March 27, 1951 T. E. NORMAN 2,546,517

METAL CASTING

Filed Sept. 4, 1945 3 Sheets-Sheet 1

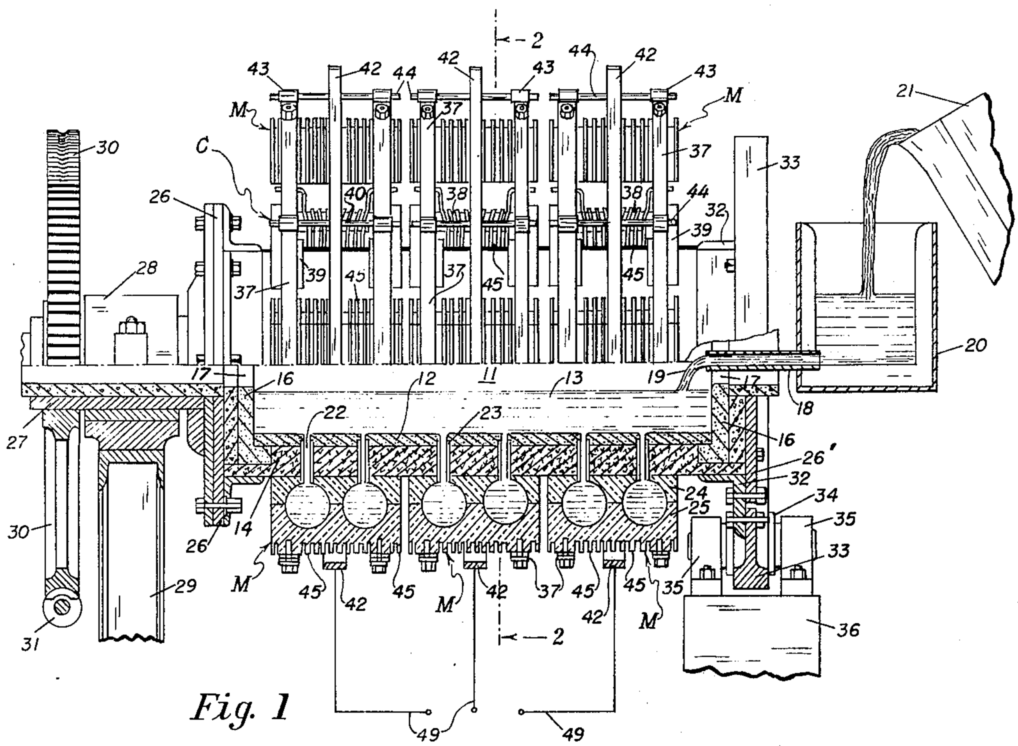

Fig. 1

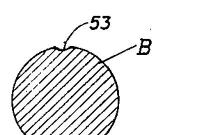

Fig. 4

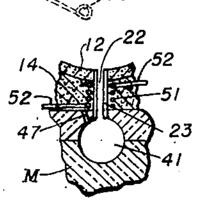

Fig. 3

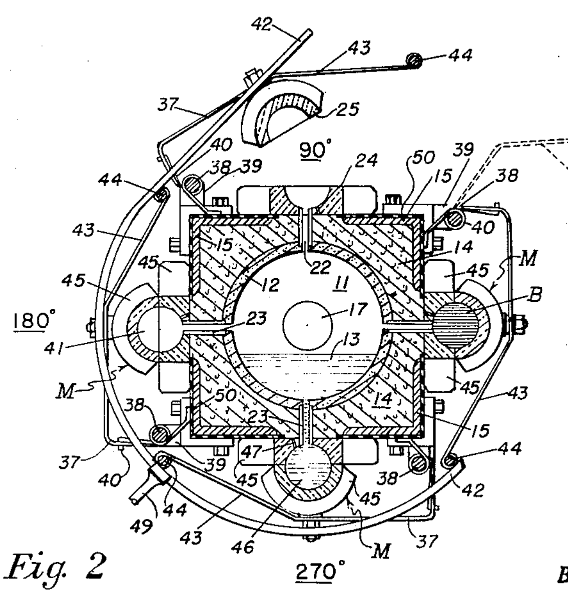

Fig. 2

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METAL CASTING

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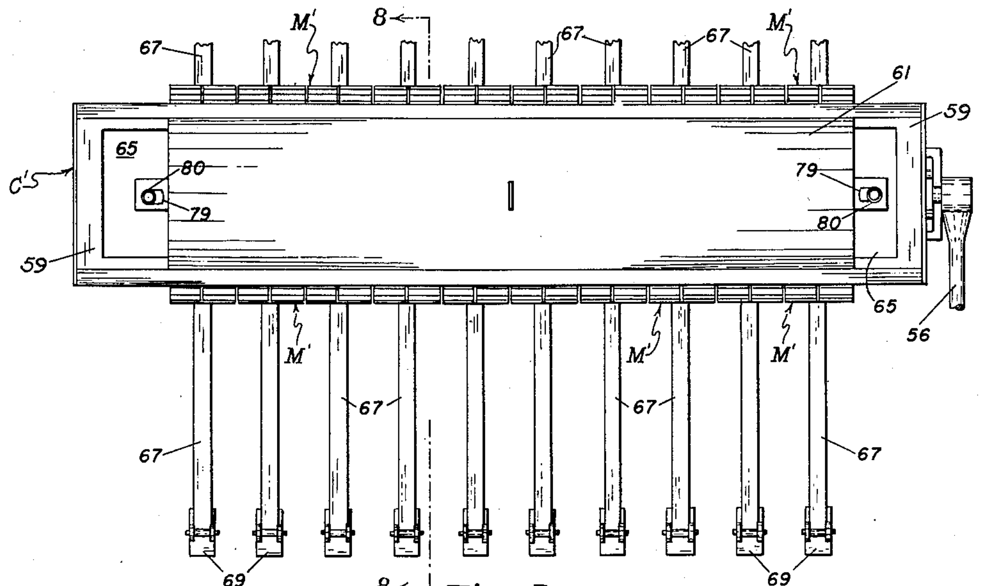


Fig. 5

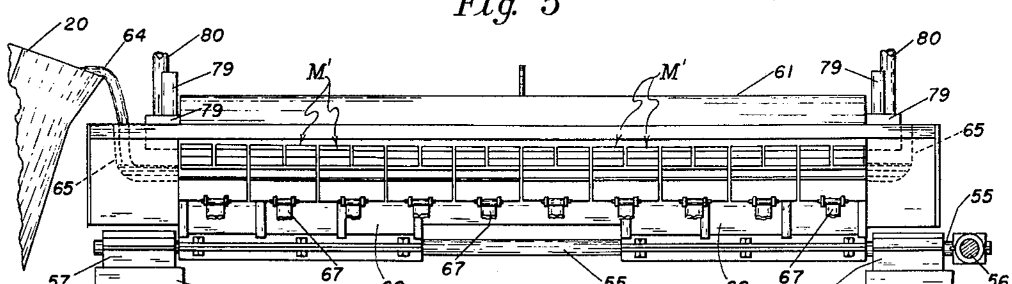
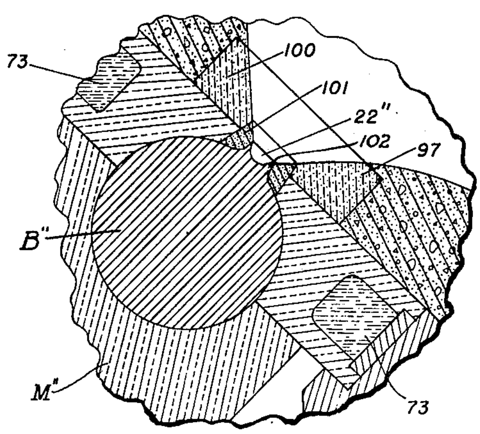


Fig. 6



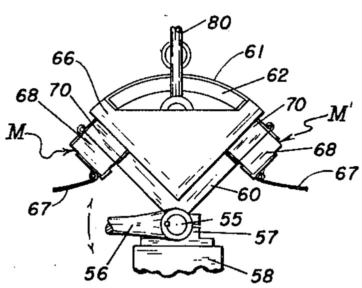


Fig. 7

Fig. 11

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METAL CASTING

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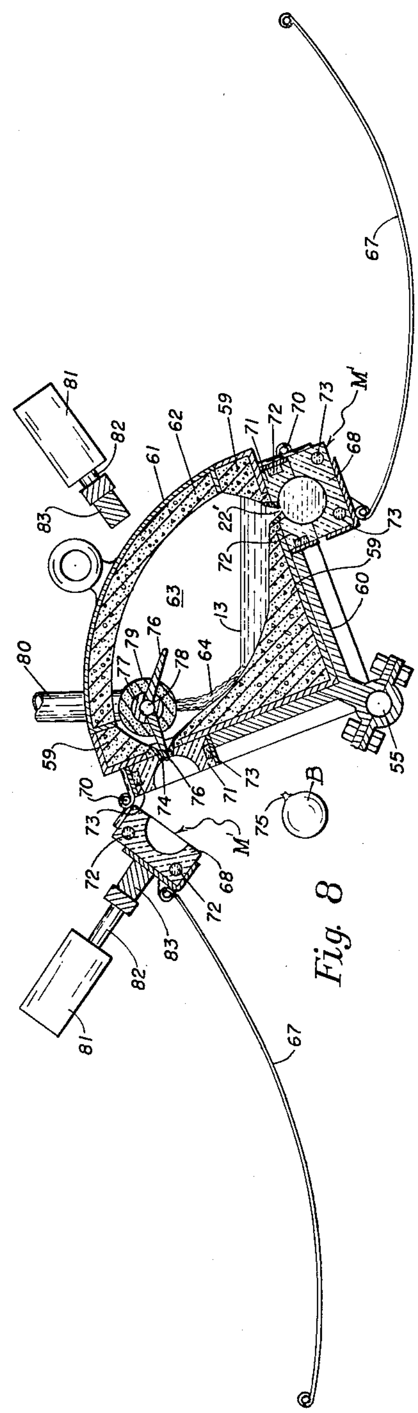

Fig. 8

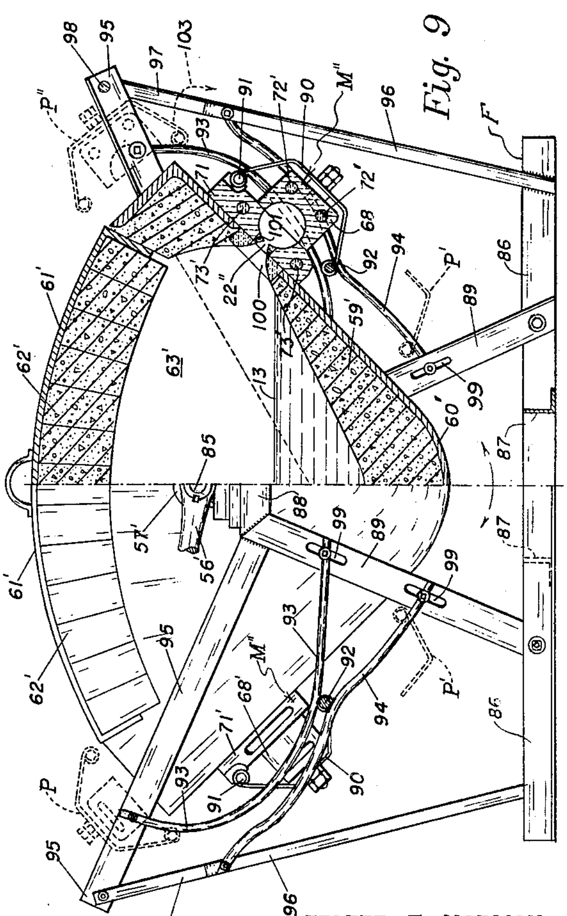

Fig. 9

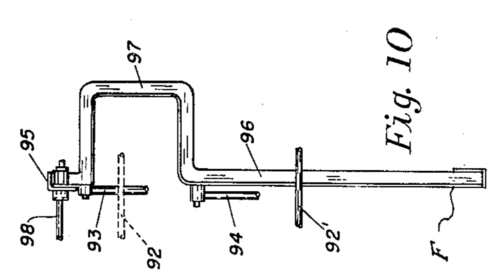

Fig. 10

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UNITED STATES PATENT OFFICE

2,546,517

METAL CASTING

Telfer E. Norman, Denver, Colo.

Application September 4, 1945, Serial No. 614,257

8 Claims. (Cl. 22—74)

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This invention relates to metal casting, and particularly to a method of metal casting by which sound castings are assured. This invention also relates to apparatus for carrying out the method of this invention, and to a metal casting machine for making a plurality of articles, such as grinding balls or the like, on a production basis.

One difficulty which must be overcome in casting articles, and particularly on a production basis, is the tendency for molten metal to shrink during solidification. In casting operations wherein molten metal is poured into a sand mold or the like, one or more reservoirs of metal are provided outside the mold cavity to feed the metal in the cavity as it shrinks during solidification, such reservoirs being provided by gates, or shrinkheads and risers, into the former of which the material is poured to reach the mold cavity, and in the latter of which the metal rises during pouring and then falls during solidification. Metal in excess of that necessary to form the article being cast is poured into the gate or gates and permitted to solidify therein, since if only the exact amount of metal necessary to fill the mold cavity is poured into or through the gate, there is a tendency for shrinkage cavities to develop in the casting near or at the point of the gate, or at other points in the casting.

In such casting operations, certain requirements must be met in order to produce sound castings. One requirement is that the casting must solidify directionally towards the openings leading to the shrinkheads, risers or other reservoirs of metal outside the casting. Another requirement is that the shrinkheads, risers, or other reservoir of metal outside the casting must remain sufficiently molten to supply metal to the casting during its solidification. Still another requirement is that the metal in the connection between the casting and the shrinkhead, riser or other reservoir outside the casting must remain molten until the casting has solidified. The fulfillment of all these requirements is often difficult to attain, and particularly when production is speeded up by "chill" casting — i. e., pouring molten metal into a metal mold or the like, which will chill or cause relatively rapid solidification of the outer layers, to hasten the total solidification time.

Furthermore, the reservoirs of metal outside the mold cavity leave gates and sprues attached to the final product, which protuberances represent scrap of low commercial value. The cost of producing the portion of molten metal which

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ends up as scrap represents an expense of substantial proportions in most foundries since, in general, from 25 to 60% of the metal poured is converted into scrap in the form of heads, gates, risers and sprues. Also, such protuberances must be removed, as by tumbling, torch cutting, machining or other similar operations to provide a final product of the desired size and shape. Needless to say, in production operations involving sometimes hundreds of articles, the removal of such protuberances is often an expensive and time-consuming operation.

Among the objects of this invention are to provide a casting method and apparatus, and also a casting machine, which will produce sound castings at a relatively high production rate; to provide a casting method and apparatus by which the desired directional solidification is accurately and readily obtained; to provide such a method and apparatus, and also a machine, which is particularly applicable to chill casting; to provide a novel casting method and apparatus which are also applicable to the production of castings in sand molds, or any other type of mold; to provide a novel casting method by which directional solidification is insured; to provide casting apparatus, and also a casting machine, particularly adapted to carry out the casting method of this invention; to provide a casting method and machine whereby shrinkheads and risers may be eliminated without the production of undesirable shrinkage cavities; and to provide such a machine which is especially adapted to produce articles such as grinding balls and other small castings, which can be produced in a split mold.

Additional objects of this invention are to provide a novel casting method which greatly increases the efficiency and lowers the cost of producing castings; to provide such a method which reduces to an almost negligible quantity the excess metal normally converted into scrap and representing the heads, risers, sprues and the like normally attached to the casting after removal from the mold; to provide such a method and machine by which sound castings are produced, yet such scrap is substantially or entirely eliminated; to provide such a method and machine whereby the cost of cleaning castings to remove heads, risers, sprues and the like is eliminated, to provide such a method and machine by which the gate feeding each mold is maintained in a molten condition for a predetermined time, and in a novel manner; and to provide such a method which is economical, efficient and readily carried out.

Additional objects of this invention are to provide a casting machine which is relatively simple in construction and which will produce sound castings at a high rate of production with a minimum of operator attention; to provide such a machine which is provided with a plurality of chilling molds which are opened and closed automatically, and which are fed in series or sequence from a reservoir of molten metal; to provide such a machine in which the reservoir is maintained at a sufficiently high temperature; to provide such a machine in which separation of the casting and the metal of the gate feeding the casting is accomplished readily and at a predetermined time; to provide such a machine by which the opening and closing of the molds, the feeding of molten metal to the molds, and the separation of the casting and gate metal are effected through a simple motion, such as rocking or rotating, applied to the machine; and to provide such a machine in which refractory material has a relatively long effective life, and deterioration is reduced to a minimum.

Other objects and the novel features of this invention will become apparent from the description which follows.

The method of this invention, as relating to the production of castings in permanent or chilling molds, may comprise the steps of maintaining a pool of molten metal; filling at least one chilling mold through a gate, and insuring feeding of molten metal to the mold during solidification of metal in the mold, by maintaining the metal in the gate in molten condition while the metal in the mold solidifies. The method of this invention may also comprise steps which insure directional solidification, by which is meant solidification towards the reservoir of molten metal which feeds the casting. In accordance with this invention, such steps may comprise retarding solidification of the metal at and adjacent the gate entrance, as well as maintaining the metal in the gate molten, as least until the metal in the mold solidifies.

During solidification in a chilling mold, the metal first contacting the mold wall solidifies, and needles or dendrites begin to grow inwardly from the walls. As these needles or dendrites grow, and other needles are formed, the tendency is to segregate in clusters, unless molten metal is immediately available to fill in the spaces between clusters due to shrinkage during solidification. An additional tendency is solidification around the walls of the mold and a deficiency of solidifying metal in the upper central portion of the mold. If the metal at and adjacent the gate entrance solidifies before the metal immediately below, a cavity will develop, due to dendrite growth and shrinkage of solidified metal robbing other portions of the mold. When solidification of metal at and adjacent the gate entrance is retarded and the metal in the gate is maintained molten until the metal in the mold solidifies, not only is there sufficient metal to feed the mold cavity to compensate for shrinkage, but also premature solidification of metal at and adjacent the gate entrance is prevented.

Maintaining the gate metal molten, as above, assists in retarding solidification at and adjacent the gate, but it is also desirable to provide refractory material or the like to surround the gate and also to form a portion of the mold wall at the gate entrance. The gate metal may be maintained molten by utilizing the heat of the pool, or by electric heating. When the heat of the pool is utilized to maintain the metal of the gate in molten condition, the gate preferably is relatively wide adjacent the pool and has tapering sides, with the narrower portion of the gate being relatively short. When an electric current is utilized to maintain the gate metal molten, the gate may be relatively long and narrow. A low voltage, high amperage electric current may be passed directly through the metal of the gate. Alternating current is preferably used, single phase current being passed through two adjacent molds and three phase current being passed through three adjacent molds, the pool of molten metal being a common terminal in each instance. Again, a high frequency, alternating current may be supplied to an induction coil surrounding the gate to heat the metal of the gate by induction; or, an alternating or direct current may be supplied to a resistance coil surrounding the gate, an induction or resistance element of any desired shape being useable in lieu of a coil.

While utilization of the heat of the pool to maintain the metal of the gate molten is primarily valuable in casting metal objects in chilling molds, heating of the gate metal electrically is adaptable to many other types of molds, such as sand molds. Thus, the method of this invention may comprise filling a mold of any type with molten metal through a gate, and maintaining the metal in the gate molten by electrical heating, until the metal in the mold solidifies. With such a method, sound castings may be produced without sprues or risers, and with little or no excess metal useable only as scrap. Preferably, the gate is relatively long and narrow, to concentrate the electrical heating effect, to minimize cooling of the pool by chilling molds, and also to minimize the metal in the gate when permitted to solidify, as when a sand mold is utilized.

When a plurality of chilling molds are filled from a pool of molten metal, they are preferably moved, either all together or in groups, to filling positions below the level of the pool and then to positions above the level of the pool, after solidification. In such case, each gate passage is preferably shaped so that it will drain molten metal back into the pool as the mold moves to a position at or above the normal level of the pool of molten metal.

The foregoing methods are particularly applicable to the casting of relatively small, symmetrical articles, especially on a mass production basis, but are also applicable to the casting of other articles. The molten metal may be ferrous metal, such as cast iron, plain carbon or alloy steel, or may be non-ferrous metal, such as brass, bronze, zinc, aluminum, alloys of aluminum, alloys of aluminum and magnesium, or others. For grinding balls, a high carbon, low alloy steel, or a low silicon, white cast iron is preferred, though other compositions may be utilized. Also, for cast iron and steel, and other higher melting point metals and alloys, gate heating is preferably by passage of current directly through the metal in the gate, but for lower melting point metals such as copper, aluminum and certain bronzes, heating by an electrical resistance coil or element is often more advantageous.

Apparatus adapted to carry out the above method may include a mold, a gate leading thereto, and electrical heating means capable of maintaining the metal in the gate molten until the metal in the mold solidifies. Such electrical heating means may comprise connections for passing a current, preferably low voltage and high amperage, directly through the metal in the gate, or an induction or resistance element, such as a coil, surrounding the gate. When utilizing metal molds, such as chilling molds, the current is preferably passed through the mold, to the metal in the mold, and then through the metal in the gate. Also, when a plurality of molds are filled from a pool of molten metal, the pool preferably comprises a common terminal, with one mold of each pair or one half of the molds comprising the opposite terminals for D. C. or single phase A. C. current, or three molds or sets of molds comprising the terminals for three phase A. C. Preferably, the metal molds are insulated from other metallic portions of the apparatus, such as supporting structure.

A novel article adapted to be produced by the method and/or apparatus of this invention, when the molten metal in the gate is drained therefrom, comprises a cast metal object having substantially no protuberances of excess metal in the as cast condition. A further novel article is a grinding ball comprising a cast metal sphere having substantially no protuberances of excess metal in the as cast condition, and also having a slight depression at one point. The slight depression is caused by drainage of the molten metal of the gate after the metal in the mold solidifies.

A casting machine constructed in accordance with this invention may include, in general, an enclosed basin adapted to contain molten metal and movable to different positions about a substantially horizontal axis; one or more series of split molds, one half of each mold being mounted on the basin and the other half being pivoted thereto; and means for opening and closing the molds at desired points in the movement thereof. Such opening and closing means may comprise cam bars or resilient rocker arms, and these may further be utilized to pass electric current through the molds, and thence through the gates to maintain the metal in the gates molten and provide directional solidification. The molds are preferably made of a highly heat conductive material, such as copper, steel, or cast iron, and may be water or air cooled, as desired.

The above and additional features, and novel details of the apparatus and machine constructed in accordance with this invention, are illustrated in the accompanying drawings, in which:

Fig. 1 is a side elevation of one form of a casting machine constructed in accordance with this invention, the lower half thereof being in section;

Fig. 2 is a vertical cross section taken along line 2—2 of Fig. 1;

Fig. 3 is a fragmentary section illustrating an alternative electric heating means for maintaining the gate metal molten;

Fig. 4 is a cross section of a grinding ball produced in the apparatus of Fig. 1 and in accordance with the method of this invention;

Fig. 5 is a top plan view of another form of casting machine constructed in accordance with this invention;

Fig. 6 is a side elevation of the machine of Fig. 5;

Fig. 7 is an end elevation of the machine of Fig. 5;

Fig. 8 is an enlarged vertical cross section taken along line 8—8 of Fig. 5;

Fig. 9 is an end elevation, partly in cross section, of still another form of casting machine constructed in accordance with this invention;

Fig. 10 is a detail of a mold opening and closing device forming a portion of the machine of Fig. 9; and

Fig. 11 is an enlarged fragmentary section of one form of construction in and about the gate to the mold.

The casting machine C of Figs. 1 and 2 is mounted for rotation about a horizontal axis, and is provided about its periphery with a plurality of split double molds M. In the form shown, there are four series of molds spaced 90° apart around the periphery of the machine, along horizontal lines parallel to the axis of the machine, and three sets of double molds in each series, although a greater or lesser number of series and/or sets of molds may be used, if desired. The exterior of the machine is rectangular for convenience only, and may be round or have any other desired shape.

A basin or enclosed container 11, as in Fig. 2, is formed within the interior of the machine by a refractory cylinder 12, constructed of suitable material such as molded graphite or baked fire clay, able to withstand the high temperatures of a reservoir or pool 13 of molten metal, such as steel or iron for casting grinding balls in molds M. Refractory cylinder 12 is surrounded by heat insulation 14, such as crushed fire brick or burned lime, although asbestos may be used when lower melting point metal is to be cast. The heat insulation is held in place and the refractory and insulation are supported by a framework of angle irons 15. The ends of the basin 11, as in Fig. 1, may be closed by discs 16 of refractory material similar to the material of which cylinder 12 is made, and one or both discs may be provided with a central aperture 17 for introduction of a nozzle 18 to feed a stream 19 of molten metal into pool 13. Aperture 17 also permits introduction of a preheating flame, to heat the basin prior to introduction of molten metal.

Nozzle 18 leads from a catch basin 20, the catch basin and nozzle being refractory lined. The molten metal may be tapped off in batches from a suitable furnace of either the cupola or electric type, into a ladle 21 from which the molten metal is poured into catch basin 20 to maintain pool 13 substantially at the desired level. Or, the molten metal may be poured directly from the tapping spout of a cupola furnace into catch basin 20.

As casting machine C rotates, each mold passes in turn beneath pool 13, and molten metal flows into a mold through a gate 22, which is relatively long and much smaller in diameter than conventional practice, but which assists in directional solidification of the metal in the molds. Gates 22 may be between 3/8 in. and 1/2 in. in diameter, as for casting grinding balls 3 in. in diameter, and corresponding gate diameters are permissible for other articles, dependent upon the amount of metal and time of flow therethrough. The gate 22 is provided by a tubular refractory liner 23, formed of fire clay, silmanite or Alundum, although only the mold end of the tube may be preformed, the remainder of the tube being rammed in place. Also, a compressed and baked mixture of carbon and a binder, or any other suitable material may be used. Each tube 23 extends through insulation 14 to refractory cylinder

12 and also into a fixed half 24 of mold M, to provide heat insulation at the entrance of the gate to the mold, the end of the tube also forming a portion of the surface surrounding the mold cavity. The fixed half of the mold is attached to the body of the casting machine, while movable half 25 of the mold is pivoted on the machine, the latter insuring accurate engagement of the mold halves.

To support the casting machine for rotation, the angle irons 15 are attached at one end to an end plate assembly 26, which in turn is attached to a hollow, refractory lined shaft 27, which permits introduction of a preheating flame from that end of the basin. Shaft 27 rotates in a bearing 28 mounted on a standard 29, and may be driven in any suitable manner, as by a gear 30 keyed to shaft 27 and engaged by a worm 31. Worm 31 is driven by any suitable means, such as an electric motor.

At the opposite end of the machine, adjacent catch basin 20, the angle irons 15 are attached to angles 32, which in turn are attached to an end plate 26′ and a flanged supporting ring 33, the periphery of the latter engaging rollers 34, disposed at equal distances on opposite sides of the vertical center line of the machine, only one of rollers 34 being shown in Fig. 1 for clarity of illustration. Each roller 34 is mounted in pillow blocks 35, in turn mounted on a foundation 36. The flange supporting ring 33 permits nozzle 18 leading from catch basin 20 to be shorter, and thereby decrease the cooling effect on the flow of stream 19 of molten metal to pool 13. As will be apparent, basin 11 is totally enclosed except for small spaces at the ends, and the metal will tend to stay molten in the basin for a long period of time. End plates 26 and 26′ are removable for relining and repair of the refractory assembly around basin 11, while the tubes forming the gates are inserted into the assembly from the outside through a hole leading from each mold cavity 41, and are cemented in place.

Molds M are opened and closed in regular sequence as the casting machine rotates, and for this purpose the pivoted half 25 of each set of double molds, as in Fig. 1, is mounted on a pair of arms 37, each of which is pivoted on a pin 38 mounted in a standard 39 at the adjacent corner of the machine, as in Fig. 2. A coil spring 40 tends to maintain the molds in open position, such as that of the upper mold of Fig. 2, the coils of spring 40 encircling pin 38 with one end thereof engaging mold supporting arm 37 and the opposite end thrusting against the adjacent angle iron 15. To maintain the molds in closed position as they move beneath pool 13 of molten metal, so as to provide a closed mold cavity 41, as in Fig. 2, a substantially semi-circular cam bar 42 extends from a point adjacent the upper position of each mold to a point adjacent the trailing corner of the machine as the molds are about to be opened to discharge a solidified ball B, as the machine rotates in the direction of the arrow of Fig. 2. The molds are maintained in closed position by an extension 43 of arm 37, which may be made integral with arm 37, if desired, the two extensions 43 for each double mold being attached at their free ends to a rod 44, the latter being adapted to engage cam bar 42, as in Fig. 2.

The molds M are preferably made of a material, such as copper, having a relatively high rate of heat conductivity so as to produce a chilling effect on the molten metal entering the mold and thereby increase the rate of solidification. The molds may be water cooled, as explained in more detail subsequently, or may be provided with a plurality of fins 45 for air cooling.

Considering the position of the right hand mold of Fig. 2 as the 0° position, as the machine rotates slightly in the direction of the arrow, the solidified ball B in the mold M at the 0° position will fall out of the mold when rod 44 reaches the end of cam bar 42, spring 40 causing the pivoted half of the mold to open to the dotted position of Fig. 2. The ball B, after falling out of the mold, may be collected in a suitable manner for storage or use, or for further cooling or other treatment, such as heating and cooling to improve the metallurgical or grinding characteristics thereof. As the casting machine turns further, each successive mold will remain open until it reaches about the 60° position (which position may be varied relatively widely, as desired), where the center of the pivoted half of the mold will engage the upper end of cam bar 42 and start to close against the force of spring 40. When in about the 160° position, the rod 44 will engage the cam bar to complete the closing of the mold. When the mold has reached the 180° or left hand position of Fig. 2, it will be completely closed and thereby ready to receive the next charge of molten metal, which flows into the mold as it moves underneath the pool 13.

The molten metal begins to flow into each mold through gate 22 as soon as the mold reaches the 200° position or thereabouts, depending upon the level of pool 13. As the molten metal flows into the mold, it is cooled and begins to solidify around the periphery of the mold. By the time the mold reaches the lower or 270° position of Fig. 2, it is completely full of molten metal 46, which may be partially solidified around the periphery, except at and adjacent the gate 22. As solidification proceeds, molten metal from gate 22 flows into the mold to compensate for the shrinkage during solidification. Gate 22, being relatively long, creates hydraulic pressure which tends, with atmospheric pressure, to press the molten interior metal out against the solidifying outer layers, thus assisting in the production of dense castings.

The machine is rotated at a suitable speed so that filling and solidification take place as desired. Thus, the casting machine C may be rotated at about ½ to 1 R. P. M., to provide about 10 sec. for filling and 20 sec. for solidification of the metal in each mold, in casting 3 in. diameter grinding balls. Appropriate rotative speeds for other articles and for grinding balls of different sizes will, of course, be correlated with the filling time, dependent upon the gate diameters, fluidity of the molten metal, and amount of metal to flow through the gates, as well as the solidification time, dependent upon the cooling rate afforded by the molds and the amount of heat to be extracted for solidification.

When the mold is being filled with molten metal, there may be some tendency for air to be trapped in the mold, and a small air vent 47 may be provided adjacent the gate. Air vent 47 may be very small, even capillary in size, so that air will pass through but molten metal will not tend to enter. As shown, vents 47 may discharge air into insulation 14, which has sufficient air spaces to receive the same, or may extend to an exterior edge of the mold.

The length of gate 22 permits a substantial amount of refractory and heat insulating material between cylinder 12 and the molds M, so that there is little tendency for a chilling or cooling effect to be transmitted to pool 13.

Due to the length and small diameter of gate 22, there would be a tendency for the metal to solidify in the gate, except for special provision made, in accordance with this invention, to prevent such solidification and maintain the metal in the gate in a molten condition throughout chilling and solidification of the metal in the mold. As indicated previously, this may be accomplished by passing a low voltage, high amperage electric current through the gates, as by leads 49 connected to cam bars 42 and which may be supplied from any suitable source of electricity. In the machine shown, three phase A. C. is supplied to leads 49, so that the three series of molds and the corresponding gates will act as a Y or open delta connection, the molten pool being a common terminal for the three phases, as the current passes through rods 44 and extension 43 to the molds. Molds M, being made of copper or similar material, are highly conductive electrically, and as soon as the molten metal begins to flow from the pool into the mold, the circuit is established and heat is generated in each gate 22. Obviously, any other type of current may be utilized, and also any other number of molds and cam bars.

Due to the low voltage, there is little tendency for arcing as rods 44 reach and leave cam bars 42. Furthermore, when the molds are insulated from the framework of angles 15, as by insulation 50, which also prevents shorting from mold to mold, there will be no tendency toward arcing when rods 44 engage the cam bars 42 at the upper end, since the connection is not complete until the molten metal begins to flow into the mold. As will also be observed, when the metal in the gate drains back into the pool, the electrical circuit through the ball and mold is broken, and prevents arcing as the rod 44 leaves the cam bar 42. This is true as long as the gate tubes 23 are non-conductors.

Insulation 50, which may be asbestos or other suitable material, may extend between each tube 23 and mold M, or a suitable insulating pad may be provided, to insulate the gate from the mold. Such insulation tends to prevent dissipation of current at and adjacent the gate, when current is passed through the mold to the gate. Such dissipation tends to occur if the gate tube 23 is conductive, as when made of carbon, since there will be some flow of current through the gate tube, and a consequent flow of some current from the mold to the gate without passage of such current through the metal in either the mold or the gate. However, when the gate is insulated from the mold, there is little or no flow of current from the mold to the gate, and the current is forced to pass through the metal in the mold to the metal in the gate.

Due to the large cross sectional area of metal in the mold and in the pool, as compared with the cross sectional area of metal in the gate, by far the greatest electrical resistance and consequent I^2R heating loss, and thus the greatest proportion of heating, will be in the metal of the gate. Due to this concentration of heating in the gate, the power consumption of the electrical circuit will be relatively low, since only a moderate amount of power is required to heat a gate having a relatively small cross sectional area.

For maintaining the gate metal molten when a sand mold is utilized, it may be necessary to make some provision for passing the current through the gate. Connection may be made with the metal in the mold by a wire leading from a chill block embedded in the sand mold. A graphite rod may be used as the other terminal, the rod being immersed in the gate metal, or extending through a mold into a shrinkhead, in case the latter is employed between the gate and mold. The casting is fed more effectively, and a sound casting is always assured, by use of such electric heating. Also, the yield of metal in the casting may be increased from the previous values of 40 to 60% to 80 to 90%. In addition, a very small connection between the gate or shrinkhead and the casting is necessary, thus eliminating a large proportion of the cost of removing excess metal.

An alternative though less preferable manner of heating the gate is that illustrated in Fig. 3. The gate tube 23 and mold M are constructed as before, but current is supplied to the metal in the gate by induction or resistance heating, as by a coil 51 supplied by electric leads 52. For resistance heating, the current may be either A. C. or D. C., preferably lower voltage and higher amperage, and the coil 51 is constructed of suitable high resistance material. Also, a heating element, such as parallel strips extending longitudinally of the tube, may be substituted for a coil. As indicated previously, external resistance heating will usually be found to be more valuable in the case of a lower melting point metal to be cast.

For induction heating, the current supplied is preferably high frequency A. C., adapted to produce a high, concentrated heating effect within the gate, while coil 51 may be hollow, so that a cooling medium may be passed therethrough to prevent damage to the coil, normally formed of copper or other low reactance material. The power consumption of induction heating is relatively low, since tube 23 is small and will consume little power, even though some heat will be generated therein when the current is maintained on at all times. The latter is an advantage, since it maintains the gate warm or hot, and reduces any tendency toward a slight chilling effect. Furthermore, by far the greatest power will be used only when metal is in the gate, thus producing a high efficiency in heating. Of course, suitable switches and relays may be provided for supplying current to coil 51 only when metal is in the mold, if desired.

When applying such alternative manner to sand castings, the induction or resistance element may be buried in the mold, or in a suitable position surrounding or closely adjacent to a portion, reduced in cross-sectional area, of the gate adjacent the casting cavity, or of a small diameter connection between a shrinkhead and the casting cavity. Such connection may lead to the lower end of the casting cavity, in accordance with conventional practice, or it may be found that, because the metal in the gate or connection is maintained molten, the gate or connection may lead to the top or upper portion of the mold cavity. Current need not be supplied during the entire time that the casting is cooling, but only until solidification is sufficiently completed. Thus, although a casting may be left in the mold to cool slowly for a number of hours, it is unnecessary to supply electricity for the entire period of time. Furthermore, provision may be made, as by a suitable drain plug, to drain the molten metal from the gate as soon as the casting solidifies.

As the metal in the mold solidifies, a shrinkage cavity will tend to develop near the gate, but since the metal in the gate is maintained in a molten condition, any cavity which does develop will be filled immediately, and also the molten metal of the gate will normally prevent any such cavity from even beginning to develop. Also, the extension of tube 23 to the mold cavity tends to insulate the area at the entrance to the mold, thereby insuring that the metal adjacent the gate will be the last to solidify and completing control of directional solidification.

As the machine rotates further in the direction of the arrow of Fig. 2 and reaches the point of discharge of the ball, the entire metal of the ball will have solidified to form a ball B, but the metal of the gate will still remain molten due to the passage of the electric current therethrough. When the ball reaches the right hand or 0° position of Fig. 2, the molten metal in the gate will begin to drain out of the gate into the pool, leaving the solidified ball B in the mold. As the machine rotates further, upwardly from the 0° position, all of the molten metal in the tube 23, and usually also a slight amount of molten metal at the entrance to the mold, will drain back into the pool, to clear the gate of metal and also permit the solidified ball B to drop readily out of the machine.

An extremely slight depression, such as depression 53 of ball B of Fig. 4, may be the result of the above drainage, but such depression does not affect in any way the serviceability of the ball and is in reality usually too slight to be noticed, except upon careful inspection. As will be evident, the presence of merely a slight depression at the point at which the gate existed leaves no metal to be removed subsequently, and the ball B is in condition for immediate use, except for cooling to room temperature and any additional heat treatment which may be desired.

It will be understood, of course, that the molds M may be made single instead of double; that any other suitable arrangement of cams, levers, or equivalent mechanical elements may be utilized in opening and closing the molds; and also that electrically controlled parts, such as solenoids, may be utilized for the same purpose.

It will also be understood that separate electrical circuits controlled in a different manner may be utilized for passing current through gates 22. It will be apparent that the gates used in the casting machine C differ radically from the gates normally used in casting practice. In normal practice, the gates are limited to a minimum size for sufficient flow of molten metal to the mold, and also to prevent a chilling effect in the gate itself. In the present invention, the gate may be made as small as desired, as long as the actual flow of molten metal is not prevented, since the smaller the gate, the more pronounced is the electrical heating effect, and the easier it is to maintain the metal in the gate in molten condition. Furthermore, the smaller the gate, the smaller the depression left at the top of the ball when the metal of the gate flows back into the pool. Thus, electrical heating of the gate in accordance with this invention introduces radical changes in the concepts of gate sizes and construction.

Casting machine C′ of Figs. 5 to 8, inclusive, is also constructed in accordance with this invention and is a smaller size machine. This machine is reciprocated through an arc, i. e., by a rocking motion, about a horizontal axis beneath the machine, for which purpose the machine may be mounted on a shaft 55 which is rocked by a crank 56, as in Fig. 7. The shaft 55 may be pivotally mounted in bearings 57 mounted atop foundation piers 58, as in Fig. 6, while crank 56 may be actuated in any suitable manner, as from a motor driven crank rotated relatively slowly through a suitable gear reduction drive.

The machine C′ includes a lining 59, made of a rammed refractory mixture, and installed within an elongated, triangular or V-shaped supporting structure 60 mounted on shaft 55, as in Fig. 8. A removable top 61 is provided with a refractory lining 62, formed of firebrick or the like, and refractory linings 59 and 62 enclose a basin 63 in which the pool 13 of molten metal is maintained. As in Fig. 6, the level of pool 13 is maintained at or near the desired depth by a stream 64 of molten metal poured from a ladle 20 into the open end 65 of basin 63. Or, the molten metal may be poured from the tapping spout of a cupola furnace, as indicated previously.

Molds M′ of casting machine C′ are preferably double molds, and are opened and closed during rocking movement of the machine by leaf springs 67. Each spring 67 is pivotally attached at one end to the lower corner of a movable half 68 of a mold M′, and at the opposite end is pivotally attached to a fixed support 69, as in Fig. 5. Movable halves 68 are pivoted on pins 70 at their upper ends, to form in closed position, with fixed mold halves 71, which are mounted on the supporting structure 60, the desired mold space for casting of balls B′, as in Fig. 8.

The casting machine C′ is adapted to be rocked through an arc of about 30° to each side of the central position; but other amplitudes of reciprocation may be utilized, if desired. As will be evident, when the machine tilts in one direction, such as to the right in Fig. 8, the pool 13 of molten metal will flow to that side and fill all of the molds on that side. Preferably, the angular sides of the basin are inclined downwardly at a suitable angle, such as 25°, when the machine is in the center position, as shown, so that all molten metal will flow into the gates 22′ when the machine is tipped to an angle of 30°. The molds are maintained in closed position by compression of leaf springs 67, formed of spring steel or similar material, which are positioned and constructed to apply compression to each mold, thus keeping the mold cavity closed during the period that metal is running into or solidifying in the mold. At the same time, a corresponding spring symmetrically placed on the opposite side of the basin causes each pivoted mold half on this opposite side to open and allow the solidified castings to be discharged from the mold cavities 41′. This action of opening and closing of the molds alternately on each side of the basin occurs automatically as the basin is tilted to the left and right through a 30° angle on each side of the centre position. Preferably, both the left and right hand molds are closed at or near the centre position of the arc through which the basin travels. Then, as the basin is tilted past this centre position, the springs hold the molds on one side closed by compression and cause the molds on the opposite side to open by tension in a direction tending to shorten their effective length. This maintains the molds M' in closed position while the molten metal pours into them. The molds are, of course, preferably made of material having a relatively high rate of heat conductivity, such as copper or copper alloy, and may be water cooled, as by passages 72 and 73 of Fig. 8, through which cooling water may be circulated by suitable hoses, or the like (not shown).

The molten metal flows into the molds through gates 22' which are substantially different from gates 22 of the machine C and are constructed so that the heat from the pool 13 maintains the metal in the gates in molten condition. Thus, the gates 22' have relatively wide mouths, are relatively short in relation to their diameter, and taper widely adjacent the basin 63, so that molten metal will tend to drain readily back into the pool 13 as the machine tilts upwardly on that side. The molds and gates are so designed that the principles of directional solidification are applied to produce sound castings free from shrinkage or gas cavities. The last portion of the metal to solidify will be in the gates 22'. By the time this starts to occur, the timing of operation will be such that the basin shall have returned to center position and the pool of metal shall have been removed from above the gates. Much of the metal in the gates, if it is still fluid, will drain back into the pool. The rest will remain in a mushy condition sufficiently long to facilitate easy removal of the castings without damage to the refractory of the gate. This mushy metal in the gates will either remain attached to the casing, or drop out of the gate separately from the casting, or be pushed out by the ejector pins or plungers 76, described subsequently.

The gates are preferably formed by an insert 74, formed of a suitable refractory material, such as baked fire clay, silmanite or Alundum, or other material, such as finely divided carbon compressed with a binder and baked, then machined to shape, if necessary. Inserts 74 are so shaped that a relatively wide mouth is produced and an insulating effect is obtained at the neck, to prevent solidification there and to permit shrinkage cavities to be filled or prevented from forming during solidification. Air vents may also be provided, as in the molds M of casting machine C.

After filling, the machine is slowly tilted in the opposite direction, the molds M' on the opposite side being closed by action of leaf springs 67, while the gates of the full molds are rising to a point about the level of pool 13. Due to the slope of the wide mouth of gates 22', the molten metal flows out of the gates and back into the pool. At the same time, the pull of leaf springs 67 begins to open the full molds, so that when the machine reaches the opposite position, the mold will be open, as at the left in Fig. 8, and the cast ball B' will drop out.

Theoretically, the entire gate should be emptied of metal, but, in practice, the chilling effect of the solidifying metal in the body of the casting on the gate metal immediately adjacent the mold, causes a small amount of metal to be solidified in the narrow portion of the gate adjacent the ball, and produces a protuberance 75, as of ball B' of Fig. 8. Preferably, the opening through the insert immediately adjacent the mold flares outwardly toward the ball so that the protuberance 75 has tapering sides. Normally, the balls will fall readily out of the molds, but in a small number of instances there may be a slight tendency for the balls to stick in the molds. To prevent such sticking, suitable ball discharge devices may be provided, such as a plurality of stationary steel plungers 76 adapted to enter the mold gates as the respective side of the machine moves to its upper position, such as in Fig. 8. The plungers 76 serve the dual purpose of cleaning metal or other obstructions from gates 22', and of ejecting any castings which stick in the fixed halves of the molds. A set of plungers 76 for each set of molds is provided, there thus being two sets of plungers oppositely disposed, the plungers being mounted on a round hollow bar 77 having an interior passage 78 through which a cooling medium may be passed. Preferably, the inner ends of plungers 76 extend to the cooling passage so as to be contacted by the cooling medium, and provide direct transfer of heat from the plungers to the cooling medium, thereby preventing damage to the ends of the plungers by preventing overheating. Bar 77 is preferably surrounded by insulating or refractory material 79, and supported in fixed horizontal position within the basin 63 adjacent the top 61, by supporting tubes 80 through which the cooling medium may be passed to the interior of bar 77. As in Figs. 5 and 6, the refractory material 79 may extend well up onto the supporting tubes 80 to protect the latter.

Additional ball discharge devices, for jarring the pivoted molds and knocking out any balls that tend to stick in the same, may include hydraulically actuated rams 81 or the like, as in Fig. 8, the plungers 82 of the rams being provided with a soft metal block 83 for striking the pivoted mold halves a blow sufficiently sharp to dislodge the balls, but not sufficiently hard to damage the molds. The hydraulic rams 81 may be controlled by any suitable valve mechanism, preferably actuated through crank 56 or in any other suitable manner in accordance with the rocking motion of the machine. It will be understood, of course, that solenoid operated plungers or any other suitable means for striking the molds, may be utilized instead of the hydraulic rams. Or, a pin or plunger to be struck by the ram or the like and adapted to be moved into the interior of the mold to strike any ball tending to stick therein, may be mounted in each pivoted half of the molds. Also, in many instances it may be found sufficient merely to provide a stationary block in position to be struck by the mold, springs 67 being sufficiently resilient to accommodate such action.

The ball B' of Fig. 8 may be cooled down to room temperature for use or for heat treatment, or may be immediately sent to the latter. The protuberance 70, if not large, will usually be found to produce no difficulty in the ball mill, but may be removed in the usual manner, if desired. As will be evident, the ball B of Fig. 3 is superior in certain respects to the ball B' of Fig. 8, in that no mechanical operations for removal of a protuberance are necessary prior to usage.

An additional embodiment of this invention comprises the casting machine C'', as in Figs. 9 to 11. Machine C'' is similar to the machine C' of Figs. 5 to 8, inclusive, in that it is pivoted about a horizontal axis and includes a series of molds M'' mounted in a horizontal row along the opposite sides of an elongated triangular supporting structure 60'. However, the supporting structure is pivoted about an axis formed by end shafts 85, on an axis above the normal level of pool 13 and at or about the center of gravity of the machine. The casting machine C'' includes refractory lining 59' in supporting structure 60' and a cover or top 61', similarly provided with a refractory lining 62'. As before, the refractory linings 59' and 62' enclose a basin 63' in the lower portion of which pool 13 is contained. The machine may be rocked by a crank 51' attached to shaft 85 at one end, and driven in a suitable manner, as before.

Machine C'' is also larger than machine C', the basin 63' preferably being sufficiently large to accommodate a full ladle of molten metal, as from a cupola furnace, or a full batch, as from an electric furnace. The basin may be charged by shifting top 61' aside, and the molten metal poured from a ladle, tapped from a cupola furnace, or poured from an electric furnace. The machine is then started up, operated until the batch is gone, and then refilled. Before the first batch is poured into the basin, it is usually desirable to heat the refractory linings, as by preheating flames, to prevent undue cooling of the first batch.

The machine C'' is mounted on a framework F, which also forms a support for the mechanism for automatically opening and closing molds M''. The framework F is similar at each end of the machine, and includes base members 86 which may be in the form of I-beams or angles, as in Fig. 9. A pair of parallel angles 87 extend longitudinally between the base members to add stability to the support. Each end shaft 85 is rotatively mounted in a bearing 57' mounted on a short transverse angle 88, the ends of which are welded or otherwise attached to the upper ends of a pair of upwardly extending and inwardly converging angles 89, attached at their lower ends to base members 86. The various parts of the framework F may be welded or bolted together, as desired, or any desired combination of welding and bolting may be used, as illustrated.

The molds M'' are somewhat similar to the molds M', except that the fixed halves 71' are somewhat wider and the pivoted halves 68' are somewhat higher, the molds being cooled in a suitable manner, as by water circulating through passages 72' and 73'. Pivoted halves 68' provide a slightly greater length for a pivoting spring 90, the central portion of which is attached to the pivoted half 68' and the bifurcated upper end of which is pivoted on a pin 91, at opposite sides of the outer upper edge of fixed half 71'.

The lower end of each spring 90 is attached to a longitudinally extending cam engaging rod 92, there being a rod 92 on each side which extends the length of the machine. For actuating the cam rods 92 to open and close the molds, four sets of upper and lower cam bars 93 and 94, respectively, are provided, one set being disposed on each side at each end of the machine. For supporting the cam bars in an adjustable position, a straight angle 95 extends upwardly and outwardly from the upper end of each angle 88, being welded or otherwise suitably attached thereto. A smaller angle 96 having a loop 97 adjacent its upper end, as in Fig. 10, is welded at its lower end adjacent the end of each base member 86 and bolted or otherwise suitably attached at its upper end to angle 95, as in Fig. 9. To provide additional stability, a reinforcing rod 98 may extend between the upper ends of angles 95, on each side of the machine.

Upper cam bars 93 and lower cam bars 94 are attached at their upper ends, respectively, to straight angles 95 and smaller angles 96, while the cam bars are attached at their lower ends to angles 89, being adjustable along slots 99 in any suitable manner, such as shown. The upper cam bars 93 force the pivoted halves of the molds outwardly and away from the fixed halves upon upward movement of the respective side of the machine, such as to the upper left hand dotted position P of Fig. 9. The lower cam bars 94 are so shaped as to engage the rods 92 upon downward movement of the respective side of the machine and to force the pivoted half of the mold against the fixed half of the mold before the gate opening 22'' reaches the level of pool 13. The lower cam bars 94 also maintain the two halves in engagement, assisted by the resiliency of spring 90, down to the lowermost position, such as the lower dotted positions P' of Fig. 9. The lower cam bars 94 also maintain the pivoted and fixed halves of the molds in engagement during the succeeding upward movement, until the upper cam bar begins to move the two halves apart. Thus, the lower cam bars maintain the two halves of the molds in engagement during filling and solidification of the material in the mold.

Slots 99 permit the position of the cam bars to be adjusted, as desired, to regulate the pressure exerted by spring 90 and also the points at which the molds will open and close. As will be evident, as the machine is tilted or rocked first from one side and then to the other through a total angle of about 30°, for instance, the molds on one side of the machine will be filled during downward movement, the metal will solidify, and the major portion of the metal in the gate maintained molten by the heat of the pool 13, will be poured out during the succeeding upward movement. Upon further upward movement, the molds on that side will be opened to permit the cast balls to drop out. On the succeeding downward movement the molds will be closed and then filled.

Since the greatest amount of wear will tend to occur in the gate, a novel gate construction may be provided, such as shown in Fig. 9 and enlarged in Fig. 11. A widely tapering passage leading to the gate may be formed in a brick 100, made of suitable refractory material and cemented or otherwise attached in a well known manner to the refractory lining 59'. This brick does not require replacement often, but when made separately, facilitates such replacement when necessary. Also, the passage in the brick may be formed more accurately when a smaller refractory piece is being handled.

The neck of the gate is formed by an insert 101, preferably formed of carbon, graphite or the like, which may be finely divided, mixed with a binder, and then formed under heat and pressure into the desired shape, or into a block from which the desired shape may be machined. As in Fig. 11, the insert 101 tapers outwardly toward the mold, so that it may readily be inserted or removed from its position. The insert may be cemented in place for installation purposes, and preferably also forms a small portion of the mold adjacent the neck of the gate, to provide insulation at that point, for the purpose previously described. Also, the aperture through insert 101 is rounded adjacent the mold, so that a circular protuberance 102, as in Fig. 11, which may be formed on ball B'' after the molten gate metal has drained back into the pool, will not produce any tendency for the ball to stick in the mold.

The pivoted halves of the molds, on each side, are adapted to be swung upwardly and out of the way, so that the inserts 101 may be inspected periodically to determine the need for replacement, the loop 97 being formed in angles 96 therefor. As in Figs. 9 and 10, the cam rod 92, when the molds are in the dotted position P'' of Fig. 9, may be swung outwardly through the loop, in the direction of the dotted arrow 103 and on the outside of angles 96, the cam bar thus moving from the dotted position to the outside or full position 92' of Fig. 10, as that side of the machine moves downwardly. As will be evident, when the cam bar 92 is outside the angles 96, the molds are held in open position so that the condition of inserts 101 may be observed and replacements made, if necessary. Such inspection may take place after the basin is substantially emptied of molten metal, and is preferably made after each batch of metal has been cast.

From the foregoing, it will be apparent that the method, machine and apparatus of this invention fulfill to a marked degree the objects and requirements hereinbefore set forth. The use of an outside source of heat, preferably electricity, to maintain the material in the gate molten is a valuable feature, not only permitting the production of articles without protuberances, but also permitting considerable reduction in gate sizes. Furthermore, a relatively small elongated gate can be used, which permits a greater distance between the pool of molten metal and the mold, thereby enhancing the chilling effect of the mold, without fear of shrinkage cavities or premature solidification in and adjacent the gate.

The application of the principles of this invention to casting in sand molds assures the production of sound castings, and, as has been shown, increases the proportion of metal in the casting and minimizes the cost and difficulty of removing a gate or shrinkhead.

The rotary movement of the casting machine C and the tilting and rocking movement of the casting machines C' and C'' permit accurate control of the filling and gate drainage times for the molds. Also, the use of an enclosed basin for containing the pool of molten metal conserves heat and renders the operations more uniform. The use of split molds, one half of which is attached to the machine, and the other half of which is pivoted with respect thereto, tends to maintain the mold halves in accurate relation to each other, thus eliminating a fin or seam, or the presence of excess metal at the dividing line between the molds, as would be the case if the two halves of the molds were to be mounted separately on different parts of the machine.

It will be evident that the various embodiments of this invention include numerous novel features, such as the leaf springs for opening and closing the molds of the casting machine C', and the removable carbon or graphite insert of the casting machine C''. The automatic opening and closing of the molds of each of the machines forming embodiments of this invention also contributes to a higher production rate and reduced labor costs.

Although three different embodiments of this invention have been described and illustrated, and variations thereof indicated, it will be understood that other embodiments may exist; that the method of this invention may be carried out by other apparatus and/or machines; and that the product of this invention may be produced in different machines. It will further be understood that various changes, other than those indicated, may be made without departing from the spirit and scope of this invention.

What is claimed is:

1. A casting method which comprises maintaining a pool of molten metal; filling at least one chilling mold through a gate by moving said mold to a filling position below the level of the molten metal in said pool; moving said mold to a gate emptying position above the level of said pool, after the metal in said mold has solidified sufficiently to prevent the drainage of metal from said mold back to said pool, except from said gate; and maintaining the metal in said gate molten by passing an electric current through said gate between the metal in said mold and the molten metal in said pool, the drainage of metal from said gate acting to terminate the flow of such electric current.

2. A casting method which comprises maintaining a pool of molten metal; filling at least two chilling molds through gates by moving said molds to a filling position below the level of the molten metal in said pool; moving said molds to a gate emptying position above the level of said pool, after the metal in said molds has solidified sufficiently to prevent the drainage of metal from said molds, back to said pool, except from said gates; and maintaining the metal in said gates molten by passing an electric current through said gates between the metal in said molds and the molten metal in said pool as a common terminal, the drainage of metal from said gates acting to terminate the flow of such electric current.

3. A casting method comprising maintaining a pool of molten metal; filling a mold from said pool through a gate; passing an electric current through the metal in said gate to maintain the metal in said gate molten until the metal in said mold has solidified sufficiently for removal of the casting from said mold; then causing the molten metal in said gate to drain therefrom; and simultaneously terminating the flow of electric current by such drainage.

4. A casting machine comprising a refractory lined basin adapted to contain molten metal; a set of three molds for forming individual cast articles, said molds being composed of electrically conductive material and being electrically insulated from each other; gates providing a passage for molten metal and connecting said basin with each mold, said gates being formed of electrically insulating material; an electrical connection for each mold; and a three wire, three phase alternating electric current supply with one wire leading to each of said connections, so that said current passes through each mold and the metal in the gate connected therewith and to said pool, said pool acting as a common terminal for said three phase current.

5. A casting machine comprising a refractory lined basin adapted to contain molten metal; a pair of molds for forming individual cast articles, said molds being composed of electrically conductive material and being electrically insulated from each other; gates providing a passage for molten metal and connecting said basin with each mold, said gates being formed of electrically insulating material; an electrical connection for each mold; and a two wire electric current supply with one wire leading to each of said connections, so that said current passes through each mold and the metal in the gate connected therewith and to said pool, said pool acting as a common terminal so that the same amount of current will pass through each gate.

6. A casting method which comprises maintaining a pool of molten metal; filling at least two spaced chilling molds through gates leading from said pool; and maintaining the metal in said gates molten, until the metal in said molds has solidified, by passing an electric current through a circuit comprising in series one mold, the metal in its gate, the metal in the pool, the metal in the gate of a second mold, and the second mold.

7. In a casting machine, a refractory lined basin adapted to contain a pool of molten metal; a split mold having an article forming cavity connected with the interior of said basin, said basin having a lining including a refractory brick at the point of connection between said mold and said basin, said brick having an aperture extending centrally therethrough which has a relatively larger diameter on the basin side and a smaller diameter on the mold side and which also tapers outwardly toward said mold; and a refractory insert having an aperture which, with a portion of the aperture in said brick, forms a gate connecting said basin with said mold, said insert being attached to said brick within the smaller diameter portion of said aperture and said insert extending into said mold to form a portion of the wall of the mold cavity, said insert being removable from the exterior of said basin with said mold open.

8. A casting method which comprises maintaining a pool of molten metal; filling at least one series of three spaced chilling molds substantially simultaneously through gates leading from said pool to said molds, said molds being electrically insulated from each other; and maintaining the metal in said gates molten, until the metal in said molds has solidified, by passing a three-phase alternating electric current through a circuit comprising a first mold and the metal in its gate, a second mold and the metal in its gate, and a third mold and the metal in its gate, with said pool as a common terminal, one phase being connected to the first said mold, a second phase to the second mold, and a third phase to the third mold.

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