

March 15, 1960

G. R. FINDLAY

2,928,349

PUMP

Filed Sept. 16, 1953

3 Sheets-Sheet 1

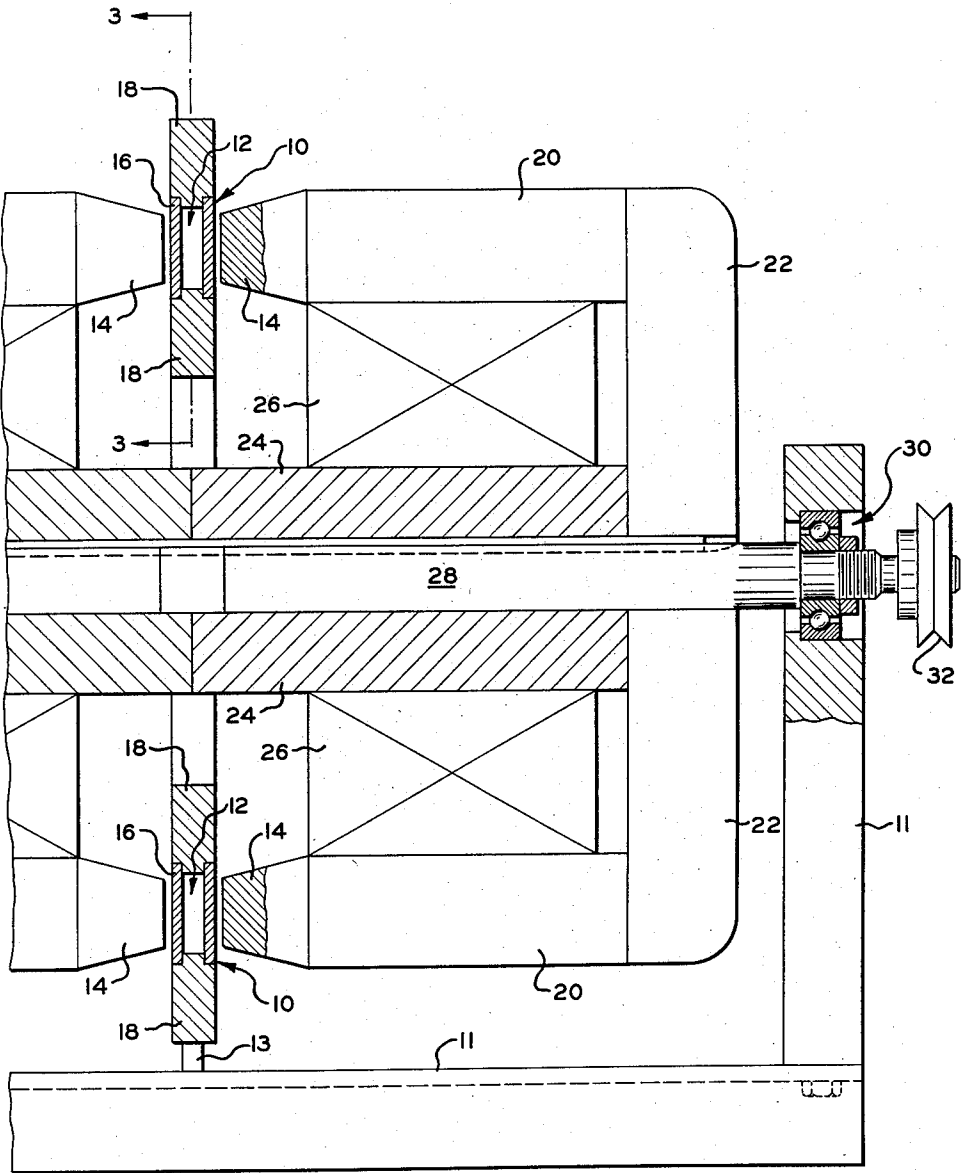


FIG. 1

INVENTOR.
Gordon R. Findlay

BY

Oliver W. Hayes

ATTORNEY

March 15, 1960

G. R. FINDLAY
PUMP

2,928,349

Filed Sept. 16, 1953

3 Sheets-Sheet 3

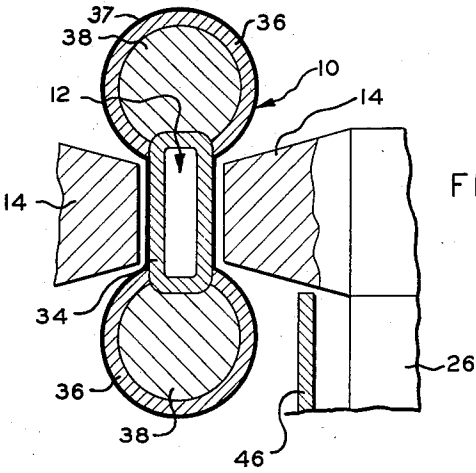


FIG. 4

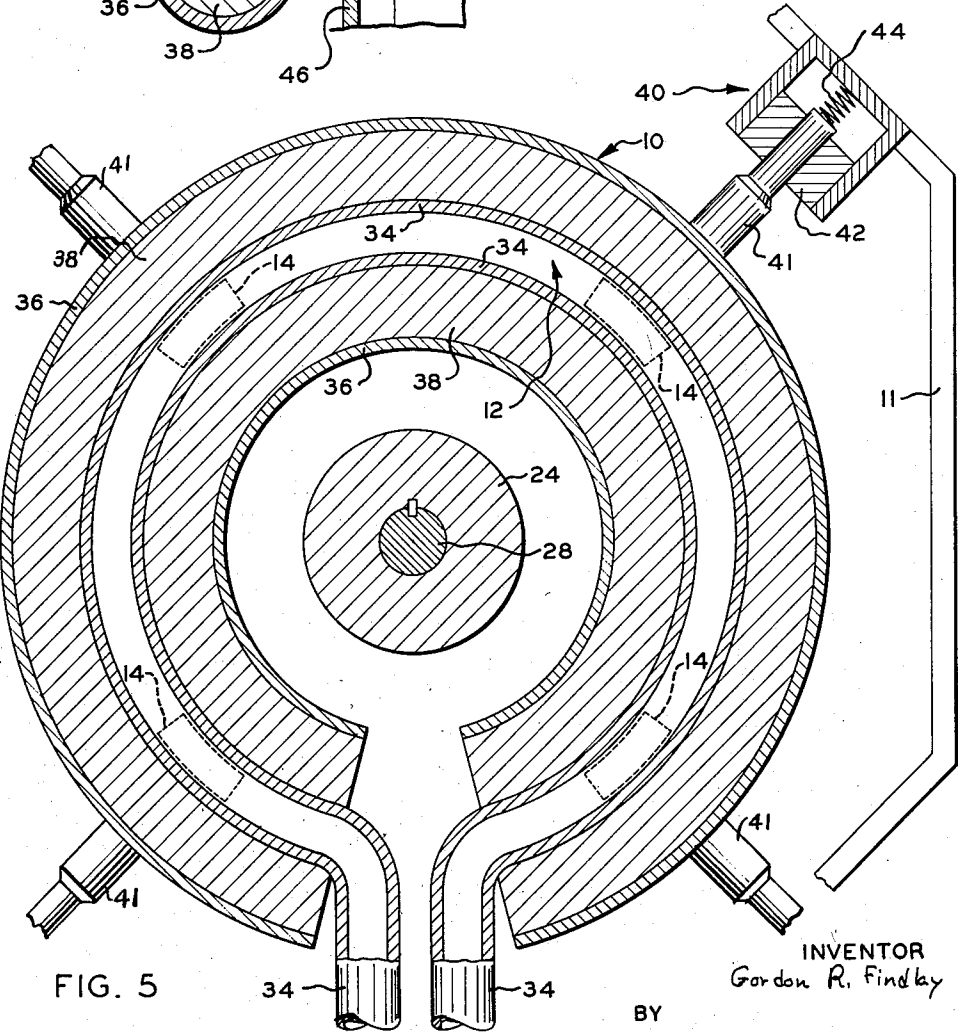


FIG. 5

BY

INVENTOR
Gordon R. Findlay
Oliver W. Hayes
ATTORNEY

1

2,928,349

PUMP

Gordon R. Findlay, Bedford, Mass., assignor to National Research Corporation, Cambridge, Mass., a corporation of Massachusetts

Application September 16, 1953, Serial No. 380,550

2 Claims. (Cl. 103—1)

This invention relates to magnetic pumps and more particularly to a magnetic drag pump for handling electro-conducting fluids such as liquid metals.

A principal object of the present invention is to provide an improved pump of the above type embodying novel features of design by which high power efficiency and improved pumping action are obtained.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the apparatus possessing the construction, combination of elements and arrangement of parts which are exemplified in the following detailed disclosure, and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention, reference should be had to the following detailed description taken in connection with the accompanying drawings wherein:

Fig. 1 is a diagrammatic, schematic, fragmentary, partially sectional view of one preferred embodiment of the invention;

Fig. 2 is an enlarged fragmentary view of a portion of Fig. 1;

Fig. 3 is an enlarged sectional view taken along the line 3—3 of Fig. 1;

Fig. 4 is an enlarged sectional view of an alternative embodiment of the invention, the view being similar to Fig. 3; and

Fig. 5 is a sectional view showing the arrangement of the inlet and outlet connections in the Fig. 4 embodiment of the invention.

The present invention comprises a magnetic drag pump which is preferably formed of a hollow member which defines a continuous passage between an inlet and an outlet. This passage is for the purpose of confining an electrically conducting liquid to be pumped, for example, sodium or the like, and preferably defines an arc of curvature around an axis. The pump includes movable means for generating a magnetic field extending transversely through the passage comprising at least one pair of pole pieces positioned on opposite sides of the arcuate hollow member, and benignly mounted for movement along opposite sides of the hollow member. In a preferred form of the invention the pair of pole pieces is spaced from, and is mounted for rotation around, an axis which is preferably coincident with the axis of curvature of the liquid-confining passage. During rotation, the magnetic flux between pole pieces of a pair defines a cylinder of revolution and the liquid-confining passage is positioned within this cylinder of revolution so that the liquid in the passage is subjected to the rotating magnetic field.

I have discovered that the electro-conductive characteristics of the passage-defining walls of such a pump in relation to their location with respect to the magnetic field constitute important factors in the efficiency of the pump. If these walls are of uniform conductive characteristics, the pump is either extremely inefficient (if the wall conductivity is high) or virtually inoperative if

2

the walls have a high electric resistance. However, I have found that by making those opposite portions of the passage walls which are interposed between the flux path and the liquid of high electrical resistance while providing high electrical conductivity in the wall portions at opposite sides of the flux path a great improvement in efficiency is obtained. This improvement is still further amplified if the highly conductive portions of the walls are located substantially entirely outside the flux path.

In order to operate such a pump with a reasonable head, it is necessary to generate eddy currents of extremely large magnitude (on the order of several thousand amperes) extending through the liquid in a plane transverse to the flux path. Due to the high magnitude of these eddy currents, it is necessary that a highly conductive return path be provided for the flow of these eddy currents outside of the liquid in a direction parallel to the flow of the liquid. On the other hand, by providing walls of low conductivity interposed in the flux path between the pole face and the liquid, the generation of primary eddy currents in the low-conductivity walls (along with secondary eddy currents in the liquid which tend to oppose and interfere with the action of the primary eddy currents in the liquid) is effectively inhibited. The tendency to generate these detrimental eddy currents in the wall between the pole face and the liquid is very great due to the fact that the relative motion between the pole face and the wall is much greater than the relative motion between the pole face and the liquid being pumped.

Additionally, by locating the highly conductive wall portions substantially outside of the flux path, the generation of eddy currents lying entirely within these highly conductive portions is minimized and the pumping efficiency enhanced, because such currents represent wasted energy, giving rise to no pumping force but, on the contrary, generating forces counteracting the movement of the field and producing undesirable heating of the walls.

Accordingly, in a preferred embodiment of the invention, those opposite liquid-confining walls of the hollow member which are adjacent the magnetic pole pieces and interposed between the liquid and the pole face are formed of a material having a high electrical resistivity which acts to minimize eddy currents in these walls due to the moving magnetic field. Additionally, these walls are preferably as thin as is consistent with adequate mechanical strength. The side wall portions (between these electrically resistant walls) provided for return of induced currents are formed of, or comprise material of, high electrical conductivity which is effective to form, with the liquid in the passage, a closed electric circuit favorable to the flow of high amperage eddy currents in a plane transverse to the flux path of the field. It is also preferred that these high-conductivity portions of the hollow member are not subjected, to any substantial extent, to the high intensity moving magnetic field, thereby avoiding the generation of eddy currents flowing entirely within these high-conductivity portions. Accordingly, these high-conductivity portions are preferably concentrically spaced from the cylinder of revolution defined by the pole faces during rotation thereof. It is not essential that the highly conductive walls be formed entirely of conductive material so long as any portion of material of high electrical resistivity between the liquid and the highly conductive portion is perpendicular to the eddy current path and is relatively thin so that the total effective impedance of the eddy current path is low.

Referring now to Figs. 1 through 3, there is illustrated a schematic representation of one type of pump embodying the present invention. In these figures, where like

numbers refer to like elements in the other figures, the hollow member is generally indicated at 10, this member having an arcuate liquid-confining passage 12 therein. The hollow member 10 is stationarily supported on a suitable frame 11 by means such as a support schematically indicated at 13. The passage 12 is provided with suitable inlet and outlet openings (not shown) for the liquid metal. Several pairs (four being shown) of electromagnetic pole pieces 14 are mounted for rotation with respect to the hollow member 10 so that the liquid within the passage 12 is subjected to a high density, moving magnetic field, this field moving along the passage 12 in the direction desired for motion of the liquid. As shown particularly in Figs. 1 and 2, those walls 16 of the member 10 which lie parallel to the planes of rotation of the pole faces, and between the pole faces, are formed of a material having a relatively high electrical resistivity. This material is preferably a material which is also inert to the liquid metal being pumped. Stainless steel has been found to be excellent for this purpose, having a relatively high electrical resistivity and being essentially inert to liquid metals such as sodium and the like. As mentioned previously, those portions of the hollow member which lie at the sides of the magnetic field are preferably formed of a highly conductive material, such as copper or silver. These highly conductive portions are indicated at 18, and define, along with walls 16, the rectangular liquid-confining passage 12.

The pole pieces 14 are supported by pole members 20 which, with flanges 22 and shaft 24, made of ferromagnetic materials, complete the magnetic circuit between the pairs of pole pieces. A pair of electromagnetic coils 26 are preferably provided for generating a strong magnetic field in the magnetic circuit constituting the members 24, 22, 20 and 14. The electromagnetic field is preferably a D.C. field so that there is a constant high unidirectional flux density extending between pole pieces 14, preferably on the order of eight to ten thousand gauss. The magnetic elements, including the pole pieces and coils 26, are preferably supported on a rotating shaft 28, carried by bearings 30 mounted on frame 11. This shaft 28 may be driven by a pulley 32 connected to a suitable motor (not shown).

In order to obtain maximum flux density, the gap between the pole pieces should be as small as possible. However, the smaller the gap, the less room for the liquid passage 12. Accordingly, the passage is preferably elongated in the radial direction transverse to the magnetic field to obtain adequate cross sectional area even with a relatively narrow gap between the pole pieces. Thus, in a preferred embodiment of the invention (as shown in Fig. 2), the radial dimension "l" of the liquid passage 12, transverse to the magnetic field, is greater than the thickness "t" of the passage 12 along the dimension parallel to the magnetic lines of force. The beneficial effect of extending the transverse dimension "l" of the liquid passage must be balanced against the increased hydraulic resistance which is obtained as the wetted perimeter of the liquid passage increases. Accordingly, in any particular case, it is necessary to compromise between the desirability of having a small gap between the pole faces and the necessity of avoiding undue hydraulic frictional losses in the passage. Similarly, the thickness "t" of the high resistivity wall 16 should be as small as possible, consistent with the mechanical requirements of this wall. The air gap "d" between a pole face and the adjacent wall 16 should also be made as small as possible, consistent with the requirements of dynamic balancing of the machine. As illustrated in Fig. 2, the transverse dimension "p" of the pole face should be less than the transverse dimension "l" of the liquid-confining passage 12 so that the transverse dimension "m" of the expanding high-density magnetic field will not penetrate appreciably into the high-conductivity portions 18. For best results, the transverse dimension of the magnetic

field "m" will be substantially equal to the transverse dimension "l" of the passage 12. It is equally important that the propulsive forces proportional to magnetic field density be uniform across the fluid channel. Therefore, it is essential that the transverse dimension "p" of the pole face not be made too small. Otherwise, the transverse dimension "m" of the magnetic field will not coincide with the transverse dimension "l" of the passage 12, and poor hydraulic efficiency resulting from nonuniform propulsive forces across the liquid passage 12 will be obtained. Thus, the magnetic circuit should preferably be such that all the liquid in the passage is subjected to a uniform moving magnetic field, this field being preferably substantially as large as the cross section of the passage, but no larger.

Referring now more particularly to Fig. 3, there is shown (on a considerably enlarged scale) the relationship between the pole pieces 14, the liquid-confining passage 12, the high-conductivity portions 18, and the liquid to be pumped. In Fig. 3 the liquid is to be pumped from left to right in the passage 12 (i.e., in a clockwise direction). The pole pieces 14 (shown in dotted lines) accordingly move in this direction, the movement of the pole pieces 14 and the liquid being shown by solid arrows. As a pair of pole pieces 14 moves to the right, they create two eddy currents in the conducting liquid. The induced currents flow in the liquid in a direction generally perpendicular to the flow of the stream and the magnetic field, and flow through the high-conductivity portions 18 in a path which is generally parallel to the passage 12.

These eddy currents generate electromagnetic fields of their own which tend to follow the magnetic field between the pole pieces. Thus, as the pole pieces move, the induced electromagnetic fields tend to move with the pole pieces, thereby producing within the conductive fluid propulsive forces moving the liquid metal. When the liquid does not move as fast as the pole pieces, the eddy currents increase as a function of the difference between the speed of the pole pieces and the speed of the liquid. Thus, the greater this difference, the greater are the eddy currents generated in the pumped liquid and the greater are the resultant electromagnetic (and consequently propulsive) forces tending to move the liquid.

In a preferred method of manufacturing the pump of Figs. 1 through 3, the liquid-conducting passage 12 is formed from two concentric recessed copper discs 18, to the two recessed faces of which are brazed two thin stainless steel discs 16. A circular passage is thus formed, this passage being provided with suitable inlet and outlet openings. The pole pieces, and the remainder of the magnetic circuit, are made of a ferromagnetic material such as iron and the coil and magnetic circuit are preferably designed to give high flux densities on the order of 8,000 to 10,000 gauss.

Referring now to Figs. 4 and 5, there is shown another embodiment of the invention which is particularly adapted to the pumping of liquid metals at relatively high temperatures on the order of 800° C. In this embodiment the liquid-confining passage 12 of the hollow member 10 is defined by an arcuate flattened tube 34, preferably formed of stainless steel. The high-conductivity portion of the hollow member 10, which is provided outside of the magnetic field but in the plane of the liquid metal flow, is furnished by stainless steel tubes 36 which are filled with copper 38. The composite hollow member 10 (including elements 34, 36 and 38 thereof) is carried by a plurality of resilient supports 40 comprising pins 41 sliding in sleeves 42 rigidly mounted on frame 11. These pins 41 are normally held against axial movement by springs 44. This arrangement of elements permits expansion and contraction of the hollow member 10, in the plane thereof (due to compression or expansion of springs 44), with changes in temperature of the hollow member. However, the support 40 holds the member 10 rigidly

5

against any changes in a direction normal to the plane thereof. This construction accordingly permits operation over a wide range of temperatures while allowing the maintenance of close tolerances between the plane of rotation of the pole pieces 14 and the sides of the flattened tube 34.

In the manufacture of this embodiment of the pump, the tubes 36 are welded to the outer and inner circumferences of the flattened tube 34, and are then heated in a hydrogen filled atmosphere to remove surface oxide and the like. While the composite structure is highly heated, molten copper is poured into the outer tubes 36 so as to completely fill these tubes with molten copper which, when solidified, is intimately bonded to the inner and outer circumferences of the flattened tube 34. The outer surfaces of the stainless steel tubes 34 and 36 are then preferably gold-plated so as to provide a surface 37 (Fig. 4) having a low coefficient of heat radiation. The pump is also preferably provided with a radiation heat shield 46 (Fig. 4) positioned between the hollow member 10 and the electromagnetic coil 26 to prevent radiation damage to this coil at extremely high temperatures.

In the specification and drawings four pairs of pole pieces have been illustrated and described. This is one preferred embodiment of the invention. However, the invention should not be so limited. While four pairs of pole pieces have been illustrated, it is quite apparent that there can be many more pole pieces or even fewer. One pair of pole pieces will operate the pump, although such a construction creates difficult dynamic balancing problems and is apt to give a pulsating pumping effect.

While the invention has been particularly described in connection with the pumping of liquid metals, it is equally applicable to the pumping of other conducting liquids, such as molten salts, and slurries. Accordingly, the expression "liquid" is intended to include slurries, as well.

In the preferred embodiment of the invention illustrated in the drawings, the magnetizing force is supplied by electric coils 26. These coils are preferably energized with a D.C. current which can be supplied through suitable commutators (not shown). Equally, the rotating shaft 28 can carry a D.C. generator so that no electrical leads need be supplied to the pump. Alternatively, the magnetic field may be supplied by permanent magnets formed of a strongly magnetic material, such as "Alnico."

Since certain changes may be made in the above process without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description, or shown in the accompanying drawings, shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In a magnetic drag pump for electrically conducting liquid which includes a passage for the liquid, and magnetic means for generating a magnetic field extending transversely through said passage and movable longitudinally thereof to exert pumping action on the liquid therein, a hollow member forming said passage and having liquid-confining walls completely surrounding the same, said walls having portions thereof at opposite sides of the flux path of said field comprising material of

6

high electric conductivity effective to form with said liquid an electric circuit favorable to the flow of high-amperage eddy currents in a plane transverse to said flux, said portions being disposed substantially entirely outside of said flux path to minimize production of eddy currents flowing entirely within said portions, said hollow member comprising a curved flattened tube arranged in a plane substantially normal to said flux path, said tube being formed of a material of high electrical resistivity and having the material of high conductivity intimately secured to the inner and outer circumferences thereof, and means supporting said tube at a plurality of points around the outer circumference thereof to permit expansion and contraction in the plane thereof while preventing movement of said tube in a direction transverse to the plane thereof.

2. In a magnetic drag pump for electrically conducting liquid which includes a passage for the liquid, and magnetic means for generating a magnetic field extending transversely through said passage and movable longitudinally thereof to exert pumping action on the liquid therein, a hollow member forming said passage and having liquid-confining walls completely surrounding the same, said walls having portions thereof at opposite sides of the flux path of said field comprising material of high electric conductivity effective to form with said liquid an electric circuit favorable to the flow of high-amperage eddy currents in a plane transverse to said flux, said portions being disposed substantially entirely outside of said flux path to minimize production of eddy currents flowing entirely within said portions, the outer surfaces of said hollow member including a coating having a low coefficient of radiant heat transfer, and a radiant-heat shield provided between said member and an electromagnetic coil serving as a portion of the means for generating the magnetic field.

References Cited in the file of this patent

UNITED STATES PATENTS

1,298,664	Chubb	Apr. 1, 1919
2,099,593	Bender et al.	Nov. 16, 1937
2,386,369	Thompson	Oct. 9, 1945
2,651,258	Pierce	Sept. 8, 1953
2,652,778	Crever	Sept. 22, 1953
2,658,452	Donelian	Nov. 10, 1953
2,686,474	Pulley	Aug. 17, 1954

FOREIGN PATENTS

126,947	Great Britain	Dec. 24, 1919
---------	---------------	---------------

OTHER REFERENCES

Publication: Argonne National Laboratory report No. 4273, dated April 5, 1949, entitled "Reactor Engineering Division Report for the Period Dec. 1, 1948, through Feb. 28, 1949," W. H. Zinn, Director.

Publication: Argonne National Laboratory report No. 4317, also known as AECD-3431, dated July 15, 1949, entitled "Electromagnetic Pump for Liquid Metals," by A. H. Barnes, F. A. Smith and G. K. Whitham, pages 1-8, 11 and 12.

Publication: Liquid Metals Handbook, dated June 1, 1950, pages 156-161.