

June 20, 1967

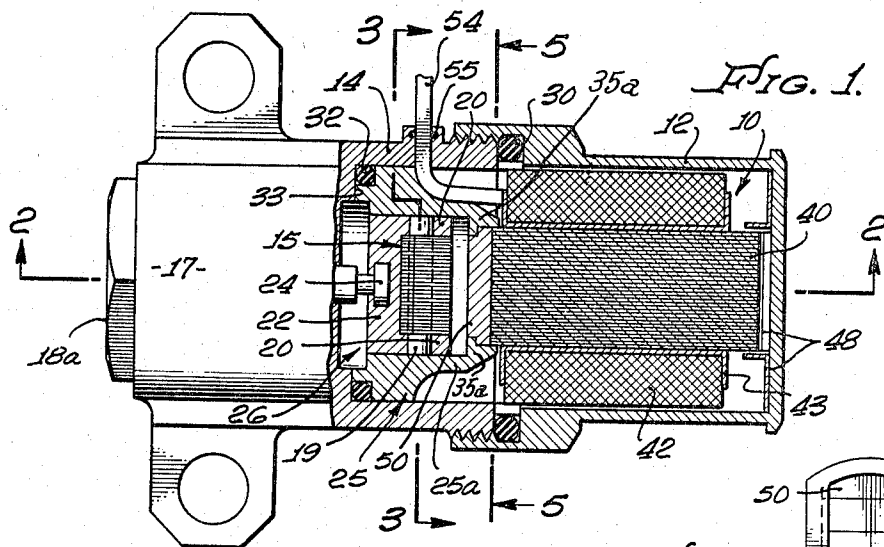
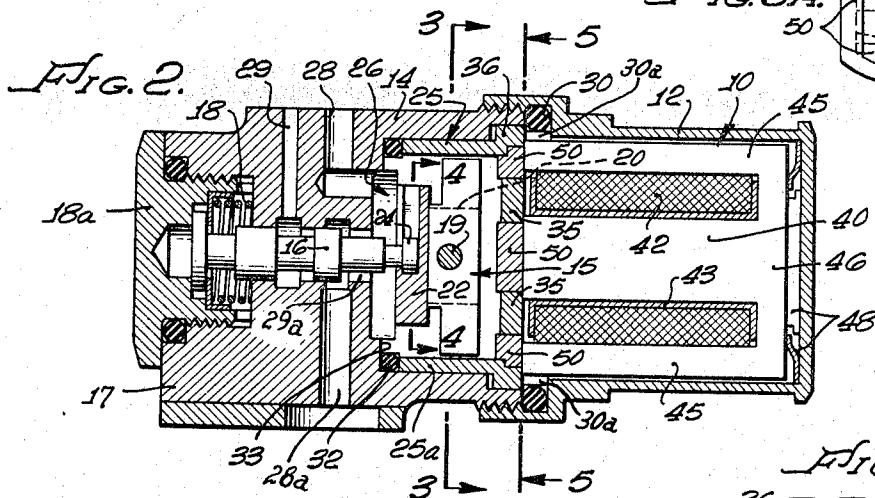
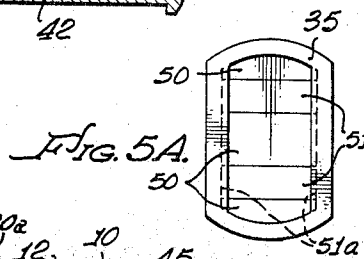
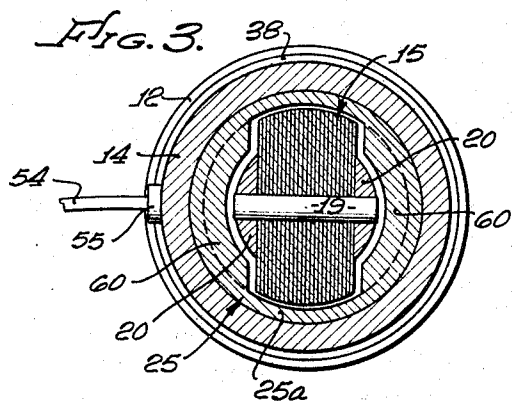
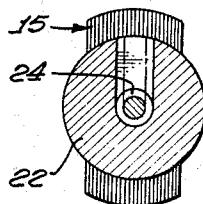
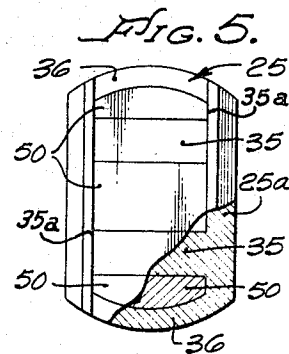
K. S. RODAWAY

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ALTERNATING CURRENT SOLENOID CONSTRUCTION

Filed April 23, 1965

3 Sheets-Sheet 1



INVENTOR.
KEITH S. RODAWAY
BY *Robert H. Thornton*

ATTORNEY.

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K. S. RODAWAY

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ALTERNATING CURRENT SOLENOID CONSTRUCTION

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3 Sheets-Sheet 2

FIG. 6.

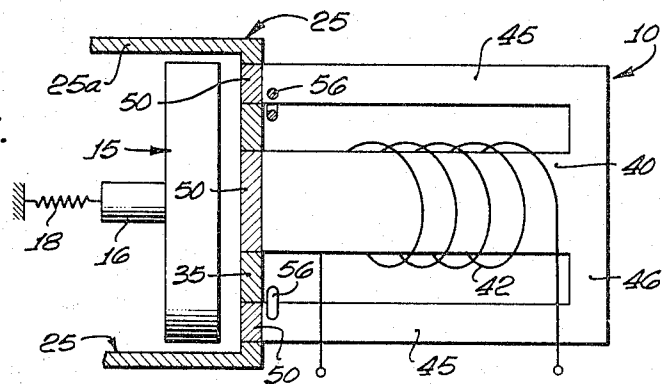


FIG. 7.

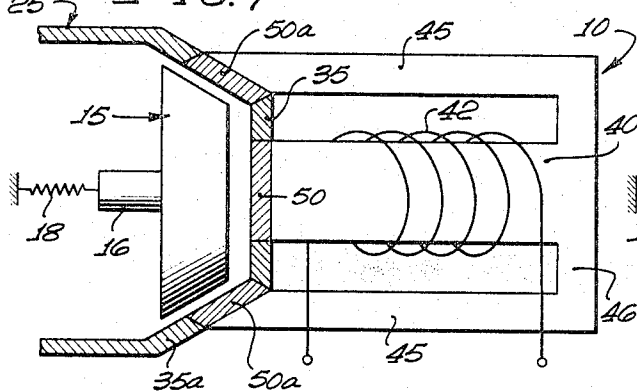
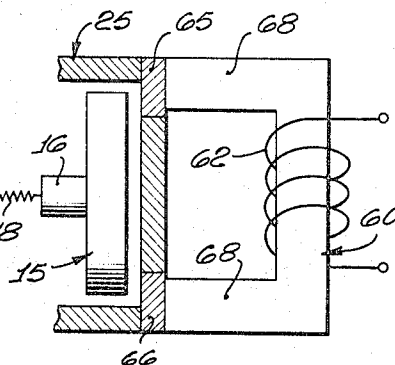


FIG. 8.

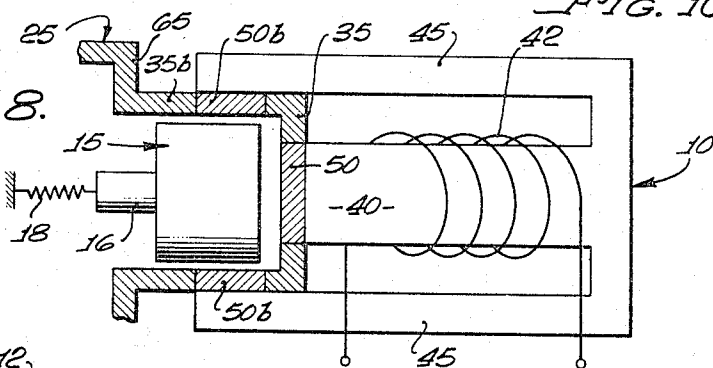


FIG. 10.

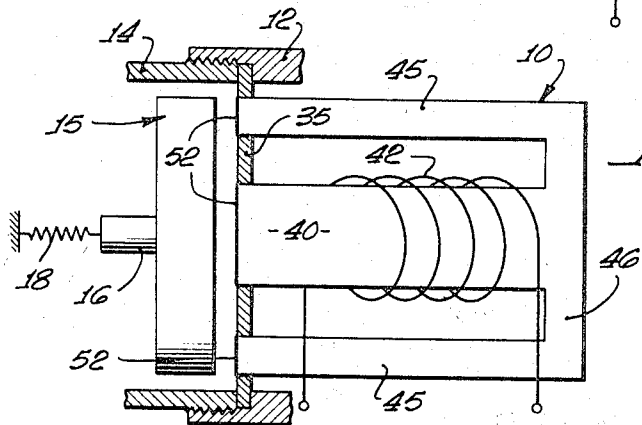


FIG. 9.

INVENTOR.
KEITH S. RODAWAY
BY *Robert K. Thornton*
ATTORNEY.

June 20, 1967

K. S. RODAWAY

3,327,264

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3 Sheets-Sheet 3

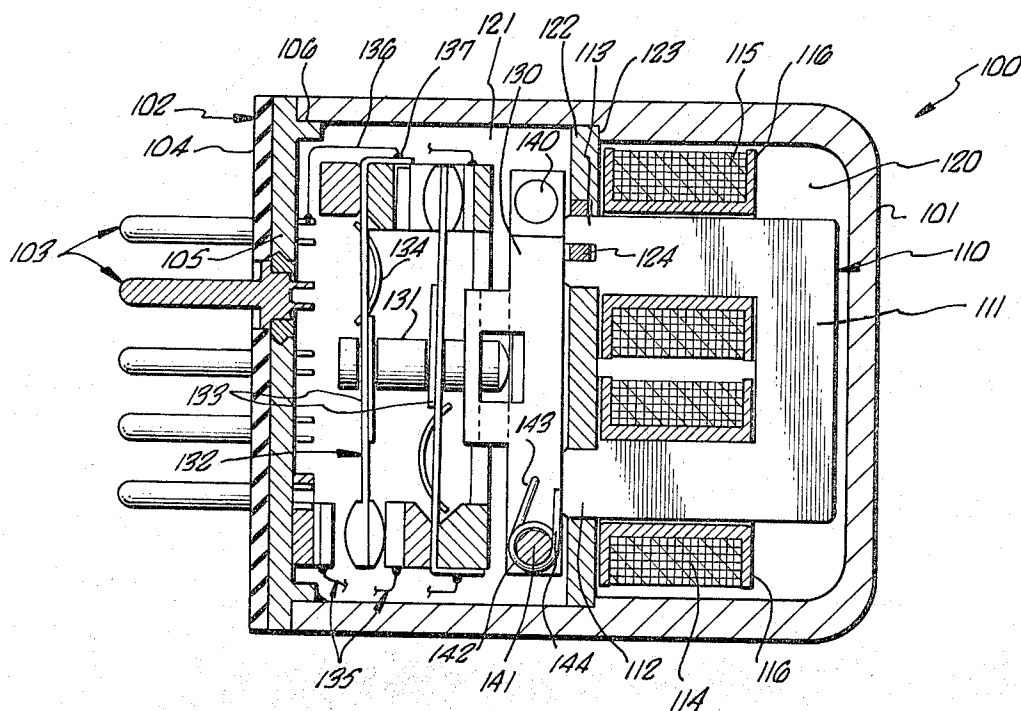


FIG. 11.

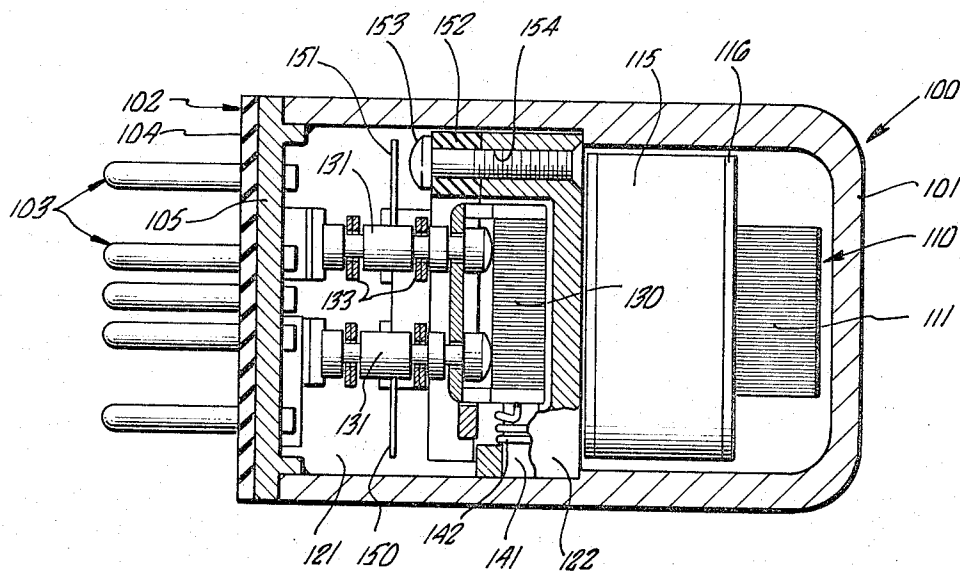


FIG. 12.

INVENTOR.
KEITH S. RODAWAY
BY *Robert L. Thornton*

ATTORNEY.

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ALTERNATING CURRENT SOLENOID CONSTRUCTION

Keith S. Rodaway, Los Angeles County, Calif. (28409)
Plainfield Drive, Palos Verdes Peninsula, Calif. 90274)
Filed Apr. 23, 1965, Ser. No. 450,490
9 Claims. (Cl. 335-188)

ABSTRACT OF THE DISCLOSURE

This disclosure relates to an electromagnet and cooperating armature in separate chambers separated by a rigid diaphragm, the armature being employed, for example, to operate a fluid valve. The diaphragm is designed with openings to receive the pole pieces of the electromagnet so that the armature can make direct engagement with the ends of the pole pieces protruding through the diaphragm. The flux gap is thus minimized, the pole pieces within the openings of the diaphragm being brazed or fused in position to provide an absolutely fluid-tight seal capable of withstanding extremely high pressure differentials without leakage. The entire solenoid construction is designed for operation with alternating currents and therefore a laminated construction for the electromagnet and armature is provided for efficient operation. The pole piece laminations are fused together and to the diaphragm hereby preventing leakage through the laminations themselves, without appreciably sacrificing the efficiency provided by the laminations.

This application is a continuation-in-part of my co-pending application Ser. No. 417,315, filed Dec. 10, 1964, now abandoned, and my co-pending application Ser. No. 857,166, filed Dec. 3, 1959, now abandoned.

This invention relates to solenoids, in general, and more particularly, to solenoids that are employed for controlling the flow of fluids, especially such solenoids that are to be operated by power from high-frequency alternating-current power sources.

In many industries, it is very desirable to provide a solenoid that can be energized by power from a conventional electrical power source, such as a house main which supplies 60 cycles per second alternating current at 115 volts. In other applications, it is very desirable to provide a solenoid which can be energized by power from a relatively high frequency power source, such as a 400 cycles per second power source, such as that which is frequently available in aircraft. It is also important to be able to provide alternating current solenoids that will operate over a very wide range of temperatures extending, when necessary, from a very low temperature, for example, of about -320° F. to a very high temperature (the Curie point), at which iron or other ferromagnetic material employed in the solenoid is no longer magnetic. It is also important to provide solenoids of the indicated character which may be used effectively in operating hydraulic systems, such as those which employ non-corrosive liquids such as oil for the control of the flow or movement of a fluid. It is also important to provide solenoids for use in systems that handle corrosive liquids such as sulphuric acid that is being pumped through a system. In all such systems, an armature, piston, plunger or other operating member is located in a chamber that is in communication with the liquid being controlled.

Heretofore, great difficulty has been experienced with solenoids of the types mentioned above which have been employed to control the flow of fluids under extreme conditions of temperature, pressure or corrosiveness. Such solenoids have frequently required the development of glands and other sealing members which are especially suitable for use under such extreme conditions. Solenoids

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of that type which have been developed heretofore have proved to be of limited effectiveness under extreme conditions. Furthermore, in the past, the most practical solenoids employed for fluid control have required the use of rectifiers adjacent the solenoids to convert the alternating current power into direct current power when the available power has been in the form of alternating current.

It is therefore an object of this invention to provide an improved solenoid construction of high efficiency which is operated directly by alternating current, and in which an armature or other operating member is located in a chamber containing the fluid, and in which the solenoid winding is mounted externally of that chamber, and is very effectively sealed from fluid in the chamber over a wide range of operating conditions.

It is also an object of the present invention to provide a highly efficient solenoid construction which may operate at high frequencies, such as the indicated 400-cycle frequency, with currently available alternating current voltages, such as 115 volts.

It is a further object of the invention to provide such a solenoid construction which is operable within wide temperature ranges, such as the indicated range between about -320° F. to around 1000° F., or possibly 1200° F.

A still further object of the invention is to provide a solenoid construction of the mentioned type which will handle high pressure liquids or other fluids, at high or low temperatures and whether corrosive or non-corrosive, including active liquid chemicals or oils which must be pumped in manufacturing establishments, or which must be controlled in various other systems, such as hydraulic oils employed for control purposes.

As with other solenoid systems, the structure of this improvement employs a relatively stationary solenoid core and a moving solenoid armature or plunger, the armature being arranged with respect to the core, to provide as small an inner gap as possible and therefore as great a pulling force, or power, as possible. Since eddy currents and skin effects are important considerations, and since resistance increases with temperature increase and temperature is a much more sensitive factor at low frequency, such as conventional 60 cycles, than at high frequency, such as 400 cycles, it has generally been considered impractical, if not commercially impossible, to produce high frequency high temperature solenoids for the handling or control of liquids, especially of dangerous, corrosive, high temperature or high pressure liquids encountered in many and various industries.

Sixty-cycle alternating current solenoids have been undertaken in the past for some industrial applications, but these have been necessarily large power-consuming devices. Such has been due in part to the fact that the solenoids have been required to operate valve pistons by means of piston rods which had to be sealed to prevent fluid loss and which therefore presented high friction loads.

In attempts to operate with 400-c.p.s. current, 400 c.p.s. being considered a very desirable optimum, the current drain has been extremely low, with the result that such solenoids had very little pulling force. Because of the wet plunger and necessity to seal the plunger rod and keep the coil dry, and because of the lower pulling force, high frequency operation heretofore has been abandoned as impractical.

It is therefore an object of this invention to provide a high-frequency alternating-current solenoid construction that will overcome such difficulties.

Additionally, in connection with aircraft manufacture, it has become very desirable to find a means for avoiding the use of the typical 29-volt DC current, and to use instead a typical 115-volt AC current, if at all possible. Such

a shift has been desired because of the numerous hydraulic solenoid valves currently found on aircraft. But efforts to make such a shift have only led toward larger, heavier valves which has been a prohibitive factor for aircraft. Therefore, along with the temperature limitations, such a shift has been abandoned heretofore in aircraft applications as impractical, especially in view of the high temperatures encountered.

It is therefore an object of this invention to apply high-frequency 115-volt alternating current to hydraulic valve operation and the like by appropriate solenoid construction.

These objects are accomplished by employment of thin lamination construction for both the solenoid core carried in a dry chamber or other dry mounting, and the armature carried in a wet chamber, and this arrangement has been made possible by dividing the dry solenoid core chamber from the wet armature chamber through a medium of an intervening sealing diaphragm. In conventional practices, a common lamination for 60-cycle alternating current is in the order of 0.05 inch per lamination. But, due to skin effects, eddy currents and resultant heating, such construction cannot be employed at high frequency.

However, high frequency use, such as around 400-cycle alternating current, which seems at present to be a very desirable optimum, can be effectively and desirably attained through the employment of much thinner laminae, which for the indicated 400 cycles desirably is about 0.007 inch per lamination. By employing a sealed diaphragm to separate the wet armature chamber from the dry core chamber, such diaphragm being of relatively non-conductive material, the effective gap beyond that required for the stroke of the armature is eliminated by introducing magnetic pole pieces into the relatively non-conductive non-magnetic diaphragm, such pole pieces being disposed in contact with whatever legs are used for the core.

While the preceding description of the invention has referred to its embodiment in an electromagnetic device of the type commonly referred to as a solenoid, the invention can equally well be adapted to use in the type of electromagnetic device commonly termed a relay. In such an embodiment, the relatively non-conducting diaphragm forms a seal between the core or flux inducing member and the movable member or armature as before. The seal is preferably formed in conjunction with the housing within which the flux inducing member is disposed. Armature movement moves an actuator or the like, which is the component actually accomplishing the switch actuation function of the relay. While in embodiments of the solenoid type, it is generally preferable for the armature or movable member to be disposed within the device so as to be capable only of linear reciprocal movement, in embodiments of the relay type it is generally preferable for the armature to be disposed so as to be capable only of reciprocal angular displacement. By such a structure, a more constant force-stroke characteristic is obtained for the force required to move the armature. Of course, the linear reciprocal motion type of structure, heretofore described, may be utilized, if desired, in the relay. Conversely, the angular displacement type of structure may be utilized with the solenoid, if desired. In order to insure rapid switch actuation for small amounts of armature movement, and good reproducibility of the switching action with respect to armature movement, the switch means of the relay preferably utilizes reed switch elements of the over-center spring type.

As used herein, the term paramagnetic is utilized in its broadest sense, that is, referring to a material having magnetic permeability of greater than unity. The term paramagnetic, thus, for the present purposes, includes materials more particularly described as ferromagnetic, that is, highly magnetizable materials. Similarly, the term non-magnetic refers to materials having substantially no magnetic characteristics, as compared to the magnetic

characteristics of the electromagnet and movable member.

Other objects of the invention and various specific features thereof will become apparent to those skilled in this art upon reference to the following specification and the accompanying drawings, wherein certain embodiments constituting means presently deemed to be the best means for practicing the invention are disclosed.

In the drawings:

FIG. 1 is principally a longitudinal transverse section illustrating one arrangement and construction of a core and armature of a solenoid of this invention;

FIG. 2 is a view similar to that of FIG. 1, and taken at right angles thereto, with the difference that there is also shown in the section a valve construction which is presented as typical of valve controls readily operable by the improved construction of this invention;

FIG. 3 is a cross section taken on the lines 3—3 of FIGS. 1 and 2 in the direction represented by the arrows;

FIG. 4 is a similar cross-sectional detail taken at the line 4—4 of FIG. 2;

FIG. 5 is a plan view of the diaphragm plate of FIGS. 1 and 2 as taken from the lines 5—5 thereof in the direction of the arrows;

FIG. 5A is a plan view of a modified form of a diaphragm plate;

FIG. 6 is largely a diagrammatic view, parts being in section, showing a closed-loop shaded-pole construction sometimes desirable to be employed, in the diaphragm arrangement of this figure being, in general, the same as that of FIGS. 1 and 2;

FIG. 7 shows diagrammatically a varied construction of the diaphragm and arrangement of the pole pieces therein;

FIG. 8 is a still further modified form and arrangement of the diaphragm and pole pieces for further increasing the gap and the stroke of the armature;

FIG. 9 is a view generally similar to that of FIG. 6, but illustrating the employment of sealed ends of the solenoid core to serve as pole pieces in the diaphragm;

FIG. 10 shows a modified form of core construction and arrangement;

FIG. 11 is a side view, partially in section, of an electromagnetic device constituting a relay which embodies the present invention; and

FIG. 12 is an end view, partially in section, of the electromagnetic relay of FIG. 11.

Referring to the construction and arrangement of the improved solenoid of FIGS. 1 and 2, a solenoid core member generally indicated at 10 is shown as enclosed in a dry chamber provided by a casing member or section 12 which is connected in sealed relation with a second section or casing member 14 providing a wet chamber for a plunger or armature 15.

Briefly stated, the armature 15 is shown as being positioned to actuate a typical reciprocating valve 16 controlling the passage in a valve block 17 of a hydraulic pressure fluid through various ports and passages as indicated, a return spring 18 being employed to return the valve 16 to a closed position against the influence of the solenoid. For this purpose, the armature 15 is connected by a pin 19 to side arms 20 of an actuated block 22, joined to the stem of the valve 16 as by the head and undercut slot arrangement 24, illustrated.

The armature 15 works in a wet chamber within the casing section 14 which is in turn enclosed by a cup-shaped diaphragm 25. The chamber 26 thus enclosed is permanently open (at least at its ends) to the pressure fluid in the system as through the vent or return line 28. Thus, for example, where a high-pressure hydraulic oil is introduced through a supply line and duct 29 at 4,000 p.s.i. (pounds per square inch) and the return line pressure is around 2,000 p.s.i., the chamber 26 and the cup diaphragm 25 will always be subjected to a pressure of about 2,000 p.s.i. In a construction such as this, the wet chamber housing 14 containing the liquid chamber 26 may be

formed as an integral portion of the valve block 17 for the valve spool 16, the latter and the spring 18 being positioned and retained by a plug 18a appropriately sealed as indicated. The liquid chamber 26 is ported by a valve opening 29a to the cylinder port 28a. Actuation of the valve controls the flow of fluid through the wet chamber between the cylinder port and the return line. As shown, the dry chamber housing 12 may be connected with the adjacent end of the wet chamber housing 14 by a threaded connection, appropriate packing 30 being used to seal the resultant joint, and another packing 32 being used to seal between the annular edge of the cup-shaped diaphragm 25 and the adjacent shouldered annular wall 33. A spacer 30a between the diaphragm plate and the dry chamber of solenoid housing holds the diaphragm against the pressure in the wet chamber. Consistent and positive angular positioning of the diaphragm with respect to the core is provided by keying shoulders 35a, which mate with the core poles as shown in FIG. 1.

As seen in FIG. 5, the cup-shaped member 25 may be somewhat elongated and provided with an integral main diaphragm wall or plate member 35 which, as shown, joins the outstanding sidewall 25a to form a flange portion 36 bearing against corresponding shoulder portions of the wet chamber housing 14. Obviously, the sealing and packing employed will be whatever is adequate to insure retention of dry conditions in the core chamber 12.

The diaphragm cup 25, including its outstanding sidewall 25a and its main top plate member 35, is made from an appropriate non-magnetic material, such as a rustless or stainless steel known in the trade as 18-8 to indicate its constitution, or according to conditions, from a totally non-conductive material such as a plastic or ceramic, or ceramic-metal composition, as more fully hereinafter described and as well known in the trades.

With particular reference to the solenoid construction, both the solenoid core 10 and the armature 15 are constructed from a multiplicity of laminated conventionally insulated ferromagnetic sheets or laminations built up in laminated form from appropriate electrical steel to insure minimum core losses.

For the present construction, to accomplish these ends for high power frequencies of the order of 400 cycles per second, such steel sheets of the laminated structure preferably have a thickness of about 0.007" or are slightly thinner, though steel having thickness in the range between about 0.001" and about 0.020" is satisfactory. The steel chosen is any appropriate "thin electrical steel," as the term is used in the trade and produced for similar purposes for the trade, reference being made, for example, to the current pamphlet (PO 4856 8M RP 12-56) entitled, "Thin Electrical Steels." Copyright 1957, of Armco Steel Corporation, Middletown, Ohio.

In connection with the use of materials for the diaphragms, it will be apparent that, other conditions being equal, the less conductive the diaphragm material carrying the magnetic pole pieces, the more efficient the apparatus.

The solenoid core 10, as illustrated in FIGS. 1 to 9, is in the form of an E-shaped structure, having a middle leg around which is disposed a field-winding or coil 42 of an appropriate number of turns which may be carried upon an insulating sleeve or bobbin 43. Parallel with the middle leg 40, which with its winding 42 constitutes a magnetic flux-inducing member, there are two spaced end legs 45 which constitute magnetic flux-carrying members. The connecting bar 46 of the core joins the legs 40 and 45 and is suitably borne in the end of the housing member 12 as by appropriate positioning members which may include spring members, generally indicated at 48. The ends of the legs 40 and 45 bear upon the face of the main top diaphragm member 35.

In order to eliminate losses which would be caused by the effective spacing of the ends of the core legs 40

and 45 from the armature member 15, which would be in addition to the normal operating gap between the armature member 15 and the diaphragm member 35, the non-magnetic material of the diaphragm member 35 opposite the ends of the legs 40 and 45 is replaced by appropriate ferromagnetic material in the form of separate, spaced pole pieces 50 set into the non-magnetic diaphragm or plate member 35. These pole pieces 50 are substantially the size and shape as the ends of the legs 40 and 45 of the core, and are in general positioned directly opposite such ends so as to be directly engaged by such ends. By the use of such pole pieces, the effective non-magnetic gap is reduced, thus providing an arrangement with lower reluctance than otherwise. Thus, resultant electromagnetic influences extend directly through the necessary gap or space in the wet chamber 26 to the attractable armature or plunger member 15. By virtue of the use of the pole pieces 50, which are of soft iron of approximately zero retentivity, and non-magnetic material for the remainder of the diaphragm, the applied force is greater than it would otherwise be when a given current flows through the coil 42. Such pole pieces 50 may be of "Armco" soft iron which is capable of carrying a flux of 100,000 lines per square inch, that is, 16 kilogausses, without saturation. However, the pole pieces may be made of other material of the "soft iron" type, that is, of a type which can carry a flux of at least about 70,000 lines per square inch and be substantially fully annealed and have low magnetic retentivity. The pole pieces 50, in conjunction with the plunger 15, thus provide a low reluctance magnetic path when the plunger is in any position over the range of its stroke.

The pole pieces 50 are hermetically sealed in the diaphragm plate member 35, as by nickel brazing, sweating in place, or other sealing procedure known to the trades and appropriate for the particular non-magnetic material used for the top diaphragm member 35.

As seen in FIG. 5A, the inserted pole pieces 50 are separated by ceramic insulating spacers 51, rather than by intervening sections of the plate or diaphragm member 35 in FIG. 5. This minimizes eddy-current losses in the spaces between the pole pieces 50 which might otherwise occur across the intervening sections of the member 35, indicated in FIG. 5. Even though complete electrically conductive areas do not encircle extensions of the core legs, nevertheless complete ferromagnetic paths are provided through the plunger 15 when it is in its operated position against the diaphragm. By substantially complete elimination of air-gaps under these conditions, maximum holding force is achieved. The ceramic inserts are readily mounted, even for high pressures, within the chamber 26 by setting them against shoulders 51a in the diaphragm plate and cementing or brazing them in place. The pole pieces in the diaphragm are thicker than the non-conductive materials in the diaphragm plate to assure free movement of the armature in the liquid chamber by providing channels through which the fluid in the chamber can circulate when the armature is moving away from or toward the plate.

Where appropriate, as is indicated in FIG. 9, the ends of the legs 40 and 45 may themselves be inset into the top diaphragm or plate member 35, the ends of such legs being fused over at 52 to seal the spaces between the laminations otherwise filled with insulation. This may be accomplished by the use of electrical fusion, which is welding with a non-consuming tungsten rod applied to the indicated ends of the legs according to known practices.

As also indicated in FIG. 9, it is possible to build the diaphragm member merely as a single dividing plate 35, clamped between the housing members 12 and 14, thereby omitting the use of the sidewall or skirt member 25a of the cup-shaped diaphragm 25 of FIGS. 1 and 2. With this arrangement, the armature 15 works directly within

the adjacent portion of the wet chamber housing 14 rather than within the wall or skirt member 25a, as indicated in FIG. 2.

Appropriate leads for the coil or winding 42 are taken off in a suitable manner, such as indicated at 54 in FIG. 1, necessary sealing means 55 being used on the housing 14.

Especially for some uses, it may be desirable, in order to eliminate a high-frequency hum, to provide each of the two outside legs 45 with a closed conductive loop or winding, as indicated diagrammatically at 56 in FIG. 6, adjacent the junction between the ends of the legs and the diaphragm plate 35, thereby to shade the poles for the outside legs. This renders the magnetic flux passing through the inside parts of the outer legs 45 out of phase with that of the middle leg 40. The secondary current in these loops 56 causes the magnetic flux to lag behind the main flux at these points, thus applying a pulling force to the armature at all times during the cycle of the alternating current flowing through the coil 42. Thus, an 800-cycle hum which might result with 400-cycle operation, for example, in using alternating current, can be greatly reduced.

The cup-shaped diaphragm 25 of FIGS. 1 to 5, with its sidewall or skirt portion 25a, is shaped at its sides for at least a considerable portion of its length, as seen in FIG. 3, to provide inner boss portions 60 that conforms to the transverse dimensions and contour to correspond generally with the shape of the armature 15 and the carrying block 22 with its retention arms 20. In this way, the laminations of the armature 15 may be maintained in alignment with the laminations of the relatively stationary E-shaped core 10, and in conforming relation generally with the correspondingly elongated top diaphragm plate member 35 and the correspondingly elongated solenoid structure 10 with its middle leg 40 and end legs 45. Thus, the cup-shaped diaphragm 25 has a generally elongated form, as indicated in FIG. 2, and is relatively narrow internally, as indicated in both FIGS. 1 and 3.

It is quite frequently desired to arrange for increasing the stroke of the armature 15 and the corresponding gap between the armature 15 and the main plate portion 35 of the cup-shaped diaphragm 25, and for correspondingly increasing the gap between the armature 15 and the middle pole 40 of the solenoid 10. Arrangements suitable for this purpose are shown in FIGS. 7 and 8. In FIG. 7, the outside legs 45 of the core 20 are extended beyond the middle leg 40 and arranged angularly at acute angles to engage correspondingly disposed angular pole pieces 50a sealed in corresponding angular portions of the upper diaphragm member 35, the middle pole piece 50 being disposed as before. With this arrangement, the ends of the armature 15 are beveled to correspond with the angular position of the end pole pieces 50a.

In FIG. 8, the extremities of the outer legs 45 are extended straight down alongside the ends of the armature 15 beyond the end of the middle leg 40 and brought into contact with longitudinal pole pieces 50b by means of a close running fit. With this construction, the cup-shaped diaphragm 25 is stepped to provide an external annular shoulder 65 beyond the ends of the end poles or legs 45, so that the diaphragm member 35 is itself cupped to provide a cylindrical sidewall 35b, carrying the end pole pieces 50b. The middle pole piece 50 contacting the middle leg 40 remains, however, in the same relationship as before in opposition to the middle portion of the armature 15. With this arrangement, a considerably deeper gap may be arranged between the armature 15 and the middle pole piece 50, whereby to provide for a much longer stroke of the armature 15. This condition corresponds in part with that provided by the angular construction of FIG. 7.

Diaphragm and solenoid aspects

With the described construction and arrangement of the cup-shaped diaphragm 25, and with the top main

diaphragm plate member 35, or 35a, or 35b, there is provided a sealed separating member which excludes high-pressure high-temperature liquid in the wet chamber within the housing member 14 from the dry chamber enclosing the solenoid core 10 within the outer housing member 12. To provide a solenoid and plunger arrangement suitable for use at high pressures, that is, at pressures of the order of 1,000 p.s.i. and above, a thick diaphragm, that is, a diaphragm having a thickness of at least about 0.060", is employed.

As has also been indicated, the flat-bar-type armature 15 cooperates with the E-shaped relatively fixed solenoid core member 10 most advantageously, by reason of the use of the non-magnetic cup-shaped diaphragm 25 and the flat plate-like dividing diaphragm member 35 using the pole pieces or inserts 50, or 50a, or 50b, in conjunction with the middle leg or pole 40 and the end legs or poles 45. This is true whether the diaphragm member 35 is of flat formation, as indicated in FIGS. 1 to 6 and in FIG. 9, or carries the end pole pieces 50a at an acute angle, as diagrammatically indicated in FIG. 7, or at an angle of 90° with respect to that of FIGS. 6 and 9, as indicated in FIG. 8.

By these means the armature 15 may be located within the wet chamber in position for direct and positive actuation of a valve, such as the valve 16, without requiring the use of a liquid-excluding packing about the stem of the valve 16. Similarly, with the arrangement disclosed, the necessity for direct contact between the solenoid core 10 and the armature or plungers 15 is overcome. In the specific form illustrated, this condition is accomplished by employing the magnetic pole pieces 50 or 50a or 50b, sealed within the diaphragm member 35 or 35a or 35b, the ends of the legs 40 and 45 of the solenoid core 10 being disposed in direct contact with the pole pieces 50, 50a or 50b, the inserts opposite the outer legs 45 are slightly offset toward the center leg 40 and the center insert is slightly narrower than the center leg. Such an arrangement provides shading and serves to focus the flux on the armature.

Otherwise stated, with the present construction a liquid-tight diaphragm is used so that, while the solenoid core 10 may be retained dry, the armature 15 may be disposed in a wet chamber, whereby to eliminate the necessity for valve-stem packing which otherwise would require the generation of much additional force by the solenoid in order to overcome the friction of the valve-stem packing.

As has been previously indicated, the diaphragm, whether in the cup form of the indicated diaphragm 25 with an upper diaphragm plate 35 as in FIGS. 1 to 6, or merely a clamped flat diaphragm plate 35 as in FIG. 9, is made of non-magnetic material, such as a non-corrosive or stainless steel having non-magnetic characteristics and being also non-conductive except to a minor and inconsequential extent. For the purposes of this invention, a material is deemed to be non-conductive if its conductivity is less than about 10% of the conductivity of copper.

For purposes where it is desirable that the diaphragm be non-conductive, other materials may be employed and, preferably, such materials also will receive the magnetic pole pieces 50 or 50a or 50b, according to the particular construction. Appropriate plastic materials, such as nylon, polyethylene and the like, in which the pole pieces may be adequately sealed, may be employed for the purpose. This will apply especially to low pressure conditions and to various temperature conditions, depending upon the particular plastic. Depending upon the strength required, ceramics in which the pole pieces may be adequately sealed and where the ceramics are non-porous may be used. Such ceramic materials are available on the market for this general type of use, which possess practically zero water absorptivity, these materials being wholly inert. There are also available ceramic-metal composi-

tions useful for this purpose and sometimes known as cermets. In other words, there are many non-magnetic materials, some of which are non-conductive, which may be used to produce sealing diaphragms according to the present invention, and in which the mentioned magnetic pole pieces may be properly placed and sealed.

With respect to the matter of the laminations of the solenoid parts, and with particular reference to the solenoid core 10, there are available thin electrical steel sheets produced for electrical usage and suitable for the present purpose.

Since, as has previously been indicated, skin effects, eddy currents, heating and other conditions resulting in energy loss must be avoided for the purpose of producing solenoids usable with high-frequency alternating-currents, and particularly 400 c.p.s. current or higher, such as 600 c.p.s. or 800 c.p.s., at voltages around 115 volts or higher, such as up to 220 volts, it is important in this invention to use for the laminations thin electrical steel sheets not exceeding about 0.007" in thickness. With such constructions, skin effects are minimized and maximum pulling force in the resultant solenoid is accomplished. If alternating currents in the order of 1,000 cycles are to be used, such plate thickness will not exceed approximately 0.005" in thickness. Thus, frequencies may be employed, ranging from about 400 c.p.s. through 700 or 800 c.p.s. and up to 1,000 c.p.s., by using thin electrical steel sheets ranging correspondingly from about 7 mils through 6 mils, down to about 5 mils. Currently, the optimum condition apparently will involve alternating current of about 400 cycles at around 115 volts. But the invention is equally applicable to higher frequencies, as just indicated, and also to higher voltages, such as 220 volts, with comparable plate thicknesses as above outlined.

Of course, the number of turns in the winding 42 will be reduced as thinner laminations and higher frequencies are employed, high pulling force still being attained. In this connection, it is to be noted that the number of laminations in a solenoid construction for use with high frequency alternating-current increases in proportion to the increase in the frequency and the thickness decreases.

It is advantageous to use high frequency power rather than low frequency power in the operation of the solenoid of this invention. By employing high power frequency, such as 400 c.p.s., instead of a lower power frequency, such as 60 c.p.s., the ratio of the resistance of the solenoid winding to its reactance is made larger. For this reason, any changes in resistance due to changes in temperature produce less effect on the flux at 400 c.p.s. than at 60 c.p.s. As a result, the pulling force of the solenoid is less temperature-sensitive at 400 c.p.s. than at 60 c.p.s. Furthermore, a predetermined pulling force may be produced with the solenoid of this invention with a smaller solenoid core and with a smaller winding and hence with lower weight at 400 c.p.s. than at 60 c.p.s.

Though the invention has been described above only with reference to solenoid cores which are E-shaped, it will be understood that cores of other shapes may be employed. For example, as shown in FIG. 10, the core 60 may be U-shaped rather than E-shaped as in the construction of FIGS. 1 to 9, and the base of the U carries the winding 62. In this form, the cup diaphragm 25 is provided with two spaced magnetic pole pieces 65 and 66 with which the extremities of the end legs 68 are in contact to complete the flux path.

Though the invention has been described above with reference to a number of embodiments thereof, it will be understood that it may be embodied in many other forms. It is therefore to be understood that many changes may be made in the form, details of construction, arrangement of the elements and materials of which they are made without departing from the scope of the invention as defined by the following claims and as required by the prior art.

Referring now to FIG. 11, there is shown a side view, partially in section, of an electromagnetic relay 100 constructed according to the invention. The electromagnetic relay 100 has a high resistance, non-magnetic housing 101 which terminates in a base portion 102. The base portion 102 has a series of terminals 103 extending outwardly therefrom and adapted to be inserted into a conventional socket. It will thus be apparent that the relay 100 may be inserted into an electrical circuit simply by plugging the device into a socket to which appropriate electrical connections have been made. The base portion 102 has an outer surface 104 which is composed of an electrical insulator and an inner portion 105, to which the plugs 103 are attached, which is similarly composed of an electrical insulator or highly resistive material which has the characteristic of being non-magnetic. It will thus be seen that the housing 101 and base inner portion 105 form a unitary and complete device enclosure by being bonded together along a peripheral shoulder 106.

Disposed within the housing 101 is an electromagnet 110. The electromagnet 110 consists of a flux inducing member 111 of a paramagnetic, and preferably ferromagnetic, material, which is generally U-shaped in configuration and terminates in a pair of legs 112, 113. The flux inducing member 111, as well as the legs 112, 113, in the embodiment illustrated in FIG. 11, consists of a series, about thirty, for example, of single laminations, each of a thickness of from five to ten thousandths of an inch, said thickness being specifically adapted for use with high frequency, i.e. 400 cycle, electromagnet energization. The electromagnet 110 is energized by the application of electrical power to a pair of windings 114, 115 disposed about the flux inducing member 111, adjacent the legs 112, 113, respectively. As shown, the windings 114, 115 are formed on conventional bobbins 116 which are bonded to the flux inducing member 111 by any appropriate conventional means.

The housing 101 is generally divided into a first portion 120, within which the electromagnet is disposed, and a second portion 121 by means of a non-magnetic diaphragm 122. The non-magnetic diaphragm contacts the housing 101 around the diaphragm periphery and at a housing inner shoulder 123, so as to form a seal which seals the first housing portion 120 from any atmospheric or moisture leakage or the like which might enter through the base portion 102. As shown in FIG. 11, the laminated legs 112, 113, which form the pole pieces of the electromagnet 110, extend through the diaphragm 122 and terminate substantially flush with that diaphragm surface which is remote from the flux inducing member 111 and windings 114, 115. The legs 112, 113 complete the diaphragm seal between the first housing portion 120 and the remainder of the housing. If desired, separate laminated pole pieces, similar to the pole pieces heretofore described, could be utilized in the diaphragm, rather than using unitary laminations to form the flux inducing member 111 and legs 112, 113. In the embodiment shown, the leg 113 has a shading ring 124 disposed therein in order to cause a magnetic lag in the adjacent armature portion so as to eliminate hum which would otherwise exist upon relay energization.

The second housing portion 121 contains a laminated armature 130 to which is attached an actuator 131. Four switches 132 (only two of which are shown in FIG. 11) are attached to the actuator 131 by reed switching elements 133. The reed switching elements 133 are of the over-center spring type, having over-center springs 134. While this type of switch is presently preferred for use in the invention, any type of fast-acting switch can be utilized in which switch action occurs at an extremely reproducible point in actuator motion. The switches 132 are shown as being both of the single pole and double pole type. That switch having electrical circuit leads 135 which connect to appropriate ones of the terminals 103

(the actual connection not being shown for purposes of clarity of this drawing), is of the double pole type with the electrical input connection formed by a lead 136 connected at a terminal 137 of the reed switching element 133. The remainder of the switch circuit connections have been omitted for purposes of clarity of the drawing and are of conventional lead types connected between the switch elements and the terminals 103.

The armature 130 is formed of a series of laminations, preferably of the same approximate thickness as the laminations forming the flux inducing member, and similarly bonded together. In addition, the armature laminations are fastened together by means of a pair of rivets 140, 141. The rivet 141 extends beyond the armature proper and functions as a pivot for the armature. Thus, the armature is fixed in linear position with respect to the diaphragm 122 and electromagnet 110 and limited to angular displacement for any movement. The rivet 141 forming the pivot may be attached directly to the housing or to the diaphragm, as desired, in order to fix its position. A torsion spring 142 is disposed about the pivot 141 and engages the armature 130 by means of a first spring leg 143 which is disposed within an aperture formed in the armature 130. Of course, any other conventional types of connection between spring 142 and armature 130 may be utilized. The torsion spring 142 also has a second spring leg 144 which engages the diaphragm 122, or the housing 101 if desired, in order to normally urge the armature 130 away from the diaphragm 122. Actuation of the relay by energization of the windings 114, 115 overcomes the spring urging and draws the armature 130 toward the diaphragm 122, so that the circuit elements assume the disposition shown in FIG. 11. The torsion spring 142 is selected to have sufficient urging to overcome the counter-urging which will result from the use of the over-center spring type of reed element in the electrical switches.

Referring now to FIG. 12, there is shown an end view of the relay 100. In FIG. 12, the alignment of the laminations of the flux inducing member 111 and, consequently, the legs or pole pieces, with the laminations of the armature 130, is particularly apparent. The pivot 141 will be seen to engage the diaphragm 122 directly, rather than the housing 101, in the embodiment shown. A pair of positioning plates 150, 151 are disposed in the second housing portion 121 as guides for the actuators 131. The entire switch assembly is attached to the diaphragm 122 by means of an insulating spacer 152 and bolt 153, the bolt 153 engaging a threaded aperture 154 formed in the diaphragm 122. Various other structural details of the relay 100 will also be more clearly apparent in FIG. 12.

The invention claimed is:

1. An alternating current solenoid construction including: an electromagnetic laminated fixed member having an electrical winding constituting a magnetic flux-inducing means, said fixed member having at least two parallel legs spaced from each other and constituting magnetic flux carrying members, the ends of said legs defining pole pieces; a relatively movable laminated armature opposing the ends of said legs; a housing providing a dry mounting for said laminated fixed member and providing a chamber enclosing said laminated armature; positioning means for aligning the laminations of said armature with the laminations of said fixed member; and a fluid-tight non-magnetic rigid diaphragm of high resistivity having openings to receive said pole pieces in sealing relationship so as to be disposed between said flux-inducing means and said chamber, said diaphragm being in sealed relation to said chamber and said pole pieces being fused to the peripheries of said openings and exposed on the chamber side of said diaphragm to attract and be engaged by said laminated armature.

2. The combination of claim 1, including insulating means positioned in said diaphragm between said pole

pieces in sealing relationship to said diaphragm and pole pieces to minimize eddy currents.

3. The combination of claim 1, in which said pole pieces constitute integral laminated extensions of said legs terminating on the said chamber side of said diaphragm in pole faces, the ends of the laminated extensions of each leg making up a face being fused together and fused to the periphery of the associated opening in said diaphragm receiving the pole piece.

4. The combination of claim 1, in which said pole pieces constitute separate magnetic inserts in abutting engagement with said legs, said inserts being brazed to the peripheries of their respective receiving openings in said diaphragm.

5. The combination of claim 4, in which said positioning means is defined by a keying surface formed on said laminated armature and a complementary, cooperating keying surface formed within said chamber to limit movement of said laminated armature to rectilinear reciprocal displacement.

6. The combination of claim 4, in which said inserts are laminated, the respective laminations being in alignment with the laminations of said fixed member and fused together at their exposed ends facing said armature.

7. The combination of claim 4, in which said pole pieces defining the ends of said parallel legs are positioned inwardly toward the center of said diaphragm to focus the flux on the armature.

8. The combination of claim 4, in which said fixed member has a middle leg disposed between and in parallel relationship to said two parallel legs, said winding being wound about said middle leg and said middle leg terminating in a pole piece received in an opening in said diaphragm in sealing relationship therewith and having an exposed surface on said chamber side of said diaphragm, said exposed surface being flush with the chamber side of said diaphragm and flush with the exposed surfaces of the remaining pole pieces, all of said exposed surfaces lying in a common plane normal to the direction of said parallel legs.

9. In an A-C relay, the combination of:

an electromagnet whose flux inducing member is formed by a plurality of thin laminations bonded together and which terminates in at least two legs;

an armature formed by a plurality of bonded paramagnetic laminations;

a non-magnetic diaphragm disposed between the armature and electromagnet so that the electromagnet legs extend through and terminate substantially flush with the diaphragm surface remote from the electromagnet;

a shading ring disposed in the face of one of the electromagnet legs;

a pivot fixed with respect to the electromagnet;

means for mounting the armature on the pivot;

spring bias means engaging the armature for normally urging the armature away from the electromagnet;

an electrical switch, including a reed switching element having an over-center spring mounted thereon; and an actuator connected between the armature and reed switching element and operable to move the reed switching element in response to movement of the armature.

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BERNARD A. GILHEANY, *Primary Examiner.*

G. HARRIS, *Assistant Examiner.*