

Aug. 11, 1964

E. DONATH
MERCURY RELAY

3,144,533

Filed March 16, 1962

2 Sheets-Sheet 1

FIG. 1

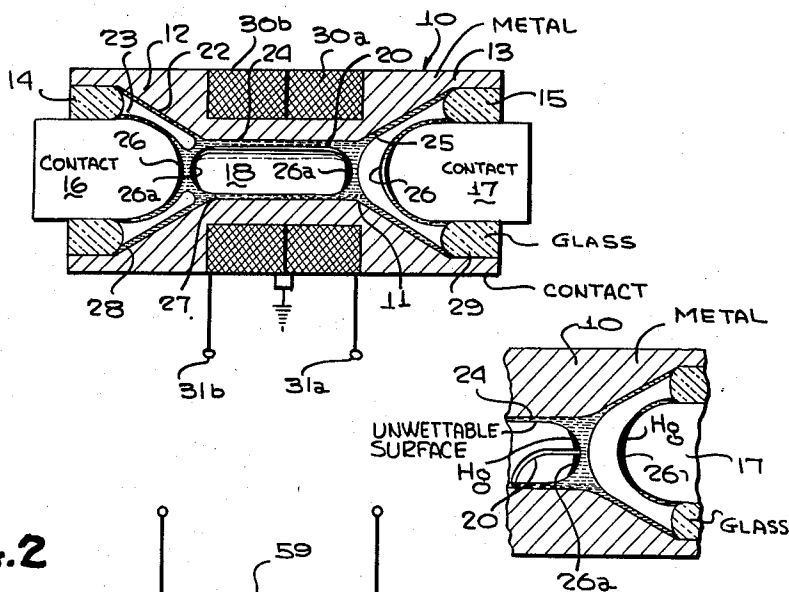


FIG. 2

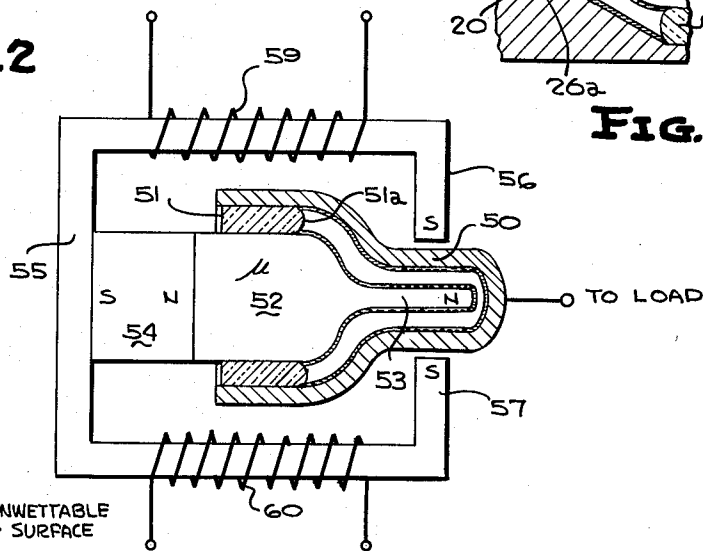


FIG. 4

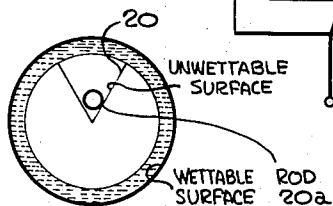


FIG. 3

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FIG. 5

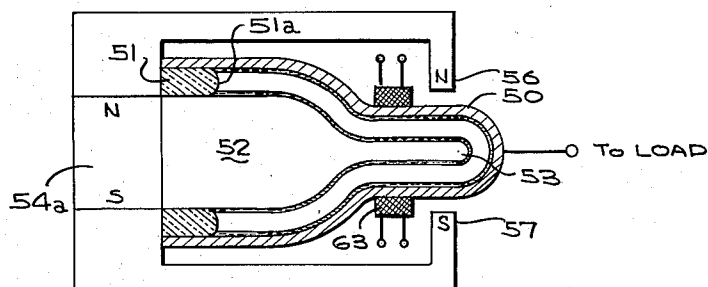


FIG. 6

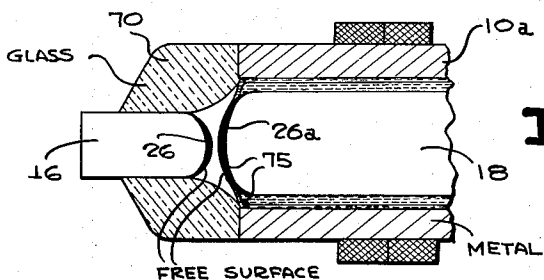
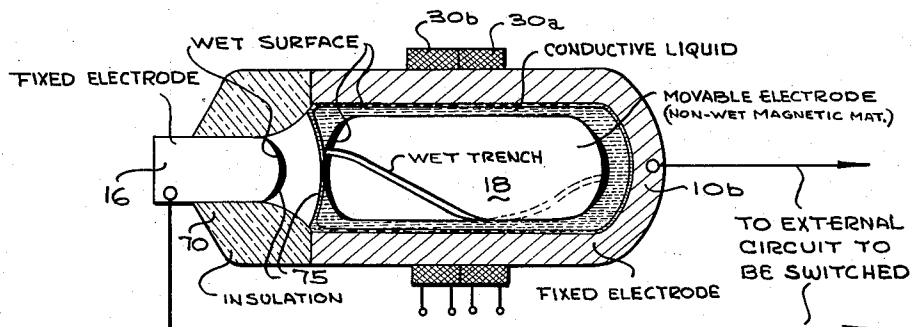


FIG. 7

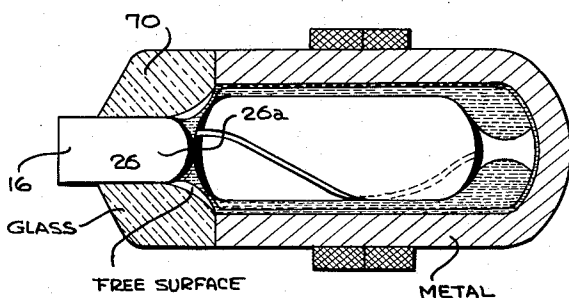


FIG. 8

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3,144,533

MERCURY RELAY

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22 Claims. (Cl. 200-112)

The present invention relates generally to circuit makers and breakers, and more particularly to relay type apparatus employing conductive liquid contact surfaces.

Liquid contact relays are known, the liquid employed being generally, though not exclusively, mercury or an amalgam or mixture employing mercury as its major element. In the following description, mercury is specified as a preferred conductive liquid but without intention of being limited to a mercury mixture or amalgam or to pure mercury. Where mercury is specified other conductive liquids may be substituted.

The relay of the present invention employs a sealed envelope, within which are located conductive elements of which at least one is movable, called contacts, and a quantity of mercury. Means are provided for moving a movable element or elements to make and break an electrical circuit, and means are also provided to maintain mercury (or other conductive liquid) intermediate the contacts at least when they make, separation of the elements being accompanied by breaking of an electrical circuit through the mercury.

The usual mercury relay employs a pool of mercury as a reservoir, and attempts to maintain mercury between the contacts by replenishment from the pool by one means or another; for example, capillary action may be employed. It is a feature of the present invention to employ or permit the existence of no pool of mercury, which is one of the features which makes possible the extremely important consequence that the device of the present invention is position insensitive.

In every liquid contact switch, enclosed in an envelope, there exists a ratio between total area within the envelope, and conductive or wet area, where the term conductive or wet area means area which is covered by a layer of mercury, or immersed in mercury, whether or not parts of that area are in fact mercury wettable. This definition is required because in certain modifications of the present invention, certain mercury unwettable surfaces are utilized to reduce friction and not to provide insulation between contacts or switch terminals. Such surfaces may be electrically conductive or they may be non-conductive, depending on switch design. They are, however, normally immersed in mercury and are not intended to provide insulation, in the open condition of the switch, between switch terminals. In prior art switches this ratio has been large, i.e., much greater than unity. It is a feature of the present invention to keep this ratio near unity, and preferably as near unity as feasible consistent with problems of insulation, mechanical strength and the like. Maintaining the ratio near unity implies existence of very little unwet area, and can be best accomplished by employing a small envelope and relatively large wet conductive areas internally thereof. The combination of a very small envelope and large conductive areas therein has the effect of avoiding a critical problem, i.e., failure of the maintenance of a liquid surface on the switch contacts over considerable time periods. Liquid on the switch contacts is continuously being lost, or depleted, during switch operation. If sufficiently depleted, the switch becomes inoperative. Depletion occurs for many reasons. Among these are transfer of mercury from one contact to another, temperature gradients within the switch envelope, which are avoided by using a small volume, droplet formation, splashing or sputtering due to de-

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sired or undesired mechanical movements of the elements or evaporation of mercury into the volume. A replenishment mechanism for the liquid must be provided, and replenishment must keep precise pace with depletion over long time periods. If the envelope is small interiorly, and the wet conductive area relatively large, occupying almost all of the interior surface of the envelope, the problem of depletion-replenishment of liquid on the switch elements is greatly ameliorated, without requirements for special auxiliary replenishment devices. Surface tension provides an inherent replenishment mechanism, which can operate rapidly because of the small mercury transfer distances involved in a very small switch.

Where the interior volume of a mercury switch is large considerable mercury can escape from wet surfaces to form a vapor. If the interior volume is sufficiently small very little vapor can evaporate into the interior volume, for lack of available internal space, and hence one depletion mechanism is substantially eliminated by the mere minimization of size of the switch. However, size is not critical, in the sense that as the switch volume increases only a gradual deterioration of performance occurs, and no sudden transition from excellent to poor operation occurs.

As an alternative description of the last mentioned feature of the invention, the conductive or wet surface area within the switch envelope is maintained large in relation to insulator or non-wet area. In a sense this implies that virtually the entire supply of liquid is that on the conductive surfaces and that essentially none is in the form of vapor or is diverted to insulating surfaces or can gather on insulating surfaces sufficiently to form a conductive bridge. Moreover, the insulating surfaces are convex surfaces, as seen from internally of the switch, and hence mercury tends to run off the insulating surface, and cannot collect and short across the insulating surfaces. The contacts are fabricated of mercury wettable material, while the insulating elements are unwettable, so that this feature of the invention may be described as providing maximum ratio of wettable to non-wet area. Mercury tends strongly to gather and be retained on the wettable area, by virtue of surface tension, so that this feature of the invention ameliorates the depletion-replenishment problem.

If there exists any slight difference of inherent geometry, i.e. radius of curvature, as between two opposed and relatively movable contacts, or if a difference of geometry develops due to differential depletion or accumulation of mercury on a pair of relatively movable contacts, a differential depletion mechanism arises. This depletion must be compensated. In order to effect compensation over a long time period, the entire volume of mercury in the switch, i.e. all the wet surfaces, must be interconnected over a time average. Clearly, when the switch is open, two electrically and hence physically separated mercury surfaces exist. When the switch is closed only one surface exists, i.e. every wet surface is interconnected by means of a mercury layer with every other wet surface. During the latter time a redistribution of mercury must take place so as to tend to equalize the layer of mercury on all the wet surfaces.

As still another feature of the invention, the moving element is made so small that forces of surface tension due to the mercury provide a retaining force for the movable switch element, tending to maintain the element in its last position until moved by a superior force. Further, the switch becomes virtually impervious to shock or vibration.

As another feature of the invention, the design is such that any movable contact, which moves along a guide surface, is not permitted to move mercury which is held between two surfaces both of which are wettable by mer-

cury. This implies that the movable contact carrier itself may be wettable, but the guide surface with respect to which it moves, if such exists, is then non-wet so that mercury attached to the movable element can slide with minimum friction with respect to the guide surface. Alternately, the guide surface may be wettable and the carrier non-wettable and the latter is the expedient in fact adopted.

The contacts themselves must be wettable, so that the quantities of mercury on the contacts can equalize during contact, and so that a virtually zero impedance junction can occur. This provides a replenishment feature, or prevents depletion of mercury on either contact. However, the carrier for any movable contacts, which in one form of the invention is in the form of a shuttle, may move between guides. In such case, the guides are normally wettable surfaces and the shuttle is non-wettable to reduce friction, except at its ends, which are contacts. There therefore exists a break in the mercury layer somewhere along the shuttle. Assuming that one end of the shuttle is a contact and hence wettable, mercury can flow to the wettable area only from the opposed contact, during contact. This is inadequate. To provide for replenishment a deep channel is provided in the shuttle, extending from a point of the wet area of the guide surface to the wet or contact portion of the shuttle. This channel contains a platinum wire, which is wettable, so that mercury can easily move to the wet or contact area of the shuttle, but without introducing frictional forces in that the wire is remote from the guide surface. The fact that the wettable wire is remote from the guide surface implies that a liquid layer exists between the two, as distinguished from a surface layer. Where two surface layers are in juxtaposition and are to be moved relative to one another, considerable force is required and frictional losses occur. Where a free liquid layer exists between the moving surfaces, very slight forces are required and very slight frictional losses exist.

The total quantity of mercury must be kept so small that (1) all wettable surfaces are covered by a layer of mercury and (2) that these surfaces can retain all the available mercury in a layer, without forming a pool. This feature of the invention may be taken as an alternative statement of the requirement that the switch must contain no mercury pool.

Switches constructed according to the concepts and features above outlined have been constructed and successfully tested, which require movements of a movable contact equal of about .055". This is not deemed a limiting lower limit. One embodiment of a relay according to the invention was found capable of handling 4 amperes of current at 10 v., the internal envelope diameter of the switch being of the order of 20 mils and its length of the order of 250 mils. The relay was found to be extremely sensitive, and yet self locking, and insensitive to vibration and shock. To provide an example, a 20 v. pulse into a 600 ohm actuating coil, extending for 1 millisecond, was found capable of actuating the relay from one condition to another. This represents a total power of 600 micro-watt-seconds. At the same time the mass of the moving element was so small that inertial forces generated by extremes of acceleration (10G) were inadequate to overcome the forces of surface tension which normally hold the movable element in its last actuated position.

Switches constructed according to the invention are substantially free of bounce and contact resistance. The switch is capable of handling dry currents without noise and does not distort wave forms of currents handled by the switch. On making and breaking a D.C. current, perfect square waves of current are generated, within the limits of visual observation of wave form on an oscillograph.

It is, accordingly, a further feature of the invention to provide a highly sensitive relay of self locking type,

which nevertheless is highly impervious to accelerative forces.

A switch constructed according to the principles of the present invention has been operated continuously to make and break at 60 c.p.s. for many months without visible deterioration, the switch dimensions being those above recited.

It is, accordingly, a further object and feature of the invention to provide a relay having extremely long life in continuous make and break operation, without sensible deterioration, which shall be of miniature size, capable of carrying large currents, or handling of dry currents, highly sensitive, free of bounce, substantially impervious to shock and vibration, and noise free.

It is feasible to actuate a shuttle or slug in diverse ways. If the slug is to be moved in response to a short pulse of current applied to an energizing coil, which is asymmetrically located longitudinally with respect to the transverse center line of the slug, in either of its actuated positions, the forces of surface tension applied to the slug must be such that the slug is pulled by these forces out of symmetry with the coil, once the slug is asymmetrically located due to current in the coil, and must proceed to one of its extreme positions. The coil, then, must start the slug on its way, and once started forces of surface tension must complete the motion.

It is, accordingly, still another object of the invention to provide a relay having a moving slug which tends to complete its motion in either direction of its travel, due to forces of surface tension, whenever such motion is initiated by an external force.

Relays according to the present invention can be constructed to be double ended or single ended, i.e. push pull or single pole. In the case of a double ended relay a mechanism exists for retaining a contact in either of two actuated positions, since the relay may be symmetrical with respect to a center line. In the case of a single pole switch, having only one movable contact and one stationary contact, the former being a slug, reliance may be placed, for retaining the slug in switch open position, on a free mercury surface which is formed only in the switch-open position. In the switch closed position surface tension at the contacts retains the contacts closed, so that a double ended switch locks itself in either condition while a single ended switch locks itself into switch closed condition. A further mechanism may preferably be applied or provided to assure that a single ended switch will lock itself into open condition, and this mechanism is provision of a free liquid surface.

When two contacts separate, in a mercury switch, the mercury between the contacts is pulled apart until rupture occurs. At the instant of rupture, tiny droplets of mercury explode in all directions, in straight lines. If no obstacle intervenes between the point of rupture and an unwettable insulating surface which is required to provide insulation between contacts in switch-open condition, mercury will reach such surface. In accordance with a further feature of the invention, contacts may be so located in respect to insulating surface, or internal geometry of the switch may be so arranged, that so free linear path exists between the point of rupture and the insulating surface. All such free paths may terminate on mercury layers, so that mercury spattered by rupture of a mercury column is immediately, and without the intervention of any other mechanism, recaptured by a mercury layer.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a view in cross-section of a first embodiment of a device according to the present invention;

FIGURE 2 is a view in cross section of a modification of the device of FIGURE 1;

FIGURE 3 is a view in cross section of a replenishment

channel utilized in the embodiment of FIGURE 1; and

FIGURE 4 is an enlarged view of opposed contacts, in the embodiment of FIGURE 1, particularly illustrating a replenishment channel;

FIGURE 5 is a view in cross section of a resonant relay, employing structural features of FIGURE 2;

FIGURES 6-8 are views in cross section of a single ended embodiment of the relay of FIGURE 1, showing open, transition and closed states of the relay, respectively.

Referring now more particularly to the accompanying drawings, the reference numeral 10 denotes a metallic enclosure for a switch, internally wettable, and having the general form of a tube 11, terminated in open ends 12 and 13. Since it is necessary to provide connections to the switch, enclosure 10 can be made of platinum and can be one switch contact or electrode. Closing the open ends 12 and 13 are nonwetable insulating rings, 14 and 15 through which axially extend snub-nosed wettable metallic contacts 16 and 17. The latter may be of circular cross-section, and the insulating rings 14, 15, preferably of glass, may provide seals between the contacts 16, 17 and the open ends 12, 13 of the tube 11. The surface of the insulators 14, 15, internally of the enclosure 10, is small relative to the total internal surface of the container, and shaped convexly to avoid pool formation. A suitable value of insulator to total area might be 5%, but the value is not critical. Internally of the enclosure 10 is provided a shuttle 18, which is slidable within the tube 11 and of about the same length, and made of non-wettable material except at its ends. A small quantity of mercury is provided internally of the enclosure 10. The surfaces of the platinum tube 10 and of the contacts 16, 17, internally of the enclosure 10, as well as the ends of shuttle contact 18, are mercury wettable. The insulator rings 14, 15, and the sliding surface of shuttle 18, intermediate its ends, are mercury unwettable. A slot or groove 20 in the surface of shuttle 18 joins its ends.

The total quantity of mercury employed is selected to avoid formation of a pool of mercury within the enclosure, as distinguished from a thin layer of mercury adherent to the mercury wettable surfaces and substantially adequate to cover all of these. Mercury layers are then identified in the drawings by the reference numerals 22, 23, 24, 25, 26, 26a. The unwet surfaces are identified by the reference numerals 27, 28, 29.

Surrounding the tube 11 are coils 30a, 30b, which may be supplied with energizing current via terminals 31a, 31b. The shuttle contact 18 is fabricated of magnetic material, or includes a core of such material and the axial center of the shuttle contact 18 is symmetrical with the axial center of coils 30a, 30b when the shuttle is equally spaced from contacts 16 and 17. The shuttle ends are movable within the tube 11, into contact with either of contacts 16 and 17, whereupon the axial center of the shuttle contact 18 is offset from the coil center. Assuming that the shuttle is in either its left or right position, as seen in FIGURE 1, then, energization of coil 30a or 30b, selectively, will actuate the shuttle to its alternative position. The shuttle 18 may be thus caused to move alternately into contact with contacts 16 and 17, in response to current applied to the coils 30a, 30b.

Coils 30a, 30b may be also energized simultaneously by short current pulses, as distinguished from D.C., to effect transfer of the shuttle due to its own inertia. Where the shuttle is to be actuated in response to short pulses the actuating coil is symmetrical with the shuttle when the latter is equally spaced from both contacts 16 and 17, but is asymmetrical when the relay is in either closed condition. It is then required that any asymmetry of the shuttle position, such as may occur in response to a pulse applied to coils 30a, 30b, give rise to forces of surface tension which serve to complete the motion of the shuttle. Otherwise stated, the shuttle must be unstable except in switch closed condition.

The shuttle 18 may have a diameter of about 20 mils and a length of about 100 mils, to provide a specific but non-limiting example. Since that part of the shuttle surface which slides on the inner surface of tube 11 is not mercury wettable, while the tube is mercury wettable, a layer of mercury collects on the tube surface, and the shuttle slides without friction or adhesive forces on this layer of mercury. The shuttle is extremely light in weight, and in consequence of the design characteristics specified hereinabove can be actuated from one to another position in response to a pulse of current applied jointly to coils 30a, 30b, which has a total energy of less than 600 microwatt-seconds. Moreover, the actuating current pulse need endure only for about 1 millisecond, or less, i.e., response time is extremely rapid.

Contact is made and broken always through a mercury layer, which collects on the wettable contacts. It is then found that contact is extremely sharp, and sudden. As observed on an oscilloscope, current flow through the switch is a true square wave, with sharp corners, and no chatter is observed. Contact resistance is almost zero and noise level is extremely low, even for dry currents.

The weight of the shuttle 18 is such, in relation to the surface tension of mercury, that once contact has been made between the shuttle and either stationary contact 16 or 17, the surface tension of the mercury which completes the circuit between metallic contacts holds the shuttle in position. The relay is thus inherently a self-locking relay. At the same time, the mass of the shuttle 18 is so small in relation to the surface forces generated by the mercury that shock and vibration of extreme amounts are not adequate to generate accelerative forces capable of overcoming the adhesive forces.

The unwettable character of the insulating areas and the inability of the device to form a free globule or pool of mercury assures insulation between the shuttle 18 and the stationary contacts in both actuated switch positions and for all orientations, and the surface forces of the mercury serve to maintain the mercury layer in place for all switch positions or orientations, without formation of a pool or of free globules.

The problem exists, in mercury switches, of replenishing mercury layers on the various surfaces involved. The structure and arrangement of the present device automatically and inherently solves the replenishment problem, since for each actuation of shuttle 18, leading to a new contact arrangement, equalization of mercury flow takes place, i.e., if contact 16 has insufficient mercury to complete its layer, mercury will flow from the end of shuttle 18 to effect replenishment, whereas if an excess exists mercury will flow to the ends of shuttle 18.

In order to facilitate equalization or redistribution of mercury film internally of the enclosure 10 resort may be had to axially directed slot 20 in the body of the shuttle 18, which serves to convey mercury from the area over the un-wet portion of shuttle 18 to the wettable ends which are contacts of the switch. The groove 20 may be quite deep and may be unwettable, but contains a rod or wire 20a of platinum along its length, to provide a flow path for the mercury.

The rod or wire 20a is placed remotely of surface 24, and is small in area, to provide a path for movement of mercury without introducing considerable friction. The presence of wettable rod 20a does not serve to introduce friction, or the necessity for relatively large forces to move the shutter, because the rod 20a is sufficiently remote from guide surface 24 to permit existence of mercury, intermediate rod 24a and surface 24, which is in liquid phase.

Referring now more particularly to FIGURE 2 of the drawings, a cylindrical internally wettable tube 50 is provided, having a smaller end which is closed and a flared end which is open. Tube 50 may be platinum. Within the open end is placed an insulating ring 51, and within the latter a magnetic armature 52 which includes

a magnetic reed 53, extending axially of the envelope 50 to a position adjacent its small closed end. The reed 53 and armature 52 are mercury wettable, as is the internally exposed surface of tube 50. The insulating ring 51 is non-wettable by mercury, and is provided with a convex surface 51a, to inhibit collection of mercury. Sufficient and only sufficient mercury is supplied internally of envelope 50 to provide a thin adherent layer of mercury on the wettable surfaces. No mercury pool or globule is formed, which can provide a short circuit across the insulator 51.

Adjacent the exposed end of armature 52 is placed a permanent magnet 54, with its N pole adjacent the armature 52 and its S pole relatively remote. The magnetic reed 53 is thus polarized N. A magnetic armature 55, of generally U-shaped, extends from the S pole of permanent magnet 54 to poles 56, 57 located in positions adjacent the end of envelope 50, where the envelope surrounds the reed, providing a film of mercury of cylindrical shape extending about the end of reed 53 but not normally in contact therewith. The pole pieces 56, 57 of the armature 55 are thus both S poles. They are balanced in their effect on the N polarized reed. Actuating coils 59, 60 are provided on the arms of the armature 55, which may be selectively energized with D.C. current, to unbalance the magnetic circuit and thus attract the reed 53 in one sense or the other, and thereby into contact with the envelope 50, completing an electric circuit through the mercury film.

The principles employed in the system of FIGURE 2 are those specified herein as applicable to mercury switches generally, i.e., pools of mercury are avoided, the total volume of the envelope 50 is very small and is occupied almost entirely by contacts, the ratio of wet to un-wet area is very great, i.e., 25 to 1, the un-wet area providing insulation, and the quantity of mercury employed is just sufficient to form the mercury layers required by the switch, i.e., to cover the wettable surfaces.

As in the system of FIGURE 1, conductive liquids other than mercury or mercury amalgam may be employed. Also as in the system of FIGURE 1 actuation of the reed 53 into either of its positions can occur in response to a pulse applied to one of coils 59, 60 locking of the reed into either actuated position being accomplished partly in response to surface tension of the mercury, and partly by unbalance of the permanent magnetic circuit which occurs in response to any initial or transient unbalance caused by unbalanced current flow in the coils.

A typical application of reed relays is resonant, continuously vibrating relays. The structure of FIGURE 2 may be employed for this purpose, as in FIGURE 5, by arranging magnet 54, as at 54a of FIGURE 5, and induce a North pole in pole 56 and a South pole in pole 57. An energizing coil 63, then, if applied with alternating current, will polarize the reed 53 alternately N and S, and thereby cause it alternately to be repelled by and attracted to the poles 56, 57, respectively. If the reed 53 is mechanically resonant to the energizing frequency, the system will operate as a resonant reed relay.

In FIGURES 6, 7 and 8 of the accompanying drawings, is illustrated a single ended analog of the double ended relay of FIGURE 1. A cylindrical slug or shuttle 18, having a groove 20 and a wettable rod 18a therein, is provided, which may duplicate the slug or shuttle of FIGURE 1 and therefore is identified by the same numeral of reference. The ends of slug 18 are mercury wettable, but not the body itself, or the surfaces of groove 20. The slug 18 is contained in a cylindrical metallic tube 10a, which supplies one electrode of a switch. The tube 10a is closed off at one end 10b, by the metal of tube 10a, but its alternate end is provided with an insulating ring 70, which supports a central fixed electrode or contact 16, the inner end of which is mercury wettable, as in FIGURE 1. Coils 30a, 30b, surround the tube 10a, and, the slug 18 being of magnetic

material, are so positioned as to actuate the slug 18 to left or to right, respectively, when supplied with energizing current, on a selective basis. In the alternative, coils 30a, 30b may be energized in parallel, or series, in which case the slug 18 will be driven from either of its terminal positions to the other.

In the structure of FIGURE 1 the slug 18 was retained in either actuated position, i.e. in contact with terminal or contact 16, or 17, respectively, by forces of surface tension. In fact, the slug 18 is drawn by surface tension to one or the other of terminals or contacts 16, 17, i.e. the nearer, whenever its position is asymmetrical with respect to them. In the system of FIGURES 6-8, however, two stationary contacts do not exist. So long as the switch is in its closed condition, surface tension tends to keep it in closed condition. The problem remains of providing forces of surface tension which will retain the slug 18 in switch open condition. Moreover, these forces should develop before the slug 18 has attained its fully open position, i.e. its extreme right position, as seen in FIGURE 6. The necessary forces should appear as soon as the mercury layer between the contacts has ruptured during a switch opening operation.

According to the present invention, the tube 10a is made appreciably longer than the slug 18. Thereby the left hand edge of slug 18 can be located inwardly of the right hand edge of tube 10a, when the switch is in fully open condition. Since the surfaces of insulating ring 70 are mercury unwettable, while the inner surface of tube 10a and the end of slug 18 are wettable, a surface of minimum area 75 will be formed by the mercury, which will include the edge of tube 10a, and the end of slug 18. This surface provides a wall retaining the slug 18 in its right hand position, and force is required to cause the slug 18 to pierce the wall during a movement to the left. Inertial forces, such as those due to gravity, vibration, or shock, are small compared with the forces of surface tension because of the small mass of the slug.

The fact that the slug 18 is wettable by mercury at its right hand end, as seen in FIGURE 6, implies that forces surface tension will tend to retain the slug 18 in its right hand position, or to return it to its right hand position, in addition to the forces generated by wall 75, for suitable switch geometry.

FIGURE 7 illustrates the formation of wall 75, i.e. a free mercury surface of minimum area, which takes place as soon as slug 18 has moved to the right sufficiently to disrupt the layer of mercury which joins surfaces 26 and 26a in switch closed condition. The forces which seek to minimize area also, then, seek to move slug 18 further to the right, until surface 75 is planar. FIGURE 8 illustrates the switch closed condition, wherein wall 75 no longer is a free surface, but terminates on electrode 16.

Dimensional and performance factors are approximately the same in the case of FIGURE 1 and of FIGURES 6-8.

While I have described and illustrated one specific embodiment of my invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A switch comprising an envelope, at least two contacts, a pair of mutually insulated conducting liquid layers within said envelope each associated with a different contact, at least one of said contacts being movable toward and away from the other of said contacts, said conducting liquid layers wetting at least said contacts and capable of completing the circuit between said contacts, the ratio of the total area of the surfaces within said envelope to the area of said conducting liquid layers being less than 2.

2. The combination according to claim 1 wherein said ratio is less than 1.5.

3. The combination according to claim 1 wherein said ratio is approximately unity.

4. A mercury switch comprising a first contact, a movable second contact, a carrier for said movable contact, said carrier and contact being a free slug floating in mercury, a guide for confining the path of said carrier, said carrier being freely slidable through said guide to carry said movable contact into and out of contact with said first contact, and the surfaces of only one of said carrier and guide being unwettable by said mercury.

5. A relay comprising an envelope, a quantity of conducting liquid having high surface tension located in said envelope, contact surfaces and surfaces mutually insulating said contact surfaces located internally of said envelope, said contact surfaces only being wettable by said liquid, and at least in part forming part of said envelope the quantity of said liquid being only adequate to cover said contact surfaces with a layer of said liquid and inadequate to form a pool of said liquid in addition to said layer.

6. The combination according to claim 5 wherein one of said contact surfaces is movable, and is included on a shuttle freely floating in said liquid.

7. The combination according to claim 6 wherein is provided a guide for said shuttle, said shuttle being slidable over said guide, only one of said shuttle and guide being wettable by said liquid in the areas of possible friction therebetween.

8. The combination according to claim 7 wherein is provided a channel for flow of said liquid from a point of said guide to a point of one of said contact surfaces.

9. The combination according to claim 8 wherein said channel is unwettable by said liquid, and wherein said channel contains an elongated element wettable by said liquid and joining said points.

10. The combination according to claim 5 wherein one of said contact surfaces is located on a deflectable element.

11. The combination according to claim 10 wherein said deflectable element includes magnetic material, and means for magnetically deflecting said element at will.

12. A mercury switch comprising a mercury wettable metallic tube, a slug located internally of said tube, a quantity of mercury located internally of said tube, said slug floating in said mercury and movable longitudinally of said tube, a mercury unwettable insulating ring terminating said tube at one end, said slug being mercury wettable at its end nearest said one end, the total length of said slug being less than the total internal length of said tube.

13. In combination, a shuttle floating in a layer of mercury, a mercury wettable element confining said mercury and said shuttle, said shuttle having a mercury unwettable surface in contact with said mercury, a channel extending along the length of said shuttle and having mercury unwettable walls, a mercury wettable member in said channel at a depth sufficient to provide a liquid unbound layer of mercury between said element and said member.

14. A switch, including an enclosing tube, a layer of mercury covering the internal surface of said tube, said layer of mercury being the major portion of the mercury within said tube a terminal insulated with respect to said tube, and a slug floating in said mercury and movable into and out of contact with said terminal, wherein is provided means for developing forces of surface tension tending to maintain said slug in or out of contact with said terminal, said forces being greater than inertial forces of gravity, vibration and acceleration attributable to said mass.

15. A mercury switch including a shuttle, said shuttle being movable between two end positions, said shuttle floating in mercury, and means for generating forces of

surface tension tending to move said shuttle to the nearest one of either of said two end positions, when said shuttle is asymmetrically located with respect to said end positions.

16. A mercury switch including an element movable between two end positions, and means including at least one layer of mercury for generating forces of surface tension tending to move said element to the nearest of either of said end positions when said element is asymmetrical with respect to said end positions.

17. A switch, comprising an envelope, a contact within said envelope including a movable component, a further contact within said envelope at least in part forming part of said envelope, said contacts including mercury wettable surfaces, at least one mercury unwettable surface within said envelope insulatedly separating said contacts, the total quantity of said mercury within said envelope being only adequate to form a thin layer of mercury on said mercury wettable surfaces held to said mercury wettable surfaces by surface tensions, said surfaces interchanging mercury during operation of said switch.

18. A mercury switch comprising a first contact, a second movable contact, a carrier for said movable contact, a guide for confining the path of said carrier, a layer of mercury being located between said guide and carrier, said carrier being slidable through said guide to carry said movable contact into and out of contact with said first contact, the surface of one of said carrier and guide being in at least major part substantially unwettable by said mercury, and the surface of the other of said carrier and guide being in at least major part substantially wettable by said mercury whereby the force required to slide said carrier through said guide is reduced.

19. A relay comprising an envelope, a quantity of conducting liquid having high surface tension located within said envelope, conducting surfaces and insulating surfaces separating said conducting surfaces within said envelope, at least one of said conducting surfaces forming at least part of said envelope, said conducting surfaces including relatively movable areas substantially wettable by said liquid, the quantity of said liquid within said envelope being substantially adequate to cover said substantially wettable areas with a thin layer of said liquid and inadequate to form a substantial pool of said liquid in addition to said layer.

20. The combination according to claim 19 wherein one of said relatively movable surfaces is located on a deflectable element.

21. The combination according to claim 20 wherein said deflectable element includes magnetic material, and means for magnetically deflecting said element.

22. The combination of claim 19 wherein one of said relatively movable surfaces is included in a shuttle floating in said liquid, a guide for said shuttle, said shuttle being slidable over said guide, one of said shuttle and guide having area wettable by said liquid and the other of said shuttle and guide having area substantially unwettable by said liquid, said areas being adjacent one another in friction producing relation during sliding of said shuttle over said guide, a channel in said unwettable surface for distributing said liquid along said unwettable surface, and a wettable element located internally of said unwettable surface within said channel.

References Cited in the file of this patent

UNITED STATES PATENTS

536,811	Lemp	Apr. 2, 1895
2,406,036	Pollard	Aug. 20, 1946
2,769,875	Brown et al.	Nov. 6, 1956
2,844,687	Gottfried et al.	July 22, 1958