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(71) Applicant: **METAL CASTING TECHNOLOGY, INC.**
Milford
New Hampshire 03055 (US)

(72) Inventors:
- **Redemske, John A.**
Milford, NH 03055 (US)
- **Oles, Mark W.**
Francestown, NH 03043 (US)
- **Rose, Terence D.**
Amherst, NH 03031 (US)

(74) Representative: **Hoeger, Stellrecht & Partner**
Patentanwälte
Uhlandstrasse 14 c
70182 Stuttgart (DE)

(54) Method and apparatus for removing a fugitive pattern from a mold

(57) A fugitive pattern, such as wax or other meltable pattern material, residing inside of a refractory mold, which can be unsupported or supported in a particulates bed, is removed by discharging steam or other condensable vapor that may include a surfactant inside the mold to contact and melt the pattern while an exterior of the mold is subjected to a non-condensing gas atmosphere such as air outside of the mold. Regardless of whether the condensable vapor includes surfactant or not, the mold can be tilted relative to gravity and rotated while it is tilted to improve the pattern removal. Condensable vapor is condensed inside the mold where the vapor has contacted the pattern while the exterior of the mold remains free of condenate. The condensed vapor and melted pattern material are drained out of the mold with the surfactant, if present, improving drainage.

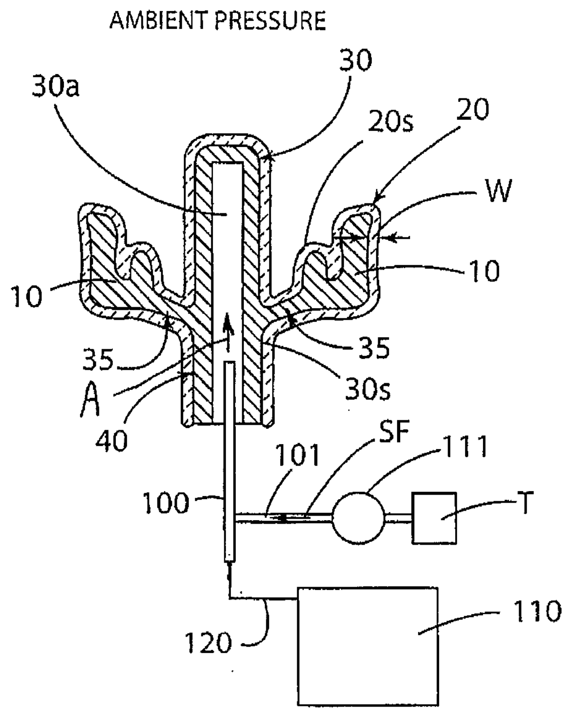

FIG. 1

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Description

Related Application

[0001] This application is a continuation-in-part of copending Serial No. 10/899,381 filed July 26, 2004.

Field of the Invention

[0002] This invention relates to method and apparatus for removing a fugitive pattern from a metal casting mold.

Background of the Invention

[0003] The well-known "lost wax" investment casting process typically uses a refractory mold that is constructed by the buildup of successive layers of ceramic particles bonded with an inorganic binder on a fugitive (expendable) pattern material such as typically a wax, plastic and the like. The finished refractory mold is usually formed as a shell mold around a fugitive pattern.

[0004] The refractory shell mold residing on the fugitive pattern typically is subjected to a pattern removal operation, wherein the pattern is melted out of the shell mold. This operation leaves an empty "green" (unfired) refractory shell mold. The fugitive pattern materials typically have a thermal expansion rate many times greater than that of the refractory shell mold. If the fugitive pattern and refractory mold are heated uniformly, the fugitive pattern material will thermally expand more than the refractory mold. This will place the refractory shell mold under tension and will ultimately crack the shell mold. The avoidance of such shell mold cracking is why the fugitive pattern material removal has been typically conducted by methods such as a high pressure steam autoclaving or flash firing pattern removal. The removal of the fugitive pattern material by a high pressure steam autoclaving or flash firing is done to expose the outside of the refractory shell mold to high temperature. This high temperature causes heat to be conducted through the refractory shell mold more quickly so as to melt the surface of the pattern before the interior of the pattern thermally expands. This surface layer of melted pattern material extends all the way to where the pattern is exposed at the open part of the mold and accommodates the expanding pattern material inside the mold by forcing some of the liquid surface pattern material out of the mold opening. Such methods can still allow cracking of the refractory shell mold if the heat is not applied in a continuum along the surface of the fugitive pattern inside the mold. The connecting together of the refractory shell mold between adjacent patterns is one of the major causes of non-uniform heating of the pattern. That is, thicker regions of the refractory shell mold will hinder the application of heat to the pattern material and locally delay the melting of the surface of the pattern and disrupting of the continuum. This prevents the passage of surface liquid pattern material from a thinner mold region more remote from the mold opening than the thicker mold region. Such prevention of the passage of surface liquid pattern material causes a buildup of pattern pressure in the remote thinner mold region due to the thermal expansion of the pattern material and can lead to mold cracking. These problems require the use of a mold strong enough (e.g. thick enough) to resist the expansion pressure of the pattern material and often require the use of supplemental holes or vents through the mold to relieve pressure from unconnected expanding patterns. Stronger or thicker molds as well as the venting method are undesirable as they increase processing costs.

[0005] A plurality of the green refractory shell molds (sans patterns) then typically are loaded into a batch or continuous oven heated by combustion of gas or oil and heated to a temperature of 1600°F to 2000°F. Alternatively, the mold may be heated by a method of US Patent 6,889,745 of common assignee herewith, which describes the heating of a mold with or without surrounded mold support sand. The heated refractory molds are removed from the oven and molten metal or alloy is cast into them.

[0006] The trend in investment casting is to make the refractory shell mold as thin as possible to reduce the cost of the mold as described above. The use of thin shell molds has required the use of support media to prevent mold failure as described by Chandley et. al. US Patent 5 069 271. The '271 patent discloses the use of bonded ceramic shell molds made as thin as possible such as less than 0.12 inch in thickness. Unbonded support particulate media is compacted around the thin hot refractory shell mold after it is removed from the preheating oven. The unbonded support media acts to resist the stresses applied to the shell mold during casting so as to prevent mold failure.

[0007] Thin shell molds however, are more prone to cracking during the pattern removal operation, such as the high pressure steam autoclave or flash fire pattern removal operation mentioned above, wherein the pattern is melted out of the shell mold.

[0008] Copending application Serial No. 10/899,381 filed July 26, 2004 discloses a method of removing a fugitive pattern from a bonded refractory mold by discharging condensable vapor, such as steam, inside the mold to contact and melt the pattern while the exterior of the mold is subjected to a non-condensing gas atmosphere, such as ambient air, outside of the mold. The condensed vapor and melted pattern material are drained out of the mold in a manner that reduces cracking of the mold.

Summary of the Invention

[0009] An aspect of the present invention provides method and apparatus for removing a fugitive pattern, such as wax or other meltable pattern material, residing in a refractory mold by introducing a condensable vapor, such as steam, that in a particular emboiment includes a surfactant inside the mold to contact and melt the pattern, while the exterior of the mold is subjected to a non-condensing gas atmosphere, such as ambient air, outside of the mold. The condensed vapor and the melted pattern material are drained out of the mold. The surfactant lowers the surface tension of the condensed vapor in contact with the fugitive pattern inside the mold and increases the ease at which the melted pattern material flows over the freshly exposed mold interior surface to improve draining of the melted pattern mateial out of the mold, leaving less residual pattern material on the interior mold surface.

[0010] A pressure differential between the condensable vapor inside of the mold and the non-condensing gas atmosphere outside of the mold is small enough as to prevent the condensable gas from exiting outside the mold exterior and the non-condensing gas from entering the mold cavity. The condensable vapor inside of the mold and the gas atmosphere outside of the mold preferably are at substantially the same pressure to this end. In this way, when steam is used as the preferred condensable vapor, the steam is condensed inside the mold where the steam has contacted the pattern while the exterior of the mold remains dry. The condensable vapor including the surfactant can be introduced inside the mold at atmospheric, subatmospheric, or superatmospheric pressure depending upon the melting point of the pattern material.

[0011] In an illustrative embodiment of the invention, steam or other condensable vapor is supplied to a discharge tube that is positionable inside the mold and/or pattern sprue to discharge steam or condensable vapor at substantially atmospheric, subatmospheric or superatmospheric pressure therein. The surfactant can be introduced into the condensable vapor in the discharge tube or outside the discharge tube after the condensable vapor is discharged.

[0012] Another aspect of the present invention provides method and apparatus for removing a fugitive pattern, such as wax or other meltable pattern material, residing in a refractory mold by subjecting the mold to a combination of rotation and inclination (tilting) during the pattern removal process in a manner to improve draining of melted pattern material from the mold. The mold can be tilted at any desired angle using a mold tilt drive motor, and the mold can be rotated about an axis using a mold rotation drive motor. The angle of mold tilting and the mold rotational speed can be adjusted as required to drain the melting wax from the mold cavities. The mold can be rotated while the mold is tilted at a fixed angle of inclination relative to gravity. Alternately, the mold can be tilted incrementally to selected angles of inclination while the mold is rotated at each of the angle of inclination or continuously. Further, the mold can be continuously tilted while being rotated continuously or intermittently. Steam or other condensable vapor can be introduced to heat and melt the fugitive pattern inside the mold while the mold is subjected to rotation and tilting, although this aspect of the invention can be practiced using any pattern removal technique where the pattern is melted or dissolved.

[0013] The above embodiments of the present invention can be practiced to remove a fugitive pattern, such as wax or other meltable pattern material, from an unsupported casting mold. The present invention also can be practiced to remove a fugitive pattern from a casting mold which is supported in particulates media in a container. For example, steam or other condensable vapor is introduced inside the mold to contact and melt the pattern while an exterior of the mold contacts the particulate media and is subjected to a non-condensing gas (e.g. steam-free) atmosphere, condensing vapor inside the mold where it contacts the pattern while the exterior of the mold and the particulate media therearound are subjected to a non-condensing gas atmosphere, and draining the melted pattern material and condensed vapor out of the mold.

[0014] The invention is advantageous to remove one or more fugitive patterns residing in a metal casting refractory mold, which may have any mold wall thickness and which may be unsupported or supported by exterior particulate media therearound. The invention is further advantageous to remove one or more fugitive patterns while avoiding saturating the mold wall with steam or other condensate, which may have adverse effects on the binder used to fabricate the mold. The invention may be practiced to reduce mold cracking during pattern removal and to remove pattern material from molds where steam cannot readily access the exterior of the mold wall such as when the mold is supported with particulate support media.

[0015] These and other advantages of the invention will become apparent from the following detailed description taken with the following drawings.

Description of the Drawings

[0016]

Figure 1 is a schematic view of a refractory casting mold having fugitive patterns to be removed pursuant to an illustrative embodiment of the invention by discharging atmospheric pressure steam including a surfactant from a discharge tube shown positioned in a hollow sprue of a pattern assembly residing inside the mold.

Figure 1A is a schematic view of a refractory casting mold having fugitive patterns to be removed pursuant to another illustrative embodiment of the invention by discharging atmospheric pressure steam and a surfactant from separate discharge tubes shown positioned in a hollow sprue of a pattern assembly residing inside the mold.

Figure 2 is a schematic view of the refractory casting mold of Figure 1 with the hollow sprue of the fugitive pattern assembly already removed by melting and with the individual gates and patterns being melted and removed.

Figure 3 is similar to Figure 2 after the patterns have been completely removed from the shell mold.

Figure 4 is an enlarged view of an individual pattern of Figure 2 illustrating removal of the pattern.

Figure 5 is similar to Figure 1 but shows a pattern assembly having a solid sprue with a steam discharge tube being moved into the solid sprue to form in-situ a hollow sprue therein.

Figure 6 is a schematic view of a refractory casting mold having fugitive patterns to be removed pursuant to still another illustrative embodiment of the invention wherein the mold is exteriorly supported by a particulate support media therearound.

Figure 7 is similar to Figure 1 and shows a refractory casting mold having fugitive patterns to be removed pursuant to a further illustrative embodiment of the invention by discharging steam at superatmospheric or subatmospheric pressure from a steam discharge tube shown positioned in a hollow sprue of a pattern assembly residing inside the mold.

Figure 8 is a perspective view of apparatus for subjecting a mold to rotation and tilting during the pattern removal process pursuant to still another illustrative embodiment of the invention.

Figure 9 is an elevational view, partially in section, of the apparatus of Figure 8.

Figure 10 is similar to Figure 9 showing the mold tilted relative to gravity.

Figure 11 is an enlarged perspective view of the top of the mold support by which a lower end of the mold is rotatably supported.

Figure 12 is an enlarged perspective view of the bottom of the mold support by which the mold end is rotatably supported.

Description of the Invention

[0017] The present invention improves upon the method and apparatus for removing one or more fugitive patterns residing inside of a refractory mold as disclosed in copending patent application Serial No. 10/899,381 filed July 26, 2004, the disclosure of which is incorporated herein by reference. In particular, one embodiment of the present invention involves method and apparatus for removing one or more fugitive patterns residing inside of a refractory mold by introducing a condensable vapor that includes a surfactant inside the mold. The condensed vapor and the melted pattern material are drained out of the mold. The surfactant lowers the surface tension of the condensed vapor in contact with the fugitive pattern inside the mold and increases the ease at which the melted pattern material flows over the freshly exposed mold interior surface to improve draining of the melted pattern mateial out of the mold, leaving less residual pattern material on the mold surface.

[0018] The method is especially useful to remove one or more fugitive patterns from inside a gas permeable "lost wax" investment casting ceramic shell mold, although the invention is not so limited as it can be practiced to remove one or more fugitive patterns from other types of refractory metal casting molds which have one or more fugitive patterns therein, which may have any mold wall thickness, and which may be unsupported or supported by exterior particulate media therearound. When steam is used as a preferred condensable vapor, the invention can be practiced to remove one or more fugitive patterns that may comprise conventional wax patterns or other pattern materials that are melted at a temperature below the boiling point of water (e.g. about 212 degrees F) under the particular ambient atmospheric pressure conditions present during the pattern removal operation.

[0019] The invention also can be practiced to remove one or more fugitive patterns that may comprise conventional wax patterns or other pattern materials and that are melted at a temperature above the boiling point of water by using superatmospheric steam to this end during the pattern removal operation pursuant to another embodiment of the invention described below. Furthermore, the invention can be practiced using subatmospheric pressure steam to remove one or more fugitive patterns that may require lower temperatures to melt them.

[0020] Alternatively in practicing the invention, the steam can be replaced by a condensable vapor of another suitable material, such as for purposes of illustration and not limitation, mineral spirits having a boiling point of about 300 degrees F wherein the vapor can be condensed and give up heat to the fugitive pattern when it makes contact with the pattern for pattern melting and removal purposes.

[0021] For purposes of illustration and not limitation, an embodiment of the present invention will be described below in connection with Figures 1-4 with respect to removing a plurality of wax patterns 10 attached by respective gate 35 to a central hollow sprue 30 of a pattern assembly 40 from inside of a "lost wax" investment casting shell mold 20. In Figure 1, the hollow sprue 30 comprises a preformed wax sprue having axially elongated interior chamber 30a and having the patterns 10 attached by wax welding or fastening technique to its exterior surface 30s. For purposes of illustration and not limitation, the wax sprue 30 can be preformed to have the interior chamber 30a by molding, extrusion, by initially forming the sprue on a cylindrical or other shape mandrel which is subsequently removed by heating the mandrel and thus adjacent wax to allow mandrel to be physically withdrawn, by drilling a solid wax sprue, or by any other suitable technique.

[0022] Although two patterns 10 are shown in Figure 1, those skilled in the art will appreciate that additional patterns 10 typically are attached about the sprue 30 at the same location as patterns 10 but are out of view in Figure 1 as a result of its being a sectional view. Moreover, additional patterns 10 can be attached by gates about the sprue 30 at other axial locations along its length (e.g. above the patterns 10 shown in Figure 1) as is well known and shown for example in US Patent 5 069 271, the teachings of which are incorporated herein by reference.

[0023] Referring to Figure 1, a "lost wax" investment casting shell mold 20 is shown invested on a plurality of wax patterns 10 attached by gates 35 about a central wax sprue 30 by the conventional "lost wax" process for making shell molds as described, for example, in US Patent 5 069 271, wherein the pattern assembly 40 including the patterns 10 attached by gates 35 to hollow sprue 30 is repeatedly dipped in a refractory slurry having a binder, stuccoed with coarse refractory stucco particles, and dried to build up the shell mold on the pattern assembly. The patent describes a gas permeable thin wall shell mold having a mold wall thickness of about 1/8 inch or less. Such a thin wall mold 20 as described in the patent can be supported in a casting container 60 by a particulate support media 50 (e.g. ceramic particulates) as shown in Figure 6 during the pattern removal operation. The invention is not limited to practice with such a thin wall shell mold supported by a particulate media therearound and, instead, can be practiced with a refractory mold of any mold wall thickness, whether exteriorly supported by particulate support media or whether unsupported as shown in Figure 1.

[0024] The shell mold 20 is shown inverted (i.e. oriented upside down) to allow the melted pattern material and condensed steam to drain by gravity from the lower end of the sprue 30. The mold 20 can be positioned in other orientations that facilitate drainage of the melted pattern material and condensed steam out of the mold. Moreover, the mold 20 may be moved during the pattern removal operation in a manner that facilitates drainage of the melted pattern material and condensed steam out of the mold.

[0025] Referring to Figure 1, pursuant to an illustrative embodiment of the invention, a steam discharge pipe or tube 100 connected to a surfactant supply conduit 101 is shown positioned in the elongated chamber 30a of the hollow sprue 30 of the pattern assembly 40 to introduce a stream (represented by the arrow "A") of steam that includes a surfactant (represented by arrow "SF") therein at substantially atmospheric pressure inside the hollow sprue 30 of the pattern assembly 40 to contact and melt the wax pattern assembly while the exterior surface 20s of the mold 20 is subjected to substantially ambient atmospheric air pressure (represented by "ambient pressure"). The ambient air forming a non-condensing gas atmosphere about the mold 20 in Figure 1 can be at ambient temperature or can be refrigerated relative to ambient temperature. A typical wax material from which the pattern assembly 40 is made melts and becomes quite fluid at about 180 degrees F for purpose of illustration and not limitation.

[0026] The steam at substantially atmospheric pressure is generated in a steam source 110, which may comprise a conventional steam generator commercially available as Model LB240 from The Electro Steam Generator Corp. The steam flows from the steam generator or source 110 through a supply tube 120 to the steam discharge tube 100. Flow of the steam from the source or generator 110 can be assisted by adjusting the pressure in the steam generator so that adequate steam will flow through the pipe into the mold to replace the amount of steam that has condensed.

[0027] Surfactant SF is introduced into the steam discharge tube 100 through the surfactant supply conduit 101 connected to a surfactant supply pump 111. The pump 111 pumps surfactant from a supply tank T. The surfactant in tank T is typically in a diluted form; i.e. the surfactant is diluted at a selected concentration in a liquid carrier vehicle. The flow of the surfactant SF in conduit 101 is regulated by using surfactant metering pump 111 or a valve arrangement to control the flow rate of the surfactant from an appropriate surfactant supply pump. For example, an alternative apparatus and method for introducing the surfactant SF into the tube 100 can involve supplying liquid surfactant at a constant pressure to an adjustable valve and regulating the flow of surfactant into tube 100 by the use of the adjustable valve.

[0028] Although surfactant SF is described as being introduced into the steam inside of the discharge tube 100, the invention is not so limited. For example, the surfactant can be introduced outside the steam discharge tube 100 using a second surfactant discharge tube 100' as shown in Figure 1A. The surfactant discharge tube 100' extends inside the mold in a way to introduce surfactant SF downstrean of the end of the steam discharge tube 100 and into the stream of steam after it is discharged from the end of the discharge tube 100 inside the mold as shown in Figure 1A.

[0029] For purposes of illustration and not limitation, an exemplary surfactant for use in practice of this aspect of the invention comprises Tomadol grade 1-5 nonionic alcohol ethoxylate liquid surfactant, which is available from Tomah Products, Inc., Milton, Wisconsin and which is diluted to a 0.5% by weight solution in water (carrier vehicle) and added at a rate of 60 ml/min to the stream of steam in the discharge tube 100 via conduit 101. The surfactant is added to the discharge tube 100 so that it will be present in the steam inside the mold as the refractory mold wall is exposed as the wax pattern is melted during the pattern removal process.

[0030] The invention is not limited to practice with the exemplary surfactant described above since other nonionic surfactants at other concentrations in the steam or condensable vapor can be used. In general, the surfactant and its concentration in the condensable vapor are selected to lower the surface tension of the condensed vapor that is in contact with the fugitive pattern inside the mold to increase the ease at which the melted pattern material flows over the freshly exposed mold interior surface, thereby improving draining of the melted pattern material out of the mold to leave less residual pattern material on the mold surface.

[0031] Moreover, although water is described in the preceding paragraph as the carrier vehicle for the surfactant when the condensable vapor comprises steam, the invention is not so limited. The surfactant can be carried in a diluted form using any liquid vehicle that is compatible with a particular non-aqueous condensable vapor being used. For example, when the condensable vapor comprises mineral spirits, the carrier vehicle can comprise mineral spirits.

[0032] The steam at substantially atmospheric pressure and containing the surfactant SF is discharged in the chamber 30a at a sufficiently high flow rate to displace air from the chamber 30a and progressively contact and melt the pattern material of the wax sprue 30 and then the gates 35 and patterns 10. The flow rate of the steam discharged into the chamber 30a may be varied during removal of the sprue and patterns depending upon the rate of condensation of the steam inside the mold. This rate will be dependant upon the surface area of the wax exposed to the steam at that point during de-waxing, and the size of the mold. When multiple rows of patterns and gates are attached to the sprue along its length, the steam progressively melts the pattern material of each pattern uniformly from the gate and sequentially proceeding into the pattern.

[0033] In practice of the invention, the wax sprue 30 may not be present or may be removed by other means prior to removal of the patterns 10 by contact with the steam. That is, if only patterns 10 are present in shell mold 20 having an empty central sprue type passage, then the steam discharge tube 100 is positioned to discharge the steam inside the mold 20 to contact and melt only patterns 10 and any gates 35 associated therewith.

[0034] Figures 2 and 4 illustrate the pattern removal process after the central hollow sprue 30 has been melted and removed and while a gate 35 and pattern 10 are being melted and removed. The steam containing the surfactant is shown being drawn toward the gate 35 and associated pattern 10 as the steam condenses where the steam has melted the wax pattern material. In particular, as the steam condenses at the surface of the gate and pattern, a relative lower pressure is generated at region V proximate where the gate and/or pattern material is melted to cause fresh downstream steam to flow toward the region of the gate and pattern that has melted. The liquid wax material that has melted soaks partially into the inner mold wall surface as illustrated at surface region S and acts as a barrier to prevent steam condensate from soaking through the thickness of the mold wall W. Moreover, the presence of atmospheric air pressure on the exterior surface 20s of the mold 20 provides no driving force to cause the steam condensate to pass through the mold wall, thereby avoiding saturation of the mold wall with steam condensate and the adverse effects on the binder present in the mold wall. During the pattern removal operation, the exterior surface 20s of the mold exposed to ambient air (as a non-condensing gas atmosphere) remains dry (devoid of liquid water) as a result. A pressure differential between the condensable vapor inside of the mold 20 and the non-condensing gas atmosphere outside of the mold 20 is small enough as to prevent the condensable gas from exiting outside the mold exterior through the gas permeable mold wall W and the non-condensing gas from entering via wall W the mold cavity occupied by the fugitive pattern assembly being removed. The condensable vapor inside the mold and the non-condensing gas atmosphere outside of the mold preferably are at substantially the same pressure to this end.

[0035] In Figure 4, inclusion of the surfactant with the condensable vapor (e.g. atmospheric pressure steam) results in wetting of the steam condensate to the wax soaked refractory mold and the formation of a surface layer of steam condensate along the surface of the wax soaked refractory wall. Molten wax pattern material draining from the area of the pattern that is melting therefore flows on a layer of steam condensate which because of its low viscosity, allows the melted wax to flow more easily along the mold wall and out of the mold cavity. This results in faster removal of the pattern material from the mold cavity and less residual wax pattern material left in the mold cavity.

[0036] As further illustrated in Figure 4, the steam condensate and the melted wax pattern material are drained out of the mold 20 by gravity through the sprue void or passage P created when the hollow wax sprue 30 has been removed. The melted wax pattern material may be collected on or in a collection tray or container (not shown) positioned below the mold 20 in Figure 1. An axis of the mold 20, such as longitudinal axis L of the mold 20 of Figure 2, containing the fugitive pattern can be tilted with respect to the direction of gravity during the melting of the fugitive pattern or after the fugitive pattern has been melted.

[0037] The steam at substantially atmospheric pressure is believed to produce only a small heat affected zone Z in the wax pattern such that the remaining unmelted portion of the solid wax pattern 10 is relatively unaffected by the steam, although Applicants do not wish to be bound by any theory in this regard. This small area of heated but not melted pattern material is free to thermally expand toward the melted surface, therefore resulting in little or no stress on the surrounding refractory mold. The thermal expansion of the wax inside the mold is the cause of the mold cracking during standard autoclave de-waxing.

[0038] The discharge of steam and surfactant SF from the steam discharge tube 100 inside the mold is continued until the entire pattern assembly 40 (including the hollow sprue 30 and patterns 10) is melted and removed from the mold 20, leaving an empty shell mold 20 that includes a plurality of mold cavities MC connected to the sprue passage P as shown in Figure 3. The mold then is ready to be fired at a suitable firing temperature to prepare the mold for receiving molten metal or alloy to be cast in the mold as is well known and forming no part of the invention.

[0039] Although the chamber 30a of the hollow sprue 30 is described above as being preformed in connection with Figures 1-4, the invention is not so limited. As shown in Figure 5, a chamber 30a' can be formed in-situ in a solid wax precursor sprue 30' of the pattern assembly, Figure 5, by relatively axially moving the discharge tube 100 such that the steam discharged at atmospheric pressure from the tube 100 and including the surfactant from tube 101 impinges against the exposed end 30e' of the solid sprue 30' and progressively melts out the chamber 30a' in-situ in the solid precursor sprue 30'. After the chamber 30a' is formed, the removal of the now hollow sprue 30' and the patterns 10 can be carried out as described above in connection with Figures 1-4. In Figure 5, like reference numerals are used for like features of Figures 1-4.

[0040] In another embodiment of the invention illustrated in Figure 6, a fugitive pattern assembly 40 is removed from a thin wall or other refractory mold 20 that is exteriorly supported or surrounded by a particulate support media 50 in a casting container 60 as described in US Patent 5 069 271. The particulate media 50 can comprise ceramic particles or grog as described in the patent. Pattern removal is effected by discharging steam at substantially atmospheric pressure from the steam discharge tube 100 and containing the surfactant from tube 101 inside the hollow sprue 30 of the pattern assembly 40 to contact and melt the hollow sprue 30 and then the patterns 10 as described in connection with Figures 1-4. The exterior surface 20s of the mold 20 contacts the particulate media 50 and is subjected to substantially ambient atmospheric pressure via a vent-to-atmosphere 61 on the casting container 60 during pattern removal. The exterior mold surface 20s and the particulates media 50 remain dry (devoid of liquid water) as a result of the melted wax soaking partially into the mold wall W as described above with respect to Figures 1-4 and preventing steam condensate from soaking through the mold wall thickness.

[0041] For purposes of further illustration and not limitation, another method embodiment of the present invention shown in Figure 7 will be described below wherein superatmospheric or subatmospheric pressure steam is discharged inside the mold to remove the pattern assembly 240 having a plurality of wax patterns 210 attached by respective gate 235 to central hollow sprue 230 from inside of "lost wax" investment casting shell mold 220. Use of superatmospheric pressure steam while the exterior of the mold is subjected to non-condensing gas at substantially the same superatmospheric pressure permits an increase in the heat capacity per unit volume of the steam as well as enables the melting of higher melt point pattern materials. Use of subatmospheric pressure steam while the exterior of the mold is subjected to noncondensing gas at substantially the same subatmospheric pressure enables melting and removal of pattern materials that, for example, require lower temperatures. The following method embodiment will be described using superatmospheric pressure steam including the surfactant SF, although the method embodiment may also alternatively use subatmospheric pressure steam instead.

[0042] The mold 220 is disposed inside of a pressure vessel 250 over a collection basin 252 to collect and contain melted wax and steam condensate exiting from the mold during the pattern removal operation. The pressure vessel 250 may comprise a casting container of the type that includes particulate support media about the mold 220 as illustrated in Figure 6. Alternately, the pressure vessel 250 may be devoid of the particulate support media; i.e. empty with only the shell mold therein. The pressure vessel 250 can be formed by a suitable pressure resistant material such as steel and configured as a typical conventional pressure vessel. A casting chamber 60 and mold contained therein as shown in Fig 6 can also be placed inside a separate pressure vessel 250 for superatmospheric pressure de-waxing.

[0043] A seal 254 is provided between the mold 220 and the pressure vessel wall 250a to substantially prevent mixing of gas from the region interior of the seal 254 to the exterior of the seal 254. The seal 254 can comprise a steel or other tubular member 254t having a rubber or other type seal 254a for sealing to the mold 220.

[0044] Steam at superatmospheric pressure and including the surfactant from tube 101 is discharged inside the mold 220 from discharge tube 300. The tube 300 is connected to a source S of the superatmospheric pressure steam, such as the previoussly described steam generator and extending through an opening in wall 250a and also to surfactant input conduit 101 as shown in Figure 6. Simultaneously to the discharge of the superatmospheric pressure steam inside the mold 220, air pressure at substantially the same pressure as the steam pressure inside the mold is provided in the pressure vessel 250 via an inlet 255. The inlet 255 for the superatmospheric air pressure is connected to a source of compressed air, such as an air compressor; for example, Kaeser model SP25 compressor. This method embodiment thus involves discharging steam including surfactant from tube 101 inside the mold 220 to contact and melt the pattern material while the exterior of the mold 220 is subjected to a steam-free gas atmosphere outside of the mold wherein the steam inside the mold and the steam-free atmosphere outside of the mold are at substantially the same pressure. The steam and corresponding air (or other gas) pressure may be adjusted to any pressure (and therefore temperature) appropriate for the rapid melting of the pattern material.

[0045] The superatmospheric pressure inside the pressure vessel can be provided by a gas other than air such as, for example, nitrogen, inert gas, or other gas at the desired superatmospheric pressure substantially equal to that of the steam inside the mold.

[0046] An air bleed valve 256 is provided on the pressure vessel wall 250 so as to reside in the region inside the seal 254 to bleed the air that was initially inside the mold 220 from the region inside the seal 254.

[0047] The pattern removal operation of the embodiment of Figure 7 proceeds as described above with respect to steam discharged atmospheric pressure together with the surfactant inside the mold 20 wherein the superatmospheric steam contacts the solid wax material of the pattern assembly and condenses. More heat is delivered to the wax surface in this embodiment of the invention since the superatmospheric steam is at a higher temperature when compressed. A slightly reduced pressure is formed at the wax surface when the steam condenses, which draws more steam into contact with the wax surface to facilitate the pattern removal operation. Molten wax from the wax surface and steam condensate flows out of the mold cavity and into the wax and condensate collection basin 252. De-waxing action occurs only internally in the mold 220 in an orderly manner from the sprue 230 to the gates 235 and then into the wax patterns 210. The mold-to-pressure vessel seal 254 results in no steam being applied to the exterior of the mold 220 in the pressure vessel 250. A steam-free atmosphere is thereby provided in the pressure vessel 250.

[0048] Referring to Figures 8 through 12, a further aspect of the invention is illustrated wherein the unsupported shell mold 500 (Fig. 10) is subjected to a combination of rotation and tilting relative to gravity during the pattern removal process using steam or other condensable vapor in the manner described above with or without a surfactant being included in the steam or other condensable vapor. This embodiment is not limited to removing the pattern using steam or other condensable vapor and envisions that other pattern removal techniques may be employed while the mold is subjected to a combination of rotation and tilting. For example, a hot air or gas stream can be introduced inside the mold in a manner to heat and melt the pattern while the mold is subjected to combined rotation and tilting. The mold also may be located in a furnace for flash heating the pattern while the mold is subjected to combined rotation and tilting. Still further, a chemsical dissolution medium may be introduced inside the mold to contact and dissolve the pattern while the mold is subjected combined to rotation and tilting.

[0049] Likewise, this further aspect of the invention can be practiced to remove one or more fugitive patterns from a mold that is exteriorly supported or supported by a surrounding particulates media in a casting container as described above in connection with Figure 6 and also in US Patent 5 069 271.

[0050] In Figure 10, an unsupported shell mold 500 is shown having a plurality of fugitive (e.g. wax) patterns 510 disposed around and along the length of a fugitive (e.g. wax) sprue 530. Each patern is shown connected to the sprue by a gate 535. The rotary action about the longitudinal aixs L of the mold while the mold is tilted relative to gravity as shown in Figure 10 pursuant to this aspect of the invention allows the melted pattern material to drain uniformly from all mold cavities MC that are arranged around the central sprue passage P when the pattern and sprue material are removed.

[0051] Figure 8 shows illustrative apparatus for practicing this aspect of the invention before the mold 500 is placed in the apparatus. Figure 9 shows the apparatus before the mold 500 is placed in the apparatus and before the mold is tilted with respect to gravity. Figure 10 shows the apparatus after the mold is placed in position and tilted with respect to gravity such that its longitudinal axis L is oriented at an angle of inclination.

[0052] In practicing this aspect of the invention, the mold 500 having the fugitive patterns and sprue therein is placed between an upper mold clamp and rotation mechanism 510 and a lower mold support mechanism 512. The shell mold 500 includes an upper annular collar 500c that is receives an end 510e of the upper mold clamp mechanism 510 as shown best in Figure 10. The end 510e closes off the mold sprue passage P. The mold includes a lower annular collar 500d that is received on rotatable nest 512n disposed on a support plate 512p of the mold support base 512b as shown best in Figures 10 and 11. The mold support base 512b is affixed to lateral arms A of the frame F of the apparatus. A cross brace plate P3 is provided between the arms A. The mold collars 500c, 500d can be formed integral with the mold 500 or can be formed separately and attached to the mold.

[0053] An end of a steam delivery pipe or tube 600 extends upwardly through an opening in the mold support base 512b and support plate 512p so as to communicate with the open lower end of the mold 500 as shown in Figure 10 to introduce steam or other condensable vapor inside the mold 500. The pipe or tube 600 is held in fixed position on the mold support base 512b by clamps 513 as shown in Figure 12. The pipe or tube 600 is connected by suitable flexible or rigid conduit to a steam generator like steam generator 110 described above in connection with Figures 1-4.

[0054] The mold support plate 512p includes a first set (three shown) of peripherally spaced apart rotatable wheels 512f that rotatably support the outer circumference of the rotatable nest 512n. The mold support plate 512p also includes a second set (three shown) of peripherally spaced apart rotatable wheels 512g on which the closure plate 512s of the rotatable nest 512n is supported for rotation. The rotatable nest 512n thereby is supported laterally by wheels 512f and from beneath by wheels 512g for rotation relative to the lower mold support base 512.

[0055] Each wheel 512f is supported by bearings (not shown) on an upstanding stud S1 mounted on the plate 512p. Each wheel 512g is supported by bearings (not shown) on a lateral stud S2 mounted on the support plate 512p.

[0056] The rotatable nest 512n includes an upwardly facing, generally cylindrical recess R configured to receive the collar 500d of the mold 500 as shown in Figure 10.

[0057] The mold clamp and rotation mechanism 510 includes a shaft 510s having the end 510e that frictionally engages in the collar 500c of the mold 500. To this end, the end 510e can be made of rubber or other mateiral to achieve friction engagement with the mold collar 500c so that rotation can be imparted to the mold by rotation of shaft 510s.

[0058] The shaft 510s is rotatable by having an upper end sprocket 510f thereof in driving engagement with a drive chain 510c. The chain is driven by an output sprocket 513s of a conventional gear reducer GR1 driven by a conventional electric or hydraulic motor M1 that is disposed on horizontal fixed plate P1 of the frame F. The shaft 510s is supported for rotation by bearing blocks 510b affixed on a vertical fixed frame plate P2, which is fastened to frame plate P1. In this way, the mold 500 clamped between the mold clamp and rotation mechanism 510 and the mold support mechanism 512 can be rotated by shaft 510s.

[0059] The mold clamp and rotation mechanism 510 is movable up and down relative to the mold support mechanism 512 by a sliding vertical shaft 700s guided at a lower end in fixed housing H1 by a pair of bearings 700b and at an upper end in fixed housing H2. An air cyclinder (not shown) is connected between the frame 512 (e.g. plate P3) and the mechanism 510 (e.g. shaft 700s) in a manner to raise the mechanism 510 to permit placement of a mold in the apparatus and to lower the mechanism 510 to clamp the mold in place. When the air cylinder is in the raised position, an anti-rotation shaft 800s exits the antirotation guide tube 800t to allow the mechanism 510 to rotate sideways out of the way for ease of loading a new mold into the apparatus.

[0060] A main shaft 550 is rotatably mounted on the frame F by bearing blocks 552 so as to be rotatable or pivotable about its longitudinal axis, which is perpendicular to the longitudinal axis of the mold 500. A square cross-section support sleeve 553 is affixed, such as by welding, on the shaft 550 for rotation therewith. The frame arms A that carry the mold support mechanism 512 are fastened such as by welding to the sleeve 553 so that they rotate or pivot with the shaft 550. The mold clamp and rotation mechanism 510 is fastened to sleeve 553 by means of the shaft 550, antirotation shaft 800s, and air cylinder. The mold clamp and rotation mechanism 510 and the mold support mechanism 512 thus are mounted on the sleeve 553 so that they rotate or pivot with the shaft 550.

[0061] The shaft 550 is rotated or pivoted by a conventional electric drive motor M2 connected to the end of the shaft 550 by a gear reducer GR2. The gear reducer GR2 is connected to the machine frame 512 by a reaction linkage L' that keeps the gear reducer from rotating with the shaft. The drive motor can be of the stepping motor type. The drive motor M2 thus can incrementally or continuously rotate or pivot the shaft 550 about its longitudinal axis. In this way, the mold 500 clamped between the mold clamp and rotation mechanism 510 and the mold support mechanism 512 can be tilted relative to gravity as shown in Figure 10 while the mold is rotated.

[0062] In operation of the apparatus, the mold 500 having the fugitive pattern and sprue therein is placed on the rotatable nest 512n with its lower collar 500d received in the recess R of the rotatable nest 512n. Then, the end 510e of the shaft 510s of the mold clamp and rotation mechanism 510 is lowered to engage the end 510e in the upper collar 500c of the mold 500 so that rotation of the shaft 510s will impart rotation to the mold.

[0063] Steam flow to pipe or tube 600 is initiated. The steam flow is introduced inside the mold via pipe or tube 600. The steam may include the surfactant FS described above in connection with Figures 1-4, or the surfactant may be omitted in certain pattern removal situations. The main shaft 550 is pivoted to tilt the mold clamp and rotation mechnsim 510 and the mold supprt mechansim 512, and thus the mold 500, to any desired angle of inclination relative to gravity, see Figure 10. The angle of the mold tilt and mold rotational speed can be adjusted as required to drain the melting wax from the mold cavities MC. In this way, the wax can be drained uniformly from all mold cavities MC arranged around a center sprue P. This aspect of the invention thus allows wax to be drained out of mold cavities even where a substantial volume of a mold cavity is below the level of the gate G when the mold is in the vertical position. The melted wax drains out of the bottom of the molds and is captured in a pan (not shown).

[0064] The mold 500 can be rotated while the mold is held tilted at a fixed angle of inclination relative to gravity. Alternately, the mold can be tilted incrementally to selected angles of inclination while the mold is rotated at each of the angle of inclination or continuously. Further, the mold can be continuously tilted while being rotated continuously or intermittently. Practice of the method is dependent on the shape of patterns being dewaxed (removed). It may be typical to start with vertical non-rotating mold de-waxing and then change to tilted mold rotary de-waxing as the de-waxing proceeds into portions of the mold that hang below the gate opening. The angle of mold tilt, rotational speed and the time duration depends on the sahpe of th patterns being dewaxed.

[0065] Steam or other condensable vapor is introduced via pipe or tube 600 inside the mold 500 to heat and melt the fugitive pattern and sprue while the mold is subjected to a combination of rotation and tilting, although this aspect of the invention is not limited to use of steam or other condensable vapor to heat and melt the pattern and sprue. For example, a hot air or gas stream can be introduced inside the mold in a manner to heat and melt the pattern while the mold is subjected to a combination of rotation and tilting. The mold also may be located in a furnace for flash heating the pattern while the mold is subjected to combined rotation and tilting. Still further, a chemical dissolution medium may be introduced inside the mold to contact and dissolve the pattern while the mold is subjected to combined rotation and tilting.

[0066] The invention is advantageous to remove one or more fugitive patterns from a metal casting refractory mold, which may have any mold wall thickness and which may be unsupported or supported by exterior particulate media therearound. The invention is further advantageous to remove one or more fugitive patterns while avoiding saturating the mold wall with steam condensate. The invention may be practiced to reduce mold cracking during pattern removal and to allow the use of thinwalled molds without mold cracking.

[0067] Those skilled in the art will appreciate that the invention is not limited to the embodiments described above and that changes and modifications can be made therein within the spirit of the invention as set forth in the appended claims.

Claims

1. A method of removing a fugitive pattern from inside a refractory mold, comprising introducing a condensable vapor and a surfactant inside the mold to contact and melt the pattern material, condensing said condensable vapor inside the mold where it contacts and melts the pattern, and draining the melted pattern material and condensed vapor out of the mold wherein the surfactant improves said draining.

2. A method of removing a fugitive pattern from inside a refractory mold, comprising introducing a condensable vapor and a surfactant inside the mold to contact and melt the pattern material while an exterior of the mold is subjected to a non-condensing gas atmosphere outside of the mold, condensing said condensable vapor inside the mold where it contacts and melts the pattern while the exterior of the mold remains free of condensed vapor, and draining the melted pattern material and condensed vapor out of the mold wherein the surfactant improves said draining.

3. The method of claim 2 where the type and amount of surfactant is selected to reduce the surface tension between the condensed vapor and the pattern material.

4. The method of claim 2 where the condensable vapor is steam.

5. The method of claim 2 where the pattern material is wax, either with or without a non-wax filler

6. The method of claim 2 where the surfactant is added to the condensable vapor before the condensable vapor exits a discharge tube and enters inside the mold.

7. The method of claim 2 where the surfactant is added to the condensable vapor after the condensable vapor exits a discharge tube and enters inside the mold.

8. The method of claim 7 where the surfactant is carried into the condensable vapor stream in a diluted form using a vehicle compatible with the condensable vapor being used.

9. The method of claim 2 wherein a pressure differential between the condensable vapor inside the mold and the non-condensing gas atmosphere outside of the mold is small enough as to prevent the condensable gas from exiting outside the mold exterior and the non-condensing gas from entering a mold cavity in the mold.

10. The method of claim 2 wherein the condensable gas and the noncondensing gas atmosphere are at substantially the same pressure.

11. The method of claim 2 wherein the condensable vapor comprises steam.

12. The method of claim 2 wherein the non-condensing gas is air.

13. The method of claim 2 wherein the condensable vapor is supplied from a source to a discharge tube from which it is discharged inside the mold.

14. The method of claim 2 wherein the condensable vapor is discharged inside the mold at atmospheric pressure.

15. The method of claim 2 wherein the condensable vapor is discharged inside the mold at superatmospheric or subatmospheric pressure and a non-condensing gas at substantially the same superatmospheric or subatmospheric pressure is provided exterior of the mold in a vessel containing the mold.

16. The method of claim 15 including preventing the condensable vapor from entering the vessel exterior of the mold using a seal between the mold and the vessel.

17. The method of claim 2 wherein the fugitive pattern comprises wax.

18. The method of claim 2 wherein an axis of the mold containing the fugitive pattern is tilted with respect to the direction of gravity during the melting of the fugitive pattern or after the fugitive pattern has been melted and the mold is rotated about a second axis.

19. The method of claim 2 including initially discharging the condensable vapor inside a hollow sprue of the

pattern.

20. The method of claim 19 wherein the hollow sprue is preformed in the fugitive pattern prior to the discharging of the condensable vapor.

21. The method of claim 20 wherein the hollow sprue is formed by condensable vapor discharged against an exposed end of the solid sprue.

22. The method of claim 2 wherein the exterior of the mold is surrounded by a support particulate media in a container.

23. The method of claim 2 wherein the exterior of the mold is not surrounded by a support particulate media.

24. Apparatus for removing a fugitive pattern from inside of a refractory mold, comprising means for introducing a condensable vapor at atmospheric, superatmospheric or subatmospheric pressure inside the mold to contact and melt the pattern material and means for providing a surfactant in the condensable vapor.

25. The apparatus of claim 24 wherein the means for introducing a condensable vapor comprises a discharge tube communicated to the inside of the mold.

26. The apparatus of claim 24 including a surfactant supply conduit for supplying the surfactant to the discharge tube.

27. The apparatus of claim 24 including a surfactant discharge tube for introducing surfactant to the condensable vapor after it is discharged from the discharge tube.

28. A method of removing a fugitive pattern from inside a refractory mold, comprising melting or dissolving the fugitive pattern and subjecting the mold to a combination of rotation and tilting to improve draining of pattern material from the mold.

29. The method of claim 28 wherien the mold is rotated about its longitudinal axis while the longitudinal axis is tilted with respect to gravity.

30. The method of claim 28 wherein the refractory mold comprises a shell mold.

31. The method of claim 30 wherein the shell mold is not surrounded by particulates media.

32. The method of claim 30 wherein the shell mold is surrounded by particulates media.

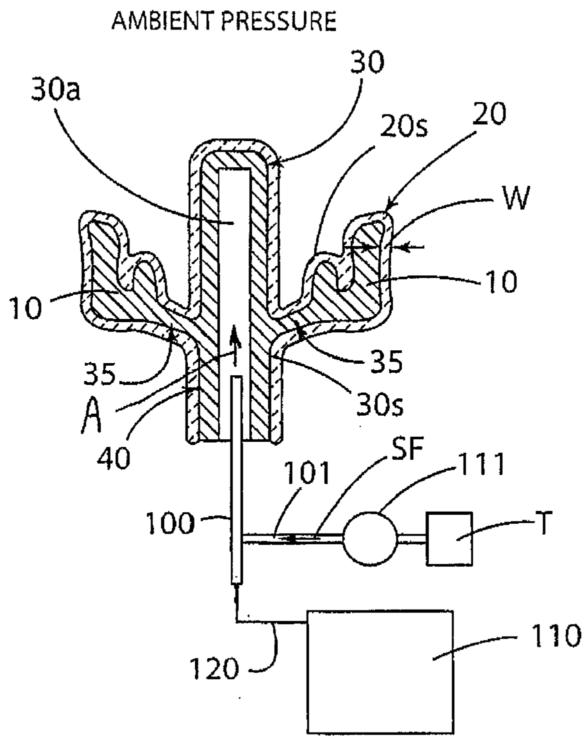
33. The method of claim 28 wherein the fugitive pattern is melted by introducing steam or a condensable vapor inside the mold.

34. Apparatus for removing a fugitive pattern from inside of a refractory mold, comprising a mold clamp and rotation mechanism and a mold support mechnism between which the mold is disposed, a pivotable shaft on which the mold clamp and rotation mechanism and the mold support mechnism are disposed, means for pivoting the shaft to tilt the mold clamp and rotation mechanism and the mold support mechnism relative to gravity, and means for removing the fugitive pattern.

35. The apparatus of claim 34 wherein the mold clamp and rotation mechanism comprises a rotatable shaft having an end frictionally enagaged to an end of the mold to impart rotation thereto.

36. The apparatus of claim 36 wherein the mold clamp and rotation mechanism is movable up and down relative to the mold to engage the end with the mold..

37. The apparatus of claim 35 wherein the mold support mechanism comprises a rotatable nest that receives an opposite end of the mold.


AMBIENT PRESSURE
30
30a
20s
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W
10
10
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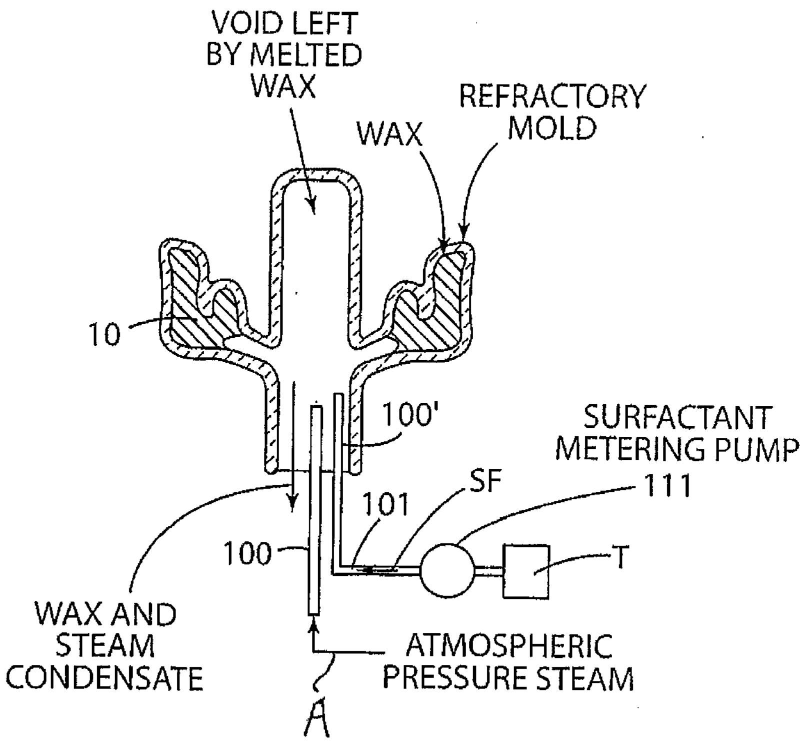
35
A
30s
40
SF
101
111
100
T
110
120

FIG. 1


VOID LEFT
BY MELTED
WAX
REFRACTORY
MOLD
WAX
10
100'
SURFACTANT
METERING PUMP
SF
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101
100
T
WAX AND
STEAM
CONDENSATE
ATMOSPHERIC
PRESSURE STEAM
A

FIG. 1A

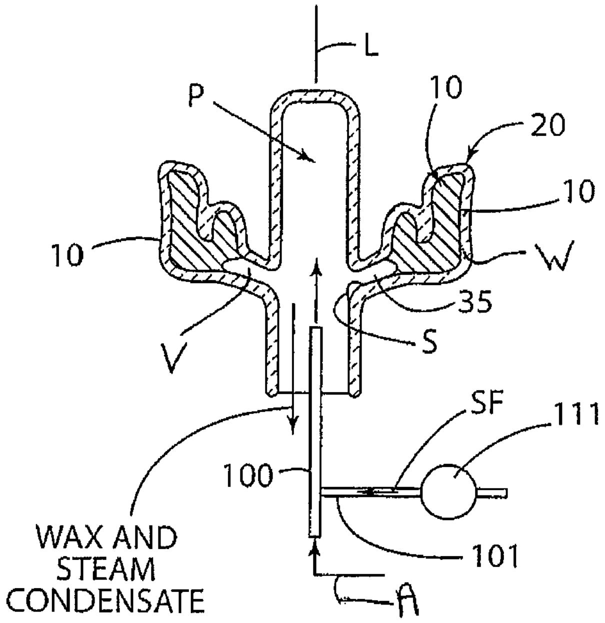


FIG. 2

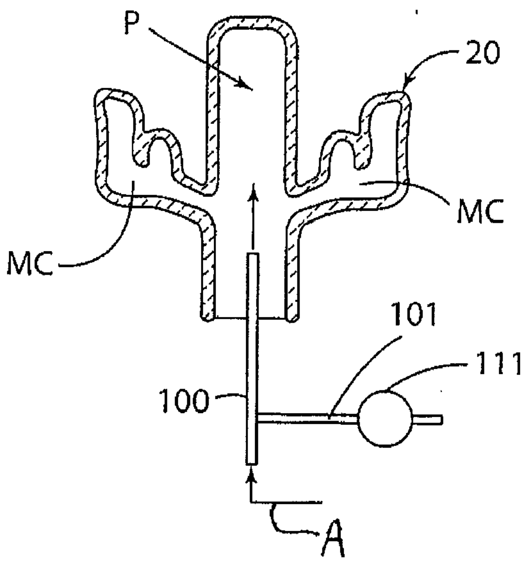


FIG. 3

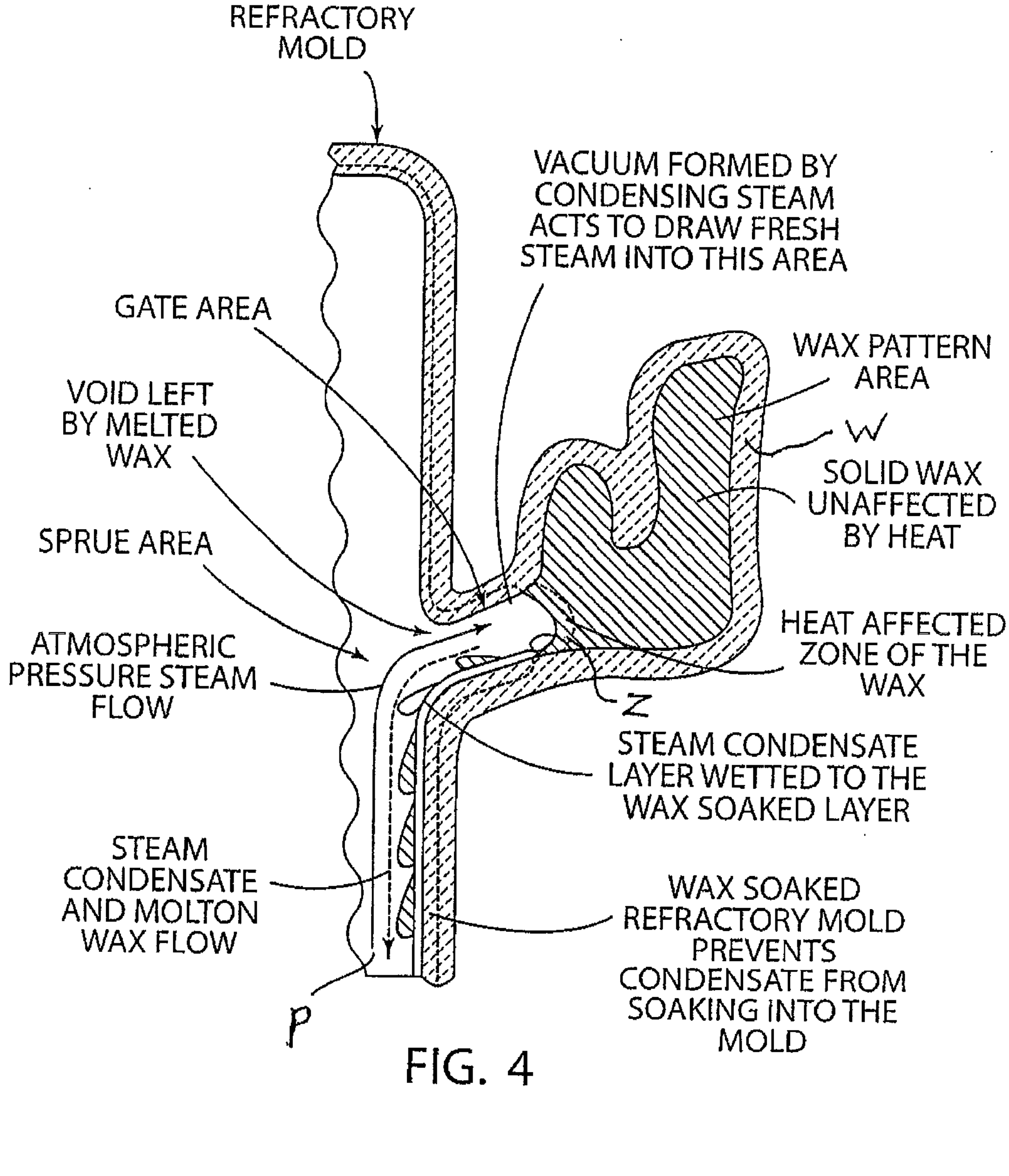

REFRACTORY MOLD
VACUUM FORMED BY CONDENSING STEAM ACTS TO DRAW FRESH STEAM INTO THIS AREA
GATE AREA
WAX PATTERN AREA
W
VOID LEFT BY MELTED WAX
SOLID WAX UNAFFECTED BY HEAT
SPRUE AREA
HEAT AFFECTED ZONE OF THE WAX
ATMOSPHERIC PRESSURE STEAM FLOW
Z
STEAM CONDENSATE LAYER WETTED TO THE WAX SOAKED LAYER
STEAM CONDENSATE AND MOLTON WAX FLOW
WAX SOAKED REFRACTORY MOLD PREVENTS CONDENSATE FROM SOAKING INTO THE MOLD
P

FIG. 4

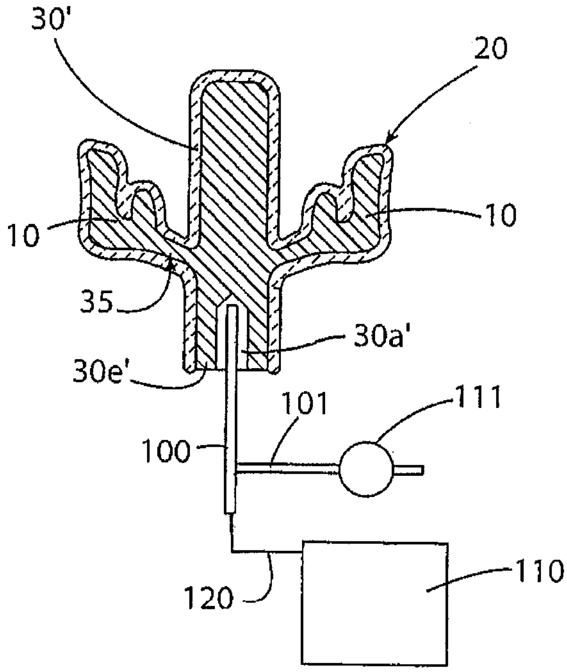


FIG. 5

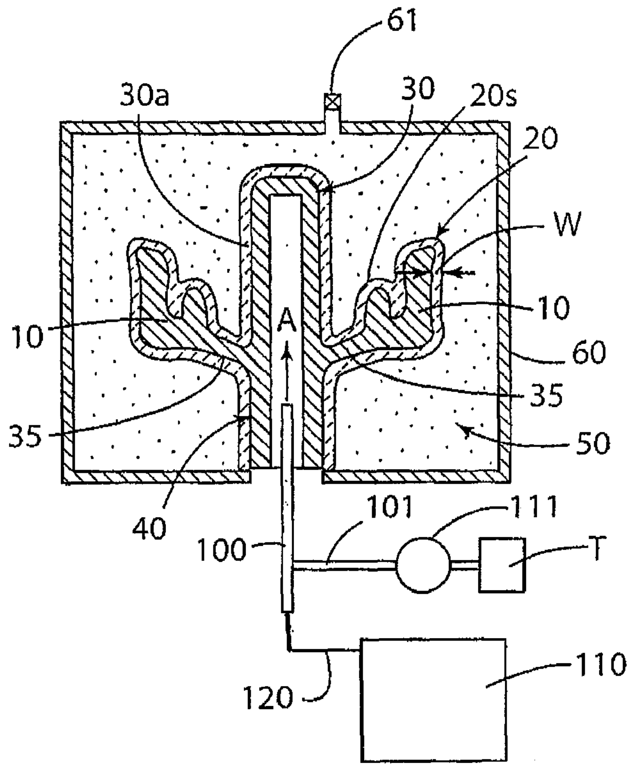
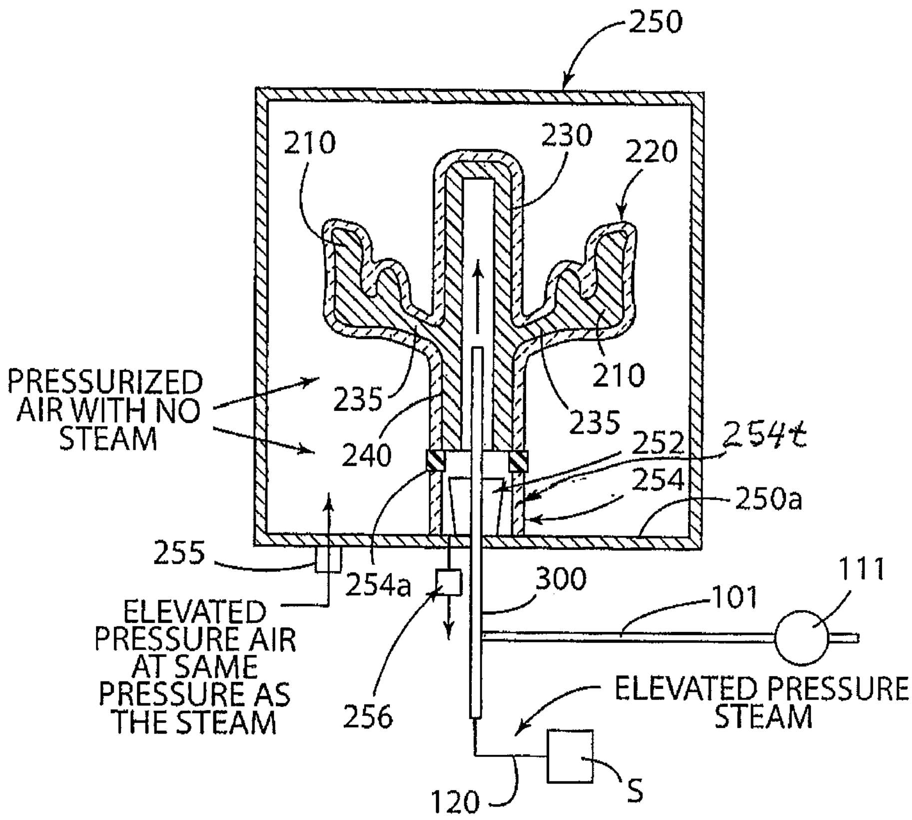


FIG. 6



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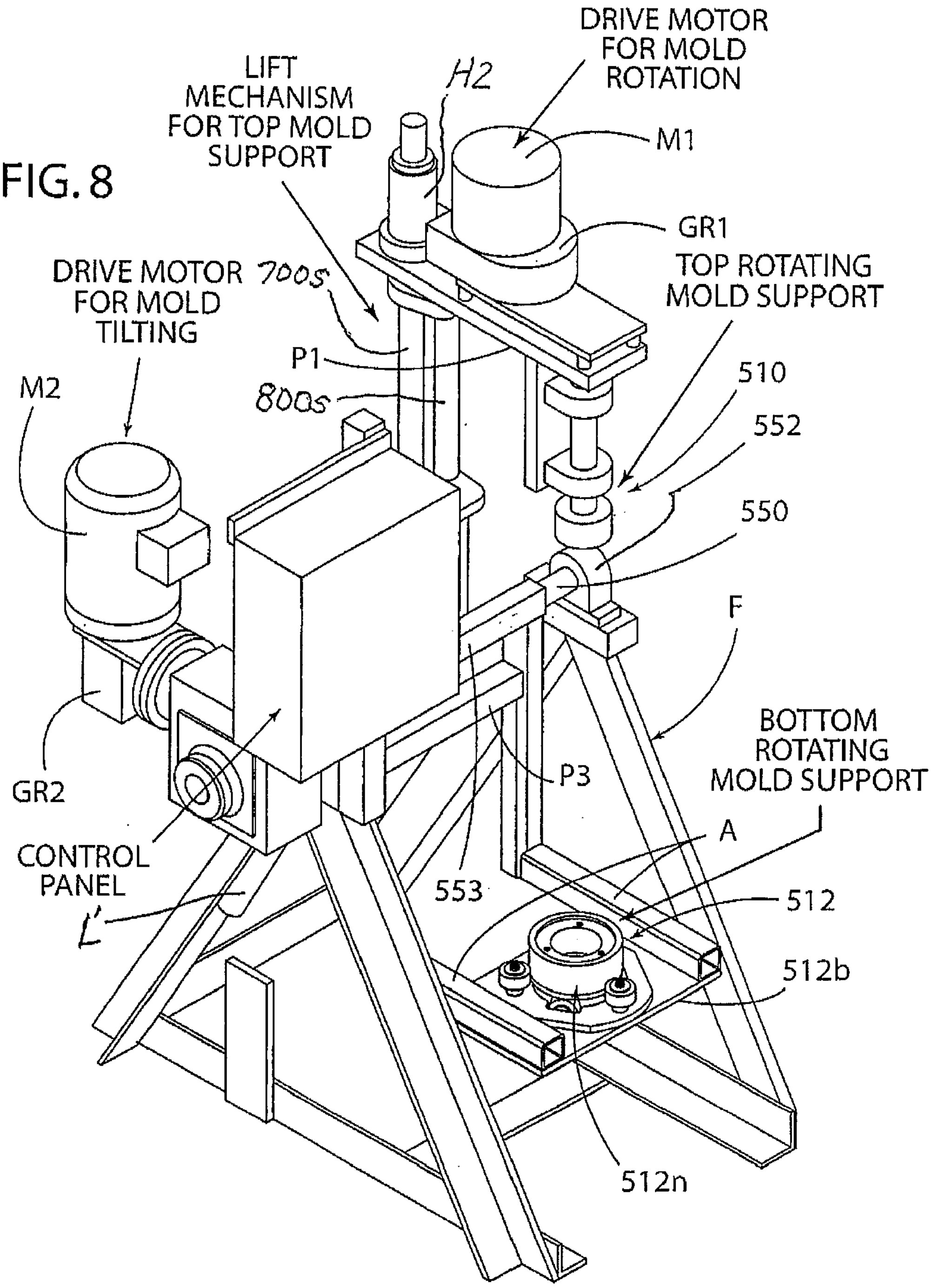
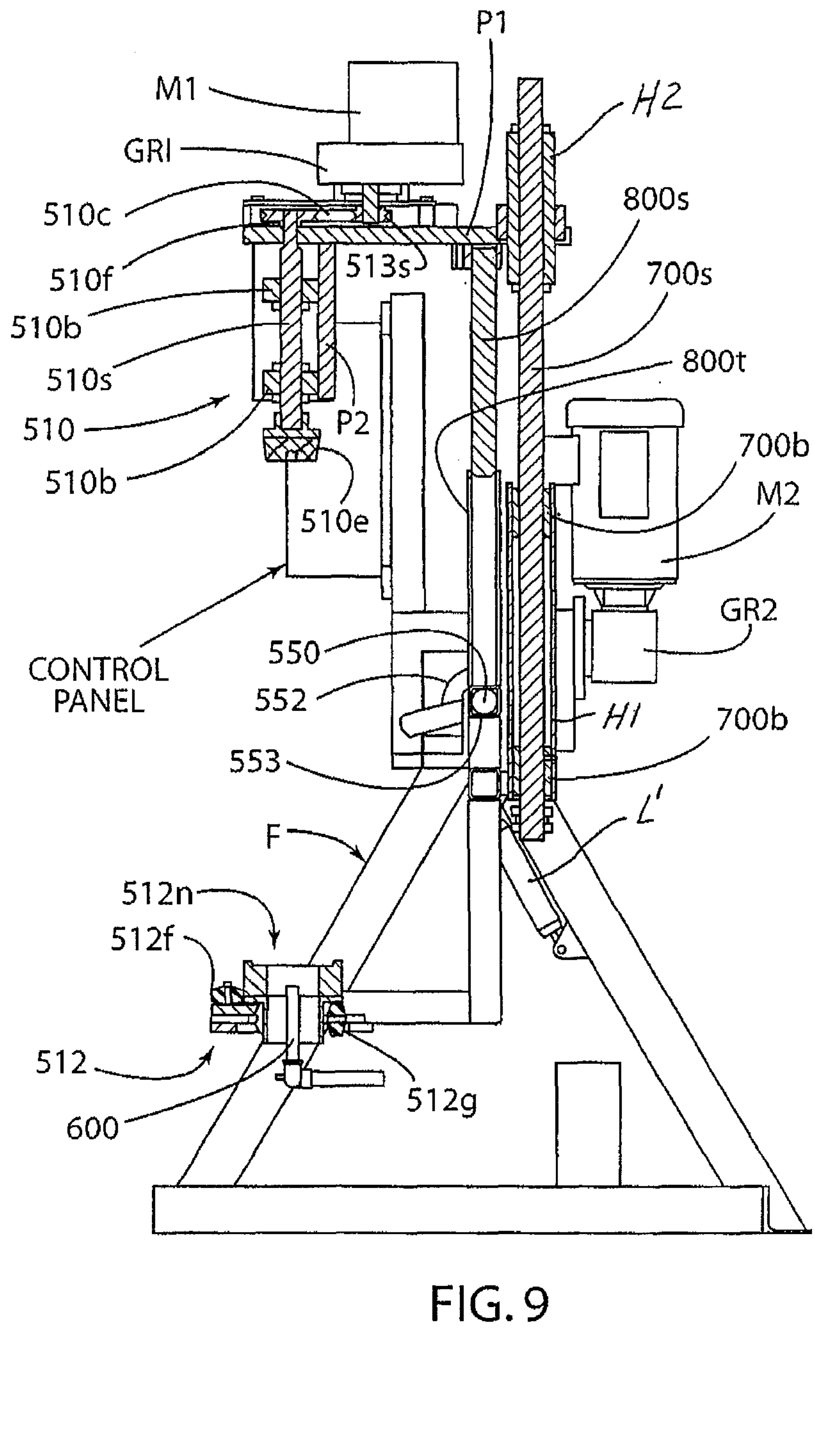
210
230
220
210
PRESSURIZED AIR WITH NO STEAM
235
240
235
252
254t
254
250a
255
254a
300
111
101
ELEVATED PRESSURE AIR AT SAME PRESSURE AS THE STEAM
256
ELEVATED PRESSURE STEAM
120
S

FIG. 7

FIG. 8


DRIVE MOTOR
FOR MOLD
ROTATION
LIFT
MECHANISM
FOR TOP MOLD
SUPPORT
H2
M1
GR1
TOP ROTATING
MOLD SUPPORT
DRIVE MOTOR
FOR MOLD
TILTING
700s
P1
800s
M2
510
552
550
F
BOTTOM
ROTATING
MOLD SUPPORT
GR2
P3
A
CONTROL
PANEL
553
512
L'
512b
512n


P1
M1
H2
GRI
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800s
510f
513s
700s
510b
510s
800t
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P2
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510b
M2
510e
GR2
CONTROL
PANEL
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552
H1
700b
553
L'
F
512n
512f
512
512g
600

FIG. 9

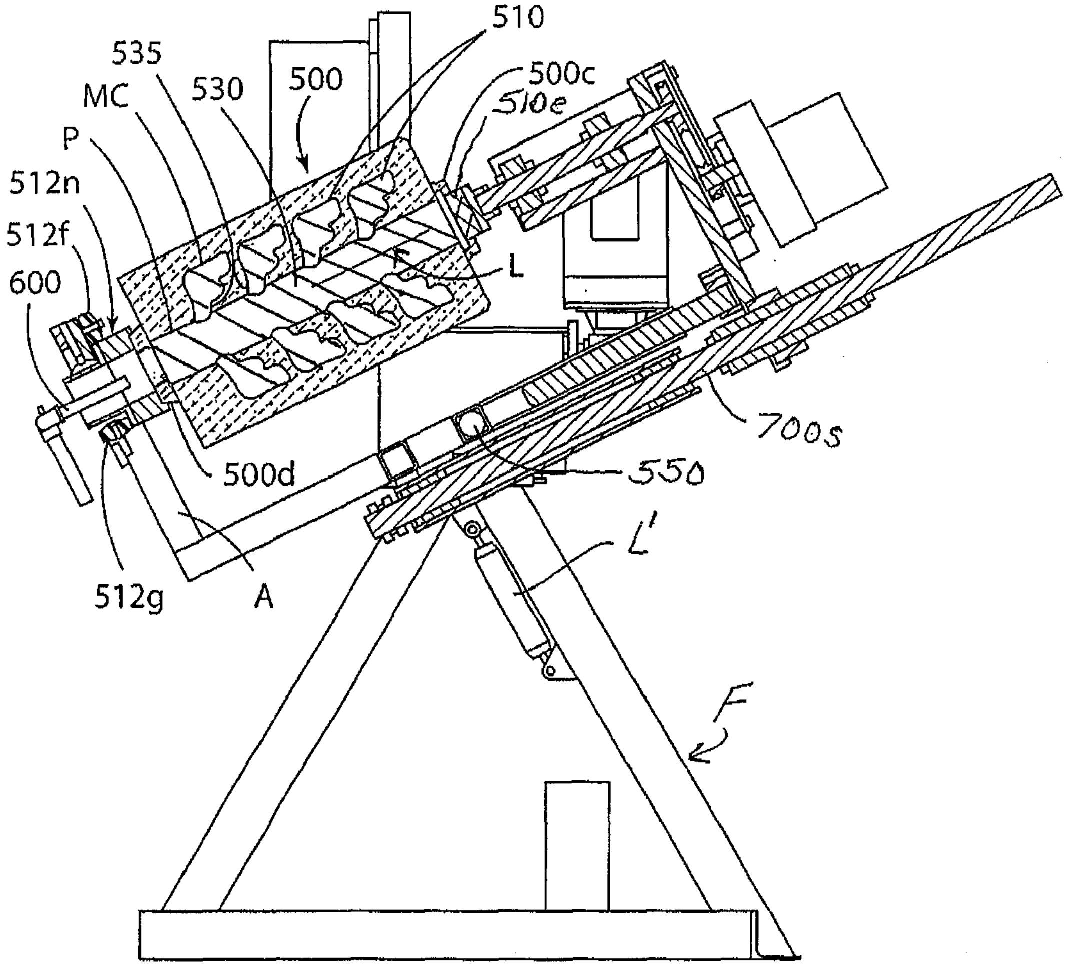
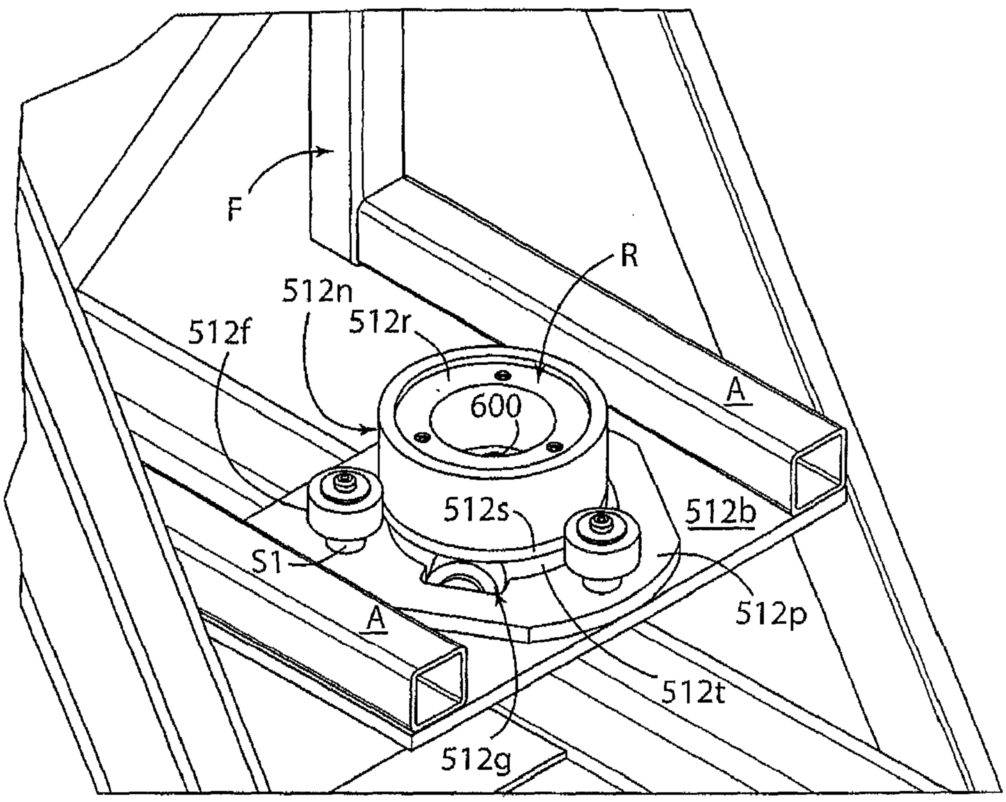

510
535
500
MC
530
500c
510e
P
512n
512f
600
L
700s
500d
550
L'
512g
A
F

FIG. 10

FIG. 11



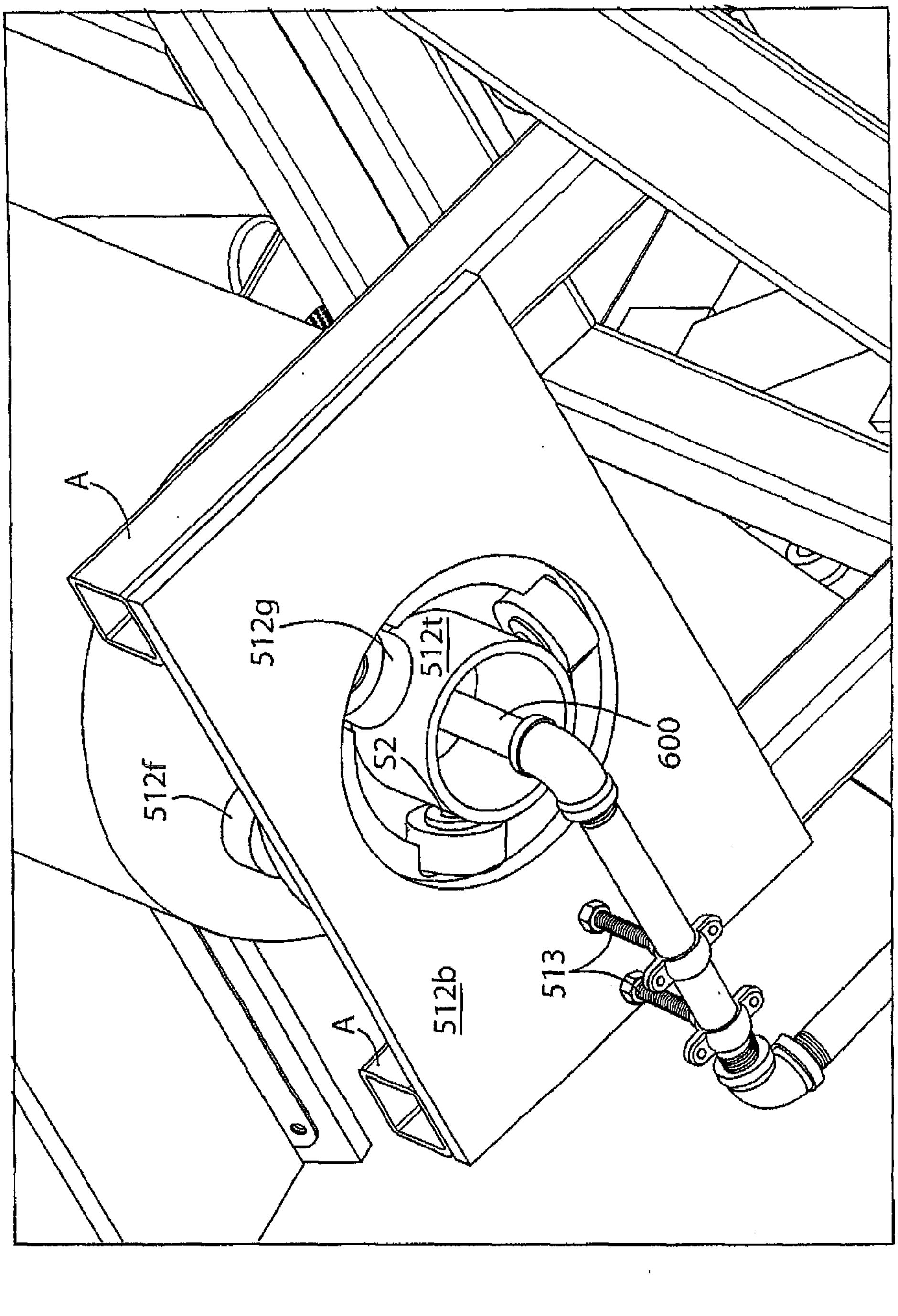


FIG.12

REFERENCES CITED IN THE DESCRIPTION

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- US 10899381 B **[0001] [0008] [0017]**
- US 6889745 B **[0005]**
- US 5069271 A **[0006] [0022] [0023] [0040] [0049]**