

Nov. 1, 1927.

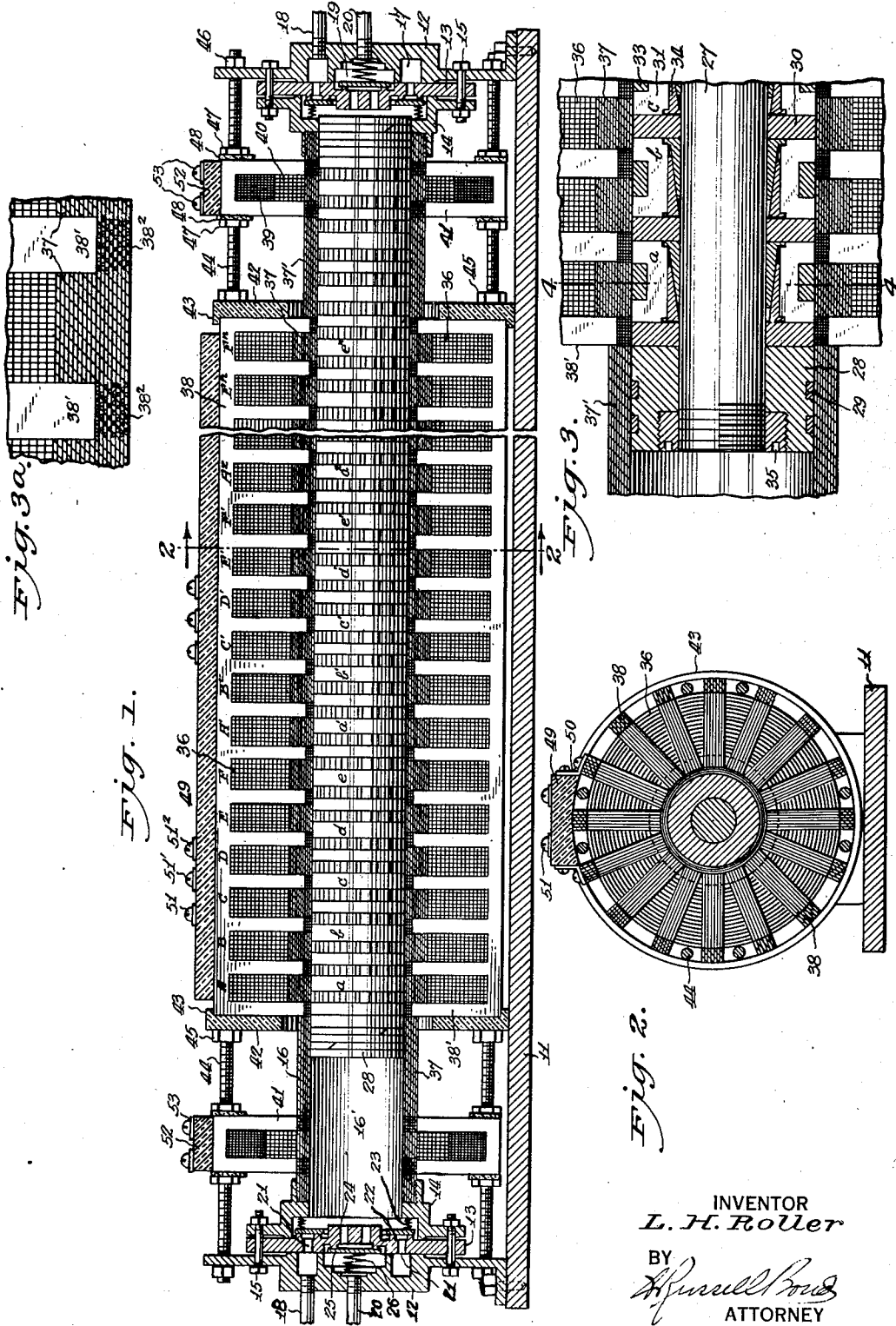
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1,647,147

ELECTROMAGNETIC PUMP

Filed May 2, 1924

3 Sheets-Sheet 1



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Fig. 6.

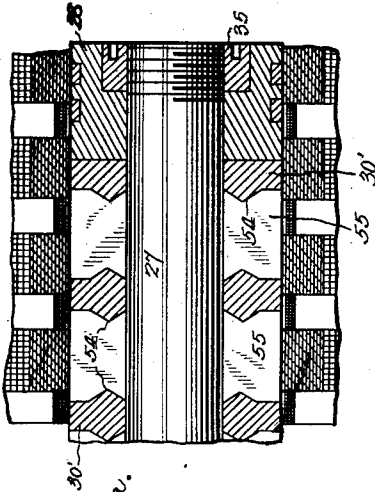


Fig. 5a.



Fig. 5.

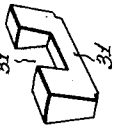


Fig. 4.

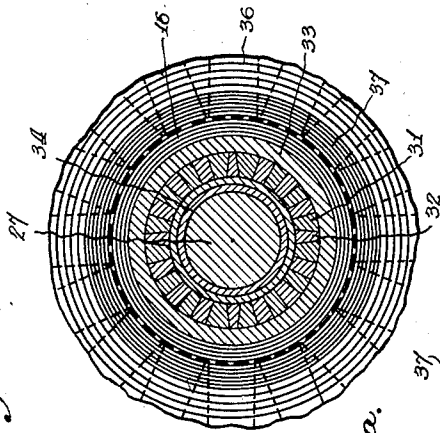


Fig. 6a.

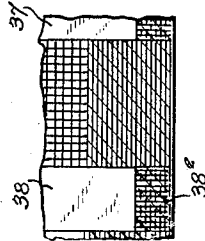
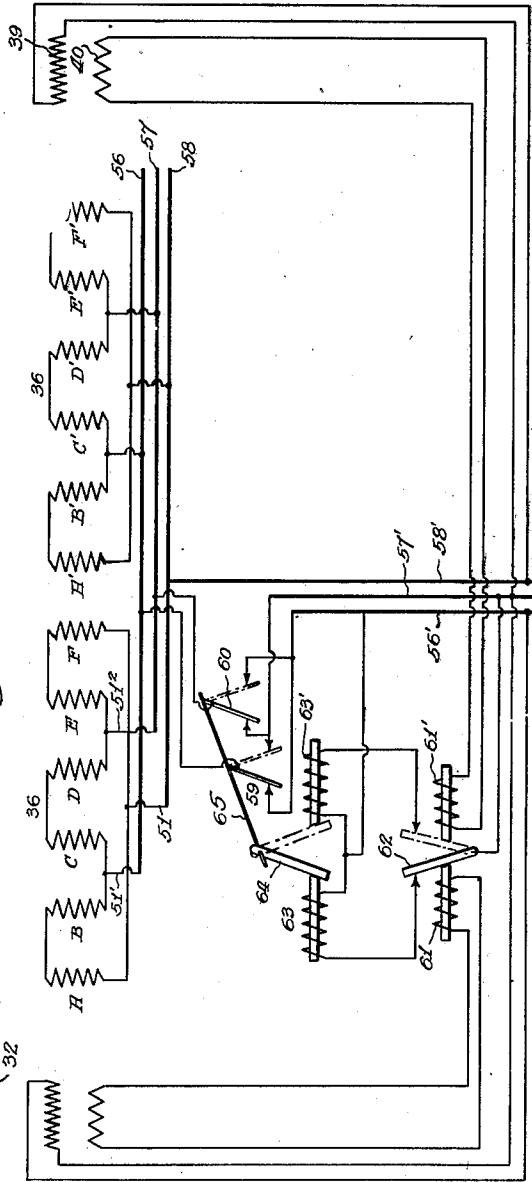


Fig. 7.



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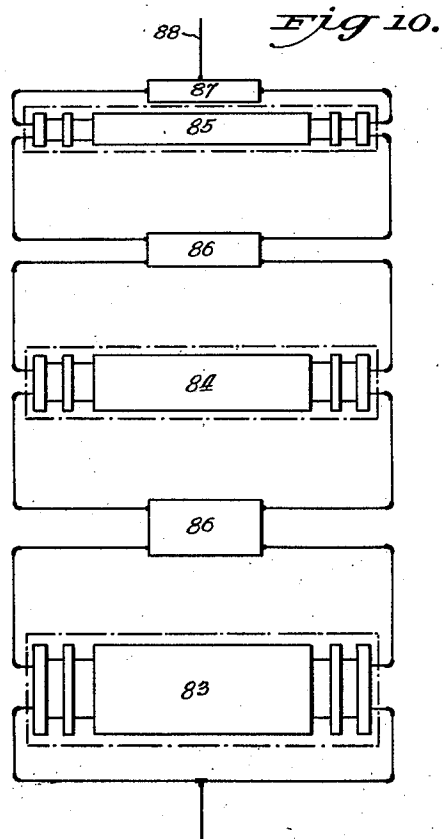
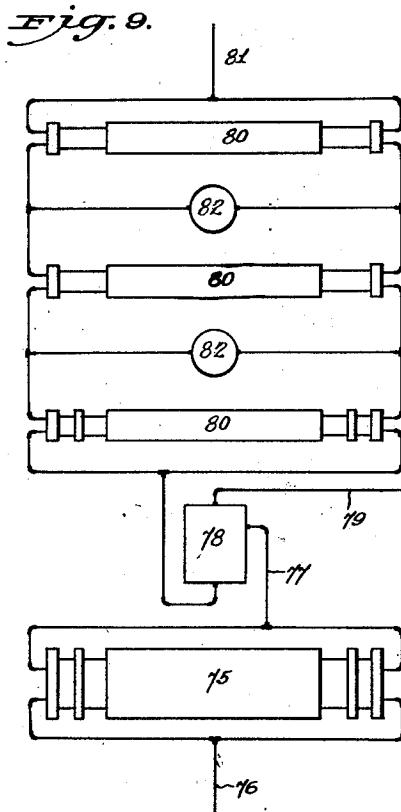
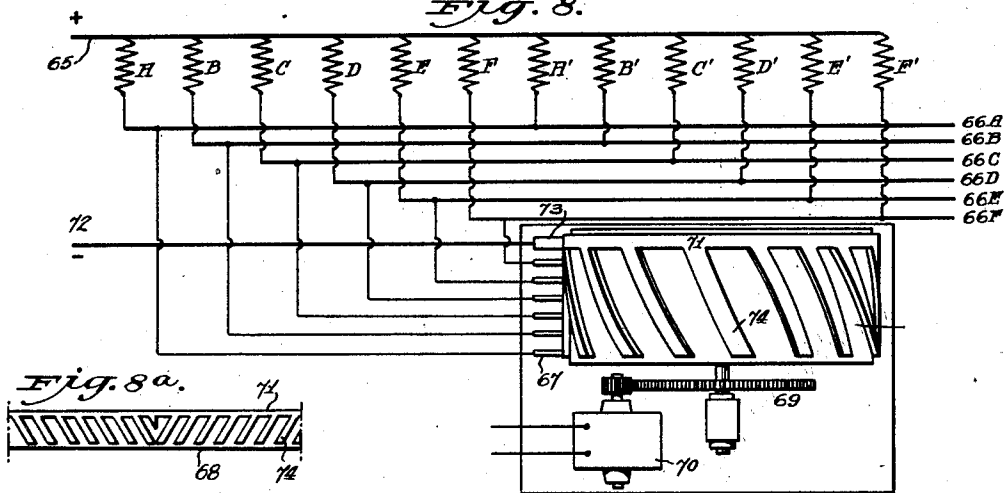
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3 Sheets-Sheet 3



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## UNITED STATES PATENT OFFICE.

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## ELECTROMAGNETIC PUMP.

Application filed May 2, 1924. Serial No. 710,680.

My invention relates broadly to pumps that operate on the principle of the solenoid. There are obvious advantages in pumps of this class; for they comprise a plunger or moving element operating within a cylinder or casing and actuated solely by magnetic pull, thereby obviating the necessity for any mechanical connection penetrating the cylinder, doing away with stuffing boxes and permitting a closed fluid system to be hermetically sealed.

Solenoid pumps as heretofore constructed have not been commercially successful because they were economically inefficient. It is an object of my invention to provide certain improvements whereby the efficiency of my pump will approach if not equal the efficiency of a rotary electric motor. This end I attain by providing sectional field windings on the cylinder and a sectional armature on the plunger, the field being progressively energized by a series of waves of electromagnetic energy, whereby the plunger receives a progressive magnetic pull at a number of different points along its length.

It is a further object of my invention to furnish improvements in details of construction of the cylinder and also of the armature and the field, whereby many of the magnetic losses common to solenoid pumps, as heretofore constructed are avoided.

A still further object of my invention is the provision of novel means for automatically reversing the operation of the plunger at the end of its stroke.

These and other objects are attained by a novel construction and combination of parts, clearly illustrated in the accompanying drawings, and described and pointed out in the following specification and claims.

Referring to the drawings,

Fig. 1 is a longitudinal section taken through my pump,

Fig. 2 is a cross section taken on the line 2—2 of Fig. 1,

Fig. 3 is an enlarged fragmentary view of a portion of the plunger showing details of the piston head, the armature sections and part of the cylinder wall and field coils,

Fig. 3<sup>a</sup> is an enlarged sectional view of a fragment of the cylinder,

Fig. 4 is a cross section taken on the line 4—4 of Fig. 3,

Figs. 5 and 5<sup>a</sup> are perspective views of

armature segments used in building up the armature sections of the pump plunger,

Fig. 6 is a sectional view of a fragment of the pump plunger and cylinder showing a modified form of armature segment,

Fig. 6<sup>a</sup> is a sectional view of a fragment of the pump cylinder similar to Fig. 3<sup>a</sup>, but showing a modified construction,

Fig. 7 is an electrical diagram of the pump showing the field connections employed with a three-phase alternating current source of power,

Fig. 8 is a diagrammatic view of the electrical connections employed with direct current or single-phase alternating current and also illustrates a form of commutator through which the field coils may be successively energized,

Fig. 8<sup>a</sup> is a plane projection of the commutator shown in Fig. 8,

Fig. 9 shows diagrammatically a method of interconnecting a series of electromagnetic pumps to provide for multi-stage pumping of liquids, and

Fig. 10 is a similar view showing the arrangement of pumps and pipe connections for furnishing a multi-stage compression of gaseous fluids.

Referring to the drawings in detail, and particularly to Figs. 1, 2 and 3, 11 represents a base on which the pump is mounted. At each end of this base, there is a bracket 12 which forms a valve head for my pump. Associated therewith is a valve body 13 and a flanged collar 14. The members 14 are internally threaded to receive the ends of the cylinder 16. Within this cylinder is located a plunger which is of a shorter length than the cylinder so as to provide a suction and compression space 16' at opposite ends of the cylinder. In each member 12, there is an annular recess 17 with which a suction or inlet pipe 18 communicates, while centrally located with respect to the annular recess is a chamber 19 with which a discharge or outlet pipe 20 communicates.

The valve bodies 13 are provided with series of suction ports 21 communicating with the annular recesses 17 and closed by annular suction valve plates 22 which are normally held in closed position by springs 23. The valve bodies are also provided with discharge ports 24, furnishing communication between the interior of the cylinder

and the chambers 19 and these ports are closed by means of discharge valve plates 25 held normally in closed position by springs 26.

5 The precise details of this construction are immaterial to my invention and are given merely as an illustration of a valve mechanism which could be employed at each end of the cylinder. It will be evident that  
10 material departures from the exact construction illustrated and described can be made without departing from the spirit and scope of my invention.

Referring now more particularly to the  
15 plunger, it will be seen to consist of a central rod 27 provided at each end with a piston head 28 which carries the usual piston rings 29 to afford a tight seal. All these parts are preferably of non-magnetic material. Intermediate these piston heads is the  
20 armature of the plunger which consists of a series of sections separated by collars 30 of non-magnetic material. Each armature section is of annular form being built up of  
25 soft iron segments 31 and 32 (see Figs. 5 and 5<sup>a</sup>). The segments are recessed at 31' and 32' respectively to receive a retaining non-magnetic ring 33. As shown in Figs. 3 and 4, the segments are clamped tightly between the retaining rings 33 and the rod 27  
30 by means of wedges 34. Were all the segments of the sector form shown in Fig. 5, they would tend to separate as the wedges were tightened leaving undesirable spaces  
35 between them. To avoid this the segments 32 are provided which are reversely tapered with respect to the segments 31. Segments 32 are introduced at several points in the armature section and as the wedges 34 are  
40 tightened the segments are crowded together into a continuous compact annular mass. The entire series of built-up armature sections with the spacer collars 30, is clamped between the piston heads 28 by means of  
45 nuts 35 which enter recesses in the piston heads and are threaded upon the rod 27.

The cylinder 16 is formed of non-magnetic material and preferably of non-conducting material. On this cylinder is provided  
50 a series of flat field coils 36 which are mounted on thickened portions 37 of the cylinder. These thickened portions serve to reinforce the cylinder and they may be either integral with the cylinder, or may  
55 consist of collars shrunk on the cylinder. It is important, however, that they be of non-magnetic material and preferably non-metallic.

In order to provide a good magnetic path  
60 for the lines of force generated by the field coils, the field is clad with yokes of laminated soft iron. The laminae are of comb-shape as indicated at 38 in Fig. 1 and the yokes are arranged radially about the cylinder  
65 with the teeth 38' of the combs project-

ing between the field coils and bearing against the cylinder wall at the points of reduced section between the thickened portions 37. These laminated yokes serve also  
70 as a reinforcement for the cylinder walls.

Intermediate between the field coils and the valves at each end of the pump is a transformer comprising a primary winding  
75 39 and a secondary winding 40. U-shaped laminated yokes 41 of soft iron are fitted radially over these coils and bear against the cylinder 16. Between the field coils and the ends of the collars 14 the cylinder walls are thickened as indicated at 37' to add  
80 strength to the cylinder.

To support the field coils, two discs 42 are provided which are apertured to pass over the cylinder 16 and fit against the yokes 38. These discs are formed with flanges 43 which overlap the yokes. Bolts 44 pass through  
85 the discs and between the yokes 38, as shown in Fig. 2, and carry nuts 45 which bear against the discs 42, clamping them against the yokes. These bolts also extend through the brackets 12 to which they are clamped  
90 by means of nuts 46. The transformers at each end of the pump are also supported on the bolts 44, as shown in Fig. 1, the bolts being provided with clamping nuts 47 which are screwed against clamping rings 48,  
95 which bear against the yokes 41. By adjusting nuts 47 the transformers may be shifted to any desired position on the cylinder.

A plate 49 is secured to the yokes 38 by  
100 means of brackets 50, as shown in Fig. 2. This plate carries the binding posts 51, 51' and 51<sup>2</sup> which form terminals of the field coils, as will be explained presently. Similar plates 52 are secured to the top of the  
105 transformers and carry binding posts 53 which serve as terminals for the transformer windings.

For the cylinder 16 I prefer to use a structure built up of layers of fabric suitably  
110 cemented together to form an integral mass. In order to increase the magnetic permeability or in other words to reduce magnetic reluctance to the minimum at the points where the teeth or legs 38' of the yokes 38 bear  
115 against the cylinder, soft iron wire or soft iron particles are embedded into the fabric. The wire may be coiled about the layers of the fabric as the cylinder is built up. Fig. 3<sup>a</sup> illustrates a portion of the cylinder in section,  
120 showing the wire 38<sup>2</sup> embedded in the fabric. Another method of increasing the magnetic permeability at these points is shown in Fig. 6<sup>a</sup>, in which the wires 38<sup>2</sup> instead of being wound circumferentially  
125 around the cylinder are inserted radially into the fabric without penetrating the inner surface of the cylinder.

In Fig. 6, I show a modified form of armature on the plunger of the pump. Spacing  
130

rings 30' are used and these are formed with V-shaped annular ribs 54 which engage recesses of similar shape in the ends of the armature segments 55, so that as the armature sections are pressed together by the nuts 35 on the plunger shaft 27, the segments are clamped in position. The rings 30', therefore, serve both as spacing rings and retaining rings, so that rings 33 may be omitted.

When my pump is designed for use on a three-phase alternating circuit, the field coils 36 may be arranged in groups of six, each group consisting of three pairs of coils. For example, coils AB, CD and EF form the first group, coils A'B', C'D' and E'F' the second group, etc. The three pairs of coils of each group are connected in delta formation to bus bars 56, 57, and 58 of the three-phase power line. Thus, when the wave of maximum potential is sweeping through coils AB, it will be simultaneously sweeping through coils A'B', A<sup>2</sup>B<sup>2</sup>, A<sup>3</sup>B<sup>3</sup>, in other words, there will be as many waves of electrical energy simultaneously sweeping through the field coils as there are groups of coils. The direction of travel of the waves may be reversed by interchanging connections of two of the bus bars. The bus bar 58 is normally connected with wire 58' of the three-phase power line, while switches 59 and 60 are interposed between bus bars 56 and 57 respectively and wires 56' and 57' respectively of the power line. With switches 59 and 60 occupying the position shown by full lines in Fig. 7, bus bar 56 is connected to line 56' and bus bar 57 to line 57' and a wave of potential then travels in the direction AB, CD, EF, A'B', etc., but when the switch is thrown to the position shown by dotted lines bus bar 56 is connected to line 57' and bus bar 57 to line 56' so that the wave travel now takes the direction A'B', EF, CD, AB. The switches 59 and 60 are thrown by means of change in flux of the transformers at each end of the pump. The primary winding 39 of each transformer takes its power from the power supply lines and the secondary windings 40 of the transformers are respectively connected to relay magnets 61 and 61'. These magnets operate to throw a switch 62 in one direction or the other depending upon which produces the greater magnetic pull. The current induced in the secondary windings 40 is normally of low value, because there is no magnetic core for the transformer. However, when the plunger moves to the end of its stroke and an armature section passes between ends of yokes 41, the change of magnetic flux causes the potential of induced current to be immediately increased to such an extent as to operate the relay magnet connected therewith and throw the switch 62. Thus, the switch 62 is thrown first in one direction and then in the other as the plunger

reaches one end or the other of its stroke. The switch 62 serves to close a circuit from power lines 56' and 57' through one or the other of two switch magnets 63 and 63', which, in turn will throw an armature 64 in one direction or another, depending upon which of the magnets 63 or 63' is energized. The armature 64 is carried by a shaft 65 on which the two switch arms 59 and 60 are secured thereby reversing the direction of travel of the waves of current as described above.

Referring to Fig. 1, it will be observed that for every group of six field coils, there are five armature sections indicated by the letters *a b c d e*, *a' b' c' d' e'* etc. When the maximum magnetic flux is generated by coils AB, A'B', etc. the sections *a b*, *a' b'*, etc. will be in position to receive the maximum pull and will center themselves with respect to coils AB, A'B' etc., thereby bringing the next pair of sections *c d* in position to receive the pull of coils CD, C'D', etc., and as the wave of maximum flux is generated by coils EF, E'F' etc. armature sections *e a'*, *e' a'*, etc. will be drawn to centered position under coils EF, EF' etc. Thus as the wave of maximum magnetic flux traverses each group in one direction, the plunger advances in the opposite direction through a space equal to the width of one armature section and this continues until the plunger reaches the end of its stroke when one of the armature sections enters the transformer yoke at that end of the cylinder reversing the direction of travel of the waves of current and thereby causing the plunger to move in the opposite direction.

The windings of each pair of field coils 36 are reversed or are so connected that there will be no neutralization of magnetic flux in the legs 38' of the yoke between the coils; for instance, when coil A is causing a flux in clockwise direction, coil B will be causing a flux in counter-clockwise direction and the two fluxes will combine instead of neutralizing each other. Hence, in designing my pump, it will be necessary to make the legs 38' of the yokes of sufficient cross sectional area to carry twice the flux that would be generated by a single coil.

The operation of valve plates 22 and 25 as the plunger reciprocates within the cylinder is obvious and needs no detailed description.

When it is desirable to use direct current or single phase alternating current instead of three-phase alternating current to operate the pump, the connections shown in Fig. 8 may be employed. The coils are arranged in groups of six indicated as before by the letters ABCDEF, A'B'C'D'E'F', etc. All the coils are connected at one end to a power line 65 and at the other end of the coils A A' etc. are connected to a bus bar 66A, the coils

B, B' etc. to a bus bar 66B etc., there being six bus bars, one for each coil of a group. Each bus bar is connected to a brush 67 which makes contact with a commutator 68.

5 The commutator is driven through suitable gearing by a motor 70. As shown in Fig. 8<sup>a</sup>, which is a plane projection of the commutator, the surface of the commutator carries an endless contact strip 71 which is electrically connected with power wire 72 through

10 brush 73. Projecting from the contact strip 71 and spirally arranged about the surface of the commutator are inclined branch strips 74 with which brushes 67 make contact. Due

15 to the pitch of the strips 74 the circuit through the coils of each group is successively closed. In other words, the pitch of the strips 74 is so chosen that just as the circuit through the bus bar 66A is being

20 broken on one strip 74, the circuit through bus bar 66B; on the next strip 74 is being closed. Owing to the successive closing of the circuits through the coils of each group, a wave of electric current passes through

25 each group and this is followed by a wave of magnetic flux which acts to attract the plunger in the opposite direction. The gearing 69 is so chosen that the commutator makes a half revolution for a complete

30 stroke of the plunger. Referring again to Fig. 8<sup>a</sup> it will be observed that the contact strips 74 are inclined to the right in one half of the commutator and to the left in the other half, so that as soon as the plunger

35 has completed its stroke in one direction, the brushes 67 engage contact strips 74 which are inclined in the opposite direction therefore reversing the direction of travel of the magnetic waves of energy.

40 While I have shown the field coils arranged in groups of six and a space relation of six to five between the field coils and the armature sections, I do not wish to limit myself to this grouping and relation. It

45 will be obvious that instead of a delta connection described a star connection could be used and material departures may be made from said groupings and space relations while keeping within the scope of my invention.

50 Figs. 9 and 10 show two applications of my pump, the former for pumping liquids and the latter for pumping gases. Owing to the cheapness and simplicity of construction

55 of my pump and also because the cylinder is completely sealed so that there are no losses due to packings, it is economical to use a number of pumps and thereby step up the pressure by stages. In Fig. 9, I show a

60 large electromagnetic pump 75 which draws a mixture of liquid and gas from an inlet supply pipe 76 and discharges it from opposite ends of the pump through pipe 77 into a separator 78.

65 Any gases that may be mixed with the

liquid are separated out in the chamber 78 and are drawn out from the top of the chamber through pipe 79 at increased pressure over 76. The liquid is then drawn from the separator by pumps 80 which operate successively to build up the pressure to any desired amount before it is finally discharged through the pipe 81. Equalizing chambers 82 are connected across opposite discharge pipes of the pumps to equalize the

7 pressure between stages. The equalizers are closed vessels each containing a gas pocket which serves as a cushion to prevent hammering.

The equipment illustrated in Fig. 10 for compressing gas is similar to that shown in Fig. 9 except that the pumps 83, 84 and 85 are progressively smaller from the low pressure to the high pressure stage. Between each pair of pumps there is an intercooler 86 and the high pressure pump discharges into an equalizer 87 whence the gas is led off through pipe 88. Each pump may be submerged in a tank of oil or other cooling liquid indicated by broken lines 88 to carry off the heat of compression.

I claim—

1. A reciprocating electromagnetic pump comprising a coil for producing a magnetic field, an armature actuated by the field, a transformer comprising a primary and a secondary winding, the armature being adapted to enter the secondary winding at the end of its stroke, thereby increasing the electrical energy induced in the secondary winding, and a switch operated by said increased electrical energy to reverse the polarity of the field.

2. An electromagnetic pump comprising a cylinder, a plunger adapted to reciprocate therein, field coils adapted to be connected to a source of current and serving to actuate the plunger, a transformer at one end of the cylinder, and a switch for reversing the polarity of the field coils, said switch being operated by current variations resulting from variations in the magnetic circuit of the transformer produced by the plunger.

3. An electromagnetic pump comprising a cylinder, a plunger adapted to reciprocate therein, field coils adapted to be connected to a source of current and serving to actuate the plunger, a transformer at one end of the cylinder, a switch for reversing the polarity of the field coils, said switch being operated by current variations resulting from variations in the magnetic circuit of the transformer produced by the plunger, and means for varying the position of the transformer to vary the stroke of the plunger.

4. An electromagnetic pump comprising a cylinder, a plunger adapted to reciprocate therein, field coils adapted to be connected to a source of current and serving to actuate the plunger, a switch for reversing the

polarity of the current, and means actuated by variations in flux produced by the plunger for operating said switch.

5 An electromagnetic pump comprising a cylinder, field coils adapted to be energized by polyphase alternating current, a plunger in the cylinder adapted to be actuated by progressive waves of magnetic flux generated by the coils, a switch for reversing the phase  
10 relation of the coils, and means electromagnetically actuated by the plunger for throwing said switch.

6. A solenoid comprising a plurality of field coils, laminated yokes of high magnetic permeability overlying the coils and formed with legs disposed between the coils, a plunger adapted to operate within the coils, and an armature carried by the plunger comprising a plurality of annular sections, the  
20 width of the sections from center to center being greater than the space from center to center of said legs.

7. In a solenoid comprising a field coil, a cylinder of non-magnetic material and a  
25 plunger actuated by magnetic flux generated by the field coil, the combination of a yoke forming a path for the flux outside the cylinder, and elements of high magnetic permeability embedded in the cylinder to complete said path through the cylinder to and  
30 from the plunger.

8. A solenoid comprising a cylinder of non-magnetic material, a field coil mounted thereon and adapted to generate magnetic  
35 flux, a plunger in the cylinder, operated by said flux, a plurality of laminated soft iron yokes spanning the coil and extending radially inward to enter annular grooves formed in the cylinder, and soft iron wire  
40 embedded in the cylinder wall at the bottom of said grooves.

9. A plunger for a solenoid comprising an arbor, a series of sector shaped armature segments mounted thereon, means for retaining the segments, and means for wedg-  
45 ing the segments between said retaining means and the arbor.

10. A plunger for a solenoid comprising an arbor, sector shaped armature segments  
50 mounted thereon, wedged shaped keys inserted between certain of the segments, means for retaining the segments, and means for wedging the segments between said retaining means and said arbor.

55 11. A plunger for a solenoid comprising a series of armature sections, each section comprising a series of sector shaped segments, non-magnetic means for retaining the segments in position, and non-magnetic  
60 means for spacing the sections one from the other.

12. A reciprocating electromagnetic motor comprising a coil for producing a mag-

netic field, an armature actuated by the field, a reversing switch for controlling the field, 65 and a switch-operating coil, said armature being adapted to enter said switch-operating coil near the end of its stroke and cause current variations therein for operating said  
70 switch.

13. A reciprocating electromagnetic motor comprising a coil for producing a magnetic field, an armature actuated by the field, a reversing switch for controlling the field, a switch-operating coil, said armature being  
75 adapted to enter said switch-operating coil near the end of its stroke and cause current variations therein for operating said switch, and means for adjusting said switch-operating coil with respect to the stroke of said  
80 armature.

14. A reciprocating electro-magnetic motor comprising a coil for producing a magnetic field, an armature actuated by the field, a transformer, the armature being adapted  
85 to enter the transformer to effect an increase of current induced by the transformer, a reversing switch controlled by such induced current, and means for adjusting the transformer axially with respect to said field. 90

15. A reciprocating electro-magnetic motor comprising a coil for producing a magnetic field, an armature actuated by the field, a transformer, the armature being adapted  
95 to enter the transformer to effect an increase of current induced by the transformer, a reversing switch controlled by such induced current, and means for adjusting the position of the transformer with respect to the  
100 stroke of said armature.

16. A reciprocating electro-magnetic motor comprising a coil for producing a magnetic field, an armature actuated by the field, a transformer having a primary and a secondary winding and having also a yoke  
105 forming an incomplete para-magnetic circuit about the primary and secondary windings, the armature being adapted to enter the secondary coil near the end of its stroke to complete said para-magnetic circuit, thereby increasing the electrical energy induced in the secondary winding, and a reversing switch operable by said increased electrical energy. 110

17. A reciprocating electro-magnetic motor comprising a coil for producing a magnetic field, an armature actuated by the field, a transformer having a primary and a secondary winding and a normally incomplete  
115 para-magnetic circuit, the armature being adapted to complete said circuit near the end of its stroke, thereby increasing electrical energy induced in the secondary winding, and a reversing switch operable by said increased electrical energy. 120

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