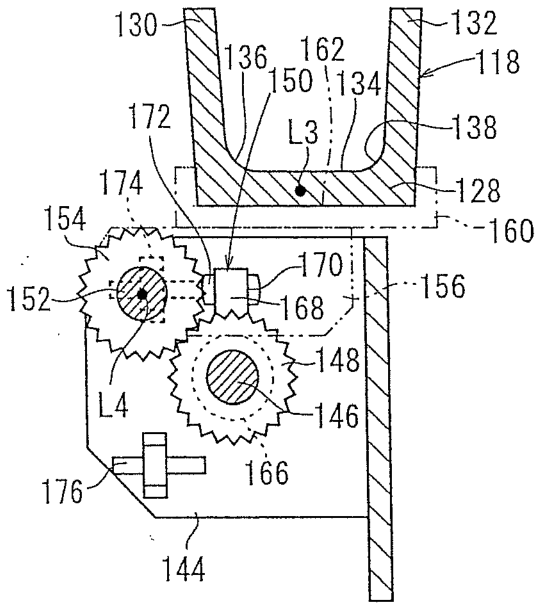
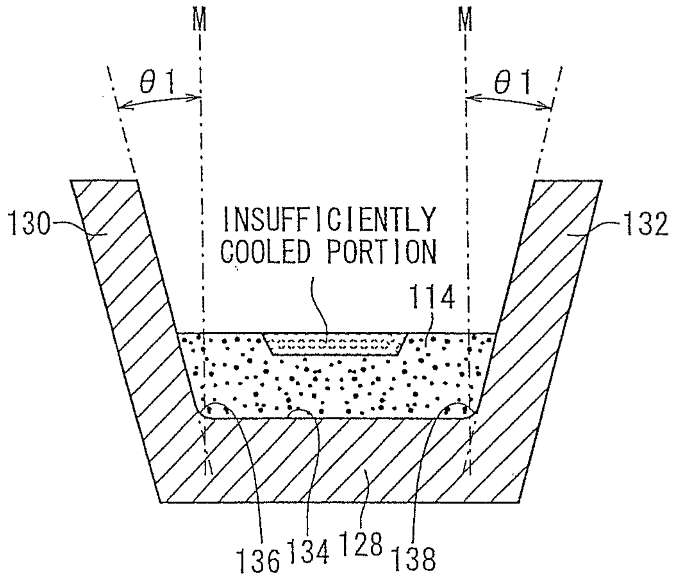
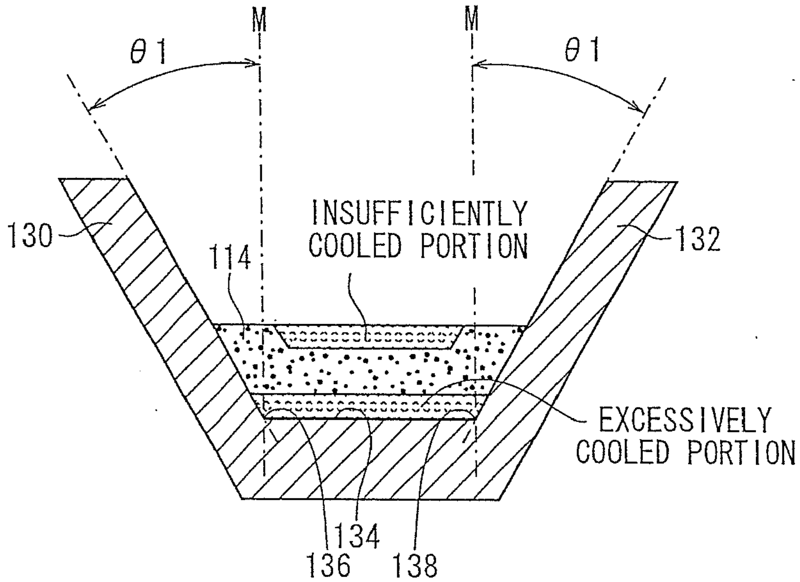


FIG. 20



(θ1=15°)

FIG. 21



(θ1=30°)

FIG. 22

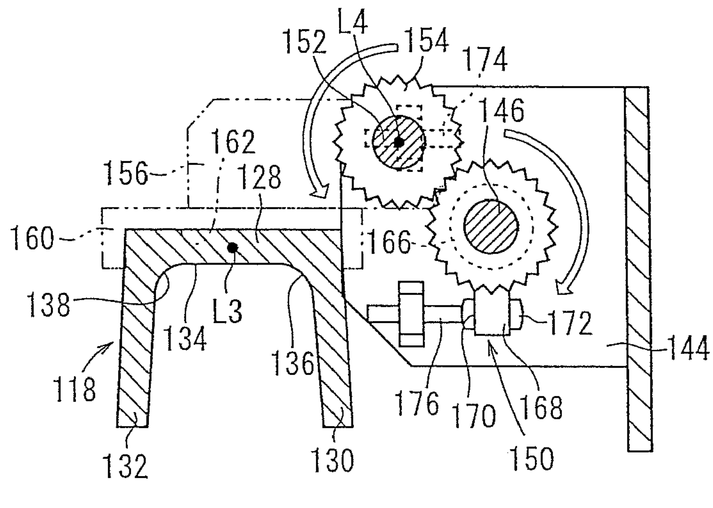


FIG. 23

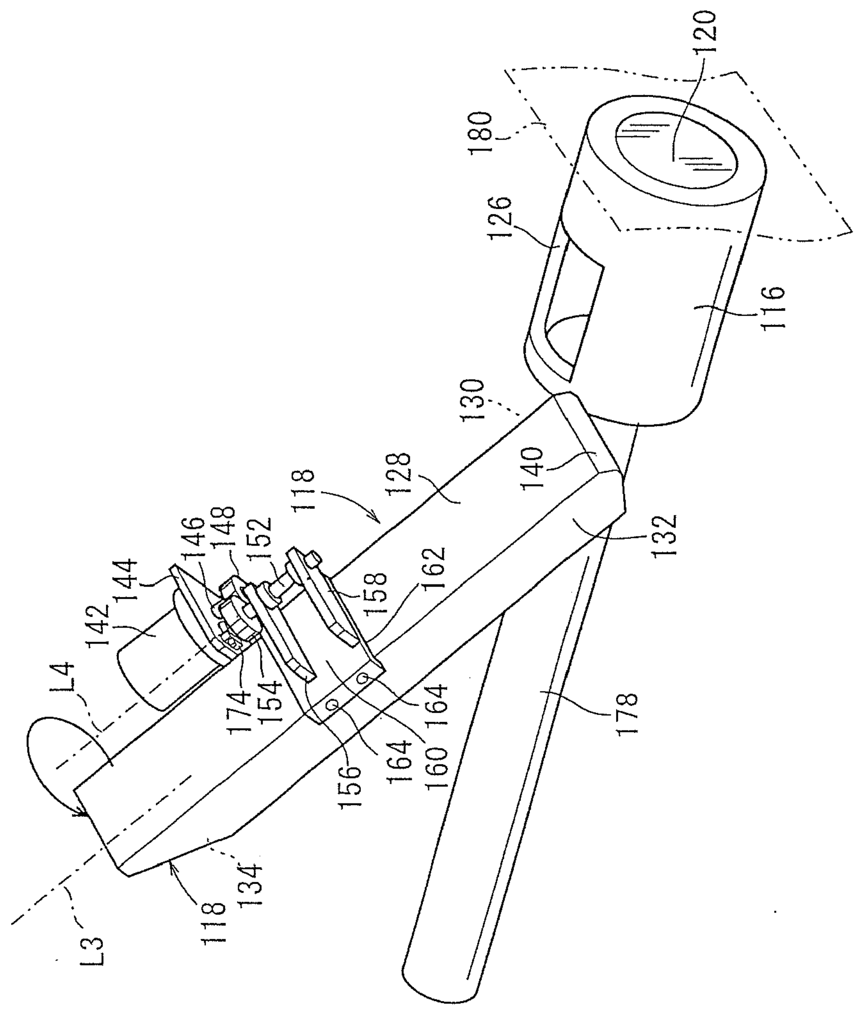
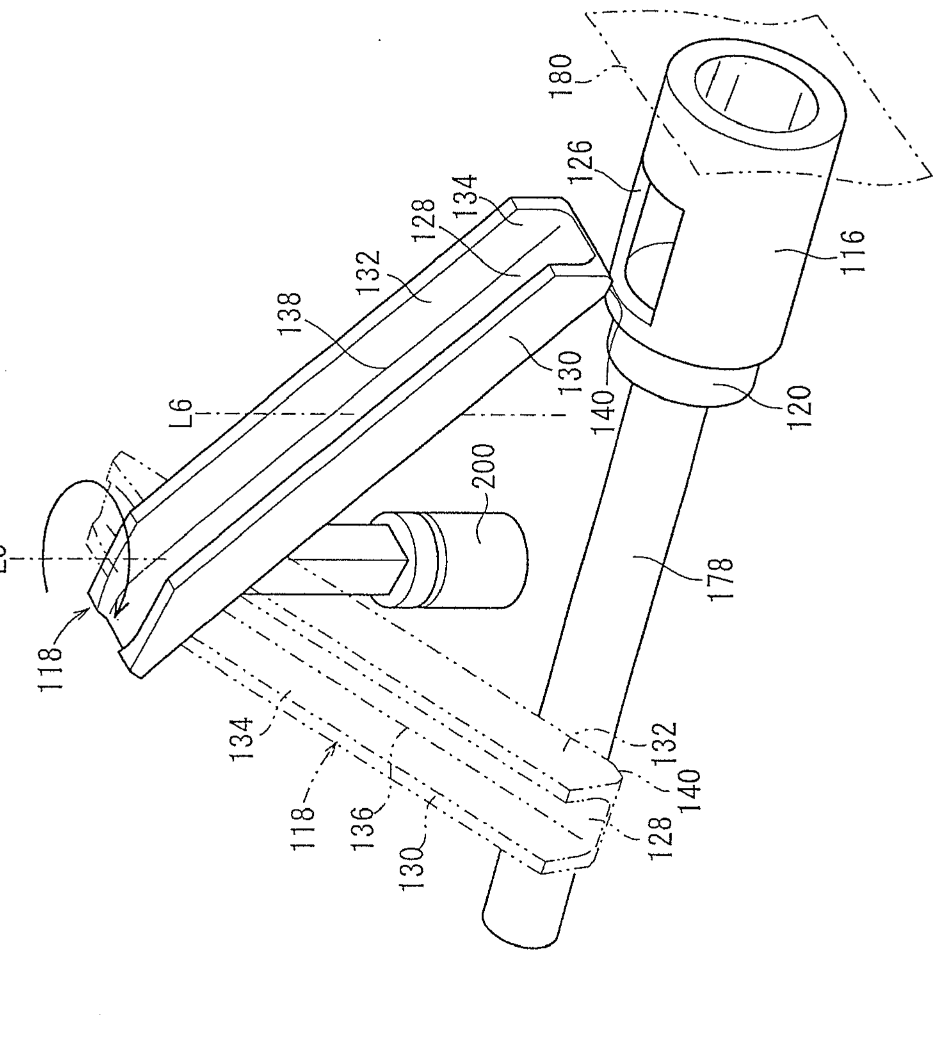

120
180
126
116
130
128
140
118
132
146
148
152
144
142
158
162
L4
174
154
164
160
164
156
178
134
118
L3

FIG. 24


180
126
134
128
132
138
116
130
140
120
L6
200
L5
118
178
134
132
140
118
136
130
128

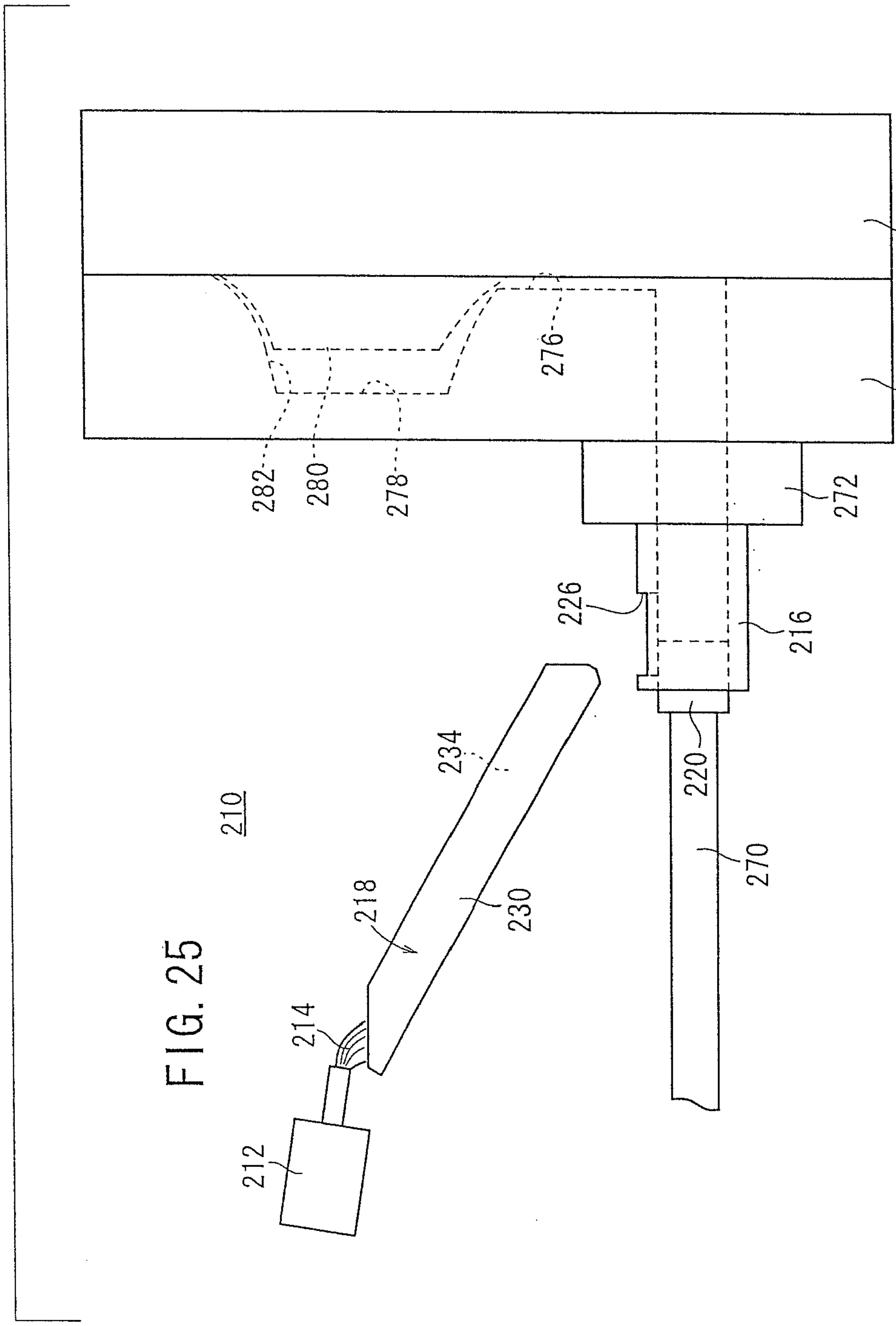

210
212
214
216
218
220
222
224
226
230
234
270
272
276
278
280
282

FIG. 25

FIG. 26

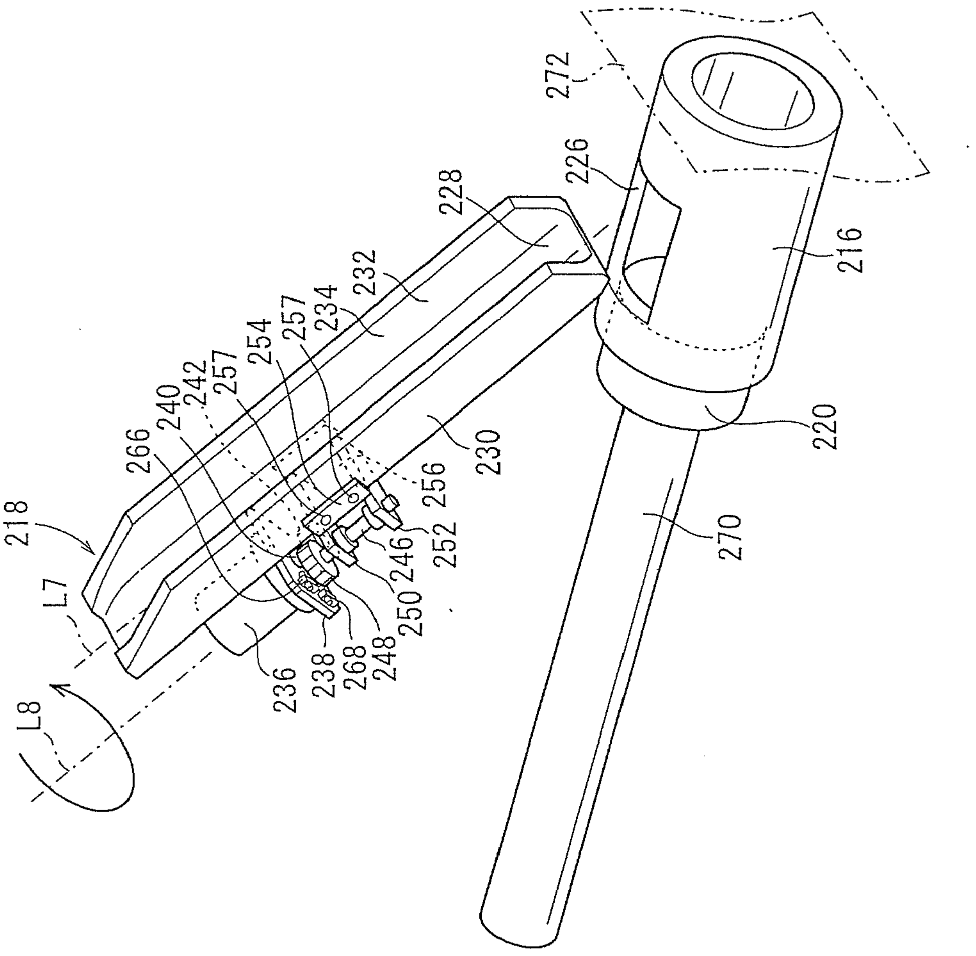

272
226
228
216
232
234
257
254
257
242
240
266
218
230
220
256
252
246
250
248
268
238
236
270
L7
L8

FIG. 27

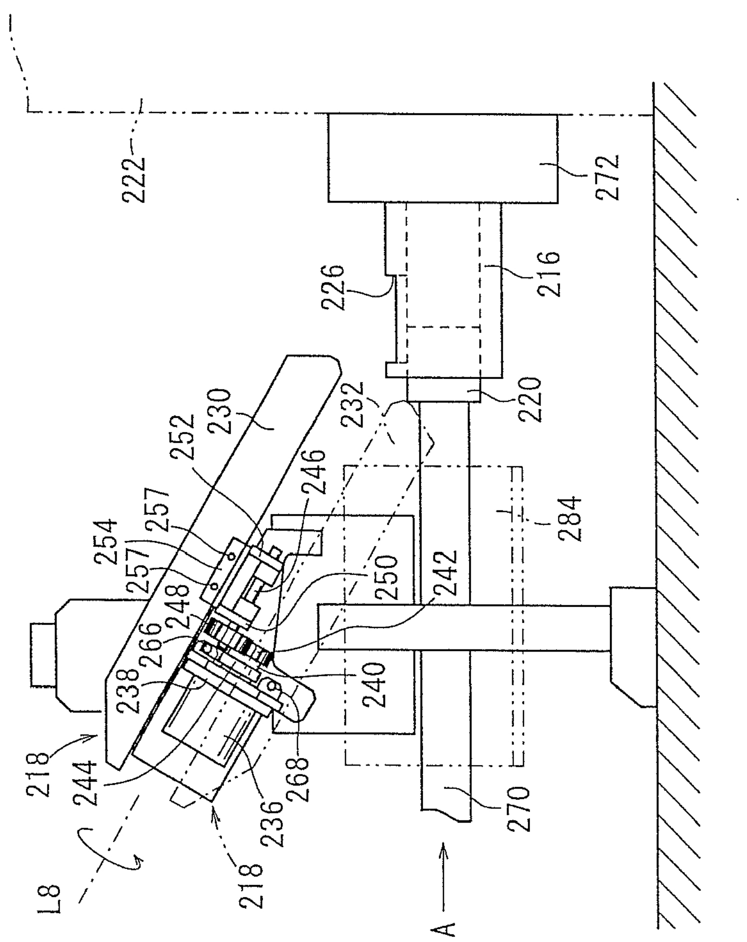

222
272
216
226
220
230
232
252
246
257
254
257
250
242
248
266
238
240
284
218
244
268
236
270
218
L8
A

FIG. 28

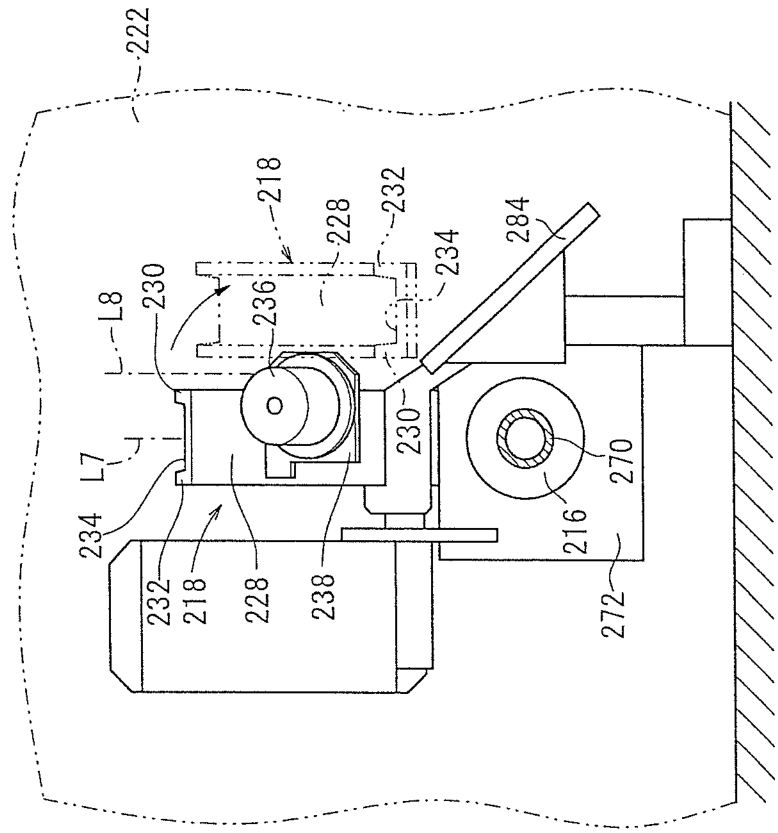

222
218
228
232
234
284
230
236
L8
L7
234
232
218
228
238
230
216
270
272

FIG. 29

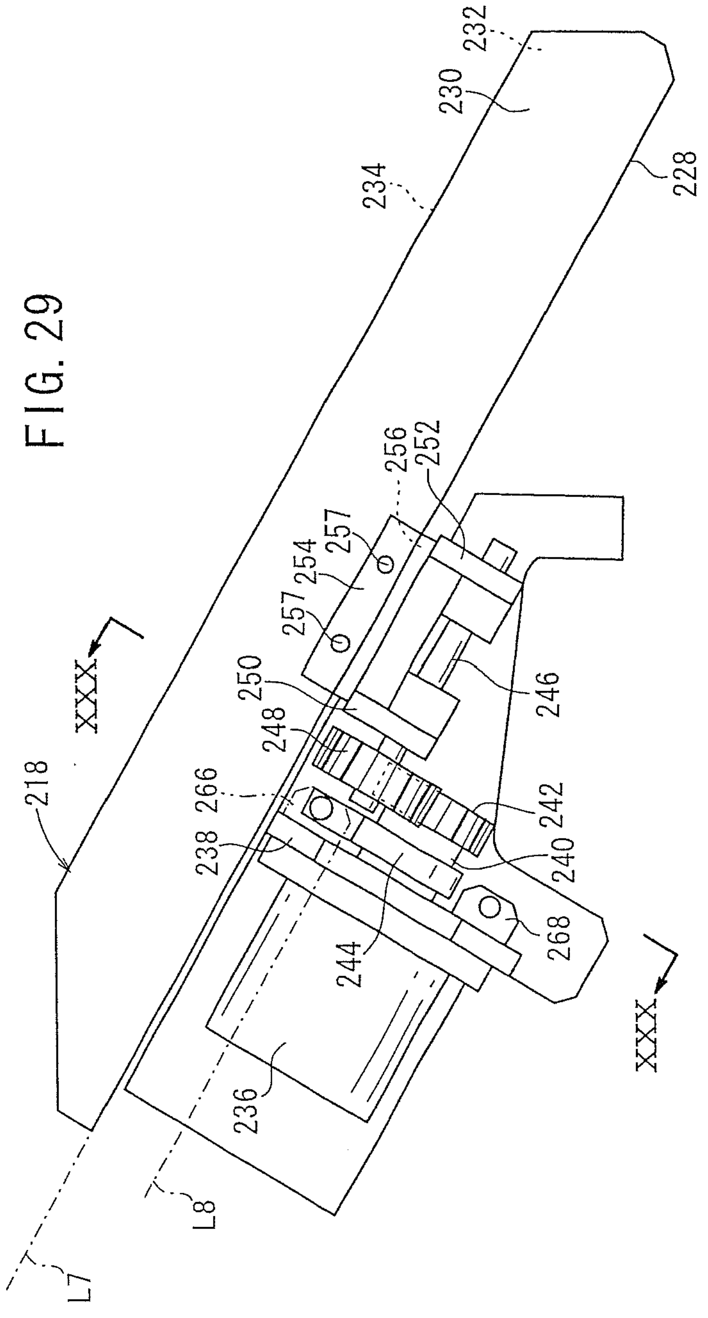

232
230
234
228
256
252
257
254
257
250
246
248
266
242
238
240
244
268
218
XXX
XXX
236
L8
L7

FIG. 30

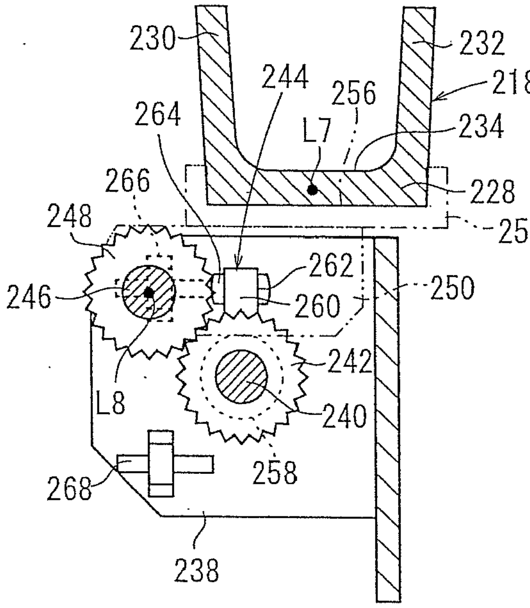

230
232
218
244
256
264
L7
234
266
228
248
254
262
246
260
250
242
L8
240
268
258
238

FIG. 31

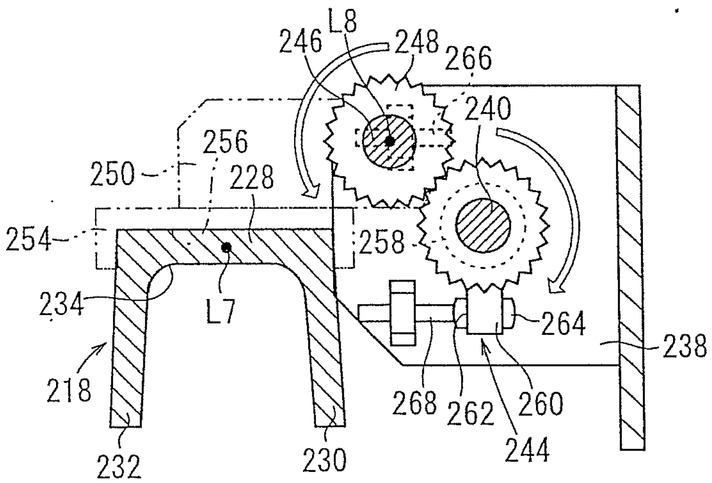
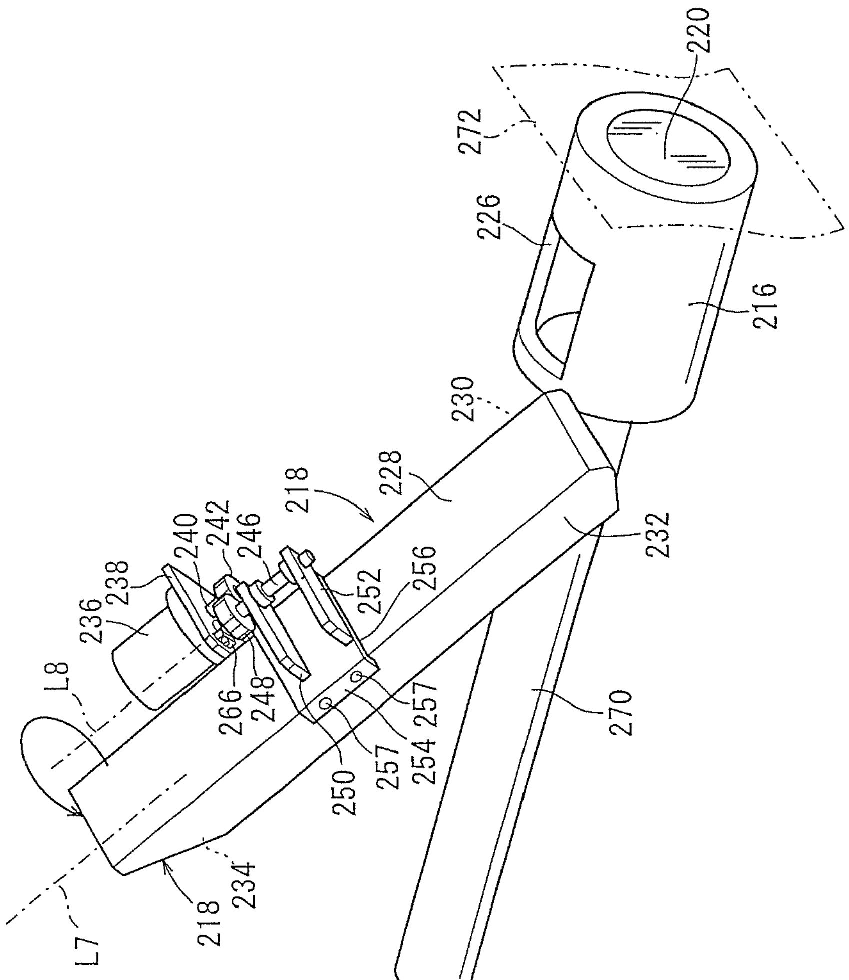

L8
246
248
266
240
256
250
228
254
258
234
L7
264
238
218
268
262
260
244
232
230

FIG. 32


220
272
226
216
230
228
218
232
240
242
246
238
236
252
256
L8
266
248
257
257
254
250
270
234
218
L7

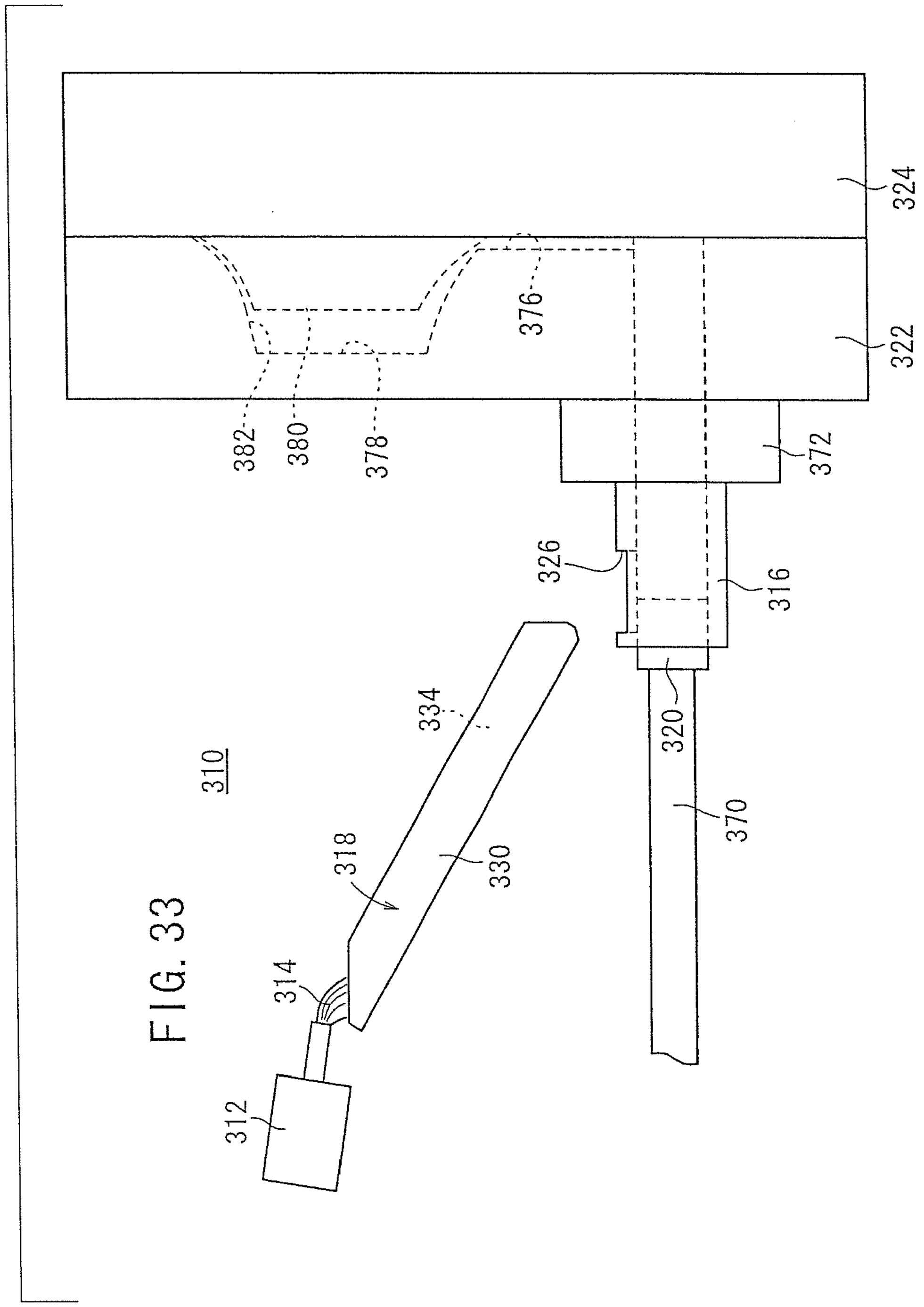

310
312
314
316
318
320
322
324
326
330
334
370
372
376
378
380
382

FIG. 33

FIG. 34

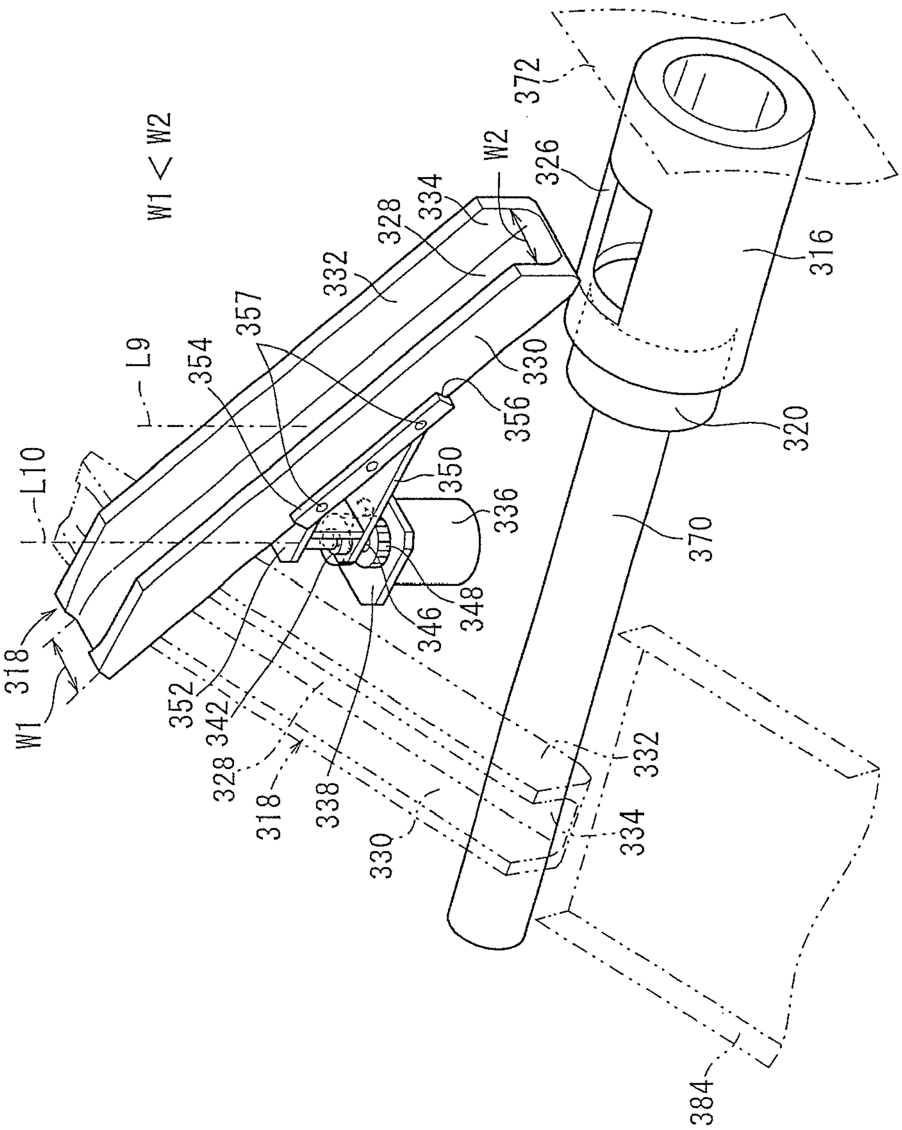

W1 < W2
W2
372
326
334
328
332
357
354
L9
330
356
316
320
L10
350
336
370
348
346
318
W1
352
342
328
318
338
330
332
334
384

FIG. 35

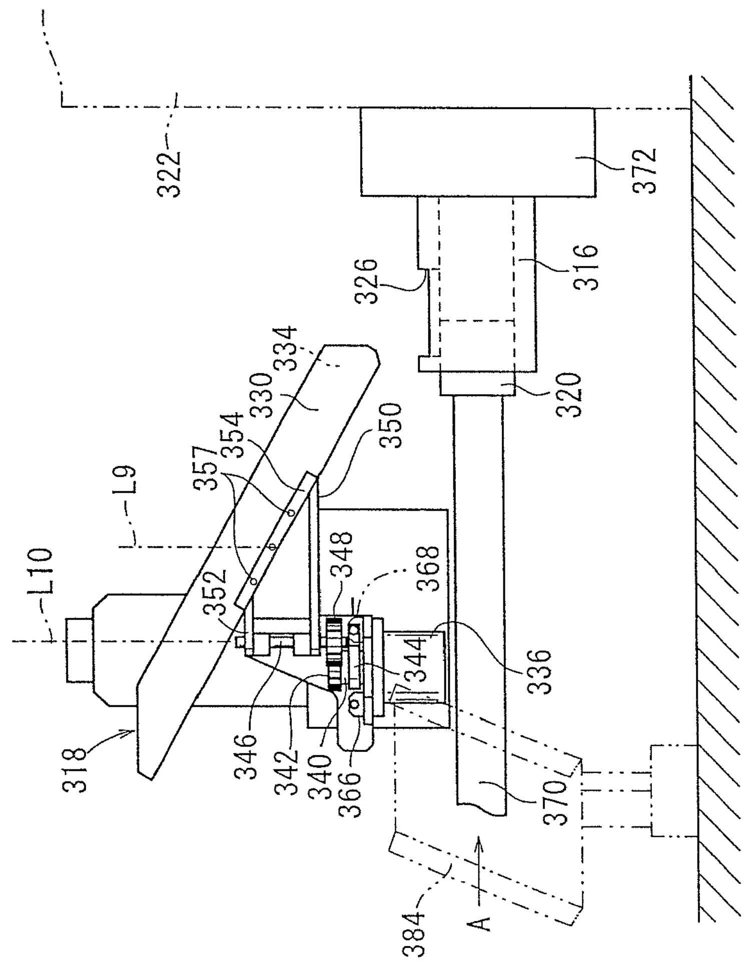
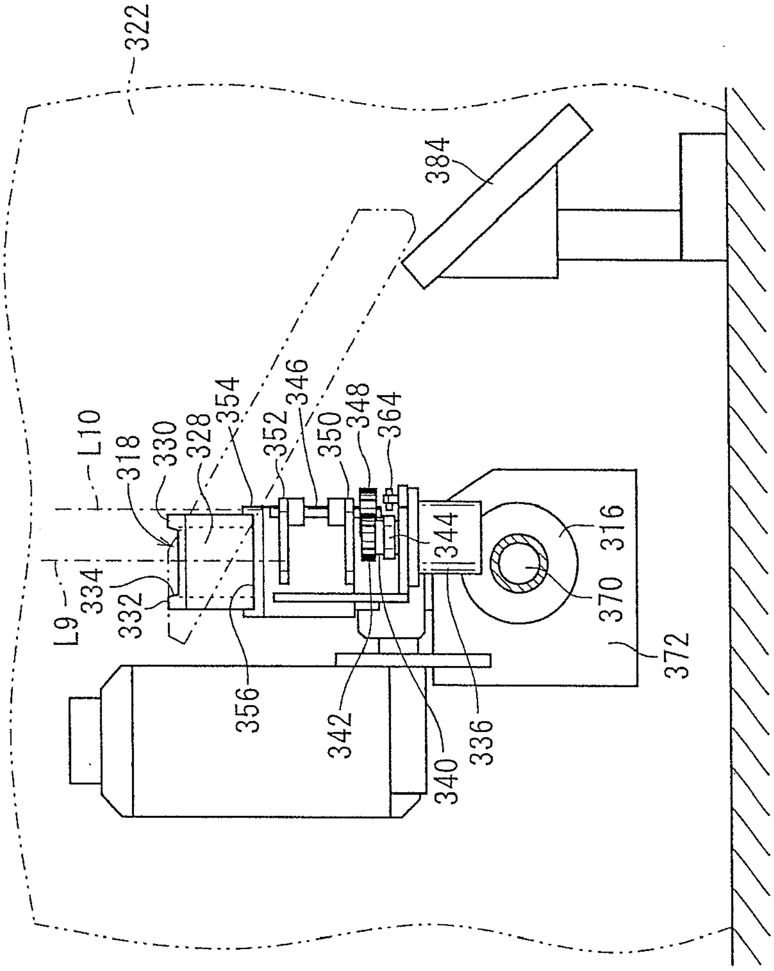

318
346
342
340
366
370
384
A
352
357
354
330
334
350
L9
L10
348
368
344
336
326
316
320
322
372

FIG. 36


322
384
L10
318
330
328
354
352
346
350
348
364
L9
334
332
356
344
316
370
372
342
340
336

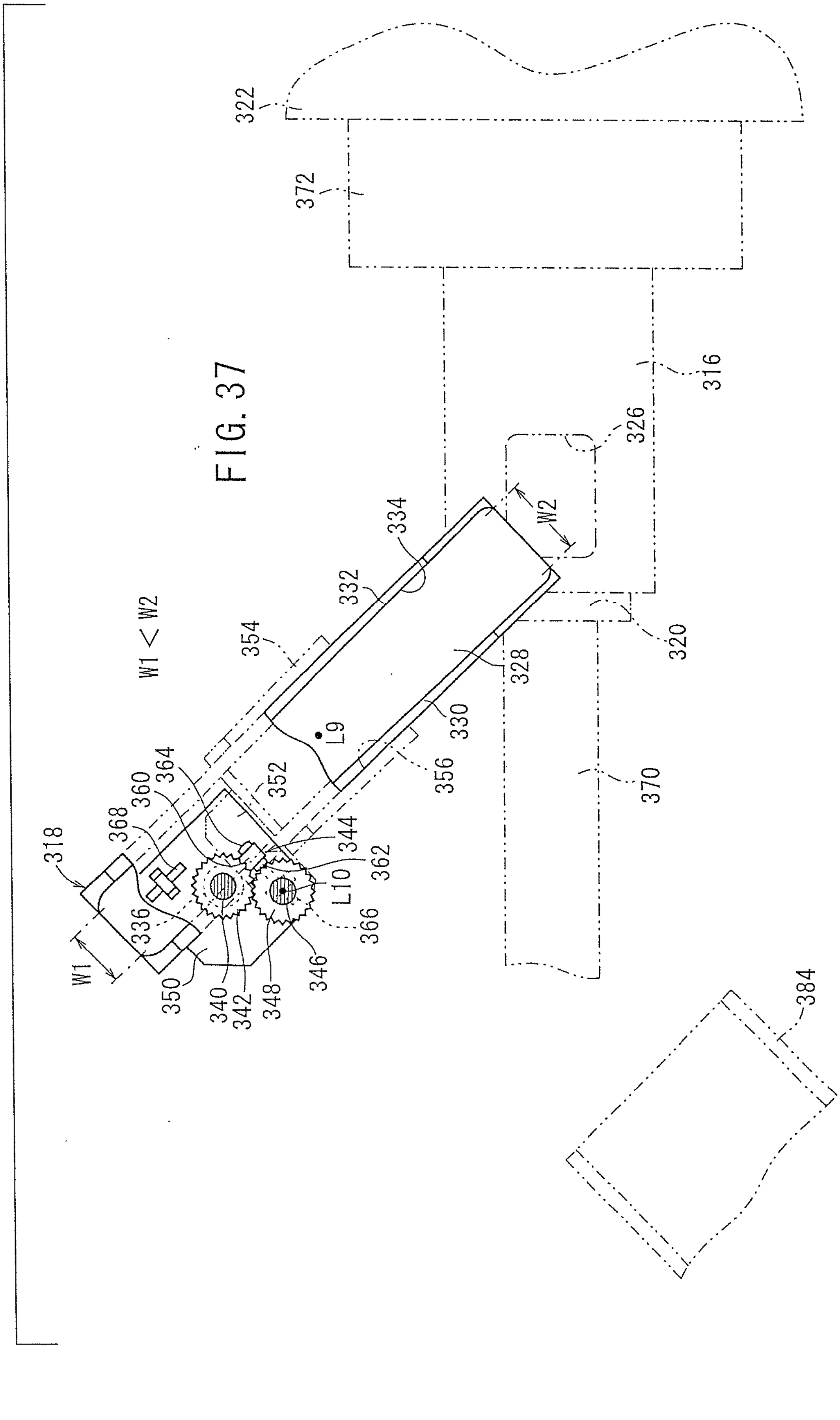

W1 < W2
322
372
316
326
334
W2
332
354
320
328
330
L9
356
352
364
360
368
318
344
362
L10
366
336
W1
350
340
342
348
346
370
384

FIG. 37

FIG. 38

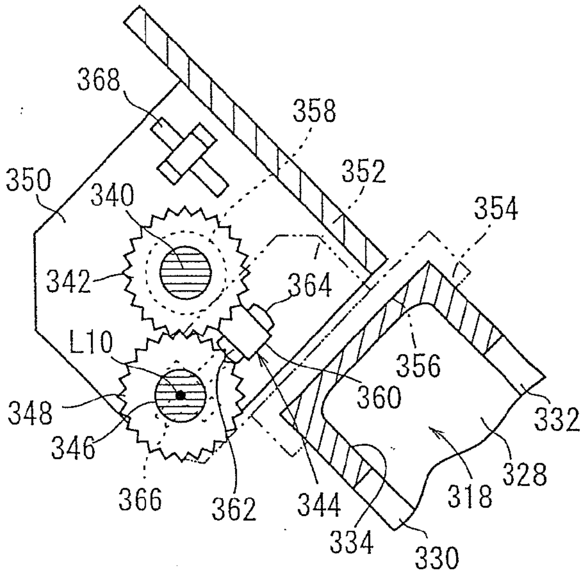
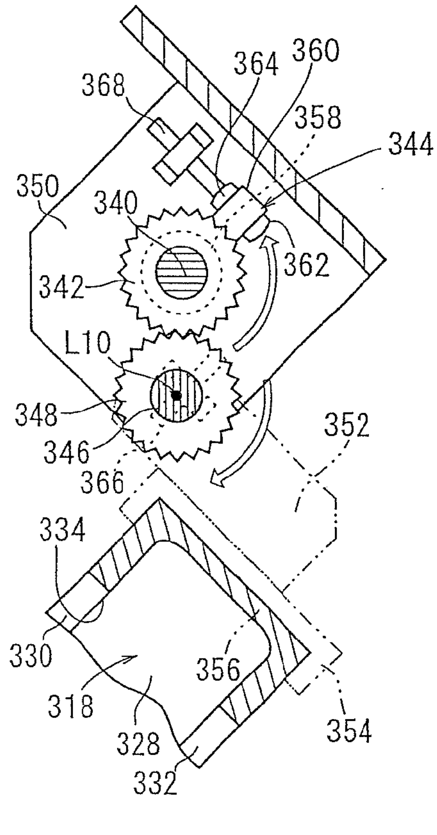

368
358
352
354
350
340
342
364
356
L10
360
332
348
346
318
328
366
362
344
334
330

FIG. 39


364
360
368
358
344
350
340
362
342
L10
348
352
346
366
334
330
356
318
354
328
332

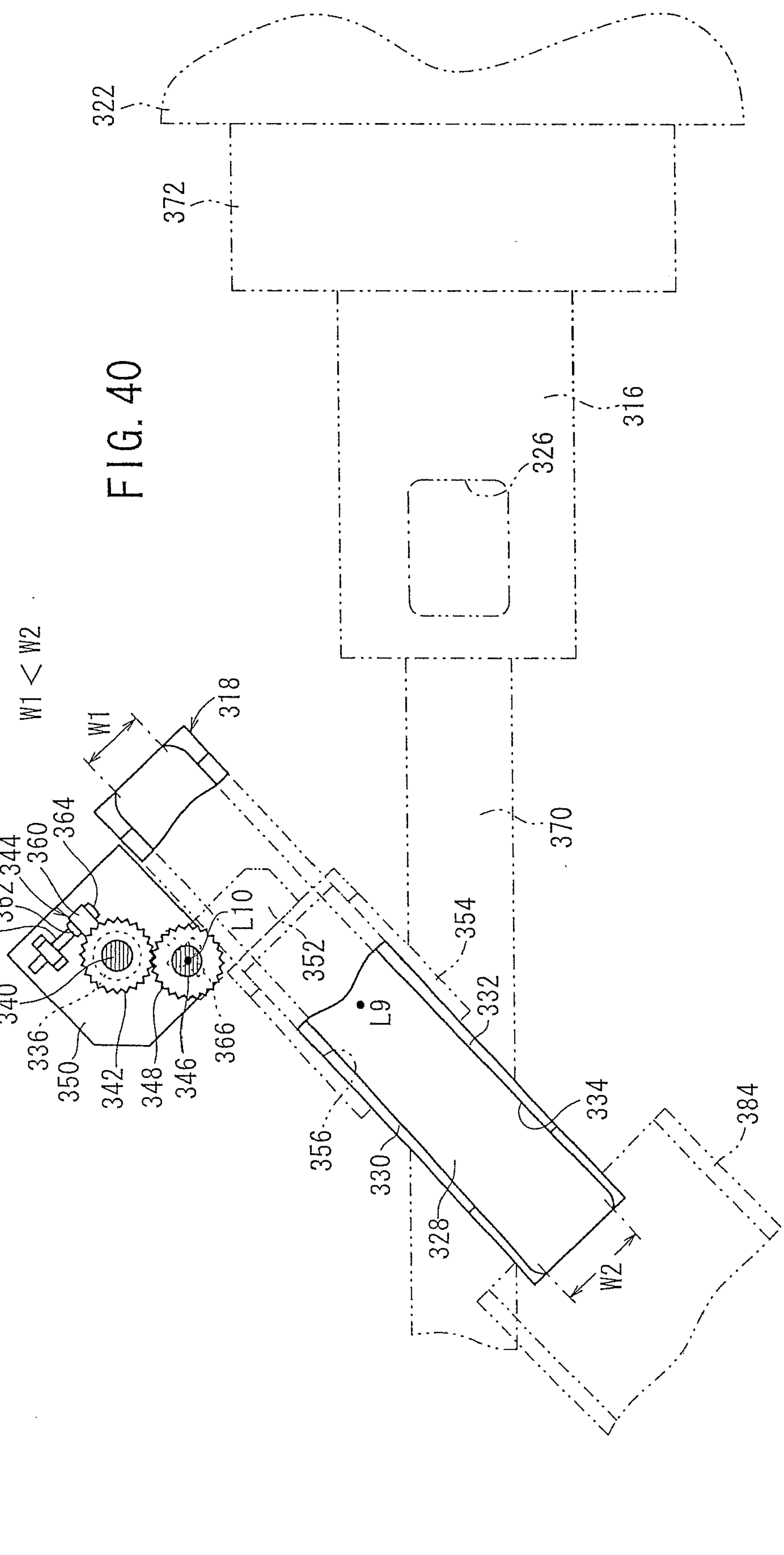

322
372
316
326
370
318
W1
W1 < W2
364
360
344
362
368
340
336
350
342
348
346
366
L10
352
354
332
L9
334
384
356
330
328
W2

FIG. 40

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