

March 10, 1953

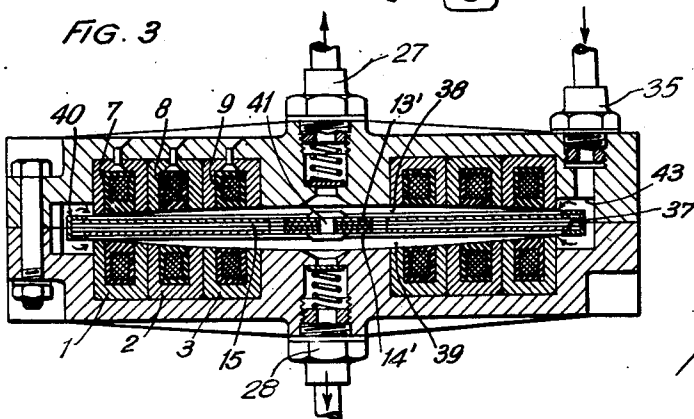
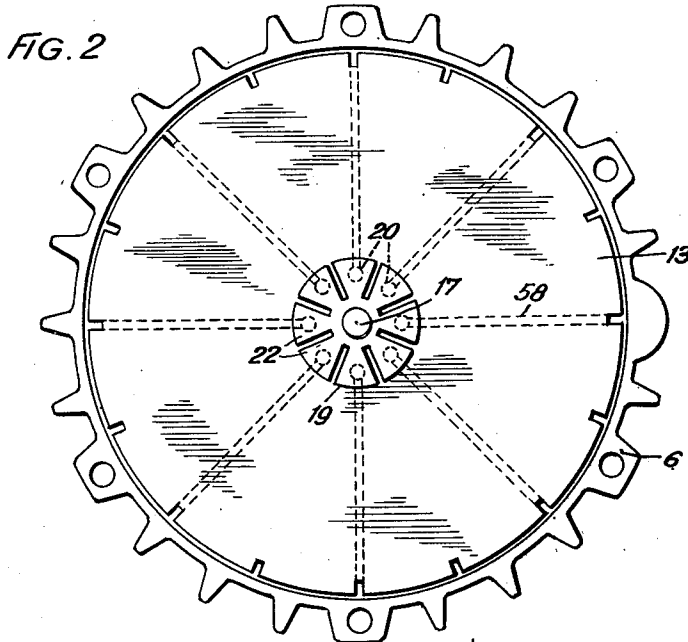
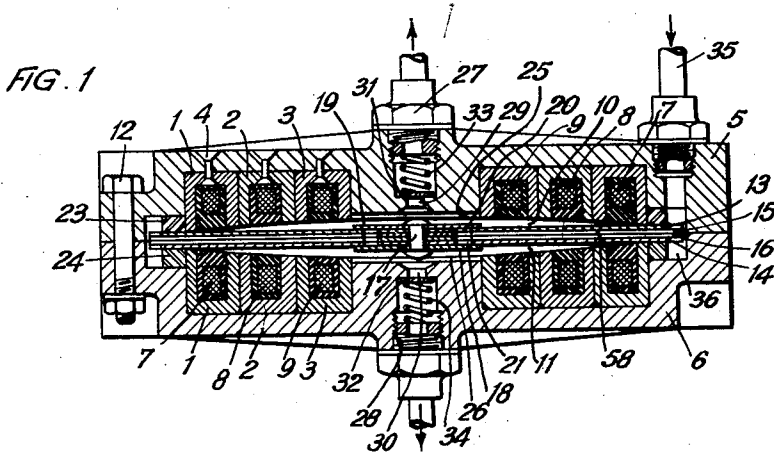
A. RYBA

2,630,760

ELECTROMAGNETIC PUMPING DEVICE FOR PUMPING FLUIDS

Filed Aug. 27, 1948

9 Sheets-Sheet 1



Inventor:
ANTON RYBA
BY
Andrew L. S. Henry
ATTORNEY.

March 10, 1953

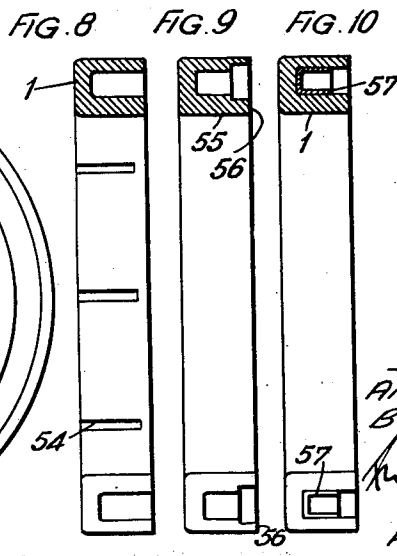
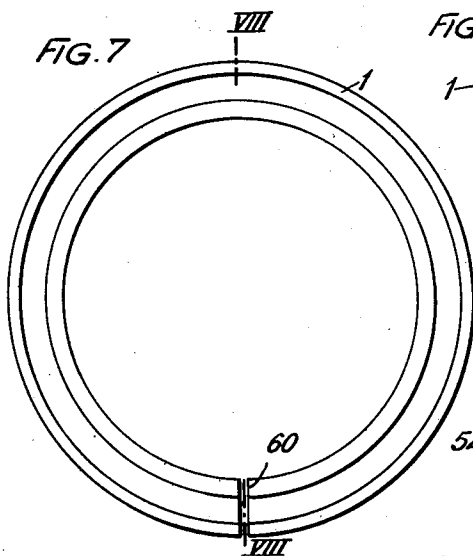
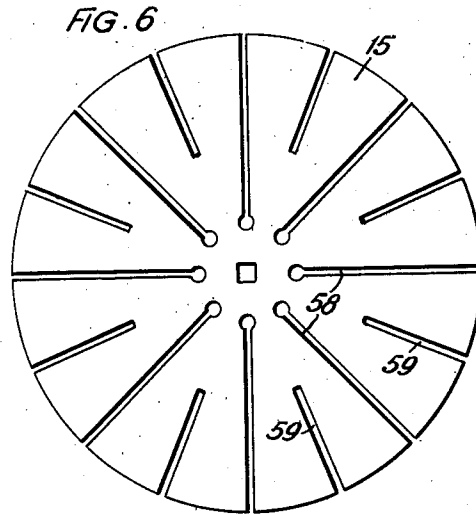
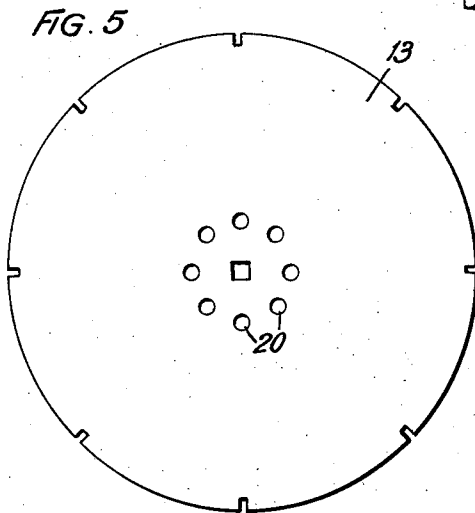
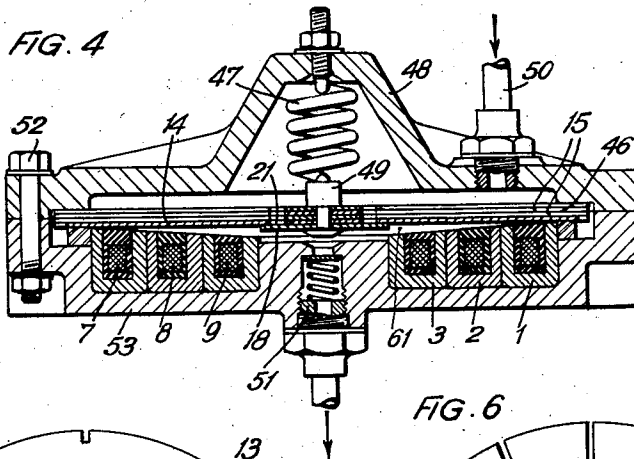
A. RYBA

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9 Sheets-Sheet 2



Inventor:
ANTON RYBA
BY
Frederick E. Hays
ATTORNEY.

March 10, 1953

A. RYBA

2,630,760

ELECTROMAGNETIC PUMPING DEVICE FOR PUMPING FLUIDS

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9 Sheets-Sheet 3

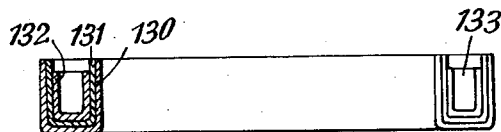


FIG. 11

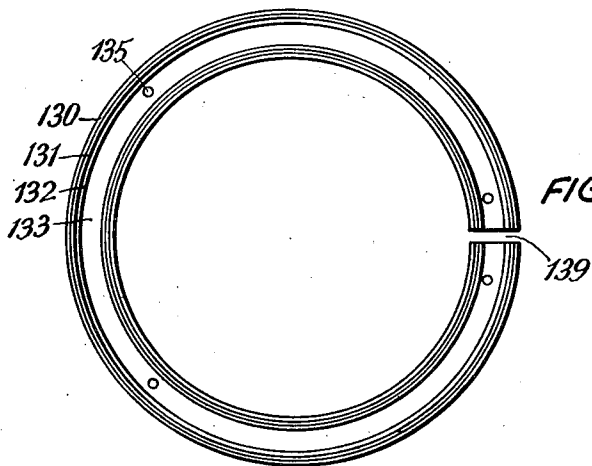


FIG. 12

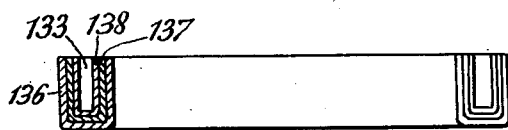


FIG. 13

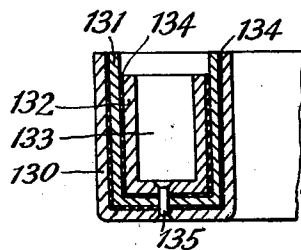


FIG. 14

Inventor:
ANTON RYBA
BY
Frederick E. Hany
ATTORNEY.

March 10, 1953

A. RYBA

2,630,760

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9 Sheets-Sheet 4

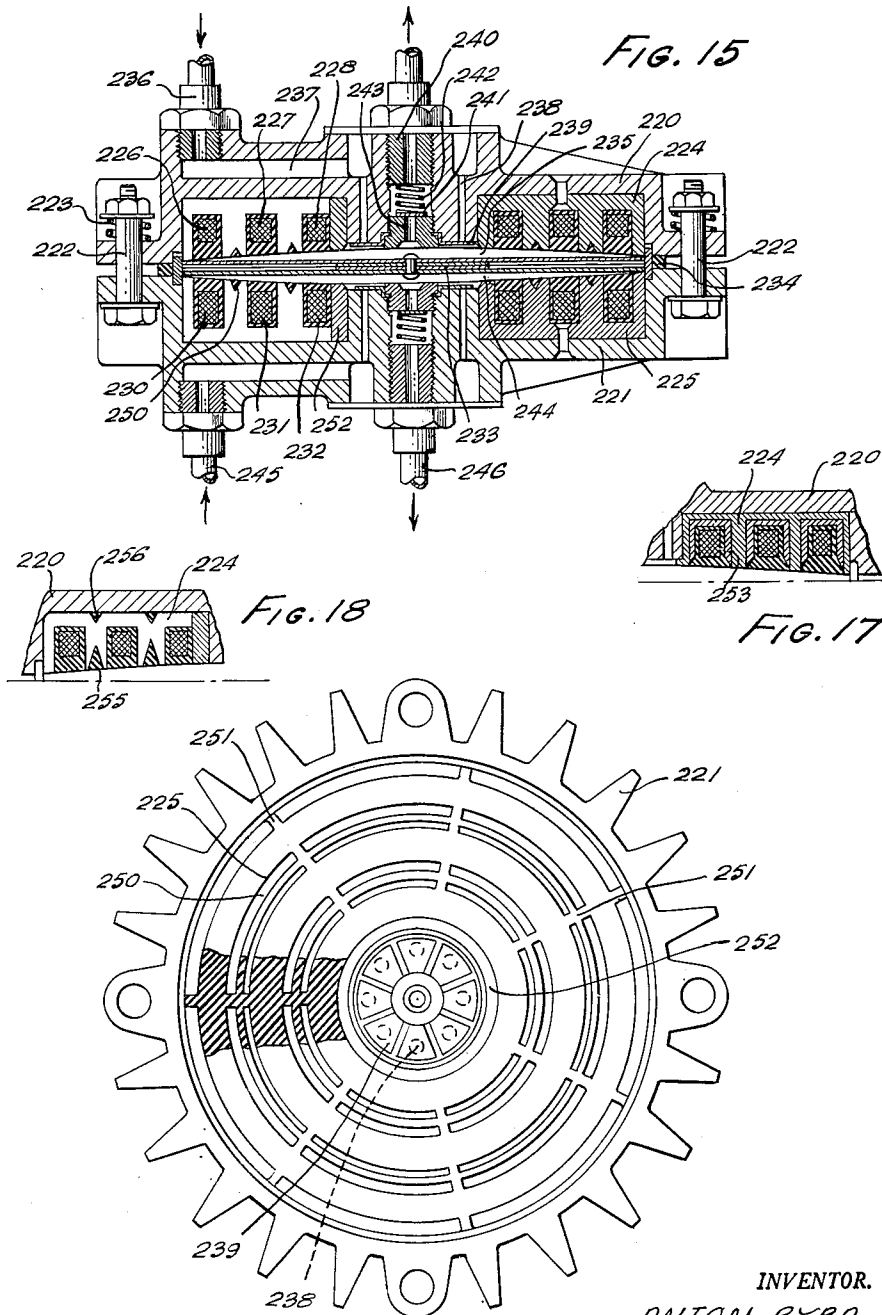


FIG. 16

INVENTOR.
ANTON RYBA
BY *Fredrick S. Hany*
ATTORNEY.

March 10, 1953

A. RYBA

2,630,760

ELECTROMAGNETIC PUMPING DEVICE FOR PUMPING FLUIDS

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9 Sheets-Sheet 5

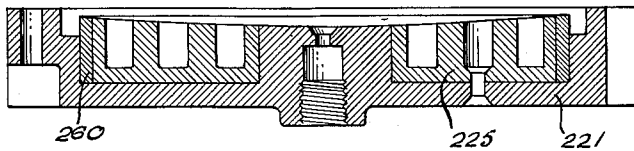


FIG. 19

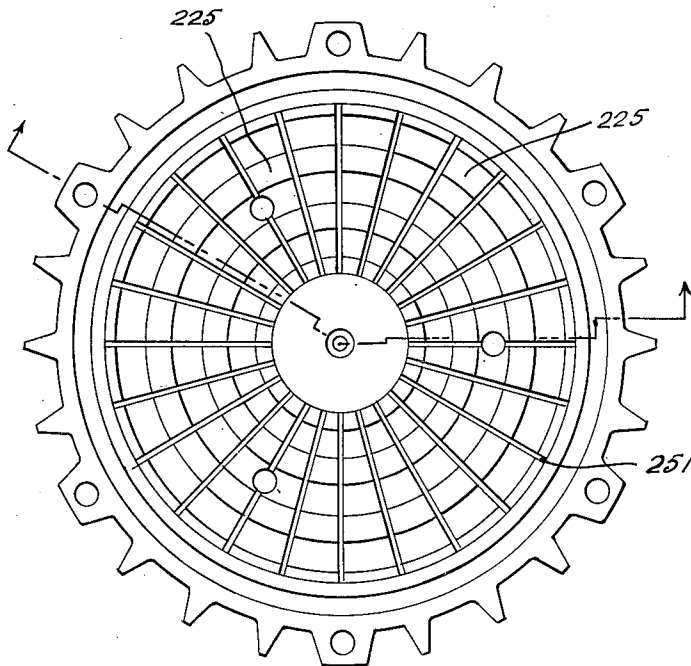


FIG. 20

INVENTOR.

ANTON RYBA

BY

Fredrick E. Harny

ATTORNEY.

March 10, 1953

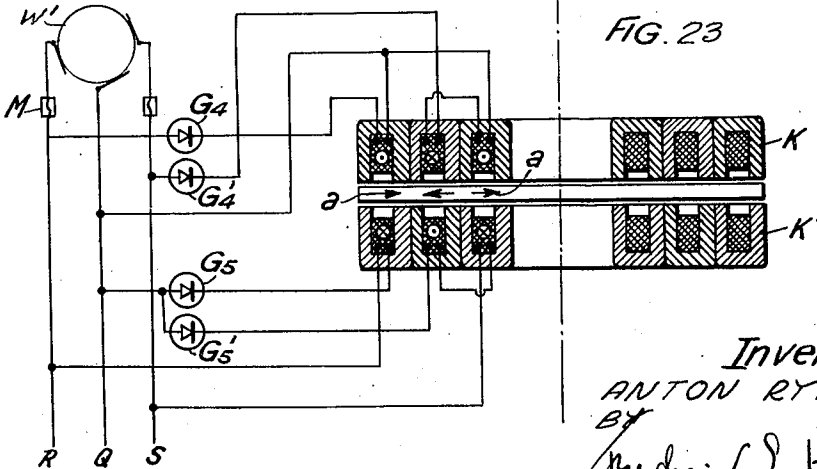
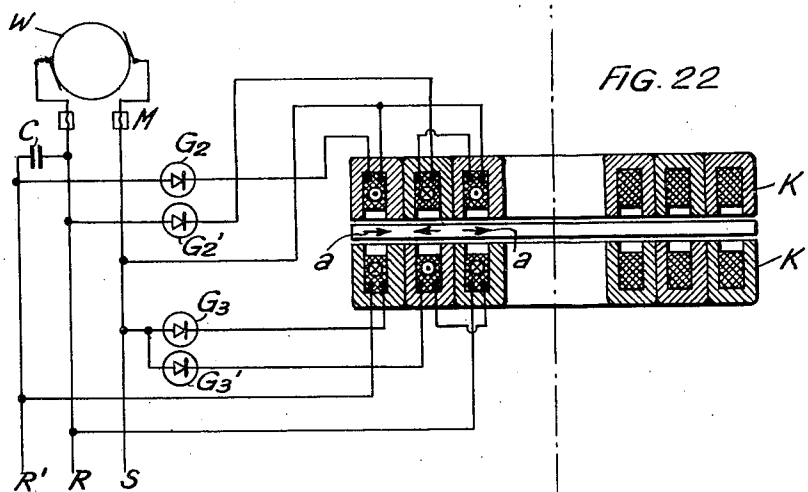
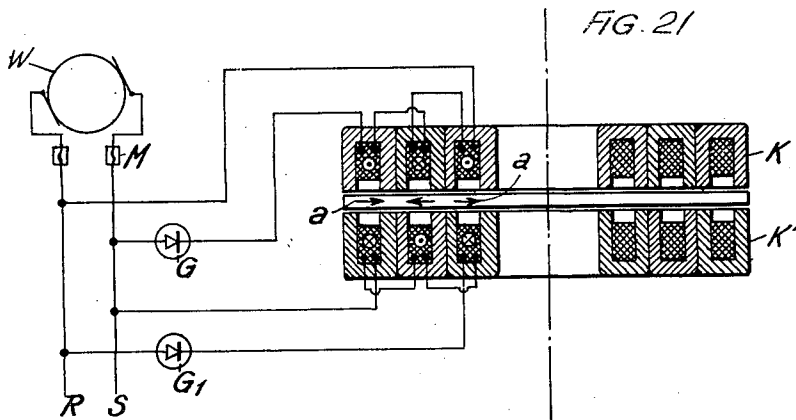
A. RYBA

2,630,760

ELECTROMAGNETIC PUMPING DEVICE FOR PUMPING FLUIDS

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9 Sheets-Sheet 6



Inventor:
ANTON RYBA
BY
Richard L. Hamy
ATTORNEY.

March 10, 1953

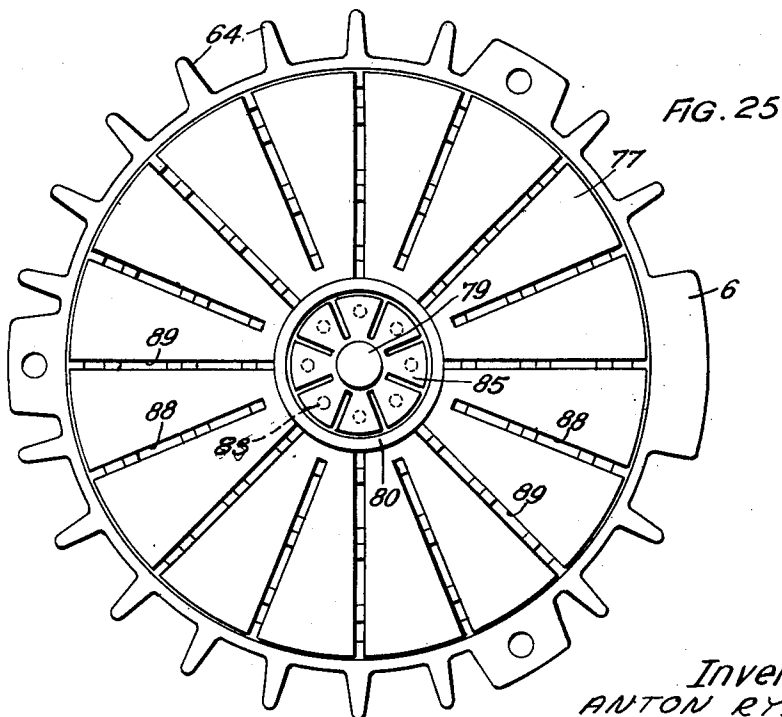
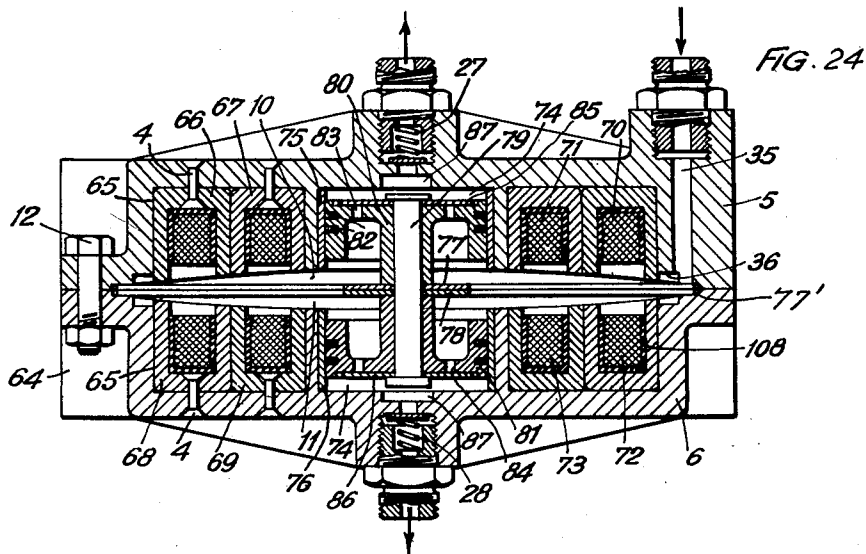
A. RYBA

2,630,760

ELECTROMAGNETIC PUMPING DEVICE FOR PUMPING FLUIDS

Filed Aug. 27, 1948

9 Sheets-Sheet 7



Inventor:
ANTON RYBA
BY
Frederick E. Haug
ATTORNEY

March 10, 1953

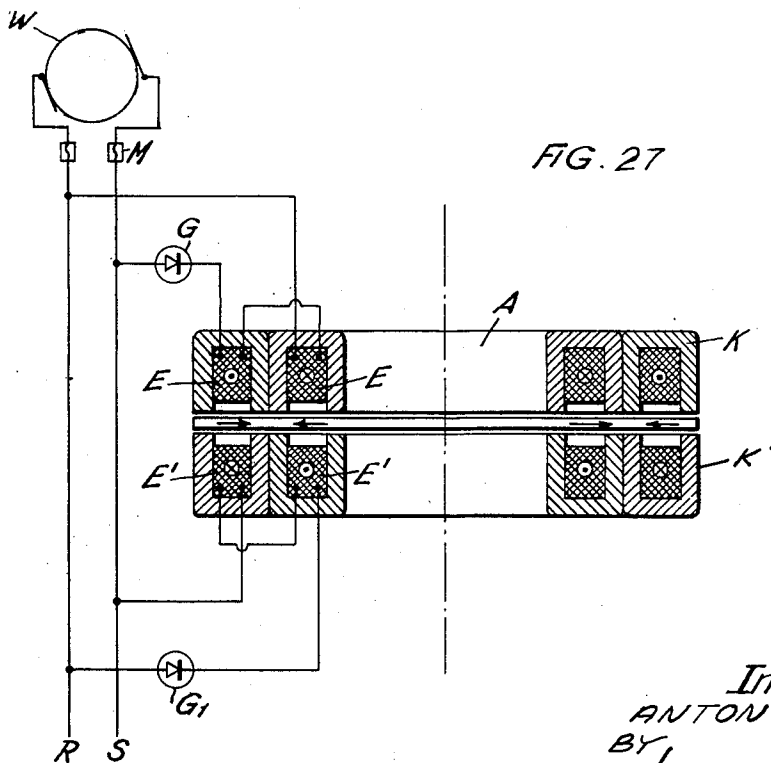
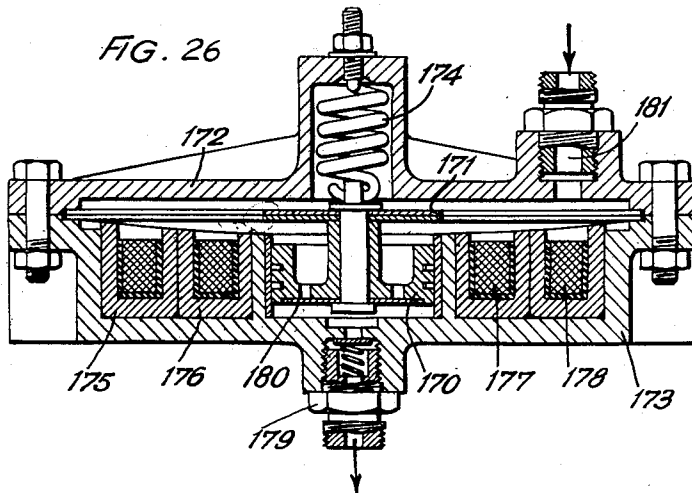
A. RYBA

2,630,760

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9 Sheets-Sheet 8



Inventor:
ANTON RYBA
BY
Andrew L. Hany
ATTORNEY.

March 10, 1953

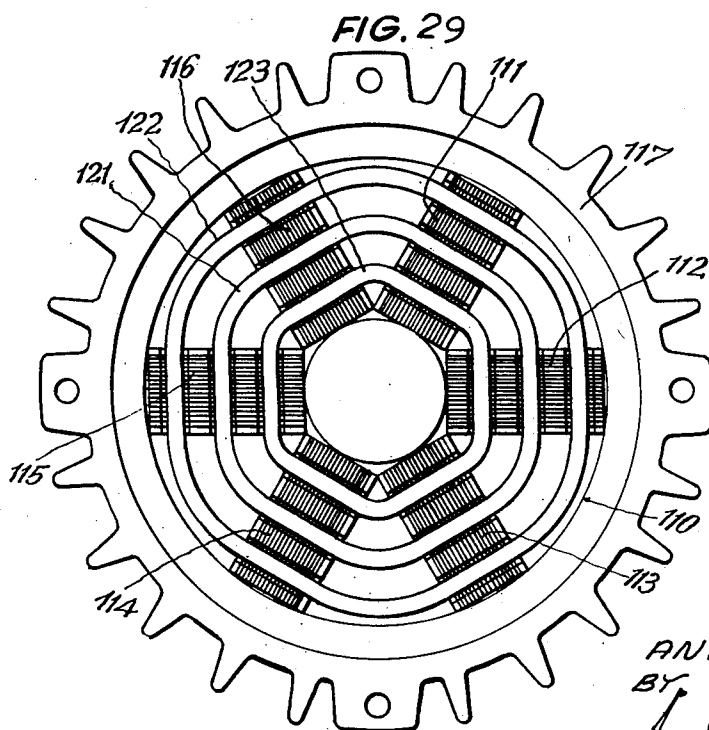
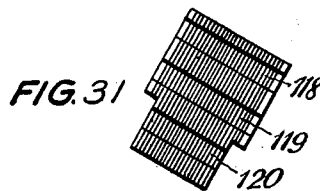
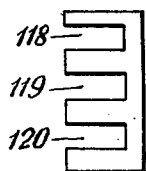
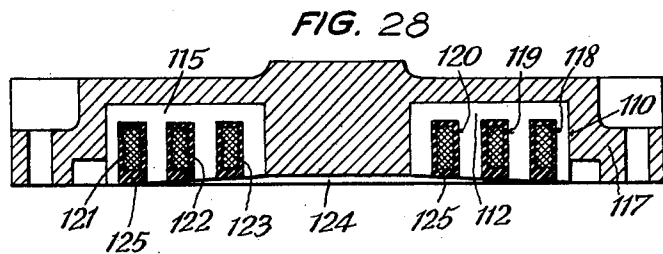
A. RYBA

2,630,760

ELECTROMAGNETIC PUMPING DEVICE FOR PUMPING FLUIDS

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9 Sheets-Sheet 9



INVENTOR:
ANTON RYBA
BY
Frederick L. Hany
ATTORNEY.

UNITED STATES PATENT OFFICE

2,630,760

ELECTROMAGNETIC PUMPING DEVICE FOR
PUMPING FLUIDS

Anton Ryba, Bolzano, Italy

Application August 27, 1948, Serial No. 46,377
In Switzerland September 26, 1947

28 Claims. (Cl. 103—53)

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This invention relates to electromagnetic pumping devices for pumping a gaseous or liquid fluid.

One of the objects of the invention is to provide a novel and improved pumping device of the general type, above referred to, by means of which a substantial volume of fluid can be rapidly and conveniently pumped with or without increase in the pressure of the fluid to be pumped.

Another object of the invention is to provide a novel and improved pumping device of the general type, above referred to, which comprises comparatively few and light moving components, thereby greatly reducing the power required for pumping a given fluid volume and simplifying the construction of the pumping device.

Another object of the invention is to provide a novel and improved pumping device of the general type, above referred to, all or most components of which can be simply and comparatively inexpensively manufactured, are reliable and rugged in operation, and can be rapidly and simply assembled or disassembled.

Another object of the invention is to provide a novel and improved pumping device of the general type, above referred to, by means of which a gaseous fluid can be pumped and compressed in several stages. This arrangement is particularly advantageous when a substantial end pressure is desired.

Further and other objects, features and advantages of the invention will be pointed out hereinafter and set forth in the appended claims forming part of the application.

The above enumerated objects of the invention and other objects hereinafter pointed out are attained by providing an electromagnetic pumping device in which an electromagnet and an armature are disposed within a housing including a pumping chamber, the volume of said pumping chamber being controlled by the armature position, said armature being arranged to oscillate in response to an intermittent energization of the electromagnet, thereby varying the volume of the pumping chamber accordingly, and in which fluid admission means admit fluid to be pumped into the pumping chamber upon oscillatory movement of the armature in a direction for increasing the pumping chamber volume, and in which fluid discharge means discharge fluid from the pumping chamber upon oscillatory movement of the armature in a direction for reducing the pumping chamber volume.

In the accompanying drawings several now

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preferred embodiments of the invention are shown by way of illustration and not by way of limitation.

In the drawings:

Fig. 1 is an elevational section through a double acting electromagnetic pumping device according to the invention.

Fig. 2 is a top plan view, the upper housing portion and magnet body being removed.

Fig. 3 is an elevational section through a modified pumping device according to the invention.

Fig. 4 is an elevational section through an electromagnetic single acting device according to the invention.

Fig. 5 is a plan view showing by way of example an outer or cover disc of the diaphragm armature.

Fig. 6 is a similar view of one of the intermediate discs of the diaphragm armature.

Fig. 7 is a plan view of one of the annular core elements of a magnet body.

Fig. 8 is a section along the line VIII—VIII of Fig. 7.

Figs 9 and 10 are similar sections of two modified annular core elements.

Fig. 11 is a sectional view of another modification of an annular core of a magnet body.

Fig. 12 is a plan view of the core of Fig. 11.

Fig. 13 is a sectional view of still another modification of a core element.

Fig. 14 is a fragmentary section of the core element according to Fig. 13, on an enlarged scale.

Fig. 15 is a sectional view of another modification of a pumping device according to the invention.

Fig. 16 is a plan view of Fig. 15, the upper magnet body and the armature being removed.

Figs. 17 and 18 are fragmentary cross-sectional views of modifications of magnet bodies as may be used in a pumping device according to Fig. 15 and other figures.

Fig. 19 is a cross-sectional view of a magnet body as may be used in the pumping device according to Fig. 15, and other figures.

Fig. 20 is a plan view of Fig. 19.

Fig. 21 is a diagrammatic circuit system for the magnet bodies of a pumping device.

Fig. 22 shows the electric circuit connections for the magnet bodies connected to a single phase net, the circuit system including a series connected capacitor to obtain a certain phase shift.

Fig. 23 shows a typical circuit diagram for connecting the magnet bodies to a two phase net.

Fig. 24 is an elevational section through a mod-

ified double acting pumping device in which the armature is operatively connected to a piston.

Fig. 25 is a plan view of Fig. 24, the upper housing portion and magnet body being removed.

Fig. 26 is an elevational section through another modification of a single acting pumping device.

Fig. 27 is a circuit diagram for a pumping unit according to Fig. 24.

Fig. 28 is an elevational section through a modified magnet body.

Fig. 29 is a bottom plan view of the magnet body according to Fig. 28.

Fig. 30 is one of the laminae out of which the cores of the magnet body are composed, and

Fig. 31 is a modified laminated core of a magnet body.

The double acting pumping device for pumping liquid or gas, as shown in Figs. 1 and 2, comprises two casing halves 5 and 6 each housing a magnet body. Each magnet is composed of three annular cores 1, 2 and 3 U-shaped in cross-section and concentrically mounted. The cores may be ring-shaped, polygonal or otherwise shaped. They are secured by rivets 4 to the respective casing halves preferably made of non-magnetic material. The annular cores 1, 2, 3 comprise ferro-magnetic material and should have at least one radial slot 60 (Fig. 7) to reduce eddy current losses. In the grooves of the annular cores there are disposed the exciting coils 7, 8 and 9. These exciting coils are embedded in the open grooves of the cores into a mass of a plastic insulation material of a type becoming very hard when dry. All the grooves and radial slots of the annular cores are filled with such insulating material so as to form a smooth outer surface. A substantially spherically curved cup-shaped depression to form chambers 10 and 11, respectively, is then made in the surface of the magnet bodies thus formed; preferably, the curvature of the two depressions is selected so as to correspond approximately to the curve of deflection of the diaphragm as will be more fully explained hereinafter. The two casing portions 5 and 6 are secured together by means of screw bolts 12.

A diaphragm operating in the manner of a pump piston is disposed within the hollow space formed by the two depressions 10 and 11 between the magnet bodies and held along its periphery so that it is secured without vertical play between the two casing portions. The diaphragm comprises advantageously several flexible discs or laminae of ferro-magnetic material, the outer laminae 13 and 14 facing the cups 10 and 11 being preferably full discs, while the inner discs (or filling discs) 15 and 16 may be provided with radial slots 58, 59 (Fig. 6) to reduce the eddy-current effect and to attain a better deflection. The diaphragm discs 13, 14, 15 and 16 are held together in the center by a rivet 17 which also serves to secure a thin resilient valve plate 18 or 19, respectively to each side of the diaphragm. Each valve plate is provided with radial slots to form flexible valve sections.

The full cover discs 13 and 14 of the diaphragm include a plurality of circularly disposed holes 20 and 21 respectively each in registry with one of the segments 22 (Fig. 2) of the radially slotted valve plates 18 and 19 forming suction valves together with holes 20 and 21. To prevent a relative rotation of the valve plates and the diaphragm discs during operation, rivet 17 and the corresponding central holes in the valve plates and diaphragm discs are unround for example

square. The radial slots 58 (Figs. 2 and 6) of the filling discs 15 and 16 are extended so far towards the center that they can register with the holes 20 or 21 of the cover discs 13 and 14.

The two chambers 10 and 11 on each side of the diaphragm may be additionally sealed along the periphery of the diaphragm by resilient sealing rings 23 and 24 which are clamped between the two casing portions and the diaphragm.

To enable the diaphragm to fit itself snugly into the spherically curved bottom of each depression in spite of the valve plates 18 and 19 on both sides of the diaphragm, each of the magnet bodies is provided with a corresponding circular recess 25 and 26 respectively into which the valve plates may enter.

Discharge valves 27 and 28 for discharge of the fluid to be pumped are secured to each casing portion 5 and 6 by screwing the valves into the centers of the casing portions. Outlets 29 and 30 from the two chambers 10 and 11 are controlled by valve plates 31 and 32, respectively of the valves. The plates are biased upon their seats by springs 33 and 34.

The fluid to be pumped is admitted into the compressor through a tube 35 communicating with an annular space 36 between the two casing portions. It flows through the radial slots 58 of the filling discs 15 and 16 of the diaphragm until it reaches openings 20 and 21 normally closed by plates 18 and 19.

In this connection it should be mentioned that in principle only two full unslotted cover discs 13, 14 (Fig. 5) are required for the diaphragm. The number of the filling discs (Fig. 6) should be selected according to the required thickness and rigidity against deflection of the diaphragm. The total thickness should be so dimensioned that full use of the flux of the magnetic circuit is obtained. In regard to the rigidity of the diaphragm, generally speaking, shallow depressions and higher fluid pressures require greater rigidity while increased concavity and lower fluid pressures require a softer diaphragm. The necessary rigidity of the diaphragm can be conveniently obtained by suitably selecting the thickness of the various laminae out of which the diaphragm is composed. The magnetic material used for the discs (or at least some of them) should possess, besides useful magnetic qualities, also good mechanical and elastic properties. Materials which have these properties are well known in practice.

The design of the current connecting terminals for the exciting coils 7, 8 and 9 may be conventional, and it is believed that a detailed showing is not essential for the understanding of the invention.

The diaphragm pumping device according to Fig. 3 is distinguished from the one of Fig. 1 in that no suction valves (plates 18, 19) are provided. A diaphragm 37 is so inserted between the two magnet bodies formed by annular cores 1, 2, 3 and exciting coils 7, 8, 9 that its circular edge can make a small vertical play, whereby an annular slot is formed along the outer periphery of the diaphragm alternately on the top and on the bottom face thereof depending upon the direction in which the diaphragm is flexed as will be more fully explained hereinafter. As a result, fluid can enter into the respective one of chambers 38 or 39. The sealing of these two chambers along the marginal portion of the diaphragm is effected at the required moment by the magnetic force urging the diaphragm toward and against the pole surfaces of the magnet bodies.

The different laminae of the diaphragm are held together along the edges thereof for example by means of a collar 40 of sheet metal. Of course, care must be taken that the edges of the laminae or discs are held in such manner that relative displacement and deflection of the several discs are not prevented. The diaphragm is advantageously composed of a plurality of filling discs 15 (according to Fig. 6) and two full cover sheets 13', 14' (according to Fig. 5), but without circularly disposed holes 20. As will be apparent, slots 58 in this embodiment merely serve to reduce eddy current losses and to increase the flexibility of the discs but not as conduits for fluid. The discs of the diaphragm are held together at their center by a rivet 41.

Fig. 4 shows a single acting magnetic pumping device similar in its essential parts to the one shown in Fig. 1 with the difference that only one magnet body comprising annular cores 1, 2, 3 and coils 7, 8, 9 is provided. Accordingly, a diaphragm 46 is attracted in one direction only by magnetic forces and no magnetic forces are available to return the diaphragm. The diaphragm 46 must spring back by its own resiliency and where this is not sufficient an auxiliary spring 47 may be provided. This spring is suspended in a casing portion 48 and connected to a rivet 49 which unites the various laminae of the diaphragm. Fluid is admitted through an intake nipple 50 and discharged through a valve 51. The cover portion 48 of the casing is secured by screws 52 to a lower casing portion 53. All other parts are in principle arranged as in Fig. 1 and are clearly shown on the drawing.

Instead of assisting the return stroke of the diaphragm by a spring, a second magnet body may be provided which exerts the function of the spring 47. This magnet body, as it does not effect any delivery work can be dimensioned correspondingly weaker.

Fig. 6 shows by way of example one of the diaphragm filling discs (15). While the two outer or cover discs 13 and 14 (Fig. 5) facing the curved surfaces of the magnet bodies consist advantageously of resilient full discs, the intermediary discs 15 and 16 which serve primarily to provide the necessary thickness of the diaphragm for conducting the magnetic flux, are advantageously provided with as many long slots 58 and short slots 59 as possible to reduce the influence of the eddy current effect and to make the discs more flexible. The slots can be arranged in any desired shape and manner, but care has to be taken that the magnetic flux of the magnetic circuit is not interrupted or appreciably affected. It is further advantageous to group the radial slots in such manner that the circular continuity of the material is interrupted and as few as possible closed concentric passages of material remain. In this manner, bending and warping of the discs by heat tensions or the like are effectively counteracted.

Figs. 7 to 10 show several modifications of the U-shaped annular cores of the magnet bodies. As previously mentioned, the several cores are advantageously at least once radially slotted (60) for the purpose of reducing the eddy current losses; in case, a single slot is not sufficient to effectively reduce the eddy current effect, several radial slots may be provided. It is not necessary to sever the ring cores into segments. Small transverse sections of the material may remain so as to retain each core as single element. The

more an annular core element is slotted, the more the eddy current effect is reduced.

Fig. 8 shows a section through a core element which is once radially slotted (at 60) and further provided with several radial slots 54 which do not completely traverse the element.

It is advantageous for an efficient operation of the described magnetic pumping devices to provide for the greatest possible flux density of the magnetic field at the pole surfaces causing a magnetic constriction in the shanks of the annular U-section core elements. For this purpose, the sectional area 55 of the core shanks is increased with respect to the pole surfaces 56 (Fig. 9), so that in spite of the influence of the magnetic stray field no narrowed path for the magnetic flux is caused. Instead of making the pole surfaces narrower according to Fig. 9, it is also possible to provide a lining 57 (Fig. 10) of ferro-magnetic material, whereby the same is obtained.

Any magnetic material is suitable in principle as material for the annular core elements, however, it is to be recommended to use an iron silicon alloy as known in the construction of electrical machinery for instance for dynamo sheets.

The number of annular cores and corresponding exciting coils out of which a magnet body is composed can be selected as desired within a wide range. The thickness of the diaphragm can be reduced by increasing the number of annular cores forming the magnet body.

Two other modifications of an annular magnetic core are shown in Figs. 11 to 14. According to Figs. 11, 12 and 14, the core is formed by an annular member of U-section, composed of three single annular elements 130, 131, 132 fitted one into the other. The innermost element 132 has slightly shorter branches than the other two elements the branch faces of which form the pole surfaces. The three single elements consist of magnetic material, preferably of alloyed dynamo sheet material and are electrically insulated one with respect to the other, as it is well known for laminated iron cores. The insulating layers are designated by the numeral 134 in Fig. 14. The exciting coil (not shown) is inserted into the annular groove 133. The various single elements 130, 131 and 132 may be held together by a rivet 135.

In the example according to Fig. 13 the annular core comprises also three distinct annular U-shaped elements 136, 137 and 138. The branches of all elements extend in this modification to the pole surfaces.

As seen in Figs. 11, 12 and 13, the annular core is radially slotted, the slot 139 traversing the entire width of the elements to reduce the eddy current effect. Additional radial slots may be provided which do not completely traverse the core, as shown in Fig. 8.

The number of single elements of which the core is composed can be selected as desired. The effects of eddy currents can be the more reduced the greater is the number of individual core elements.

The radial slot 139 prevents closing of the path of the eddy currents formed in the core in a continuous circular path in which case the core would act as a short-circuited secondary coil. By reason of the radial slot in the core, the paths of the eddy currents must reverse themselves at the slot so that for the entire eddy current loop only the difference of the potentials induced in the inner and outer layers, respectively, of the

core can become effective as electromotive force of the loop.

The separation of the annular core into several single annular elements has the purpose of rendering the mentioned difference in induced potentials as small as possible, in that the current loop which must be formed within each individual element is constricted according to the thickness of the element profile. As a result, the difference in potential between the inner and outer surface layer decreases in proportion to the thickness of the individual elements of the core when these latter are electrically insulated one from the other.

The effect of the element 132 (Fig. 14) having shorter branches than the two other elements is that the magnetic flux which is increased by the leakage or stray field in the annular grooves and which in turn increases the magnetic saturation from the pole surface towards the bottom of the grooves, provided the thickness of the branches would be constant, can be carried without decreasing the saturation at the pole surfaces. Moreover, the element 132 cannot only carry the magnetic stray flux, but also permits to obtain any desired ratio between the magnetic saturation at the pole surface and in the branches of the core elements.

The pumping device according to Figs. 15 and 16 is in many respects similar to the pumping devices as previously described. According to Figs. 15 and 16, the housing is composed of two cup-shaped sections 220 and 221 held together by bolts and nuts 222. Coil springs 223 may be employed to provide a certain elasticity between the sections of the housing. Each section houses a magnet body 224 and 225 respectively made of ferro-magnetic material. The two magnet bodies are each provided with three concentric grooves in which the exciting coils 226, 227, 228 and 230, 231, 232, respectively are inserted.

The remaining space in the grooves is again filled with a suitable insulation material so that smooth curved surfaces are formed at the pole faces, the pole faces of each magnet body forming a pumping chamber with the adjacent side of an armature 235. This armature is again shown as a diaphragm composed of several flexible discs made of ferro-magnetic material and held along its periphery between the housing sections. A sealing ring 234 may be provided to secure fluid tightness between the housing sections. Fluid is admitted into pumping chamber 235 by means of an inlet valve 236 which communicates with a duct 237. This duct issues into a plurality of channels 238 leading into pumping chamber 235. The admission of fluid into pumping chamber 235 is controlled by a suction valve comprising a flexible cup-shaped valve plate 239. This valve plate normally closes channels 238 and is lifted off these channels by the suction of a vacuum that is created in pumping chamber 235 when diaphragm 233 is attracted toward magnet body 225.

For the purpose of discharging fluid from pumping chamber 235 a discharge valve 240 is provided. This valve comprises a valve member 241 normally pressed by a spring 242 against a duct 243 leading into pumping chamber 235. As a result, duct 243 is normally closed but is opened when valve 241 is lifted off its seat by increased fluid pressure in chamber 235 in response to the attraction of diaphragm 233 toward magnet body 225.

Fluid admission into and fluid discharge from

the second pumping chamber 244 is similarly controlled by inlet valve means 245 and outlet valve means 246.

For the purpose of increasing the flux density at the pole faces, annular recesses 250 are provided between each two coil grooves. These recesses 250 are preferably also filled with insulation material to retain a smooth surface at the pole faces.

Each of the magnet bodies 224 and 225 is divided by radial slots 251 into sectors for the purpose of reducing eddy-current losses. The sectors thus formed are held together by retaining an inner continuous ring 252.

The fragmentary view of Fig. 17 shows a magnet body distinguished from the magnet bodies of Fig. 15 by providing U-shaped inserts 253 made of ferro-magnetic material in the coil grooves. Fig. 18 shows a magnetic body 224 with grooves 255 and 256. The purpose of these grooves 255 and 256 is to increase further the flux density at the poles, and to separate, at least to a certain extent, the magnetic circuits produced by the individual coils.

The magnet body as shown in Figs. 19 and 20 is distinguished from the magnet bodies of Figs. 15 and 16 by providing completely separated sectors which are held together by a ring 260 encompassing the individual sectors rather than by a ring such as ring 252 formed by the material of the magnet bodies proper. Ring 260 may be shrunk upon the sectors and may be slightly conical at the inside to secure the ring upon the sectors.

The individual sectors as shown in Figs. 16 and 20 may be insulated from each other.

It should be noted in this connection that it is of course also possible to provide less or more than three coils for each magnet body. As a result, each coil with its ferromagnetic core material forms an independent magnetic circuit. Furthermore, the design according to Figs. 15 to 20 is not limited to a circular shape but any other suitable cross-section may be provided.

Referring now to the operation of the armature, the same, when oscillated, alternately sucks a certain quantity of fluid admitted through intake nipple 35 into one of the chambers 19 or 11 (Fig. 1), or 38, 39 (Fig. 3), and expels it therefrom through one of the discharge valves 27, 28.

To avoid partial back-flow of the fluid sucked in by reason of improper timing of the opening and closing of the chamber intake and discharge openings of the chambers, for instance in the embodiment according to Fig. 3, or to obtain maximal magnetic attraction as caused by the individual coils or coil groups of the magnet bodies at predetermined time intervals, the exciting coils can be connected in two or more groups for each magnet body. Each group is then excited by a periodically acting alternating potential, preferably in such manner that an outer group of coils acting upon the marginal portions of the diaphragm is energized by a current with a phase lead with respect to an inner group of coils. This shift in phase can be obtained by any suitable phase shifter for example in single phase nets by a capacitor C (Fig. 22) connected in series, and in polyphase nets by connections to several phases (Fig. 23) as will be more fully explained hereinafter.

The connections of the individual exciting coils in each magnet body may be so made that the direction of current is reversed in the coils of

adjacent annular cores and that the direction of the current flow in the corresponding exciting coils of the upper magnet body and in the lower magnet body is opposite. As a result, the magnetization of the diaphragm during the alternate excitation of the upper and the lower magnet body is not reversed and the iron losses of the diaphragm are thus reduced.

Suitable connections are shown in Figs. 21, 22 and 23. The arrows *a* indicate the direction of the magnetic flux for each annular core element, and the marks in the coils (circle with point and circle with cross) indicate the direction of current in the respective coil.

While Figs. 21, 22 and 23 represent suitable circuit diagrams, there are various possible modifications, which are known to any person skilled in the art.

In the diagrams, K indicates the upper and K' the lower magnet body; a single phase alternating current generator (Figs. 21 and 22) is designated by W; and a double phase alternating current generator (Fig. 23) with W'. G and G' indicate the rectifiers in the one phase net of Fig. 21, R and S the main lines from the generator, G2, G2' and G3, G3' are the rectifiers in Fig. 22; G4, G4' and G5, G5' are the rectifiers in Fig. 23; R', R, S are the main conductors in Fig. 22; and R, Q, S the main conductors in Fig. 23; M are cut-out fuses; and C is a capacitor in Fig. 22.

The operation of a double acting diaphragm compressor or pumping device according to Fig. 1 is as follows:

When the compressor is connected to an alternating voltage according to the diagram of Fig. 21, the rectifiers (each group of coils must be connected to a rectifier) G and G' let each pass one half wave of the alternating current; accordingly, during each half period the lower and the upper magnet body are alternately excited. Magnetic attraction forces are thus created which pull the diaphragm alternately in opposite directions. Since the diaphragm is resilient and flexible, it is flexed by the magnetic attraction with one of its faces toward or against the curved surface of the excited magnet body, whereby at the same time a partial vacuum is formed in the chamber 10 or 11 bounded by the opposite face of the diaphragm so that gas or liquid is sucked through the annular space 38, the radial slots 58 of the filling discs 15, 16, and the temporarily uncovered apertures 20 or 21 of the respective cover disc 13 or 14 into the respective one of the chambers 10 or 11, the suction valve plate 18 or 19 (accordingly, whether the diaphragm abuts against the upper or lower magnet body) opening by the action of the sucked-in fluid.

Let it be assumed that the upper magnet body is excited, then first the outer marginal zone of the diaphragm is attracted since the air gap is smallest in this zone. Hence, induction and the magnetic attraction are highest while towards the center of the magnet body the magnetic force decreases rapidly. By reason of the strong magnetic force exerted upon the marginal zone of the diaphragm, the latter will be attracted first along this zone and produce a reduction of the chamber volume, at the same time slightly compressing fluid in the chamber and slightly bulging the diaphragm. As a result of this bulging starting in the marginal zone of the diaphragm, the air gaps are successively reduced from the exterior toward the center. Accord-

ingly, the action of the magnetic attraction forces acting upon the diaphragm also increases towards the center thereof simultaneously with the corresponding increase in the compression of the sucked-in fluid. When a predetermined pressure is obtained, the pressure valve plate 31 opens against the action of spring 33 and the discharge begins which is ended when the diaphragm is attracted into contact with the bottom of the magnet body. At the same time, new fluid is sucked into the other chamber 11.

At the time the fluid has been expelled from chamber 10, the lower magnet body becomes excited and by reason of the alternating periodic excitation of the two magnet bodies the cycle repeats itself according to the frequency of the half waves of the applied alternating potential, one side of the diaphragm always sucking and the other side compressing and expelling.

The operation of the compressor according to Fig. 3 differs from the one according to Fig. 1 only in that admission of the fluid to be supplied into the suction and compression spaces 38 and 39 is effected without a special suction valve. The operation is as follows: As already mentioned, the diaphragm is mounted between the magnet bodies so that its marginal portion is held with a small vertical play. When the diaphragm is flexed for example toward the curved surface of the lower magnet body an annular slot is formed on the opposite side of the diaphragm along the outer circumference of the outermost annular core 1, through which fluid is sucked into the upper chamber 38. When the upper magnet body is now excited, then first the outer marginal zone of the diaphragm is attracted, since the air gap is the smallest in that zone and the chamber 38 is thereby closed. The further operation is the same as described with reference to Fig. 1.

The arrangement of the electromagnetic compressor according to Fig. 3 is particularly suitable for liquid pumps, since a continuous flow of the liquid is created without reversal of the direction of flow.

In Fig. 1 and also in Figs. 3 and 4 the arrows indicate the direction of the fluid flow.

In the electromagnetic compressor according to the invention, the electric connections can also be made as shown in Fig. 22 in which the exciting coils of each magnet body are arranged in two groups in such manner that the outer coil group operates with a phase-displacement relative to the inner group. This is advantageous for the compressor according to Fig. 3, to prevent, as previously mentioned, a back flow of the fluid out of the chambers 38 or 39 in case the marginal slot does not close in the correct moment, and in the other described examples of the compressor to obtain a progressive bulging movement of the diaphragm from the edge towards the center.

The diagram of Fig. 22, in which phase shifting is obtained by connecting capacitor C in series, possesses in certain instances further advantages in connection with the compressor according to Fig. 1 as it allows to obtain a forced travelling of the field wave from the exterior towards the interior.

The electric function of the diagrams is as follows:

Fig. 21 (connection to a single phase net): When the alternating potential has for example momentarily a direction R—S, a flow of current is possible only through the rectifier G1, and the

lower magnet body is excited; when the potential is reversed, the current flows through the rectifier G and the upper magnet body is excited. This operation is repeated in accordance with the periods of the applied alternating voltage.

Fig. 22 (connection to a single phase net having an auxiliary phase connected through a capacitor): When the alternating potential has for example the momentary direction R—S, the rectifier G2' (central zone) passes the corresponding half wave. The potential R'—S leads in phase relatively to the potential R—S by reason of the capacitor C, that is, the rectifier G2 controlling the marginal zone of the diaphragm passes also a half wave though slightly shifted in phase and leading relative to the half wave for the middle zone of the diaphragm. In other words, in the central zone, the electromotive force acts upon an inductive impedance and in the marginal zone upon a capacitive impedance. Hence, when the coil group associated with the marginal zone is energized and begins to attract the diaphragm in the marginal zone, the coil group associated with the central zone of the opposite magnet body is still energized and attracts the central zone of the diaphragm in opposite direction. In this manner, the opening and closing of the suction slot formed along the outer edge of the diaphragm takes place at the correct moment without back flow of the fluid towards the suction chamber 36 or 43, and a field wave is created progressing from the exterior towards the center of the diaphragm.

The same effect as obtained with an auxiliary phase according to the diagram of Fig. 22 can also be obtained by employing a polyphase net.

Fig. 23 shows diagrammatically the connection of the compressor to a two phase net. When for example the potential R—Q leads by 90°, the outer coil group of the upper magnet body receives its half wave a quarter of a period earlier than the inner coil group. Since the connected inductive impedances are approximately equal, the currents are lagging relatively to their voltages with about the same angles, and the relative phase shift between the outer and inner coil groups will always be approximately 90°. After one half period, the voltages have changed their sign, and now the corresponding coil groups of the lower magnet body become effective in quite analogous and symmetric manner.

The operation with phase shifted excitation and connection of the compressor to a polyphase net is the same as when an auxiliary phase is artificially formed by interposing a capacitor. It will be obvious that various phase shifts can be obtained by means of different impedances for the outer and the inner coils or coil-groups obtainable by providing chokes and capacitors.

The single acting magnetic pumping device or compressor according to Fig. 4, in regard to electrical and magnetic operation, will function in principle in the same manner as has been described with reference to the compressor of Fig. 1. Current is supplied through rectifiers with or without an auxiliary phase; analogous connections to one phase or polyphase nets are also possible. Of course, connections are necessary for only one magnet body.

When the magnet body according to Fig. 4 is excited there is created a magnetic attraction force which attracts the diaphragm 46, compressing fluid in chamber 61. The trapped fluid is discharged through the pressure valve 51. As the action of the magnetic traction forces ceases,

the diaphragm 46 returns into its original or flat position by reason of its inherent resiliency, the return movement being assisted by spring 47. The entire operation is analogous to that according to Fig. 1 with the difference that only one side of the diaphragm is effective. Fluid to be pumped is admitted through the inlet 50 and traverses the apertures 21 in the cover sheet 14 of the diaphragm 46, when the valve plate 18 opens, to fill the chamber 61.

The suction and compression stroke of the diaphragm is repeated periodically according to the intermitting excitation of the magnet body.

The single-acting magnetic compressor according to Fig. 4 can be connected to an alternating current source without including rectifiers (contrary to the compressors according to Figs. 1 and 3) when the return of the diaphragm is not effected by magnetic forces but by a spring force only. In such case, an oscillatory magnetic field is created, the attraction forces of which have two maximum and two zero values for each current period. Hence, the diaphragm is twice attracted during one full current period. Accordingly, two suction and pressure actions are obtained, that is, the number of strokes of the diaphragm, without using rectifiers, is always double the frequency of the applied alternating potential.

The operation of the pumping device according to Figs. 15 and 16 will be easily understandable from the previous specification so that it need not be described in detail. It suffices to say that the armature is alternately attracted by the magnet bodies, the attraction progressing from the margin toward the center. As a result, the two pumping chambers 235 and 244 are alternately filled through valves 235 and 245 and alternately emptied through valves 240 and 240.

The periodic excitation of the magnet bodies can also be obtained by using direct current and providing suitable control switches to effect closure and opening of the magnet body circuits. The operation with direct current and control switches is quite similar to the operation with alternating current and rectifiers. The individual coils or coil-groups can be successively connected and disconnected and the same effects are obtained as with polyphase connections or with the creation of an auxiliary phase by means of a capacitor.

It has been found that the number of oscillations of the diaphragm, that is the number of strokes is the same as the number of periods of the applied alternating current. In many instances the normal net frequency, usually 50 to 60 periods per second, results in an undesirably high number of strokes, particularly for larger compressors. In such event, the frequency may be stepped down by means of period transformers as are well known in the electric art.

Figs. 24 and 25 show a modified compressor in which the two casing portions 5 and 6 are provided with cooling ribs 54 and confine each an annular recess 65 housing annular magnet cores 66, 67, and 68, 69 respectively. These magnet cores have a U-shaped cross-section and are made of ferromagnetic material. The cores support exciting coils 70, 71 and 72, 73, respectively in their respective grooves, said coils being embedded in an insulation material 103 such as plastic. The two casing portions 5 and 6 are each provided with a cylindrical central bore 74 lined with a cylindrical sleeve 75 and 76, respectively. A circular diaphragm preferably composed of two or more flexible discs 77 and 78 of

ferromagnetic material serves as armature and is clamped with its edge between the two casing portions at 77'. The armature has a central opening traversed by a piston rod 79 on which are mounted two pistons 80 and 81 each disposed on one side of the armature discs 77, 78. The pistons are provided with normal piston rings 82. To form suction valves, each piston includes circularly disposed holes 83 and 84 which are closed and opened by the deflection of springy plates 85 and 86 held in position by flanges on the central piston rod 79. The plates are deflected by variations in the gas pressure and the kinetic energy affecting the plates. Recesses 87 are provided in the casing portions 5 and 6 to receive the flanges of the rod 79 and plates 85, 86 to limit the dead space in the compressor to a minimum.

The armature 77, 78 is advantageously provided with radial slots 88, 89 extending over the portions of the armature discs affected by the magnetic flux. The slots serve to reduce the eddy current losses and also to increase the resiliency of the discs. Fluid is again admitted through intake 35 and can enter chambers 10 and 11 through the circular slots formed between the discs and the outer cores, as described in connection with Fig. 3. The provision of an armature composed of several discs has the additional advantage that relatively silent operation can be obtained in spite of the impact of the armature, when attracted, against the magnet bodies since then elastic forces become effective which greatly reduce the shock. When the armature is formed of several discs, the different discs are never absolutely even and plane. As a result, small tensions are present producing a certain yielding movement of the armature resulting in the mentioned noise reducing effect. Furthermore, the construction of the armature out of several discs permits an easier flexion thereof, even when the armature is relatively heavy.

Fig. 26 shows a single acting piston compressor according to the invention. A single piston 170 is rigidly connected to an armature 171. The casing comprises two portions 172 and 173, the lower portion 173 housing a magnet body. To assist the return of the armature 171 after attraction thereof by the magnet body a return magnet may be provided or a return spring 174 may be connected to the armature and suspended in the cover portion 172 of the casing. Spring 174 is necessary when the inherent springiness of the armature mounted in the casing in the same manner as the armature in Fig. 24 is not sufficient to cause rapid return of the same.

Fig. 27 represents a diagram of the electrical connections suitable for instance for a compressor according to Fig. 24. The two magnet bodies are designated with K and K' and the diagrammatically represented armature with A. A source of alternating current W feeds through the maximum current switches or fuses M the two conductors R and S of the single phase net. The connection of the several exciting coils E, E' for each magnet body is made so that the direction of the flow of current changes each time between one element and the adjacent one; moreover the exciting coils E of the upper magnet body are so connected that each opposite exciting coil E' of the lower magnet body is traversed by the current in opposite direction. The circuit connections are clearly shown in the diagrammatic circuit of Fig. 27. The arrows indicate the direction of the magnetic flux, and the signs in the

annular spaces (circle with point and circle with cross) indicate the direction of flow of the current.

The operation of the double acting electromagnetic piston compressor according to Fig. 24 is as follows:

When the compressor is connected to an alternating voltage according to the diagram of Fig. 27, rectifiers G and G' each pass one half wave of the alternating current. Hence, the lower and the upper magnet body are each excited for the time of one half period. In this manner magnetic traction forces are obtained which alternately pull the armature in opposite direction. Since the armature 77, 78 according to Fig. 24 forms a flexible diaphragm it will be alternately pulled toward the curved bottoms of the respective chambers 10 and 11 and the pistons will oscillate in unison with the armatures. As a result, the suction valves alternately fill the upper and the lower cylinder space and the sucked-in fluid is alternately expelled through the pressure valves 27 and 28. The suction and pressure operation is periodically repeated according to the intermittent excitation of the magnet bodies.

The operation of the single acting compressor according to Fig. 26 is in principle identical with the one according to Fig. 24, according to whether the armature 171 carrying the piston is with its edge mounted in the casing or is freely oscillating.

The connections of the exciting coils 177, 178 are also in principle the same, with the difference that only one connection for the one magnet body is required.

The single acting magnet compressor according to Fig. 26, contrary to the double acting compressors according to Fig. 24, can be connected to an alternating current source without the inclusion of a rectifier when the retraction of the armature is not effected by magnetic forces but by a spring, in which case an oscillating magnet field is created in which the magnetic forces have two maximal and two zero values per current period. As a result, the diaphragm armature is twice attracted during each full current period so that the suction and pressure actions are effected twice. In other words, the number of strokes, without using current rectifiers, will always be the double of the frequency of the applied alternating potential.

Figs. 28 to 31 show six laminated magnet cores 111, 112, 113, 114, 115 and 116 radially disposed in star-shaped relation in a circular casing 117 formed advantageously of non-magnetic material. The laminated bodies are provided with transverse grooves 118, 119 and 120 so positioned that all grooves of the bodies lie in the outlines of several concentric polygons. In these grooves, three polygonally-shaped coils 121, 122 and 123 are inserted.

The iron cores 111 to 116 and the coils are embedded in an insulating mass 125 such as a synthetic resin substance or a plastic, so shaped that a magnet body is formed having a shallow curved depression 124 in which oscillates the diaphragm (not shown).

To maintain the inactive spaces of the magnet body between the laminated cores as small as possible, the core discs may be stepped as shown in Fig. 31; there may be provided one or several steps.

Any desired number of core disc packages may be provided. The casing 117 need not to be necessarily of circular shape, but can be adapted for example to the polygonal shape of the exciting

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coils; for example, when only two laminated cores are used, the magnet body can be of rectangular shape.

While the invention has been described in detail with respect to certain now preferred examples and embodiments of the invention it will be understood by those skilled in the art after understanding the invention, that various changes and modifications may be made without departing from the spirit and scope of the invention and it is intended therefore, to cover all such changes and modifications in the appended claims.

What is claimed is:

1. In an electromagnetic pumping device for pumping a fluid, in combination a housing, electromagnetic means mounted therein, said electromagnetic means comprising a plurality of concentrically disposed electromagnetic members each including a ferromagnetic core having a pole face and an exciting coil, the adjacent coils and pole faces of said cores forming a substantially continuous surface, armature means in form of a flexible circular diaphragm, said diaphragm being arranged within the housing in a position relative to the diaphragm so as to form a pumping chamber between the diaphragm and an adjacent continuous surface, electrical means for alternately and intermittently energizing said coils progressively from the outermost coil to the innermost coil so as to cause the diaphragm to oscillate, thereby varying the capacity of said chamber, said coils of the electromagnetic means, when energized, attracting corresponding adjacent circular surface areas of the diaphragm in the sequence of the energization of the coils, fluid admission means arranged to communicate with said chamber and to admit fluid into the chamber upon oscillatory movement of the armature means in one direction relative to said surface, and fluid discharge means arranged to communicate with said chamber and to discharge fluid therefrom upon oscillatory movement of the armature means in opposite direction.

2. An electromagnetic pumping device as described in claim 1, wherein said diaphragm comprises a plurality of stacked flexible discs, at least one of said discs made of ferromagnetic material and having at least one radial slot to reduce eddy-current losses.

3. An electromagnetic pumping device as described in claim 1, wherein said housing is composed of two portions forming an annular peripheral slot therebetween leading into the pumping chamber, and wherein said diaphragm is held with play along its periphery in said slot between said housing portions so as to close said chamber upon oscillatory movement of the diaphragm toward the electromagnetic means and to open said slot upon oscillatory movement of the diaphragm away from the electromagnetic means, said oscillatory movements of the diaphragm being substantially vertical to the plane of the diaphragm.

4. An electromagnetic pumping device, as described in claim 1, wherein said continuous surface of the electromagnetic means is concavely curved relative to the diaphragm, and wherein the diaphragm is held within the housing along its periphery and in a position in which the distance between the diaphragm and said curved surface decreases from the center of the diaphragm toward the periphery thereof when the diaphragm is in an unattracted position.

5. An electromagnetic pumping device as described in claim 1, wherein each of said ferro-

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magnetic cores has a substantially U-shaped cross-section, the open side of each core facing the diaphragm and receiving the respective exciting coil, said cores being slotted to reduce eddycurrent losses.

6. An electromagnetic pumping device as described in claim 1, wherein each of the said ferromagnetic cores has a substantially U-shaped cross-section so as to form two side arms, the cross-sectional area of the side arms of said cores being larger at the bottom of the cores than near the pole faces.

7. An electromagnetic pumping device as described in claim 1, wherein said electric means comprise a source of alternating current connected in circuit with said electromagnetic means, and wherein half-wave rectifiers are included in the circuit connections to said electromagnetic means, said rectifiers each passing one-half wave of current to the electromagnetic means, thereby causing intermittent energization of the electromagnetic means.

8. An electromagnetic pumping device as described in claim 1, wherein said electrical means comprise a source of A.-C. connected in circuit with the electromagnetic means, and wherein half-wave rectifiers are included in the circuit connections to said electromagnetic means, said rectifiers each passing one half-wave of current alternately to the electromagnetic means thereby causing an intermittent energization of said electromagnetic means, and wherein capacitance means are included in the coil circuits, said capacitance means causing a shift in the phase of the alternating current supplied to the electromagnetic means, thereby causing the electromagnetic means to be successively energized.

9. An electromagnetic pumping device as described in claim 1, wherein said housing is composed of two portions, the facing surfaces of said housing portions being spaced apart, and wherein the peripheral marginal portion of the diaphragm extends with play into said space thereby forming an annular slot leading into said pumping chamber between the marginal diaphragm portion and the respective housing surface, oscillatory movement of the diaphragm toward said continuous surface closing said annular slot and oscillatory movement in opposite direction opening said slot.

10. An electromagnetic pumping device as described in claim 1, wherein said diaphragm comprises a plurality of stacked flexible outer and intermediate discs, at least one of said discs made of ferromagnetic material, at least one outer disc being a full disc having at least one aperture therein, each intermediate disc having at least one slot to reduce eddycurrent losses and to conduct fluid, said slots communicating with each aperture and said fluid admission means, and wherein valve means are supported on said diaphragm and arranged to close said apertures upon oscillatory movement of the diaphragm toward the curved pole faces and to uncover the apertures upon oscillatory movement of the diaphragm away from the pole faces.

11. An electromagnetic pumping device as described in claim 10, wherein said housing is composed of two portions, and wherein said diaphragm is fluid-tightly held along its periphery between said housing portions.

12. In an electromagnetic pumping device for pumping a fluid, in combination a housing, a pair of electromagnets mounted therein, each of said electromagnets comprising a plurality of concentrically disposed electromagnetic mem-

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bers, each including a ferromagnetic core having a pole face and an exciting coil, the pole faces of the concentric electromagnetic members of each electromagnet and the respective concentric coils forming a substantially continuous surface, said surfaces being positioned to face each other spaced apart, an armature in form of a flexible circular diaphragm disposed between said surfaces to form a first pumping chamber between the diaphragm and one of said surfaces and a second pumping chamber between the diaphragm and the other surface, electrical means for alternately and intermittently energizing said coils progressively from the outermost coil to the innermost coil so as to cause the diaphragm to oscillate between opposite pole faces, thereby varying the capacities of said chambers, the coils of each electromagnet, when energized, attracting corresponding adjacent circular surface areas of the diaphragm in the sequence of the energization of said coils, fluid admission means arranged to communicate with said chambers and to admit fluid into one of the chambers upon oscillatory movement of the armature in one direction and into the other chamber upon oscillatory movement of the armature in the opposite direction, and a pair of fluid discharge means communicating with said chambers, one of said discharge means being arranged to discharge fluid from one of said chambers upon oscillatory movement of the armature in one direction and the other discharge means being arranged to discharge fluid from the others of said chambers upon oscillatory movement of the armature in the opposite direction.

13. In an electromagnetic pumping device for pumping a fluid, in combination a housing, an electromagnet mounted therein, an armature in form of a flexible diaphragm disposed within the housing spaced apart from the electromagnet and arranged to be attracted by the electromagnet when the same is energized and to return into its original position upon deenergization of the electromagnet, a piston supported on the diaphragm for movement in unison therewith, said housing including wall portions defining a compartment in which said piston is slidably guided for reciprocatory movement, said compartment including a pumping chamber formed by the piston and the wall portions defining said compartment, electric means for intermittently energizing said electromagnet thereby causing the diaphragm to oscillate and the piston to vary the capacity of said pumping chamber, fluid admission means arranged to communicate with said chamber and to admit fluid into said chamber upon oscillatory movement of the armature and the piston in one direction relative to the electromagnet, and fluid discharge means arranged to communicate with said chamber and to discharge fluid from said chamber upon oscillatory movement of the armature and the piston in the opposite direction.

14. In an electromagnetic pumping device for pumping a fluid, in combination a housing, a pair of electromagnets mounted within the housing spaced apart, each electromagnet including core means having a pole face thereon, the pole faces of the electromagnets facing each other, an armature in form of a diaphragm disposed between the pole faces of the electromagnet and arranged to oscillate relative to said pole faces upon alternating energization of the electromagnets, a piston supported on one side of the diaphragm for movement in unison therewith, said housing including wall portions defining a com-

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partment in which said piston is slidably guided for reciprocatory movement, said compartment including a first pumping chamber formed by the piston and the wall portions defining said compartment, a second pumping chamber being formed and confined by the other side of said diaphragm and the pole faces of the electromagnet facing the said diaphragm side, conduit means connecting the said pumping chambers, valve means included in said conduit means, said valve means being arranged to be normally closed and to be opened for passage of fluid from the second chamber to the first chamber in response to a predetermined fluid pressure in the second chamber, electric means for alternately and intermittently energizing said pair of electromagnets so as to cause the diaphragm and the piston to oscillate relative to the pole faces thereby alternately varying the capacities of said chambers, fluid admission means communicating with the second pumping chamber for admitting fluid to be pumped into the said chamber, and fluid discharge means communicating with the first pumping chamber for discharging fluid from the said chamber, said discharge means including second valve means normally closed and arranged to be opened for discharge of fluid in response to a predetermined fluid pressure in the first pumping chamber.

15. In an electromagnetic pumping device for pumping a fluid, in combination a housing, electromagnetic means having a plurality of independently magnetizable concentric portions mounted within the housing, said adjacent concentric portions forming a substantially continuous surface, armature means in form of a flexible circular diaphragm, said diaphragm being supported along its periphery within the housing and positioned to form a pumping chamber between the diaphragm and the adjacent continuous surface, electric means for alternately and intermittently energizing said concentric magnetizable portions progressively from the outermost portion to the innermost portion so as to cause the diaphragm to oscillate thereby varying the capacity of the pumping chamber, said concentric portions, when magnetized, attracting corresponding adjacent circular surface areas of the diaphragm in the sequence of the magnetization of said concentric portions, fluid admission means arranged to communicate with the pumping chamber and to admit fluid into a chamber upon oscillatory movement of the armature means in one direction, and fluid discharge means arranged to communicate with the pumping chamber and to discharge fluid from the chamber upon oscillatory movement of the armature means in opposite direction.

16. In an electromagnetic pumping device for pumping a fluid, in combination a housing, electromagnetic means mounted therein, said electromagnetic means comprising a plurality of concentric electromagnetic portions each having a core formed with a pole face and an exciting coil, armature means in form of a flexible diaphragm comprising a plurality of stacked flexible circular discs, at least one of said discs made of ferromagnetic material and having at least one radial slot to reduce eddy-current losses, said diaphragm being supported along its periphery within the housing, adjacent coils and pole faces of said cores being aligned and positioned to form a substantially continuous surface curved relative to the diaphragm to form a pumping chamber with the adjacent side of the diaphragm,

electrical means for alternately and intermittently energizing said coils progressively from the outermost coil to the innermost coil so as to cause the diaphragm to oscillate, thereby varying the capacity of said chamber, said concentric electromagnetic portions of the electromagnetic means, when energized, attracting corresponding adjacent circular surface areas of the diaphragm in the sequence of the energization of said concentric portions, fluid admission means arranged to communicate with the pumping chamber and to admit fluid into the chamber upon oscillatory movement of the armature means in one direction relative to said surface, and fluid discharge means arranged to communicate with the pumping chamber and to discharge fluid from the chamber upon oscillatory movement of the armature means in opposite direction.

17. An electromagnetic pumping device as described in claim 16, wherein the cores of said concentric electromagnetic portions are formed by a plurality of annular core members concentrically arranged, each of said core members having a U-shaped cross-section, the open sides of said core members facing the diaphragm and receiving said exciting coils, and wherein said core members are radially slotted at least once to reduce eddy-current losses.

18. An electromagnetic pumping device as described in claim 16, wherein the cores of said concentric electromagnetic portions are formed by a plurality of annular core members concentrically arranged, each of said core members comprising a plurality of U-shaped, at least once radially slotted core elements nested one in another, the open side of said core members facing the diaphragm and receiving said exciting coils.

19. An electromagnetic pumping device as described in claim 16, wherein the cores of said electromagnetic portions are formed by a common ferromagnetic body having several annular concentric grooves, and wherein said exciting coils are fitted in said grooves, and wherein a hard insulation material fills the spaces between the grooves and the respective coils so as to form the said continuous surface.

20. An electromagnetic pumping device as described in claim 16, wherein the cores of said concentric electromagnetic portions are formed by a common ferro-magnetic body having several annular concentric grooves, and wherein said exciting coils are fitted in each one of said grooves.

21. An electromagnetic pumping device as described in claim 20, wherein at least one face of said core body includes annular concentric recesses positioned between each two grooves for the coils.

22. An electromagnetic pumping device as described in claim 16, wherein the cores of said concentric electromagnetic portions are formed by a common ferro-magnetic body having several annular concentric grooves, and wherein said exciting coils are fitted in each one of said grooves, and wherein said core body is radially slotted at least once to reduce eddy-current losses.

23. An electromagnetic pumping device as described in claim 22, wherein said core body is laminated.

24. An electromagnetic pumping device as described in claim 16, wherein the cores of said concentric electromagnetic portions are formed by a plurality of annular core members concentrically arranged, each of said core members having a U-shaped cross-section, the open sides

of said core members facing the diaphragm and receiving said exciting coils.

25. An electromagnetic pumping device as described in claim 24, wherein each of said core members comprises a plurality of U-shaped core elements nested one in another.

26. An electromagnetic pumping device as described in claim 25, wherein the arms of the core members formed by said nested core elements are reduced in cross-section toward the pole faces.

27. An electromagnetic pumping device for pumping a fluid, in combination a housing made of non-magnetic material, electromagnetic means mounted therein, said electromagnetic means including a plurality of concentrically disposed electromagnetic portions, each of said portions comprising a ferro-magnetic ring core having a pole face and an exciting coil, adjacent coils and pole faces of said cores forming a substantially continuous surface, armature means in form of a flexible circular diaphragm, said diaphragm being mounted within the housing in a position relative to said continuous surface so as to form a pumping chamber between said surface and the adjacent side of the diaphragm, electric means for alternately and intermittently energizing said coils progressively to the outermost coil to the innermost coil so as to cause the diaphragm to oscillate thereby varying the capacity of said chamber, said concentric electromagnetic portions, when energized, attracting corresponding adjacent circular surface areas of the diaphragm in the sequence of the energization of said electromagnetic portions, spring means operatively connected with the other side of the diaphragm and biased to move the latter in a direction opposite to the direction of the magnetic attraction for retracting the diaphragm in the intervals between intermittent energization of said coils, fluid admission means arranged to communicate with said chamber and to admit fluid into said chamber upon oscillatory movement of the diaphragm in one direction relative to the electromagnetic means, and fluid discharge means arranged to communicate with said chamber and to discharge fluid from said chamber upon oscillatory movement of the armature means in opposite direction.

28. In an electromagnetic pumping device for pumping a fluid, in combination a housing made of non-magnetic material, electromagnetic means mounted within the housing, said electromagnetic means including a plurality of concentrically disposed electromagnetic portions, each of said portions comprising a ferro-magnetic ring core having a pole face and an exciting coil, adjacent coils and pole faces of said cores forming a substantially continuous surface, armature means in form of a flexible circular diaphragm, said diaphragm being mounted within the housing in a position relative to said continuous surface so as to form a pumping chamber between the said surface and the adjacent side of the diaphragm, a piston supported on the opposite side of the diaphragm for movement in unison therewith, said housing including wall portions defining a compartment in which said piston is slidably guided for reciprocatory movement, said compartment including a second pumping chamber formed by the piston and the wall portions defining said compartment, electric means for alternately and intermittently energizing said coils progressively from the outermost coil to the innermost coil so as to cause the diaphragm to

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oscillate thereby varying the capacity of said pumping chambers, said concentric electromagnetic portions, when energized, attracting corresponding adjacent circular surface areas of the diaphragm in the sequence of the energization of said concentric electromagnetic portions, fluid admission means arranged to communicate with said chambers and to admit fluid into one of the chambers upon oscillatory movement of the diaphragm in one direction and into the other chamber upon oscillatory movement of the diaphragm in the opposite direction, and a pair of fluid discharge means each communicating with one of said chambers, one of said discharge means arranged to discharge fluid from the respective chamber upon oscillatory movement of the diaphragm in one direction and the other discharge means being arranged to discharge fluid from the respective chamber upon oscilla-

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tory movement of the diaphragm in the opposite direction.

ANTON RYBA.

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