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June 20, 1961 H. G. ELROD, JR 2,988,997

ELECTROMAGNETIC PUMP

Filed March 22, 1955 3 Sheets-Sheet 1

FIG. 1

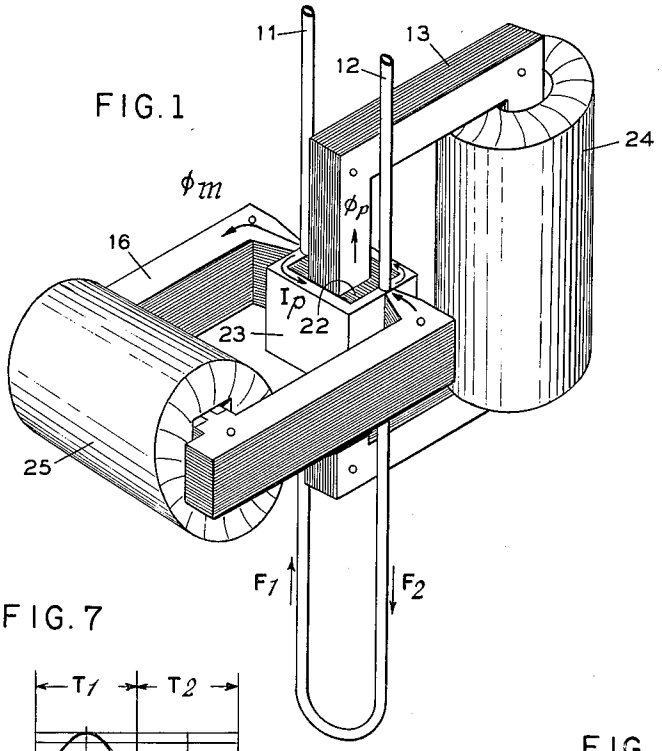



FIG. 7

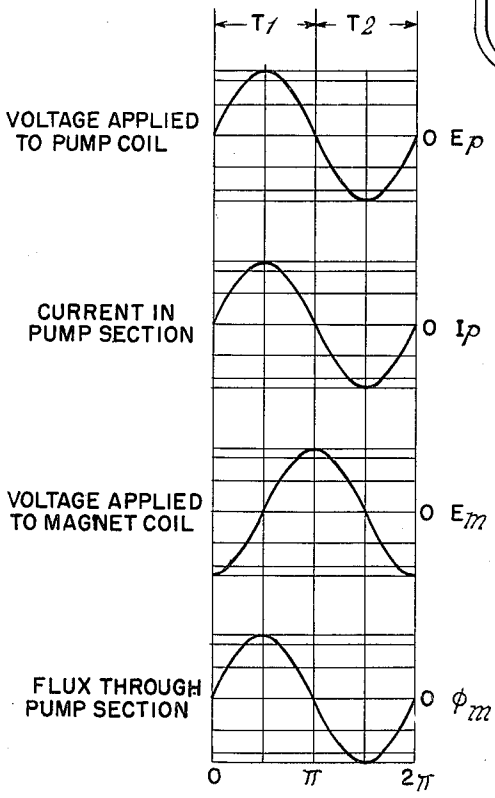
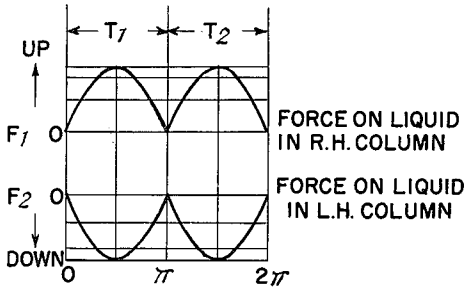



FIG. 8




$\phi m$ AND Ip AS SHOWN DURING TIME T1, AND IN OPPOSITE DIRECTION DURING TIME T2

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ELECTROMAGNETIC PUMP

Filed March 22, 1955 3 Sheets-Sheet 2

FIG. 2

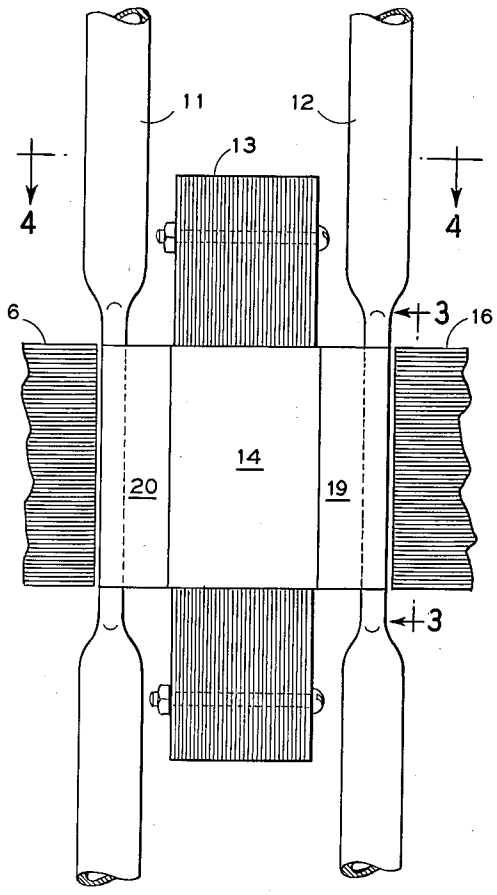



FIG. 3

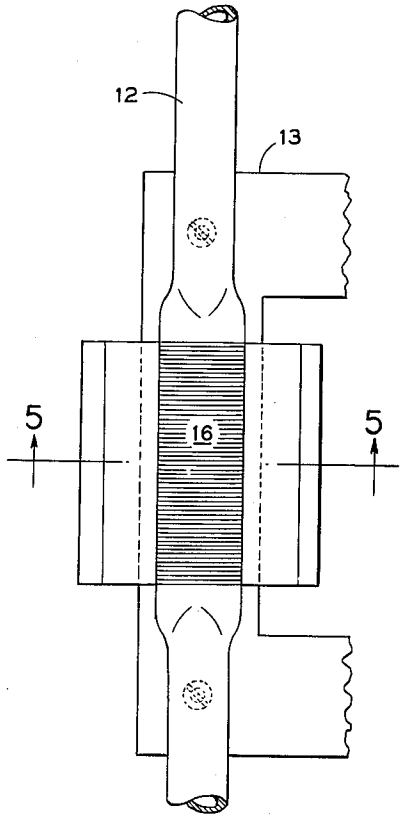



FIG. 4

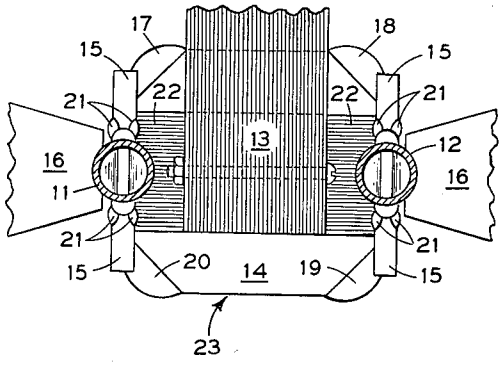
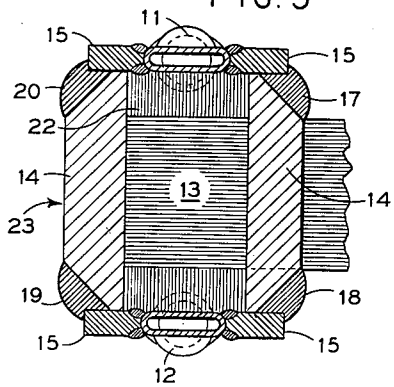



FIG. 5

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ELECTROMAGNETIC PUMP

Filed March 22, 1955 3 Sheets-Sheet 3

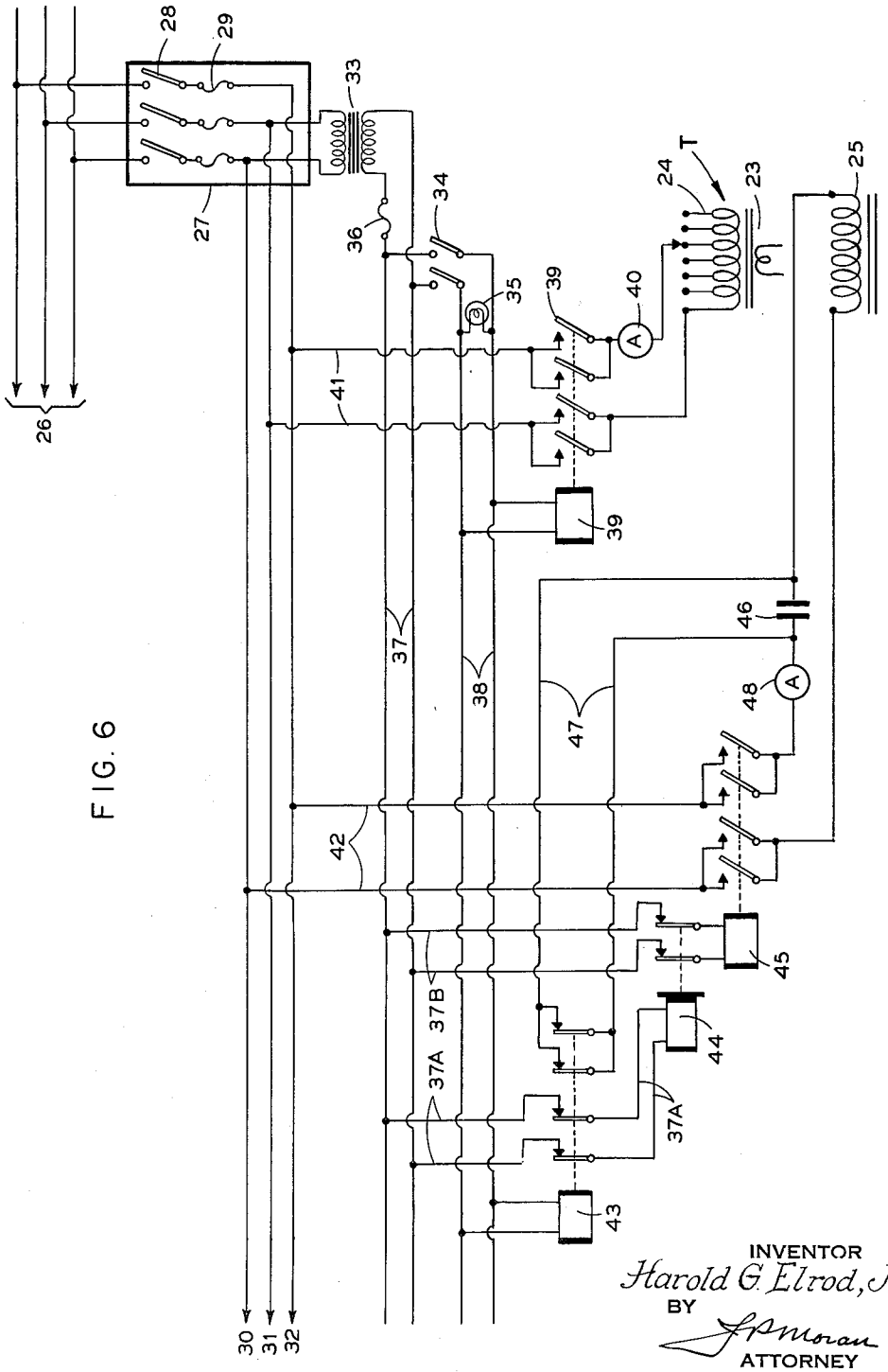


FIG. 6

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United States Patent Office 2,988,997 Patented June 20, 1961



2,988,997

# ELECTROMAGNETIC PUMP

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Filed Mar. 22, 1955, Ser. No. 496,006
8 Claims. (Cl. 103—1)

The present invention relates to an improved construction of an electromagnetic pump of the type in which an electrically conducting fluid is forced to flow through a conduit by the reaction on an electrically conducting fluid resulting from the presence of an applied magnetic field in accordance with the standard right-hand rule on the physics of electricity.

In recent years there has developed a need for an electromagnetic pump which could be operated at high temperatures. A high temperature, as used herein, is defined as a temperature which, for a particular type of metal of construction, reduces the probability of maintaining the mechanical and electrical integrity of the pump construction. For example, ordinary carbon steel when exposed to temperatures above 850° F. in an oxidizing atmosphere, will corrode to such extent that the thickness of metal will be reduced to an unsafe value in a relatively short time. In addition, the allowable stress of the steel at these high temperatures, is so low that the metal thickness required to carry any given load would be impracticably great. Another example is the AISI 300 series stainless steels and most of these alloys oxidize rapidly at temperatures above 1600° F. while their allowable stresses are quite low at temperatures above 1200° F. Materials such as copper will be subject to serious oxidation at temperatures above 600° F.

From the electrical standpoint, high temperature pumps create an insulation problem in that the temperature range of 300° to 500° F. causes serious deterioration of many electrical insulations. The prior art arrangements of insulated electrical conductors expose the conductors to serious insulation failure when the pump is operating with the fluid at a temperature beyond that which the insulation can stand.

The efficiency of electromagnetic pumps has been very low, primarily because of the large electrical losses attendant upon the constructional features of the pumps. Magnetic core losses have been high due to extended core lengths. Magnetic flux reductions caused by large air gaps have been common with pumps of this type. Other losses such as those due to induction effects and magnetic field interaction have been prevalent.

An object of this invention is to produce an electromagnetic pump arrangement which is particularly adapted to more advantageous use of construction materials so as to obtain a pump which can operate at a high temperature. This object is obtained by utilizing a pump current transformer which causes current to flow through the pumped electrically conducting fluid, which fluid is part of the transformer secondary winding. Further, a magnetic field producing means is so disposed that its field causes a reaction on the pump fluid in the well-known manner of an electric motor. In the accomplishment of this object, the core of the transformer is used as the magnetic conducting path of the exciting magnet and also as the magnetic conducting path of the transformer.

For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter in which there is illustrated and described a preferred embodiment of my invention.

Of the drawings:

FIG. 1 is an isometric view showing a preferred embodiment of the pump construction;



FIG. 2 is a vertical, sectional view of the pump, showing the pumping conduits and the single turn transformer secondary;

FIG. 3 is a vertical sectional view of the pumping section, taken on the line 3—3 of FIG. 2;

FIG. 4 is a horizontal sectional view of the pumping section, taken on the line 4—4 of FIG. 2;

FIG. 5 is a horizontal sectional view taken on the line 5—5 of FIG. 3;

FIG. 6 is a schematic wiring diagram of the power supply and control circuits for the pump;

FIG. 7 is a group of curves showing the instantaneous relations of voltages, current, and magnetic flux occurring in the operation of the pump, plotted against time; and

FIG. 8 is a set of two curves illustrating the pumping forces plotted against time.

In FIG. 1 a return bend conduit having connected conduit sections **11** and **12** carry the electrically conducting fluid which is to be pumped and may be conveniently connected to any flow system. The conduit sections **11** and **12** form part of a single turn secondary winding **23** of a transformer T. The transformer T is composed of a closed transformer magnetic core **13**, a primary winding **24** disposed on one leg of the core **13** and the single turn secondary winding **23**. The primary winding **24** may be energized by connection to one phase of a polyphase power source to generate an alternating magnetic flux in the core **13**. This flux induces a current flow in the single turn secondary **23**, with the current flowing across the conduits **11** and **12** as indicated by the arrow $I_p$.

A magnetic field is imposed across the conduit sections **11** and **12** by an electromagnetic exciting means which consists of a C-shaped magnetic core **16**, which has its pole-pieces placed adjacent and encompassing sections **11, 12**, and a magnetic exciting coil **25** disposed on one leg or at the bight of the C-shaped core **16**. The magnetic exciting core **25** may be connected to a second phase of the polyphase source.

FIGS. 2, 3, 4 and 5 more particularly show the construction of the single turn secondary winding **23**, the arrangement of the transformer core **13**, and the magnetic exciting core **16**. The single turn secondary winding **23** is composed of heavy metal shorting bars **14**, tube shorting bars **15**, and the flow conduit sections **11** and **12**, all of which are joined by weld deposits **17, 18, 19, 20** and **21**. Thus there is formed a single turn secondary winding, of large cross sectional area, and which includes the flow conduit sections **11** and **12**.

The pole faces of the C-shaped magnetic exciter core **16** are disposed adjacent, but in spaced relationship, to the flow sections **11** and **12** in such a manner that there is a magnetic field across the fluid sections which is substantially perpendicular to the longitudinal axes of the sections. Passing through the single turn secondary **23** is the core **13** of the transformer T, which is so constructed as to have a magnetic shunt **22** which, in conjunction with the core **13**, completely fills the internal volume of the single turn secondary **23**. The cooperative association of the magnetic shunt **22** and the transformer core **13** acts to maintain a high flux density inside the single turn secondary coil **23**, whereby the maximum magnetic force is available to induce a current flow in the secondary. This association also provides a means for obtaining a maximum magnetic field strength for the magnetic exciter means.

The flow conduit sections **11** and **12** are preferably flattened into a long oval shape, as depicted in FIG. **5** where they are part of the single turn secondary. This flattening allows the pole pieces of the exciter core to be placed adjacent the conduits **11** and **12** with a minimum

of air gap. The flattening of the sections 11 and 12 also allows the secondary single turn 23 to be completely filled by the transformer core 13 and the magnetic shunt 22, whereby the air gap of the magnetic field is maintained at a minimum. The transformer core 13 and exciter core 16 are laminated as is well known in the art.

Referring to FIG. 6 power is supplied to the primary winding 24 of the pump transformer T and to the magnet coil 25 from a three-phase line comprising conductors 30, 31 and 32 which are selectively connectible to three-phase A.C. supply main 26 through the medium of a three-pole switch 28 mounted on a panel 27, fuses 29 being supplied for protective purposes. A transformer 33, having its primary winding connected across one phase of the supply line, is used to supply control or operating potential for the pump controls. The secondary winding of transformer 33 supplies control potential to a pair of conductors 37, and control potential may be applied to a second pair of conductors 38 by means of a double pole switch 34 selectively operable to connect conductors 38 to conductors 37. A pilot lamp 35 is connected across conductor 38 and energized whenever switches 28 and 34 are closed.

The control system includes relays 39, 43, 44 and 45. Relay 39 has its operating coil energized from conductors 38 and is a normally open relay arranged, when energized, to have its armatures connect the primary winding 24 of the pump transformer to a second phase of the supply conductors 31 and 32. As shown, relay 39 is arranged to connect winding 24 across conductors 31 and 32, and an ammeter 40 is connected in series between the relay and the transformer winding 24.

Relay 43 is a normally closed relay, also energized from conductors 38. In its normally cloesd position, relay 43 connects the operating coil of a normally closed time delay relay 44 to conductors 37 through the medium of conductors 37A.

Relay 44 controls the connection of the operating coil of a normally open relay 45 to conductors 37, the energizing conductors for relay 45 being conductors 37B. Normally open relay 45 is arranged, when energized to close its contacts, to connect magnet coil 25 across conductors 30 and 32 through the medium of conductors 42. For a purpose to be described, there is included a phase shifting means comprising a condenser 46 connected in series with coil 25, and arranged to be shunted by means of conductors 47 there are in turn arranged to be connected together or shorted by the contacts of relay 43. An ammeter 48 is connected in series with winding 25.

To place the pump in operation, switch 28 is closed, thus applying three-phase alternating power to conductors 30, 31 and 32, and single phase A.C. power to transformer 33, to energize conductors 37. Relay 44 is thus energized through conductors 37A and the normally closed contacts of relay 43. However, as relay 44 is a time delay relay, it does not immediately open its contacts so that relay 45 is also energized to close its contacts and thus energize magnet coil 25.

After a time delay sufficient for saturation of the magnetic core 16, relay 44 opens, thus de-energizing coil 25. As relay 39 has not yet been energized, the pump transformer T remains de-energized.

When switch 34 is closed, conductors 38 are energized. This picks up relay 39, which closes its contacts to energize primary winding 24 of the pump transformer. Relay 43 is picked up or energized to open its contacts, which operation effects de-energization of time delay relay 44 and opens the shunt circuit around condenser 46. Time delay relay 44 closes its contacts, thereby effecting energization of relay 45 to again energize the magnet winding 25. Both the pump transformer coils 23, 24 and the magnet coil 25 are now energized. Condenser 46, being now effectively in series with coil 25, counteracts the reactance of this coil and tunes the energizing circuit of coil 25 to be substantially a series resonant circuit.

To stop the operation of the pump, switch 34 is first opened, removing power from conductors 38. Relay 43 drops, closing its contacts to energize time delay relay 44 and to shunt condenser 46. The pump transformer coils 23, 24 are also de-energized by virtue of the dropping of relay 39 so that the latter opens its contacts. After the preset time delay, time delay relay 44 opens its contacts, breaking the energizing circuit for relay 45. The latter then opens its contacts to de-energize magnet coil 25.

Main control switch 28 is now opened, removing power from three-phase lines 30, 31 and 32, and de-energizing control transformer 33 to de-energize conductors 37. Time delay relay 44 is thus de-energized, reclosing its contacts.

It can be seen from the operating description above that the relay system, in conjunction with the condenser shunt, allows the magnetic coil to be de-energized in a sequential series of steps which first discharges the high voltages of the condenser 46 and then disconnects the power supply from the magnetic exciter coil 25. This eliminates danger of arcing at the control switch when the latter is opened. The condenser 46 is placed in the magnetic exciter power circuit to permit a reasonable high flow of current while using a moderate voltage, thus offsetting the high inductive loading.

The operation of the electromagnetic pump of this invention can be best understood by reference to FIGS. 7 and 8 wherein there is shown in curve form the relationships of the various voltages, currents, magnetic fluxes, and pumping forces when plotted against time. As can be seen from the foregoing description, all power applied to any particular part of the pump is single phase alternating current. The magnitude of the voltage $E_p$ is shown plotted against the times $T_1$ and $T_2$ and, because the voltage wave is a sine wave, it may be plotted as in terms of $\pi$ for each time period. In FIG. 1, the arrows show the direction of the various electrical and magnetic flows during the period $T_1$.

When a voltage is applied to the primary coil 24 of the pump section, a current $I_p$ is induced in the single turn secondary 23 and is in phase with the voltage $E_p$ applied to the pump coil 24. Due to the unique construction of the single turn secondary 23 current flows partially through the wall of the conduit sections 11, 12, but mostly through the electrically conducting fluid in a direction substantially perpendicular to the longitudinal axes of the flow conduit sections. A voltage $E_m$ is applied to the magnetic exciter coil 25 from a different phase of the three phase power supply shown in FIG. 6. By the tuning of the phase shifting means in the power supply circuit of the magnetic exciter coil 25, the resultant reactance, i.e. the cooperative or total effect of the capacity reactance and the inductive reactance of the circuit can be varied so that the phase of the voltage $E_m$ is displaced so as to be 90° out of phase with the voltage $E_p$ applied to the pump coil. The phase displacement of 90°, instead of the 120° which would normally occur with a three-phase supply, causes a flux $\Phi_m$ to be generated in the exciter core 16 which is substantially in phase with the current $I_p$ in the single turn secondary 23. Due to the well-known physical reaction, whereby a current carrying conductor exposed to a magnetic field is repulsed therefrom, the electrically conducting fluid inside the conduits 11, 12 is forced out of the magnetic field imposed across the conduits. The forces effecting this displacement are shown in FIG. 8, whereby the force $F_1$ is up and the force $F_2$ is down. Thus, there is created a push-pull pumping action on the electrically conducting fluid and, by virtue of the U-loop connecting conduit 11 and conduit 12, the forces $F_1$ and $F_2$ are additive. During the time period $T_2$, the direction of the exciting flux and the current in the single turn secondary 23 reverses, thus giving the forces $F_1$ and $F_2$, by operation of the physics right-hand rule, the same direction as during the time period $T_1$.

The relative phase displacement of the voltage applied to the magnetic exciter coil **25** results in the exciting flux $\Phi_m$ being in phase with the pump current in the single turn secondary $I_p$ and also allows the magnetic shunt **22**, in cooperation with transformer core **13**, to be effective in maintaining the exciting magnetic field at its maximum without interference with the transformer magnetic flux. This occurs because the flux in the transformer core **13** is at zero at angular position

$$\frac{\pi}{2}$$

whereas the flux $\Phi_m$ due to the exciter magnetic coil **25**, is then at its maximum.

The invention as described herein provides constructions which makes the electromagnetic pump a more desirable high temperature pump. The single turn secondary transformer winding which is integrally associated with the flow conduits provides a low resistance current flow path of large cross section and small length. Every possible means was utilized, such as welding the shorting bars to the conduits to reduce the electrical resistance of the single turn secondary wiring in order that high temperature materials may be used. This construction makes the most effective use of any type of diamagnetic metals. This would allow copper for intermediate temperatures and austenitic steels for high temperatures. This feature of the invention is particularly useful when pumping electrically conducting fluids at temperatures in the order of 1600° F. because of this effective use of the known high temperature metals.

Another feature of the invention is the phase displacement means which provides that an exciting magnetic flux across the conduits and the secondary current flow are both at a maximum simultaneously, thereby giving a maximum pumping effectiveness.

A further feature of the pump is that magnetic field interaction is a minimum because the axis of the transformer secondary is perpendicular to the applied magnetic field. Thus the secondary surrounds none of the applied flux, and there is no interaction between the magnet and the transformer. In the more usual type of construction, the secondary loop encloses a portion of the applied magnetic field, and compensating coils are necessary to prevent this field from being lessened by the counter magnetomotive forces generated by the heavy pumping currents.

Due to the lack of magnet-transformer interaction, the phase of the pumping current can be adjusted with respect to the applied magnetic field. In particular, with the use of a three-phase electrical supply, there are six different possible ways of connecting the magnet and transformer, but regardless of the phase shifts in the magnet and transformer, the phase angle between the pumping current and the applied magnetic field can be made to be 0 degrees, plus or minus 30 degrees. Thus the pumping action can definitely be held to within 14 percent of maximum without any need of finer adjustment.

A further feature is that the pump geometry is so simple that the cost of fabrication is relatively low. Furthermore, the short length of the transformer secondary makes possible the use of temperature-resistant alloys without increasing the secondary resistance to a prohibitive extent. This, instead of copper or aluminum, stainless steel can be used to complete the secondary loop, and welding, instead of brazing, can be used for joints. Typical stainless steels are those classified by the American Iron and Steel Institute in their three hundred series which includes alloys, such as type 301 (18% Cr and 8% Ni) type 316 (16% Cr, 13% Ni and 3% Mo) etc. The specification for these steels are in the AISI Steel Products Manual, Section 24, published by the American Iron and Steel Institute, 350 Fifth Avenue, New York, New York.

The pump differs from other pumps operating on a similar principle in several respects. The most distinctive difference is the push-pull arrangement of its pumping sections, involving the common use of the laminations passing through the transformer secondary loop by both the transformer and the magnet.



While in accordance with the provisions of the statutes, I have illustrated and described herein a specific form of the invention now known to me, those skilled in the art will understand that changes may be made in the form of the apparatus disclosed without departing from the spirit of the invention covered by my claims, and that certain features of the invention may sometimes be used to advantage without a corresponding use of the other features.

I claim:

1. An electromagnetic pump, for electrically conductive fluid, comprising, in combination a single core type, transformer means including a closed magnetic core having opposed leg portions, a primary winding on one leg of said core, and a single-turn secondary winding on an opposed leg of said core; at least a pair of electrically conductive connected, conduit sections for the flow of fluid therethrough incorporated in said secondary winding and arranged so that the flow of secondary current is in a direction substantially perpendicular to the axes of said sections; electromagnetic means arranged to apply a magnetic field across said sections substantially perpendicular to the axes thereof and to the direction of flow of secondary current thereacross; said electromagnetic means including an open end core having a winding disposed on said open end core, the latter being in a plane perpendicular to a plane intersecting the longitudinal axes of said conduit sections; the transformer means primary winding and the electromagnetic means winding being disposed on opposite sides of said single-turn secondary winding and at right angles to each other; and means, including phase shifting means, for connecting said transformer means and said electromagnetic means to a common source of A.C. energy in such manner that their magnetic fields have a substantially 90° phase relation.

2. An induction electromagnetic inter-action pump for electrically conductive fluid comprising in combination, a core type transformer having a closed magnetic core with opposed leg portions, a primary winding disposed about one leg of said core, and a single-turn secondary winding disposed about a core leg opposite said primary winding and remotely therefrom, said secondary winding including a shunt, an electrically conductive conduit having a pair of connected sections for the flow of fluid therethrough incorporated in said secondary winding, said sections being arranged so that the flow of secondary current is in a direction substantially perpendicular to the axis of each conduit section, electromagnetic exciting means arranged to apply a magnetic field across said sections substantially perpendicular to the axes thereof and to the direction of flow of secondary current thereacross a source of A.C. energy, and means including phase shifting means for connecting said transformer and said electromagnetic exciting means to a common source of A.C. energy in such a manner that their magnetic fields have a substantial 90° phase relation.

3. An induction electromagnetic inter-action pump for electrically conductive fluid comprising in combination a transformer means including a closed magnetic core having opposed leg portions, a primary winding disposed about one leg portion of said transfer core, a single turn secondary winding disposed on an opposed leg portion of said transformer core, said secondary winding including a magnetic shunt, a return bend electrically conductive conduit for the fluid incorporated into said secondary winding, said conduit having a pair of pumping sections arranged in said secondary winding so that the flow of secondary current is in a direction substantially perpendicular to the longitudinal axes of said conduit pumping sections, electromagnetic exciting means arranged to

apply a magnetic field across each of said conduit pumping sections substantially perpendicular to the axes thereof and to the direction of secondary current thereacross to provide opposed fluid flow through said pumping sections, said exciting means including a C-shaped magnetic core having a pole positioned adjacent and encompassing each of said conduit sections and an exciting coil disposed at the bight of said C-shaped core.

4. An induction electromagnetic inter-action pump for electrically conductive fluid comprising in combination a transformer means including a closed magnetic core having opposed leg portions, a primary winding disposed about one leg portion of said transfer core, a high temperature, heat resistant single turn secondary winding disposed on an opposed leg portion of said transformer core, said secondary winding including a magnetic shunt, a return bend electrically conductive conduit for the fluid incorporated into said secondary winding, said conduit having a pair of pumping sections extending perpendicularly to the plane of said secondary winding and the flow of secondary current being in a direction substantially perpendicular to the longitudinal axes of said conduit pumping sections, electromagnetic exciting means arranged to apply a magnetic field across said conduit pumping sections substantially perpendicular to the axis thereof and to the direction of secondary current thereacross to provide opposed fluid flow through said pumping sections, said exciting means including a C-shaped magnetic core having a pole positioned adjacent and encompassing each of said conduit sections and exciting coil disposed at the bight of said C-shaped core.

5. In combination, a three phase A.C. supply main, an electromagnetic pump for electrically conductive fluid including a pump transformer having a primary winding, an electromagnetic exciting means having an exciting coil, and control means connecting said primary winding across one phase of said supply main and said exciting coil across another phase of said supply main, said control means including a phase shifting means connected in series with said electromagnetic exciting means for putting the flux generated by the exciting coil in phase with the current in the secondary of said pump transformer.

6. In combination, a three phase A.C. supply main, an electromagnetic pump for electrically conductive fluid including a pump transformer having a closed core having opposed leg portions, a primary winding disposed about one leg of said transformer core and a single turn secondary disposed about an opposed leg portion of said transformer core, a return bend conduit having longitudinally extending parallel sections incorporated in opposed portions of said secondary winding, said sections being arranged in said secondary so that the secondary current is in a direction substantially perpendicular to the longitudinal axes of said conduit sections, an electromagnetic means having an exciting coil and control means connecting said primary winding across one phase of said supply main and said exciting coil across another phase of said supply main, said control means including a phase shifting means connected in series with said electromagnetic means for putting the flux generated by the exciting coil in phase with the current induced in the secondary of said pump transformer.

7. An induction electromagnetic inter-action pump for electrically conductive fluid comprising in combination



a transformer means including a closed magnetic core having opposed leg portions, a primary winding disposed about one leg portion of said transfer core, a single turn secondary winding disposed on an opposed leg portion of said transformer core, said secondary winding including opposed shorting bars, a shunt, and a return bend electrically conductive conduit for the fluid, said conduit having a pair of opposed longitudinally extending pumping sections connected to and between said shorting bars so that the flow of secondary current induced in said secondary is in a direction substantially perpendicular to the longitudinal axes of said conduit pumping sections, electromagnetic exciting means arranged to apply a magnetic field across said conduit sections substantially perpendicular to the longitudinal axes thereof and to the direction of secondary current thereacross to provide opposed fluid flow through said pumping sections, said exciting means including a single C shaped magnetic core having a pole positioned adjacent and encompassing each of said conduit pumping sections and an exciting coil disposed at the bight of said C shaped core.

8. An induction electromagnetic inter-action pump for electrically conductive fluid comprising in combination a transformer means including a closed magnetic core having opposed leg portions, a primary winding disposed about one leg portion of said transfer core, a single turn secondary winding disposed on an opposed leg portion of said transformer core, said secondary winding including opposed shorting bars and a return bend electrically conductive conduit for the fluid, said conduit having a pair of opposed pumping sections connected to and between said shorting bars so that the flow of secondary current induced in said secondary is in a direction substantially perpendicular to the axes of said conduit pumping sections, a shunt occupying the interior volume of said secondary winding, electromagnetic exciting means arranged to apply a magnetic field across said conduit sections substantially perpendicular to the axes thereof and to the direction of secondary current thereacross to provide opposed fluid flow through said pumping sections, said electromagnetic exciting means including a C shaped magnetic core having a pole positioned adjacent and encompassing each of said conduit pumping sections and an exciting coil disposed at the bight of said C shaped core.


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