United States Patent

[11] 3,559,718

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[21] Appl. No. **758,018**
[22] Filed **Sept. 6, 1968**
[45] Patented **Feb. 2, 1971**

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[54] **METHOD AND APPARATUS FOR CENTRIFUGAL CASTING OF MOLTEN METAL**
7 Claims, 17 Drawing Figs.

[52] **U.S. Cl.** 164/114, 164/289, 164/336, 164/136
[51] **Int. Cl.** B22d 13/06, B22d 13/10
[50] **Field of Search** 164/114, 136, 289, 298, 336; 249/137

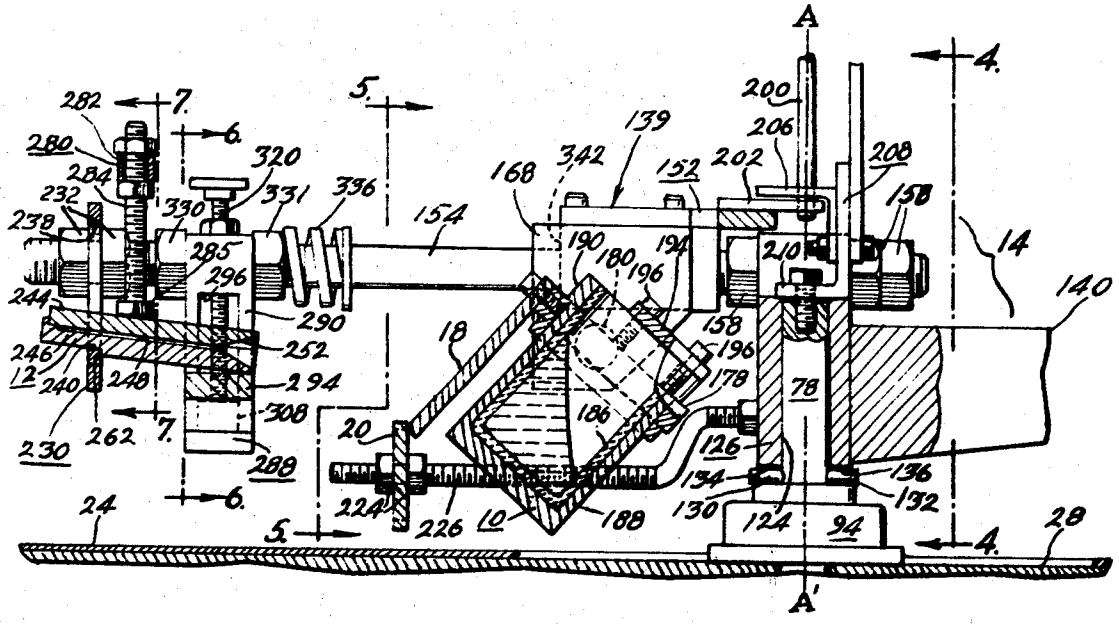
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Primary Examiner—J. Spencer Overholser
Assistant Examiner—R. Spencer Annear
Attorney—Howson and Howson

ABSTRACT: Apparatus and method especially suitable for casting low-density, high-surface tension, molten materials of high chemical activity into thin sheets. A crucible containing the molten material and having a top opening is mounted on a carriage which is in turn slidably mounted on one arm of a centrifuge. A mold for receiving the molten material is also mounted on the centrifuge arm, radially-outward of the crucible. The carriage is initially held at a radially inward position as the centrifuge is started up, and then released to slide rapidly outward against a stop arrangement which arrests its outward motion abruptly. During its radially-outward motion the crucible is tilted outwardly to a substantially horizontal position so that, when its outward motion is abruptly arrested, the crucible opening confronts the fill opening in the mold. The molten metal is thereby thrown out of the crucible through the top opening thereof into the mold-fill opening with a high velocity sufficient to cause injection of the molten material into the mold despite small lateral dimensions of the mold cavity. The mold may be of metal and operated relatively cool.



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SHEET 1 OF 4

FIG. 1.

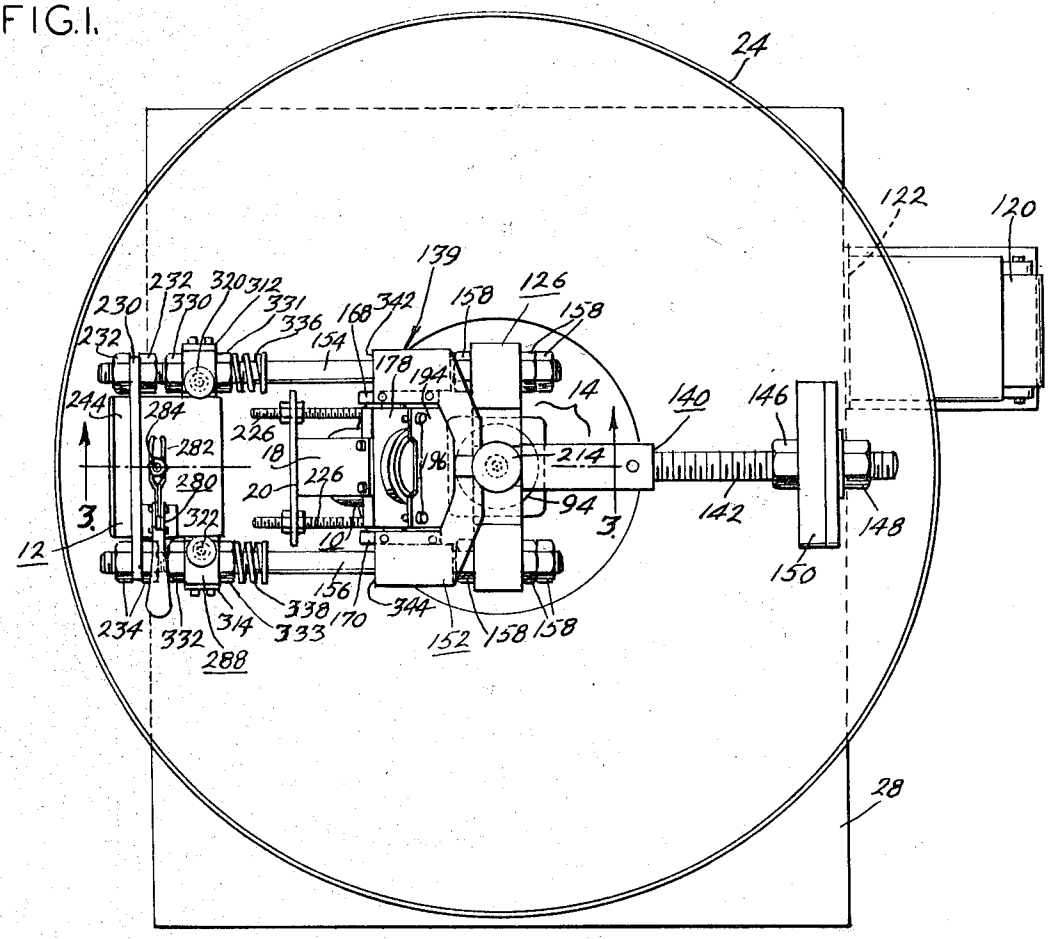
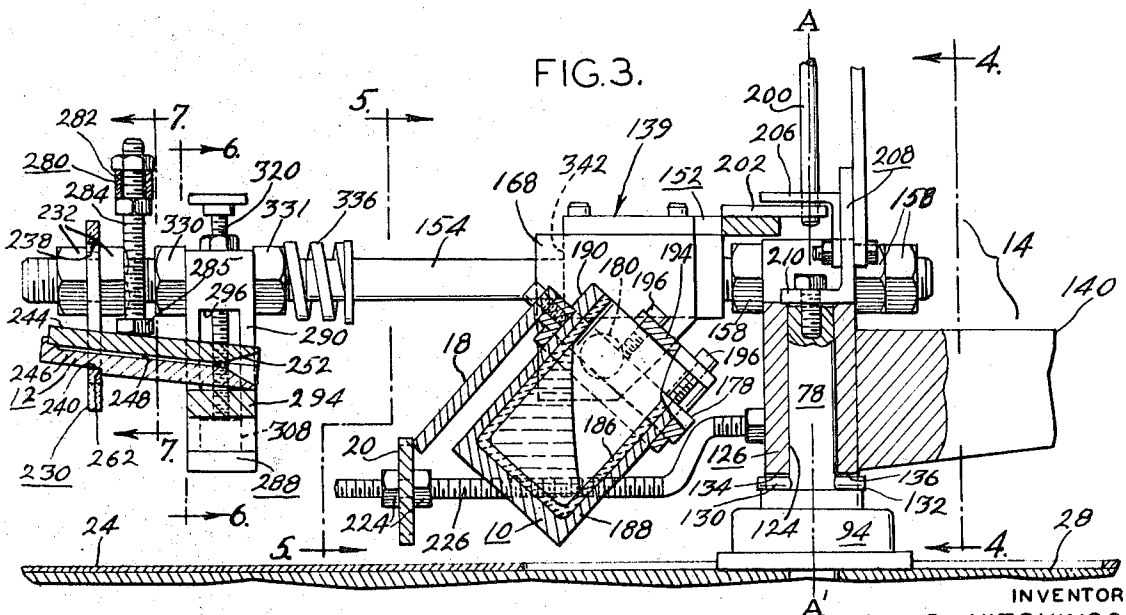


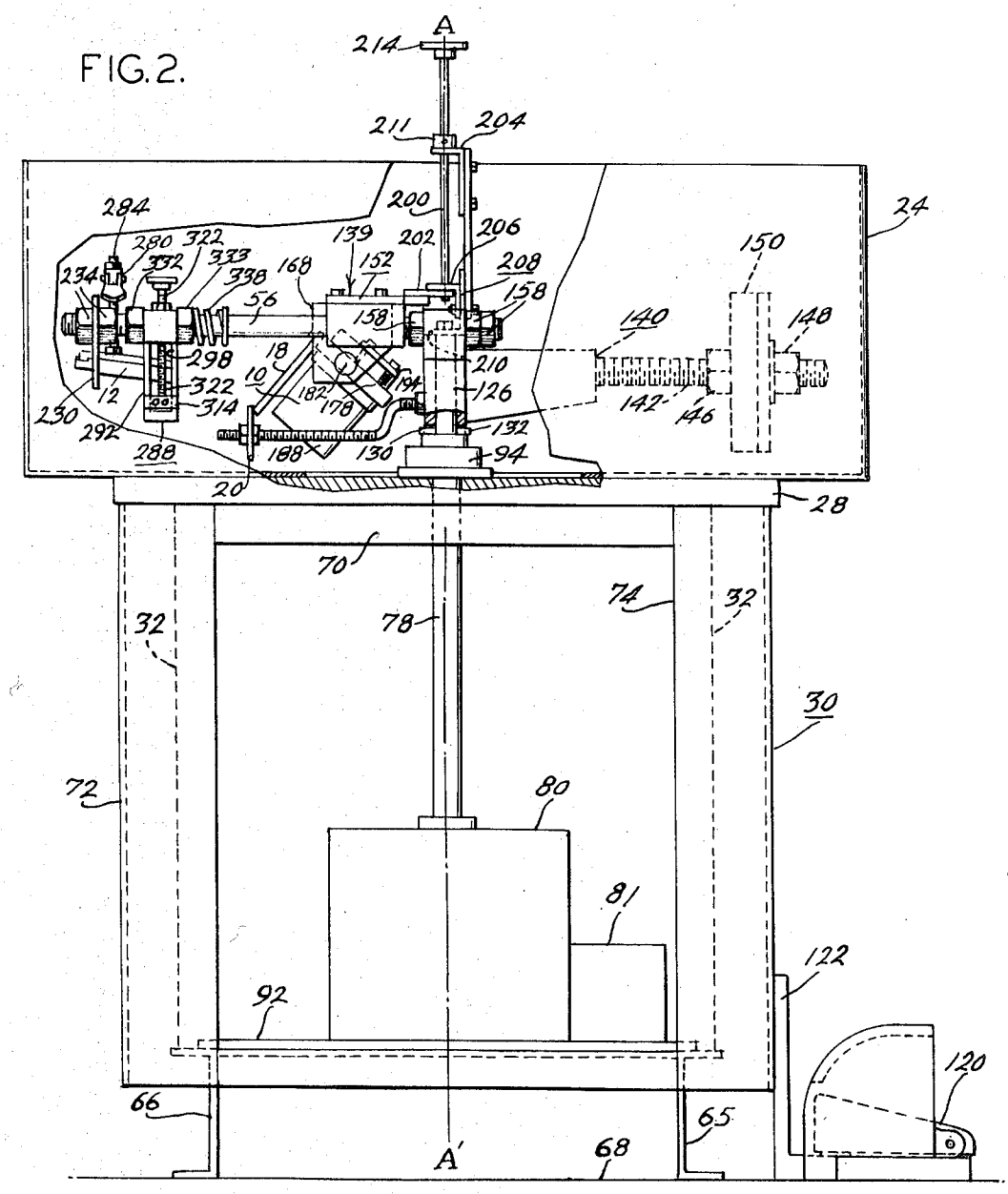
FIG. 3.



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FIG. 2.



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FIG. 4.

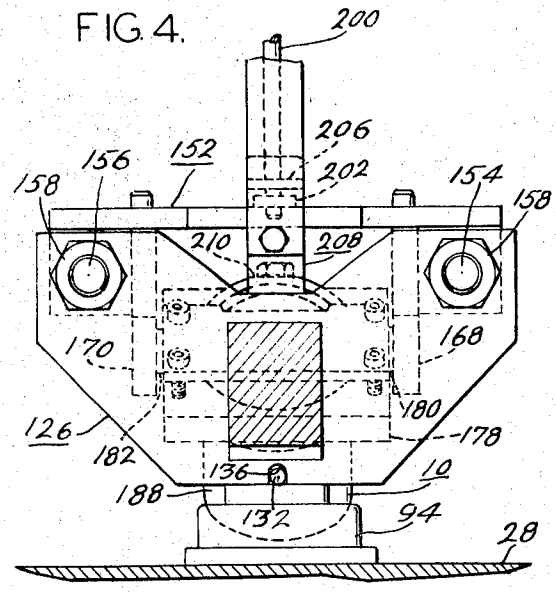


FIG. 5.

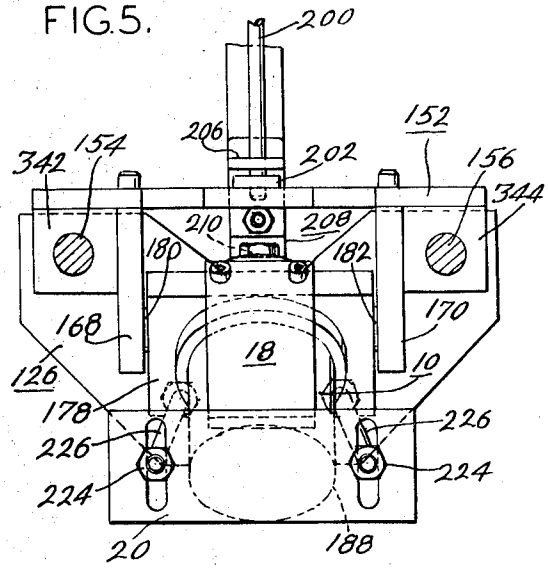


FIG. 6.

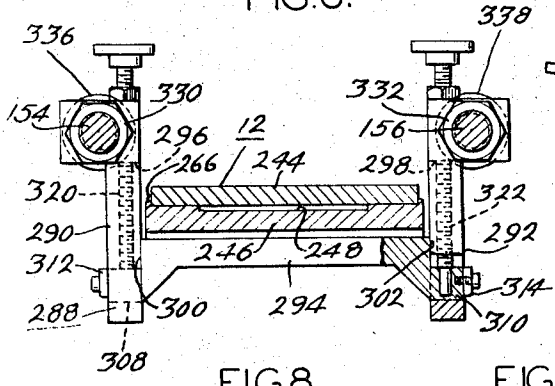


FIG. 7.

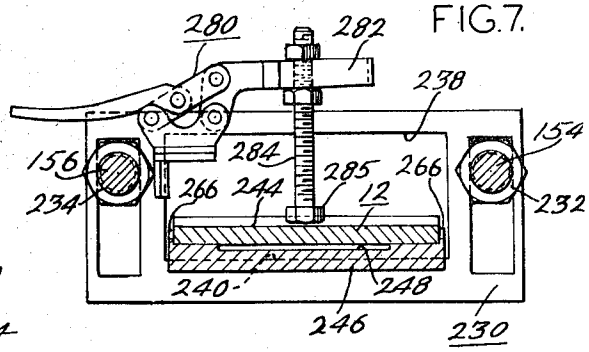


FIG. 8.

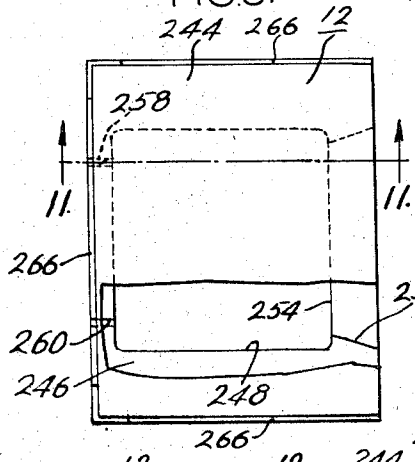


FIG. 9

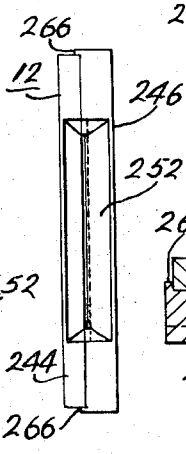


FIG. 11.

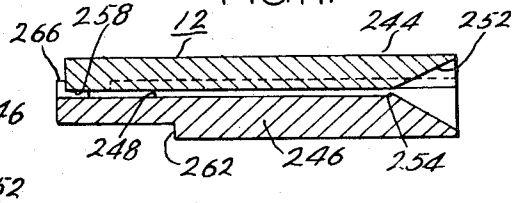


FIG. 12.

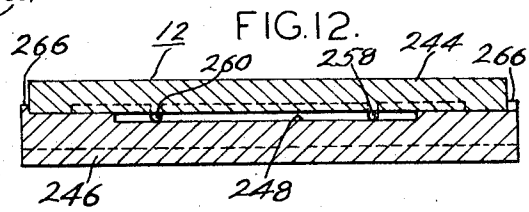
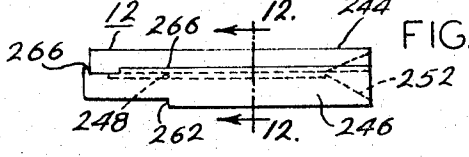


FIG. 10.



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FIG.13.

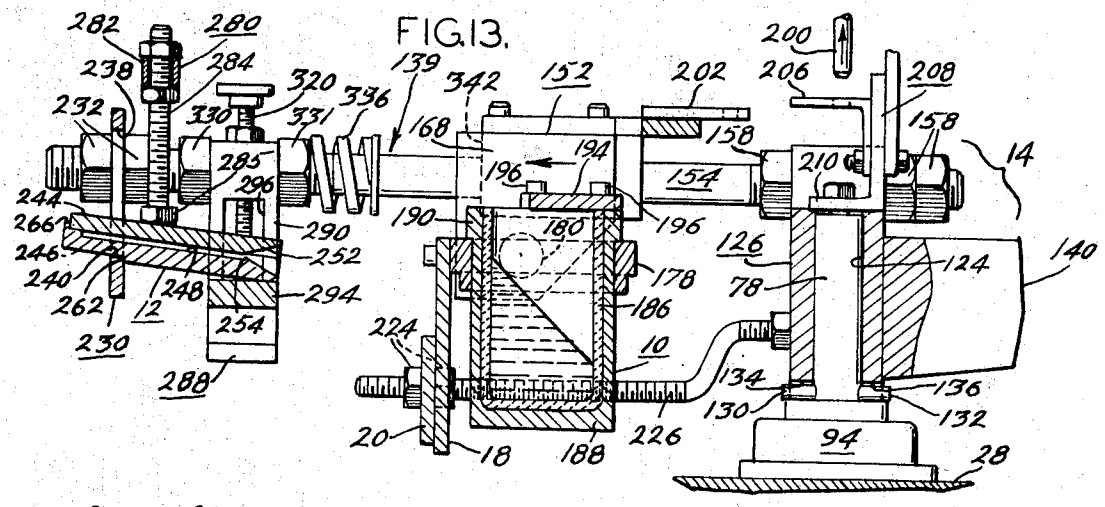


FIG.14.

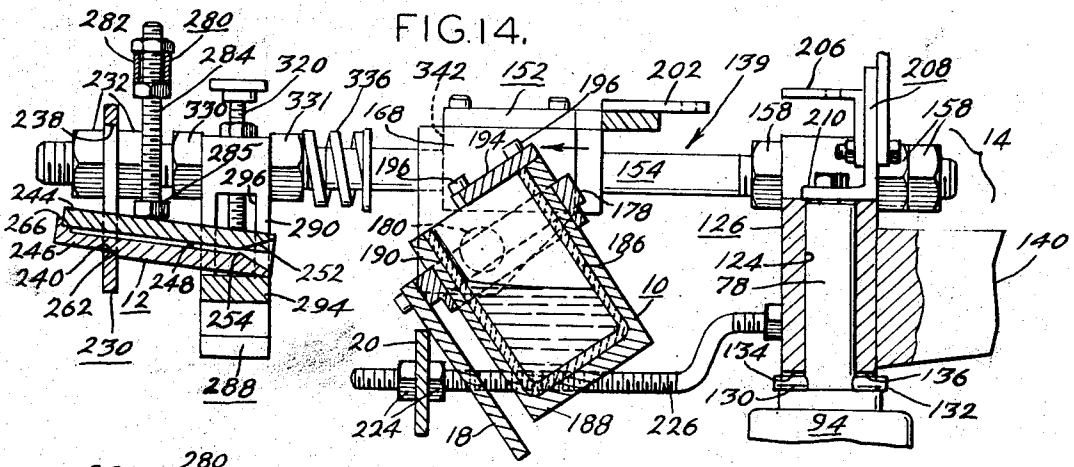


FIG.15.

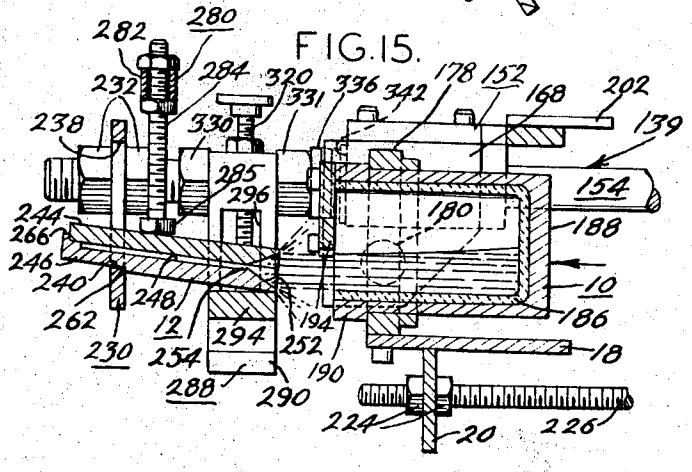


FIG.16.

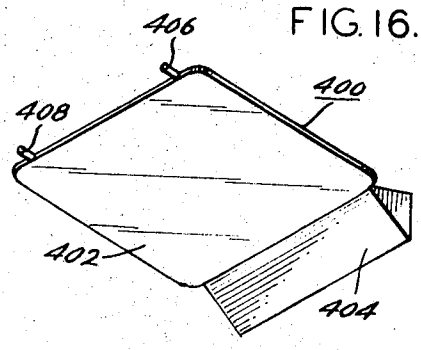
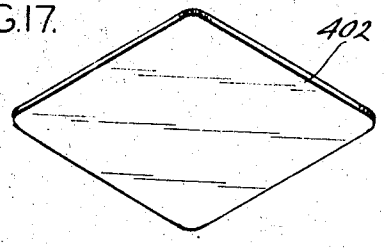


FIG.17.



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METHOD AND APPARATUS FOR CENTRIFUGAL CASTING OF MOLTEN METAL

BACKGROUND OF THE INVENTION

There are a variety of applications in which it is desirable to cast a flowable material into a mold cavity to produce a cast object having a narrow dimension. For example, it is sometimes desirable to cast thin sheets or plates having a thickness of about 0.050 inch or even less; such plates are, for example, desirable for use as the plates in certain types of batteries. Particularly where the material to be cast is a molten material of relatively high surface tension and relatively low density, gravity filling of the usual enclosed mold through a fill opening is impractical or impossible in such cases.

Methods are known in the prior art for forcing molten materials into and through narrow passages in mold cavities by means of a piston, but where the material to be cast is highly active chemically and/or must be maintained free of contamination, conventional equipment available for this purpose is generally unsatisfactory. This is primarily because the piston used to force the material into the mold cavity, when made of a material suitable for its mechanical function, is generally undesirable from the viewpoints of chemical reaction with, and contamination of, the molten material. Conversely, if a material is selected for the piston which is satisfactory from the viewpoints of reaction with, or contamination of, the molten material, it is generally deficient in its desired mechanical properties.

Another known method for forcing flowable material into narrow passages in mold cavities avoids the need for contact with a piston by applying centrifugal forces to the molten material. In such arrangements, the flowable material is supplied to the mold-fill opening and the mold rotated rapidly on an arm spinning about a centrifuge axis. To prevent premature solidification of the molten material, the mold and crucible are generally maintained at high temperatures.

In one form of apparatus utilized for such centrifugal casting, a heated crucible is provided with a spout on one side above the normal level of the molten material and is mounted on a centrifuge arm along with the mold, the mold being positioned radially outward of the crucible with the spout of the crucible radially aligned with the fill opening in the mold. The heating coil for the crucible is then removed, the centrifuge operated, and the crucible moves radially outward until the spout enters the mold fill-opening; the molten material climbs up the radially-outward wall of the crucible and flows through the spout into the mold-fill opening, and continued operation of the centrifuge then forces the molten material radially outward and into the narrow passageways in the mold. While satisfactory for some purposes, it has been found that the centrifugal forces tending to inject the molten material into the mold is insufficient in the case of very narrow mold passageways; for example, incomplete filling of the mold is generally found if one attempts to use such methods to cast lithium or lithium alloy plates of 0.100 inch thickness or less.

In another known form of apparatus the crucible is spun on the axis of rotation of the centrifuge while subjected to heating, with the mold mounted above and in alignment with the crucible top opening; when casting is to be performed, the axis of the crucible and mold is rotated to a horizontal radial position with the mold outward of the crucible, so that the molten material flows up the sides and out of the top of the crucible into the fill opening of the mold, and is forced into the mold by the continued centrifugal action. Again, while satisfactory for certain purposes, there are limits on the narrowness of the passageways into which molten material can thus be injected.

Accordingly it is an object of the invention to provide new and useful method and apparatus for the casting of flowable materials.

Another object is to provide such method and apparatus having improved characteristics with respect to the ability to fill narrow passageways in a mold cavity.

Another object is to provide such method and apparatus capable of producing thin plates of material.

A further object is to provide such method and apparatus which does not require strong heating of the mold or of the crucible.

It is still another object to provide such method and apparatus in which the mold may be of metal.

It is also an object to provide a method and apparatus which is quick and convenient in operation, and susceptible of a wide range of control for use in different applications.

SUMMARY OF THE INVENTION

In accordance with the invention these and other objects are achieved by the provision of a new and useful method and apparatus in which a container carrying the flowable material to be cast is provided with an opening above the level of the material therein when the container is at rest, and is accelerated toward an opening in the mold for receiving the flowable material. As the container approaches the mold, it is turned so that the opening in the container confronts the opening in the mold, and the container is then abruptly decelerated so that the flowable material is ejected through the container opening into the mold opening with a substantial velocity. Because of this velocity, the molten material penetrates into even narrow passageways in the mold cavity.

In a preferred embodiment of the invention, significant further improvement in casting of molten material into a narrow mold passageway is obtained as follows. Both the mold and the container are rotated about a common centrifuge axis with the container spaced radially inward from the mold with respect to the axis of rotation, the container being provided with an opening initially positioned above the level of the material in the container. The container is held against radially-outward motion during initial operation of the centrifuge. When the desired rotational speed has been obtained, the container is released so as to move rapidly radially-outward toward the mold and, as it moves outward, it is rotated to substantially a horizontal position in which the opening therein confronts the fill opening of the mold. Just prior to reaching the mold, the container is abruptly arrested in its radially-outward movement and the molten material is thrown forcefully out of the container, by way of the container opening, and into the mold-fill opening, the rotation of the centrifuge assisting in the further complete penetration of the mold cavity by the molten material.

Preferably the desired coordinated tilting or turning of the container for the molten material is provided by pivoting the container about a pivot axis in a carriage mounted to slide radially outward on the centrifuge arm, and by providing a trip arrangement which applies a restraining force to a portion of the container spaced from the pivot axis. Preferably this is accomplished by means of a trip arm connected to an off-axis portion of the container, cooperating with trip means which engages the trip arm to apply the desired tilting force in response to progressive radially-outward motion of the container.

With this method and apparatus, mold cavities having very narrow passageways may be entirely filled, and relatively cool molds, particularly metal molds, may be utilized even for casting of highly-reactive materials such as lithium and alloys thereof, without causing serious contamination of the cast material or substantial harmful effects on the casting apparatus.

BRIEF DESCRIPTION OF FIGURES

These and other objects and features of the invention will be more readily comprehended from a consideration of the following detailed description, taken in connection with the accompanying drawings, in which:

FIG. 1 is a plan view of apparatus embodying the invention, useful in performing the method of the invention;

FIG. 2 is a front elevation view of the apparatus of FIG. 1;

FIG. 3 is a fragmentary sectional view taken along lines 3–3 of FIG. 1;

FIGS. 4 through 7 are sectional views taken along lines 4–4, 5–5, 6–6 and 7–7, respectively, of FIG. 3;

FIG. 8 is a plan view, with parts broken away, of a mold suitable for use in the apparatus and method of the invention;

FIG. 9 is a front view of the mold of FIG. 8;

FIG. 10 is a side view of the mold of FIG. 8;

FIG. 11 is a sectional view taken along lines 11–11 of FIG. 8;

FIG. 12 is a sectional view taken along lines 12–12 of FIG. 10;

FIGS. 13 through 15 are fragmentary sectional views similar to FIG. 3 and showing the crucible in successive different tilted positions during operation of the apparatus;

FIG. 16 is a perspective view of a casting made by the method and apparatus of the invention; and

FIG. 17 is a perspective view of the casting of FIG. 16 after incidental portions undesired in the final product have been broken away.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the specific embodiment of the invention shown in the drawings by way of example only, and first with particular reference to FIGS. 1 and 2, there is shown a crucible 10 containing a molten material which is to be cast into the fill opening in the adjacent edge of a mold 12 by means of the centrifuge 14. In operation of the apparatus, the centrifuge 14 initially rotates the crucible 10 about the vertical axis A–A′ while the crucible is in the radially-inward position shown in FIGS. 2 and 3, after which the crucible is released and permitted to accelerate radially outward from axis A–A′ while its top is caused to tilt progressively outward by means of a trip arm 18 and a trip 20 as shown in FIGS. 3 and 13—15, until its radially-outward motion is abruptly arrested by a stop on the centrifuge arm thereby causing the molten material to be ejected from the container through its top opening into the fill opening of the mold 12, as shown in FIG. 15.

The centrifuge arrangement 14 is contained within the usual cylindrical centrifuge tub 24. Centrifuge tub 24 is secured to the top 28 of the base 30, formed by a plurality of upright angle iron members such as 32 secured to the tops of a pair of U-shaped channel members 65 and 66 which rest on their sides on the floor 68. The vertical angle irons are interconnected by horizontal angle irons, such as top angle iron 70, to which the base top 28 is appropriately secured. A metal cabinet 72 surrounds the base on three sides and along the vertical edges of the front, leaving a front opening 74 for access to the mechanism within the cabinet.

The vertical drive shaft 78 for rotating the centrifuge apparatus is driven from a conventional electrical motor drive 80 the speed of which is controllable by a conventional speed control 81. Drive shaft 78 is supported by the motor bearing and by an upper bearing 94 mounted on the base top 28. Also provided is a foot pedal 120, secured to a bracket 122 on the lower edge of the cabinet 72 which foot pedal, when depressed, closes a switch (not shown) for running the motor.

Centrifuge tub 24 is provided with a central opening to accommodate upper drive shaft bearing 94. As shown particularly clearly in FIG. 3, the upper end of drive shaft 78 extends into sliding engagement with the interior of a bore 124 in an arm support block 126, drive shaft 78 being provided with a pair of radially-extending pins 130 and 132 which extend through corresponding conforming cutouts 134 and 136 in the lower edge of arm support block 126 so as to provide rotational drive for the block. Secured to arm support block 126 is the centrifuge arm apparatus 139 extending radially at right angles to axis A–A′ on one side thereof for supporting and operating the crucible and mold, and a counterweight arm 140 extending radially on the opposite side of axis A–A′. The radially-outward portion of counterweight arm 140 is provided with a threaded region 142 and with a pair of clamp nuts 146 and 148 between which is clamped the counterweight 150, the radial position of the counterweight being adjustable by appropriate adjustment of the clamp nuts. The counterweight serves the usual purpose of providing dynamic balance for the centrifuge arm apparatus 139 during rapid rotation of the centrifuge.

Crucible 10 is pivotably supported on a carriage 152 slidably mounted on a pair of guide rods 154 and 156, which rods pass through a corresponding pair of bores in arm support block 126 and are secured thereto by means of nuts 158. The desired sliding support of the carriage 152 on the guide rods is provided by cylindrical bores in opposite sides of the carriage in which the guide rods fit slidably.

To provide pivotable mounting for the crucible 10 on the carriage 152, there are provided a pair of downwardly-extending side members 168 and 170 secured to the undersurface of carriage 152 on opposite sides of the crucible. A mounting plate 178 is provided with a pair of trunnions 180 and 182 at opposite sides thereof, which are journaled in the side pieces 168 and 170 respectively for rotation about a horizontal axis.

Crucible 10 comprises an inner cylindrical refractory liner 186 having an open top, and a generally-cylindrical metal outer casing 188 provided with an outwardly-extending peripheral flange 190 near its top. Crucible 10 fits within a circular opening in mounting plate 178 and rests therein on the lower side of flange 190. A partial closure member 194 is mounted over and against a portion of the top opening in crucible 10 by means of screws 196 threaded into corresponding holes in the mounting plate 178 so as to clamp the crucible in position and also to close off all but about one-third of the top opening located on the side of the crucible radially-outward from axis A–A′.

Accordingly, the crucible 10 is adapted to move radially-outward on carriage 152 in response to centrifugal force generated by rotation about axis A–A′. However, it is initially restrained from so doing by a retaining pin 200 which engages an aperture in a tab 202 mounted on the top of carriage 152 and extending radially-inward toward axis A–A′. Alignment for the retaining pin 200 is maintained by a pair of aligned, loosely-fitting apertures in brackets 204 and 206, both of which are mounted on another bracket 208 having a foot 210 bolted to the top of drive shaft 78, the latter foot extending laterally sufficiently also to hold arm support block 126 in its downward position. A pin-positioning collar 211 is secured to retaining pin 200 just above the point at which the pin passes through bracket 204 to limit the downward motion of the pin so that its lower end just extends through the aperture in tab 202. A knob 214 is provided at the top of retaining pin 200 to permit rapid manual upward movement of the pin when it is desired to disengage the lower end thereof from tab 202, thereby to release carriage 152 and permit it to move radially outward.

To control the tilt angle of the crucible during operation, there are also provided a trip arm 18 in the form of a plate secured to, and extending downwardly from, one edge of mounting plate 178, and a trip 20 which engages the lower end of trip arm 18 and is held in a fixed but adjustable position between a pair of clamp nuts 224 on a threaded rod 226 extending from and secured to the arm support block 126.

Between guide rods 154 and 156 and near their radially-outward ends there is disposed an outer mold-supporting panel 230, shown in detail in FIG. 7. The radially-outward ends of guide rods 154 and 156 are threaded and the panel is mounted on them by a pair of clamp nuts 232 on guide rod 154 and a corresponding pair of clamp nuts 234 on guide rod 156, the guide rods extending through rectangular slots near opposite edges of the panel 230. These slots provide for limited lateral adjustment of the position of the panel 230, and for substantial vertical adjustment of its position. Panel 230 contains a central rectangular window 238 at its center, the lower edge 240 of the window 238 serving to support the outer end of mold 12, which extends through the window.

As shown in FIGS. 8—12 particularly, the mold 12 in this case is a split mold comprising an upper mold plate 244 and a lower mold plate 246 which bear against each other and the lower mold plate 244 is provided with a shallow generally-rectangular recess 248, which forms the main mold cavity in

which the cast plate is to be formed. At the edge of the mold toward axis A–A' both mold plates are beveled outwardly so as to diverge in a vertical plane and form a fill opening or gate **252** through which the molten material is to be injected into the interior of the mold. Preferably the mold cavity is necked-down slightly by an upwardly-extending shoulder **254** on lower plate **246**, to form a weakened line across the cast object between the desired cast plate itself and material which hardens within the gate; this facilitates later removal of the solidified gate material. A pair of air-vent holes **258** and **260** extend from the rear of the mold cavity to the exterior of the rear edge of the mold to permit the escape of trapped air from the mold cavity during casting. The lower surface of the lower mold plate **246** is provided with a step or shoulder **262** along its width, which shoulder bears against the inner side of the lower edge **240** of outer mold-supporting panel **230**, as shown particularly clearly in FIG. **3**. In this way the lower half of the mold is prevented from moving outwardly during the centrifuging operation. An upwardly-extending shoulder **266** is also provided along the rear and side edges of the lower mold plate, against which the rear and side edges of the upper mold plate **244** are seated to restrain it from outward and sideways motion.

As shown particularly clearly in FIG. **7**, the upper and lower mold plates are clamped together and against panel **230** during operation by means of a rapid release, overcenter, manually-operable clamp actuator **280** having a lever arm **282** to which is attached a generally-vertical bolt **284**, the head **285** of the bolt being disposed downwardly to bear against the upper surface of the upper mold plate **244** when the clamp is operated to one position and to be raised from the upper mold plate when the clamp is operated to its other position so as to permit removal of the mold.

The radially-inward end of the mold **12** is held by the inner mold-supporting assembly **288**, details of which are shown in FIGS. **3** and **6** for example. This assembly comprises two downwardly-extending legs **290** and **292**, mounted on guide rods **154** and **156** respectively and joined near their lower ends by a bridging member **294**. Legs **290** and **292** are provided with corresponding rectangular windows **296** and **298**, respectively, extending through each of them transversely to the lengths of the guide rods. Bridging member **294** is provided at opposite ends thereof with a pair of shoulders **300** and **302** which bear against the inner sides of the legs **290** and **292**, respectively, to hold them apart from each other with a fixed spacing. Bridging member **294** is also provided at its opposite ends with a pair of lateral extensions **308** and **310** which fit within windows **296** and **298**, respectively, and are vertically slidable therein. A pair of retaining tabs **312** and **314** are screwed to the outer ends of the extensions **308** and **310**, respectively, and extend outwardly along the adjacent outer surface of the two legs **290** and **292** to prevent the latter legs from diverging. The windows **296** and **298**, the bridging member **294**, and the retaining tabs **312** and **314** are so positioned and configured that the bridging member **294** is readily slidable vertically with respect to the leg members **290** and **292**.

A pair of lag screws **320** and **322** are threaded vertically into the upper portions of leg members **290** and **292**, respectively, the lower ends of the latter screws being retained rotatably in the lateral extensions **308** and **310** of the bridging member **294**. Accordingly, by turning one or both of the lag screws, the bridging member **294** (and hence the radially-inward end of mold **12**) can be adjusted along the vertical direction as desired.

The position of the inner mold-supporting assembly **288** along the guide rods **154** and **156** is adjustable by adjustment of the positions of two pairs of clamping nuts **330**, **331** and **332**, **333** for the two leg members **290** and **292**, respectively, the two pairs of nuts being in threaded engagement with the guide rods **154** and **156**, respectively. The clamping nuts **331** and **333** also provide a stop for arresting the outward motion of the carriage **152**, this arresting being cushioned by means of a pair of strong helical springs **336** and **338** disposed around guide rods **154** and **156**, respectively. When carriage **152** moves radially outward, the flat end portions **342** and **344** of carriage **152** which surround the guide rods **154** and **156**, respectively, strike the inner ends of the springs **336** and **338**, respectively, until they are totally compressed against the clamp nuts **331** and **333**, respectively, and the carriage motion thereby completely arrested.

In the operation of the system, before the centrifuge is started the carriage **152** is slid manually to its retracted, radially-inward position, and retaining pin **200** is lowered to engage the aperture in tab **202** on the carriage. The mold clamp structure **288** is operated to its release position, the two halves of the mold assembled and placed in the outer mold-supporting panel **230** and in the inner mold-supporting assembly **288** as shown in the drawings, with the fill opening **252** directed generally radially inwardly and nearly horizontal, although the radially-outward end of the mold is tilted slightly upward from horizontal; the clamp structure **280** is then operated to clamp the mold tightly in position The mold and crucible are preheated with a torch, and the molten material is then introduced into the crucible **10** by way of the portion of the top opening thereof which is not covered by cover plate **194**. The foot pedal **120** is then pressed to start the motor drive **80** and to begin rotation of the centrifuge. When the centrifuge has come up to the desired steady-state speed, retaining pin **200** is withdrawn upwardly and the carriage **152** is immediately accelerated rapidly outward along guide rods **154** and **156**, until it is abruptly arrested by the springs **338** and **336**. During its radially-outward motion, the crucible is tilted by the action of trip arm **18** and trip **20** so as to progress through the successive different tilt positions shown by way of example in FIGS. **3** and **13**—**15**. FIG. **13** shows the crucible when it has moved sufficiently outwardly to be tilted to a vertical position, FIG. **14** shows it when it has progressed to the point at which the crucible is approximately at 45° to the vertical, and FIG. **15** shows the final condition in which the crucible has turned to the horizontal position and has been arrested to eject its contents radially outward and into the fill opening **252** in mold **12**. Motor drive **80** is then turned off, the centrifuge comes to rest, the clamp actuator **280** is released, the mold is removed, the two mold halves are separated, and the casting **400** represented in FIG. **16** removed from the mold. In addition to the desired generally rectangular thin plate portion **402**, casting **400** initially also has attached thereto a gate portion **404** and a pair of small pinlike projections **406** and **408** due to the air vent holes **258** and **260** in the rear portion of the mold. The gate portion and the two pinlike projections are readily knocked off and broken away to produce the final desired thin plate **402** of FIG. **17**.

The following example of materials and values which may be used is given merely by way of specific illustration, without in any way thereby limiting the scope of the invention. In this example a 200 gram charge of aluminum-lithium alloy comprising 13 percent of lithium by weight was prepared in a clay-graphite crucible in a gas-fired furnace and heated so that it had a temperature of about 1,700° F. when it was ladled into the top opening in the preheated crucible **10**. The crucible was preheated to about 500°—600° C. and the mold to about 200° C. by application of an oxygen-propane torch. The liner of crucible **10** was a cylinder of clay-graphite approximately 2 inches in diameter and 3½ inches high, about two-thirds of the top opening of the crucible **10** on the side toward axis A–A' being covered by top cover **194** so that the uncovered portion of the top opening approximated the size and shape of the mold-fill opening. The mold was a copper beryllium alloy and weighed about 4 pounds; the mold cavity provided therein was about 0.050 inch in thickness, 3 inches long and 3 inches wide. The lower half of the mold cavity had an upward step or shoulder at **254** along its front edge about 0.015 inch in height. The gate comprising the fill opening was about 2.56 inches long along the edge presented to the crucible, and had upper and lower inner surfaces diverging at about a 48° angle.

The mold vent holes were one-sixteenth inch in diameter. The carriage when retracted placed the crucible pivot axis initially about 4 inches from the axis of rotation A–A', and the subsequent outward radial motion of the carriage before its complete arrest was about 4 inches. The casting arm of the centrifuge on which the carriage and crucible were mounted weighed about 66 pounds, and the carriage and crucible assembly weighed about 12.5 pounds additional. The final cast plate weighed about 15 grams.

The motor drive system was set to produce a steady state rotational rate of about 350 r.p.m., which it reached within a few seconds after being turned on by the foot pedal. The carriage was then released by removing the retaining pin, and the motor turned off immediately after arrest of the radially-outward motion of the carriage. The casting arm was permitted to coast to a stop, which required about 10—15 seconds, the mold was immediately unclamped and removed, and the cast article was then taken out of the mold.

As represented in FIG. 3, in its retracted position the crucible **10** was tilted at about 45° inwardly toward the axis A–A' to prevent overflow of the molten material during initial rotation, and at the time of discharge of its contents was turned outwardly from the axis A–A' substantially to a horizontal position. The mold **12** was placed at a few degrees from the horizontal. Upon discharge, the mold material in this example tended to be ejected with a slight upward angle, which is the reason for providing a slight corresponding angle for the mold. In any given example it will be understood that the discharge angle of the crucible and the angle and precise location of the mold may be adjusted by the means hereinbefore described in order to obtain full, quick filling of the mold cavity.

The locations and surface configurations of the molten mass **500** in the crucible, as shown in FIGS. **3** and **13—15**, are diagrammatic only, since it will be understood that the crucible moves outwardly at a very rapid rate while it is also being rapidly tilted, and the exact form of the liquid is difficult to determine and depict. In general, however, while the carriage is retained in its radially-inward position and is being rotated by the centrifuge, as shown in FIG. 3, the centrifugal force generated causes the molten material to be pressed against the radially-outward portion of the crucible and to climb up the walls thereof, the force on the molten metal charge in the specific example above being of the order of 14 gravities before the carriage is released. When the carriage is released for outward motion and the crucible also begins tilting, the outward acceleration and the tilting of the crucible cause the molten material to be so disposed within the crucible that, upon subsequent sudden arresting of outward motion of the crucible, the molten material is in a position to be thrown more or less directly through the opening in the top of the crucible, without appreciable slowing due to viscous flowing over the sidewalls as it exits from the crucible. It is believed to be this factor which causes the molten material to be discharged with exceptionally high velocities, which in the specific example given above is approximately 18 feet per second, and it is apparently this high velocity of ejection which provides sufficient force to insure injection of the molten material through the mold cavity despite the narrow thickness dimension of the mold cavity.

It has been found that if the carriage is not initially restrained during the initial rotation of the centrifuge, the efficiency of the operation is substantially degraded, and that this initial restraining by the retaining pin is highly advantageous in insuring the high velocity of ejection of the molten material into the mold fill opening which is desired for best results. This initial restraining permits the centrifuge to come up to full speed before the carriage is released, and also provides an initial position of the molten material along the crucible side which apparently facilitates the subsequent high-velocity discharge.

While a variety of molten metals may advantageously be cast by the method and apparatus described, it is with those materials of low density and high corrosiveness or chemical activity with which it is most advantageous. Aluminum-lithium alloys, for example, typically have densities of about 2 and in molten state will normally react with a metal mold. In the method and apparatus of the invention, the high-velocity discharge forces even low-density material into very narrow mold passages, and the rapid solidification of the material in the relatively cool metal mold prevents appreciable chemical reaction with the mold. Other examples of alloys which are cast with advantage by the above-described method and apparatus include, but are not limited to, pure lithium; lead lithium; 1 percent aluminum 14 percent lithium 85 percent magnesium; and pure aluminum.

While the method and apparatus set forth herein by way of example has been found especially advantageous in providing complete filling of molds having narrow passageways, particularly where the material is corrosive or highly active chemically and of low density, some of the advantages of the invention may be derived by quite different apparatus and methods than those specifically set forth. Thus, in essence, according to the invention the molten material is placed in a container which is accelerated to impart a relatively high velocity thereto, after which it is decelerated just before reaching the mold so as to eject the molten material forcefully and at a relatively high velocity into the mold, the container being subjected to tilting during its motion so as to provide optimum conditions for ejecting the molten material at a high velocity; as mentioned hereinbefore, special advantage is obtained when the motion is imparted to the container by centrifugal force, particularly where the container is first restrained against motion in response to the centrifugal force and then released for rapid radially-outward travel and subsequent impact against a stop which abruptly arrests the outward motion.

Accordingly, while the invention has been described in the interest of definiteness in particular connection with specific embodiments thereof it will be understood that it may be embodied in a variety of forms diverse from those specifically described without departing from the scope of the invention as defined by the appended claims.

I claim:

1. The method of casting a material which comprises:

imparting a linear velocity to a container carrying a molten metal to be cast and having an opening therein, to cause said container to approach a mold having a fill opening for receiving said molten metal, said container initially being oriented so that said opening therein is turned away from said fill opening;

rapidly decelerating said container as it approaches said opening in said mold; and

turning said container, while it is moving toward said mold, so that said opening in said container is turned toward said fill opening in said mold when said deceleration occurs, whereby said molten metal is ejected from said opening in said container and injected into said fill opening in said mold.

2. The method of casting a molten metal material, which comprises:

placing said material in a container having an opening above the level of said material in said container;

rotating said container and said material therein about an axis outside said container to impart to said container a radially-outward motion with respect to said axis;

thereafter abruptly arresting said radially-outward motion while holding the fill opening of a receiving mold in a position adjacent and radially outward of said container with respect to said axis; and

during said radially-outward motion and prior to said arresting, turning said container so that said opening therein is directed toward said opening in said mold, whereby said material is ejected from said container and injected into said mold by way of said opening in said container and by way of said fill opening in said mold.

3. The method of claim **2**, comprising initially restraining said container against said radially-outward motion with

respect to said axis while said container is rotating about said axis and thereafter releasing said container from said restraining while continuing said rotating thereof.

4. The method of casting a molten metal material, comprising:

providing said material in molten form in a chemically-inert crucible having a top opening;

rotating said crucible containing said material about a substantially vertical axis outside said crucible while initially holding said crucible generally upright and while restraining it against radially-outward motion with respect to said axis;

rotating a mold along with said crucible but in a position radially outward therefrom with respect to said axis, said mold having a fill opening facing radially inward with respect to said axis, said mold being maintained at a temperature substantially below the melting point of said material and composed of a substance which tends to react with said material when said material is in the molten state;

releasing said crucible from said restraining while continuing said rotation of said crucible to impart to said crucible an accelerated radially-outward motion with respect to said axis;

thereafter abruptly arresting said radially-outward motion adjacent, and radially inward of, said fill opening in said mold; and

during said radially-outward motion and prior to said arresting, turning said crucible so that it is substantially horizontal with said top opening confronting said fill opening when said arresting occurs.

5. The method of casting into the form of a thin sheet a molten material consisting principally of lithium or aluminum, or alloys thereof, comprising:

melting said material;

introducing the molten material into a refractory crucible having an opening at its top;

rotating said crucible containing said molten material about a substantially vertical axis outside said crucible, together with an unheated metal mold containing a cavity for forming a thin sheet of said material, said mold being positioned radially of said crucible with its fill opening facing radially inward with respect to said axis;

initially restraining said crucible in a generally upright position at a first distance from said axis during said rotating;

thereafter releasing said crucible from said restraining to permit radially-outward motion thereof with respect to said axis while continuing said rotating;

abruptly arresting said radially-outward motion at a second radial distance from said axis greater than said first distance; and

while said crucible is traveling from said first position to said second position, turning said crucible from said generally-upright position to a generally-horizontal position with said opening in the top thereof aligned with and confronting said fill opening of said mold, whereby said molten material is thrown out of said crucible and into said mold.

6. Apparatus for injecting a molten material into a mold, comprising:

centrifuge means comprising an arm extending radially from, and rotatable about, a predetermined axis of rotation;

a carriage mounted on said arm for rotation therewith and for easy radial motion along said arm;

means for abruptly arresting radially-outward motion of said carriage along said arm at a predetermined first radial position;

means for rotating said arm with said carriage spaced radially inward of said first position, whereby said carriage is provided with a radially-outward motion and then abruptly arrested at said first position;

crucible means pivotably mounted on said carriage and having a top opening;

means for holding said crucible initially in a generally-upright orientation and at a position spaced radially inward of said first position;

means for tilting said crucible, during said radially outward motion, about an axis of pivot from said initial generally upright orientation to a substantially horizontal orientation, whereby said molten material is ejected from said crucible when said motion is abruptly arrested by said arresting means; and

mold means positioned radially outward of said first position and having a fill opening adjacent and confronting said top opening when said crucible is abruptly arrested by said arresting means, whereby said ejected material is injected into said mold.

7. The apparatus of claim 6, in which said tilting means comprises trip means having a fixed radial position with respect to said predetermined axis, and arm means contacting said trip means and connected to said crucible off said axis of pivot to tilt said crucible in response to radial motion of said carriage.