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[54] Title: CONTINUOUS METHOD TUBE CASTING METHOD APPARATUS AND PRODUCT

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U. S. Pat. No. 4,414,285 11/1983 Lowry et. al.

[57] A B S T R A C T

Dense, homogeneous tubular metal products such as pipe is cast in long lengths continuously by introducing liquid metal into the lower portion of an annular-shaped casting vessel. The liquid metal is withdrawn in the presence of at least one elongated upwardly travelling alternating electromagnetic levitation field and a second inner electromagnetic containment field for maintaining the tubular liquid metal column in a substantially weightless and pressureless condition while solidifying. The resulting solidified tubular metal product is withdrawn from the upper portion of the field, cooled and further processed to result in a desired end product.

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CONTINUOUS METAL TUBE CASTING METHOD
APPARATUS AND PRODUCT

'91 AUG 26 P2:46
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ABSTRACT

Dense, homogeneous tubular metal products such as pipe is cast in long lengths continuously by introducing liquid metal into the lower portion of an annular-shaped casting vessel. The liquid metal is withdrawn in the presence of at least one elongated upwardly travelling alternating electromagnetic levitation field and a second inner electromagnetic containment field for maintaining the tubular liquid metal column in a substantially weightless and pressureless condition while solidifying. The resulting solidified tubular metal product is withdrawn from the upper portion of the field, cooled and further processed to result in a desired end product.

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'91 AUG 22 P2:46
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FIELD OF INVENTION

This invention relates to a new and improved method and apparatus for the continuous manufacture of tubular metal products, such as pipe, and to the resulting product.

More specifically, the invention relates to the continuous manufacture of tubular metal products, such as pipe, in long lengths by casting in the presence of electromagnetic levitating fields for minimizing gravitational, frictional and adhesive forces acting on the cast tubular metal product while still in a molten state and while maintaining maximum effective heat transfer between the tubular molten metal forming the product and a heat exchanger during solidification.

BACKGROUND PRIOR ART

Tubular metal products in the form of pipe, etc., have been produced in the past by a variety of techniques including casting which have been described in detail in the published literature relating to this art. U.S. Patent No. 4,274,470 - issued June 23, 1981 in the prior art statement thereof appearing in columns 1 and 2, for example, lists a number of prior art patents and technical articles which describe electromagnetic casting apparatus suitable for use in the fabrication of tubular metal products, such as pipe, and discusses the short-comings of these known prior art procedures. Included amongst these prior art disclosures are U.S. Patent No. 3,467,166 - Getselev, et al.; U.S. Patent No. 3,605,865 - Getselev; U.S. Patent No. 3,735,799 - Karlson; U.S. Patent No. 4,014,379 - Getselev; and U.S. Patent No. 4,126,175 - Getselev which describe the use of an electromagnetic mold to

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contain a pool of molten metal within specified dimensions while the pool is moving downwardly and in which outer, laterally extending portions of the pool are being solidified. In this procedure, accretion of the solidified metal is longitudinally extending and melt being delivered, either semi-continuously or continuously, if by gravity flow to the upper end of the descending pool that forms the solidifying ingot. One of the more serious drawbacks of this procedure is the fact that the "fail safe" characteristics of previously known upward casting technique, is absent. Hence, in the event of an unexpected electric power failure, etc., molten metal may spill out of the downwardly moving pool of molten metal instead of merely running back as would be the case in an upward casting system. In addition, the molten metal overflow and break-out possibility in these known downward casting techniques require constant careful control of both the molten metal feed rate and the solidified ingot removal rate with both rates being drastically limited by a heat exchange problem which consequently diminishes the commercial potential for this method of continuous casting.

U.S. Patent No. 3,746,077 to Lohikoski, et al., and U.S. Patent No. 3,872,913 to Lohikoski, both assigned to Outokumpo Oy of Finland, describe an upward casting technique wherein molten metal either is hydrostatically forced or pulled by vacuum upwardly into an open-ended, vertically disposed mechanical mold as freshly-formed. By this procedure cooled cast product intermittently is removed from physical contact with the upper end of the mechanical mold into which the molten metal continuously is being introduced. In this system, the desirable "fail-safe" characteristics of an upward-casting technique is attained but only at the expense of considerable wear and tear on an external contact mold which wears out in unacceptably short time periods during continuous or semi-continuous operation of the system. Thus, there is a need for an improved system of continuous casting of tubular metal product which avoids the shortcomings of the known prior art electromagnetic casting systems.

Summary of Invention

It is therefore a primary object of the present invention to provide a new and improved continuous casting method and apparatus for fabricating tubular metal products such as pipe in continuous long lengths and which overcomes the shortcomings and deficiencies of the presently known and used continuous tubular metal product casting techniques and systems as discussed above.

A feature of the invention is the provision of an improved method and apparatus for the continuous manufacture of tubular metal products such as pipe in long lengths by casting the products in the presence of an upwardly travelling electromagnetic levitating field for minimizing gravitational, frictional and adhesive forces acting on the cast tubular metal product while maintaining maximum effective heat transfer between the solidifying tubular metal product and a heat exchanger.

In practicing the invention a method and apparatus is provided for producing tubular metal products of long length which comprises means for forming an elongated, upwardly-travelling, alternating electromagnetic levitation field within the interior of a surrounding annular-shaped casting vessel and providing a coextensive electromagnetic containment field component which is directed at right angles to the upwardly travelling levitation field. Second electromagnetic field producing means are provided for forming at least a second electromagnetic containment field component which acts in a direction opposite to the first mentioned electromagnetic containment field within the center of the annular-shaped casting vessel. Liquid metal is introduced into the lower portion of the annular-shaped casting vessel and the electromagnetic fields to form a tubular liquid metal column. The value of the electromagnetic levitation field acting on the tubular liquid metal column is established by suitable means to reduce the hydrostatic head of the column to a minimum while maintaining a predetermined dimensional relationship between the outer and inner surfaces of the tubular liquid metal column and the opposed interior surrounding surfaces of the annular-shaped casting vessel. The electromagnetic fields acting on the tubular liquid metal column are so maintained that the cross sectional dimension of the tubular liquid metal column is sufficiently large to provide pressureless contact but precludes formation of a substantial gap between the inner and outer surfaces of the tubular liquid metal column and the opposed interior surrounding surfaces of the annular-shaped casting vessel thereby effecting pressureless contact and maximum obtainable heat transfer between the tubular liquid metal column and the casting vessel while simultaneously reducing gravitational, frictional and adhesive forces to a minimum. The tubular liquid metal column is moved upwardly through the casting vessel while thus being levitated and solidified in a solidification region surrounded by a heat exchanger and the solidified tubular metal product thereafter is removed from the upper portion of the casting vessel.

While being operated in the continuous casting mode, liquid metal is introduced continuously into the lower portion of the casting vessel and solidified tubular metal product is continuously removed from the upper portion of the vessel with the rate of production of the tubular metal product being determined by controlling the rate of removal of the solidified tubular metal product from the upper portion of the vessel and the corresponding rate of introduction of liquid metal into the lower portion of the vessel.

In a preferred embodiment of the invention, the second electromagnetic field component producing means is produced by a second upwardly travelling, electromagnetic levitation field producing means disposed within the central opening of the annular-shaped casting vessel.

When initially starting the process, a starting metal tube is joined to the tubular molten metal column moving upwardly through the levitating field by cooling and solidifying the upper end of the tubular liquid metal column within the fields to the lower end of the starting metal tube within the solidification zone. Means are provided for withdrawing the starting lifting tube and attached solidified tubular metal product at a rate which determines the rate of production of the tubular metal product. The withdrawn tubular metal product is precooled as it emerges from the upper portion of the casting vessel and if desired thereafter rolled to a desired finish and subsequently cooled to an ambient temperature. Alternatively, if initially cast in a desired dimension, the tubular metal product as it emerges from the upper portion of the casting vessel is precooled and thereafter further cooled to an ambient temperature and stored.

Brief Description of Drawings

These and other objects, features and many of the attendant advantages of this invention will be appreciated more readily as the same becomes better understood from a reading of the following detailed description, when considered in connection with the accompanying drawings, wherein like parts in each of the figures are identified by the same reference character, and wherein:

Figure 1 is a partial, schematic functional diagram of a new and improved tubular metal product casting apparatus according to the invention and illustrates the important elemental parts of the apparatus and there inter-relationship in fabricating tubular metal products according to the invention; and

Figure 2 is a functional block diagram of an overall continuous casting system according to the method of the invention and which employs the apparatus shown in Figure 1.

Best Mode of Practicing the Invention

United States Patent No. 4,414,285 - issued November 8, 1983 for a "Continuous Metal Casting Method, Apparatus and Product" - Hugh R. Lowry and Robert T. Frost - inventors, assigned to the General Electric Company discloses a novel continuous metal casting method, apparatus and product for casting dense homogeneous solid metal rod in long lengths by introducing liquid metal into the lower portion of a casting vessel in the presence of an elongated upwardly-travelling alternating electromagnetic levitation field. The present invention is an improvement in Patent No. 4,414,285 in that it discloses a method and apparatus for extending the principle taught in Patent No. 4,414,285 to the manufacture of tubular metal products in the form of pipe, etc.

Figure 1 is a functional diagrammatic sketch of a modified apparatus suitable for producing tubular metal products of long length in a continuous manner in accordance with the present invention and employing the principles disclosed in U.S. Patent No. 4,414,285. The apparatus shown in Figure 1 is comprised by an annular-shaped molten metal reservoir 10 into which is supplied molten metal out of which the pipe of other tubular metal product is to be fabricated. It is understood that the molten metal reservoir 10 will be supplied with suitable refractory liner insulation and heating elements for maintaining the molten metal contained therein in a molten state. An annular-shaped combined casting vessel/heat exchanger shown generally at 11 is disposed on the upper end of reservoir 10 with the annular-shaped interior passageway of the annular-shaped casting vessel/heat exchanger 11 being aligned with and having access to a correspondingly shaped opening in the top of molten metal reservoir 10.

The annular-shaped casting vessel/heat exchanger 11 is comprised by an outer cylindrically-shaped ceramic liner 12 which is supported on and projects into the annular passageways formed in the top of reservoir 10. An inner ceramic lining 13 is formed in the shape of an upside down cup disposed over a central opening 14 formed in the center of the annular-shaped molten metal reservoir 10. The side walls of the inner ceramic cup liner 13 in conjunction with the outer ceramic liner 12 define an elongated annular-shaped casting vessel in which the molten metal in reservoir 10 is to be solidified in the form of a desired tubular metal product such as pipe.

Disposed around the outer ceramic liner 12 in the region immediately above the molten metal reservoir 10 is an annular-shaped heat exchanger 15 which may be constructed and operates in the same manner as the heat exchanger shown and described with relation to Figure 3 of U.S. Patent No. 4,414,285, the disclosure of which is hereby incorporated into this application in its entirety. Cooling water is supplied to the heat exchanger 15 through an inlet indicated by the arrow 16 and heated water is withdrawn from the heat exchanger from an outlet indicated by an arrow 17. A second, internal annular-shaped heat exchanger 18 is physically dispose immediately adjacent the interior surfaces of the inner cup-shaped ceramic liner 13 for withdrawing heat away from liner 13. The internal heat exchanger 18 is designed with an upper header portion 18A which seats against the bottom surface of the upside down ceramic cup liner 13 and feeds cooling water down through the downwardly depending side portions 18B. The downwardly depending side portions 18B contact and withdraw heat away from the downwardly depending side portions of the upside down ceramic cup liner 13 that in conjunction with outer cylindrically-shaped ceramic liner 12 define the annular-shaped casting vessel in which the tubular products are to be formed. Cooling water is supplied to the header portion 18A through a central inlet pipe 18C and then branches in the manner shown by the arrows 19 and 21 to supply the downwardly depending side portions 18B of the inner heat exchanger 18. The entire structure is supported physically within the central opening 14 of the annular-shaped molten metal reservoir 10 by suitable physical supports (not shown). It will be appreciated therefore that cooling water is supplied to the inner heat exchanger 18 via the central conduit 18C as indicated by the inlet arrow 19, circulates through the header portion 18A and then is withdrawn via the downwardly depending cup side portions 18B and outlet conduits 18D which drain the side portions 18B as indicated by the outlet arrows 21.

A multi-turn winding 22 circumferentially surrounds the exterior of the outer heat exchanger 15 in the manner shown in Figure 1. The multi-turn coil 22, for example, may comprise twelve coils disposed in vertical spaced relationship around the outer ceramic liner 12 with the planes of the windings arranged substantially normal to the axis of the ceramic liner tube 12. As explained more fully in the above-referenced U.S. Patent No. 4,414,285, and specifically with relation to Figure 3 thereof, the respective coils of the multi-turn winding 22 are connected in groups of three to successive phases of a polyphase electric current source such as shown in Figure 2 of the drawings to create an upwardly travelling electromagnetic levitation field.

A somewhat similar multi-turn winding shown at 23 is provided with the individual coils of the multi-turn winding lying in planes at right angles to the central axis of the inner ceramic inverted cup liner 13. The coils of winding 23 are circumferentially wound around the interior surface of the side skirts 18B of the interior inverted cup-shaped heat exchanger 18. Supply electric current is provided to the interior multi-turn windings 23 via supply conductors 24. While the inner, multi-turn windings 23 preferably are excited with multi-phase currents to provide a second, inner upwardly travelling electromagnetic field, it is also feasible to construct this inner coil as a single phase winding as will be explained more fully hereafter. However, in the preferred embodiment of the invention, the inner, multi-turn coil 23 is connected as a multi-phase winding that is supplied with polyphase currents via the supply conductors 24. This results in the production of an upwardly travelling electromagnetic levitation field which is substantially in phase with the upwardly travelling levitation field produced by the outer multi-turn coil 22 but which has a containment field component that extends in a direction at right angles to the upwardly travelling levitation fields and acts in opposition to the containment field component produced by the exterior multi-turn coil 22.

Figure 2 of the drawings shows the exterior multi-turn coil 22 connected to a multi-phase current supply and controller 25 which in turn may be independently controlled in frequency by a frequency control 26 and independently controlled in power level output by a power control 27 all of conventional, known construction. Similarly, the inner multi-turn coil 23 of Figure 1 is connected via supply conductors 24 to an inner coil current source and controller 28 having an independent frequency control 29 and an independent power control 31 for controlling the frequency value and current magnitude (power) of the supply current supplied by controller 28 to the inner multi-turn coil windings 23. As stated above, the multi-turn coil 23 may comprise a multi-phase winding similar to the exterior multi-phase winding

22 in which case the current supplied by controller 28 via supply conductors 24 would be a multi-phase current capable of producing an upwardly travelling electromagnetic levitation field. This field preferably is substantially in-phase with the upwardly travelling levitation field produced by the external multi-turn coil 22, but which has a containment field component that is substantially at right angles to the upwardly travelling levitation fields and acts in opposition to the containment field component produced by exterior multi-turn coil 22.

In operation, molten metal prepared in a furnace (not shown) is supplied to the crucible reservoir 10 via an inlet 10A where it is displaced from the reservoir upwardly into the lower portion of the annular casting vessel defined by the opposed interior surfaces of the outer ceramic liner 12 and the exterior depending skirt surfaces of the inverted ceramic cup liner 13. The arrangement is such that either by gravity flow or due to pressurization by an inert gas cover, the molten metal is caused to rise within the annular casting vessel defined between ceramic walls 12 and 13 to a level just above the lower ends of the outer and inner sets of multi-turn coils 22 and 23. The holding furnace delivers inlet molten metal into reservoir 10 either intermittently or continuously as necessary during continuous operation process in order to maintain this starting level of molten metal within the annular-shaped casting vessel 12, 13. At this level, the molten metal will come under the influence of the upwardly travelling electromagnetic levitating fields produced by the exterior coil 22 as well as the electromagnetic field components produced by the interior multi-turn coil 23. This is true whether the field produced by multi-turn coil 23 is only a horizontally applied containment field or a combined upwardly travelling electromagnetic levitating field having a containment component that acts in opposition to the containment component of the levitating electromagnetic field produced by exterior multi-turn coil 22.

During initial start-up, a starter lifting tubular member (not shown) is introduced from the upper end of the annular-shaped casting vessel 12, 13, to bring the lower end of the starter tube into contact with the top of the tubular liquid metal column formed by the rising molten metal within the annular-shaped casting vessel 12, 13. With cooling water running at full velocity through the respective heat exchangers 15 and 18, the upper portion of the tubular liquid column will be solidified in contact with the starter tubular member. The starter tubular member and accreted solidified tubular column then will be withdrawn upwardly from the annular-shaped casting vessel 12, 13 by suitable withdrawal rolls as shown in Figure 2. The starter tube and accreted tubular metal column will be withdrawn at a rate determined by the rate of formation of solid rod and which in turn determines the rate of production of the continuous casting system. During solidification within a solidification zone defined essentially by the length of the multi-turn coils 22 and 23, the liquid metal column both in its molten and solidified form will be maintained in a substantially weightless and pressureless condition by the upwardly travelling, electromagnetic levitation field as explained more fully in the above-referenced and incorporated U.S. Patent No. 4,414,285.

During operation, the tubular liquid metal column within the solidification zone and during levitation in the above described manner, becomes subject to a unique and unexpected self-regulating characteristic. Due to this self-regulating characteristic, if the tubular liquid metal column is accelerated upwards because the levitation force is greater than the weight force of the liquid metal column , it produces a reduction in cross-sectional area of the column. This then results in an automatic reduction in the lifting force as a consequence of the reduction of the cross section of the liquid metal column caused by the greater levitation force. Consequently, a slowing of the upward movement of the tubular liquid metal column automatically will occur so that the system stabilizes itself and becomes self-regulating. The opposite situation also is true in that if the tubular metal column is decelerated due to a reduction in the levitation force, there will be an increase in the cross section of the tubular liquid metal column which results in increasing the levitation force acting on the column and thereby accelerating the upward movement of the tubular liquid metal column. Thus, within the levitation zone (i.e. the zone where the upwardly travelling electromagnetic levitation field acts on the tubular metal column either in its molten or solidified state) it will be seen that the system is inherently self-regulating once it is placed in operation to effect substantially weightless and pressureless levitating support of the solidifying tubular liquid metal column within the solidification zone as described above.

While the full effect of the levitation electromagnetic field applies to a large part of the length of the tubular liquid metal column and the solidified tubular metal product within the solidification zone, the part of the column in the lower and upper extremities of the solidification zone (where levitation forces average only about one-half of the those produced in the central portion of the zone) is supported, respectively, by the pressure head provided to raise the liquid column to an initial height and by the lifting force applied through the starter tube described earlier. Thus, as the tubular liquid metal column is being established, a small upward acceleration is provided by those lower end region levitation forces, but as the liquid metal column moves upwardly so that it is within the central portion of the levitation zone, it enters fields strong enough to establish and maintain the column in an essentially weightless condition and that its contact with the walls 12 and 13 of the annular-shaped casting vessel becomes substantially pressureless. By pressureless, it is meant that there is no substantial continuous pressure contact between the inner and outer surfaces of the liquid metal column and the interior surrounding surfaces of the annular-shaped casting vessel 12, 13 and the tubular liquid metal column is without substantial hydrostatic head in the critical solidification zone and gravitational, frictional and adhesive forces acting on the solidifying metal column are reduced to a minimum in this critical zone.

The inside diameter of the outside cylindrical ceramic liner 12 and the outside diameter of the cylindrical depending skirt portion of inner ceramic cup liner 13 are be so designed that there is a minimum annular gap provided between the exterior surface of the tubular liquid metal column and the opposing surfaces of the ceramic liners 12, 13. This gap which in actuality is not a gap but a sporatically or randomly occuring open space between the exterior surfaces of the tubular metal column and side walls of the casting vessel, is too small to be shown in the drawings since it is important for good heat transfer to maintain the dimensions of this gap to a very small value. However, an attempt was made to illustrate the place where the gap occurs in Figures 2 and 3 of the above-referenced and incorporated U.S. Patent No. 4,414,285 keeping in mind that the illustration is schematic and not intended as an actual representation of the locations or dimensions of the gap. The gap does occur however randomly and erratically and its existence is evidenced by the exterior surface of the resultant solidified tubular metal product which have a shiny wavy exterior appearance. The gap if allowed to become too large due to the containment components of the upwardly travelling levitating electromagnetic fields, could seriously impair effective heat transfer between the tubular liquid metal column and the opposing side surfaces of the ceramic liners 12 and 13 since there is known to be a strong inverse relationship between field strength and heat removal rate. Consequently, the levitation field strength should be adjusted at the start of a casting operation to provide the desired pressureless contact as defined above with minimum gap spacing consistent with good thermal transfer. The field strength then should be maintained at this setting and should not be changed during the casting operation even though the rate of removal (line speed) of the tubular liquid metal column through the solidification zone region might be changed.

Referring to Figure 2 of the drawings, it will be seen that as the solidified tubular metal product is withdrawn from the upper end of the levitator tube assembly, it is discharged into a pre-cooling chamber 34 and through withdrawal rolls 35 and 36 to two tandem hot-rolling stations 37 and 38 and then finally cooled and coiled at a coiling station 39. Alternatively, if the solidified tubular metal product 33 has the right diameter and finish for use in an as-cast condition, it is withdrawn from the pre-cooling chamber 34 by withdrawal rolls 35 and 36 and delivered for subsequent cooling and coiling without further processing.

During operation the casting speed (i.e., the line speed of the tubular liquid metal column passing through the heat exchanger/-levitator assembly 11) should be controlled by control of the drive motors for the rod removal rolls 35 and 36 which are synchronized with the rolling mills 37 and 38 and the coiling mechanism 39. The levitation field strength and excitation frequency should be established at a value calculated for the particular size and resistivity of the tubular metal being cast to give a levitation ratio in range between 75% and 200%. In a practical process and system employing the invention, it would be started at lower than normal line speed and higher than normal levitation ratios in order to insure reliable start-up. After reaching steady-state operating conditions (within two to three minutes) the line speed then would be increased manually in steps and the levitation field strength decreased in steps until close to a maximum casting rate in terms of tons per hour of conversion of molten metal to the solidified tubular metal product. The sytem then is maintained at this setting during the course of the run. Normally, it would be desirable to monitor the temperature of the emerging solidified tubular metal product by monitoring the product as it exits the annular-shaped casting vessel either visually or with a pyrometer to assure successful production runs.

Industrial Applicability

The invention makes available a novel method and apparatus for continuously casting tubular metal products such as pipe in the presence of a levitating electromagnetic field which greatly reduces the forces required and wear and tear on the machinery normally employed in the casting of such products.

Having described a method and apparatus and resulting solidified tubular metal product according to the invention, it is believed obvious that other modifications and variations of the invention will be suggested to those skilled in the art in the light of the above teachings. It is therefore to be understood that changes may be made in the particular embodiments of the invention described which are within the full intended scope of the invention as defined by the appended claims.

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WHAT IS CLAIMED IS:

1. The method of producing tubular metal products of long length which comprises the steps of forming an elongated upwardly-travelling alternating electromagnetic field within the interior of a surrounding casting vessel, introducing liquid metal into the lower portion of the casting vessel and the field, establishing the value of the electromagnetic levitation field acting on the liquid metal column to reduce the hydrostatic head of the column to a minimum, maintaining the value of the electromagnetic fields, solidifying the metal while moving upwardly through said vessel and said fields, and removing solidified metal product from the upper portion of the casting vessel, is characterized by that the elongated upwardly-travelling alternating electromagnetic field is formed within the interior of the surrounding annular-shaped casting vessel and further comprises a coextensive electromagnetic containment field component directed at right angles to the upwardly travelling levitation fields, and the methods further comprises the step of forming at least a second electromagnetic containment field component acting in a direction opposite to the first mentioned electromagnetic containment field within the center of the annular-shaped casting vessel so that a predetermined dimensional relationship between the outer and inner surfaces of the tubular liquid metal column and the opposed interior surrounding surfaces of said annular-shaped casting vessel is maintained, and the cross-sectional dimension of the tubular liquid metal column is sufficiently large to provide pressureless contact but precludes formation of a substantial gap between the inner and outer surfaces of the tubular liquid metal column and the opposed interior surfaces of the annular-shaped

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casting vessel thereby effecting pressureless contact and maximum obtainable heat transfer between the tubular liquid metal and the casting vessel while simultaneously reducing gravitational, frictional and adhesive forces to minimum.

2. The method of claim 1, wherein the rate of production of the tubular metal product is determined by controlling the rate of removal of the solidified metal product from the upper portion of the vessel, and controlling the corresponding rate of the introduction of liquid metal into the lower portion of the vessel, and wherein the second electromagnetic containment field component is produced by a second upwardly travelling electromagnetic levitation field acting within the central opening of the annular-shaped casting vessel.

3. The method of claim 2 in which the tubular liquid metal column extending upwardly through the electromagnetic fields is maintained at the point of weightlessness so that it is substantially without hydrostatic head over a major part of its length in said field and the electromagnetic field strength is set to maintain a predetermined dimensional relationship between the inner and outer surfaces of the tubular liquid metal column and the interior surrounding surfaces of the annular-shaped casting vessel such that the cross sectional dimensions of the tubular liquid metal column are maintained at values to prevent substantial continuous pressure contact between the inner and outer surfaces of the tubular liquid metal column and the interior surrounding surfaces of the annular-shaped casting vessel and it is without substantial hydrostatic head to thereby reduce gravitational, frictional and adhesive forces acting on the solidifying tubular metal column to a minimum without impairment of heat transfer between the surrounding casting vessel

and the solidifying metal column within the solidification zone.

4. The method of claim 3 in which as a step in the initial stage of the process a starting metal tube is joined to the tubular molten metal column moving upwardly through the fields by cooling and solidifying the upper end of the tubular liquid metal column within the field to the lower end of a starting metal tube.

5. The product of the process according to claim 1 comprising a continuous fully dense metal tube of substantially uniform composition and diameter and having shiny, rippley surface portions produced by introducing liquid metal into the lower portion of the elongated upwardly travelling electromagnetic levitation field and coacting containment electromagnetic fields, solidifying the metal while maintaining the tubular liquid metal in the solidification zone in a condition to reduce the hydrostatic head of the liquid metal to a minimum while maintaining a predetermined dimensional relationship between the inner and outer surfaces of the tubular liquid metal column and the surrounding surfaces of the annular-shaped casting vessel at a value such that the cross sectional dimensions of the tubular liquid metal is sufficiently large to preclude formation of a substantial gap between in inner and outer surfaces of the tubular liquid metal and the surrounding surfaces of the annular-shaped casting vessel thereby effecting maximum obtainable heat transfer between the tubular liquid metal and the casting vessel while simultaneously reducing gravitational, frictional and adhesive forces to a minimum, the solidification of the rod occuring while moving upwardly through the electro-magnetic levitation and coacting containment fields and being stirred thereby.

6. Continuous tubular metal product casting apparatus which comprises an elongated casting vessel in upright position to receive liquid metal for solidification, means for delivering liquid metal into a lower portion of the vessel to thereby form a liquid metal column, heat exchange means associated with the vessel for cooling and solidifying the liquid metal column therein, an electromagnetic levitation field producing means for reducing the hydrostatic head of the column and maintaining a predetermined dimensional relationship between the surface of the liquid metal column and the surrounding surface of the casting vessel, means for maintaining the value of the electromagnetic levitation field, means for moving the liquid metal column upwardly through the casting vessel, and means for removing solidified metal product from the upper portion of the vessel, is characterized by that the casting vessel is an elongated annular-shaped tubular casting vessel disposed in upright position to receive the liquid metal for solidification, the electromagnetic levitation field producing means comprises first electromagnetic levitation field producing means disposed around the outside of the annular-shaped casting vessel along a portion of its length and second electromagnetic field producing means disposed within the center of the annular-shaped casting vessel for producing at least a second electromagnetic containment field component acting in a direction opposite to an electromagnetic containment field component produced by the first electromagnetic levitation field producing means, the first and second electromagnetic field producing means serving to reduce the hydrostatic head of the column and maintain a predetermined dimensional relationship between the outer and inner surfaces of the tubular liquid metal column and the surrounding surfaces of the annular-shaped casting vessel, and the means for

maintaining the value of the electromagnetic levitation and containment fields maintain the cross sectional dimensions of the tubular liquid metal column to be sufficiently large thereby to preclude formation of a substantial gap between the inner and outer surfaces of the tubular liquid metal column and the surrounding surfaces of the annular-shaped casting vessel thereby effecting maximum obtainable heat transfer between the tubular liquid metal column and the casting vessel while simultaneously reducing gravitational, frictional and adhesive forces to a minimum.

7. The apparatus of claim 6 in which the second electromagnetic field producing means also comprises an electromagnetic levitation field producing means and wherein both the first and second electromagnetic levitation field producing means comprise a plurality of electromagnetic coils for connection to successive phases of a polyphase electric current source for producing an upwardly travelling alternating electromagnetic field.

8. The apparatus of claim 7 further including a crucible to contain a bath of molten metal communicating with the lower end of the annular-shaped casting vessel, and means associated with the crucible to establish and move a tubular column of liquid metal upwardly into the annular-shaped casting vessel to a level above the lower end of at least the first electromagnetic levitation field producing means.

9. The apparatus of claim 8 in which the polyphase source is a three-phase generator whose output power and frequency can be set to produce a uniform and balanced upwardly travelling electromagnetic levitation force in accordance with the type

and size of metal being cast.

10. The apparatus of claim 9 further including means operable during initial start-up of the apparatus for joining a metal lifting tube to the top of the tubular liquid metal column by contacting the top of the lifting tube to the top of the tubular liquid metal column while still in the solidification zone and thereafter solidifying the tubular metal column to the end of the lifting tube and means for withdrawing the lifting tube and attached solidified tubular metal column at a rate which determines the rate of production of the tubular metal product.

11. The apparatus of claim 10 further including means for precooling the solidified tubular metal product as it emerges from the upper portion of the casting vessel, means for rolling the product to a desired dimension and means for cooling the rolled product to an ambient temperature.

12. The apparatus of claim 10 further including means for precooling the solidified tubular metal product as it emerges from the upper portion of the casting vessel, and further means for cooling the pre-cooled tubular metal product to an ambient temperature.

13. The apparatus of claim 6 wherein the second electromagnetic containment field component producing means comprises a single phase electromagnetic containment field producing means for producing an outwardly acting electromagnetic containment field acting on the tubular liquid metal column.

14. The apparatus of claim 13 further including means operable during initial start-up of the apparatus for joining a metal lifting tube to the top of the tubular liquid metal

column by contacting the top of the lifting tube to the top of the tubular liquid metal column while still in the solidification zone and thereafter solidifying the tubular metal column to the end of the lifting tube and means for withdrawing the lifting tube and attached solidified tubular metal column at a rate which determines the rate of production of the tubular metal product.

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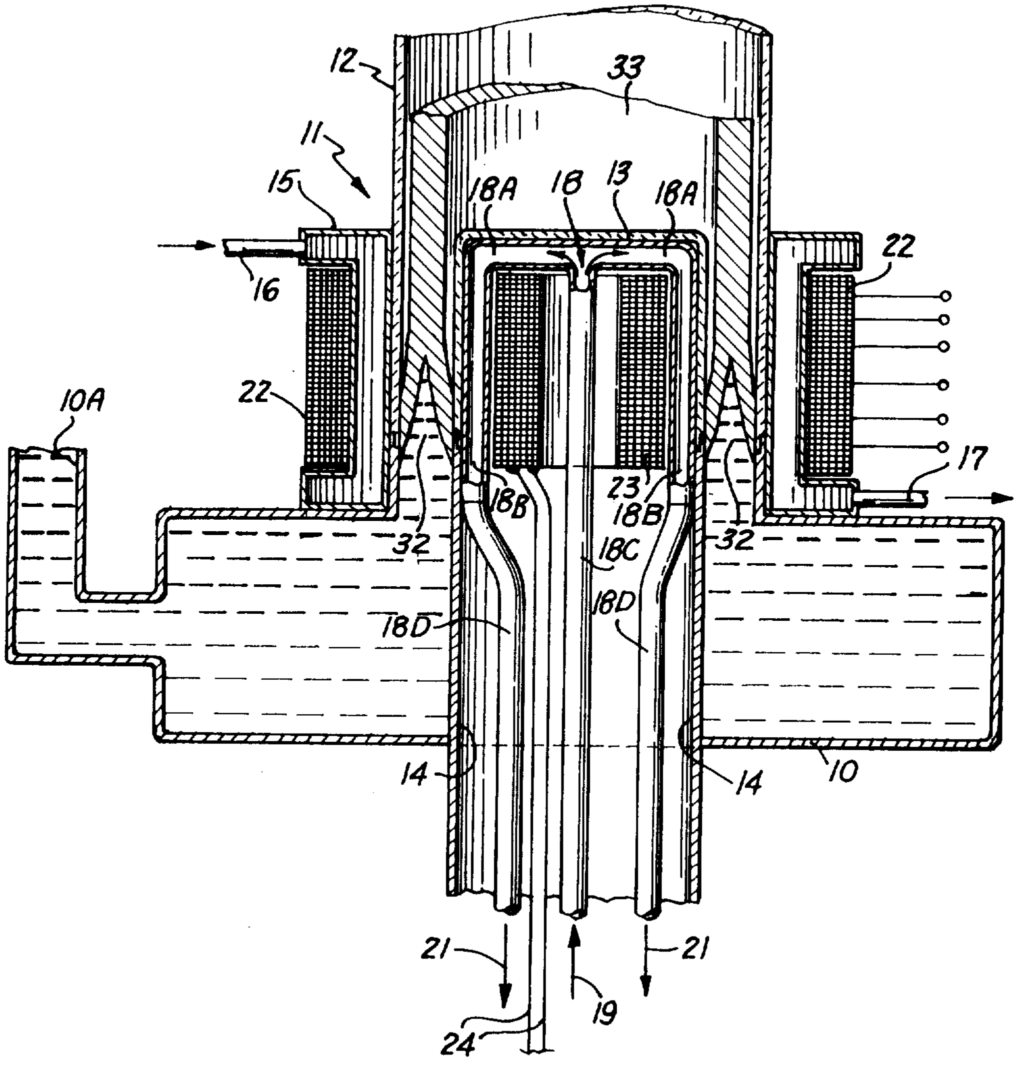

Fig. 1

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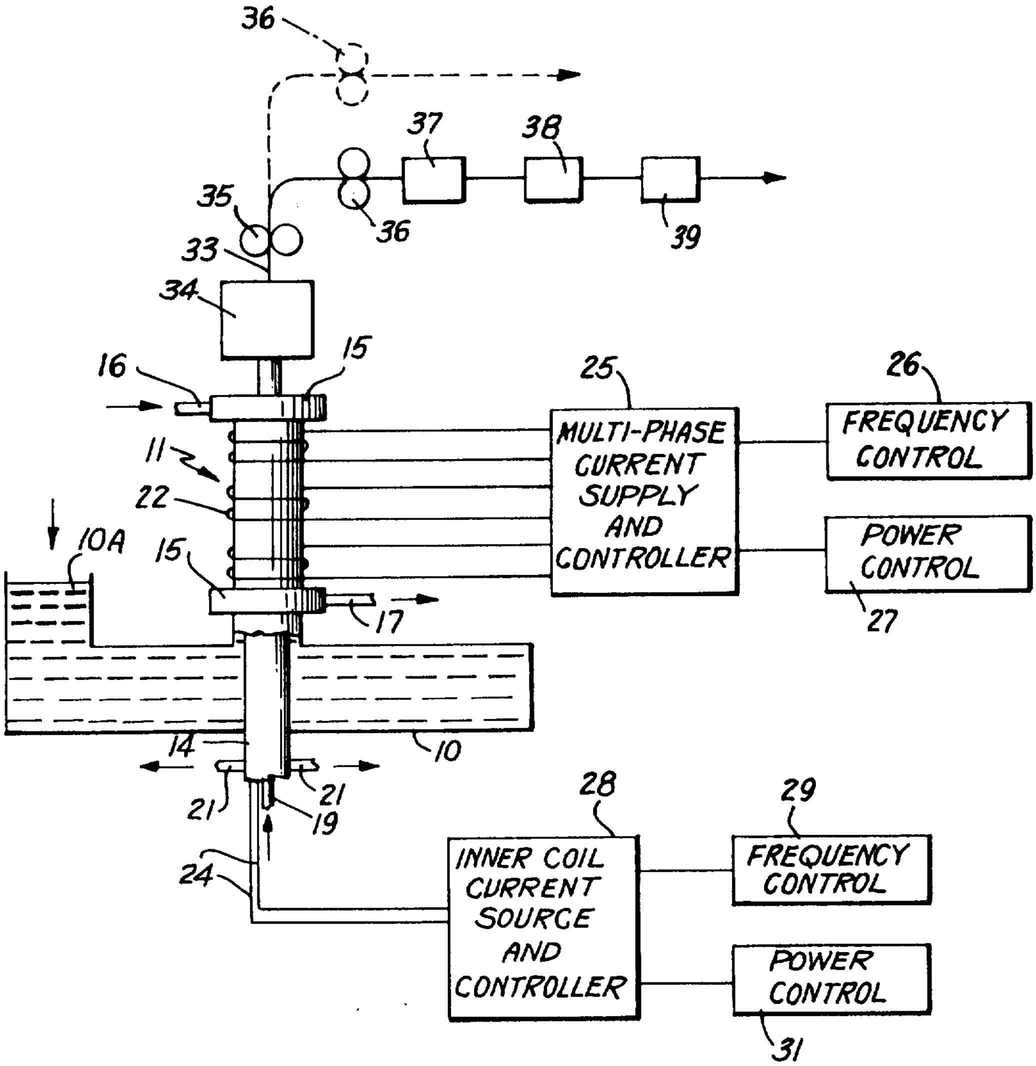

Fig. 2

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