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2,802,918

ELECTROSTATIC RELAY

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FIG. 1

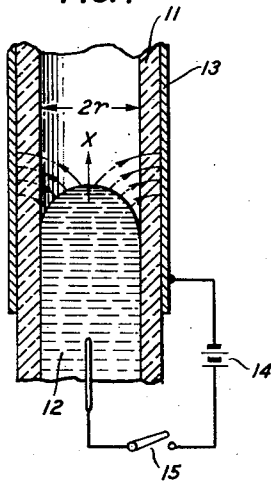


FIG. 2

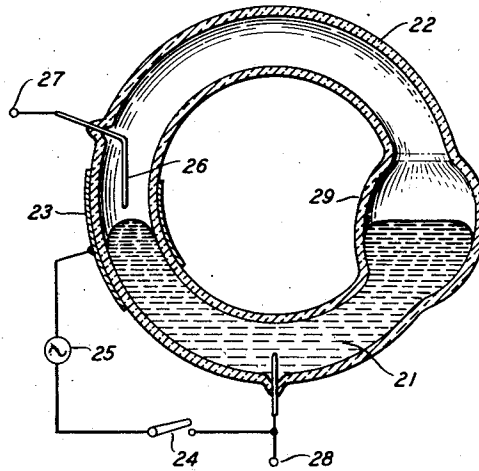


FIG. 3

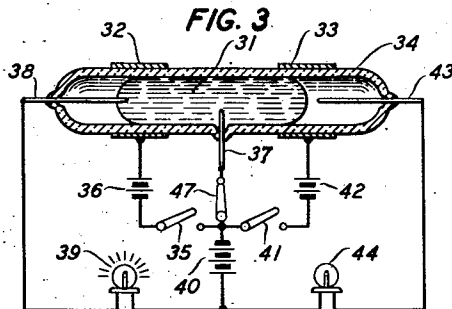


FIG. 4

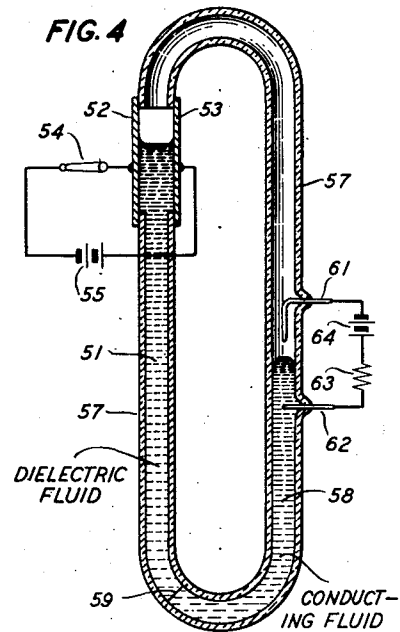
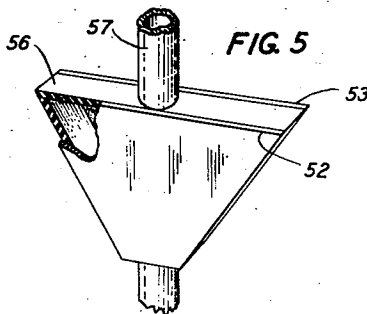


FIG. 5



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1

2,802,918

ELECTROSTATIC RELAY

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12 Claims. (Cl. 200—87)

This invention relates to electrostatic relays.

The major problem in the electrostatic switch field has been that of obtaining consistent operation at relatively low voltage levels. The electrostatic switches which have been proposed heretofore have been of the mechanical type. Generally, in order to obtain consistent operation at low potentials, the operating mechanisms of such switches have been delicate and costly.

Accordingly, a principal object of the present invention is to simplify and to reduce the cost of electrostatic switches.

A collateral object of the invention is to reduce the voltage required for the operation of electrostatic switches.

In accordance with the present invention, the foregoing objects are achieved by the use of a fluid as the moving portion of an electrostatic switch. When an electrostatic field is applied to the fluid, it moves and causes the opening or closure of contacts. In an illustrative embodiment of the invention, an insulating tube is partially filled with mercury. An electrostatic field is applied between the mercury and a conducting sleeve which encircles the insulating tube, drawing the mercury toward the sleeve. As the mercury is displaced within the tube, electrical connections between contacts extending into the tube are opened or closed.

A feature of the invention is a relay structure in which the conducting fluid performs three distinct functions. First, the conducting fluid is the active portion of the relay which is moved by the electrostatic forces; secondly, it conducts electricity between contacts; and thirdly, the conducting fluid performs a memory function.

In another embodiment of the invention, the electrostatic forces are applied to a dielectric fluid. In the second form of electrostatic relay, a fluid-tight space is formed by insulating material located between the edges of two conducting plates. The space between the conducting plates opens into a tube containing dielectric fluid. When a potential is set up between the plates, the dielectric fluid is drawn up between them. The tube containing the dielectric fluid is generally U-shaped, and contains a column of mercury, or another conducting fluid, in addition to the column of dielectric fluid. As the dielectric fluid is drawn up between the conducting plates, the mercury column moves in the U-shaped tube and operates contacts extending into the tube.

Other objects and various advantages and features of the invention will become apparent by reference to the following description taken in connection with the appended claims and the accompanying drawings forming a part thereof.

In the drawings:

Fig. 1 is a diagram illustrating the principles of the invention;

Fig. 2 is an electrostatic switch employing a conducting fluid in accordance with the invention;

Fig. 3 is a form of the electrostatic switch of Fig. 2 in which the conducting fluid also performs a memory function; and

2

Figs. 4 and 5 illustrate another form of the invention in which the electrostatic forces act on a dielectric fluid.

Referring more particularly to the drawings, Fig. 1 shows a tube of dielectric material 11 containing conducting fluid 12 which may, for example, be mercury. An outer conducting sleeve 13 encloses the dielectric tube. When a potential from the source 14 is applied between the conducting fluid 12 and the sleeve 13 by the closure of switch 15, the conducting fluid tends to rise in the dielectric tube 11. This is a result of the attraction between the positively charged mercury column 12 and the negatively charged sleeve 13. The upward direction is designated "x" in Fig. 1 for the purposes of the following mathematical analysis. In the following analysis, the "absolute" system of units is employed throughout.

The upward force on the column of mercury 12 is as follows:

$$F_1 = \frac{V^2}{2} \frac{\partial C}{\partial x} \quad (1)$$

where

V is the applied voltage in statvolts,

C is the capacitance between the mercury 12 and the sleeve 13 in statfarads, and

x is the position of the upper surface of the mercury column 12 in centimeters.

This equation is derived from page 53 of "Principles of Electricity and Electromagnetism" by G. P. Harnwell, first edition, McGraw-Hill Book Company, New York, 1938.

Capacitance in the "absolute" system of units is expressed as follows:

$$C = \frac{AK}{4\pi t} \quad (2)$$

where

C is the capacitance in statfarads,

A is the area in square centimeters,

K is the dielectric constant (which is dimensionless in the "absolute" system of units), and

t is the space between the plates in centimeters.

For the geometry shown in Fig. 1, the capacitance between the column of mercury 12 and the conducting sleeve 13 is as follows:

$$C = \frac{\pi x K}{2t} \quad (3)$$

where

r is the radius of the dielectric tube in centimeters, and t is the thickness of the tube, and where t is small relative to r.

Accordingly, from Expressions 1 and 3, the force in the upward direction in Fig. 1 is given by the following expression:

$$F_1 = \frac{V^2 r K}{4t} \quad (4)$$

When the electrostatic forces are applied in the vertical direction as shown in Fig. 1, the counterbalancing force is the weight of the column of conducting fluid 12. With the circular geometry shown in Fig. 1, the expression for this downward force is as follows:

$$F_2 = \pi r^2 \rho g h \quad (5)$$

where

ρ is the density of the conducting fluid in grams per cubic centimeter,

g is the acceleration due to gravity (980 centimeters per second per second), and

3

h is the effective height of the column of mercury in centimeters.

With the foregoing Expressions 4 and 5 being set equal to one another, it may be shown that the displacement of the conducting fluid is dependent upon the applied voltage in accordance with the following formula:

$$h = \frac{V^2 K}{4 \pi r \rho g} \quad (6)$$

The displacement of the fluid is thus seen to be directly proportional to the square of the applied voltage and inversely proportional to the thickness of the tube, the radius of the tube, and the density of the conducting fluid. The dielectric strength of the material employed in the dielectric tube is a limitation which determines how thin a tube may be used. This is determined by the breakdown field of the material in volts per centimeter. The expression for the electric field E is as follows:

$$E = \frac{V}{t} \quad (7)$$

When Expression 7 is substituted in Equation 6 and Equation 6 is solved for V , the following equation results:

$$V = \frac{4 \pi r \rho g h}{E K} \quad (8)$$

Expression 8 indicates the voltage (in statvolts) required to move the conducting fluid under the conditions given by the right-hand portion of the equation. It may particularly be noted that the voltage V required is inversely proportional to the electric field E in the dielectric tube and to the dielectric constant K of the material of the dielectric tube. To obtain high values of electric field (E) with relatively low voltages (V), it is desirable to use a dielectric material having a high dielectric strength, so that it will not break down when it is made very thin. Typical dielectric materials having relatively high dielectric strength are glass and Mylar, which is the trade name for polyethylene terephthalate. The dielectric constant K may be increased by employing one of the ferroelectric materials, such as barium titanate, for specific example.

In the relay of Fig. 2, a column 21 of conducting fluid is shown in its neutral position in an annular dielectric tube 22. The conducting fluid may, for example, be mercury, and the tube 22 may be made of glass. A conducting sleeve 23 encircles the glass tube 22 near one end of the column of mercury 21. When switch 24 is closed, a source of alternating current 25 is applied between the body of mercury 21 and the conducting sleeve 23. The mercury then rises within the dielectric tube 22 and contacts a conducting probe 26, which extends into the tube 22. This closes an external work circuit which may be connected between contacts 27 and 28. An alternating current source 25 is employed instead of the direct current source 14 shown in Fig. 1 in order to hold the conducting fluid in its elevated position for substantial periods of time. It has been determined that films of low conductivity may gradually reduce the effectiveness of a direct current source of voltage by building up a charge of one polarity on the inner wall of the dielectric tube. When an alternating current source is used, however, this action is avoided, and a constant holding force is maintained which keeps the column of mercury in contact with the probe 26.

In Fig. 2, the dielectric tube 22 is enlarged at 29 to reduce the difference in level between the mercury within the conducting sleeve 23 and in the bulb 29 when the relay is energized. The difference in levels determines the value h in Equations 6 and 8. If the tube 22 were of uniform cross-section, the upward movement of the mercury within the conducting sleeve 23 would be accompanied by a corresponding drop in the level of the other mercury surface. The value h would then be equal to twice the movement of the mercury column with respect

4

to the conducting probe 26. However, in the device of Fig. 2, the mercury in the enlarged portion 29 of the dielectric tube 22 drops but slightly in level; and the value of h in Equation 6 is determined principally by the movement of the mercury within the conducting sleeve 23.

In Fig. 3, a preferred form of the invention is shown in which the conducting fluid 31 performs several functions. In the device of Fig. 3, there are two external conducting sleeves 32 and 33 which may pull a globule of mercury 31 to either end of an evacuated dielectric tube 34. When switch 35 is closed, a potential source 36 is applied between the sleeve 32 and a conducting probe 37 extending into the mercury 31, and the mercury is drawn to the left-hand end of the dielectric tube 34. The mercury then bridges the conducting probes 37 and 38 and energizes an external work circuit including a lamp 39 and a voltage source 40. When the switch 35 is opened, the mercury remains in its position at the left-hand end of the dielectric tube 34, and the work circuit remains energized. This is the condition shown in Fig. 3. When switch 41 is closed, voltage from a source 42 is applied between the probe 37 and the conducting sleeve 33, and the mercury is drawn to the right-hand end of the dielectric tube 34. The mercury then bridges conducting probes 37 and 43, and energizes an external work circuit including lamp 44 and the voltage source 40. When the relay of Fig. 3 is not in operation, the switch 47 is opened.

In Fig. 3, it may be noted that the mercury performs three distinct functions. First, it is the moving element of the relay, and it is operated on directly by the electrostatic forces. Secondly, the mercury forms the conducting path between the contacts extending into the dielectric tube. The third function is a memory function. This is indicated in Fig. 3 by the illumination of the lamp 39, even after the operating potential 36 has been removed from the conducting sleeve 32 by the opening of switch 35. Thus, no power is required to maintain the relay in a given operated state.

In Fig. 4, a relay structure is shown in which the movement of dielectric fluid causes the movement of conducting fluid which, in turn, opens and closes a set of contacts. In Fig. 4, dielectric fluid 51 is drawn up between a pair of conducting plates 52 and 53 when switch 54 is closed. Closure of the switch 54 applies a potential 55 between the conducting plates 52 and 53.

The triangular shape of the conducting plates 52 and 53 is shown more clearly in Fig. 5. The edges of these plates are separated and sealed by insulating material 56 forming a fluid-tight space which opens into the dielectric tube 57. When a potential is applied across the plates 52 and 53, the dielectric fluid tends to rise between the plates to increase the capacitance between the plates 52 and 53 in a known manner (see page 70 of the Harnwell text cited above). The conducting fluid 58 is located within the dielectric tube 57, and is not miscible with the dielectric fluid 51. However, the two fluids are in contact with one another at point 59 within the dielectric tube 57. Accordingly, when the dielectric fluid 51 rises between the triangular shaped plates 52, 53, the conducting fluid 58 drops in the other arm of the U-shaped tube 57. When the conducting fluid 58 drops, the load circuit connected to the conducting probes 61 and 62 is opened. This de-energizes the load resistance 63, and the voltage source 64 no longer draws power.

The enlarged space between the triangular plates 52, 53 in Fig. 4 serves much the same function as the bulb 29 of Fig. 2. In both devices, the portion of enlarged cross-section is in one arm of the U-shaped tube and the contact probe is in the other. Thus, in Fig. 4, a relatively small rise in level of the dielectric fluid 51 reduces the level of the conducting fluid 58 to a substantially greater extent. The available force is accordingly utilized to provide a maximum movement of the fluid in the U-shaped tube at the critical contact breaking point.

It is to be understood that the above-described arrange-

ments are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In combination, a fluid, at least a part of said fluid being conductive liquid, a container enclosing said conductive liquid, electrostatic field producing means located asymmetrically with respect to said fluid for drawing said fluid toward said means, an electrical circuit, and means including a pair of electrical contacts in series with said circuit and extending into said container for changing the electrical conditions in said circuit when said conductive liquid is moved.

2. In combination, a fluid, at least a part of said fluid being conductive liquid, means for applying an electrostatic field to said fluid to attract the same toward said means and thereby move said conductive liquid from a first predetermined space to a second predetermined space, a first electrical contact extending into only one of said predetermined spaces, and a second electrical contact extending into the same predetermined space as said first contact.

3. A combination as set forth in claim 2 wherein said first and said second predetermined spaces overlap, and wherein said second contact extends into the common portion of said two predetermined spaces.

4. In combination, a fluid, at least a part of said fluid being conductive liquid, a U-shaped tube enclosing said conductive liquid, electrostatic field producing means located asymmetrically with respect to said fluid for moving said conductive liquid, an electrical contact extending into one arm of said U-shaped tube, the other arm of said U-shaped tube including an enlarged portion.

5. A combination as defined in claim 4 wherein said enlarged portion is bounded by two conducting plates which are insulated from each other, and wherein means are provided for applying a voltage between said plates.

6. In an electrostatic relay, a dielectric tube, two conducting sleeves encircling respectively different portions of said tube, conducting fluid within said tube, a first conducting probe extending through said tube into said conducting fluid between said two conducting sleeves, and additional conducting probes extending into said tube adjacent each of said sleeves.

7. An electrostatic relay as defined in claim 6 wherein means are provided for applying a voltage pulse to said conducting sleeves for moving said conducting fluid into contact with the conducting probes associated with said sleeves.

8. In an electrostatic relay, a dielectric tube, first and second conducting sleeves encircling respectively different portions of said tube, conducting fluid within said tube, a first conducting probe extending through said tube into said conducting fluid between said two conducting sleeves, and second and third conducting probes extending into said tube adjacent said first and second sleeves, respectively.

9. In an electrostatic relay, a dielectric tube, first and second conducting sleeves encircling respectively different portions of said tube, conducting fluid within said tube, a first conducting probe extending through said tube into said conducting fluid between said two conducting sleeves, second and third conducting probes extending into said tube adjacent said first and second sleeves, respectively, a first load circuit in series with said first and second conducting probes, a second load circuit in series with said first and third conducting probes, means for applying a voltage impulse to said first conducting sleeve to energize said first work circuit, and means for applying a voltage impulse to said second conducting sleeve to energize said second work circuit.

10. In combination, a curved dielectric tube having a bulge located along its length, a conducting sleeve enclosing another portion of said tube, a column of conducting fluid in said tube having one surface in said bulge and the other surface within said conducting sleeve, a first conducting probe extending through said tube into said conducting fluid, a second conducting probe extending through said dielectric tube above the surface of said conducting fluid and adjacent said conducting sleeve, and means for applying a voltage between said sleeve and said first probe to move said conducting fluid and close the circuit between said two conducting probes.

11. In combination, a dielectric tube, a conducting element adjacent a portion of the outer surface of said tube, conducting fluid within said tube having one surface located near said conducting element, a first conducting probe extending through said dielectric tube into said conducting fluid, a second conducting probe extending through said dielectric tube adjacent said conducting element, and means for applying a voltage between said conducting element and said first probe to move said conducting fluid and close a circuit between said two conducting probes.

12. An electrostatic relay comprising a dielectric tube, a fluid in said tube, at least a part of said fluid being conducting, a plurality of conducting probes extending into said tube, and electrostatic means adjacent a portion of said tube for applying an electrostatic force to said fluid to draw the same toward said electrostatic means and thereby alter fluid contact with at least one of the conducting probes.

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