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(73) Proprietor: **GENERAL ELECTRIC COMPANY**
1 River Road
Schenectady New York 12305 (US)

(72) Inventor: **Peterson, Jeffrey Norling**
2054 Atwood Terrace
Coshocton Ohio 43812 (US)

(74) Representative: **Sieb, Rolf, Dr.**
General Electric - Deutschland Patentabteilung
Praunheimer Landstrasse 50
D-6000 Frankfurt/Main (DE)

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Description

This invention relates to a method and apparatus for the continuous manufacture of tubular metal products, such as pipes.

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.

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. US—A—4,274,470 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 US—A—3,467,166; 3,605,865; 3,735,799; 4,014,379; and 4,126,175 which describe the use of an electromagnetic mold to 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.

US—A—3,746,077 and 3,872,913 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" characteristic 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.

EP—A—0050581 forming the opening part of claim 1 describes a process for continuously making tubular metal products using electromagnetic fields for the formation of an upwardly directed tubular liquid metal column.

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 using electromagnetic fields for the formation of an upwardly directed tubular liquid metal column comprising the steps of 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 heat transfer sufficient to solidify the liquid metal 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.

In a preferred development of the method according to the invention, 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, whereby 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.

Claim 5 defines a continuous tubular metal product casting apparatus and claim 14 a continuous casting method according to the invention.

These and other objects, particularities 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.

US—A—4,414,285 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 US—A—4,414,285 in that it discloses a method and apparatus for extending the principle taught in US—A—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 US—A—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 or 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 US—A—4,414,285. 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 disposed 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 US—A—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 shown at 32 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 intermit-

tently 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 shown at 33 will be solidified in contact with the starter tubular member. The starter tubular member and accreted solidified tubular column 33 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 33 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 US-A-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 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 so designed that there is a minimum annular gap provided between the exterior surface of the tubular liquid metal column 32 and the opposing surfaces of the ceramic liners 12, 13. This gap which in actuality is not a gap but a sporadically or randomly occurring 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 US-A-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 system 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.

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.

Claims

1. Method of producing tubular metal products of long length using electromagnetic fields for the formation of an upwardly directed tubular liquid metal column characterized in that it comprises the steps of forming an elongated, upwardly-travelling, alternating electromagnetic levitation field within the interior of a surrounding annular-shaped casting vessel (11) and providing a coextensive electromagnetic containment field component directed at right angles to the upwardly travelling levitation field, 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, introducing the liquid metal into the lower portion of the annular-shaped casting vessel and the electromagnetic fields to form a tubular liquid metal column (32), establishing the value of the electromagnetic levitation field acting on the tubular liquid metal column 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 said annular-shaped casting vessel, maintaining the value of the electromagnetic fields so 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 heat transfer sufficient to solidify the liquid metal between the tubular liquid metal column and the casting vessel while simultaneously reducing gravitational, frictional and adhesive forces to a minimum, moving the tubular liquid metal column upwardly through the casting vessel, solidifying the metal while moving upwardly through said vessel and said fields, and removing solidified tubular metal product from the upper portion of the casting vessel.

2. The method of claim 1 operated in the continuous casting mode in which liquid metal is introduced continuously into the lower portion of the casting vessel and solidified tubular metal product (33) is continuously removed from the upper portion of said vessel, and the rate of production of the tubular metal product is deter-

mined by controlling the rate of removal of the solidified metal product from the upper portion of the vessel, controlling the corresponding rate of introduction of liquid metal into the lower portion of the vessel characterized in that the second electromagnetic field component is produced by a second upwardly travelling electromagnetic levitation field acting within the central opening of the annular-shaped casting vessel (11).

3. The method of claim 2 characterized in that 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, friction 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 characterized in that 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 the starting metal tube.

5. Continuous tubular metal product casting apparatus using electromagnetic fields for the formation an upwardly directed tubular liquid metal column characterized in that it comprises an elongated annular-shaped tubular casting vessel (11) disposed in upright position to receive liquid metal for solidification, means (10A) for delivering liquid metal into a lower portion of the annular-shaped vessel to thereby form a tubular liquid metal column, heat exchange means (15, 18) associated with the vessel for cooling and solidifying the tubular liquid metal column therein, means for removing solidified tubular metal product from an upper portion of the vessel, first electromagnetic levitation field producing means (22) disposed around the outside of the annular-shaped casting vessel along a portion of its length, second electromagnetic field producing means (23) disposed within the center of the annular-shaped vessel for producing at least a second electromagnetic containment field component acting in a direction opposite to an electromagnetic containment field component produced by said first electromagnetic levitation field producing means, said first (22) and second (23)

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, means for maintaining the value of the electromagnetic levitation and containment fields so that the cross sectional dimensions of the tubular liquid metal column is sufficiently large 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, means independent from said electromagnetic levitation and containment field producing means for moving the tubular liquid metal column upwardly through the casting vessel, and means for removing solidified tubular metal product from the upper portion of the vessel.

6. The apparatus of claim 5, characterized in that the second electromagnetic field producing means (23) 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.

7. The apparatus of claim 6 further including a crucible (10) 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 (11) to a level above the lower end of at least the first electromagnetic levitation field producing means (22).

8. The apparatus of claim 7 in which the polyphase source (25) 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.

9. The apparatus of claim 8 characterized in that it further includes 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.

10. The apparatus of claim 9 further including means (34) for precooling the solidified tubular metal product as it emerges from the upper portion of the casting vessel, means for rolling

(35—38) the product to a desired dimension and means for cooling (39) the rolled product to an ambient temperature.

11. The apparatus of claim 9 characterized in that it further includes means for precooling (34) the solidified tubular metal product as it emerges from the upper portion of the casting vessel, and further means for cooling (39) the precooled tubular metal product to an ambient temperature.

12. The apparatus of claim 5 characterized in that the second electromagnetic containment field component producing means (23) comprises a single phase electromagnetic containment field producing means for producing an outwardly acting electromagnetic containment field acting on the tubular liquid metal column.

13. The apparatus of claim 12 characterized in that it further includes 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.

14. A continuous casting method of producing a metal tubular product of long length using electromagnetic fields for the formation of an upwardly directed tubular liquid metal column characterized in that it comprises the steps of forming a tubular liquid metal column, advancing the tubular liquid metal column into a solidification zone, simultaneously electromagnetically maintaining a substantial part of the length of the column in said solidification zone electromagnetically levitated to reduce the hydrostatic head of the column and electromagnetically contained to establish a predetermined dimensional relationship between the outer surface of the tubular liquid metal column and the surrounding surfaces of a casting vessel, maintaining the value of the electromagnetic levitation and containing fields so that the cross sectional dimension of the liquid metal column is sufficiently large to prevent formation of a substantial gap between the inner and outer surfaces of the tubular liquid metal column and the surrounding surfaces of the 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, and removing solidified tubular metal product from the said zone as the column is being electromagnetically maintained.

15. The method of claim 14 characterized in that the major portion of the length of the tubular liquid metal column in the solidification zone is electromagnetically maintained with a predetermined dimensional relationship between the inner and outer surfaces of the tubular liquid metal column and the surrounding surfaces of the

casting vessel such that the cross sectional dimensions of the tubular liquid metal column are in pressureless contact with the preclude substantial continuous pressure contact between the inner and the outer surfaces of the tubular liquid metal column and the surrounding surfaces of the casting vessel and the column is without substantial hydrostatic head to thereby reduce gravitational, frictional and adhesive forces acting on the solidifying metal column to a minimum without substantial impairment of heat transfer between the surrounding casting vessel and the solidifying tubular metal column.

16. The method of claim 15 characterized in that the tubular liquid metal column is continuously formed and advanced into the solidification zone and in which the solidified tubular metal product is continuously removed from the said zone by means other than said levitating electromagnetic field to thereby control the rate of production of the solidified tubular metal.

17. The method of claim 16 characterized in that the upwardly travelling electromagnetic levitation field has a frequency in excess of one kilohertz.

18. The method according to claim 16 characterized in that the strength of the electromagnetic upwardly travelling levitation field is set in accordance with the type and size of metal being cast to provide a levitation ratio of from 75% to 200% of the weight per unit length of the liquid metal.

Patentansprüche

1. Verfahren zum Herstellen rohrförmiger Metallprodukte großer Länge unter Anwendung elektromagnetischer Felder für die Bildung einer nach oben gerichteten rohrförmigen flüssigen Metallsäule dadurch gekennzeichnet, daß sie die Stufen umfaßt:

Ausbilden eines langgestreckten, nach oben wandernden elektromagnetischen Wechsel-Schwebefeldes im Inneren einer ringförmigen Gießkokille (11) und Schaffen einer elektromagnetischen Eindämmungs-Feldkomponente gleicher Ausdehnung, die im rechten Winkel zum dem nach oben wandernden Schwebefeld gerichtet ist, Ausbilden mindestens einer zweiten elektromagnetischen Eindämmungs-Feldkomponente, die in einer entgegengesetzten Richtung zum dem erstgenannten elektromagnetischen Eindämmungsfeld innerhalb des Zentrums der ringförmigen Gießkokille wirkt, Einführen des flüssigen Metalles in den unteren Abschnitt der ringförmigen Gießkokille und der elektromagnetischen Felder zur Bildung einer rohrförmigen flüssigen Metallsäule (32), Einstellen des Wertes des elektromagnetischen Schwebefeldes, das auf die rohrförmige flüssige Metallsäule wirkt, um den Flüssigkeitsdruck der Säule auf ein Minimum zu reduzieren, während eine vorbestimmte abmessungsmäßige Beziehung zwischen den äußeren und inneren Oberflächen der rohrförmigen flüssigen Metallsäule und den gegenüberstehenden inneren umgebenden Oberflächen der ringförmigen Gießkokille auf-

rechterhalten wird, Aufrechterhalten des Wertes der elektromagnetischen Felder, so daß die Querschnittsabmessung der rohrförmigen flüssigen Metallsäule ausreichend groß ist, um einen drucklosen Kontakt zu schaffen, wobei die Ausbildung eines beträchtlichen Spaltes zwischen der inneren und äußeren Oberfläche der rohrförmigen flüssigen Metallsäule und den gegenüberstehenden inneren umgebenden Oberflächen der ringförmigen Gießkokille vermieden wird, was einen drucklosen Kontakt und eine Wärmeübertragung bewirkt, die ausreichend ist, um das flüssige Metall zwischen der rohrförmigen flüssigen Metallsäule und der Gießkokille zum Erstarren zu bringen, während gleichzeitig Schwer-, Reibungs- und Haftkraft auf ein Minimum vermindert werden, Bewegungen der rohrförmigen flüssigen Metallsäule nach oben durch die Gießkokille, Erstarrenlassen des Metalles, während es sich durch die Kokille und die Felder nach oben bewegt und Entfernen des erstarrten rohrförmigen Metallproduktes aus dem oberen Abschnitt der Gießkokille.

2. Verfahren nach Anspruch 1, ausgeführt als kontinuierliches Gießverfahren, bei dem das flüssige Metall kontinuierlich in den unteren Abschnitt der Gießkokille eingeführt und das erstarrte rohrförmige Metallprodukt (33) kontinuierlich vom oberen Abschnitt der Kokille entfernt wird und die Produktionsgeschwindigkeit des rohrförmigen Metallproduktes durch Steuern der Entfernungsgeschwindigkeit des erstarrten Metallproduktes vom oberen Abschnitt der Kokille und durch Steuern der entsprechenden Zufuhrgeschwindigkeit des flüssigen Metalles in den unteren Abschnitt der Kokille bestimmt wird, dadurch gekennzeichnet, daß die zweite elektromagnetische Feldkomponente erzeugt wird durch ein zweites nach oben wanderndes elektromagnetisches Schwebefeld, das innerhalb der zentralen Öffnung der ringförmigen Gießkokille (11) wirkt.

3. Verfahren nach Anspruch 2, dadurch gekennzeichnet, daß die sich nach oben durch die elektromagnetischen Felder erstreckende rohrförmige flüssige Metallsäule gewichtslos gehalten wird, so daß sie über einen großen Teil ihrer Länge im genannten Feld im wesentlichen ohne Flüssigkeitsdruck ist und die Stärke des elektromagnetischen Feldes so eingestellt ist, daß eine vorbestimmte abmessungsmäßige Beziehung zwischen den inneren und äußeren Oberflächen der rohrförmigen flüssigen Metallsäule und der inneren umgebenden Oberflächen der ringförmigen Gießkokille derart aufrechterhalten wird, daß die Querschnittsabmessungen der rohrförmigen flüssigen Metallsäule bei Werten gehalten werden, die einen wesentlichen kontinuierlichen Druckkontakt zwischen den inneren und äußeren Oberflächen der rohrförmigen flüssigen Metallsäule und den inneren umgebenden Oberflächen der ringförmigen Gießkokille verhindern und die Säule ohne wesentlichen Flüssigkeitsdruck lassen, um dadurch die auf die erstarrende rohrförmige Metallsäule wirkenden Schwer-, Reibungs-

und Haftkräfte zu einem Minimum zu reduzieren, ohne den Wärmeübergang zwischen der umgebenden Gießkokille und der erstarrenden Metallsäule innerhalb der Erstarrungszone zu beeinträchtigen.

4. Verfahren nach Anspruch 3, dadurch gekennzeichnet, daß in der Anfangsphase des Verfahrens als eine Stufe ein Ausgangs-Metallrohr mit der rohrförmigen geschmolzenen Metallsäule, die sich durch die Felder nach oben bewegt, durch Abkühlen und Erstarrenlassen des oberen Endes der rohrförmigen flüssigen Metallsäule innerhalb des Feldes mit dem unteren Ende des Ausgangs-Metallrohres verbunden wird.

5. Vorrichtung zum kontinuierlichen Gießen rohrförmiger Metallprodukte unter Anwendung von elektromagnetischen Feldern zur Bildung einer nach oben gerichteten rohrförmigen flüssigen Metallsäule, gekennzeichnet durch, eine langgestreckte ringförmige, rohrförmige Gießkokille (11), die zu Aufnahme von flüssigem Metall zur Erstarrung in aufrechter Position angeordnet ist, eine Einrichtung (10A) zur Lieferung von flüssigem Metall in einen unteren Abschnitt der rohrförmigen Kokille, um dadurch eine rohrförmige flüssige Metallsäule zu bilden, eine Wärmeaustauscher-Einrichtung (15, 18), die der Kokille zugeordnet ist, um die rohrförmige flüssige Metallsäule darin zu kühlen und erstarren zu lassen, eine Einrichtung zum Entfernen des erstarrten rohrförmigen Metallproduktes von einem oberen Abschnitt der Kokille, eine erste elektromagnetische Schwebefeld erzeugende Einrichtung (22), die um die Außenseite der rohrförmigen Gießkokille entlang einem Abschnitt seiner Länge herum angeordnet ist, eine zweite elektromagnetische Feld erzeugende Einrichtung (23), die innerhalb des Zentrums der ringförmigen Kokille angeordnet ist, um mindestens eine zweite elektromagnetische Eindämmungs-Feldkomponente zu erzeugen, die in einer entgegengesetzten Richtung zu einer elektromagnetischen Eindämmungs-Feldkomponente wirkt, die von der ersten, das elektromagnetische Schwebefeld erzeugenden Einrichtung geschaffen wird, wobei die erste (22) und die zweite (23) elektromagnetische Felder erzeugenden Einrichtungen zu Verminderung des Flüssigkeitsdruckes der Säule und zum Aufrechterhalten einer vorbestimmten abmessungsmäßigen Beziehung zwischen den äußeren und inneren Oberflächen der rohrförmigen flüssigen Metallsäule und der umgebenden Oberflächen der ringförmigen Gießkokille dienen, eine Einrichtung zum Aufrechterhalten der Werte der elektromagnetischen Schweb- und Eindämmungs-Felder, so daß die Querschnittsabmessungen der rohrförmigen flüssigen Metallsäule ausreichend groß sind, um die Bildung eines beträchtlichen Spaltes zwischen den inneren und äußeren Oberflächen der rohrförmigen flüssigen Metallsäule und der umgebenden Oberflächen der ringförmigen Gießkokille auszuschließen und dadurch die maximal erhältliche Wärmeübertragung zwischen der rohrförmigen flüssigen Metallsäule und der Gießkokille zu

bewirken, während gleichzeitig die Schwer-, Reibungs- und Haftkräfte auf ein Minimum reduziert werden, eine Einrichtung zum Bewegen der rohrförmigen flüssigen Metallsäule durch die Gießkokille nach oben, die unabhängig ist von den die elektromagnetischen Schwebe- und Eindämmungs-Felder erzeugenden Einrichtungen und eine Einrichtung zum Entfernen des erstarrten rohrförmigen Metallproduktes vom oberen Abschnitte der Kokille.

6. Vorrichtung nach Anspruch 5, dadurch gekennzeichnet, daß die zweite, ein elektromagnetisches Feld erzeugende Einrichtung (23) auch eine ein elektromagnetisches Schwebefeld erzeugende Einrichtung umfaßt, wobei die beiden, das erste und zweite elektromagnetische Schwebefeld erzeugenden Einrichtungen mehrere elektromagnetische Spulen zur Verbindung mit aufeinanderfolgenden Phasen einer mehrphasigen elektrischen Stromquelle umfassen, um ein nach oben wanderndes elektromagnetisches Wechselfeld zu erzeugen.

7. Vorrichtung nach Anspruch 6, weiter einen Tiegel (10) einschließend, der ein Bad aus geschmolzenem Metall enthält, das in Verbindung steht mit dem unteren Ende der ringförmigen Gießkokille sowie mit einer Einrichtung, die dem Tiegel zugeordnet ist, um eine rohrförmige Säule aus flüssigem Metall nach oben in die ringförmige Gießkokille (11) bis zu einer Höhe oberhalb des unteren Endes mindestens der ersten, ein elektromagnetisches Schwebefeld erzeugenden Einrichtung (22) zu bewegen.

8. Vorrichtung nach Anspruch 7, worin die Mehrphasenquelle (25) ein Dreiphasen-Generator ist, dessen Leistungsabgabe und Frequenz eingestellt werden können, um eine gleichförmige und ausgewogene, nach oben wandernde elektromagnetische Schwebekraft gemäß der Art und Größe des gegossenen Metalles zu erzeugen.

9. Vorrichtung nach Anspruch 8, dadurch gekennzeichnet, daß sie weiter eine Einrichtung einschließt, die während des anfänglichen Anfahrens der Vorrichtung betrieben werden kann, um ein Metall-Heberohr mit dem Oberteil der rohrförmigen flüssigen Metallsäule zu verbinden, indem man das Ende des Heberohres mit dem Oberteil der rohrförmigen flüssigen Metallsäule in Berührung bringt, während sich dieses noch in der Erstarrungszone befindet und man danach die flüssige Metallsäule bis zum Ende des Heberohres erstarren läßt und mit einer Einrichtung zum Herausziehen des Heberohres und der daran befestigten erstarrten rohrförmigen Metallsäule mit einer Geschwindigkeit, die die Produktionsgeschwindigkeit des rohrförmigen Metallproduktes bestimmt.

10. Vorrichtung nach Anspruch 9, weiter einschließend eine Einrichtung (34) zum Vorkühlen des erstarrten rohrförmigen Metallproduktes in dem Maße, in dem es aus dem oberen Abschnitt der Gießkokille austritt, eine Einrichtung zum Walzen (35—38) des Produktes zu einer erwünschten Abmessung und eine Einrichtung

zum Kühlen (39) des gewalzten Produktes auf eine Umgebungstemperatur.

11. Vorrichtung nach Anspruch 9, dadurch gekennzeichnet, daß sie weiter eine Einrichtung zum Vorkühlen (34) des erstarrten rohrförmigen Metallproduktes, in dem Maße, in dem es aus dem oberen Abschnitt der Gießkokille austritt, und weiter eine Einrichtung zum Kühlen (39) des vorgekühlten rohrförmigen Metallproduktes zu einer Umgebungstemperatur einschließt.

12. Vorrichtung nach Anspruch 5, dadurch gekennzeichnet, daß die zweite elektromagnetische Eindämmungs-Feldkomponente erzeugende Einrichtung (23) eine einphasige Einrichtung zur Erzeugung des elektromagnetischen Eindämmungsfeldes umfaßt, um ein nach außen wirkendes elektromagnetisches Eindämmungsfeld zu erzeugen, das auf die rohrförmige flüssige Metallsäule wirkt.

13. Vorrichtung nach Anspruch 12, dadurch gekennzeichnet, daß sie weiter eine Einrichtung einschließt, die während der anfänglichen Anlaufphase der Vorrichtung betrieben werden kann, um ein Metall-Heberohr mit dem Oberteil der rohrförmigen flüssigen Metallsäule zu verbinden, indem man das Ende des Heberohres mit dem Oberteil der rohrförmigen flüssigen Metallsäule in Berührung bringt, während diese sich noch in der Erstarrungszone befindet und man danach die rohrförmige Metallsäule bis zum Ende des Heberohres erstarren läßt, sowie mit einer Einrichtung zum Herausziehen des Heberohres und der daran befestigten erstarrten rohrförmigen Metallsäule mit einer Geschwindigkeit, die die Produktionsgeschwindigkeit des rohrförmigen Metallproduktes bestimmt.

14. Kontinuierliches Gießverfahren zum Herstellen eines rohrförmigen Metallproduktes großer Länge unter Anwendung elektromagnetischer Felder zur Bildung einer nach oben gerichteten rohrförmigen flüssigen Metallsäule, dadurch gekennzeichnet, daß es die folgenden Stufen umfaßt: Bilden einer rohrförmigen flüssigen Metallsäule, Befördern der rohrförmigen flüssigen Metallsäule in eine Erstarrungszone, wobei man gleichzeitig einen beträchtlichen Teil der Länge der Säule in der Erstarrungszone elektromagnetisch schweben läßt, um den Flüssigkeitsdruck der Säule zu vermindern und man die Säule elektromagnetisch hält, um eine vorbestimmte abmessungsmäßige Beziehung zwischen der äußeren Oberfläche der rohrförmigen flüssigen Metallsäule und den umgebenden Oberflächen einer Gießkokille zu einzustellen, Aufrechterhalten des Wertes der elektromagnetischen Schebe- und Haltenfelder, so daß die Querschnittsabmessung der flüssigen Metallsäule ausreichend groß ist, um die Bildung eines beträchtlichen Spaltes zwischen den inneren und äußeren Oberflächen der rohrförmigen flüssigen Metallsäule und der umgebenden Oberflächen der Gießkokille zu verhindern und dadurch einen drucklosen Kontakt und eine maximal erhältliche Wärmeübertragung zwischen der rohrförmigen flüssigen Metallsäule und der Gießkokille zu

bewirken, während gleichzeitig die Schwer-, Reibungs- und Haltekräfte auf ein Minimum reduziert werden und Entfernen des erstarrten rohrförmigen Metallproduktes aus der genannten Zone, während die Säule elektromagnetisch aufrechterhalten wird.

15. Verfahren nach Anspruch 14, dadurch gekennzeichnet, daß der Hauptabschnitt der Länge der rohrförmigen flüssigen Metallsäule in der Erstarrungszone elektromagnetisch mit einer vorbestimmten abmessungsmäßigen Beziehung zwischen der inneren und äußeren Oberfläche der rohrförmigen flüssigen Metallsäule und den umgebenden Oberflächen der Gießkokille gehalten wird, so daß die Querschnittsabmessungen der rohrförmigen flüssigen Metallsäule in drucklosem Kontakt stehen mit und einem beträchtlichen kontinuierlichen Druckkontakt zwischen der inneren und äußeren Oberfläche der rohrförmigen flüssigen Metallsäule und den umgebenden Oberflächen der Gießkokille ausschließen und die Säule ohne beträchtlichen Flüssigkeitsdruck ist, wodurch die Schwer-, Reibungs- und Haltekräfte, die auf die erstarrende Metallsäule wirken, auf ein Minimum reduziert sind, ohne daß die Wärmeübertragung zwischen der umgebenden Gießkokille und der erstarrten rohrförmigen Metallsäule beträchtlich beeinträchtigt ist.

16. Verfahren nach Anspruch 15, dadurch gekennzeichnet, daß die rohrförmige flüssige Metallsäule kontinuierlich gebildet und in die Erstarrungszone befördert wird, aus der das erstarrte rohrförmige Metallprodukt kontinuierlich durch eine andere Einrichtung als das elektromagnetische Schwebefeld entfernt wird, um dadurch die Produktionsgeschwindigkeit des erstarrten rohrförmigen Metalles zu steuern.

17. Verfahren nach Anspruch 16, dadurch gekennzeichnet, daß das nach oben wandernde elektromagnetische Schwebefeld eine Frequenz von mehr als 1 kHz hat.

18. Verfahren nach Anspruch 16, dadurch gekennzeichnet, daß die Stärke des nach oben wandernden elektromagnetischen Schwebefeldes in Übereinstimmung mit der Art und Größe des gegossenen Metalles eingestellt wird, um ein Schwebeverhältnis von 75 bis 200% des Gewichtes, bezogen auf die Einheitslänge des flüssigen Metalles, zu schaffen.

Revendications

1. Procédé de fabrication de produits métalliques tubulaires de grande longueur, par l'utilisation de champs électromagnétiques pour la formation d'une colonne de métal liquide tubulaire dirigée vers le haut, caractérisé en ce qu'il comprend les opérations suivantes: on forme un champ de lévitation électromagnétique alternatif en mouvement ascendant et de forme allongée, à l'intérieur d'une enceinte de coulée environnante de forme annulaire (11), et on établit une composante de champ de confinement électromagnétique de même étendue, dirigée perpendi-

culairement au champ de lévitation en mouvement ascendant, on forme au moins une seconde composante de champ de confinement électromagnétique agissant dans une direction opposée au champ de confinement électromagnétique mentionné en premier, au centre de l'enceinte de coulée de forme annulaire, on introduit le métal liquide dans la partie inférieure de l'enceinte de coulée de forme annulaire et des champs électromagnétiques, pour former une colonne de métal liquide tubulaire (32), on établit la valeur du champ de lévitation électromagnétique qui agit sur la colonne de métal liquide tubulaire de façon à réduire à un minimum la charge hydrostatique de la colonne, tout en maintenant une relation dimensionnelle prédéterminée entre les surfaces extérieure et intérieure de la colonne de métal liquide tubulaire et les surfaces environnantes intérieures en regard de l'enceinte de coulée de forme annulaire, en maintenant la valeur des champs électromagnétiques de façon que la dimension de section droite de la colonne de métal liquide tubulaire soit suffisamment grande pour assurer un contact sans pression, mais empêche la formation d'un espace notable entre les surfaces intérieure et extérieure de la colonne de métal liquide tubulaire et les surfaces environnantes intérieures en regard de l'enceinte de coulée de forme annulaire, pour établir ainsi un contact sans pression et un transfert de chaleur suffisant pour solidifier le métal liquide entre la colonne de métal liquide tubulaire et l'enceinte de coulée, tout en réduisant simultanément à un minimum les forces de gravité, de friction et d'adhérence, on fait monter la colonne de métal liquide tubulaire à travers l'enceinte de coulée, on solidifie le métal pendant qu'on le fait monter en traversant l'enceinte en les champs, et on enlève le produit métallique tubulaire solidifié à la partie supérieure de l'enceinte de coulée.

2. Le procédé de la revendication 1, mis en oeuvre dans la mode de coulée continue, dans lequel un métal liquide est introduit de façon continue dans la partie inférieure de l'enceinte de coulée, et le produit métallique tubulaire solidifié (33) est enlevé continuellement de la partie supérieure de l'enceinte, et la vitesse de production du produit métallique tubulaire est déterminée par la commande de la vitesse d'enlèvement du produit métallique solidifié à la partie supérieure de l'enceinte, et la commande de la vitesse d'introduction correspondante du métal liquide dans la partie inférieure de l'enceinte, caractérisé en ce que la seconde composante de champ électromagnétique est produite par un second champ de lévitation électromagnétique en mouvement ascendant qui agit à l'intérieur de l'ouverture centrale de l'enceinte de coulée de forme annulaire (11).

3. Le procédé de la revendication 2, caractérisé en ce que la colonne de métal liquide tubulaire qui s'étend vers le haut à travers les champs électromagnétiques est maintenue au point d'apesanteur, de façon qu'elle soit pratiquement dépourvue de charge hydrostatique sur une par-

tie principale de sa longueur dans le champ, et l'intensité du champ électromagnétique est fixée de façon à maintenir une relation dimensionnelle prédéterminée entre les surfaces intérieure et extérieure de la colonne de métal liquide tubulaire, et les surfaces environnantes intérieures de l'enceinte de coulée de forme annulaire, de façon que les dimensions de section droite de la colonne de métal liquide tubulaire soient maintenues à des valeurs qui empêchent un contact sous une pression continue notable entre les surfaces intérieure et extérieure de la colonne de métal liquide tubulaire et les surfaces environnantes intérieures de l'enceinte de coulée de forme annulaire, et la colonne ne supporte aucune charge hydrostatique notable, pour réduire ainsi à un minimum les forces de gravité, de friction et d'adhérence qui agissent sur la colonne de métal tubulaire en cours de solidification, dans dégrader le transfert de chaleur entre l'enceinte de coulée environnante et la colonne de métal en cours de solidification dans la zone de solidification.

4. Le procédé de la revendication 3, caractérisé en ce qu'une étape dans la phase initiale du processus consiste à réunir un tube de métal de départ à la colonne de métal un fusion tubulaire qui s'élève à travers les champs, en refroidissant et en solidifiant l'extrémité supérieure de la colonne de métal liquide tubulaire à l'intérieur du champ, au niveau de l'extrémité inférieure du tube de métal de départ.

5. Appareil de coulée continue pour un produit métallique tubulaire utilisant deux champs électromagnétiques pour la formation d'une colonne de métal liquide tubulaire dirigée vers le haut, caractérisé en ce qu'il comprend une enceinte de coulée tubulaire de forme annulaire et allongée (11) qui est disposée en position verticale de façon à recevoir un métal liquide devant être solidifié, des moyens (10A) pour alimenter en métal liquide une partie inférieure de l'enceinte de forme annulaire, afin de former ainsi une colonne de métal liquide tubulaire, des moyens d'échange de chaleur (15, 18) associés à l'enceinte pour refroidir et solidifier la colonne de métal liquide tubulaire qui se trouve à l'intérieure, des moyens pour enlever le produit métallique tubulaire solidifié dans une partie supérieure de l'enceinte, des premiers moyens de génération de champ de lévitation électromagnétique (22), disposés autour de l'extérieur de l'enceinte de coulée de forme annulaire, sur une partie de sa longueur, des seconds moyens de génération de champ électromagnétique (23) disposé au centre de l'enceinte de forme annulaire, pour produire au moins un seconde composante de champ de confinement électromagnétique, agissant dans un direction opposée à une composante de champ de confinement électromagnétique qui est produite par les premiers moyens de génération de champ de lévitation électromagnétique, les premiers (22) et seconds (23) moyens de génération de champ électromagnétique ayant pour fonction de réduire la charge hydrostatique de la

colonne et de maintenir une relation dimensionnelle prédéterminée entre les surfaces extérieure et intérieure de la colonne de métal liquide tubulaire, et les surfaces environnantes de l'enceinte de coulée de forme annulaire, des moyens pour maintenir la valeur des champs de lévitation et de confinement électromagnétiques de façon que les dimensions de section transversale de la colonne de métal liquide tubulaire soient suffisamment grandes pour empêcher la formation d'un espace notable entre les surfaces intérieur et extérieur de la colonne de métal liquide tubulaire et les surfaces environnantes de l'enceinte de coulée de forme annulaire, pour établir ainsi le transfert de chaleur maximal possible entre la colonne de métal liquide tubulaire et l'enceinte de coulée, tout en réduisant simultanément à un minimum les forces de gravité, de friction et d'adhérence, des moyens indépendants des moyens de génération du champs de lévitation et de confinement électromagnétiques, destinés à faire monter le colonne de métal liquide tubulaire en lui faisant travers l'enceinte de coulée, et des moyens pour enlever le produit métallique tubulaire solidifié à la partir supérieure de l'enceinte.

6. L'appareil de la revendication 5, caractérisé en ce que les seconds moyens de génération de champ électromagnétique (23) comprenant également des moyens de génération de champ de lévitation électromagnétique, et dans lequel les premiers et les seconds moyens de génération de champ de lévitation électromagnétique comprennent un ensemble de bobines électromagnétiques destinées à être connectées à des phases successives d'une source de courant électrique polyphasé, pour produire un champ électromagnétique alternatif en mouvement ascendant.

7. L'appareil de la revendication 6, comprenant en outre un creuset (10) destiné à contenir un bain de métal en fusion, qui communique avec l'extrémité inférieure de l'enceinte de coulée de forme annulaire, et des moyens associés au creuset pour établir une colonne tubulaire de métal liquide et pour faire monter cette colonne dans l'enceinte de coulée de forme annulaire (11), jusqu'à un niveau situé au-dessus de l'extrémité inférieure des premiers moyens de génération de champ de lévitation électromagnétique (22), au moins.

8. L'appareil de la revendication 7, dans lequel la source polyphasé (25) est un générateur triphasé dont on peut fixer la puissance de sortie et la fréquence de façon à produire une force de lévitation électromagnétique à mouvement ascendant uniforme et équilibrée, conformément au type et aux dimensions du métal qui est coulé.

9. L'appareil de la revendication 8, caractérisé en ce qu'il comprend en outre des moyens qu'on peut faire fonctionner pendant le démarrage initial de l'appareil, pour joindre un tube de tirage en métal à la partie supérieure de la colonne de métal liquide tubulaire, en mettant en contact l'extrémité du tube de tirage avec la partie supérieure de la colonne de métal liquide tubulaire,

pendant qu'elle est encore dans la zone de solidification, et en solidifiant ensuite la colonne de métal tubulaire à l'extrémité du tube de tirage, et des moyens destinés à extraire le tube de tirage et la colonne de métal tubulaire solidifié qui lui est fixée, à une vitesse qui détermine la vitesse de production du produit métallique tubulaire.

10. L'appareil de la revendication 9, comprenant en outre des moyens (34) destinés à pré-refroidir le produit métallique tubulaire solidifié, au moment où il émerge de la partie supérieure de l'enceinte de coulée, des moyens pour laminier (35—38) le produit pour lui donner une dimension désirée, et des moyens (39) pour refroidir jusqu'à la température ambiante le produit laminé.

11. L'appareil de la revendication 9, caractérisé en ce qu'il comprend en outre des moyens destinés à pré-refroidir (34) le produit métallique tubulaire solidifié, lorsqu'il émerge de la partie supérieure de l'enceinte de coulée, et des moyens supplémentaires pour refroidir (39) jusqu'à la température ambiante le produit métallique tubulaire pré-refroidi.

12. L'appareil de la revendication 5, caractérisé en ce que les seconds moyens de génération de composante de champ de confinement électromagnétique (23) comprennent des moyens de génération de champ de confinement électromagnétique monophasés, destinés à produire un champ de confinement électromagnétique, agissant vers l'extérieur sur la colonne de métal liquide tubulaire.

13. L'appareil de la revendication 12, caractérisé en ce qu'il comprend en outre des moyens capables de fonctionner pendant le démarrage initial de l'appareil, pour réunir un tube de tirage en métal à la partie supérieure de la colonne de métal liquide tubulaire, en mettant l'extrémité de tube de tirage en contact avec la partie supérieure de la colonne de métal liquide tubulaire, pendant qu'elle est toujours dans la zone de solidification, et en solidifiant ensuite la colonne de métal tubulaire à l'extrémité du tube de tirage, et des moyens pour extraire le tube de tirage et la colonne de métal tubulaire solidifié qui lui est fixée, à une vitesse qui détermine la vitesse de production du produit métallique tubulaire.

14. Un procédé de coulé continue pour produire un produit tubulaire métallique de grande longueur en utilisant des champs électromagnétiques pour la formation d'une colonne de métal liquide tubulaire dirigée vers le haut, caractérisé en ce qu'il comprend les opérations suivantes: on forme une colonne de métal liquide tubulaire, on fait avancer la colonne de métal liquide tubulaire dans une zone de solidification, on maintient simultanément par des moyens électromagnétiques une partie notable de la longueur de la colonne dans la zone de solidification, dans un état de lévitation électromagnétique pour réduire la charge hydrostatique de la colonne, et dans un état de confinement électromagnétique pour établir une relation dimensionnelle prédéterminée entre la surface extérieure de la colonne de métal liquide tubulaire et les surfaces

5 environnantes de l'enceinte de coulée, on maintient la valeur des champs de lévitation et de confinement électromagnétiques de façon que la dimension de section droite de la colonne de métal liquide soit suffisamment grande pour empêcher la formation d'un intervalle notable entre les surfaces intérieure et extérieure de la colonne de métal liquide tubulaire et les surfaces environnantes de l'enceinte de coulée, pour établir ainsi un contact sans pression et le transfert de chaleur maximal qu'il est possible d'obtenir entre la colonne de métal liquide tubulaire et l'enceinte de coulée, tout en réduisant simultanément à un minimum les forces de gravité, de friction et d'adhérence, et on enlève de la zone précitée le produit métallique tubulaire solidifié, pendant que la colonne est maintenue de façon électromagnétique.

15. Le procédé de la revendication 14, caractérisé en ce que la majeure partie de la longueur de la colonne de métal liquide tubulaire dans la zone de solidification est maintenue par des moyens électromagnétiques avec une relation dimensionnelle prédéterminée entre les surfaces intérieure et extérieure de la colonne de métal liquide tubulaire et les surfaces environnantes de l'enceinte de coulée, de façon que les dimensions de section droite de la colonne de métal liquide tubulaire établissent un contact sans pression avec les surfaces environnantes de l'enceinte de coulée, et empêchent un contact sous une pression continue notable entre les surfaces intérieure et extérieure de la colonne de métal liquide tubulaire et les surfaces environnantes de l'enceinte de coulée, et de façon que la colonne ne présente pas une charge hydrostatique notable, pour réduire ainsi à un minimum des forces de gravité, de friction et d'adhérence qui agissent sur la colonne de métal en cours de solidification, dans dégrader notablement le transfert de chaleur entre l'enceinte de coulée environnante et la colonne de métal tubulaire en cours de solidification.

16. Le procédé de la revendication 15, caractérisé en ce qu'on forme et on fait avancer de façon continue la colonne de métal liquide tubulaire dans la zone de solidification, et en ce qu'on enlève de façon continue de la zone précitée le produit métallique tubulaire solidifié, par des moyens autres que le champ électromagnétique de lévitation, pour commander ainsi la vitesse de production du produit métallique tubulaire solidifié.

17. Le procédé de la revendication 16, caractérisé en ce que le champ de lévitation électromagnétique en mouvement ascendant a une fréquence supérieure à 1 kilohertz.

18. Le procédé de la revendication 16, caractérisé en ce que l'intensité du champ de lévitation électromagnétique en mouvement ascendant est fixée conformément au type et aux dimensions du métal qui est coulé, de façon à établir un rapport de lévitation de 75% à 200% du poids par unité de longueur du métal liquide.

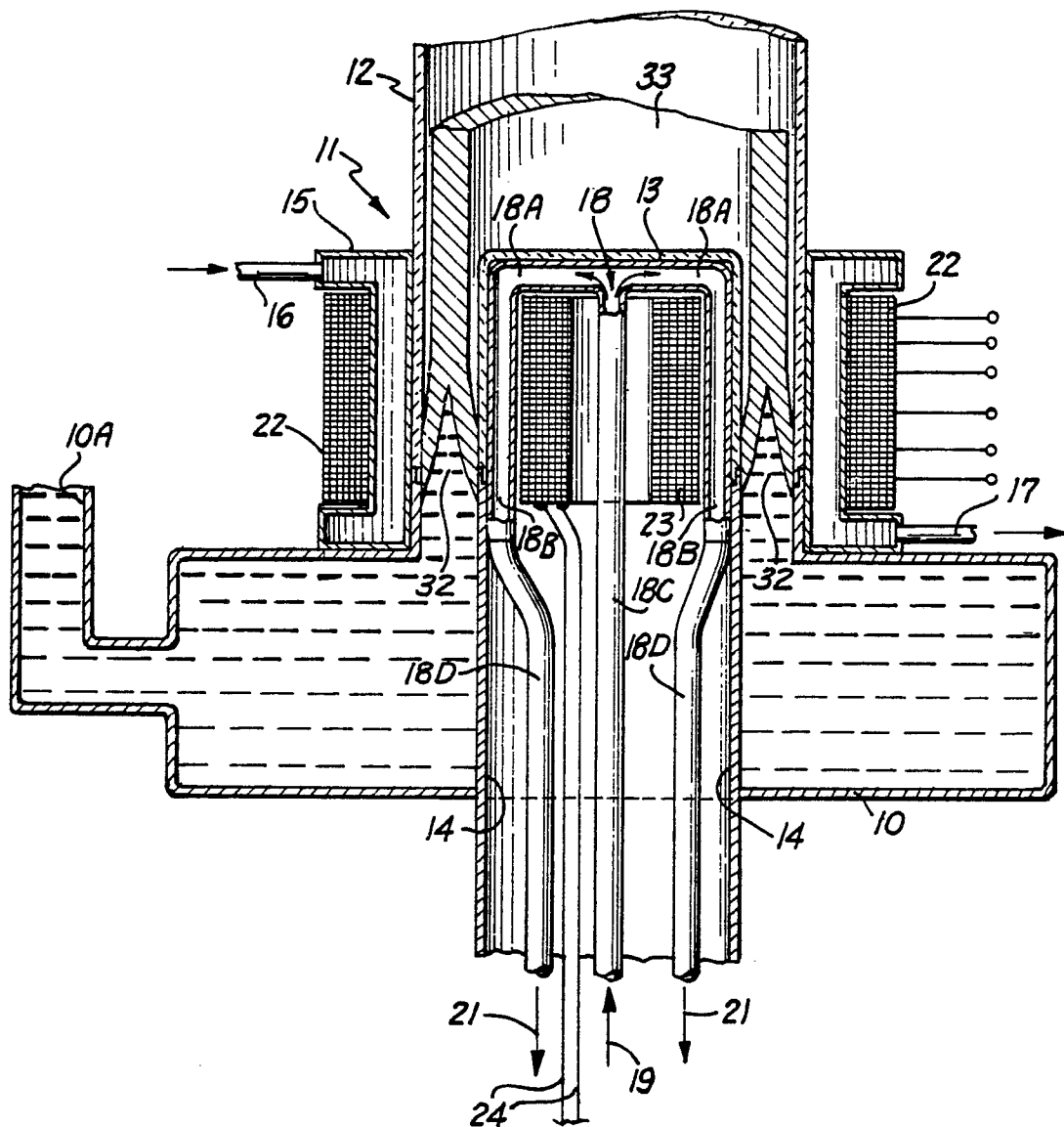


Fig. 1

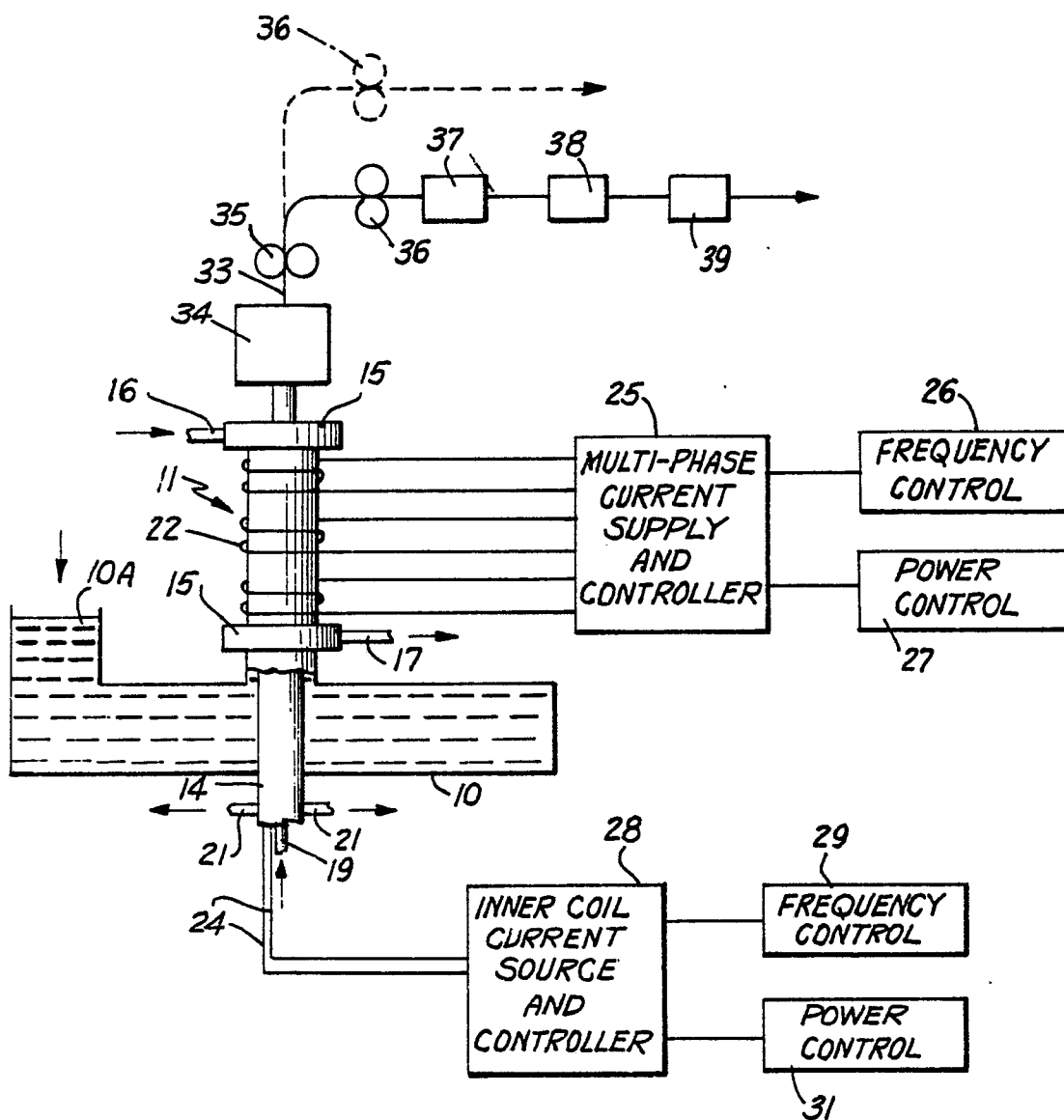


Fig. 2