

Dec. 8, 1959

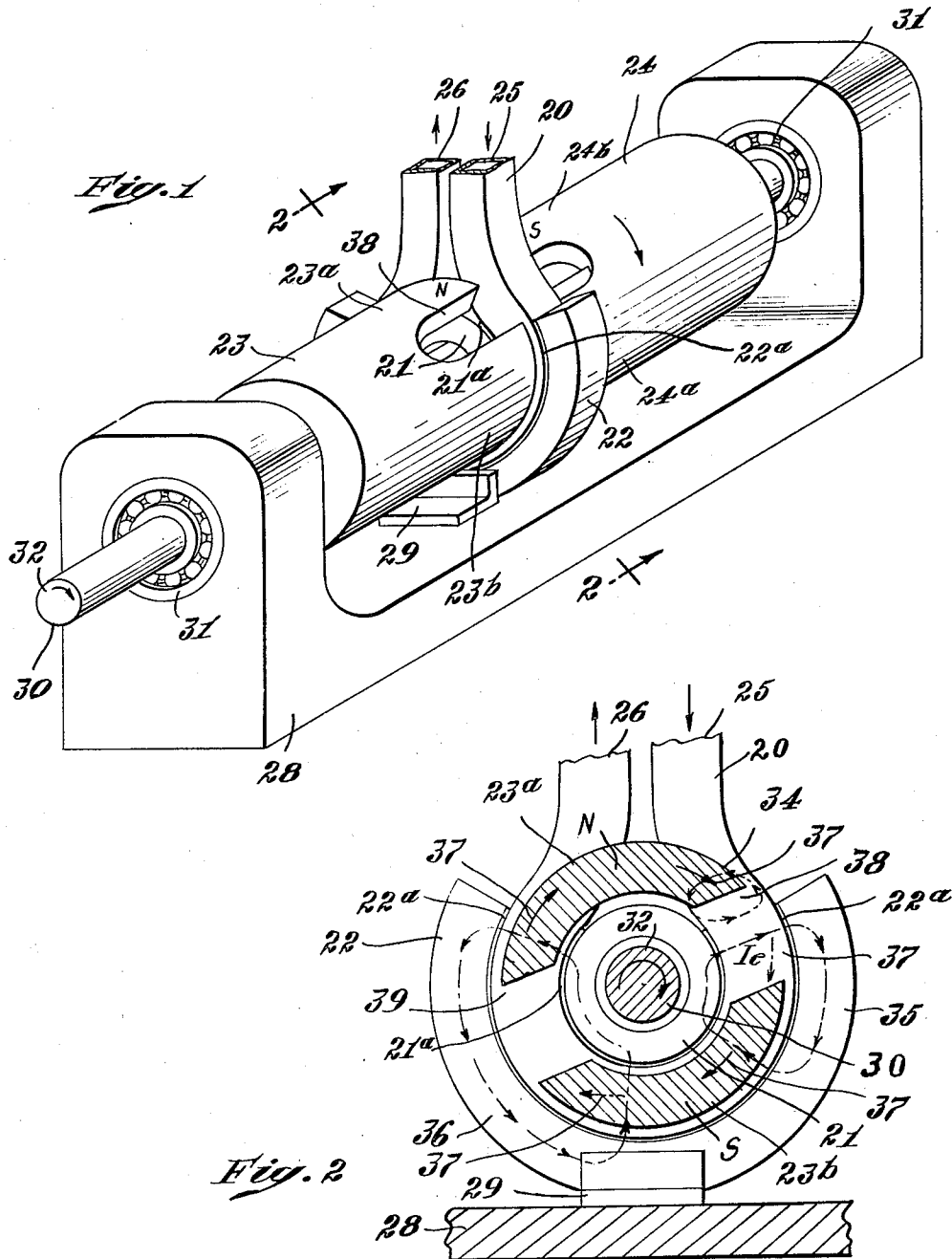
J. M. FINDLAY

2,915,973

APPARATUS FOR PUMPING LIQUID METAL

Filed Aug. 18, 1953

3 Sheets-Sheet 1



Inventor
Jacquetyn M. Findlay
by Duke Thompson, Sanborn
Att'y's

Dec. 8, 1959

J. M. FINDLAY

2,915,973

APPARATUS FOR PUMPING LIQUID METAL

Filed Aug. 18, 1953

3 Sheets-Sheet 2

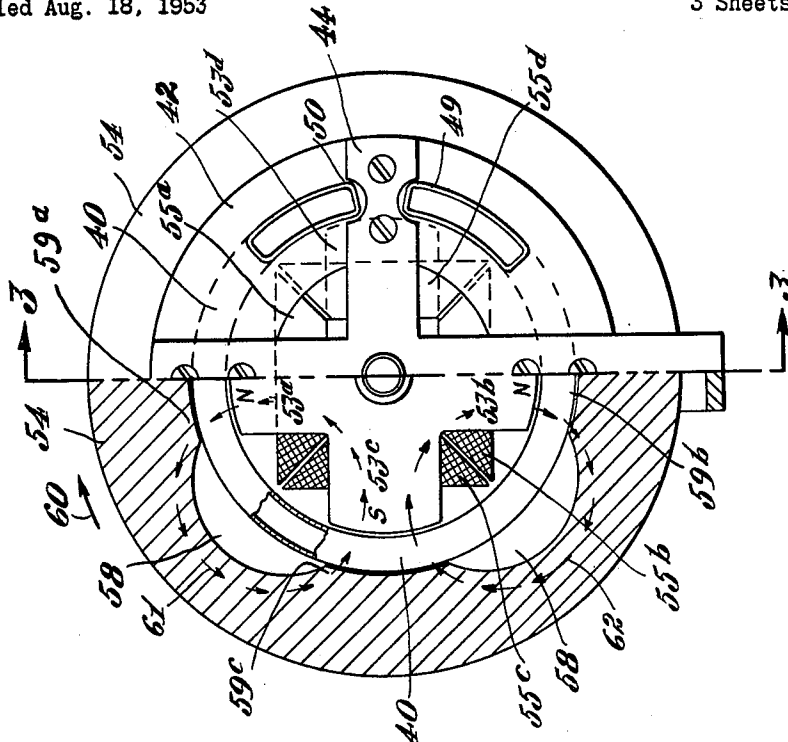


Fig. 4

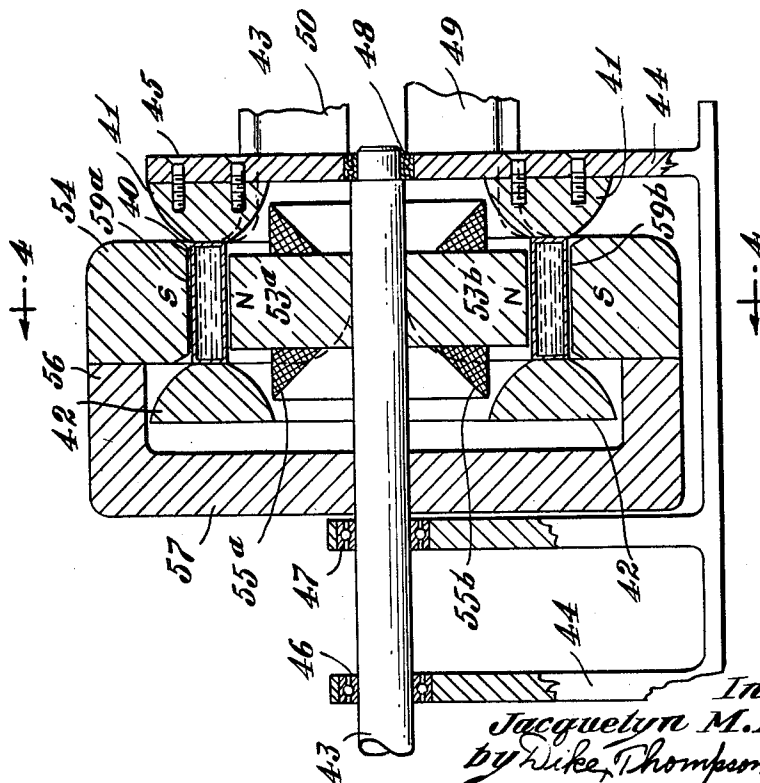


Fig. 3

Inventor
Jacqueton M. Findlay
By Mike Thompson & Sanford
Att'ys

Dec. 8, 1959

J. M. FINDLAY

2,915,973

APPARATUS FOR PUMPING LIQUID METAL

Filed Aug. 18, 1953

3 Sheets-Sheet 3

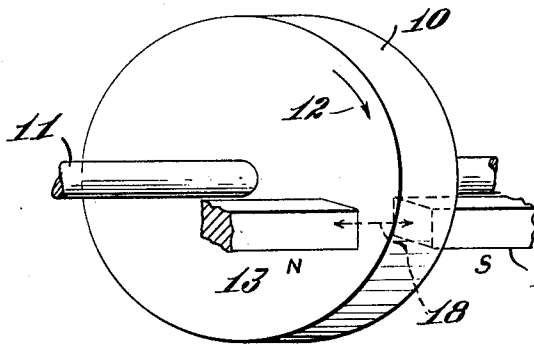


Fig. 5

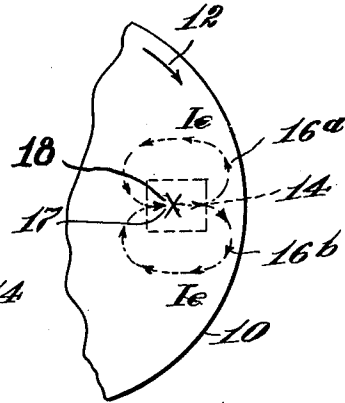


Fig. 6

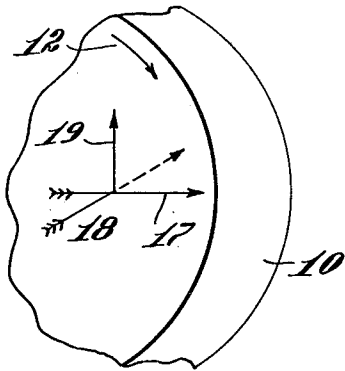


Fig. 7

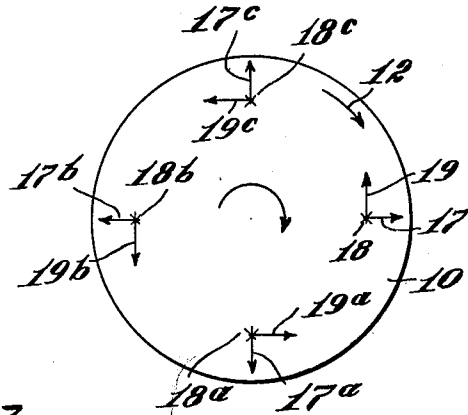


Fig. 8

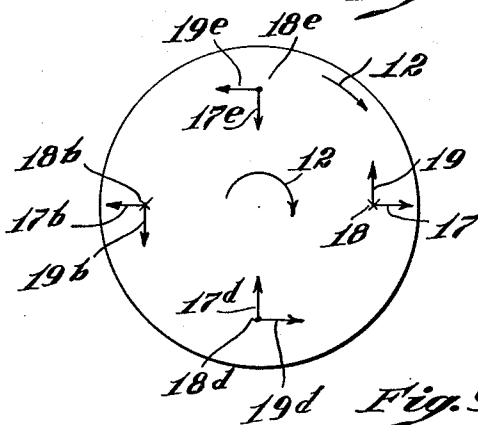


Fig. 9

Inventor
Jacquelyn M. Findlay
by Hike, Thompson & Sanborn
Atty's

1

2,915,973

APPARATUS FOR PUMPING LIQUID METAL

Jacquelyn M. Findlay, Bedford, Mass.

Application August 18, 1953, Serial No. 374,947

13 Claims. (Cl. 103—1)

The present invention relates to pumps, and more particularly it relates to an electro-magnetic type pump for pumping metals which are in a liquid state.

Most liquid metals are difficult and dangerous to handle because of the characteristics of some of them which are liquid at low temperatures and because some of the other metals must be raised to high temperatures before becoming liquid. In providing a pump for pumping liquid metals it is desirable that there be no moving parts in contact with the liquid metal as in conventional pumps so as to eliminate seals or stuffing boxes through which the liquid metal might leak. Therefore, it has been found that the safest and most practical pumps are of the electro-magnetic type in which electro-magnets outside a conduit are used to build up forces within the liquid metal in the conduit thereby to move the liquid metal through the conduit.

At present I believe that there are four types of electro-magnetic pumps, first the direct current or Faraday, second the alternating current conduction, third the alternating current polyphase conduction, and fourth the electro-magnetic centrifugal. These four types of electro-magnetic pumps have various well known disadvantages and considerable effort has been directed to the development of more practical and efficient liquid metal pumps for commercial operation.

For example, the Faraday pump requires a source of extremely high amperage at low voltage in order to produce reasonable pumping pressures at good flow rates. Thus, expensive direct current generators or rectifiers and large and costly bus bars for conducting the current to the pump are required. The result is an expensive and complicated installation having an overall efficiency considerably lower than that of the pump itself.

In the alternating current conduction pumps, high amperage circulating eddy currents are generated which makes the I^2R eddy loss extremely high. In addition it is usually necessary to use expensive condensers for the phase shift of the alternating current. These pumps are limited to applications involving small capacities and low heads where the initial cost must be kept to a minimum and where efficiency is not important.

In the alternating current polyphase conduction pumps, it is usually necessary to have a 10 or 20 cycle current to get optimum efficiency, but such current requires expensive frequency conversion equipment. However, the most serious defect with this pump is the problem of cooling the windings in the pump when the liquid metal being pumped is at a high temperature. Air must be blown over the windings to keep them cool, but since the windings are close to the liquid metal there is a great heat loss within the pump which greatly lowers its practical temperature of operation.

The fourth type of pump, the electro-magnetic centrifugal pump, is described in an article by Edward S. Brill, entitled "Developments of Special Pumps for Liquid Metal," appearing in Mechanical Engineering, volume 75, No. 5, pages 369 to 370. As described in that article,

2

this pump is a centrifugal pump in which the liquid metal is caused to rotate within a circular container with increasing speed until the liquid metal is pumped centrifugally outward through a conventional volute. As in the usual types of centrifugal pumps it is to be expected that this pump suffers from high hydraulic losses.

The present invention provides an electro-magnetic type liquid metal pump which is simple in construction, economical to manufacture, and which will pump liquid metals over a wide range of temperatures, pressures and flow rates and with greater efficiency than presently available in electro-magnetic pumps.

Two embodiments of a pump embodying the present invention are illustrated in the drawings. In addition the construction and operation of an eddy brake have been illustrated diagrammatically in certain figures of the drawings, because the pump of the present invention operates upon physical principles which are similar to the principle of operation of an eddy brake.

Further objects and advantages of the present invention will be apparent from the following description and accompanying drawings in which:

Fig. 1 is a perspective view of one embodiment of a pump of the present invention;

Fig. 2 is a vertical section along the line 2—2 of Fig. 1.

Fig. 3 is a longitudinal section through the center of a second embodiment of pump of the present invention taken on the line 3—3 of Fig. 4.

Fig. 4 is an end elevation of the pump shown in Fig. 3, looking at the pump from right to left of the position shown in Fig. 3, and with the left hand half shown in vertical section, taken on the line 4—4 of Fig. 3.

Fig. 5 is a perspective view illustrating an eddy brake schematically;

Fig. 6 is an enlarged side elevation of a portion of a disk of an eddy brake indicating the paths of the eddy currents induced by the motion of the disk through the flux between the magnetic poles;

Fig. 7 is a perspective view of a portion of the disk of an eddy brake in which the direction of the flux between the magnetic poles, the induced eddy current and the resultant force are illustrated;

Fig. 8 is a side elevation of the disk of an eddy brake showing the direction of the induced eddy currents and resultant forces when a plurality of pairs of magnetic poles are spaced around the disk with the poles of like polarity on the same side, and

Fig. 9 is a view similar to Fig. 8 but showing the direction of the induced eddy currents and resultant forces when alternate pairs of magnetic poles are reversed.

The embodiment of the pump of the present invention illustrated in Figs. 1 and 2 of the drawings comprises a conduit 20, electrical conductors 21 and 22 adjacent to opposite sides of the conduit, permanent magnets 23 and 24 spaced apart and located adjacent to the opposite sides of the conduit which extend between the electrical conductors. The conduit 20, which may be made of stainless steel, extends in a substantially arcuate path through the gap between the poles of the permanent magnets 23 and 24. The entrance portion 25 and exit portion 26 of the arcuate path of the conduit are spaced a relatively short distance apart.

The electrical conductor 21 is a solid ring of material of high electrical conductivity, such as copper. As shown, it is secured to the inside of the adjacent arcuate portion of the conduit, for example by a thin continuous film of high temperature, high electrical conductivity solder 21a, for example silver solder (Fig. 2). The other electrical conductor 22, also made of material with high electrical conductivity is secured to the outside of the adjacent arcuate portion of the conduit, for example by a thin continuous film of high temperature, high electrical conductivity

solder 22a. The conduit 20 and electrical conductors 21 and 22 are thus attached together and they are secured to the frame 28 by the bracket 29 which is attached to the frame and to the electrical conductor 22.

The magnets 23 and 24, which are spaced apart and arranged on opposite sides of the conduit 20, are permanent magnets with their poles adjacent to opposite sides of the conduit 20. The north pole 23a and south pole 23b of the magnet 23 are respectively opposite the south pole 24b and the north pole 24a of the magnet 24 so that flux, which is the magnetic lines of force, existing between the opposite magnetic poles passes through the conduit 20.

The magnets are secured to the shaft 30 which extends loosely through the passage at the center of the electrical conductor 21 and is journaled for rotation in the bearings 31 which are mounted in the frame 28. The shaft 30 is rotated continuously in the direction of the arrow 32 by any conventional means, such as an electric motor.

As shown the major portion of the arcuate path of the conduit 20 is substantially circular and the axis of the shaft 30 coincides with the center of said portion of the arcuate path of the conduit. Thus when the shaft is rotated, the poles of the magnets 23 and 24 are carried orbitally around the axis of the shaft and they are thus moved along the conduit adjacent to the sides of the arcuate portion thereof, the conduit being located in the gap between the poles.

In operation liquid metal from a supply (not shown) enters the entrance portion 25 of the arcuate path of the conduit and the movement of the poles of the magnets 23 and 24 along the conduit 20 creates forces which act on the liquid metal in the conduit and move the liquid metal through the conduit. Thus liquid metal is forced out through the exit portion 26 by the pressure of the liquid metal being moved through the arcuate portion of the conduit.

The creation of the forces which move the liquid metal through the conduit 20 will now be explained with reference to Figs. 5 to 9 which illustrate diagrammatically an eddy brake and its operation, the principle of which is similar to the principle of operation of the pump of the present invention. In Fig. 5 a disk 10 of material with high electrical conductivity, such as copper, is attached to the shaft 11 and is rotated in the direction of the arrow 12. Permanent magnets 13 and 14, the poles of which are north and south respectively, are located at opposite sides of the rotating disk 10, so that the rotating disk cuts the flux 18 which exists between the poles of the magnets 13 and 14.

Referring to Fig. 6, as the flux 18 is cut by the rotation of the disk 10, eddy currents I_e are produced in the disk. The eddy currents I_e move in the arcuate paths 16a and 16b in opposite directions about the flux and merge in a coincident path 17 which is normal to the flux 18 and in a radial direction relative to the axis of the disk 10.

In Fig. 7 the direction of the coincident path 17 of the eddy currents, which is the maximum intensity of the eddy currents, is shown and it is perpendicular to the flux 18. The flux 18 and the coincident path 17 of the induced eddy currents I_e produce a resultant force 19 which extends in the direction indicated. This force 19 is perpendicular both to the flux 18 and to the coincident path 17 of the eddy currents I_e and is opposite to the direction of movement of the disk 10; hence it tends to stop the rotating disk 10 and acts as a brake.

Fig. 8 illustrates the four coincident paths 17, 17a, 17b and 17c of eddy currents I_e and the resultant forces 19, 19a, 19b and 19c which are created when the rotating disk 10 cuts the flux 18 between four sets of magnetic poles located on opposite sides of the disk and spaced equal distances apart. In this instance all the poles of similar polarity are on the same side of the disk. The four coincident paths 17, 17a, 17b and 17c of the eddy

currents extend radially from the axis of rotation of the disk as indicated, and the resultant forces 19, 19a, 19b and 19c are all opposite to the direction of rotation of the disk.

Fig. 9 is like Fig. 8 except that two sets of magnetic poles, the ones at the top and bottom, are reversed so that of the four poles on each side of the disk two are north poles and two are south poles. As indicated by the coincident paths 17d and 17e of eddy currents I_e , reversing the magnetic poles reverses the direction of the coincident paths of the eddy currents created. However, this does not affect the direction of the resultant forces 19d and 19e which remain opposite to the direction of rotation of the disk as indicated.

Therefore it makes no difference on which side of the disk 10 a pole of particular polarity is located. As long as the flux passes through the disk, to be cut by the rotation of the disk and the disk is of material with high electrical conductivity, eddy currents I_e are induced and a resultant force which opposes motion of the disk is created.

The pump of the present invention operates on the same principle of operation as the eddy brake. However, in the pump of Figs. 1 and 2 it is the magnets 23 and 24 which are rotated and the flux between their poles thus moves relative to the conduit 20 and the electrical conductors 21 and 22 which are equivalent to the disk 10 of an eddy brake. The pump of Figs. 1 and 2 thus amounts to forming an arcuate conduit in the disk 10 of the eddy brake of Fig. 8 or 9 and rotating the magnets instead of the disk 10, the conduit being located between the poles of the magnets.

Referring to Fig. 2, the movement of the magnet 23 and 24 (in the direction of the arrow 32) causes the flux between their poles to be cut by movement relative to the conduit 20 and to the electrical conductors 21 and 22. Three main eddy currents are induced as indicated at 34, 35 and 36, and the interaction of the flux and these eddy currents produces resultant forces 37 acting on the liquid metal within the conduit 20. Since it is the magnets which rotate, the resultant forces 37 are in the same direction as the movement of the magnets, as indicated because, the motion of the magnets relative to the conduit 20 and the electrical conductors 21 and 22 is in the opposite direction to what it would be if the magnets were stationary and the conduit and electrical conductors were rotated as was the disk of the eddy brake.

Spaces 38 and 39 are provided between the poles of the magnets 23 and 24 at each side of the conduit 20. These spaces are larger than the gap between the opposed poles 23a and 24b and 23b and 24a of the magnets 23 and 24, so that the flux which passes between the closest poles of opposite polarity will pass through the conduit 20 between the opposed poles on opposite sides.

It will be appreciated that any desired number of pairs of magnetic poles may be used and that they may be of either the permanent magnetic type or the direct current electromagnetic type. Also, the magnetic poles at a given side of the conduit may all be of the same polarity. However, for the effective creation of an eddy current necessary for the operation of the pump, there should be portions of the conduit 20 which are at some instant free of flux in order for the eddy current to make a complete path through the conduit between the magnetic poles into one electrical conductor, back through the conduit, and returning through the other electrical conductor to its starting point. Otherwise the flux while tending to create eddy currents will prevent their creation by preventing their return through the conduit in the opposite direction which would occur if there were flux in the same direction traversing the entire arcuate portion of the conduit. The conduit is illustrated as being rectangular in cross-section, but this is not a limiting configuration, and the word "sides" as used herein is used in a

broad sense and will embrace non-planar boundaries or borders of the conduit.

The forces 37 acting on liquid metal in the conduit 20 try to move it through the conduit at the same speed at which the magnets 23 and 24 move. However, if the liquid metal could move as fast as the magnets, there would be no relative motion between the flux transversely through the liquid metal and the liquid metal. As a result no eddy currents and no resultant forces 37 would be produced to continue to move the liquid metal and the above described operation of the pump would cease until the movement of the liquid metal was retarded below the speed of movement of the magnets. This situation does not arise, however, due to slippage of the liquid metal. This slippage or difference in speed of movement of the liquid metal in the conduit and the magnets is due to resistance to the flow of liquid metal through the conduit. This resistance is caused by a combination of hydraulic losses as the liquid metal flows and the external resistance or pressure head against which the liquid metal is being pumped. Therefore, eddy currents are continuously created and pressure developed in the liquid metal by the operation of the forces 37.

In addition to hydraulic losses there are also losses associated with the eddy currents that circulate through the wall of the conduit. Consequently, the material forming the walls of the conduit should preferably be of high electrical resistivity material or be kept thin to produce optimum efficiency. Moreover, optimum efficiency is obtained when the proportioning of the pump is such that the slip of the liquid metal in the conduit is small for the desired head and flow rates. Furthermore, the electrical resistance around the eddy currents should be kept as small as possible by making the elements through which the paths of the eddy currents travel of relatively large cross section and of material having good electrical conductivity. It is for this reason that the electrical conductors 21 and 22, which are of material which has high electrical conductivity, are also solid and of relatively large cross section.

The pressure that is developed in the liquid metal in the conduit at each eddy current is equal to

$$\frac{8.85Ble \times 10^{-8}}{d}$$

where pressure is in pounds per square inch; the density of the flux B in the gap between the magnetic poles is in lines per square inch; the eddy current I_e is in amps.; and d , the width of the conduit between the magnetic poles is in inches. The current developed in the eddy is proportional to the density of the flux in the gap between the magnetic poles 23a and 24b and 23b and 24a; consequently for optimum efficiency the density of the flux should be as high as it is possible to provide.

A second embodiment of the pump of the present invention is shown in Figs. 3 and 4. This embodiment is preferred for industrial size units, for example of 3,000 gallons per minute capacity at 30 pounds per square inch pressure head, whereas the first embodiment is preferred for laboratory scale uses. In this embodiment the conduit 40 is attached between two electrical conductors 41 and 42 which are solid rings of material with high electrical conductivity, such as copper. The conduit and electrical conductors are fixed in position concentric to the shaft 43 by securing the electrical conductor 41 to the frame 44 by the screws 45. The shaft 43 is rotated by any well known means such as an electric motor and is journaled in the frame 44 by the bearings 46, 47 and 48. The conduit 40 is formed in an arcuate path having its entrance 49 and its exit 50 spaced a relatively short distance apart and which extend outwardly from the arcuate portion of the conduit. The entrance 49 and exit 50 extend outside the pump through passages formed in the electrical conductor 41 and the frame 44 of the pump. A direct current electro-magnet is secured on the shaft

43 so as to be rotated thereby and is located adjacent to the conduit and within its arcuate portion. As shown in Fig. 4, electromagnetic means in the form of a cross provides four arms, each of which is a pole of a magnet, the two arms 53a and 53b being north poles and the other two arms 53c and 53d being south poles. Electro-magnetic forces are built up in the four poles 53a, 53b, 53c and 53d by the respective windings 55a, 55b, 55c and 55d which are connected to any suitable sources of direct current (not shown). Surrounding the outside of the arcuate portion of the conduit 40 and concentric with the axis of the shaft 43 is a ring 54 of magnetizable material such as soft iron which is supported for rotation with the shaft 43 by being connected to the inwardly extending edge 56 of the generally dish-shaped circular supporting member 57 which is attached to the shaft 43. The inside diameter of the ring 54 is undercut at four intervals 58 to provide four projections 59a, 59b, 59c and 59d (59d is opposite 59c) with their ends adjacent to the conduit 40. These four projections are spaced apart and located respectively opposite the electro-magnetic poles 53a, 53b, 53c and 53d. When energized the poles of the electro-magnets 53a, 53b, 53c and 53d magnetize the projections 59a, 59b, 59c and 59d by induction and these projections thus become magnetic poles of opposing polarity to the electrically energized poles 53a, 53b, 53c and 53d respectively. In the claims the expression "magnetic pole" includes magnetizable material such as one of these projections magnetized by an electro-magnet spaced therefrom.

As the poles (53a, 53b, 53c, 53d and 59a, 59b, 59c and 59d) are rotated in the direction of the arrow 60, the magnetic lines of force indicated by the arrows 61 and 62 are cut by the motion of the poles relative to the conduit 40 and liquid metal therein. Eddy currents thereby induced circulate transversely through the conduit 40 and into the electrical conductors 41 and 42 so that resultant forces are built up and act on the liquid metal in the conduit in the desired direction of flow and move the liquid metal through the conduit.

From the foregoing it will be apparent to persons skilled in the art that this invention provides a novel and efficient electro-magnetic liquid metal pump which is simple in construction, economical to manufacture, which will pump metals over a wide range of temperatures, pressures and flow rates and with greater efficiencies than electro-magnetic pumps heretofore available.

It will be understood that the above description is of two preferred embodiments of the present invention and that various changes may be made without departing from the spirit thereof.

I claim:

1. Apparatus for pumping electrical conductive fluid comprising a tubular conduit for conducting said fluid from an entrance to an exit position, electrical conductor means extending lengthwise along oppositely-disposed sides of said conduit in electrical connection with said fluid between said entrance and said exit positions, magnetic pole means including at least one pair of spaced magnetic poles producing at least one discrete magnetic field therebetween adjoining substantially field-free regions, means mounting said magnet pole means to direct said flux field through said fluid between and substantially parallel with said oppositely-disposed sides of said conduit, said magnetic poles encompassing a distance lengthwise along said conduit and producing said uni-directional flux field for a distance lengthwise along said conduit which are less than the distance which said conductor means extend along said conduit, and means operatively connected to said mounting means for mechanically moving said magnetic pole means along said conduit in one direction lengthwise of said conduit, whereby said conductor means circulate the currents generated in said fluid through said substantially field-free regions and through paths of interaction with said flux field wherein propulsive forces are produced on said fluid substantially

in one direction alone from said entrance to said exit.

2. The combination of claim 1 wherein said magnetic pole means comprises a plurality of magnet poles disposed along each of two oppositely-disposed sides of said conduit transverse to said first-named sides with adjacent poles on each of said second-named sides in spaced relationship, said adjacent poles being of opposite polarity, and wherein said magnetic pole means produces a plurality of spaced magnetic flux fields separated by said substantially field-free regions, each of said magnet poles and the spacing to an adjacent magnet pole encompassing a total distance lengthwise along said conduit which is less than the distance which said conductor means extend along said conduit.

3. The combination of claim 1 wherein said magnetic pole means comprises an electromagnet winding energized by unidirectional current and wherein said magnet poles are magnetized by said electromagnet winding.

4. The combination of claim 1 wherein said conduit includes side walls extending intermediate said oppositely-disposed sides of said conduit and which are of high electrical resistance in relation to the electrical resistance of said conductor means, and wherein said means for mechanically moving said magnet pole means moves said magnetic pole means adjacent said side walls of high electrical resistance.

5. Apparatus for pumping electrically conductive fluid comprising a tubular conduit for conducting said fluid, electrical conductor means extending lengthwise along first oppositely-disposed sides of said conduit in electrical connection with said fluid from a conduit entrance to a conduit exit, at least one pair of opposed magnet poles of opposite polarity producing a discrete unvarying unidirectional magnetic flux field adjoining substantially field-free regions and disposed on second oppositely-disposed sides of said conduit transverse to said first sides to direct said field through said fluid between said first sides of said conduit, said magnetic poles each encompassing a distance lengthwise along said conduit which is less than the distance which said conductor means extend along said conduit, and means mechanically moving said magnet poles along said conduit in one direction lengthwise of said conduit to move said discrete unvarying flux field along said conduit in said one direction, whereby said conductor means circulate the currents generated in said fluid through said substantially field-free regions and through paths of interaction with said field wherein propulsive forces are produced on said fluid substantially in said one direction alone.

6. Apparatus for pumping electrically conductive fluid comprising a tubular conduit extending in an arcuate path lengthwise from a fluid entrance to a fluid exit, electrically conductive material extending lengthwise along oppositely-disposed sides of said conduit in electrical connection with said fluid in said conduit, rotatable magnet pole means including at least one pair of spaced oppositely disposed magnet poles producing at least one discrete unidirectional magnetic flux field adjoining substantially field-free regions and along an arcuate path corresponding in shape to said conduit path, said magnet pole means encompassing an arcuate distance and producing said discrete field for a distance less than the distance which said conductive material extends along said conduit, means mounting said magnet pole means to direct said flux field through said fluid between and substantially parallel with said oppositely-disposed sides of said conduit, and motive means operatively connected to said mounting means for rotating said magnet pole means in one direction, whereby said conductive material circulates the currents generated in said fluid through said substantially field-free regions and through paths of interaction with said flux wherein propulsive forces are produced on said fluid substantially in said one direction alone.

7. Apparatus for pumping electrically conductive fluid

comprising a tubular conduit extending in a path arcuately about an axis from a fluid entrance to a fluid exit, arcuate electrical conductors extending lengthwise along oppositely-disposed sides of said conduit in electrical connection with said fluid in said conduit, a plurality of pairs of oppositely disposed magnet poles angularly spaced about said axis and producing unidirectional magnetic flux along a plurality of discrete angularly-spaced arcuate flux paths each corresponding in shape to said conduit path and each angularly adjoining substantially field-free regions, said magnet poles each encompassing an arcuate distance and each producing flux along one of said paths for an arcuate distance less than the distance which said conductors extend along said conduit, means mounting said magnet poles to direct said flux through said fluid between and substantially parallel with said conductors, and motive means operatively connected with said mounting means for rotating said magnet poles in one direction about said axis, said magnet poles and flux paths being angularly spaced by amounts permitting currents generated in said fluid to circulate from said conductors in return paths through said fluid in said regions which are substantially free of said flux, whereby propulsive forces on said fluid are produced substantially in said one direction alone.

8. Apparatus for pumping electrically conductive fluid comprising a tubular conduit extending in a path arcuately about an axis from a fluid entrance to a fluid exit, arcuate electrical conductors extending lengthwise along oppositely-disposed sides of said conduit in electrical connection with said fluid in said conduit, a plurality of pairs of oppositely disposed magnet poles rotatable and angularly spaced about said axis and producing unidirectional magnetic flux along a plurality of discrete angularly-spaced arcuate flux paths each corresponding in shape to said conduit path and each angularly adjoining substantially field-free regions, said magnet poles each encompassing an arcuate distance and each producing flux along one of said paths for an arcuate distance less than the distance which said conductors extend along said conduit, angularly adjacent ones of said magnet poles being of different polarity, means mounting said magnet poles to direct said flux through said fluid between and substantially parallel with said oppositely-disposed sides, means operatively connected to said mounting means for rotating said magnet poles in one angular direction about said axis with said flux disposed to intercept said fluid in space between said conductors, whereby currents generated in said fluid by flux in any one of said flux paths circulate from said conductors through return paths through said fluid in said substantially field-free regions and produce propulsive forces on said fluid substantially in said one angular direction alone.

9. Apparatus for pumping electrically conductive fluid comprising a tubular conduit extending in a path arcuately about an axis from a fluid entrance to a fluid exit, arcuate electrical conductors extending lengthwise along first oppositely-disposed sides of said conduit in electrical connection with said fluid in said conduit, first and second magnetic members rotatable about said axis and each having a plurality of discrete magnetized magnet poles extending in angularly spaced relationship therefrom, angularly adjacent ones of said magnet poles of each of said members being of different polarity and being angularly spaced to have angularly adjoining substantially field-free regions, means mounting said magnet members for rotation together about said axis with magnet poles of opposite polarity disposed opposite one another on second oppositely-disposed sides of said conduit transverse to said first sides with a predetermined spacing therebetween and directing magnetic flux in discrete angularly-spaced fields through portions of said conduit intermediate said conductors, said magnet poles each encompassing an arcuate distance and producing said discrete flux fields along arcuate distances less than the distance

which said conductors extend along said conduit, and means operatively connected to said mounting means for rotating said magnetic members about said axis, said predetermined spacing between opposite magnet poles being less than the angular spacing between magnet poles, whereby currents generated in said fluid by any one of said flux fields circulate from said conductors through return paths through said fluid in said substantially field-free regions and produce propulsive forces on said fluid substantially in one direction alone.

10. The combination of claim 9 wherein each of said magnet poles and the angular spacing between two adjacent poles encompasses a total arcuate distance less than the distance which said conductors extend along said conduit.

11. The combination of claim 9 wherein said first magnetic member orients said magnet poles thereof for rotation concentrically inside said arcuate path of said conduit, wherein said second magnetic member orients said magnetic poles thereof for rotation concentrically outside said arcuate path of said conduit, and wherein said arcuate conductors are substantially parallel in spaced axial relationship along said axis.

12. The combination of claim 9 wherein one of said conductors extends concentrically along the inside arcuate portion of said conduit and the other of said conductors extends concentrically along the outside arcuate portion of said conduit, and wherein said magnetic members each orient the magnet poles thereof for rotation about said axis along said second oppositely-disposed sides of said conduit.

13. The combination of claim 9 wherein said conduit is of substantially rectangular cross-section and is in the form of an arc of a circle with said fluid entrance and fluid exit closely adjacent to each other, wherein said conductors extend along said conduit over substantially the full width of said first sides, wherein said second

sides comprise walls of said conduit between said conductors which are of high electrical resistance in relation to the electrical resistance of said conductors, and wherein said magnet poles are disposed for movement adjacent said conduit walls of said high electrical resistance.

References Cited in the file of this patent

UNITED STATES PATENTS

	443,044	Finney	Dec. 16, 1890
10	889,589	Donnell	June 2, 1908
	1,071,847	Wilson	Sept. 2, 1913
	1,298,664	Chubb	Apr. 1, 1919
	1,307,210	Newcomb	June 17, 1919
	1,448,712	Pool	Mar. 13, 1923
15	1,646,989	Blecker	Oct. 25, 1927
	1,660,407	Bainbridge	Feb. 28, 1928
	2,099,593	Bender et al.	Nov. 16, 1937
	2,651,258	Pierce	Sept. 8, 1953
	2,652,778	Crever	Sept. 22, 1953
20	2,658,452	Donelian	Nov. 10, 1953

FOREIGN PATENTS

	126,947	Great Britain	Dec. 24, 1919
	661,756	Great Britain	Nov. 28, 1951

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.