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July 27, 1965 R. S. BAKER 3,196,795

ELECTROMAGNETIC PUMP SYSTEM

Filed Jan. 2, 1963 5 Sheets-Sheet 1

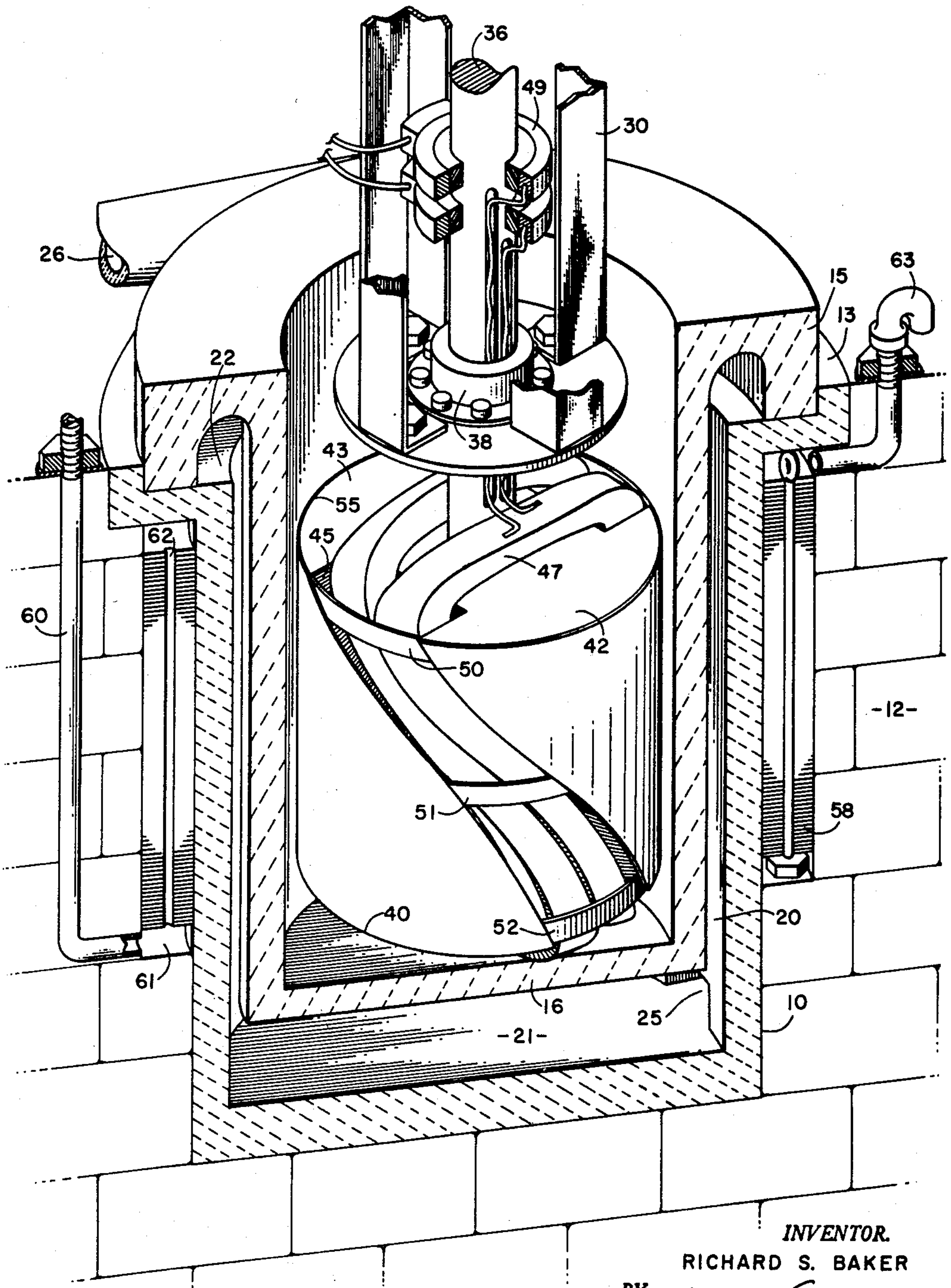

FIG. 1

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ELECTROMAGNETIC PUMP SYSTEM

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5 Sheets-Sheet 2

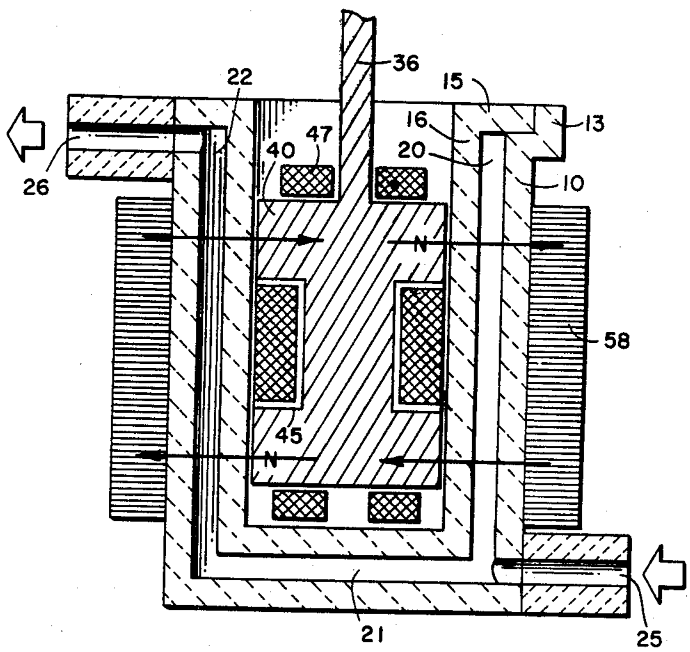

FIG. 3

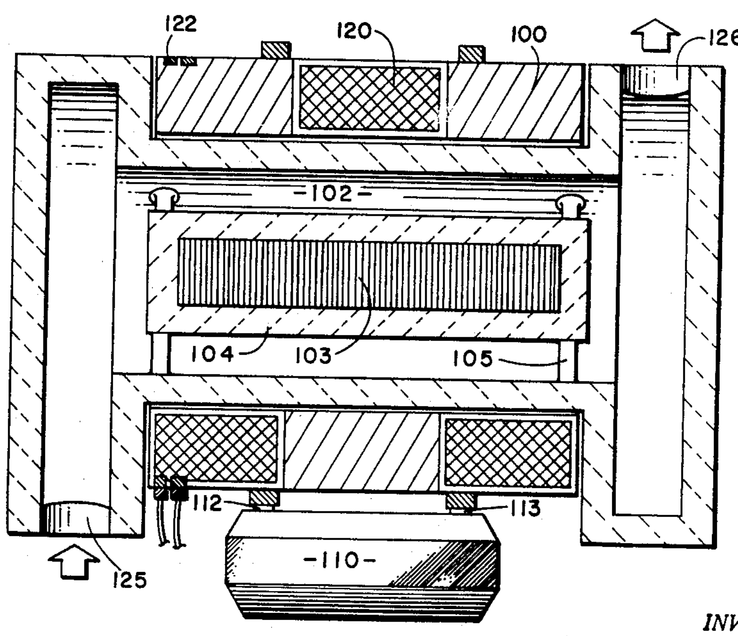

FIG. 6

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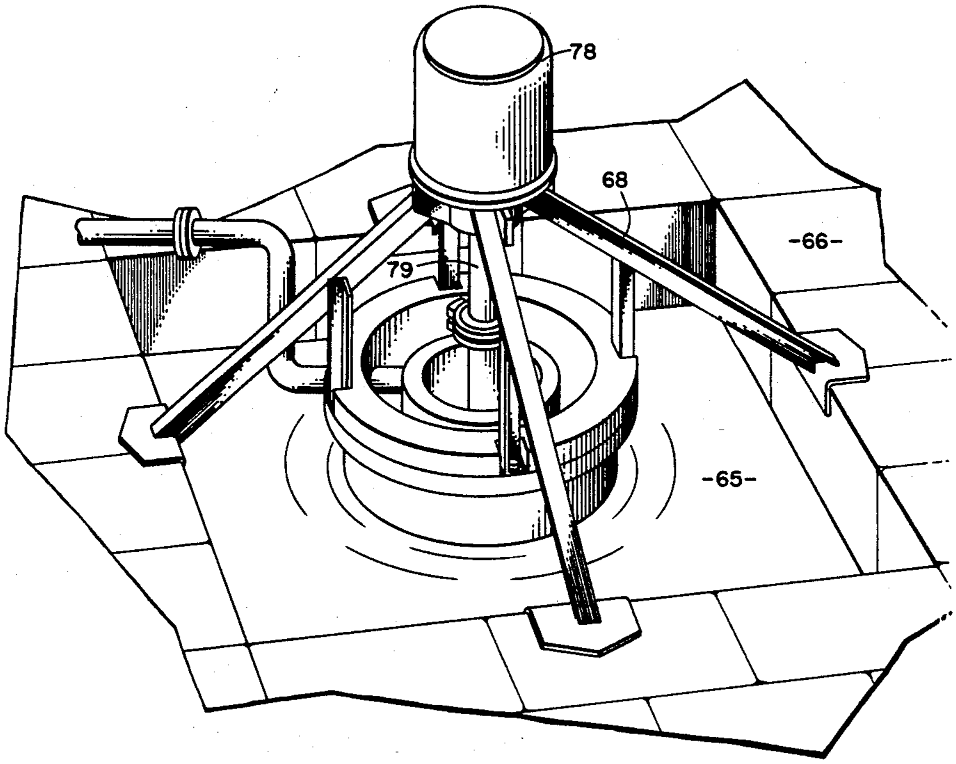

FIG. 4

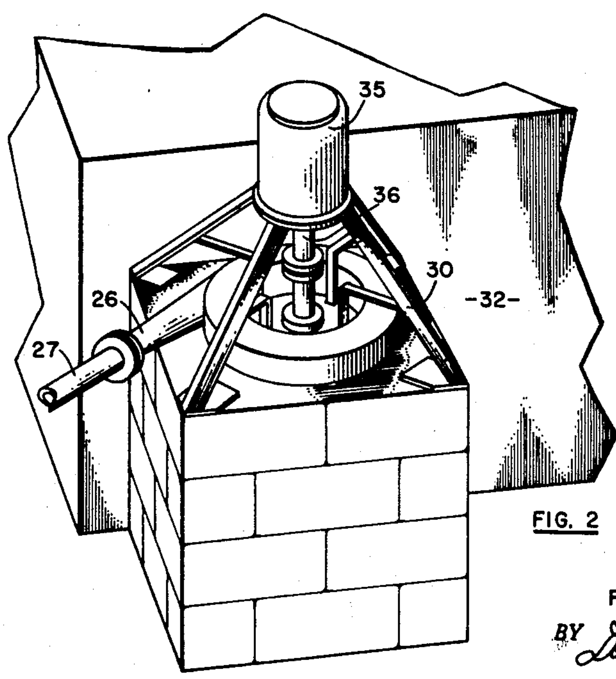

FIG. 2

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ELECTROMAGNETIC PUMP SYSTEM

Filed Jan. 2, 1963 5 Sheets-Sheet 4

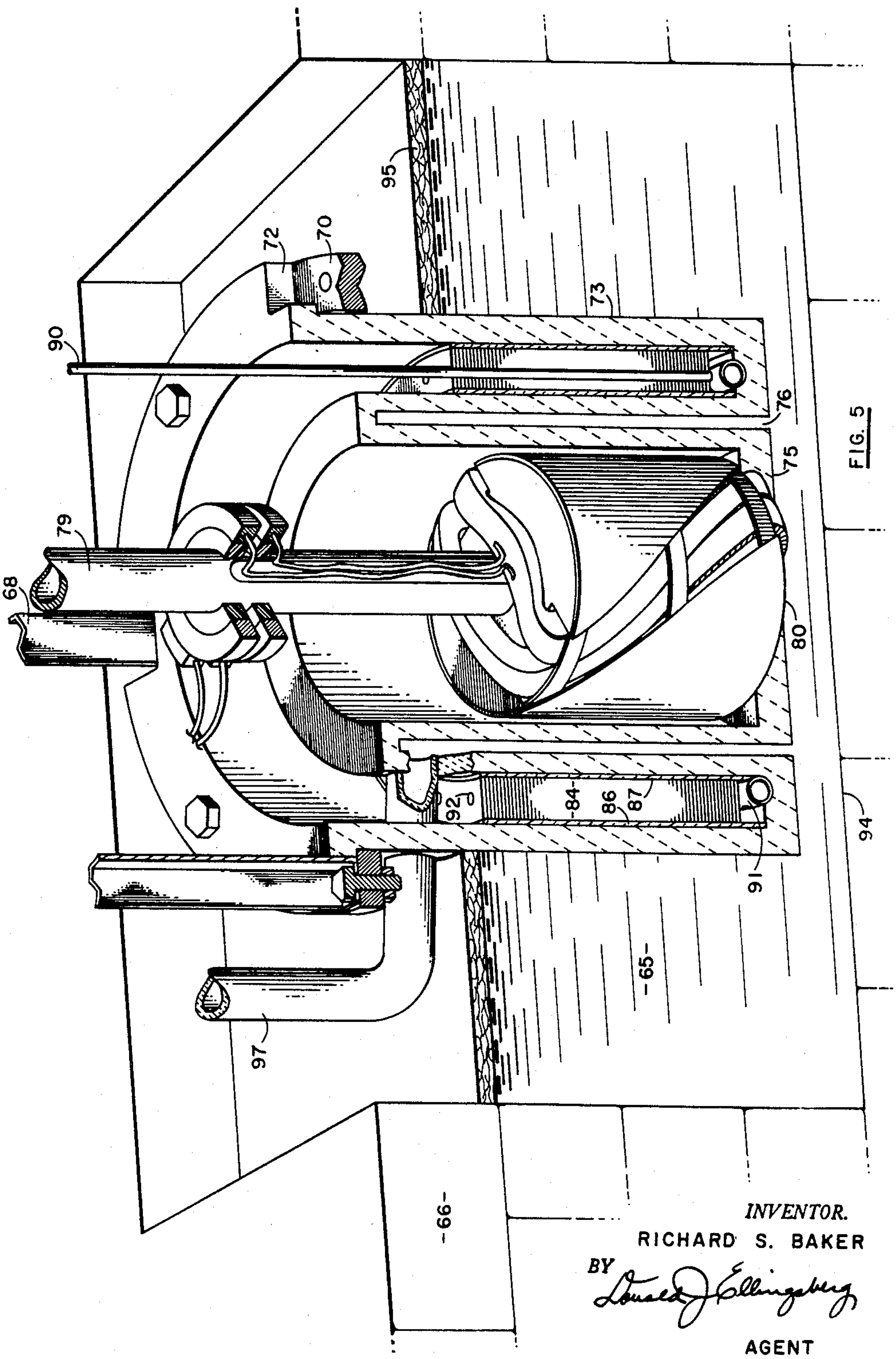

FIG. 5

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ELECTROMAGNETIC PUMP SYSTEM

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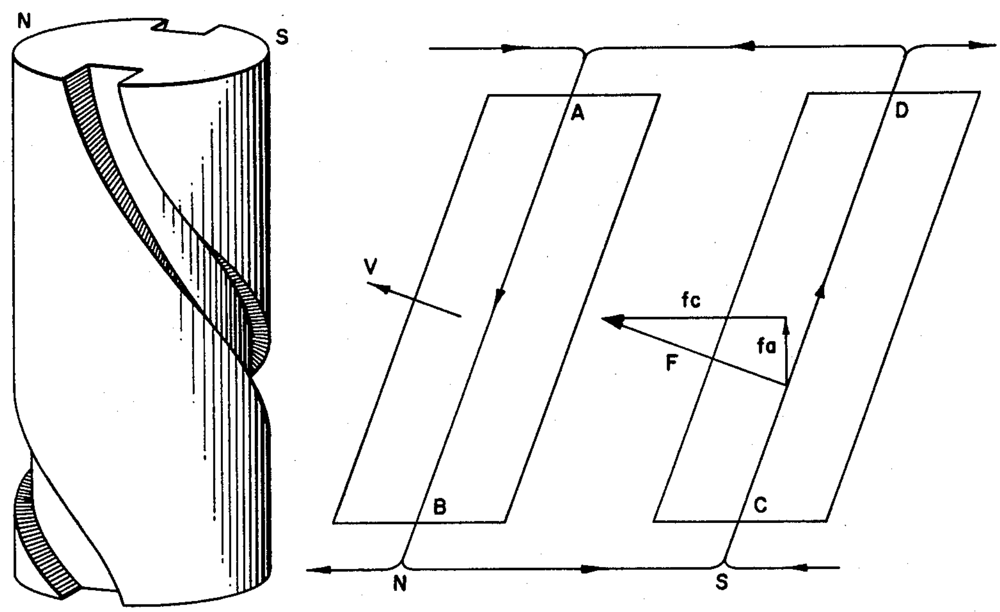

FIG. 7

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3,196,795

ELECTROMAGNETIC PUMP SYSTEM

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Filed Jan. 2, 1963, Ser. No. 248,935
7 Claims. (Cl. 103—1)

The present invention relates to an electromagnetic pump system for the transfer of electrically conductive liquids and more particularly to an electromagnetic interaction pump system for the transfer of high temperature liquid metals. The improved pump system of the present invention is based upon the principle of operation of my helical rotor electromagnetic pump disclosed in United States Patent No. 2,940,393, issued June 14, 1960, and assigned to the same assignee as the present invention.

Although conventional mechanical and electromagnetic pumps are generally well-known in the prior art, modern foundry practice depends primarily on gravity and siphon-induced flow arrangements to transfer liquid metals, particularly very high temperature liquid metals such as aluminum, zinc, nickel, brass and the like. Conventional mechanical pumps for practical reasons have been limited in modern foundry practice to low temperature, non-corrosive liquid metals. These pumps cannot be used for pumping high temperature liquid metals since the moving parts generally formed from iron or steel rapidly deteriorate in the corrosive environment of most liquid metals.

Electromagnetic pumps are adapted for use in modern foundry practice, particularly in the transfer of conductive liquids, since there are no moving parts in contact with the liquid being pumped. The "magnetic impeller" in an electromagnetic pump replaces the mechanical impeller of a mechanical pump. Electromagnetic pumps develop a pumping force by converting magnetic energy into pressure energy in accordance with the electromagnetic thrust that is generated by the passage of an electric current, either applied or induced, through an electrically conductive liquid transversely to a magnetic field. The direction of force acting upon the conductive liquid and the resulting liquid motion are determined by the well-known three finger rule of electrophysics.

The major problem in the operation of any electromagnetic pump in modern foundry practice is the vulnerability of the conductors and the insulation in the field winding to high temperature. This factor is commonly the result of high temperatures associated with the liqiud metal being pumped. For example, electromagnetic conduction pumps have relatively heavy conductors or bus bars which serve as electrode connections to the pumping section. These bus bars are generally secured to the pumping section by brazing or welding and are therefore susceptible to breaking away from the pumping section when a high temperature liquid metal is being pumped. When the bus bars in a conduction pump are formed from materials having better metallurgical properties, lower pump efficiencies result which are frequently no greater than 2 or 3 percent in pumps having any appreciable capacity. Linear induction pumps which operate on the theory of an induction motor generally require expensive polyphase field windings. An electrical current is induced in the liquid metal being pumped by a magnetic field set up by alternating currents flowing in windings in a magnet structure surrounding the pump section. While efficient pumping generally results, induction pumps are expensive, structurally expansive, and susceptible to the high temperature factor.

Modern foundry practice, therefore, has had to depend primarily on gravity and siphon-induced flow arrangements to transfer liquid metals, particularly the very high temperature liquid metals. The transfer of the liquid metal or melt in foundry practice is preferably without excessive agitation of the melt and without rupture of a protective oxide skin that forms on the surface of the melt. This oxide skin substantially reduces both the gas adsorption by the melt and the related accumulation of dross or slag therein. When the oxide skin remains unbroken and the melt transfer is calm, a relatively clean molten metal results that is suitable for pouring high quality castings having a desirable low porosity. Without exacting control provisions, the gravity and siphon-induced transfer flows currently used by modern foundry practice substantially increase the probability of high gas adsorption by the melt since rupture of the oxide skin and excessive agitation of the melt are unavoidable.

A rotating field electromagnetic pump is particularly adapted for the desired calm transfer of liquid metals in modern foundry practice. However, high temperature liquid metals require an improved field coil winding and rotor geometry which promotes adequate cooling and substantially increases the efficiency of the pump during high temperature pumping. The necessary bearing arrangements in rotating field electromagnetic pumps are also subjected to the high temperature environment. It is desirable to position the bearing arrangements for a rotating field pump in a region removed from the high temperature environment without sacrificing stability of the rotating pump components.

Accordingly, it is a primary object of the present invention to provide an electromagnetic pump system for pumping electrically conductive liquids, particularly high temperature liquid metals.

It is also an object of the invention to provide an electromagnetic pump system that pumps a liquid metal from beneath the surface of a melt without rupture of the protective oxide skin on the melt surface.

A further object of the invention is to provide an electromagnetic pump system which transfers the liquid metal from one location to another without an appreciable increase in gas adsorption by the melt or related dross formation therein.

Another object of the invention is to provide an electromagnetic interaction pump system for pumping electrically conductive liquids against the action of gravity by developed electromagnetic forces.

Yet another object of the invention is to provide an electromagnetic pump system that develops a pumping action by the production of a force on the liquid in the desired direction of flow by an electromagnetic interaction that is produced by the helical geometry of the pump rotor.

It is also an object of the invention to provide an electromagnetic pump system with adequate cooling of the helical pump rotor.

Yet another object of the invention is to provide an electromagnetic pump system having an improved bearing arrangement for the helical pump rotor.

An additional object of the invention is to provide an electromagnetic pump system that develops a calm flow of liquid metal under pump induced pressure without complex guide vane configurations in the pump liquid flow passages.

Likewise an object of the invention is to provide an electromagnetic pump system that facilitates accurate control of the flow of a liquid under pump induced pressure.

A further object of the invention is to provide a method and apparatus to stir a melt to maintain homogeneity thereof.

Yet another object of the invention is to provide a method and apparatus for substantially cleaning pump system flow passages of liquid by a reversal of the developed electromagnetic forces.

Further objects, features and the attending advantages of the invention will be apparent with regard to the following description read in connection with the accompanying drawings in which:

FIGURE 1 is a perspective view, partly broken away, of one form of the electromagnetic pump system of the invention;

FIGURE 2 is a perspective view of the pump system of FIGURE 1 in an operating location;

FIGURE 3 is a longitudinal section, partly schematic, of the pump system of FIGURE 1;

FIGURE 4 is a perspective view of another form of the electromagnetic pump system in an operating location;

FIGURE 5 is a perspective view, partly broken away, of the pump system of FIGURE 4;

FIGURE 6 is a longitudinal section, partly schematic, of yet another form of the electromagnetic pump system of the invention; and

FIGURE 7 is both a perspective view and a developed view of one form of my helical pump rotor as disclosed.

Briefly, in accordance with one form of the invention, an electromagnetic pump system for pumping electrically conductive liquids is provided having at least one pump region that is juxtaposed between a magnetic helical rotor, which sets up a magnetic flux field across the pump region and distributes the field in a generally helical curve, and a flux return path so that when the rotor is rotated by a suitable drive means, the magnetic flux field induces electrical eddy-currents in a liquid in the pump region that flow in patterns which conform with the helical geometry of the rotor and interact with the magnetic field to impart desired pumping forces on the liquid in the pump region.

Referring to FIGURE 1, one form of the electromagnetic pump system of the invention has an outer crucible member **10** supported by a plurality of refractory bricks **12** or the like. The bricks **12** protect the pump system components and provide thermal insulation for the pump system. A radially extending flange **13** of the crucible **10** provides a bearing surface or platform for a lip edge **15** of an inner crucible member **16** that is nested within the outer crucible. Both the outer and inner crucibles **10** and **16** are oriented in a generally vertical alignment about a vertical axis. It is contemplated that the certain degrees of tilt from the vertical alignment shown by FIGURES 1 and 2 also are within the inventive concept. A spring clamping means, not shown, can be provided to ensure the relative positions of the crucibles **10** and **16** since the inner crucible **16** may have a tendency to be buoyed up when certain liquid metals and their alloys are being pumped by the pump system of the invention.

The outer and inner crucible members **10** and **16** are preferably formed from a suitable refractory material such as silicon carbide, boron nitride and the like. The particular metal or refractory material utilized for the flow passages of the pump system is not critical to the principle of operation of my electromagnetic pump system. The choice of material is a function of pressure, type of liquid being pumped, and temperature; the flow passages should be particularly adapted to withstand high operating temperatures such as those incurred when pumping molten metals like aluminum, zinc, brass and the like. While the crucible members **10** and **16** are shown by FIGURE 1 as integral, individual units that are preformed from a refractory material, it is contemplated that for ease of construction and assembly the members **10** and **16** could be sectionalized, bonded together by a suitable mortar or sealing agent, and built up into the generally cup-shaped crucible members.

In the nested arrangement, the outer and inner crucible members **10** and **16** are spaced apart to develop a pump region or annulus **20** therebetween. The crucible members also form an inlet region **21** that communicates with the pump annulus **20**. The lip edge **15** of the inner crucible **16** develops an outlet region or discharge scroll **22** that also communicates with the pump annulus **20**. Suitable spacer members, not shown, may be provided between the nested outer and inner crucibles **10** and **16**.

At least one inlet port **25** and one outlet port **26** communicate with the inlet region **21** and the outlet region **22**, respectively, as shown by FIGURE 1. The inlet port **25**, while shown in the side wall of the outer crucible **10** can also be positioned in the bottom wall of the outer crucible. Further, the inlet port **25** can be tangentially directed with regard to the inlet region **21**. It is contemplated that more than one ingress duct can communicate with the inlet port **25** of the pump system so that melt can be pumped from one or more levels beneath the protective oxide skin on the surface of a melt body. The gentle pumping action developed by the electromagnetic interaction pump system of the invention further ensures a clean liquid metal for subsequent pouring without rupturing the oxide skin during pumping.

If any dross or slag accumulation should occur in the pump annulus **20** or its related regions **21** and **22**, the nested arrangement of the outer and inner crucibles **10** and **16** facilitates the removal of the inner crucible to expose such accumulation for easy cleaning by mechanical tools and the like. However, during pumping, the continuous "scrubbing" of the pump annulus **20** by the developed pumping action, to be subsequently described, minimizes such dross or slag accumulation therein and maintains a relatively clean pump annulus at all times. Thus the need for mechanical tools to clean the pump annulus **20** and the inlet and outlet regions **21** and **22** is substantially avoided by the structural arrangement and principle of operation of the present invention. Although it is not critical to the operation of the present pump system, the bottom wall of the outer crucible **10** may slope to facilitate drainage of the inlet region **21**, the pump annulus **20**, and the outlet region **22**.

FIGURE 2 shows one form of a structural beam arrangement **30** for the electromagnetic pump system when the pump system is positioned adjacent to a melting furnace or hold pot **32** such as those well-known in the foundry art. The pump system of the invention can also be positioned, for example, between one or more melting furnaces and hold pots, or any combination thereof, or between separate hearths of one or more reverberatory furnaces, or at any other location in a foundry operation where it is desirable to transfer liquid metal.

A prime mover, such as an electric drive motor **35**, is supported and positioned by the beam arrangement **30** above the nested crucible members **10** and **16**. A rotor shaft **36** is connected to the drive motors **35**. The shaft **36** can be either solid or hollow, the latter being particularly desirable for the introduction of a cooling medium such as air to the rotating pump components subsequently described. A suitable bearing arrangement **38**, more clearly shown by FIGURE 1, rotatably positions the rotor shaft **36** so that the shaft depends into the cup region of the inner crucible **16**. The bearing arrangement **38** is positioned above and external to the volume defined by the pump annulus **20** and the inlet region **21**. This arrangement removes the bearings from the primary high temperature environment developed during the pumping of high temperature liquid metals and permits adequate cooling by the open location.

A helical rotor **40** is field wound and can be attached to or integrally formed with the rotor shaft **36**. The helical rotor **40**, as shown in FIGURE 1, has the form of a two-pole electromagnet with pole pieces **42** and **43**; however, the helical rotor **40** can also have a cruciform or any other suitable multipolar form. Both the rotor shaft **36** and the helical rotor **40** are preferably formed from a magnetic material such as mild carbon steel. The helical rotor **40** is formed with at least one helical thread **45**, more clearly shown by FIGURE 3. It is desirable that both the pitch of the helical thread 45 and the width of the thread crest permit a separation between adjacent thread traces on one side of the rotor 40 to reduce flux leakage paths. Further, it is desirable that the helical thread 45 have a sufficient trace length to travel approximately the axial length of the pump annulus 20 during rotation of the helical rotor 40.

A field coil winding 47 is wound in the thread 45 between the adjacent poles 42 and 43 of the helical rotor 40. The field coil winding 47 is preferably formed from silicone-impregnated double glass insulated copper wire which is particularly adapted for high temperature operating conditions. For rotor operating temperatures in the range 600° F. to 1100° F., nickel-clad copper wire with ceramic insulation is preferred. The field winding 47 is insulated from the rotor 40 by means of glass saddles or blades, not shown. These also serve to produce ventilating ducts or flow passages between the rotor and the winding. The field coil winding 47 is electrically connected to an external direct current power source, not shown, by means of suitable slip rings 49. The field winding 47 is connected so that adjacent field poles, such as pole pieces 42 and 43, produce magnetic poles of opposite polarity. All the turns of the field coil winding 47 on each pole piece 42 and 43 act along the same axis, thereby concentrating the magnetomotive force. This makes the helical rotor electromagnetic pump particularly suitable for use where the pump annulus 20 must be relatively thick-walled. The slip rings 49 are connected through suitable brushes and leads to the external power source. A plurality of clamping strips or bands 50–52 retain the field coil winding 47 within the helical thread 45.

A protective jacket 55 can be secured to and generally enclose the helical rotor 40. The jacket 55 is preferably formed from a suitable material such as stainless steel and protects the field coil winding 47 from the effects of high temperature operating conditions when handling molten metals. Based upon design parameters, additional heat transfer barriers, in addition to the jacket 55, can be positioned within the inner crucible 16 between the periphery of the helical rotor 40 and the wall of the crucible while maintaining a coolant flow path therebetween.

The rotating pump components, which include the rotor shaft 36, helical rotor 40, and the field winding 47, depend as a unit into the generally cup-shaped interior of the inner crucible member 16 with the pump annulus 20 generally circumjacent to the helical rotor 40. The pump annulus 20 is not in fluid communication with the rotating components. The mechanically rotating components therefore are not wetted by direct immersion in the liquid metal that is being pumped. The geometry of the helical rotor 40 and the field coil winding 47 complements the cup-shaped inner crucible member 16 and provides an unobstructed flow of cooling air to the rotating pump components while maintaining a total nominal air gap which insures a highly efficient helical rotor electromagnetic pump system. If a higher flow rate is desired, suitable blower arrangements such as those known in the art can be utilized to increase the normal airflow.

A suitably constructed magnetic structure 58 is arranged circumjacent to the pump region or annulus 20 and provides a flux return path to improve the over all pump system efficiency by reducing leakage flux. The magnetic structure 58 is preferably built-up from a plurality of laminations formed from a good grade of magnetic material as silicon steel which may be individually coated with a suitable insulating material. It is generally desirable, particularly when pumping high temperature liquid metals, to maintain the magnetic structure 58 at a temperature that is less than the Curie temperature of the laminations. A cooling medium, such as air, is introduced to the magnetic structure 58 from an external source, not shown, through at least one inlet conduit 60. A plenum region or tube 61 distributes the cooling air to a plurality of similar circumferentially spaced ducts 62, and then exhausts the cooling air from the magnetic structure through at least one discharge pipe 63.

In operation, the field coil winding 47 of the electromagnetic pump system shown by FIGURE 1 and 2 is energized from the direct current power supply, not shown, so that the helical rotor 40 as a source of magnetic flux has alternate north and south polarities skewed circumferentially and axially relative to the axis of rotation of the helical rotor. The helical rotor 40 is not homopolar in my helical rotor pump since the opposing north and south polarities develop related opposite polarities in the regions immediately adjacent to the rotor shaft 36. The magnetic flux field set up by the energization of the field winding 47 is more clearly shown by FIGURE 3. The magnetic flux field passes from the skewed north poles of the helical rotor 40 through the pump annulus 20 and the conducting liquid therein to the flux return path provided by the magnetic structure 58. The magnetic field divides into at least two flow paths, each of which returns to the regions immediately adjacent to the skewed south poles of the helical rotor 40. The flux field then passes back through the pump annulus 20 to the south poles. The direction of the magnetic flux field in the pump section 20 is substantially radial to the axis of rotation of the helical rotor 40, and is distributed in flux patterns or paths that define at least one generally helical curve about the rotor.

Rotation of the energized field wound helical rotor 40, for example, in a counter-clockwise direction, i.e. from left to right as viewed in FIGURES 1 and 2, develops a variance in the magnetic flux field across the pump region or annulus 20. Referring to FIGURE 7, this variance induces voltages such as along current paths A–B and C–D in the pump annulus 20 in accordance with the right-hand rule of electrophysics. These voltages interact with the magnetic field to produce the electromagnetic thrust or force F on the conducting liquid in the pump annulus 20 in accordance with the left-hand rule of electrophysics. My helical rotor pump develops the resultant vector force F that has both axial and circumferential vector components, f_a and f_c respectively. The development of the axial component f_a permits the use of a partionless pump region such as pump region 20 shown by FIGURE 1, since the axial component f_a imparts a desired velocity V to the conducting liquid and results in axial liquid flow through the pump region under pump induced pressures. The forces, such as force F, that are impressed upon the liquid metal in the pump annulus 20 of FIGURE 1 move or pump the liquid metal from the inlet port 25 to the outlet port 26. The movement of the liquid metal in the pump annulus 20 will continually "scrub" or flush the annulus of any dross or slag accumulation therein. Whip or runout characteristics of the depending pump components also are minimized by the energization of the field winding 47 which assists in obtaining virtually vibrationless running characteristics of the rotating pump components. For example, in one test run, .004 inch runout or variance from the vertical axis of rotation was observed for the rotating pump components without field energization. When the field winding 47 was energized, the magnetic field set up by the helical rotor geometry significantly reduced the runout to .002 inch.

The directionalized laminar flow of the molten metal under the pump induced pressures created by the described electromagnetic forces provides a relatively calm liquid flow from the outlet port 26 with a minimum of turbulence. While the outlet port 26 is tangentially directed to the outlet region 22 and contributes to the calm flow, the tangential attitude is not critical to the operation of the pump system of the invention.

The introduction of the pumped metal from the discharge or outlet port 26 to a closed conduit 27 for transfer to another location also reduces the probability of additional gas adsorption and related dross accumulation by the melt. If necessary, the conduit 27 may be suitably insulated or heated to minimize temperature losses in the liquid metal during transfer. Thus, the pumped metal flows under pump induced pressure at a near optimum pouring temperature without requiring additional heating in a subsequent holding or pouring ladle, not shown. The liquid metal also can be pumped at the near optimum pouring temperature without requiring prior overheating in the melt body to compensate for subsequent temperature losses during transfer such as those experienced in the known prior art pump systems.

Accurate successive or continuous flow of liquid metal under pump induced pressures is achieved by control of either the drive motor 35, the energization of the field winding 47, or both, so that measured flow and instantaneous stoppage of the calm liquid flow from the pump system of the invention is possible. For example, in one pump system formed in accordance with the invention, a 25 ampere field current was maintained in the field winding 47 when the drive motor 35 was stopped. A prior 3000 gallons per minute discharge flow from the pump system rapidly decreased to zero flow with a time constant of three seconds. The field current was turned off only after the discharge flow of liquid metal had terminated.

Known gravity or syphon transfer arrangements require approximately one hour to transfer 40,000 pounds of a liquid metal, such as aluminum, with no assurance of a calm metal flow. One of my electromagnetic pump systems pumps 500 gallons per minute and transfers 600,000 pounds of aluminum in one hour; the transfer being accomplished with a calm laminar flow and under pump induced pressure against the effects of gravity by use of the previously described electromagnetic forces.

The electromagnetic pump system particularly shown by FIGURES 1 and 2 will pump 2620 gallons per minute at a developed pressure of 31.5 p.s.i. when the helical rotor 40 is driven at 374 r.p.m. with a direct current input to the field winding 47 of 28 amperes total at 200 volts. When the rotor is driven at constant speed, the discharge flow from the pump may be varied by a field rheostat in series with the direct current power source for the field winding 47 to obtain a smooth, stepless variation of flow and pressure.

A simple reversal of the drive motor 35 provides reverse travel of liquid in the pump region or annulus 20 to rapidly clean the discharge port 26, conduit 27, and related flow passages of liquid metal. This avoids solidification of liquid metal in the flow passages during periods when no liquid flow is desired.

FIGURES 4 and 5 show another form of the electromagnetic interaction pump system of the present invention. The principle of operation is similar to the pump system shown by FIGURES 1 and 2. The pump system shown by FIGURES 4 and 5 operates in a partly submerged position in a liquid metal pool or body of melt 65. The melt 65 may be contained by suitable bricks 66 or other suitable structure common to foundry practice.

FIGURE 4 shows one form of a structural beam arrangement 68 positioned generally above the melt 65 and bearing upon the bricks 66. Other support arrangements are also contemplated to be within the concept of the pump system being described and the arrangement 68 shown by FIGURES 4 and 5 is not critical. A support ring 70 is retained by the beam arrangement 68 and engages a radially extending flange portion 72 of an outer channel portion 73. The outer portion 73 is spaced from and circumjacent to an inner crucible portion 75 to develop a pump region or annulus 76 therebetween.

The outer and inner portions 73 and 75 respectively are shown by FIGURE 5 as an integral unit either preformed from metal or a suitable refractory material such as those materials previously described. It is again contemplated that for ease of construction and assembly the portions 73 and 75 can be sectionalized and built up into the general configuration as shown by FIGURE 5. If

desired, suitable spacer members, not shown, can be provided between the outer and inner portions.

The structural beam arrangement 68 also supports a prime mover, such as an electric motor 78, with a depending rotor shaft 79 connected thereto. A field wound helical rotor 80, similar in all structural aspects to the field wound helical rotor 40 shown by FIGURES 1 and 2, is secured to or integrally formed with the rotor shaft 79. The helical rotor 80 depends into the inner crucible portion 75 so that the pump annulus 76 is generally circumjacent to the rotor.

A magnetic structure 84 provides a return path for the magnetic flux field set up by the magnetic rotor. The magnetic structure 84 is positioned within the outer channel portion 73 and is preferably formed from a plurality of mild steel laminations. The magnetic structure 84 may also be supported from the beam arrangement 68 to reduce the loading on the outer channel portion 73, particularly when the channel portion is formed from a refractory material. Secondary insulating barriers 86 and 87, formed from asbestos or the like, are positioned between the magnetic structure 84 and the walls of the outer portion 73 to reduce the heat transfer from the melt 65 to the magnetic structure 84. A cooling medium, such as air, is introduced to the magnetic structure 84 through an inlet conduit 90 to maintain the laminates below their Curie temperature. The cooling air passes from the inlet conduit 90 to a plenum region or tube 91 and then exhausts from the magnetic structure 84 through a plurality of cricumferentially spaced ducts, such as duct 92. It is contemplated that additional heat transfer barriers, similar to heat barriers 86 and 87, may be positioned within the inner crucible portion 75 between the periphery of the helical rotor 80 and the walls of the inner portion 75.

The pump annulus 76 is open to the melt 65 on a plane that is suitably spaced from the hearth or pot bottom 94. Ingress of molten or liquid metal to the pump section 76 during operation of the pump system, shown by FIGURES 4 and 5, develops a gentle swirling or stirring action in the melt 65 which assists in maintaining a homogenous melt and aids in the escape of absorbed gases in the melt without rupture of the protective oxide skin 95 on the melt surface.

Operatively, the electromagnetic pump system shown by FIGURES 4 and 5 develops a pumping action similar to that previously described with regard to the pump system shown by FIGURES 1 and 2. The electromagnetic forces developed within the pump section 76 upon the electrically conductive liquid therein are in accordance with those forces previously described and effect the lifting and conveying of the liquid metal to an outlet or discharge conduit 97.

FIGURE 6 shows yet another modification of the electromagnetic interaction pump system of the invention. Again the theory and principle of operation is similar to that previously described with regard to the pump systems of my invention as shown by FIGURES 1–5.

The helical rotor 100 is positioned generally circumjacent to a pump region or annulus 102 as shown by FIGURE 6. A magnetic structure 103, structurally similar to those previously described, is positioned within an insulating core member 104 and provides a flux return path means. The core member 104 is centrally positioned within the volume defined by the pump annulus 102 by a plurality of spacer members similar to spacer member 105.

An external drive means, such as an electric motor 110, rotates the helical rotor 100 through a suitable power transmission means, such as the intermeshing spur gear arrangements 112 and 113. The power transmission gear arrangements are not critical to the operation of the inveniton and are shown only as an illustration of suitable arrangements.

A field winding 120 threaded on the skewed poles of the helical rotor 100 is energized from an external direct current power supply, not shown, through well-known leads and brushes cooperating with suitable slip rings 122. When the field winding 120 is energized and the helical rotor 100 driven by the drive motor 110, the electrically conductive liquid in the pump annulus 102 moves from an inlet port 125 to an outlet port 126 by the forces imparted in the pump annulus.

The electromagnetic pump system shown by FIGURE 6 is particularly adapted for operation in a horizontal orientaiton. However, it is contemplated that the pump system can be used in a generally vertical orientation such as shown for the pump systems of FIGURES 1 and 5.

The helical rotor electromagnetic pump systems, as shown and described, offers distinct advantages over known mechanical pump systems and other electromagnetic pump systems, i.e. induction and conduction pumps. The helical rotor pump system has (1) no moving parts in contact with the liquid being pumped, (2) no seals or stuffing boxes required, and (3) operability in either horizontal or vertical orientation.

In addition, the helical rotor pump system of the invention offers several unique features: flow rates are easily varied; highly efficient operation; reduced entrance losses so that the pump system can operate at low net positive suction with cavitation; large running clearances between the rotating pump components and the pump region components; concentrated field winding sets up a strong magnetic field across a wide gap which makes it possible to use a thick-walled pump channel or region; operational flexibility since the rotating pump components are not secured to the pump region components; and no capacitors are required for power factor correction since direct current is preferably used to set up the magnetic field.

As will be evidenced from the foregoing description, certain aspects of the invention are not limited to the particular details of construction as illustrated. While the source of magnetic flux is shown by FIGURES 1–6 as a helical rotor with a field winding suitably energized, the magnetic flux can be developed by suitably arranged permanent magnets skewed to form a helical rotor, or by a combination of electromagnets and permanent magnets. A skewed or helical permanent magnet rotor as a source of magnetic flux has particular use in small pump systems to develop the magnetic forces on the liquid being pumped. It is contemplated that other modifications and applications will occur to those skilled in the art. Accordingly, it is intended that the appended claims shall cover such modifications and applications that do not depart from the true spirit and scope of the invention.

Having described my invention, what I claim and desire to secure by Letters Patent of the United States is:

1. An electromagnetic pump system for pumping electrically coductive liquids comprising:
 (a) first and second generally cup-shaped members,
 (b) a rim portion on said first cup-shaped member cooperating with a rim portion on said second cup-shaped member to nest said first member within said second member in a spaced apart relationship to each other,
 (c) a pump region developed between said first and second members,
 (d) at least one inlet port to said pump region in said second member,
 (e) at least one outlet port form said pump region,
 (f) a field wound helical rotor rotatably positioned within said first cup-shaped member and spaced therefrom to define a coolant flow path,
 (g) support means for said helical rotor including a bearing arrangement removed from said first cup-shaped member,
 (h) flux return path means circumjacent to said pump region,

 (i) cooling means for said flux return path,
 (j) means electrically connecting said field wound rotor to a power source to set up a substantially radial magnetic flux field across said pump region distributed in at least one helical curve about said rotor, and
 (k) drive means to rotate said helical rotor so that the magnetic field induces eddy-currents in a conductive liquid in said region which flow in paths that conform with the helical geometry of said rotor means and interact with the magnetic field to impart pumping forces on the liquid.

2. The pump system of claim 1 in which said pump region is an annulus.

3. The pump system of claim 1 in which said cup-shaped members are formed from a suitable insulating material.

4. An electromagnetic pump system for pumping electrically conductive liquids comprising:
 (a) an inner crucible portion,
 (b) an outer channel portion generally circumjacent to said inner portion and spaced therefrom,
 (c) a pump region developed between said inner and outer portions,
 (d) at least one outlet port from said pump region,
 (e) a field wound helical rotor rotatably positioned within said inner crucible portion and spaced therefrom to develop a coolant flow path,
 (f) support means for said helical rotor and said inner and outer portions including a bearing arrangement removed from said inner and outer portions,
 (g) flux return path means positioned within said outer channel portion,
 (h) cooling means for said flux return path,
 (i) means electrically connecting said field wound rotor to a power source to set up a substantially radial magnetic flux fluid across said pump region distributed in at least one helical curve about said rotor, and
 (j) drive means to rotate said helical rotor so that the magnetic field induces eddy-currents in a conductive liquid in said region which flow in paths that conform with the helical geometry of said rotor means and interact with the magnetic field to impart pumping forces on the liquid.

5. The pump system of claim 4 in which said pump region is an annulus.

6. The pump system of claim 4 in which said cup-shaped members are formed from a suitable insulating material.

7. An electromagnetic pump system for pumping electrically conductive liquids comprising:
 (a) a central core member,
 (b) flux return path means positioned within said core member,
 (c) a field wound helical rotor rotatably positioned circumjacent to said core,
 (d) a pump region juxtaposed between said helical rotor and said flux return means,
 (e) at least one inlet and outlet port from said pump region,
 (f) means electrically connecting said field wound rotor to a power source to set up a magnetic flux field across said pump region, and
 (g) drive means to rotate said helical rotor so that the magnetic field induces eddy-currents in a conductive liquid in said region which flow in paths that conform with the helical geometry of said rotor means and interact with the magnetic field to impart pumping forces on the liquid.

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