This invention relates to process and apparatus for teeming refined molten metal for the casting of ingots of all industrial sizes including macroingots at a relatively slow rate substantially corresponding to the rate of freezing of such teemed metal in the mold into which it is cast for production of uniform and sound ingots without the need for slow teeming substantially without segregation. More particularly, this invention pertains to such process and apparatus in combination with tap degassing under a vacuum of moderate pressure for the production of microclean alloys and alloy steels, e.g., those used for large steam turbine rotors, generator rotors, tool steels, missile and special purpose steels including those used for aircraft landing gears.

In the manufacture of very high quality so-called Ni-Cr-Mo and Ni-Cr-Mo-V alloy rotor steels, for example, a vacuum degassing double melting procedure has been used to produce high quality, microclean alloy steel of relatively uniform chemical analysis from side-to-side and top-to-bottom of the ingot, one such analysis, for example, being

<table>
<thead>
<tr>
<th>Element</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.22</td>
</tr>
<tr>
<td>Mn</td>
<td>0.22</td>
</tr>
<tr>
<td>P</td>
<td>0.007</td>
</tr>
<tr>
<td>S</td>
<td>0.013</td>
</tr>
<tr>
<td>Si</td>
<td>0.025</td>
</tr>
<tr>
<td>Cr</td>
<td>1.56</td>
</tr>
<tr>
<td>Ni</td>
<td>1.15</td>
</tr>
<tr>
<td>Mo</td>
<td>0.76</td>
</tr>
<tr>
<td>Cu</td>
<td>0.14</td>
</tr>
<tr>
<td>V</td>
<td>0.04</td>
</tr>
<tr>
<td>Al</td>
<td>0.007</td>
</tr>
</tbody>
</table>

with low gas content: O₂—<12 p.p.m.; N₂—<41 p.p.m. and H₂—<1 p.p.m., too low to cause any flaking; the vacuum degassing having been carried on in the second melting stage at a pressure below 5 microns of H₂, absolute. To obtain such high quality results involved the preparation of a refined alloy steel in an electric furnace which then was tap degassed into a bottom pour tapping ladle evacuated to a pressure of about 1 to 6 mm. of Hg absolute before tapping therein following which the degassed molten steel was air cast into a consumable electrode mold. The consumable electrode so made, after removal of the surface by machining, was fastened to the lower end of an electrode rod in an enclosed vacuum arc furnace, the lower end of which comprises a copper ingot mold with a jacket through which cooling water was circulated to freeze the molten metal after the arc had been struck and the consumable electrode portion melted thereby. Such operations required expensive equipment, multiple handling and expense and involved certain hazards including the possibility that the consumable portion of the arc would move off center and cause some portion of the arc to jump to the wall of the final mold leading to the danger of short circuit and/or the possibility of breeching the water-tight integrity of the mold which would cause a steam explosion, or leaks in the mold might otherwise develop. Still further, despite such handling, the size of such ingots in terms of diameter was less than the size desired by the purchasing industry and the final ingot had a considerable amount of discard at the top and bottom, being principally at the top where the inverted cone top, as shown by sulfur prints, had a depth of as much as 1/2 of the diameter even on the largest final ingot so made.

In the slow pouring and casting system of this invention final high quality and microclean ingots desired by the purchasing industry ranging in size from ingots 6 inches wide to macroingots of 100 inches or more in diameter may be made directly in a single operation without having to go through any intermediate step of first forming a consumable electrode to be remelted, or having to utilize high vacuum in the microzone, or involving the double sets of equipment, special handling and hazards of the prior practice outlined above. Instead, in a combinative practice of this invention preferably with the employment of the employment of tap degassing, there is a regulation of the casting of refined molten metal at a rate which is slow, continuous, and one that corresponds relatively precisely to the rapid rate of freezing forced upon the teemed molten metal in the mold, while maintaining a very shallow open pool at the top of the teemed metal and preventing eroding or bridging over of the surface thereof and while inhibiting turbulence, segregation and formation of dendrites in the freshly converging metal stratum at the bottom of the pool. Thereby, very high quality microclean, low segregation, alloys and steels may be produced in a single casting operation at enormous saving of equipment, time and other expense. And, it is possible by this system to make very large ingots using a single furnace of smaller capacity so that the tapping of up to several successive heats from the same furnace can be utilized in teeming that one ingot.

Other objects, features and advantages of this invention will be apparent from the following description and the accompanying drawings, which are illustrative only, in which

FIGURE 1 is a view in elevation and cross section through the vertical axis of one combination of equipment in one embodiment which may be employed in a practice of this invention utilizing tap degassing, controlled teeming in vacuo and a ring mold in the casting of a rivoting ingot;

FIGURE 2 is a top plan view in section taken along line II—II of FIGURE 1 to show the lower portion of the equipment in such embodiment;

FIGURE 3 is a bottom plan view taken along line III—III of FIGURE 1 to illustrate further features of such equipment including resistance heating means to maintain the top of the molten metal layer in the ingot open and free of bridging or crusting;

FIGURE 4 is a view in elevation and cross section through the vertical axis of the upper portion of a further combinative embodiment of this invention in which the molten metal may be subjected to pressure in the teeming ladle to control or assist in controlling the teeming rate into a casting chamber, wherein the heat source provided may be by consumable electrode electric arcs;

FIGURE 5 is a view in top plan taken along line V—V of FIGURE 4 illustrating a casting ring mold in which the moldinging is polygonal in shape;

FIGURE 6 is an enlarged view of a nozzle portion of a teeming ladle utilizable in a practice of this invention and capable of employing electrical field effects to at least assist in maintaining the required rate of teeming through such nozzle in a practice of this invention;

FIGURE 7 is a view in elevation and cross section through the vertical axis of a further modification of this invention utilizing an ingot mold and a teeming ladle for the casting of a hollow ingot in a practice of this invention;
FIGURE 8 is a view in top plan section taken along line VIII—VIII of FIGURE 7.

FIGURE 9 is a view in elevation and cross section through the vertical axis of another combination of equipment in an embodiment which may be utilized for the selected teeming, casting and pouring of molten metal having an opening through the center thereof; and

FIGURE 10 is a view in plan and cross section of the embodiment shown in FIGURE 9 taken along line X—X thereof.

Referring to FIGURES 1 to 3 of the drawings, the components of equipment 10 shown therein comprises a tapping spout 11 having a channel 12 therein for the discharge of tapped molten metal from a furnace (not shown) such as an electric furnace of the tilting type, to discharge molten metal into a pouring funnel 13 when the furnace is tilted. Funnel 13 is refractory lined and provided with a bottom pouring nozzle 14 having a passage 15 therein of selected size. When desired, nozzle 14 is closed by a stopper rod 16 operated by external linkage connected to a remotely controllable operating cylinder 17, or to a manual control. A safety overflow channel 18 is provided in the funnel. An annular peripheral flange 19 on the funnel is adapted to be seated on a peripheral flange 20 at the top of a sealing cylinder 21 forming a part of a vacuum cover 22 surrounding an opening 23 therein through which nozzle 14 extends. A vacuum sealing gasket is provided between flanges 19 and 20 to maintain a vacuum seal therebetween.

Vacuum cover 22 has a lower flange 24 adapted to seat upon a peripheral flange 25 which is part of a refractory lined bottom pour teeming ladle 26 having lifting lugs 26a. The bottom of ladle 26 is provided with a teeming nozzle 27 of any suitable material having a teeming passageway 28 therethrough of predetermined diameter. The top of passageway 28 may be closed by a vertical movement stopper rod 29 covered with refractory and connected through a vacuum sealing sleeve 30 to a manipulator rod 31 which may be manually or mechanically raised and lowered for the operation of rod 29, cover 22 being provided with a bay portion 32 to accommodate such movement. A vacuum sealing gasket is provided between flanges 24 and 25 so that the interior 33 of ladle 26 may be evacuated through an elbow section of pipe 34 comprising a port to the ladle interior 33. A flexible vacuum hose 35 is fixed to pipe 34 for the pre-evacuation preferably of interior 33 when cover 22 and a refractory radiation shield 36 are in place as shown. A refractory lined basket 37, open at its top and bottom, is supported in opening 38 in shield 36 to shield the stopper rod refractory and confines the fragments into which the molten metal discharge from passageway 15 divides upon encountering the evacuated interior 33 of teeming ladle 26.

Such fragments upon leaving the bottom of basket 37 tend to spread as they fall through the interior space of such ladle and expose considerable surface to the vacuum conditions, thereby readily yielding up gases in the molten metal including oxygen, nitrogen and hydrogen. The pressure of such vacuum need only be moderate to produce very high quality and microclean relativley segregation-free alloy steel under this invention, a vacuum in the order of from about 1 to 6 mm. of Hg, absolute, usually being sufficient. Preferably means (not shown) connected to flexible vacuum pipe 35 are left on as the level of molten metal in ladle 26 rises to provide vacuum degassing of the fragmented molten metal as it falls and of the body of molten metal which collects in the lower portion of ladle 26 at the end of such fall.

A circular stand 39 is provided around the bottom of teeming ladle 26 and a sealing cylinder 40 is provided inwards thereof around nozzle 27. Induction heating coils 41, which may also be used to stir, may be provided in the side walls of ladle 26 to maintain any desired non-freezing temperature in the molten metal in ladle 26 for fluidity and/or other control. Further, flow control induction coils 42 may be provided in the bottom of the ladle immediately surrounding, or in, the teeming nozzle 27 which, as shown, is made of a high temperature ceramic, e.g., zirconium oxide, resistant to thermal shock and corrosion from feeding of a moving ingot having an opening through the center thereof.

When ladle 26 is in its normal teeming position atop a bell cover 43, cylinder 40 is in vacuum sealing relation with an annular platform 44 at the top of the bell, a vacuum sealing gasket being therebetween for sealing security. The lower end of nozzle 27 within sealing cylinder 40 may also be covered by a fusible diaphragm 45, e.g., one of aluminum, to insure separation of the interior 33 of ladle 26 from the interior 46 of bell cover 43 during evacuation and before teeming.

Coil or coils 42 may be utilized to provide an alternating current field of selected frequency and intensity, and in one or more phases, to regulate and/or vary the rate at which molten metal flows out through the teeming passageway 28. This may be done without rectifying, or by rectifying, so that energy is generated to act in an upward direction relative to the vertical axis of passageway 28 to a greater or lesser intensity as desired to produce the selected rate of teeming (see FIGURE 6).

Inasmuch as, in the case of molten alloy steel, such is substantially non-magnetic, nevertheless there is an energy effect exercised by the coil or coils 42 which may be due to eddy currents. Other forms of electric current may be used to increase the downward electrical seal therebetween, e.g., may be hollow tubes and a coolant, such as air or carbon dioxide, may be circulated through such tubes. Further, any such cooling can be limited so as not to chill nozzle 27 and cause any freezing or flow impeding effect in passageway 28.

Bell cover 43 in this embodiment is provided with a strong circular casing 47 which extends up and over the conical frustum top 48 to terminate in a central opening 49 surrounding diaphragm 45 and nozzle 27. Inside bell 43, a separate structural steel frame 50 is provided having rafter members 51 to support with bell 43 the considerable weight of teeming ladle 26, particularly when there is molten metal therein. The lower flanged end of frame 50 sits on an annular ring 52 in the floor of the plant, a sealing gasket being provided therebetween. In turn, the lower flanged end of bell 43 sits on the annular bottom 53 of the bell and is also covered by a bell body 54 for a hermetic seal between to form a gas-tight enclosure. A pipe end 55 forms a part of cover 43 and provides a vacuum or pressure port into the interior of bell 43 through the circumferentially spaced columns of frame 50. Pipe 53 is connected to a flexible pipe 54 which leads to a vacuum source (not shown), or in some cases as desired for a flow of non-oxidizing gas therein, or to a source of gas pressure if interior 46 is to be operated under pressure which sometimes is useful in further minimizing any tendency to form a denticular structure in the congealing molten metal. The lower end of bell 43 is closed by a foundation well 55 having a deeper central axial bore 56 the purpose of which is herein below described.

Each of the support columns in frame 50 is provided with an inwardly extending bracket 57 to support a ring mold 58 made of a highly thermally conductive metal such as copper, the vacuum being depressed at 59 to form a notch or channel for any overflow that may chance to occur or if an operation of this invention therein is not properly conducted. The inside wall of mold 58 is generally circular or polygonal but flares somewhat outwardly and downwardly around the central vertical axis to free itself from a mold 61 being made. Mold 58 is provided with a series of peripheral passageways 62 some or all of which may be in parallel and connected by an insulated pipe 63 to the outside of bell 43. Header pipe 63 is connected to a coolant pipe 65. Another header pipe 64 is connected to the other end of the passageways 62 and then to a further coolant
pipe 66. Union and valve shut-off connections are provided at 50 in frame 59 to enable it to be disconnected and lifted away if desired at the end of a casting operation, and, further such may be provided near the plant floor as shown in FIGURE 1. In this way, enforced circulation of fluid coolant through the passageways 62 is obtained in the cooling of the casting and of the mold itself. Flow is passed through the uppermost passageways 62 where the greatest instantaneous heat removal effect is desired. Such coolant may be water, but preferably is carbon dioxide, or other non-explosive coolant, the quantity and speed of circulation of the coolant being a function of the circulating equipment (not shown) connected to the pipes 56 and 66. If water is used as such coolant, at the start of an operation, it is preferable to begin with the circulation of cooling air through the passageways 62 to be followed in increasing measure by the flow of cooling water to prevent any too sudden rise in the temperature of that water and consequent thermal shock to the material of construction. Such also inhibits unwanted condensation on the outside of mold 58 at the start of an operation.

In the embodiment of FIGURES 1 to 3, casting begins against a freeze block 67 which preferably is a relatively massive cast iron block having upstanding studs 68 welded to the upper surface thereof. The initial freeze in the formation of ingot 61 grips the block and studs block 67 is moved downwardly by a motor drive 69 at the selected speed of formation of ingot 61. The freezing by mold 58 at the top of ingot 61 is rapid under a practice of this invention and virtually at the slow rate of 55 mm per hour. The contraction of ingot 61 as it freezes toward the center frees it from wall 60 to all material extent leaving but a very shallow liquid layer 70 at the top in physical contact with wall 60, such layer being virtually flat and having an almost conical transition portion or sub-stratum 71 of bond in flake shape in about 45 mm of length. Such freeze contraction in uniform and continuous contact with the already frozen top of ingot 61 immediately there-beneath. The embodiment shown in FIGURES 1 to 3 provides for dynamic casting in that as motor-reducer 69 is operated at selected speed it rotates a worm 72 to rotate a worm wheel 73 and thereby a nut 74 in engagement with the threads of a threaded plunger 75 strong enough to support ingot 61 and block 67 steadily on a plate 77, from which block 67 is readily separable, at the top of the plunger 75. Rotation of nut 74 does not rotate plunger 75 about its axis due to a spline 75a engaging a splined section 75b in the plunger, but will bring it downwardly at the prescribed speed corresponding to the rate of teeming of the molten metal from ladle 26. A removable cover 76 for motor-reducer 69 is attached to its fixed base and is provided with a collar to which spline 75a is fixed.

A variety of heating means may be used to keep the surface of layer 70 open and free from crusting or bridging as ingot 61 is built up by teeming and freezing, such openness also aiding in degassing when the interior of bell 43 is evacuated, and, in all cases, the movement to the top of layer 70 of any oxide residuals that may be in such freeze condition, as well as avoiding voids in the ingot. In the illus-trated embodiment being described, the underside of the ramper 51 is lined with a radiant refractory 78 beneath which are suspended sets of so-called glow bars 80, which may be made of a material such as silicon carbide arranged in a plane 75b parallel to the vertical axis so that heat therefrom is most intense at substantially one-third of the radial distance from the perimeter of the ingot toward its center. Holders 81 are provided for each chordal group of bars 80, at least one of the holders being conductive and in clamping relation to one end of its particular group and the other end by mitting the glow bars 89 to slide therethrough in accordance with their change in length with differences in temperature. Conductive leads 82 for each set of glow bars are brought out through the refractory 78 and by suitable conductive buses are led down through electrical conduits 83 in one or more of the columns 59 to a junction box 84 from which further leads 85 pass to the outside of bell 43 beneath the floor plate 52 in the manner of the coolant circulation pipes 56 and 66, suitable vacuum sealing provision being employed in connection therewith to preserve the heating of the space 46. The use of such heating means also tends to maintain a minimum slope of temperature gradient between the center of layer 70 and the edge of that layer next to wall 60 to thereby keep it flat and thin. Other suitable heating means may be utilized, such as consumable electrode heating means as illustrated in FIGURE 4, or electron beam (EM) of high energy output such as are shown in FIGURE 9 for use when a higher vacuum, in the order of 10⁻⁶ mm of Hg, absolute, may be employed in the space 46.

Thus, in an operation of the slow pouring and casting system shown in FIGURES 1 to 3, the refractory of the pouring funnel 13, ladle 26 and bell cover 43 preferably are preheated. Then tapping starts and when the tapped molten metal rises to a predetermined intermediate level in the pouring funnel 13, stopper rod 16 is opened and the metal will dissolve a fusible diaphragm preferably sealing the lower end of welding tube 20 and flow into the teem-ing ladle 26 in fragmented form for vacuum tap degassing. At a selected height of molten metal in teeming ladle 26, its stopper rod 29 will be opened and a stream of molten metal will flow therethrough at a rate predetermined by the selected height of metal in ladle 26 to some extent, more importantly by the diameter of passage 28 in nozzle 27 and by coil or coils 42 to the extent they may be used. The first flow of such metal to passageway 28 will melt diaphragm 45 thus disposing thereof and providing a vacuum seal throughout the entire height of the apparatus between the molten metal level in the pouring funnel 13 and the interior of bell 43. Such pouring rate through passageway 28 will correspond substantially to the freezing rate in the thin layer 70 and thin sub-stratum 71 for obtaining of advantages hereinbefore described. Ring mold 58 is fixed because the contraction, as the successive substrata 71 congeal, will cause the peripheral surface of that portion of ingot 61 to readily pull free from the top of wall 60. However, provision may be made if desired for slight relative axial movement between ingot 61 and mold 58 to inhibit any freezing difficulty. There will be little turbulence because nozzle 27 purposefully is relatively close at all times to the top of mold 58 where freezing takes place quickly and as nearly as possible in a planar layer. Covered visual port means 47a are provided at least in the frustum top of casing 47 to insure proper observation and operation. Such, slow teeming, lack of troublesome turbulence and fast freezing corresponding to the teemi-ing rate inhibits migration of residual inclusions in the steel and prevent segregation, just as the steel is micro-clean by virtue of the tap and casting degassing following careful preparation of the alloy steel itself in whatever furnace is selected for that purpose, although alloying additions may also be in pouring funnel 13 and/or in ladle 26. Sometimes, the stopper rod 29 can be raised or lowered slightly to adjust the speed of teeming through nozzle 27, or any heating by coils 41 may be regulated to change fluidity sufficiently for control purposes. In cases where pouring funnel 13 is fed by a tapping spout 11, or by a tapping ladle rather than directly from a furnace, such a furnace or ladle may make several heats or trips to the pouring funnel 13 for replenishment of the teeming ladle 26 without detriment to the ingot 61 or loss of the vacuum seal because, in this invention, of the unusually slow rate of pouring and casting consonant with the rate of freezing of the metal in bell 43 under the combined heat removal devices for mold 58. Moreover, by having separate evacuation means connected respectively to ports 34 and 53, double degassing is effected in a single operation at moderate and readily achievable vacuum.
pressure levels with fewer inclusions and greater micro-

nature, may be placed and maintained on top of layer 70' and normally will surround the area and will pick up, particularly when reducing, oxide formations and inclusions from layer 70'. While two pairs of electrodes 97 are shown, additional ones at angularly spaced positions around the vertical axis of the ingot may be provided as desired, and one electric arc heating may be utilized under the vacuum conditions within cover 43 in the first above-described embodiment. The polygonal ring shape of wall 60' in mold 58' assists in deterring shrinkage defects in larger ingots as ingot 61' contacts and pulls away from wall 60'. The embodiment of FIGURES 4 and 5 has a relatively coherent stream of metal ingot passing out from passageway 28' even though teemed at a selected rate, and while it strikes the layer 70' with somewhat more mass and force than is the case in the first above-described embodiment and may have a tendency somewhat to deepen such layer, the equipment parts are so close as to prevent detrimental splash and turbulence even though long high ingots are made. Indeed, in some operations particularly in those in which smaller lighter ingots are made, a lip pouring ladle with a precise tip-
docing device such as a gear mechanism may be utilized with other equipment shown in a practice of this invention to provide a very slow pouring rate corresponding to the freezing rate of the teemed metal in the mold.

FIGURE 6 represents a somewhat enlarged detail view of a modified nozzle portion of any of the teeming ladles 26 shown in the drawings to illustrate a teeming rate control utilizing three phase alternating current coils immediately surrounding the nozzle, which coils may or may not be internally cooled as desired depending upon the characteristics thereof. In the FIGURE 6 detail, the steel bottom 100 of the teeming ladle is lined with refractory 101 and is provided with an opening through which a refractory or ceramic teeming nozzle 102 extends. A cylindrical metal guard 103 welded to bottom 100 surrounds the nozzle 102 and the radial space therebetween is filled with a rammed refractory. Nozzle 102 is provided with a teeming passageway 104 of predetermined size which is closed when stopper rod tip 105 is in the position shown. A cylindrical box 106 depends from bottom 100 and is closed at its bottom by an annular plate 107 through which the tip of nozzle 102 extends. Box 106 and cover 107 preferably are coated with refractory, unless a slag layer, such as slag layer 99, is used as a radiation shield floating on top of the molten metal layer 70 in the case of the formation of a moving ingot 61, although a device of FIGURE 6 may be used in any embodiment of the invention. Box 106 is provided with coils 108a, 108b and 108c respectively to the three lines of a three-phase power system of desired frequency. In the course of an operation of the device of FIGURE 6 when stopper rod 105 is raised and the coils 108a, 108b and 108c are energized through conductive leads properly insulated and extending to the side of the bell cover, for example, an upward energy effect is generated as shown by the arrows pointing upward in the passageway 104 even though the current is alternating in the case of many molten metals, alloys and steels, such as non-magnetic even though they may be magnetic in the solid state. Nevertheless, the teeming rate of the molten metal from ladle 100 downwardly through passageway 104 can be controlled by such coils either as an adjunct of other control means, or in lieu thereof. Still further, the electrical energy effect provided by the coils 105 is more intense near the inside wall of passageway 104 than it is at the central vertical axis of the passageway, a matter indicated by some change in the length of the arrows which, are not to any scale. Consequently, the teeming metal indicated by the downwardly. pointing arrows will tend to flow more along the central vertical axis of passageway 104, still at the selected overall quantitative rate per unit of time, than it will at the walls, with the consequence that
not only is there a pouring rate control for use in a practice of this invention, but there is also thereby provided a device for inhibiting erosion of the wall of the passageway 104 by the relative movement therealong of the molten metal, such erosion with certain refractories occurring relatively soon and causing a change in the effective diameter of the passageway by enlargement thereof.

FIGURES 7 and 8 show an embodiment comprising an annular mold 120 having hollow outer circumferential walls 121 and a hollow center 122, the interior of center 122 and the outer wall interiors being connected by a hollow base 123. The cavity 124 in mold 120 is an annulus which has a selected diameter relatively low in relation to its height. Preferably, a coolant such as water, chilled compressed air, or carbon dioxide, is circulated through circulation inlet pipe 125 and outlet pipes 126 bringing coolant to the entire jacket wall of the ingot mold. Inlet pipe 125 is provided with a rotary ball joint 110 so that the upper end pipe 111 thereof may rotate with mold 120 if and when it is turned. Mold 120 is mounted on a rotatable table 112 which in turn forms the upper part of a fixed base 113, the table being turned by a manually-reducer 114 when it is energized to turn table 112 at a speed of up to about six r.p.m. To prevent entrapment of air in the hollow center 122 the mold 120, a bent pipe 115 extends from the upper interior end of portion 122 to the entry side of one of the pipes 126 in the outer wall 121 of mold 120. Consequently, when water is admitted to the interior of the mold, for example, it will fill up the whole interior around the annular cavity 124 and drive out any air, the efficient water leaving discharge pipes 126 and falling into a circumferential through 117 from which a drain 118 leads to a sewer. An overflow notch 116 is provided in the mold 120 for safety in the case of overflow. Hence, the cooling of mold 120 to provide a molten metal freezing rate corresponding to the molten metal teeming rate will be operative whether or not mold 120 is being rotated by table 112. Preferably, mold 120 is fed by molten metal at a selected teeming rate from a teeming ladle 127 having a plurality of sized bottom-pouring ceramic nozzles 128 with sized passageways therein and respectively closed by stopper rods 129 all at one time operated by a common linkage 129a and operating cylinder 129b while suspended from a ladle crane. As shown, ladle 127 is provided with a pressure cover 130, like cover 91, kept on in pressure tight relation by clamps 130a so that any desired pressure or change in the pressure in ladle 127 above the molten metal therein can be supplied by gas under pressure supplied through a flexible pipe 131 to the interior of ladle 127, such gas preferably being non-oxygenizing and non-contaminating gas relative to the molten metal in question. Hence, even if there is some erosion of the passageways in nozzles 128, an adjustment in the pressure through flexible pipe 131 will enable the teeming rate to be brought into virtually exact correspondence with the freezing rate thereof in ingot mold 120. It will be noted that the respective dimensions of mold 120 are such that even at the beginning of teeming, the teemed metal does not fall a great distance and, in any event, the freezing thereof is so rapid and uniform as to inhibit segregation substantially irrespective thereof.

In the case of the use of a teeming ladle, for example, of the bottom pour type having a single teeming nozzle, teeming therefrom into mold 120 preferably should be accompanied by rotation of mold 120 about its vertical axis at a slow speed of, say, 1 to 6 r.p.m., to insure that the molten metal layer will be a complete annulus around the entire cavity 124 of the mold, particularly in view of the rapid freezing rate employed and following so quickly and in such correspondence with the relatively slow teeming of metal in its molten state from the ladle immediately above.

In the still further embodiment of FIGURES 9 and 10, a practice of this invention is provided for the making of a hollow moving ingot which is open along the vertical axis thereof. Parts corresponding generally in structure and in functioning to parts of the first above-described embodiment in FIGURES 1 to 3, inclusive, are provided with the same reference numbers with the addition of a double prime accent, "", respectively. In embodiment 109, hollow ingot 110 is formed with the use of an external ring mold 58"" and an internal ring mold 158", which functions in the same manner but to fashion the internal periphery 61"" of ingot 61", just as wall 60"" fashions the external surface 61"" of ingot 61"". Wall 160"" of internal ring mold 158"" tapers downwardly and inwardly somewhat as shown. Further, internal mold 158"" is provided with coolant passageways 162"" which function in the same manner as passageways 62" and are supplied by coolant through the same set of pipes which are extended for the internal mold across one of the bridge members 140 across the top of bell cover 43"" in the frame 50"". The sector-like openings 141 left between the bridging portions 140 are lined with refractory 145 and form openings in bell cover 43"" and frame 50"" through which the teemed molten metal falls onto the top of layer 70", now an annulus forming the topmost portion of annular ingot 61", the layer 70"" having a substantially conically-shaped portion 71"". Molten metal comes from a ladle 26"" with teeming nozzles 27"" which, like the teeming ladle in FIGURES 7 and 8, are four in number, each of such nozzles being closable by a stopper rod 29"". All stopper rods 29"" being operable together by a common operating linkage. The underside of each of the nozzles 27"" at the start of operations may be provided with a fusible diaphragm seal in the event that either ladle 26"" or interior 46"", or both, is to be operated under evacuated conditions. At the start of an operation, the opening of the stopper rods 29"" will teem molten metal through the refractory lined sector openings onto block 67"" which, for purposes of the start of an operation, is up against the underside of internal ring mold 158"". Ring mold 158"" may, if desired, be made half the height of ring mold 58" and is suspended against any escape of molten metal in the initial freezing stage of the ingot. In this stage, as the filling begins, that is, the ring mold 58"", on the other hand, is joined to an annulus 57"" which acts as a bracket except instead of being fixed to frame 50", such annulus 57"" is connected to a plunger 145 for cyclic axial movement if desired, up, or down, or both, by a remotely operable cylinder 144 fixed to frame 50"". The annular ring 57"" cannot be rotated in any way inasmuch as it is notched at angularly spaced places along its external periphery for engagement by projections 147 fixed to the columns in frame 50". The use of such cylinders 144, circumferentially spaced around the inside of frame 50", enables ring mold 58" to be provided with so-called positive or negative stoppers that are intensified relative movement between wall 60" and the exterior surface of ingot 61" to insure against any sticking, there being no possibility of breakout of molten metal in an ingot made in accordance with this invention because of the relatively rapid freeze rate and correspondence of that rate to the teeming rate. By the course of such teeming, the ripple that occurs in the surface of the molten layer 70" helps to form a skin at the edges in a solid state against the respective mold walls 60" and 160" very quickly. For heating means 80" in the embodiment of FIGURES 9 and 10, electron bombardment high energy "guns" have been shown which can be "aimed" by the use of a ball and socket connection 146,
such guns working best in a relatively high vacuum of the order of \( \frac{1}{200} \) of one mm. of Hg, absolute, or even lower pressure. Where the heating means 80° extend through the top of bell cover 43°, vacuum or pressure tight seals are provided in the form of plastic chunking or by other means.

Prior to the advent of this invention, for example, in the casting of industrial size ingots including some of the largest made, the teeming of a tapped heat, often comprising the entire content of a large furnace, took place in a matter of minutes and the solidification of the molten metal so teemed took place, as a general rule, in a matter of hours, at least several multiples of the period of time comprising the entire teeming period, with persistent problems in the nature and composition of ingots so cast. In practices of this invention, a twenty ton ingot, for example, would usually be teemed at a rate between two and three tons of molten metal per hour, with freezing being accomplished in virtually the same period of time; while in the case of macroingots of 100 tons each and larger, it is conceived that the teeming rate will be in the order of from 7 to 10 tons per hour with freezing occurring at the same rate and within the same overall length of time. Providing such combinative steps of action and equipment to eliminate coincident teeming and freezing rates to be obtained with or without single or double vacuum degassing, yields many advantages as pointed out above in describing this invention.

While various embodiments and steps of action of this invention have been described, it will be recognized that many changes may readily be made in aspects thereof and other embodiments provided without departing from the spirit of this invention or the scope of the appended claims.

What is claimed is:

1. Slow pouring and casting method for metals comprising, in combination, tapping a heat of refined molten metal into a pouring member, providing an evacuated ladle below said pouring member, pouring molten metal from said pouring member into said evacuated ladle for fragmentation of such poured molten metal as it falls in said evacuated ladle, heating said degassed molten metal in said evacuated ladle to a predetermined temperature requisite for fluidity and teeming rate control, providing a teeming nozzle having a teeming passageway of predetermined size in the bottom of said evacuated ladle, teeming molten metal through said teeming nozzle at a selected rate determined at least in part by the pressure differential between the pressure in said evacuated ladle and the pressure on the discharge side of said teeming nozzle, providing an evacuated mold chamber below said evacuated ladle and teeming nozzle, providing in said mold chamber a coolable ring mold having a movable ingot block at least adjacent the mold cavity therein, freezing initially teemed molten metal in said mold cavity and against said block to start formation of an ingot, continuing to freeze teemed molten metal at said rate while maintaining a thin molten metal layer at the top of said ingot and maintaining the surface of said thin molten metal layer open, and moving said block downwardly in correspondence with said rate of freezing said teemed molten metal.

2. Slow pouring and casting method for metals comprising, in combination, tapping a heat of refined molten metal into a pouring member, providing an evacuated ladle below said pouring member, pouring molten metal from said pouring member into said evacuated ladle for fragmentation of such poured molten metal as it falls in said evacuated ladle, heating said degassed molten metal in said evacuated ladle to a predetermined temperature requisite for fluidity and teeming rate control, providing a teeming nozzle having a teeming passageway of predetermined size in the bottom of said evacuated ladle, teeming molten metal through said teeming nozzle at a selected rate determined at least in part by the pressure differential between the pressure in said evacuated ladle and the pressure on the discharge side of said teeming nozzle, providing a pressure-tight mold chamber below said teeming nozzle, pouring molten metal from said pouring funnel into said teeming ladle, maintaining a selected temperature of said molten metal in said teeming ladle, providing a teeming nozzle having a teeming passageway of predetermined size in the bottom of said teeming ladle, teeming molten metal through said teeming nozzle at a selected rate determined at least in part by the pressure differential between the pressure in said evacuated ladle and the pressure on the discharge side of said teeming nozzle, providing a pressure-tight mold chamber below said teeming ladle and nozzle in pressure-tight relation therewith providing in said mold chamber a mold for teemed molten metal, cooling said mold at a selected rate to freeze teemed molten metal substantially at the rate of said teeming.

3. Slow pouring and casting method for metals comprising, in combination, pouring molten metal into an evacuated teeming member and degassing such poured molten metal as it falls, maintaining a selected temperature of the degassed molten metal in said teeming member, teeming degassed molten metal from said teeming member without exposure to air at a selected relatively slowly rate, freezing a mold chamber below said teeming member to receive and further degas said teemed molten metal, quickly molding and freezing the teemed molten metal in ingot form in a coolable mold with a relatively thin molten metal layer at the top of said ingot, freezing said teemed molten metal substantially at the rate of its teeming, maintaining the surface of said thin molten metal layer open without custing and bridging, and moving said ingot downwardly relative to said molding mold in correspondence with the rate of teeming and freezing.

4. Slow pouring and casting method for metals comprising, in combination, pouring molten metal into a pressure-tight teeming member, maintaining a selected pressure and temperature in said teeming member, teeming degassed molten metal from said teeming member substantially without exposure to air at a selected relatively slowly rate, providing a pressure-tight mold chamber below said teeming member to receive said teemed molten metal, maintaining a selected pressure and temperature in said mold chamber, freezing the teemed molten metal in ingot form in said mold chamber with a relatively thin molten metal layer at the very top of said ingot, freezing said teemed molten metal substantially at the rate of its teeming, maintaining an open surface on said thin molten metal layer as it progressively rises relatively slowly in the building up of said ingot.

5. Slow pouring and casting method for metals comprising, in combination, pouring a heat of refined molten metal into a heatable pouring funnel, providing a pressure-tight heatable teeming ladle below said pouring funnel, pouring molten metal from said pouring funnel into said teeming ladle, maintaining a selected temperature of said molten metal in said teeming ladle, providing a teeming nozzle having a teeming passageway of predetermined size in the bottom of said teeming ladle, teeming molten metal through said teeming nozzle at a selected rate determined at least in part by the pressure differential between the pressure in said evacuated ladle and the pressure on the discharge side of said teeming nozzle, providing a pressure-tight mold chamber below said teeming ladle and nozzle in pressure-tight relation therewith providing in said mold chamber a mold for teemed molten metal, cooling said mold at a selected rate to freeze teemed molten metal substantially at the rate of said teeming.

6. Method as set forth in claim 5 comprising, in combination, at least assisting in regulating the rate of teeming by electromagnetically induced energy effects resistant to downward flow of the molten metal in the
course of such teeming, said effects being exerted more strongly nearer the wall of said teeming passageway and less strongly along the vertical central axis of said teeming passageway.

7. Method as set forth in claim 5 comprising, in combination, providing a ring mold having a bottom initially comprising a downwardly movable block for the formation of a moving ingot below said ring mold as the ingot forms and moving said ring mold a short distance axially at a predetermined speed sequence and cycle to maintain said ring mold free of sticking to said ingot.

8. Method as set forth in claim 7 comprising, in combination, heating the top of said ingot in said mold chamber a selected distance radially inwardly of said mold to maintain the top surface of the molten metal layer on top of said ingot open and free of bridging and crustling as its substratum congeals to progressively build up said ingot.

9. Method as set forth in claim 8 comprising substantially directing said heating upon said molten metal layer wherever crustling and bridging are more likely to occur and moving said directing of said heating as required by observation of the openness of the top surface of said molten metal layer.

10. Method as set forth in claim 8 comprising, in combination, maintaining a layer of non-oxidizing at least neutral slag floating on the top surface of said molten metal layer in said mold chamber.

11. Method as set forth in claim 5 comprising, in combination, covering said teeming ladle with a pressure-tight cover, regulating the pressure inside said teeming ladle to a predetermined pressure above atmospheric, and teeming molten metal from said teeming ladle at a selected rate controlled in part at least by said pressure.

12. Method as set forth in claim 5 comprising, in combination, said ring mold being an external ring with a generally vertical internal wall to mold the exterior of said ingot and an internal ring having a generally vertical outwardly facing peripheral wall to form the interior of said annular ingot said respectively cooling said rings at the respective appropriate rates for production of said annular ingot.

13. Slow pouring and casting method for metals comprising, in combination, tapping a heat of refined molten metal into a pouring member, providing an evacuated container for molten metal below said pouring member, pouring molten metal from said pouring member into said evacuated container, providing an evacuating chamber having a rapid freezing mold therein, teeming molten metal from said evacuated container into said evacuated chamber and the mold therein, and rapidly freezing said teemed molten metal in said mold at a rate substantially corresponding to said rate of teeming.

14. Slow pouring and casting apparatus for metals comprising, in combination, a teeming ladle, a pressure-tight cover for said teeming ladle, means for evacuating said teeming ladle, means for heating the molten metal in said teeming ladle to desired temperature, a teeming nozzle having a passageway of predetermined size positioned in the bottom of said teeming ladle, a bell cover and frame in pressure-tight relation thereto, said bell cover and frame having an opening immediately below said teeming nozzle, means for teeming molten metal through said teeming nozzle at a selected relatively slow rate, a ring mold immediately below said opening to receive said teemed molten metal, means for circulating coolant through said ring mold in desired quantities for particular cooling rates to freeze said teemed molten metal substantially at said teeming rate, said ring mold having an interior molding wall slightly flaring outwardly and downwardly, a casting block against which the initially teemed molten metal discharged from said teeming nozzle is cast to form an ingot, said block initially substantially closing the bottom of said ring mold, means for heating the thin molten metal layer at the top of said ingot, said last-named heating means being more intense about one-third of the radial distance from the outside toward the center of said molten metal layer, and means for moving said block downwardly in accordance with the rate of freezing of an ingot molded by said ring mold.

15. Apparatus as set forth in claim 14, comprising, in combination, a second ring internal mold suspended from said bell cover and frame in radially spaced relation to said first-named ring mold, means for cooling said internal ring mold at any selected predetermined rate, teeming openings in the upper part of said bell cover and frame, said teeming ladle having a plurality of teeming nozzles in angularly spaced arrangement adapted to be positioned in registry with said teeming openings respectively, and a like plurality of stopper rods for said teeming nozzles, whereby a hollow moving ingot may be made in said apparatus.

16. Apparatus as set forth in claim 14 comprising, in combination, said interior molding wall being a continuous curve or polygonal in plan, said means for teeming molten metal at a selected relatively slow rate including electromagnetic coils substantially surrounding said teeming nozzle to provide resistant to gravity flow energy effects operative to regulate the flow of teemed molten metal through said passageway, said means for heating the molten metal in said teeming ladle comprising a fluid-cooled electrical induction heating coil, and said means for heating said layer being direct and directional for maximum effect upon selected portions of the surface of said layer.

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