March 26, 1974 C. D'A. HUNT ET AL **Re. 27,945**

APPARATUS FOR PROCESSING MOLTEN METAL IN A VACUUM

Original Filed May 7, 1969 4 Sheets-Sheet 1

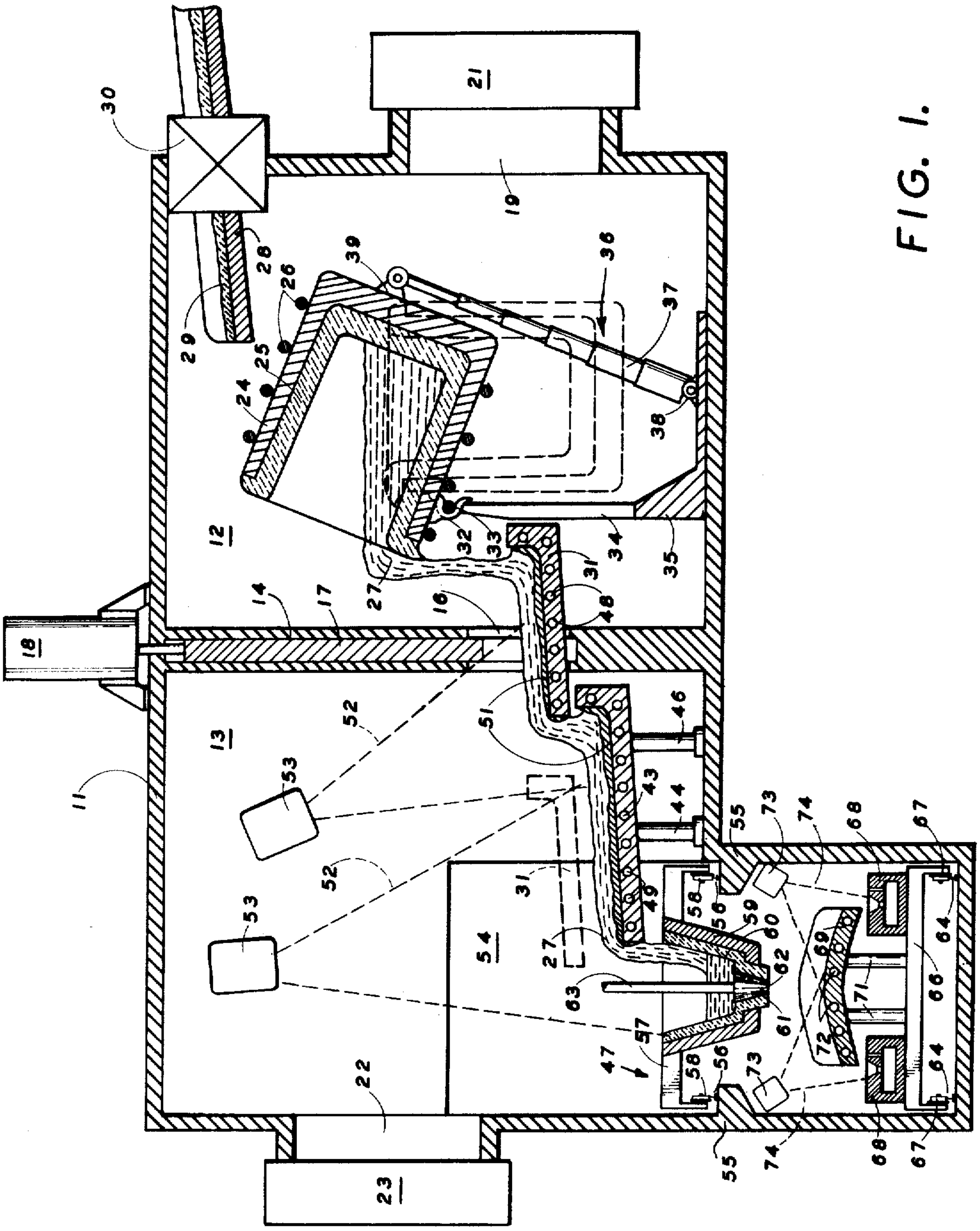

FIG. 1.

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Original Filed May 7, 1969 4 Sheets-Sheet 2

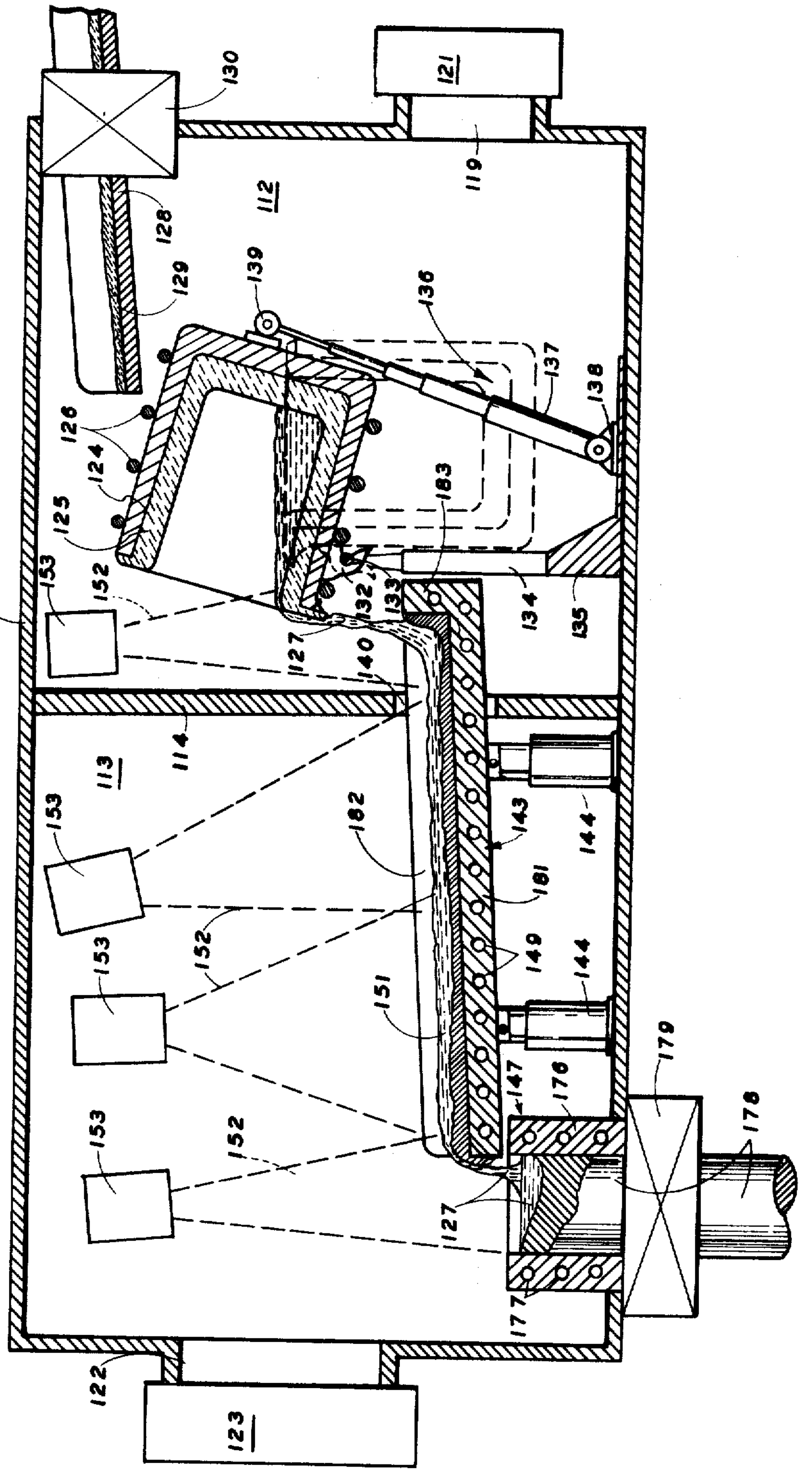

FIG. 2.

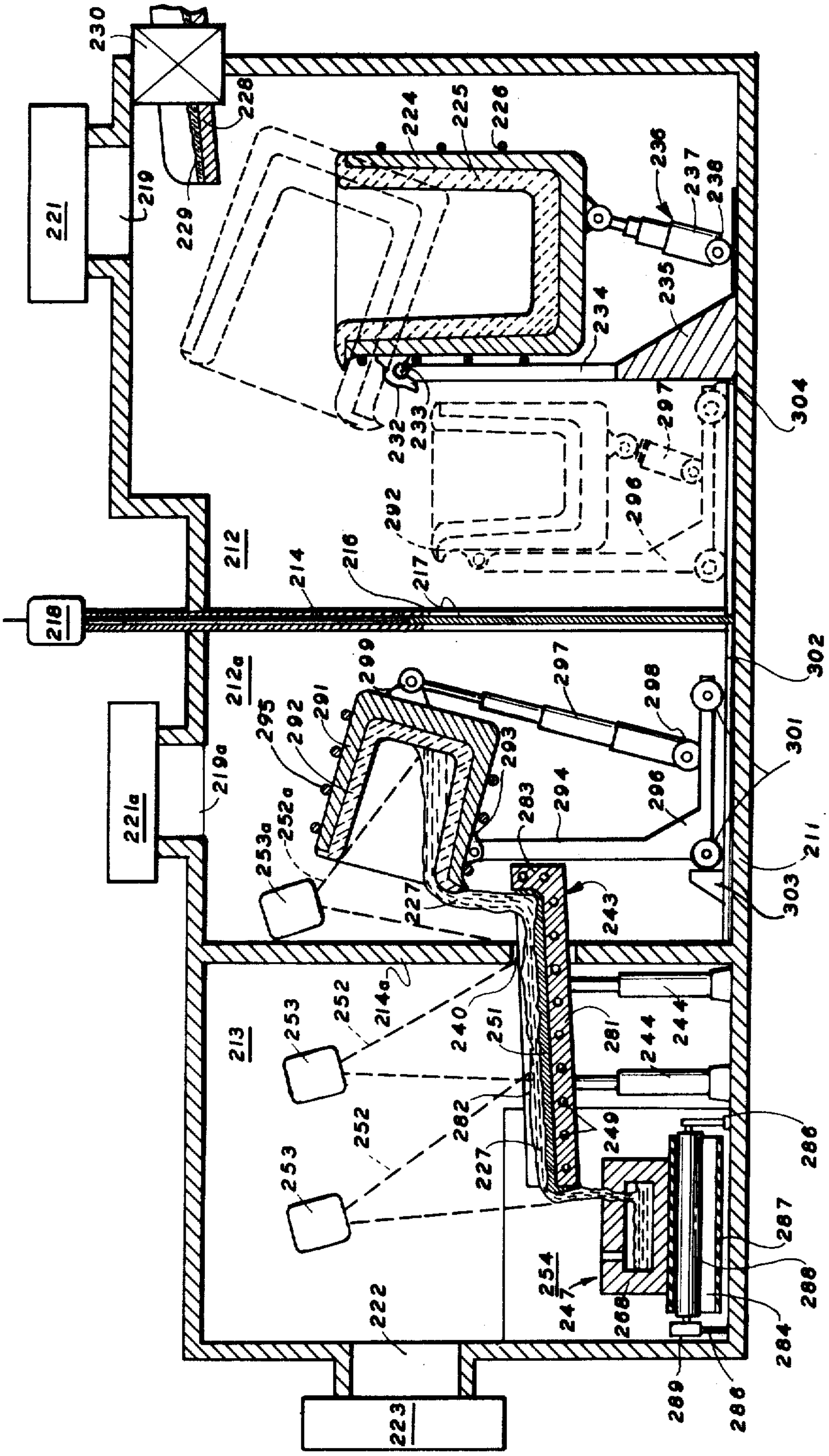
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FIG. 3.

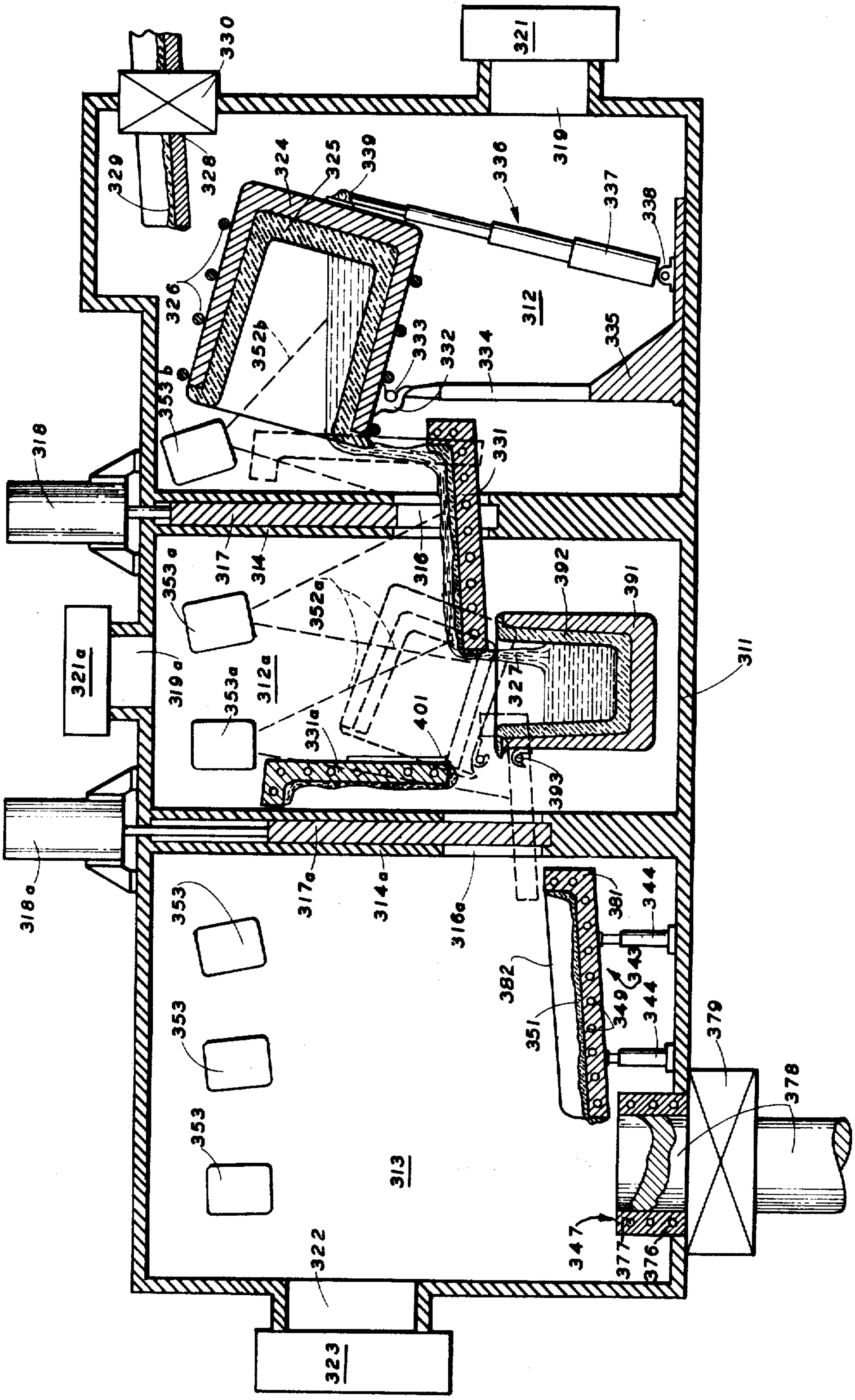
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FIG. 4.

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APPARATUS FOR PROCESSING MOLTEN METAL IN A VACUUM

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Original No. 3,658,119, dated Apr. 25, 1972, Ser. No. 824,030, May 7, 1969. Application for reissue Oct. 18, 1972, Ser. No. 298,462
Int. Cl. B22d *11/10, 27/02, 27/16*
U.S. Cl. 164—250 11 Claims

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

ABSTRACT OF THE DISCLOSURE

A method and apparatus are described for producing a solidified metal product. Molten metal is heated in a refractory crucible within a vacuum enclosure. The contents of the crucible are poured across a cooled transfer structure while being simultaneously heated with an electron beam. The metal leaving the transfer structure is then solidified to form the metal product.

This invention relates generally to melting and casting and, more particularly, to an improved method and apparatus for producing a solidified metal product. [This application is a continuation-in-part of application Ser. No. 718,586 filed Apr. 3, 1968 (now abandoned), and assigned to the assignee of the present invention.]

Vacuum induction processing of metal is a useful step in the manufacture of certain solidified metal products, such as castings, ingots, and particles, where a high level of purity is to be maintained. By carrying out operations in a vacuum, the production of oxide slag and the reaction of constituents in the molten metal with the atmosphere, are minimized.

Vacuum induction processing generally involves the utilization of a refractory material crucible in which the molten metal is contained. The molten metal may be placed in the crucible in a molten condition, or may be melted in the crucible. The crucible is surrounded by an induction coil to which current is supplied for heating the metal in the crucible. The term "heating" as used herein is intended to include melting as well as merely maintaining molten. Once a desired temperature has been reached in the molten metal, the molten metal is poured into a solidifying means such as a continuous casting mold or ordinary casting mold, or over splash plates (for producing particles).

In order to properly transfer the molten metal from the crucible into a mold or over splash plates, transfer structures are utilized. Such transfer structures may consist of ladles, launders or tundishes, or a combination of several of these, for conducting the molten metal from the crucible to the solidifying means. Heretofore, such transfer structures have generally been constructed with liners of refractory material. Where molten metal flows across parts of the refractory material, erosion of the refractory material occurs, frequently necessitating replacement. Erosion of refractory material may also result from high temperatures or frothing in the molten material. Frequent replacement of refractory material liners in transfer structures may be costly, both as to the cost of material and labor, and as to the cost of manufacturing (because of excessive down time). In large scale teeming of ingots, and similar operations, many ladles, launders and tundishes may be used. Reduction of erosion in such cases can effect a substantial cost saving.

In particular types of operations, vacuum induction heating may not preserve a desired degree of purity. This is because a certain amount of the refractory material of transfer structures or of the crucible itself may dissolve in the melt to a sufficient degree to contaminate the melt. Furthermore, the nature of known types of vacuum induction heating equipment does not usually cause a large improvement in purity (e.g., nitrogen content may be reduced no more than about 25 percent in typical commercial apparatus). Even where only a negligible amount of refractory material dissolves in the melt, the heat is not significantly higher in quality than a good grade of non-vacuum processed material. This is because the molten metal is not normally exposed to the vacuum in amounts such that a significantt quantity of volatile impuritiesc in the melt are drawn off. Because of such difficulties, some types of operations requiring very high purity have heretofore been unable to take advantage of the large scale production efficiencies achievable with induction melting.

It is an object of this invention to provide an improved method and apparatus for producing solidified metal products.

Another object of the invention is to provide a crucible heating type vacuum processing method and apparatus wherein excessive erosion of transfer structures is prevented.

Still another object of the invention is to provide a crucible heating type vacuum processing method and apparatus in which a relatively higher degree of purity is attainable than with heretofore known types of such methods and apparatus.

Other objects of the invention will become apparent to those skilled in the art from the following description taken in connection with the accompanying drawings wherein:

FIG. 1 is a schematic side view, partially in section, of apparatus embodying the invention;

FIG. 2 is a schematic side view, partially in section, illustrating another embodiment of the invention;

FIG. 3 is a schematic side view, partially in section, illustrating still another embodiment of the invention; and

FIG. 4 is a schematic side view, partially in section, illustrating a further embodiment of the invention.

Very generally, the method and apparatus of the invention include heating molten metal in a vacuum. A cooled transfer structure is provided for conveying the molten metal to solidifying means while causing a skull to form between the molten metal and the transfer structure. At least one electron beam gun is provided for heating the molten metal while it is moving across the transfer structure.

The method of the invention will be best understood in connection with a description of apparatus embodying the invention. Referring now particularly to FIG. 1, the apparatus of the invention includes a vacuum enclosure **11**. The enclosure **11** is divided into two regions **12** and **13** by a wall **14** having a port **16** therein. Heating, pouring and solidification of molten metal is carried out within the enclosure **11**. A gate valve **17**, operable by a hydraulic unit **18** mounted exteriorly of the chamber, is provided for selectively opening and closing the port **16**. When the valve **17** is closed, the regions **12** and **13** are vacuum sealed from each other.

The region **12** is evacuated through a duct **19** by means of a suitable vacuum pump **21**. The region **13** is evacuated through a duct **22** by means of a suitable vacuum pump **23**. The two regions of the vacuum enclosure may thereby be maintained at different pressures and may be separately pumped down, providing the gate valve **17** is closed. As will be described in greater detail subsequently, the degree to which the regions **12** and **13** of the enclosure **11** are evacuated depends upon particular steps in operating the apparatus of the invention.

The molten metal of which the solid metal product is to be made is contained within a crucible **24** having a liner **25** of a suitable refractory material. An induction coil **26** surrounds the crucible **24** and means, not illustrated, are provided for conducting a current through the coil. The current is selected to be such as to provide induction heating of the material in the crucible, as is known in the art.

The molten metal **27** may be placed in the crucible **24** in any suitable manner. The particular means illustrated for accomplishing this comprise a launder **28** having a refractory material liner **29** and passing through a suitable vacuum valve **30** in the wall of the enclosure **11**. The metal is passed into the crucible **24** when the crucible is in its upright position, below the lower end of the launder **28**, indicated in phantom in FIG. 1. The material which is fed into the crucible **24** may be passed into the crucible in molten form and may flow along the launder **28** by gravity. Alternatively, depending upon the particular requirements of the system, the metal may be placed in the crucible **24** in solid form and heated in the crucible to a sufficient degree to melt the metal. In the former case, the metal is heated in the crucible **24** merely to maintain it in its molten condition until ready for pouring.

Once a desired quantity of molten metal is contained within the crucible **24**, it is poured out of the crucible onto a transfer structure or launder **31**. The crucible is pivotally supported below its pouring lip by a pivot hook **32** secured to and extending from the outer wall of the crucible. The pivot hook rests on a horizontal support bar **33** which extends between two uprights **34** of a frame **35**. Movement of the crucible **24** from its upright position, indicated in phantom, to a position for pouring, as indicated in solid lines in the FIG. 1, is accomplished by an actuating mechanism **36**. The actuating mechanism, which is supported on the frame **35**, is shown in the illustrated embodiment as comprising an extensible hydraulic lift **37** pivotally supported between a support bracket **38** on the frame **35** and a support bracket **39** on the bottom of the crucible. With the lift **37** extended as shown, the crucible is tipped for pouring. When the lift is fully telescoped, the crucible is upright for heating. As an alternative to the hydraulic lift **37**, the tipping may be accomplished by a suitable chain hoist system, not shown, as is known in the art.

The launder **31** directs the molten metal **27** from the region **12** of the enclosure **11** to region **13** through the port **16**. The launder **31** discharges into a second launder **43** which is supported on posts **44** and **46** from the floor of the enclosure **11**. The launder **43** carries the molten material **27** to the solidifying means **47**, described below. The launder **31** is movable by suitable means, not illustrated, such as a sliding type hydraulically operated mechanism, out of the port **16** and into the region **13**, to the position shown by the dotted lines. This permits the gate valve **17** to move across the port **16** and close the port.

As previously indicated, the flow of hot material over a transfer structure, such as a launder or tundish, can result in a significant amount of erosion of the bed of the transfer structure. Erosion problems are particularly prevalent in the processing of steel, especially of high alloy contents. Frequent replacement of the transfer structures because of excessive erosion can result in high cost of equipment and an excessive amount of down time. To prevent such erosion, the transfer structures as used in the apparatus of the invention are cooled.

In the illustrated embodiment, cooling of the launders **31** and **43** is accomplished by providing passages **48** and **49** therein, respectively, through which a suitable coolant, such as water, is circulated. Due to the cooling of the transfer structures, a skull or layer **51** of solidified metal forms between the molten metal **27** and the launders **31** and **43**. This skull, being of the same material as the molten metal, does not contaminate the molten metal. Moreover, any erosion of the skull **51** is constantly replaced by solidifying molten metal. Accordingly, the material of which the launders **31** and **43** are made may be a convenient metal such as copper, and the launders need not be provided with relatively expensive refractory material liners. The skull thickness depends on the amount of heat removed from the transfer structure relative to the temperature and quantity of the molten material passing thereacross. With proper regulation, the amount of heat removed may reach a desired equilibrium with that added to maintain a constant skull thickness.

In order to insure that a free flow of molten material across the transfer structure is maintained, the molten material is constantly heated while on the launders **31** and **43** by means of a plurality of electron beams **52**. The electron beams are produced by a plurality of electron guns **53**, suitably mounted by means, not illustrated, within the vacuum enclosure. The guns **53** may be of any type for producing a desired level of electron beam heating, many types of such guns being well known in the art.

In the apparatus illustrated in FIG. 1, the soldifying means **47** are for teeming ingots at a high production rate. A mold tunnel **54** communicates with the region **13** of the enclosure **11** and extends on either side thereof (extending perpendicularly of the paper ih FIG. 1). The mold tunnel **54** is, accordingly, evacuated by the pump **23** through the duct **22**. Two ledges **55** are provided along the sides of the mold tunnel and support a pair of parallel tracks **56**. The tracks extend along the sides of the mold tunnel a distance above the floor thereof and support a ladle car **57**, guiding the wheels **58** thereof. A ladle **59** is supported by the ladle car **57** and is able to travel the length of the mold tunnel **54** with the car **57**. The ladle **59** includes a refractory material liner **60** and a bottom spout **61** in which a refractory plug **62** is disposed. A refractory rod **63** extends upwardly from the plug **62** above the ladle **59** and may be drawn upwardly by suitable means, not illustrated, to remove the plug **62** from the spout **61** when it is desired to pour molten metal **27** from the ladle **59**.

A further pair of tracks **64** are disposed along the sides of the mold tunnel **54** at the floor thereof. A mold car **66** is supported and guided on the tracks **64** by wheels **67**. A plurality of molds **68** are placed on the mold car **66** for teeming ingots. An arrangement of tundishes **69** is provided for directing molten material poured from the ladle **59** to the various molds **68**. The tundishes **69** are supported by a suitable structure **71** from the mold car **66**. Alternatively, the tundishes may be supported on the car **57** and may be of a configuration to carry molten metal directly from the launder **43** to the molds distributed in the mold tunnel **54**.

In either the illustrated case, or the alternative mentioned above, the tundishes **69** are provided with coolant passages **72** therein for removing heat from the tundishes. Accordingly, a skull is formed similar to the skull **51** on the launders **31** and **43** to prevent erosion of the tundishes and to prevent contamination of the molten metal. To maintain the flow of the molten metal on the tundishes **69**, electron beam guns **73** are provided. The guns direct electron beams **74** on the surface of the molten metal as it passes over the tundishes **69**.

The foregoing described apparatus may be constructed on a scale capable of solidifying very large quantities of metal at high rates and in complete vacuum. For example, apparatus of the type described, built to the proper scale, is capable of processing nickel base alloy at rates as high as 15 tons during a 2-hour melt period. Rates as high as 30 tons every 3 hours are feasible. The two separate regions **12** and **13** of the vacuum enclosure **11** can be evacuated or brought to atmospheric pressure independently. Accordingly, filled molds can be cooling in a vacuum environment while the crucible **24** is being recharged or sculled after a heat. Conversely, the molten metal may be treated in the crucible **12** in a vacuum environment while the region **13** is brought to atmospheric pressure in order to remove molds from the mold tunnel or for purposes of refractory preparation in the ladle **59**. Erosion problems in the launders **31** and **43** and in the tundishes **69** are non-existent. Moreover, lower superheat is necessary, since heat is continuously added to the metal as it flows over the transfer structures. For example, only about ⅓ to ½ the superheat may be required in many cases. Not only does lower superheat improve overall efficiency, but less erosion of refractory material occurs in the ladle and crucible. In addition, because of lower superheat, less time is required in the crucible, improving the through-put.

The apparatus of the invention is also of advantage in systems where pouring rates are much slower than teeming and similar operations. In the apparatus illustrated in FIG. 2, items with similar functions to items in FIG. 1 have been given reference numbers in which the last two numerals are identical and in which the first numeral is a **1**. In FIG. 2, the solidifying means **147** are for accomplishing continuous casting of the molten material and comprise a cylindrical mold **176** having suitable passages **177** formed therein for cooling the walls of the mold. As the material solidifies in the mold **176**, the resultant solidified product (consisting of a round or rod shaped ingot **178**) is moved downwardly by suitable means, not illustrated, through a vacuum valve **179** in a wall of the enclosure **111**. Although the foregoing described continuous casting means are of particular advantage in a system of the type described, other solidifying means may be used within the scope of the invention. Such means may include molds of various shapes and types, splash plates (for particle formation), etc.

The transfer structure **143** is a hearth for slow pouring and includes a bed **181** and side walls **182** for confining the molten material on the bed. An end wall **183** is provided to insure that the flow of molten material is downward along the gradually slanting bed to the solidifying means. The hearth extends through an opening **140** in the wall **114**. Although no gate is provided for closing the opening **114**, some pressure differential may be maintained between the two chambers **112** and **113** if desired. Because of the isolation between the two chambers provided by the wall **114**, the large amounts of gases which evolve during melting and pouring in the chamber **112** are segregated from the chamber **113** to enhance purification as described below. The hearth is provided with adjustable hydraulic supports **144** which extend upwardly from the floor of the enclosure **111**. The tilt of the hearth **143** may be regulated by adjusting the supports **144** to facilitate the metering of the flow into the continuous casting means **147**. Thus, for example, the hearth may be tipped repeatedly to cause intermittent flow of molten metal for casting a succession of discrete items. Moreover, the tilt of the hearth may be changed as desired to vary the casting rate in continuous casting operations. In addition, if it is desired to process a metal after first processing a different kind of metal, the hearth may be easily cleaned and prepared for the different metal without having to bring the chamber to atmospheric pressure. This may be done by tilting the hearth and reducing the cooling rate enough that the skull melts and runs off the hearth.

As previously indicated, the flow of hot metal over a transfer structure, such as a launder or hearth, can result in a significant amount of erosion of the bed of the transfer structure. Frequent replacement of the transfer structures because of excessive erosion can result in a high cost of equipment and an excessive amount of down time. To prevent such erosion the hearth used in the apparatus of FIG. 2 is cooled. At the same time, the temperature of the molten material thereon is maintained at a desired temperature, as explained below.

In the illustrated embodiment, cooling of the transfer structure is accomplished by providing the hearth **143** with passages **149** therein through which a suitable coolant, such as water, is circulated. Due to the cooling of the hearth, a skull or layer **151** of solidified molten metal forms between the molten metal **127** and the transfer structure. The material of which the transfer structure is made may, accordingly, be a convenient metal such as copper, and the transfer structure need not be provided with a relatively expensive refractory material liner. Moreover, the skull, being of the same material as the molten metal, does not contaminate the molten metal. The skull thickness depends upon the amount of heat removed from the transfer structure relative to the temperature and quantity of the molten metal passing thereacross.

In order to insure that a free flow of molten metal across the hearth **143** occurs, and to insure sufficient superheat for volatilization of impurities, the surface of the molten metal on the hearth is heated by electron beams **152**. The electron beams are produced by a plurality of electron guns **153** suitably mounted by means, not illustrated, within the vacuum enclosure **111**. The guns **153** may be of any suitable type for producing a desired level of electron beam heating, many types of such guns being well known in the art. The beam impact pattern on the metal is selected to produce thermal gradients and induce agitation of the molten metal on the hearth. This insures maximum exposure of the molten metal to the vacuum, to draw off volatile impurities. The beams also strike the molten top of the ingot **78** to help form smooth sides and to cause lighter solid impurities to float on the top and not be frozen into the ingot. An additional gun **153** is disposed in the chamber **112** to provide an electron beam **152** for heating the lip region of the crucible **124** as the molten metal **127** is poured into the hearth.

Because of the degree of purification attainable in the apparatus of FIG. 2, a vacuum arc re-melt operation for the purpose of getting rid of slags, etc., as is sometimes required in the vacuum induction processing of high alloy steels, is unnecessary. Even at relatively high pressures within the enclosure **11**, that is, pressures of the order of 10^{-2} to 10^{-1} Torr, sufficient purification may be obtained in one stage of vacuum induction melting that a re-melt operation is not required. This is particularly true for metals and alloys for which a high degree of purification is often not required, such as super alloy steels and high alloy tool steels. The invention, however, is not limited to such materials.

When the area of the hearth is made great enough to allow exposure of the molten material to the vacuum environment at a rate of about 300 to 200 pounds per hour per square foot of hearth, significant amounts of volatile impurities may be removed. The invention, however, is not limited to such an exposure rate, since purification is merely one of several advantages flowing from the invention. Depending upon the scale of operation, the electron beam heating requirement in order to make up heat losses to a cold hearth and to the vacuum environment, may be in the range of 20 to 50 kilowatts per square foot of hearth.

The heath may be used in a two region system as shown in FIG. 1. In such as case, the hearth may be positioned as is the launder **43**. Where hearth volume is sufficient, pouring may continue in the region **13** while the region **14** is brought to atmospheric pressure for recharging.

In FIG. 3, a further embodiment of the invention is illustrated. Items with functions similar to items in the previous two described embodiments have been given reference numbers in which the last two numerals are identical to the corresponding item and in which the first numeral is a **2**. The embodiment of FIG. 3 utilizes a movable tilt pour ladle **291** as the first stage of a two-stage transfer structure (the second stage of which is a hearth **243**) between the melt crucible **224** and the solidifying means **247**. An intermediate chamber **212a** is provided defined between walls **214** and **214a**. The chamber **212a** is evacuated through a duct **219a** by a vacuum pump **221a**. An electron beam gun **253a** is provided in the chamber **212a** for heating the molten metal **227** by means of an electron beam **252a**.

In the embodiment of FIG. 3, the solidifying means **247** are for accomplishing teeming of ingots and comprise one or more molds **268**. A mold tunnel **254** extending in the manner of the mold tunnel **54** in FIG. 1 includes belt type conveyor apparatus **284** comprising supports **286**, an endless belt **287**, and a series of supporting rollers **288**. The belt is driven on the rollers by suitable means such as a drive chain, not illustrated, contained in a housing **289**. The molten metal **227** is poured into the molds **268** from the hearth **243** similar to the hearth **143** in FIG. 2. The hearth is adjustable by hydraulic lifts **244** to start and stop pouring as desired for teeming the ingots. Accordingly, successive molds may be positioned to receive molten metal from the hearth by operating the conveyor system **284**. Molten metal on the hearth is heated from the electron beam guns **253**.

In the embodiment of FIG. 3, the molten metal is not poured directly into the hearth from the crucible **224**, as was the case in the embodiment of FIG. 2, but rather an intermediate transfer structure is utilized. This intermediate transfer structure comprises the tilt pour ladle **291** having a refractory material liner **292**. The ladle is pivotally supported by a bracket **293** on an upright **294** extending from a ladle cart **296**. Tilting of the ladle **292** is accomplished by a hydraulic lift **297** having one end pivotally secured to a bracket **298** on the cart **296** and having the other end pivotally secured to a bracket **299** on the bottom of the ladle **291**.

The cart **296** moves between the chambers **212** and **212a** through the opening **216** in the wall **214**, being guided in its movement by wheels **301** which ride on suitable tracks **302** secured to the bottom of the enclosure **211**. Stops **303** and **304** are provided at each end of the tracks **302** to stop the cart **296** in the appropriate position for the operations subsequently described. Movement of the cart is effected by suitable means, not illustrated, such as cables or chain drives. The extreme ends of the movement of the cart are illustrated by the solid lines in the chamber **212a** and by the dotted lines in the chamber **212**. Naturally, the gate **217** must be raised to permit passage of the cart and ladle between the chambers.

When the cart and ladle **292** are positioned in the chamber **212**, the crucible **224** may be tilted by the hydraulic mechanism **236** to pour molten material into the ladle. The ladle may then be moved through the opening **216** into the chamber **212a** and tilted to the position shown in solid lines to pour the molten material **227** into the hearth **243**. During the latter pouring operation, the gate **217** may be closed to prevent vapors and gases evolved from the relatively impure melt in the crucible **224** from affecting the purification process in the hearth **243**. The gate **217** may also be closed while pouring molten material into the ladle **292**, if desired.

The crucible **224** may be made about three times the volume of the ladle **292** in order to accommodate froth and various other products of the melting operation. If faster pouring is desired, a launder may be substituted for the hearth **243**. The electron beam gun **253a** aids in making up any heat losses in the molten metal while contained in the ladle **291**. As an alternative, the ladle may be provided with an induction heater coil *295* and suitable trailing cables (not shown) to maintain a desired temperature in the molten metal while in the ladle.

In operating the apparatus illustrated in FIG. 3, typical pressure may be as follows: **1** atmosphere to **10** microns in chamber **212**; 10 microns to **1** micron in the chamber **212a**; and less than **1** micron in the final chamber **213**. Because heat losses may be made up by electron beam heating during slow pouring, excessive superheat need not be attained in the crucible **224**. Accordingly, the metal in the ladle **291** may be at a relatively lower temperature and less wear to the refractory results. Moreover, because froth and similar products are easily retained in the crucible **224** and because no frothing need occur in the ladle **291**, a further reduction in wear to the refractory liner **292** of the ladle results. The advantages of less refractory wear are magnified since, because of the economic factors involved, less refractory wear may permit the use of more expensive and better refractory materials, further reducing refractory wear.

In FIG. 4, a further embodiment of the invention is illustrated. Items with functions similar to items in the previous three described embodiments have been given reference numbers in which the last two numerals are identical to the corresponding item and in which the first numeral is a **3**. The embodiment of FIG. 4 uses a four-stage transfer structure between the melt crucible **324** and the solidifying means **347**. The four stages of the transfer structure are a launder **331**, an intermediate tilt pour ladle **391**, a further launder **331a** and a hearth **343**. An intermediate chamber **312a** is provided defined between walls **314** and **314a**. The chamber **312a** is evacuated through a duct **319a** by a vacuum pump **321a**. Two electron beam guns **353a** are provided in the chamber **312a** for heating the molten metal **327** by means of electron beams **352a**.

In FIG. 4, the solidifying means **347** are for accomplishing continuous casting of the molten material and are identical with the solidifying means illustrated in FIG. 2. If desired, a vacuum enclosure (not shown) contiguous with the chamber **313** may be provided for retaining the continuous cast ingot in a vacuum environment. The unillustrated contiguous vacuum enclosure may include means for conditioning the surface of the cast ingot prior to its removal from the vacuum environment through a suitable lock, also not illustrated.

The chambers **312**, **312a** and **313** may be completely isolated from each other by the gates **317** and **317a**, controlled by the actuators **318** and **318a**, respectively. The launders **331** and **331a** are movable into and out of the openings **316** and **316a** (as illustrated in phantom) by suitable means, now shown. This permits closure and sealing of the openings. The launder **331** is shown in place for passing molten material between chambers, whereas the launder **331a** is shown in a stored position with the opening **316a** closed. Molten material is transferred from the crucible **324** to the crucible **391** by the launder **331**.

The ladle **391** is of the tilt pour type and may be displaced vertically by a suitable hoist, not shown, in a vertical guide **401**. A further chain or other suitable means (not shown) is provided for tilting the ladle **391** into the dotted position when raised to pour molten material therefrom into the launder **331** when the launder is positioned properly, as indicated by the dotted lines.

In operating the apparatus illustrated in FIG. 4, slow pouring into the hearth **343** from the ladle **391** may be accomplished while the crucible **324** is being re-charged or while the chamber **312** is brought to atmospheric pressure for preparation of the refractory material therein. Moreover, a sufficient inventory of molten material in the hearth may allow uninterrupted continuous casting while the gate **317a** is closed and the ladle **391** returned to its lower position for refilling. The ability to completely isolate the chamber **313** from the chamber **312** at all times insures that such vapors and gases will not interfere with the purification process in the hearth **343**. Isolation may also be attained between the two chambers **312** and **312a** to avoid contamination of the material in the ladle **391** and to prevent vapors and gases evolved from the relatively impure melt in the crucible **324** from re-contaminating the molten material in the ladle **391**. Thus, the apparatus of FIG. 4 facilitates a reasonably continuous type of operation, since slow pouring over the hearth may occur simultaneously with the melting of feed material in the crucible **324**.

It may therefore be seen that the invention provides improved method and apparatus for producing a solid metal product. The invention effects a minimization of the wear of transfer structures utilized in vacuum induction heating and casting processes. Moreover, a significantly higher degree of purification is attainable in accordance with the invention that has been heretofore attainable in vacuum induction melting operation. All the economic advantages of vacuum induction processing are retained with the additional advantages of low contamination, low refractory wear, and the elimination of the need for high levels of superheat in the crucible to maintain sufficient fluidity throughout the process.

Various modifications of the invention will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such other modifications are intended to fall within the scope of the appended claims.

What is claimed is:

1. Apparatus for producing a solid metal product, including in combination, a vacuum enclosure, means for evacuating said vacuum enclosure, a heating crucible positioned within said enclosure and adapted to contain molten metal, a first transfer stage including a [movable] ladle adapted to be filled by said crucible, means for pouring molten metal from said crucible into said ladle, a second transfer stage adapted to receive molten metal from said ladle, means for cooling said second transfer stage to form a solid skull between the molten metal and said second transfer stage, at least one electron beam gun for heating the molten metal in said second transfer stage, and means at the opposite end of said second transfer stage from said ladle for solidifying the molten metal to form a solid metal product.

2. Apparatus according to claim **1** wherein said vacuum enclosure is divided into first, second and third regions, wherein said crucible is disposed in said first region, wherein said solidifying means are disposed in said third region, wherein said [movable] ladle is adapted to move between said first and second regions, and wherein said second stage extends between said second and third regions, means for sealing said first region from said second region, said evacuating means being adapted to maintain each of said regions in an evacuated condition.

3. Apparatus according to claim **1** wherein said second stage comprises a hearth.

4. Apparatus according to claim **1** wherein said vacuum enclosure is divided into first, second and third regions, wherein said crucible is disposed in said first region, wherein said solidifying means are disposed in said third region, wherein said [movable] ladle is disposed in said second region, wherein said first stage further includes a first launder which extends between said first and second regions, and wherein said second stage of said transfer structure comprises a second launder adapted to receive molten metal from said ladle and extending between said second and third regions, said first launder and said second launder each being movable to a non-operating position, means for sealing said first region from said second region with said first launder in the non-operating position, and means for sealing said second region from said third region with said second launder in the non-operating position, said evacuating means being adapted to individually maintain each of said regions in an evacuated condition when sealed.

5. Apparatus according to claim **4**, wherein said second stage further comprises a cooled hearth adapted to receive molten metal from said second launder.

6. Apparatus according to claim **1** wherein said transfer structure includes a tilted hearth, and comprising means for varying the angle of tilt of said hearth for regulating the flow of molten metal thereon.

7. Apparatus according to claim **6** wherein said varying means include at least one hydraulically adjustable support.

8. Apparatus according to claim **1** wherein said vacuum enclosure is divided into first, second and third regions, wherein said crucible is disposed in said first region, wherein said solidifying means are disposed in said third region, wherein said [movable] ladle is disposed in said second region, wherein said first transfer stage includes a launder which extends between said first and second regions, said launder being movable to a non-operating position, means for sealing said first region from said second region with said launder in the non-operating position, said second transfer stage comprising a cooled hearth adapted to receive molten metal from said ladle.

9. Apparatus for the vacuum melting, refining, and casting of metal to form a solid metal product, including in combination, an induction heated vacuum melting furnace for melting metal in a vacuum, an induction heated transfer ladle for holding molten metal received from said melting furnace, a refining hearth for receiving molten metal from said transfer ladle, enclosure means for maintaining said transfer ladle and said hearth in a vacuum electron beam heating means for heating in a vacuum the molten metal flowing over said hearth, and vacuum casting means for receiving and solidifying in a vacuum molten metal which has passed over said vacuum refining hearth.

10. Apparatus according to claim 9 including means for cooling said hearth to form a skull of solid metal underlying the flowing molten metal.

11. Apparatus according to claim 9, in which a vacuum valve is provided for isolating said melting furnace from the transfer ladle.

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