

Jan. 20, 1948.

F. LAGO

2,434,705

GAS COMPRESSOR

Filed Sept. 9, 1944

5 Sheets-Sheet 1

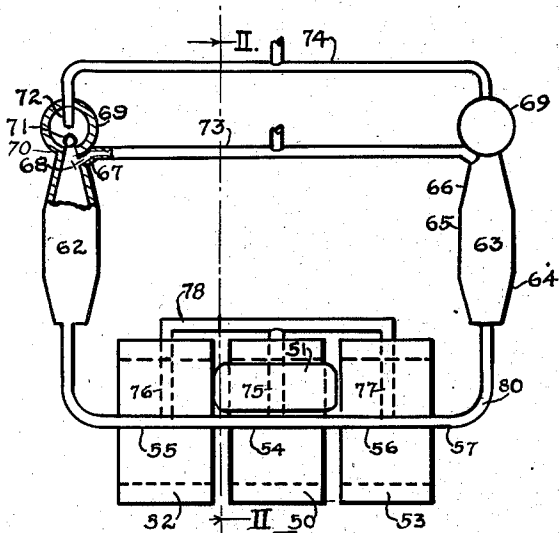


Fig 1

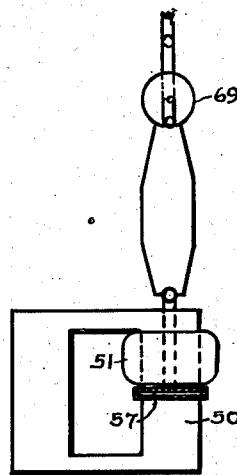


Fig 2

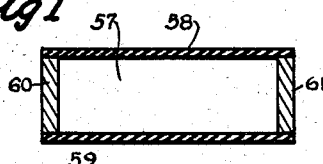


Fig 3.

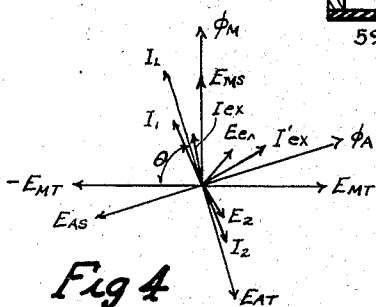


Fig 4

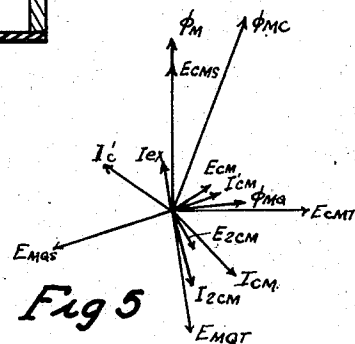


Fig 5

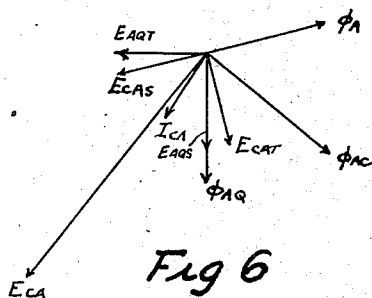


Fig 6

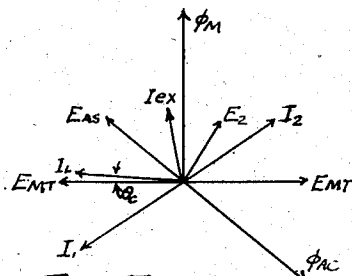


Fig 7

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5 Sheets-Sheet 2

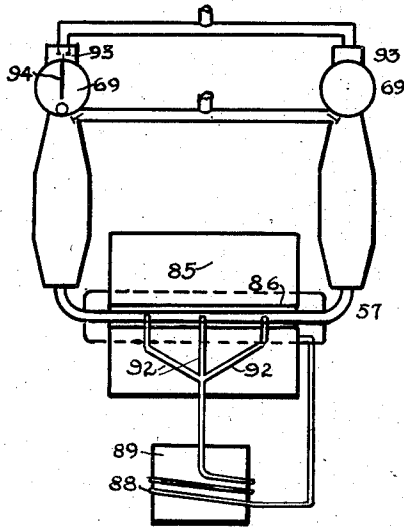


Fig. 8

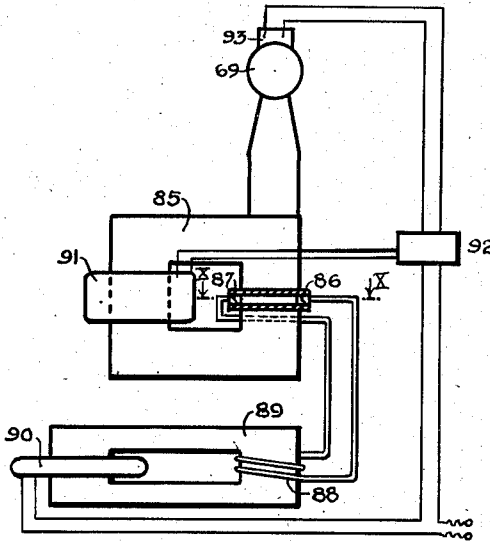


Fig. 9

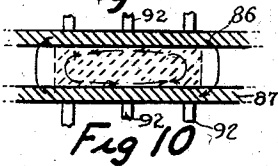


Fig. 10

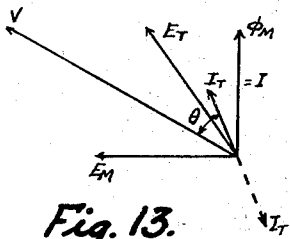


Fig. 13.

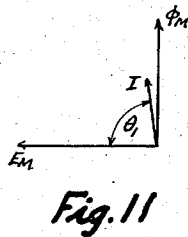


Fig. 11

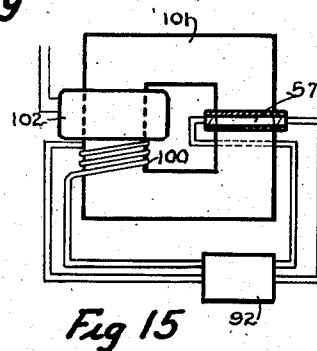


Fig. 15

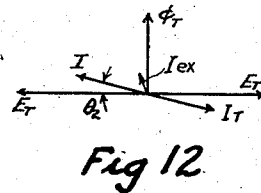


Fig. 12

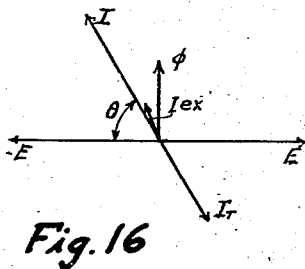


Fig. 16

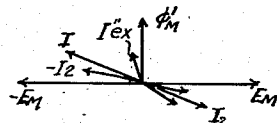


Fig. 14

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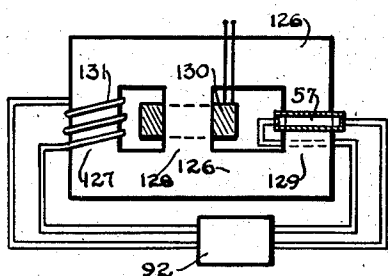


Fig. 17.

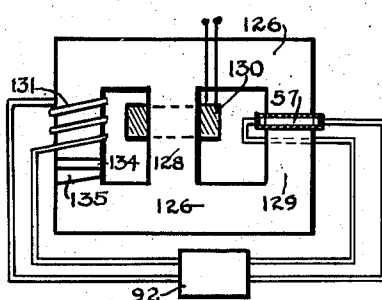


Fig. 18.

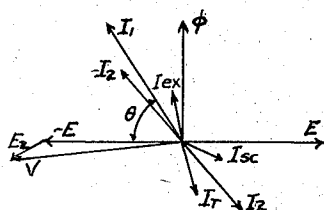


Fig. 19.

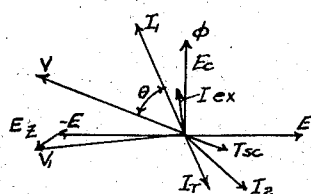


Fig. 20.

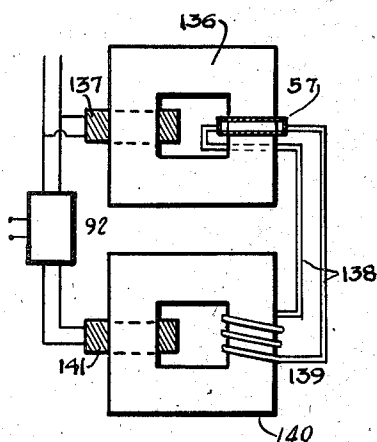


Fig. 21.

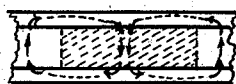


Fig. 22.

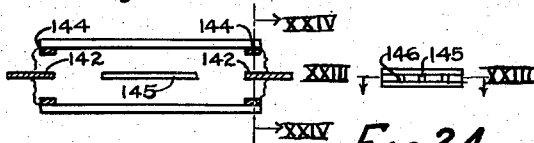


Fig. 23.

Fig. 24.

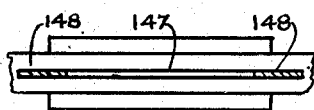


Fig. 25.

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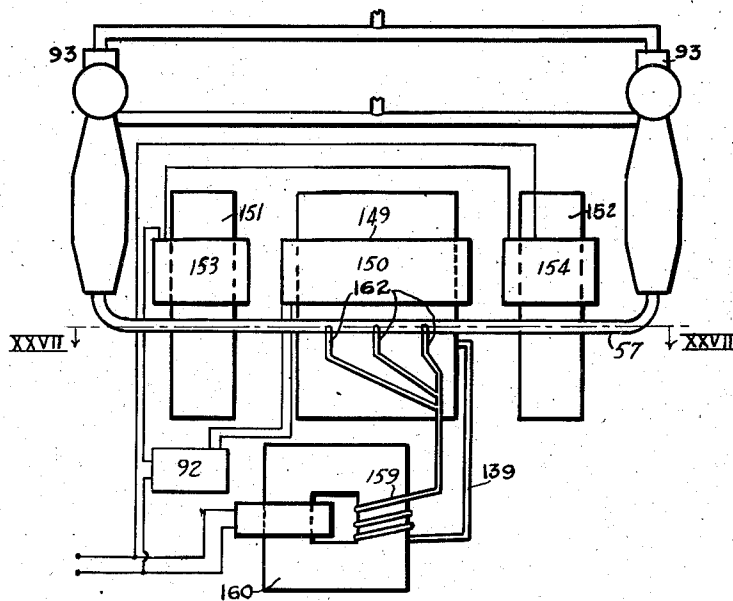


Fig. 26.

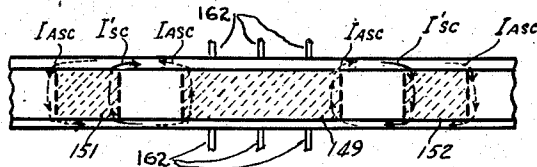


Fig. 27.

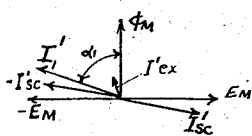


Fig. 28.

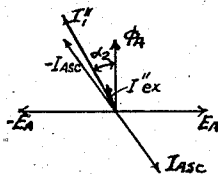


Fig. 29.

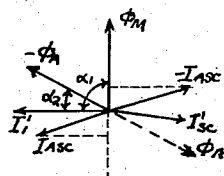


Fig. 30.

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UNITED STATES PATENT OFFICE

2,434,705

GAS COMPRESSOR

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Application September 9, 1944, Serial No. 553,359

33 Claims. (Cl. 230—85)

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This invention relates primarily to a pumping device, and more particularly to a compressor adapted for use in various special applications, as for example in a refrigerator or the like.

This invention is an improvement on the invention disclosed in my U. S. patent, No. 2,258,415, in which the compression of a fluid is effected by the reciprocal movement of a column of liquid, such as mercury, back and forth from one compression chamber to another under the influence of electrical currents. This invention is an improvement upon the invention of that patent involving simplification of the apparatus and improvement in the efficiency and reliability.

It is an object of this invention to provide an apparatus by which the liquid may be made to flow back and forth through a conduit to perform its function so that the compression is obtained without the need of any mechanically moving parts and with regard to some of its embodiments without the need of any contacts or switches except such as are employed to disconnect the apparatus from the line.

It is a further object to provide a device of the character described in which the number of parts are reduced to a minimum and the space required for the apparatus is minimized, thus saving expense of manufacture and reducing upkeep and making the device more compact.

The invention accordingly comprises a device possessing the features, properties and the relation of elements which will be exemplified in the article hereinafter described and the scope of the application of which will be indicated in the claims.

It is a further object of this invention to provide a mechanism in which the moving element may be started in movement by an oscillation of limited amplitude while the device is not under load and may gradually be brought up to a full amplitude, gradually increasing its pressure until it is able to assume the load without requiring a heavy starting current.

It is a further object to provide a device in which the circuits themselves without any auxiliary elements may be designed to effect a power factor correction as far as it is necessary or desirable to do so.

It is a further object to provide a device which by reason of its construction will give no radio interference and which will produce no flickering of lights and which will draw from the line a uniform current with a high power factor.

The device of this invention may be constructed to operate with its elements directly energized

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from the power line in series or in parallel with each other, or to operate on the induction principle with one or more of the elements energized by induction. In one of the preferred forms both of these principles are employed.

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, in which:

Fig. 1 is an elevation of apparatus embodying this invention.

Fig. 2 is a section on the line II—II of Fig. 1.

Fig. 3 is a cross section of the conduit employed, drawn to a larger scale.

Figs. 4, 5, 6 and 7 are vector diagrams of the electrical and magnetic quantities at different points in the operation.

Fig. 8 is an elevation of a modified form of the device showing a separately excited secondary.

Fig. 9 is a side elevation of the construction shown in Fig. 8, part being removed.

Fig. 10 is a section of the conduit along the lines 10—10 of Fig. 9, with the major portion of the core removed.

Figs. 11, 12, 13 and 14 are vector diagrams of the quantities involved in the operation of the construction of Figs. 8 and 9.

Fig. 15 is an elevation of further modification in which the exciting coil for the secondary is placed upon the same core with the primary.

Fig. 16 is a vector diagram of the quantities involved in the operation of the construction as shown in Fig. 15.

Fig. 17 is an elevation of a further modification of the construction shown in Fig. 15, in which the secondary exciting coil is placed on a different portion of the core, thereby creating the effect known as the constant current effect.

Fig. 18 is a further modification in which the core through the secondary exciting coil has an air gap introduced therein to increase the constant current effect.

Figs. 19 and 20 are vector diagrams pertaining respectively to operation of the constructions of Figs. 17 and 18.

Fig. 21 is a construction similar to that of Fig. 9, save that the coils are placed in parallel.

Fig. 22 is a view similar to Fig. 10 of a modified construction.

Fig. 23 is a section on the line 23—23 of Fig. 24 showing an alternative construction in which insulating barriers are introduced into the conduit to localize the secondary currents.

Fig. 24 is a section of the conduit on the line 24—24 of Fig. 23.

Fig. 25 is an alternative construction in which the conducting barriers are introduced into the tube to direct the flow of the fluid.

Fig. 26 is a modification of the device having a sweeping field directly energized by the line current.

Fig. 27 is a section on the line 27—27 of Fig. 26.

Figs. 28, 29 and 30 are vector diagrams of the construction shown in Fig. 26.

Fig. 31 is a perspective elevation of a modified form of the device.

Fig. 32 is a detail of the apparatus of Fig. 31.

Figs. 33, 34, 35 and 36 are vector diagrams showing different phases of the operation of the device in Fig. 31.

Fig. 37 is a view identical with Fig. 31 except that it shows auxiliary chamber connected to the compression side of the pump.

Referring now to Figs. 1 to 3, the numeral 50 designates a core, C-shaped in cross section, of laminated iron, having a primary coil 51 upon it, wound to take the line voltage. The numerals 52 and 53 designate auxiliary cores similar in shape to the core 50, but having no primary coils thereon. Between the poles 54, 55 and 56 of the cores 50, 52 and 53, there is placed a conduit 57, which, as will be seen in Fig. 3, is composed of two insulated plates 58 and 59 held in spaced relation by and sealed to a pair of conducting plates 60 and 61.

This conduit 57 at its ends bends upwardly and is joined to compression chambers 62 and 63, similar to the compression chambers shown in my former patent, U. S. Ser. No. 2,258,415, of October 7, 1941. These compression chambers are alike and each comprises generally a lower expansion portion 64 in the form of an upwardly expanding cone, a central portion 65 which is generally cylindrical, and a top portion 66 which is in the form of an inverted cone. The purpose of the shape of these parts is to avoid loss of energy through sudden changes of speed of the flow of liquid within the conduit.

At its open upper end each compression chamber is provided with an inlet 67 for gas under control of a valve 68. Above each compression chamber is a cushioning chamber 69 connected with the compression chamber through a valve seat 70 under control of a ball valve 71. An outlet 72 for the compressed gases extends into the cushioning chamber 69 far enough so that as the liquid rises in the cushioning chamber beyond the lower end of the outlet, the outlet is closed by the ball 71 and the force of the movement of the liquid is absorbed in compressing the gas trapped in the cushioning chamber. The two inlet openings are joined to the source of gas by conduit 73, and the two outlet openings are similarly joined by conduit 74.

Auxiliary conduits 75, 76 and 77 extend from the center of the pole faces 54, 55 and 56, where they communicate with the conduit 57 upwardly through the cores 50, 52 and 53 respectively, where they are joined together by a common conduit 78.

The conduit 57 and one of the compression chambers are filled with a conducting liquid 80, preferably having a good magnetic permeability and electrical conductivity. Mercury may be used as the liquid, but certain mercury alloys having a higher permeability, such as those containing iron, nickel or cobalt, are for that reason preferable.

With the above construction, when the coil 51 is placed upon the line, the poles 54 of the core 50 are directly excited. They will hereinafter be called the main poles. The poles 55 and 56 of the cores 52 and 53 are in space quadrature and they are excited by currents within the secondary, that is, within the conduit itself and the liquid which it contains. We use the term "space quadrature" as particularly appropriate when a plurality of primary poles are placed in series having opposite polarity, with these consequent poles between them. In such case, if we regard the primary poles as spaced 180° apart, in accordance with their electrical polarity, the auxiliary poles will be midway between them and so may be considered as spaced 90° . The whole arrangement may be considered as a huge stator of infinite radius, with 180° electrical angle from main pole to main pole. In any case the auxiliary poles must be so spaced relative to the main pole that they can react with the currents generated herein at 90° phase angle to the main flux. The same principles apply and hence the same language is applicable by analogy when only three poles are used since the functioning of the device is similar and the spacing of the poles and the timing of the currents has the same relation. They will herein be called the auxiliary poles. It is possible to employ a plurality of these poles alternately disposed. They need not be salient poles, and may take any form.

Coil 51 acts as the primary of a transformer and transmits power from the line to the short-circuit secondary which consists of the conductor plates 60—61 and the fluid 80. We may call this secondary current I_2 . Motion of the fluid past the pole 54 once started generates an E. M. F. and the resulting current I'_{ax} circulates about the auxiliary poles 55 and 56 and thereby excites them. Since I'_{ax} is mainly an exciting current, it is approximately in time quadrature with its E. M. F. The field of the auxiliary poles is nearly in time quadrature with the main field and it is in space quadrature. A sweeping field is thus produced and it moves in the direction of motion of the fluid. Power is developed by the reaction between I_2 , the current in the secondary, and the auxiliary field flux.

Motion of the fluid under poles 55 and 56 also generates an E. M. F. which acts in approximate opposition to the transformer secondary voltage at pole 54 and therefore is of the nature of a counter-E. M. F. and limits the value of I_2 . A transformer voltage about poles 55 and 56 similarly limits the currents I'_{ax} .

Motion continues until the fluid reaches the cushioning chamber 69 where it is decelerated and stopped. Since the auxiliary poles 55—56 owe their excitation to the motion of the fluid, they are de-energized when the motion is stopped. The forces now acting on the fluid are those due to the energy of compression in chamber 69 and the difference in elevation of the surface of the fluid which is now at the bottom of one cylinder and at the top of the other. This stored energy initiates motion in the opposite direction. When the direction of motion is reversed, the direction of I'_{ax} is reversed and hence the polarity of the auxiliary poles is reversed. The direction of I_2 is independent of motion and is therefore not reversed. Since it reacts with the reversed field of poles 55 and 56, the developed power is reversed and maintains the reversal of flow of the fluid. This continues until the other cushioning chamber is reached whereupon the cycle repeats itself.

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In the preferred form of the device, an electrically conductive fluid which is magnetic is used. The reluctance of the air gap is thereby decreased. A small exciting current is thus needed and the efficiency and power-factor of the device are improved, the flux across the air gap will be increased and the developed power is increased.

The short-circuit currents circulating about the pole faces have a reactive component that reacts with the flux and a force is developed that is directed toward the center of the pole. Tubes 75, 76 and 77 (Fig. 1) are shown located at the center of the poles and are connected by a common tube 78. The fluid tends to flow through these tubes and away from conduit 57. During periods of maximum velocity in tube 57, the poles 54, 55 and 56 have nearly the same strength. The force along tubes 76 and 77 will be nearly equal to that in tube 75, and little motion will take place in common tube 78. As the fluid in conduit 57 is decelerated, the strength of poles 55—56 is decreased and the force along 76 and 77 is then decreased. The fluid will then circulate from 57 through 75 and 78 and back through 76—77 to 57. The motion in this auxiliary circuit is a maximum when that in the main tube is a minimum. The auxiliary flows is in approximate time quadrature with the main flow.

The motion of the fluid across the face of pole 54 to tube 75 generates a counter-E. M. F. that limits the current I_2 , since this E. M. F. is in approximate time phase with that due to flow along tube 57. Since the flows are in approximate time quadrature, there always exists a counter-E. M. F. to limit I_2 and the power demand from the line is made more uniform through the entire cycle of operation.

As before mentioned, there is always some motion in the auxiliary circuit directed along 73 away from pole 54. As the fluid flows from 76 and 77 to 75 along 57, it is moving across the face of poles 52 and 53 in a direction opposite to "motor" motion and we have "generator" action. Since there is no outside connection, the generated energy is used in exciting poles 55 and 56. Motor energy for this generator is received from pole 54 where the fluid moves toward the pole center. The "motor" takes a relatively small power current from coil 51 by transformer action. Since the "generator" current is largely an exciting current, it circulates in a reactive circuit and is in approximate time quadrature referred to the motor current. For the same power consumption we need a small current in the "motor" end and we get a large exciting current from the "generator" end. Since a small additional line current increases greatly the excitation of the auxiliary poles, we greatly improve the power-factor of the device, its efficiency, and the output power developed.

The excitation of poles 55 and 56 is obtained from the motion of two fluid circuits; that in conduit 57 and that in tubes 76—77. Since these motions are in approximate time quadrature, we have a more uniform excitation throughout the operating cycle except at the point where the polarity of the poles is reversed. The output does not fall away as the fluid in tube 57 is decelerated, but remains more nearly uniform with consequent improvement in efficiency.

As shown, these tubes are balanced because this makes for the best correction during operation. If, however, one of these tubes, either 76 or 77, is omitted, an unbalanced condition will exist which provides a starting torque.

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The flux in the auxiliary poles 55 and 56, when excited by motion of the fluid along conduit 57, lags nearly in time quadrature with respect to that of pole 54. Motion in the auxiliary circuit increases the angle of lag of the resultant auxiliary pole flux. This corresponds to the condition generally obtained for power-factor compensation. The resultant primary current is rotated more nearly in phase with the transformer secondary voltage. Consequently the line current is rotated more nearly in phase with the line voltage and the power-factor is improved. By sufficient auxiliary pole flux lag, over-compensation or a leading power factor may be obtained.

The various magnetic and electrical quantities may be shown as vector quantities on Figs. 4, 5, 6 and 7 of the drawings, but for the purpose of illustration these diagrams have been simplified by omitting resistance and reactance voltages.

In Fig. 4 ϕ_M is the flux due to the winding connected to the line. Ems is a voltage generated by the motion of the mercury through this flux. The corresponding current I'_{ex} excites a field ϕ_A in time and space quadrature which is the field of the auxiliary poles. This field induces a transformer voltage E_{AT} that is nearly in opposition to Ems. Their resultant E_{ex} determines the value of I'_{ex} . E_{MT} is the transformer voltage induced by the main field and is nearly in opposition with E_{AS} which is generated by motion of the mercury through ϕ_A . Their resultant E_2 determines the value of the secondary current I_2 which reacts with ϕ_A to sustain motion. I_2 also reacts with the primary and is balanced by a component current I_1 from the line by transformer action. The line supplies the power which is proportioned to needs by a counter-E. M. F. E_{AS} . The line current I_1 is the sum of I_2 and the exciting current I_{ex} . Note that ϕ_A and I_2 react to give power, that the auxiliary field is excited by motion of the mercury, and that the polarity is such that motion is sustained.

When the mercury has risen to the top of one leg of the U, it is decelerated and stopped by the cushioning chambers. The combined forces of the compressed gas and the unbalanced legs of U-tube initiate motion in a direction opposite to the previous direction. This motion now excites the auxiliary poles with opposite polarity and the motion is sustained in the new direction until the fluid is again stopped and reversed by the cushioning chambers. The device is self-reversing and does not need extraneous devices as reversing switches. It generates its own "armature" current and it excites its own field with the proper polarity.

The auxiliary path for the mercury comprising passages 75, 76, 77 and 78 is provided from the center of one pole to the center of the next. This means, as has been explained, prevents the line current from varying to locked-rotor values as would otherwise obtain when the mercury column is stopped.

As has been referred to above, the reaction between the secondary current circulating beneath the pole face and the flux of the pole produces a force that directs the mercury towards the pole center-line in a manner similar to "pinch-effect." This applies to both the main and the auxiliary pole which are nearly equal in strength while the main column is in motion and the "pinch-effect" of one tends to buck the "pinch-effect" of the other and little motion results in the auxiliary path. However, when the velocity

of the main mercury column decreases, the field strength of the auxiliary poles decreases, and the bucking force decreases. The velocity of the mercury in the auxiliary path increases. Note that the velocity in one path increases while that in the other decreases. The two motions may, in a sense, be considered as being in time quadrature with each other. Since each motion must generate a counter-E. M. F., the current is always kept within limits.

The vector diagram for conditions during motion is shown in Fig. 5; ϕ_m is the main flux and E_{cm} is the voltage generated by motion of the mercury to the center of the pole. The corresponding current I'_{cm} is largely an exciting current and excites flux ϕ_{mr} . Reasoning as before, we get the generated voltage E_{mq} and the induced voltages E_{cm} and E_{mq} . E_{cm} determines the value of the current component I'_{cm} . Similarly E_{cm} determines the value of the power component I_{cm} . Since all the vectors are in space phase, they are added and we get a resultant flux ϕ_{mc} and current I_{cm} which reacts with the stator and a balancing component I_{lc} appears in the line current.

It has been pointed out that there is always some motion of the fluid in the auxiliary path. Obviously, the main poles will act as "motors" and the auxiliary poles as "generators" since in the case of the latter, the direction of flow is reversed, in the sense that it is counter to the direction of increasing lag of flux toward the pole center which is shown as ϕ_{aq} . The "generator" voltages are plotted in Fig. 6. ϕ_A is the flux of the auxiliary poles. E_{cas} is a generated voltage and since the motion is opposite, the voltage is opposite in direction and is in phase opposition with ϕ_A . The voltage generated by cutting this flux is E_{aqs} . E_{cat} and E_{act} are induced voltages. Adding all the voltages we get E_{ca} and the value of I_{ca} is determined. It is nearly entirely an exciting current since there is no connection with any other circuit and therefore aids ϕ_{aq} . ϕ_{aq} adds with ϕ_A and the resultant is ϕ_{ac} . Since this has been rotated clockwise, the direction of the voltages in the main mercury column must be changed. These changes are shown in Fig. 7.

We note that E_{as} has now been rotated clockwise and the resultant E_2 has been rotated counter-clockwise. Consequently, I_2 now leads E_{mr} . The component in the primary, I_1 , now leads and thereby brings the line current, I_L , more nearly in phase with the voltage. We thereby have power-factor correction. We now know that the device generates its own exciting power. Since the motion through the auxiliary tap is a minimum when the auxiliary pole flux is a maximum and vice-versa, this compensation can be held to limits.

In the form of invention disclosed in Figs. 8 to 10, there is provided but a single core which is here designated as 85 corresponding to the core 50 in the first embodiment. This core is also C-shaped and between its poles is placed the conduit 57 as in the preceding embodiment. In this embodiment, however, the conducting plates 86 and 87 forming the sides of the conduit 57 are connected across the secondary 89 of a transformer 89, the primary 90 of which is in series with the primary 91 on the core 85. I prefer to connect this secondary 89 to the plates 86 and 87 by means of a plurality of leads 92, these leads being connected to the transformer in multiple in order to insure as uniform a density of current across the pole faces as possible.

By this construction a secondary current is caused to flow in the fluid which is substantially in phase with the flux across the conduit between the pole pieces of the core. These conditions are such as to cause the fluid to flow through the conduit in a direction dependent upon the relative polarity of coils 90 and 91. With this arrangement there is provided a reversing switch 92 of any conventional form, for reversing the polarity of one of these coils. This switch may be operated by an actuating member 93 mounted, as shown, on the cushioning chamber 89 and having a stem 94 extending into the path of the ball valve 71, so that the actuating member 93 will operate the reversing switch as soon as the ball valve strikes stem 94.

In the construction shown in Fig. 9, the transformer 89 is shown as of the constant current variety and its coil 90 is shown as connected in series with the exciting coil 91 of the core 85. The coil 91 has inherently a high reactance and the transformer coil is deliberately designed for high reactance. The angle between the primary current and the flux of each of these units can thus be made nearly the same.

Fig. 10 is a plan view of the conduit 57 and illustrates the portion in the gap. The pole face of core is shown in dotted lines. It is to be noted that the mercury and the conducting end walls constitute short-circuited secondaries in parallel with each other and reacting through transformer action on coil 91 which thereby becomes the primary of the transformer. The currents in the short-circuits I'_2 and I''_2 are not only a source of energy loss, but also adversely affect the phase relationship between the mercury current and the flux in gap 2 and thereby seriously affects the motor action above described.

In Figs. 11-14 there are shown the approximate vector diagrams of the conditions of this current, the various quantities being assumed to be represented by sine waves.

Fig. 11 indicates approximately the conditions obtained in core 85 if no short-circuited currents existed. ϕ_m is the flux, E_m the voltage, and I the current in the coil 91. I and ϕ_m are nearly in phase. The phase angle θ between I and E_m is nearly 90° and the power consumed in excitation is correspondingly low.

A constant-voltage transformer in series with the coil 91 under the above theoretical conditions would perform approximately as shown in Fig. 12 where all quantities are referred to the primary. The transformer primary current is I . The secondary current I_r is nearly in phase opposition to I and nearly in phase with its voltage E_r .

Fig. 13 combines those vectors of Figs. 11 and 12 which react with each other in the gap of core 85. $-I_r$ is nearly in phase with the flux ϕ_m and hence, since they are also in space phase, a motive force is developed that is proportional to the projection of $-I_r$ on ϕ_m . I_r indicates the condition where it is in phase opposition to ϕ_m which obtains when the current (or ϕ_m) is reversed. θ is the phase angle between $-I_r$ and the line voltage v .

Fig. 14 shows the actual conditions which exist when the short-circuit currents exist in the conduit 57 where it passes under the pole faces of core 85 if the same voltage drop E_m is permitted across coil 89. I_2 is the vector sum of I'_2 and I''_2 (Fig. 10). I now is the vector sum of both I_2 and I''_{ex} . Since I is no longer the total exciting current, the flux decreases from a value of ϕ_m to

ϕ , the latter corresponding I'_{ex} which is less than I . A study of Figs. 11 and 12 indicates that I_r is nearly in phase with I . Referring to Fig. 14, since I is rotated away from ϕ , so would I_r be thrown further of phase. The motive force is then reduced by both a decrease in flux and a decrease in the projection of I_r on the flux. In addition, I_2 dissipates energy in the form of heat. The short-circuit currents should be minimized or utilized. Means and methods for achieving these results will be later described.

As is evident from the description of the operation of the device, the mercury column reciprocates in the conduit; its speed varies from a maximum to standstill just before reversal. As it moves along the gap, a counter-E. M. F. is generated which limits the current flowing from transformer secondary 88. At a standstill, the secondary is, in effect, short-circuited. The current demand from the line varies in accordance with the motion of the mercury and is greatest at the "dead" period during reversal. Objectionable flicker of lighting and energy losses might thus result. This effect is substantially corrected by installing a constant current type of transformer. The current demand is made more nearly uniform by utilizing the varying reactance of the constant current transformer.

A simplified form of such a device is shown in Fig. 15 in which the transformer has been eliminated by placing a secondary coil 100 on a common core 101 with exciting coil 102 which now becomes the primary coil also and is connected directly to a source of alternating current. The coil 100 is connected to the electrode tube 57 of a form hereinbefore described and is in series with a reversing switch 92 which is connected to a pilot circuit operated by the rod 94. The secondary current is approximately in phase with the primary current. Due to the air gap in the core 101, the leakage flux is great and the reactance is thereby increased. The voltage characteristic drops sharply and the performance approaches that of a constant current transformer. Besides limiting the current and holding it approximately constant, the current across the electrode tube is more nearly in phase with the flux and the electromotive force in the mercury is correspondingly increased. These conditions are vectorially plotted in Fig. 16. I_r lags considerably behind E , and is more nearly in phase (or phase opposition) with the flux ϕ .

Another form of this device is shown in Fig. 17 where the core 126 is divided into three legs 127, 128 and 129. The coil 130 sets up a magnetomotive force which establishes the flux in legs 127 and 129 which are magnetically in parallel with each other. The flux in leg 128 is a mutual flux and a voltage is induced in secondary coil 131 which is connected across mercury tube 57 and in series with a reversing switch 92. Coil 130 is connected to a source of alternating current. Switch 92 is actuated by the rise and fall of mercury, as was described for the device shown in Fig. 9. The characteristics of this device are similar to those of Fig. 15 except that the reactance is greater and the current regulation is better.

Fig. 18 shows a similar device except that an auxiliary air gap 134 has been added and the constant current characteristic is thereby improved. A movable piece 135 may be added for adjusting the length of the gap and consequently the transformer characteristics.

The vector diagrams of Figs. 13 to 16 have

been for the series unit under standstill conditions and all have indicated that a starting force exists. It is to be noted that the constant current principle improves the operation of this device. The power factor of the unit is apparently lowered at the standstill conditions, but it improves greatly when the unit is in motion and since the current is substantially constant, the overall performance is improved.

The vector diagram under static conditions for the devices of Figs. 15, 17 and 18 is shown in Fig. 19. I_{sc} is the short circuit current in the mercury, I_r is the transformer secondary current and is the useful current. I_2 is the sum of these currents. I_{ex} is the exciting current which is added vectorially to $-I_2$ to give the total primary current in coil 130. E is the voltage induced by the flux ϕ . V is the impressed voltage and is equal to $-E$ added vectorially to E_z , the primary impedance drop. θ is the power factor angle. The projection of I_r on ϕ is a measure of the motive force developed in the mercury.

The vector diagram for the above devices when the mercury is moving is shown in Fig. 20. When the mercury is moving along the air gap of an excited core, it is cutting lines of force and a voltage, E_c , is generated which is in opposition to that voltage or its component that causes I_r to flow across the mercury. This component is in phase with the flux ϕ . The line voltage V , being a constant, must now supply E_c , and $(-E + E_z)$. The latter voltage, V_1 , must therefore decrease as $-E$ decreases, which in turn causes E to decrease. With constant voltage transformation E and consequently I_1 would decrease. Remembering that with the mercury at rest at the end of the stroke no counter-E. M. F. exists and also that as motion is resumed in the opposite direction by the combined action of the cushioning chambers, gravity, and the reversed secondary current, compression has just started and were it not for the inertia of the mercury, a no-load condition would obtain. With such transformation the current would vary widely. By using constant current transformation, however, I_2 would remain substantially constant from no-load to full load conditions. Excepting the variation of the exciting current which may be small, I_1 , the line current, would be nearly constant and the power requirements would be taken care of by a varying power-factor which with constant potential transformation would remain nearly constant. These vector diagrams, for the sake of simplicity, have been drawn with resistance and reactance voltages omitted.

We have called attention in connection with Fig. 9 to the fact that the flux in the transformer core 89 and the flux in the main core 85 can be made substantially the same. On this account these coils can be electrically connected in parallel. Such an arrangement is shown in Fig. 21. The motor core 136 contains the electrode tube 57 within a gap, as heretofore described. The core is excited by coil 137 connected to a source of electrical energy. The electrode tube 57 is connected by wires 138 to the secondary 139 of transformer 140 whose primary coil 141 is connected through a reversing switch 92 in parallel to the same source of energy as the coil 137. This switch is actuated by the rise and fall of the mercury. The operation of this unit is similar to that of the unit shown in Fig. 9.

In an alternate form, reversing switch 92 is connected in the line between electrode tube 57 and secondary coil 139. The operation of the unit

depends on the reversal of the secondary instead of the primary current, but is otherwise the same.

In Fig. 10 short-circuit currents, due to transformer action, were shown. In Fig. 20 we see that, during movement, a counter-E. M. F., E_c , is generated.

Fig. 22 shows the same form of electrode tube as Fig. 10. If motion is as indicated, the generated E. M. F. short-circuit path is represented by the arrows. The flux is directed upward from the surface of the paper. It is obvious that the field becomes distorted due to the M. M. F. set up by these currents. If the poles are near saturation, the aiding currents do not increase flux, but the bucking currents will decrease the flux at their end of the pole face. The net result is increased reactance and decreased flux at the pole face. The latter makes for a decreased motive force in the mercury and increased reactance.

To effectively minimize all short circuit currents that circulate around the outside of the pole face, insulating barriers such as shown in Fig. 23, which is a section cut as shown in 24 are provided. These barriers 142 lie across the path of a short circuit current and consist of an insulating material. I prefer to use metallic strips coated with an insulating coating. The electrodes may be insulated at various sections to aid in accomplishing the same purpose. Such areas are indicated as 144. Also, the electrodes may be wholly contained within the pole face area if the magnitude of the short-circuit currents justify this.

Uninsulated metallic strips may be located along the tube as 145, Fig. 23. Since they are conductors they do not prevent the passage of the secondary current, but aid in streamlining the flow of mercury and also serve as stays to reinforce the sides 146 against internal pressure.

A preferred form is shown in Fig. 25. An electrical conductor 147 is insulated electrically at the sections 148 and also serves as a stay for the sides of the tube as described above for 142 and 145 staying the sides 146.

A modification of the device is shown in Fig. 26. The motor core is shown at 149 and is excited by the coil 150. This portion of the device is designed for low reactance. Two additional cores are shown at 151 and 152 and they are excited respectively by coils 153 and 154. This portion of the device is designed for high reactance. The coils 153 and 154 are connected either in series with each other or in parallel, and this circuit is connected in parallel or in series with the coil 150, but one of these circuits, as the coil 150, is controlled by a reversing switch 92.

The electrode tube 57 is similar in construction to those hereinbefore described, but in this embodiment it is extended through the auxiliary poles 151 and 152.

The operation of this device is similar to that shown in Figs. 8 and 9, except that the motor field 149 is reversed with respect to both the current of the secondary 159 of the transformer 160 which is connected across the electrode tube and the fields of the auxiliary poles 151 and 152. The exciting coil 161 of this transformer may be connected either in series or in parallel with the coils 150, 153 and 154, depending on its reactance characteristics as hereinbefore described. Also, transformer 160 may be of the constant potential or constant current type.

The section XXVII of the electrode tube 57 is shown in Fig. 27 where the poles 149, 151 and 152 are indicated by the shaded areas. The leads 162 are from the secondary of the transformer.

It is to be noted that the short-circuit current I_{sc} that lies entirely outside the motor pole 149 also passes under poles 151 and 152 which are, in effect, in space quadrature with the pole 149 from an electrical standpoint. The flux of 151 and 152 are in phase opposition with each other and out of phase, preferably in quadrature, with the motor pole 149. The phase sequence is in the direction of motion.

The vector diagram of the motor pole 149 is shown approximately in Fig. 28 where I'_{sc} is the short circuit current shown in Fig. 27, E_m is the induced voltage and I_1' is the coil current. The flux ϕ_m lags behind the coil current by the angle α_1 .

A similar diagram is shown in Fig. 29 for the auxiliary poles 151 and 152. The flux is ϕ_A and the short-circuit current in the mercury is I_{asc} which also passes under the main pole as shown in Fig. 27. E_A is the induced voltage and I'_{ex} is the exciting current. I_1'' is the primary current in coil 153 and 154. Since all coils are connected in series, the currents I_1' and I_1'' are identical and the vector diagrams of Figs. 28 and 29 can be combined as shown in Fig. 30 with I_1' as the common current and the fluxes ϕ_m and $-\phi_A$ lagging by the angles α_1 and α_2 . If $-\phi_A$ is the flux in coil 153, then ϕ_m is, of course, the flux in coil 150 and ϕ_A is the flux in coil 154 which is equal to that of coil 153 reversed. Since the fluxes are not co-axial, they do not react upon each other. It is to be noted that they are distinct, in space displacement, and that there is in effect a flux progression from pole 151 to pole 152 which is also the direction of flow of mercury due to the flux in pole 149 and the secondary current of transformer 160 across the tube 57. The fluxes of Fig. 30 represent, in effect, a two-phase system. I prefer to make the angle ($\alpha_1 - \alpha_2$) between $-\phi_A$ and ϕ_m as nearly 90° as possible. This may be approximated by inserting suitable inductance and capacitance in the circuit as is common practice.

It will be noted from Fig. 27 that I'_{sc} passes under the auxiliary poles. Since I'_{sc} lags behind ϕ_m (Fig. 28) and so does ϕ_A lag behind ϕ_m (Fig. 30), I'_{sc} and ϕ_A are nearly in phase or, as shown in Fig. 30, a component of I'_{sc} entirely in phase with ϕ_A and consequently we get motor action in the direction the mercury has been made to move as mentioned above. In other words, the portion of the short-circuit current entirely around the outside of the pole (as I_1' in Fig. 10 or I'_{sc} in Fig. 27) has been made to exert a useful force.

It is also to be noted the short-circuit current entirely on the outside of auxiliary poles, I_{asc} , passes across main pole 149 and by similar reasoning and as indicated in Fig. 30 exerts useful force in the direction of motion.

In the form of the invention disclosed in Fig. 31, two cores, 180 and 181, are provided. These cores are of identical construction but oppositely placed. Each is generally of a C-shaped cross section having the conduit 57 lying between the open ends of the C, as in the previous embodiments. One pole piece of each core, however, is divided into three sub-poles, 180a, 180b and 180c, and 181a, 181b and 181c. Since these two cores are alike, the remaining parts will be described for one core only, and the numbers applied to both.

The central pole of each core, 180b or 181b, is energized by coil 182 directly from the line and these coils are preferably connected in se-

ries. Each leg of the conduit 57 terminates in a compression chamber 65, such as we have previously described. A by-pass conduit 183 leads from the center of the face of the magnet pole opposite the center of the central sub-pole, as shown at 184, to a point opposite the center of one of the side sub-poles, as shown at 185. This by-pass conduit can, if desired, also be connected to the center of the other sub-pole face, as shown in the construction of Fig. 1, but in this embodiment I have chosen to illustrate it in the unbalanced form with both cores unbalanced in the same direction of motion of the mercury, in order to afford a starting torque.

The vector diagram showing the reason for this starting current is shown in Fig. 36, in which ϕ_M is the main pole flux and ϕ_L is what we may call the leakage flux through one-half of the auxiliary pole. E_{MT} is induced voltage circulating in the mercury around the main pole and E_L is the counter-E. M. F. due to leakage flux. The resultant voltage E_M and its current determine the power taken to cause motion of the mercury in the auxiliary path. E_{MS} is a voltage generated by motion of the mercury under ϕ_M and E_{LT} is a voltage induced by the leakage flux. The resultant voltage E_C causes a current I_C to circulate, and a flux due to this current aids the leakage flux ϕ_L , as may be seen from the figure. We see then that we have strengthened the flux in the auxiliary pole and that this flux is out of phase with the main pole. As a result, we have a sweeping field even before the mercury starts in motion in the main conduit, which can initiate the movement of the mercury in the main conduit, and thus the device becomes self-starting because of the unbalanced connections of the auxiliary conduit.

It will also be seen that the power factor correction can be effected by the by-pass conduit going through the main pole alone, if it be connected to the main conduit outside the main pole, since the flow of mercury into the auxiliary conduit generates an E. M. F. which causes a current to circulate in the mercury in quadrature with the main flux. The flux due to this current combines with the main flux to produce a resultant flux lagging behind the main flux. The flux in the auxiliary poles is thus rotated with a consequent improvement in power factor, as indicated in Fig. 7. We would get the same result, only in less degree, if the center tap conduit be placed in the auxiliary pole instead of the main pole.

The auxiliary poles 180a and 180c and 181a and 181c are low reluctance magnetic paths and are excited by virtue of an E. M. F. generated by motion of the mercury by the main poles 180b and 181b. When the mercury is in stationary condition, a starting torque is provided by the unbalanced flow of mercury through the conduit 183, which energizes the pole 180c and 181c, thereby producing a sweeping field which can start the mercury in motion.

There is also shown in this figure an auxiliary chamber 190 connected to the center of the bottom portion of the U-conduit 57.

During the operation of the device, this auxiliary chamber functions as follows: Mercury descending from one of the legs of the conduit 57, say for example the left-hand leg, will divide. Part will go up the right-hand leg, while part will go up into the auxiliary chamber 190, compressing the gas therein. When the mercury in the right-hand leg has reached its upper limit and is

stopped for reversal, all further flow of mercury from the left-hand leg is diverted into the auxiliary chamber 190. Thus it will be seen while the mercury in the right-hand leg is stopped, that in the left-hand leg continues in motion for a time.

Coil 182 upon the left-hand leg cannot demand a locked rotor current because it is in series with the coil upon the left-hand leg, and the latter current demand is still limited by the counter-E. M. F. generated by the mercury still flowing past it. A second later the mercury in the right-hand leg is accelerated in the reverse direction and momentarily the flow from both legs moves into the auxiliary chamber 190. Thus it will be seen that the flow in the right and left-hand legs is out of phase with each other, and while the mercury in the left-hand leg is decelerating and its counter-E. M. F. decreasing, the mercury in the right-hand leg is accelerating and its counter-E. M. F. is increasing.

Shortly afterwards the mercury in the left-hand leg is stopped and reversed by the combined forces of gravity, the cushioning chamber, the force developed in the right-hand leg and that due to the gas compressed in the auxiliary chamber. The reversal is quickly affected since these forces operate upon only a portion of the total mercury. The entire mercury column is now reversed and the gas in the chamber 190 expands and returns its energy to the moving column. This action now continues until the mercury rises to the top of the left-hand compression chamber 65 and the above mentioned cycle is repeated.

The vector diagram showing the operation just described, omitting, for the moment, the by-pass conduits, is given in Fig. 33 in which the main pole flux ϕ_M induces E_{MT} by transformer action. The motion of the mercury by the pole generates E_{MS} . Since there is no outside connection, E_{MS} is of the nature of an exciting voltage for the auxiliary pole and the flux ϕ_A lags by nearly 90°. This flux also induces a transformer voltage E_{AT} which reacts with E_{MS} to limit its value to the resultant E_{AR} . Motion of the mercury by the auxiliary pole generates E_{AS} which is of the nature of a counter-E. M. F. and it reacts with E_{MT} and reduces the short-circuit voltage under the main pole to E_{MR} .

From the foregoing it will be seen that the mercury moves into and out of the auxiliary chamber 190 at double the frequency of the mercury in the main conduit. It will also be seen that a counter-E. M. F. always exists in the line and the current demand is made more uniform throughout the cycle of operations.

In the foregoing description the mercury is stopped and reversed, first, in one leg of the tube, and then reversed in the auxiliary chamber 190. The force-speed characteristics and the volume of the auxiliary chamber, however, may be so chosen as to make the opposite true, so that the mercury is reversed, first, in the auxiliary chamber and the low level of mercury leg, and thereafter reversed in the leg where the mercury is at its high level. The advantages above referred to are obtained in either case.

The auxiliary chamber may be open to the atmosphere, as shown in Fig. 32, it being understood, of course, that in such instance it would be high enough so that all the energy stored in it is stored in the form of a column of mercury. It may on the other hand, if desired, be vented to either the suction or the pressure side of the system.

In the preferred form where the auxiliary chamber is open at the top, a floating ball valve is supplied to prevent the escape of mercury into the system and also to prevent gas from entering the electrode tube. These two functions may be combined by one ball valve, as shown in Fig. 32.

The auxiliary chamber 224 containing mercury 225 is connected to the electrode tube conduit 226, and floating on the surface of the mercury is a ball valve 227. The venting pipe 228 is provided with a neck to form a valve seat at 229, and another seat is provided at the bottom, as shown at 230. Thus the mercury level cannot rise above the point where the valve 227 closes the neck 229, nor can it fall below the point where the valve closes the neck 230.

It will also be clear that the upper venting 228 of the auxiliary chamber 224 may be connected by suitable valves with the inlet and exhaust 73 and 74, so that the movement of mercury within this auxiliary chamber contributes a quota toward the useful compression of the gas.

Fig. 33 shows the relationship between the primary and secondary values of the electromagnetic system of Fig. 31 of the exciting coils 182, indicating the reflection of power from the line into the mercury system.

The secondary voltage in the mercury is E_{MT} and the secondary or mercury current is I_2 . These are the only two that react with the primary. All other voltages are due directly or indirectly to the motion of the mercury past the main pole. All other currents have a component that appears in I_2 .

Referring to Fig. 33, E_{MT} reacts on the primary coils and it has a component $-E_{MT}$ in the primary. Under standstill conditions I_2 would be determined by E_{MT} and the secondary impedance. The velocity of the columns depends on resistance and excitation requirements, and this determines the value of the counter-E. M. F. which modifies E_{MT} to some value such as E_{MR} . This, together with the impedance, determines the value of I_2 during running conditions.

Fig. 34 is the motor-generator vector in which $-E$ is the line voltage, I_M is the motor current, that is the primary current required to drive the mercury, and I_G is the generator current, that is a current in the mercury that circulates about and excites the auxiliary pole. The power is the product of the voltage and the projection I_1 of the current I_M , and I_2 , the projection of I_G , which are herein shown equal. For the same power a small motor current I_M can cause a much larger exciting (low power factor) current I_G to circulate. Note the improvement in power factor from θ_G to θ_M in so far as the line is concerned. It is obviously better to generate I_G than to draw it from the line.

Since certain changes may be made in the above construction and different embodiments of the invention could be made without departing from the scope thereof, 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.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention which, as a matter of language, might be said to fall therebetween.

Having described my invention, what I claim as new and desire to secure by Letters Patent is: 75

1. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit creating a magnetic field, and means associated with said conduit for modifying said magnetic field to cause the same to sweep in the direction of extension of the conduit.

2. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, an auxiliary core having its pole pieces embracing said conduit adjacent to said energized core, whereby movement of a conducting liquid within said conduit through the flux of said energized core will energize said second mentioned core, thereby creating a sweeping field.

3. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, an auxiliary core having its pole pieces embracing said conduit adjacent to said energized core, whereby movement of a conducting liquid within said conduit through the flux of said energized core will energize said second mentioned core, thereby creating a sweeping field, and a by-pass conduit connecting a point in said conduit at the center of the pole face of said second mentioned core with another point in said conduit.

4. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, a pair of permeable cores, each having pole faces embracing said conduit, one on each side of and adjacent to said energized core, whereby motion of a conducting liquid within said conduit through the magnetic field of said energized core will energize said adjacent cores out of phase with the flux in said energized core, whereby a sweeping flux is obtained.

5. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux

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across said conduit, a pair of permeable cores, each having pole faces embracing said conduit, one on each side of and adjacent to said energized core, whereby motion of a conducting liquid within said conduit through the magnetic field of said energized core will energize said adjacent cores out of phase with the flux in said energized core, whereby a sweeping flux is obtained, and a by-pass conduit connecting a point in said conduit at the center of a pole face of the energized core with a point in the conduit at the center of the pole face of one of said other cores.

6. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, a pair of permeable cores, each having pole faces embracing said conduit, one on each side of and adjacent to said energized core, whereby motion of a conducting liquid within said conduit through the magnetic field of said energized core will energize said adjacent cores out of phase with the flux in said energized core, whereby a sweeping flux is obtained, and an auxiliary conduit connecting a point in said conduit at the center of a pole face of the energized core, with points in said conduit at the centers of the pole faces of each of said other cores.

7. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, and means for passing across said conduit from one electrode to the other a current substantially in phase with the flux within said core, including a constant current transformer having its primary in series with the primary of the exciting coil.

8. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, and means for passing across said conduit from one electrode to the other a current substantially in phase with the flux within said core, including a secondary coil upon said main core having its terminals connected to said electrodes.

9. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, and means for passing across said conduit from one electrode to the other a current substantially in phase with the flux with-

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in said core, including a secondary coil upon a closed branch of said main core having its terminals connected to said electrodes.

10. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, and means for passing across said conduit from one electrode to the other a current substantially in phase with the flux within said core, including a secondary coil upon a separate portion of said main core having an adjustable air gap therein, and having its terminals connected to said electrodes.

11. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, a pair of auxiliary cores, each having pole faces embracing said conduit between them, and each of said auxiliary cores having a magnetizing coil, which magnetizing coils are connected together, auxiliary means for passing an electric current through said conduit from one electrode to the other, including a transformer having its secondary connected across said electrodes, and means for reversing the current in the energizing coil for said first mentioned core.

12. A device in accordance with claim 1, having a magnetic electrically conducting liquid in said conduit.

13. A device in accordance with claim 2, having a magnetic electrically conducting liquid in said conduit.

14. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid, a magnetic core having pole faces embracing said conduit, an electric coil for energizing said core to create an alternating magnetic flux across the conduit, and means associated with said conduit for modifying said magnetic field to cause the same to sweep in the direction of extension of the conduit.

15. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid, a magnetic core having pole faces embracing said conduit, an electric coil for energizing said core to create an alternating magnetic flux across the conduit, an auxiliary core having pole faces embracing said conduit adjacent to the energized core, whereby movement of a conducting liquid within said conduit through the flux of said energized core will energize said second mentioned core, thereby creating a sweeping field.

16. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid, a magnetic core having pole faces embracing said conduit, an electric coil for energizing said core to create an alternating magnetic flux across the conduit, means associated with said conduit for modifying said electrical field to cause the same to sweep in the direction of extension of the conduit, and

a magnetic electrically conducting liquid within said conduit.

17. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, an auxiliary core having its pole faces embracing said conduit adjacent to said energized core, whereby movement of a conducting liquid within said conduit through the flux of said energized core will energize said second mentioned core, thereby creating a sweeping field, and a by-pass conduit connecting a point in said conduit at the center of the pole face of said energized core with another point in said conduit.

18. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, a permeable core adjacent to said first mentioned core having pole faces embracing said conduit, whereby motion of a conducting liquid within said conduit through the magnetic field of said energized core will energize said adjacent core out of phase with the flux in said energized core, whereby a sweeping field is obtained, and a by-pass conduit connecting a point in said conduit at the center of a pole face of the energized core with a point in the conduit at the center of a pole face of said permeable core.

19. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid, a plurality of paths for said conducting liquid, magnetic means for moving a liquid within said conduit along each of said paths with alternating motions out of phase with each other, whereby a substantially continuous flow is obtained.

20. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid, said conduit having means to permit oscillatory motion of liquid in one part, out of phase with oscillatory motion in another part, a plurality of electrical means for inducing a reciprocating flow of a conducting liquid within said conduit, through said conduit, said means being out of phase with each other, whereby the reversal of the liquid in one portion of said conduit occurs while the liquid in another portion of the conduit is moving.

21. In a system for reciprocating a conducting liquid through a conduit against a load by electromagnetic means, including a magnetic field reacting upon the liquid the method of reducing the starting current which comprises providing an unloaded by-pass for said conducting liquid from within said conduit.

22. In a device for the reciprocation of a conducting fluid through a conduit by means of an alternating flux passed across the conduit, the method of improving the power factor which comprises impressing upon the conducting liquid a voltage in such phase as to shift the phase of

oscillatory motion of the secondary current in the liquid in the direction of lead, with respect to the main voltage.

23. In a device for the reciprocation of a conducting fluid through a conduit by means of an alternating flux passed across the conduit, the method of reducing the starting current which comprises providing an initially unloaded pathway for said conducting liquid and starting a portion of said liquid in motion through said pathway while not under load before starting the remainder in motion.

24. A device of the character described comprising a conduit having a pair of electrodes longitudinally disposed therein, a compression chamber at each end of said conduit including a valve mechanism for pumping fluid by the movement of said conducting fluid, a pair of motor units, each comprising a magnetic core having its poles spaced apart in a direction transverse to the spacing of said electrodes to embrace said conduit, and an electric coil for energizing said core to create an alternating magnetic flux across said conduit, and means associated with said conduit for modifying said electric field to cause the same to move a conducting liquid contained within said conduit in the direction of motion of the conduit, and an auxiliary chamber connected to said conduit intermediate between said motors whereby the movement of said conducting fluid through one of said motors may be out of phase with the movement of the fluid through the other of said motors.

25. A device of the character described comprising a conduit having a pair of electrodes longitudinally disposed therein, a compression chamber at each end of said conduit including a valve mechanism for pumping fluid by the movement of said conducting fluid, a pair of motor units, each comprising a magnetic core having its poles spaced apart in a direction transverse to the spacing of said electrodes to embrace said conduit, and an electric coil for energizing said core to create an alternating magnetic flux across said conduit, each of said motors having a core having its pole face divided into a plurality of pole sections, one of said sections being energized by said coil whereby the movement of said conducting fluid past said energized section will induce secondary currents to energize said other section whereby said electric field is caused to sweep in the direction of extension of the conduit, and an auxiliary chamber connected to said conduit intermediate between said motors whereby the movement of said conducting fluid through one of said motors may be out of phase with the movement of the fluid through the other of said motors.

26. A device of the character described comprising a conduit having a pair of electrodes longitudinally disposed therein, a compression chamber at each end of said conduit including a valve mechanism for pumping fluid by the movement of said conducting fluid, a pair of motor units, each comprising a magnetic core having its poles spaced apart in a direction transverse to the spacing of said electrodes to embrace said conduit, and an electric coil for energizing said core to create an alternating magnetic flux across said conduit, each of said motors having a core having its pole face divided into three pole sections, the center of one of said sections being energized by said coil whereby the movement of said conducting fluid past said energized section will induce secondary currents to energize each of said

other sections whereby said electric field is caused to sweep in the direction of extension of the conduit in either direction of motion, and an auxiliary chamber connected to said conduit intermediate between said motors whereby the movement of said conducting fluid through one of said motors may be out of phase with the movement of the fluid through the other of said motors.

27. A device of the character described comprising a conduit having a pair of electrodes longitudinally disposed therein, a compression chamber at each end of said conduit including a valve mechanism for pumping fluid by the movement of said conducting fluid, a pair of motor units, each comprising a magnetic core having its poles spaced apart in a direction transverse to the spacing of said electrodes to embrace said conduit, and an electric coil for energizing said core to create an alternating magnetic flux across said conduit, each of said motors having a core having its pole face divided into three pole sections, the center of one of said sections being energized by said coil whereby the movement of said conducting fluid past said energized section will induce secondary currents to energize each of said other sections whereby said electric field is caused to sweep in the direction of extension of the conduit in either direction of motion, and an auxiliary chamber connected to said conduit intermediate between said motors whereby the movement of said conducting fluid through one of said motors may be out of phase with the movement of the fluid through the other of said motors, and an auxiliary conduit connecting a point in said conduit at the center of the energized pole with a point on said conduit at the center of one of said other poles.

28. A device of the character described comprising a conduit having a pair of electrodes longitudinally disposed therein, a compression chamber at each end of said conduit including a valve mechanism for pumping fluid by the movement of said conducting fluid, a pair of motor units, each comprising a magnetic core having its poles spaced apart in a direction transverse to the spacing of said electrodes to embrace said conduit, and an electric coil for energizing said core to create an alternating magnetic flux across said conduit, each of said motors having a core having its pole face divided into three pole sections, the center of one of said sections being energized by said coil whereby the movement of said conducting fluid past said energized section will induce secondary currents to energize each of said other sections whereby said electric field is caused to sweep in the direction of extension of the conduit in either direction of motion, and an auxiliary chamber connected to said conduit intermediate between said motors whereby the movement of said conducting fluid through one of said motors may be out of phase with the movement of the fluid through the other of said motors, said auxiliary chamber being open at its upper end and having a check valve in said opening.

29. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, and means for passing across said conduit from one electrode to the other a

current substantially in phase with the flux within said core, and auxiliary poles embracing said conduit adjacent to the poles of said core whereby the short circuit currents in said conduit are reduced and a flux is generated in said auxiliary poles, which assists in driving said liquid.

30. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, and means actuated by motion of the liquid through said conduit for giving a sweeping motion to the flux in the direction of motion, whereby the motor force generated by the flux ceases when the motion ceases and is reversed when the motion ceases and reverses.

31. A device of the character described comprising, in combination, a conduit adapted to contain a conducting liquid and having a pair of electrodes within it spaced from each other in a direction transverse to the conduit, a magnetic core having its poles embracing said conduit and spaced in a direction transverse to the spacing of said electrodes, an electric coil for energizing said core to create an alternating magnetic flux across said conduit, an auxiliary core having its pole pieces embracing said conduit adjacent to said energized core, whereby movement of a conducting liquid within said conduit through the flux of said energized core will energize said second mentioned core, and auxiliary means for energizing said auxiliary core.

32. A device of the character described comprising a conduit having a pair of electrodes longitudinally disposed therein, a compression chamber at each end of said conduit including a valve mechanism for pumping fluid by the movement of said conducting fluid into said compression chamber, a pair of motor units, each comprising a magnetic core having its poles spaced apart in a direction transverse to the spacing of said electrodes to embrace said conduit, and an electric coil for energizing said core to create an alternating magnetic flux across said conduit, each of said motors having a core having its pole face divided into three pole sections, the center of one of said sections being energized by said coil whereby the movement of said conducting fluid past said energized section will induce secondary currents to energize each of said other sections whereby said electric field is caused to sweep in the direction of extension of the conduit in either direction of motion, and an auxiliary chamber connected to said conduit intermediate between said motors whereby the movement of said conducting fluid through one of said motors may be out of phase with the movement of the fluid through the other of said motors, said auxiliary chamber connecting at its upper end to the compression chamber and having valve mechanism to permit the discharge of gas against said compression chamber.

33. A device according to claim 1 having means to define the path of currents in the electrode tube comprising an insulating barrier within the conduit parallel to the direction of extension of said electrodes.

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