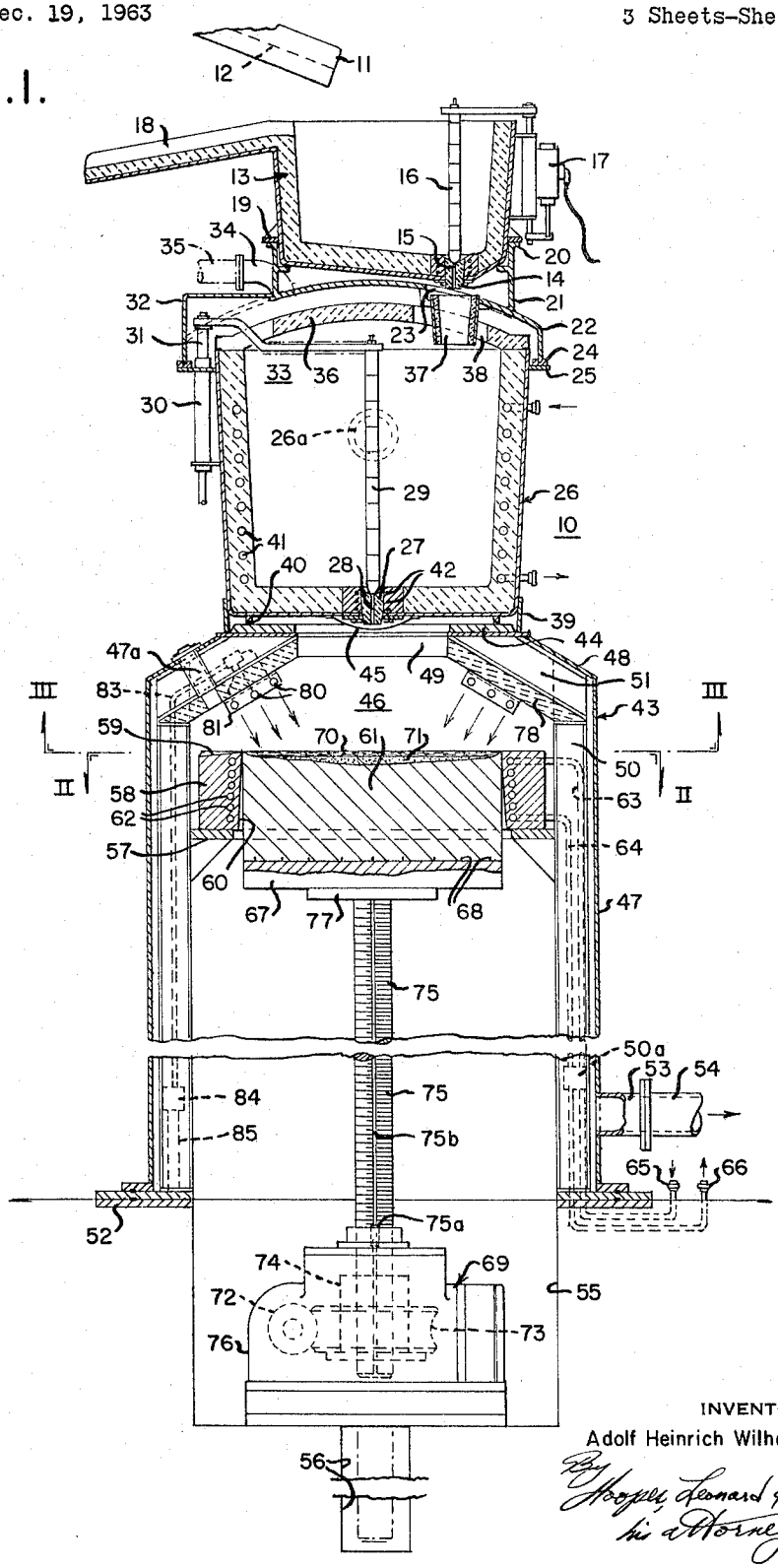
Aug. 30, 1966 A. H. W. SICKBERT 3,268,958

SLOW POURING AND CASTING SYSTEM FOR FERROUS AND OTHER METALS

Filed Dec. 19, 1963 3 Sheets-Sheet 1

Fig. 1.



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SLOW POURING AND CASTING SYSTEM FOR FERROUS AND OTHER METALS

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Fig. 2.

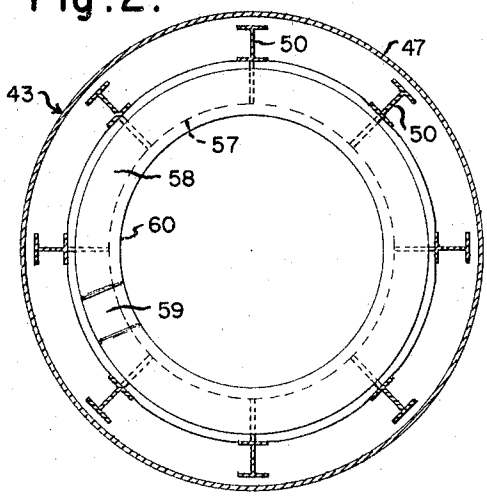


Fig. 3.

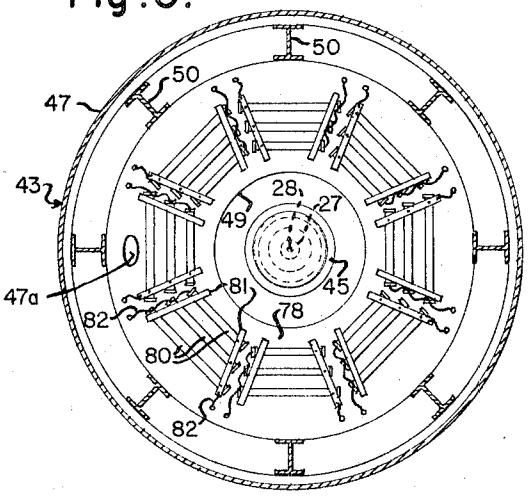


Fig. 4.

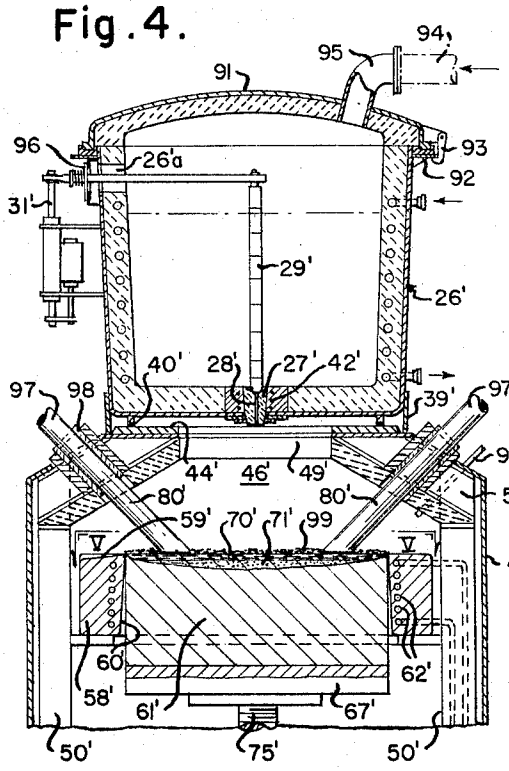


Fig. 5.

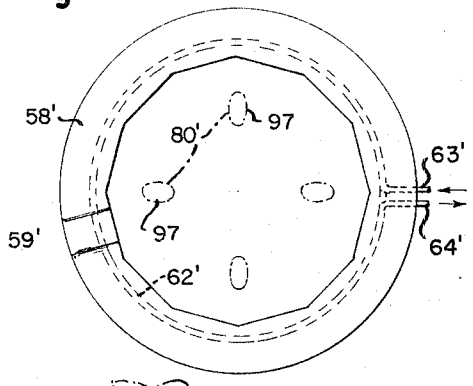
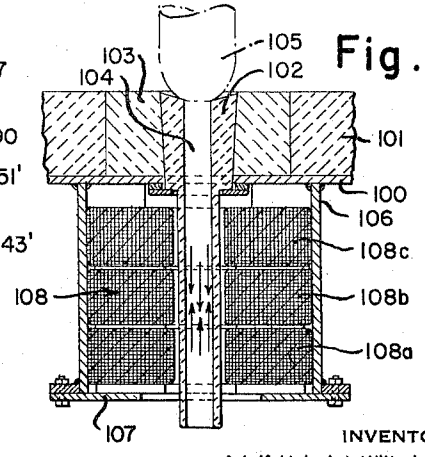


Fig. 6.



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SLOW POURING AND CASTING SYSTEM FOR FERROUS AND OTHER METALS

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Fig. 7.

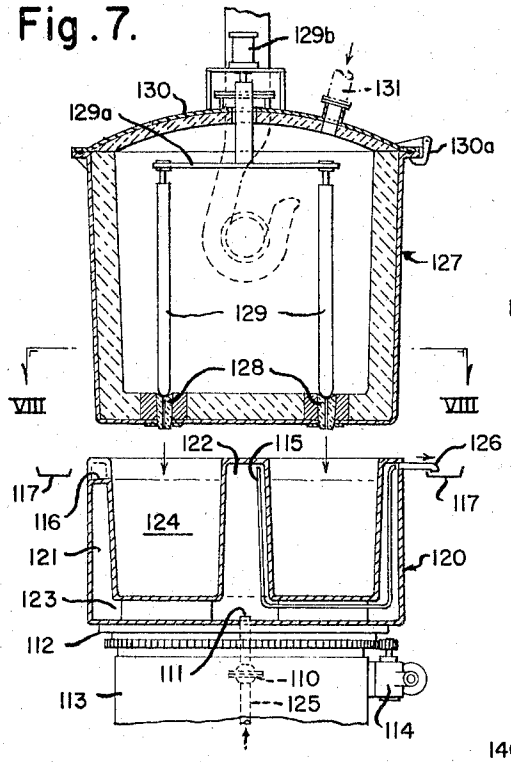


Fig. 8.

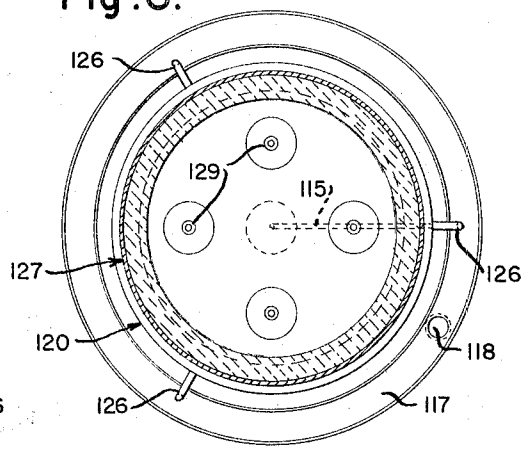


Fig. 10.

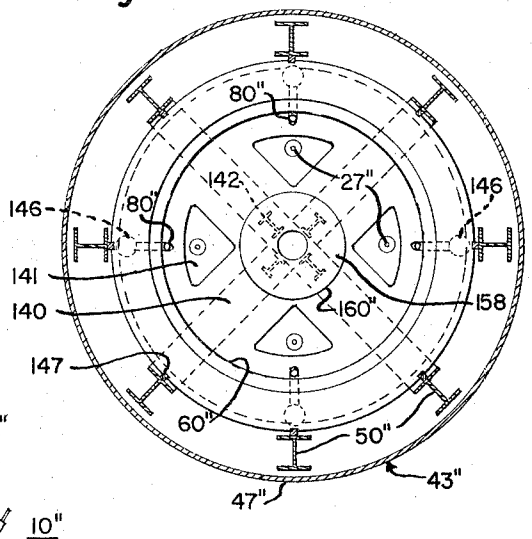
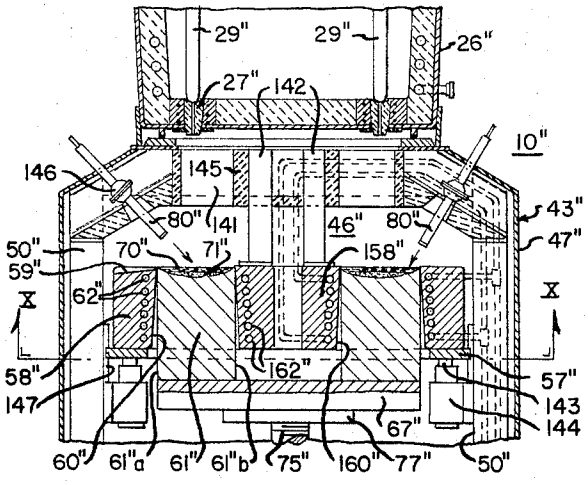


Fig. 9.



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United States Patent Office 3,268,958 Patented August 30, 1966

3,268,958

SLOW POURING AND CASTING SYSTEM FOR FERROUS AND OTHER METALS

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Filed Dec. 19, 1963, Ser. No. 331,731
16 Claims. (Cl. 22—57.2)

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 pipe and blow holes and 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 provide 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

C	.22
Mn	.22
P	.007
S	.013
Si	.025
Cr	1.56
Ni	3.15
Mo	.37
Cu	.14
V	.04
Al	.007

with low gas content: O_2—12 p.p.m.; N_2—41 p.p.m.; and H_2—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 Hg, 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 thereinto 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 extensive equipment, multiple handling and expense and involved certain hazards including the possibility that the consumable electrode 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 breaching the water-tight integrity of the mold which would cause a steam explosition, or leaks in the mold might otherwise develop. Still further, despite such very careful 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 ½ 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 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 vacuums in the micron range, 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 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 crusting or bridging over of the surface thereof and while inhibiting turbulence, segregation and formation of dendrities in the freshly congealing 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 moving 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 molding ring 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 selected 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 freezing of a moving ingot 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 combinative 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 passageway **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** so that there is 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 **26***a*. 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 pasageway **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 relatively 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, the vacuum producing 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 inwardly 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 erosion by molten metal being teemed therethrough. 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 **32** during evacuation and before teeming.

Coil or coils **42** may be utilized to provide an alternating current field of selected frequency and intensity, 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 for such flows control. If desired, the coil turns 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** whih 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 flange of frame **50** with a sealing gasket therebetween to form a gas-tight enclosure. A pipe end **53** 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 therethrough, 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 dentritic 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 hereinbelow 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 top annular surface of mold **58** is depressed at **59** to form a notch or channel for any overflow that may chance to occur 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 an ingot **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*a* in frame 50 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, the incoming colder coolant preferably being 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 65 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 conversion thereof into steam. 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 steel 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 and 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 teeming. 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 congealed transition portion or substratum 71 of but slightly dished shape in about to final freeze condition in uniform and continuous contact with the already frozen top of ingot 61 immediately therebeneath. 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 75*a* engaging a splineway 75*b* 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 75*a* 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 layer, as well as avoiding voids in the ingot. In the illustrated embodiment being described, the underside of the rafters 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 an annular pattern and positioned at a distance from 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 holder permitting the glow bars 80 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 50 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 65 and 66, suitable vacuum sealing provision being employed in connection therewith to preserve the sealing of the space 46. The use of such heating means 80 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 relatively flat and thin. Other suitable heating means may be utilized, such as consumable electrode arc heating means as illustrated in FIGURE 4, or electron beam "guns" of high energy output such as are shown in FIGURE 9 for use when a higher vacuum, in the order of $\frac{1}{100}$ of 1 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 nozzle 14 and flow into the teeming 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 passageway 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. Further, such pouring rate through passageway 28 will correspond substantially to the freezing rate in the thin layer 70 and thin substratum 71 for obtaining of advantages hereinbefore described. Ring mold 58 is fixed because the contraction, as the successive substratum increments 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 freeing 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 47*a* 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 teeming rate inhibits migration of residual inclusions in the steel and prevent segregation, just as the steel is microclean 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 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 ingot 61 under the control of the 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 microcleanliness of the ingot **61**. When all of the metal which is to be teemed into space **46** to make up ingot **61** has been discharged from ladle **26**, the completion of the freezing of the top layer of the ingot will take but little remaining time because of its relative thinness and smallness and then the vacuum seals can be broken and bell casing **47** removed by the shop crane and if desired the frame **50** may then be so removed with its mold **58** after appropriate disconnection at stations **50***a* and **84**, leaving ingot **61** with block **67** on plate **77** with plunger **75** in the bore **56**. An ingot tong can be used to pick up ingot **61** and block **67** to take it to a point where block **67** can be freed therefrom for return to plate **77** after new studs **68** are welded to the surface of the block, leaving ingot **61** to be taken to its place of storage or deposit. After block **67** has been returned to its position on plate **77**, the pouring funnel **13** and ladle **26** rereadied, and frame **50** and bell cover **43** replaced, the equipment is ready for a new evacuation and operation.

In the practice illustrated by the embodiment shown in FIGURES 4 and 5, the equipment therein to the extent that it corresponds generally in structure and function with equipment in the first above-described embodiment, is provided with the same reference numerals with the addition of a prime accent thereto, respectively. In such embodiment of FIGURES 4 and 5, the molten metal is received either from a furnace, or from a tapping ladle, and then poured into teeming ladle **26'**. Preferably, the molten metal fed to teeming ladle **26'** will have been deoxidized in the furnace or tapping ladle supplying such teeming ladle **26'** as by the use of a deoxidizing ingredient, or by other means. In any event, the substantially deoxidized molten metal received in teeming ladle **26'** is fed through passageway **28'** at a predetermined rate as was done in the first above-described embodiment so that the rate of teeming and the rate of freezing respectively corresponds. Moreover, after tapping or pouring into ladle **26'**, a refractory lined pressure cover **91** may be placed thereon in sealing relation with a peripheral flange **92** of ladle **26'**. The cover is clamped in place to the flange by clamps **93** at peripherally spaced locations therearound. A source of pressure gas, preferably non-oxidizing such as argon, is supplied through a flexible pipe **94** to an elbow **95** comprising a port into the interior of ladle **26'**, so that a selected pressure on top of the molten metal in ladle **26'** will provide a further regulating control for the discharge of molten metal through passageway **28'** when stopper rod **29'** is raised, opening nozzle **27'**. Rod **29'** is operated through a side opening **26'***a* in the upper portion of the ladle, such opening being closed and made pressure tight by a sliding plate **96** where the stopper rod cross arm passes thorugh such plate **96**. To assist in maintaining as little oxidation and/or dendritic formation as possible at the top of the forming ingot **61'** in the shallow liquid layer **70'** and congealing substratum **71'**, a stream of non-oxidizing gas, such as argon, may be fed under pressure into interior **46'** through a pipe **90** from a source not shown and removed below through a pipe corresponding to pipe **53–54**.

The heating means **80'** used in space **46'** are consumable electrodes **97** each of which are axially movable through a pressure sealing sleeve **98** in the frustum top portion of bell cover **43'** and frame **50'**, the electrodes **97** being automatically fed in a known manner by voltage control means to provide the direct current amperage usually at low voltage for the creation of a heating arc between the lower end of each of the lower electrodes **97** and molten metal layer **70'**, such heating also melting the electrodes **97** in such further embodiment. Such consumable electrodes are made in advance preferably with the desired composition of ingot **61'**. If desired, further, the electrodes **97** may be mounted for oscillation about the vertical axis of ingot **61'** to cover more area with each such electrode. Slag **99**, of a reducing or neutral nature, may be placed and maintained on top of layer **70'** and normally will surround the arcs 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, such 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 molten metal issuing 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 those in which smaller lighter ingots are made, a lip pouring ladle with a precise tipping 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 preterminded 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 **108***a*, **108***b* and **108***c* 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 **108** 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 up in the passageway **104** even though the current is alternating in the case of many molten metals, alloys and steels, such are 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 **108** is more intense near the inside wall of pasageway **104** than it is at the central vertical axis of that 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 motor-reducer **114** when it is energized to turn table **112** at a speed usually of not more than six r.p.m. To prevent entrapment of air in the hollow center **122** of 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 effluent 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 **129***a* and operating cylinder **129***b* 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 **130***a* 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-oxidizing 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 thereto, respectively. In embodiment **10″**, hollow ingot **61″** 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″***b* of ingot **61″**, just as wall **60″** fashions the external surface **61″***a* 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 on for the internal mold across one of the bridge members **140** across the top of bell cover **43″** and 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 substratum congealing portion **71″**. The teemed 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 closeable 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″** to insure against any escape of molten metal in the initial freezing stage as the ingot **61″** starts being formed. Once started, the movement downwardly of block **67″** is substantially continuous as the ingot is formed by the congealing layer on top. The internal ring mold **158″** is suspended by hangers **142** from the center of the bridging portions **140** rigidly joined to the remainder of frame **50″** in the instant embodiment being described. 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 **143** 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 strip, that is, 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. In the course of such teeming, the ripple that occurs in the surface of 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 1/100 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 chinking 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, or 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 enable such 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 with the edge thereof against the molding wall of said mold cavity, controlling at least the cooling of said ring mold such that said rate of teeming and freezing substantially correspond in point of weight and time, directionally heating said thin molten metal layer to inhibit crusting and bridging and maintain the surface thereof 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, 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 with the edge thereof against the molding wall of said mold cavity, controlling said respective rates of teeming and freezing to substantially correspond in point of weight and time, 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.

3. Slow pouring and casting method for metals, comprising, in combination, pouring molten metal into an evacuated teeming member to fragment and degas 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 slow rate, evacuating 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 ring mold 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 the surface of said thin molten metal layer open without crusting and bridging, and moving said ingot downwardly relative to said ring mold in correspondence with the rate of teeming and freezing.

4. Slow pouring and casting methods for metal 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 slow 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, molding and 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 speaking 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 **5** 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 crusting 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 crusting 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 **7** 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 respectively 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 evacauted 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 to the surrounding atmosphere, means for evacuating said bell cover and frame, said teeming ladle adapted to sit atop said 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 sustantially 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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