

Jan. 18, 1949.

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CONTACT PROTECTION FOR MERCURY  
WETTED SWITCH-CONTACTS  
Filed July 21, 1944

2,459,306

FIG. 1

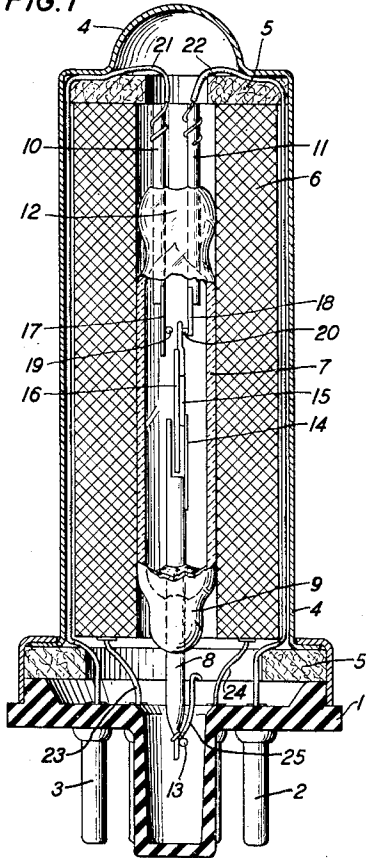


FIG. 2

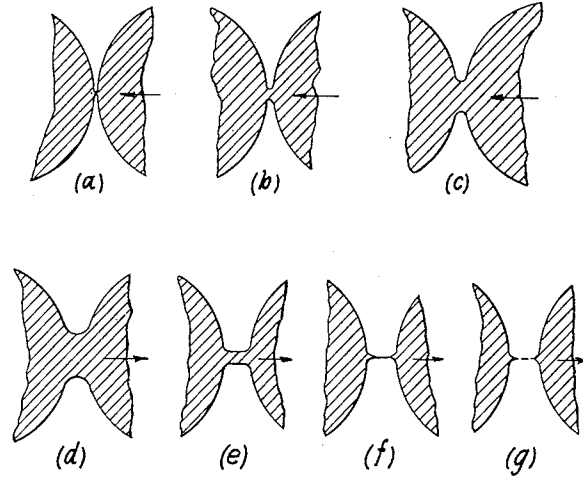


FIG. 3A

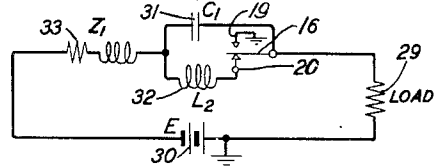


FIG. 4

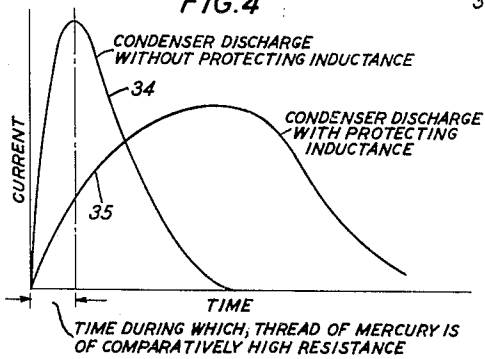
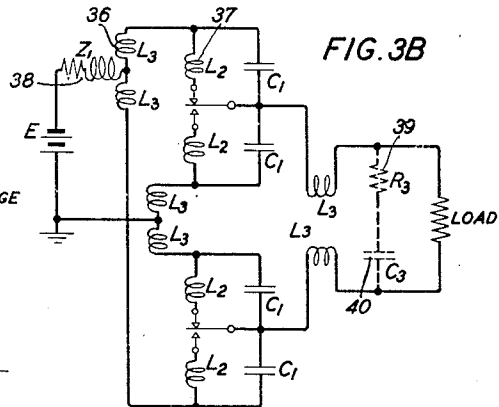


FIG. 3B



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## UNITED STATES PATENT OFFICE

2,459,306

CONTACT PROTECTION FOR MERCURY  
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Application July 21, 1944, Serial No. 545,985

2 Claims. (Cl. 175-294)

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This invention relates to circuit makers and breakers and particularly to problems of contact protection.

The object of the invention is to provide means to prevent undue erosion of contacts of a particular nature. The use of mercury wetted contacts is becoming more general and this has led to considerations which may apply to the operation of what might be termed dry contacts. The mercury wetted contact has been found to have certain particularly valuable qualities and at the same time certain peculiar operating characteristics. By way of example, such contacts when closed even through extremely light contact pressure present extremely low contact resistance whereby comparatively heavy currents may be carried thereby. On the other hand, when such contacts are separated the process involves the drawing out of a thread of mercury so that over a given period the contact resistance changes from a very low resistance through intermediate values to a comparatively high resistance before the circuit controlled thereby is definitely broken. Therefore if the current flowing there-through is comparatively high a considerable heating effect measured by the  $I^2R$  loss may be developed and if the time element is sufficient may produce an explosive effect which will result in disruption of the mercury surface and exposure of the underlying contact metal and the consequent production thereon of a condition inhibiting the free flow of mercury thereafter to repair the damage.

This same effect may be present on closure of the contacts. Due to surface tension the mercury presents substantially spherical surfaces approaching each other and first contact is at a point. Thereafter a neck of rapidly expanding cross-section forms between the two surfaces. Growing under force of surface tension, this neck draws its mercury from the two contacts. In the end the neck loses its identity as it merges with the mercury of the contacts, resulting in a connection of large cross-section and very low resistance. During a contacting operation, the contact resistance varies with the neck dimensions. Since the period during which a neck of small cross-section exists is known to be very short, it may be assumed that practically no transfer of heat away from the neck occurs

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during the critical period. Therefore it follows that substantially all the heating due to current through the neck is applied to the mercury of the neck. It is evident that the safe limit of heating is reached when the temperature of the mercury neck reaches the vaporizing point. After that, any additional heating results in vaporization starting at the center of the neck.

When vaporization occurs, the metallic neck is severed. If the voltage is sufficient, a discharge across the gap is then established resulting in increased voltage drop at the contact with increased heating substantially in direct proportion to the increase of voltage. If the current is momentarily high, for example, at a contact closure, this may be accompanied by vaporization of explosive violence which drives the mercury from the contacts and may even expose the underlying solid contact surfaces.

It is therefore apparent that to avoid contacting trouble, currents and voltages must be controlled that the mercury necks, on both closing and opening, are not heated to vaporization. Therefore provision must be made so that on contact closure the initial surge of current, resulting mainly from discharge of capacitance, including both a condenser bridged across the contacts and conductor capacitances which under some condition may have important values, must be regulated to not exceed the safe thermal storage capacity of the neck at any instant during the first few microseconds. At contact opening the protection must prevent rapid voltage rise during the drawing of the mercury neck so that vaporization does not occur. Furthermore, the voltage between the opening contacts during the initial stage of retraction of the ends of the broken mercury thread must not be permitted to reach the arcing potential.

Some authorities hold that any contacting surface carrying current even though solid metal becomes momentarily fluid at the instants of either first closure or final contact before opening. The present invention therefore is intended to provide contact protection for all fluid contact devices whether the contacts are originally fluid or become fluid only for a short time, the protection being provided to avoid ruin of the contact through the explosive effect of a too high current concentration.

In accordance with the present invention, circuit elements are employed to limit the flow of current through the comparatively high resistance mercury neck both on closing and opening operations. Generally speaking such elements consist of a capacitance effective on opening of the contacts and an inductance effective on the closure of the contacts. In its simplest form the protective network consists of a series impedance leading to a divided circuit, one branch of which leads through a capacitance connected to one of a pair of contacts and the other branch of which leads through an inductance to the other of said pair of contacts. Other more complicated networks may be employed in accordance with the functions of the contacts but each will basically include the simple circuit above described.

A feature of the invention is an electrical contact protecting network comprising a series current limiting element and a parallel circuit one branch of which consists of a capacitance and the other branch of which consists of an inductance and the said contacts in series.

Another feature of the invention is an electrical network for protecting contacts which on closure produce a progressively comparatively high to very low resistance circuit consisting of a circuit element having timing characteristics to prevent a great flow of current during the comparatively high resistance period of said contact closure.

The drawings consist of a single sheet having five figures as follows:

Fig. 1 is a cross-sectional view of a relay structure employing the features of the present invention;

Fig. 2 is a diagrammatic illustration of the action of mercury wetted contacts. This figure consists of two lines of diagrams, the first showing in three figures the action of the mercury as the contacts close and the second lower line consisting of four small figures showing the action of the mercury as the contacts move away from each other;

Fig. 3A is a schematic circuit diagram showing the arrangement of the electrical elements in the circuit used in protecting the contact surfaces;

Fig. 3B is a similar schematic circuit diagram showing a complex arrangement wherein a pair of moving armatures each having a front and back contact is employed; and

Fig. 4 is a diagram showing the relation between current and time under two different conditions, one graph being used to show the action under each condition.

The relay of the present invention consists of a glass sealed unit located in the center of a coil. This glass sealed unit has a moving armature supported on a reed and arranged to move between a back and a front contact. These contacts are wetted with mercury and the whole is immersed in an atmosphere of hydrogen under high pressure.

The relay is built by using a plastic base 1 with a number of contact pins 2 and 3 arranged in a manner similar to the well-known electronic tubes. Secured to the base and enclosing the whole is a metal cover 4. Within this cover and held snugly in position by resilient means, such as sponge rubber 5, is a coil 6. Spaced axially within this coil is the contact unit consisting of the glass wall 7 having a single electrode 8 sealed in the lower press 9 and a pair of electrodes 10 and 11 sealed through the upper press 12.

The lower electrode 8 is in the form of a tube

which is useful for evacuating the vessel and later introducing therein a specified amount of mercury and the necessary amount of hydrogen gas under pressure. After this tabulation process, the lower end of the tubular electrode 8 is pressed together and sealed by a welding process. In this welding process a small piece of wire 13 is used as one of the electrodes and this becomes welded to the crushed end of the tube 8 and is allowed to remain. This piece of metal 13 is useful in producing the weld since its contact with the crushed end of the tube 9 is through an area of small dimension and therefore the concentration of current is high.

Within the envelope a spring 14 is welded to the upper end of tube 8 and to the upper end of spring 14 there is in turn welded a pair of wires 15 laid close together and having a surface which is easily wetted by mercury. This comprises a device known as a mercury wick up which mercury will readily ascend to form a mercury contact surface at the upper extremity thereof. An armature 16 of magnetizable material is welded to the mercury wick 15 and extends downwardly into a recess formed between the spring 14 and a portion of the tube 8. Within this recess a pool of mercury will be held and this will be useful in feeding the mercury wick 15.

Both the electrode 10 and the electrode 11 have attached thereto a downwardly extending contact piece 17 and 18 respectively, to which small pieces of contact material 19 and 20 respectively are welded. These materials are wettable by mercury and therefore will maintain a constantly wetted surface.

Wires 21, 22, 23, 24 and 25 will connect the various portions of the device to the pins, such as 2 and 3.

This relay is a transfer arrangement comprising mercury wetted contacts sealed in a hydrogen atmosphere at 250 pounds pressure. An electrode of this type of relay when not in contact presents a smooth rounded surface which for this discussion will be considered a spherical section. When in the act of closing, the two spherical surfaces of mercury connect first at a point. This is illustrated in Fig. 2, sketches A, B and C. In sketch A the two rounded surfaces are just making the first contact with each other. Thereafter, as illustrated in sketches B and C, a neck of rapidly expanding cross-section forms between the two surfaces. Growing under force of surface tension, this neck draws its mercury from the two contacts. In the end the neck loses its identity as it merges with the mercury of the contacts, resulting in a connection of large cross-section and very low resistance.

On opening, the two contact surfaces are connected by a neck of reducing cross-section which draws to a relatively long and fine thread before breaking. The fact that a mercury thread extends momentarily between the opening electrodes results in this relay performing a closed transfer; that is, for a few tenths of a millisecond during each switching operation the three electrodes are in common electrical contact. This is known as "bridging." Sketches D, E, F and G represent various successive stages in the formation and final breaking of the thread of mercury extending between the two contact surfaces as such surfaces move away one from the other.

Contact protection on this type of relay resolves into three categories. These may be associated with three transient phenomena, contact closure, bridging and contact opening. The

first and third types are normally of very short duration, in the order of a few microseconds at most. The second type is usually of about three-tenths of a millisecond duration. These three transients occur once for each half cycle of relay operation in a connected sequence; the order being as given above. Since at all other times during a cycle the contacts are either definitely closed or open, and therefore incapable of more than very slight power dissipation, it follows that adequate protection demands effective functioning of the protective networks for the very short switching time intervals only. It is important to note that, given adequate protection for the critical transient periods, the contacts are capable of controlling relatively large powers.

Before entering into discussion of protective networks, it may be desirable to consider further the phenomena associated with the existence of the transient mercury necks. During a contacting operation the contact resistance varies with the neck dimensions. Since the period during which a neck of small cross-section exists is known to be very short, it is safe to assume that practically no transfer of heat away from the neck occurs during the critical period. Therefore it follows that substantially all the heating due to current through the neck is applied to the mercury of the neck. It is evident that the safe limit of heating is reached when the temperature of the mercury neck reaches the vaporizing point. After that any additional heating results in vaporization presumably starting at the center of the neck.

Where vaporization occurs the metallic neck is severed. If the voltage is sufficient, a discharge across the gap is then established resulting in increased voltage drop at the contact with increased heating substantially in direct proportion to the increase of voltage. If the current is momentarily high, for example, at a contact closure, this may be accompanied by vaporization of explosive violence which drives the mercury from the contacts and may even expose the underlying solid contact surfaces. It is apparent that to avoid contacting trouble, currents and voltages must be so controlled that the mercury necks on both closing and opening are not heated to vaporization. Experiment has shown that these necks in their thinnest stage may have considerable resistance in the order of perhaps a few ohms, but that the high resistance stage is short, usually well under a microsecond.

Therefore it becomes apparent that on contact closure the initial surge of current resulting mainly from discharge of capacitance, must be regulated to not exceed the safe thermal storage capacity of the neck at any instant during the first few microseconds. At contact opening the protection must prevent rapid voltage rise during the drawing of the mercury neck so that vaporization does not occur. Furthermore, the voltage between the opening contacts during the initial stage of retraction of the ends of the broken mercury thread must not be permitted to reach the arcing potential.

While it is known that electrostatic attraction may considerably affect surface contours when a voltage difference exists between very slightly separated electrodes, no attempt has been made to determine this effect on mercury contacts. It is probable that the formation of mercury necks is appreciably altered when relatively high voltages are used.

A network to protect the contacts under the

transient conditions mentioned above is shown in Fig. 3A. The contact consists of a movable armature 16 moving between a back contact 20 and a front contact 19.

The armature 16 is employed to connect a load 29 alternately to a battery 30 of voltage E and to ground. To prevent short-circuiting the source of voltage during the bridging operation, a series impedance  $Z_1$  is used. In cases where low power is being dealt with, a resistor whose value is equal to about  $\frac{1}{5}$  the load impedance may be adequate. Where the power is high, an inductance whose reactance bears that relationship to the load impedance may be satisfactory. The important feature to be considered in each case is that this impedance must be sufficiently large to prevent establishment of excessive magnitudes of current during the bridging operation. Tentatively 10 amperes has been specified as the maximum current which may be safely handled by the contacts of a relay of this type and dimension. On the other hand, since the load current must be supplied through this impedance, there is a practical upper limit to the magnitude of  $Z_1$ .

The foregoing discussion of  $Z_1$  pertains to normal bridging times in the order of a few tenths of a millisecond. If the relay is to be used in locations where severe jolting or tipping may occur, the value of  $Z_1$  must be adequate to prevent damaging magnitudes of current in case the free mercury by such rough treatment is thrown into the contact assembly. It is apparent that where the supply is direct current,  $Z_1$  must include series resistance for current limitation unless some form of circuit interrupter is employed. Where alternating current is used the resistance is not necessary, providing  $Z_1$  comprises adequate inductance.

Where  $Z_1$  represents load impedance and E is the RMS supply voltage, the value of  $Z_1$  may be defined thus:

$$Z_1 = \frac{Z_l}{5} \text{ ohms} \quad (1)$$

However, in any case  $Z_1$  should not be less than

$$\frac{E}{10} \text{ ohms}$$

For opening contacts adequate protection is provided by a shunt condenser 31 directly across the contacts concerned. It has been determined that a reasonable minimum condenser value is that which permits the maximum current which may be interrupted to produce a rate of voltage rise not exceeding 5 volts per microsecond or

$$\frac{de}{dt} = 5 \times 10^6$$

Where  $I_0$  is the maximum current to be interrupted

$$C_1 = \frac{I_0}{de/dt} = \frac{I_0}{5} \text{ microfarads} \quad (2)$$

This condenser value is the minimum which may be tolerated. Under some conditions a larger value is to be preferred.

At contact closure it is necessary that the condenser 31 as well as the capacitance of lead wires be safely discharged under maximum voltage conditions. Since the mercury neck on initial contact is capable of safely absorbing only a small amount of energy, it is required that the discharge current rise gradually from a low value. The desired result is accomplished by the use of an inductance 32, preferably of low Q, located

at the contact as shown in Fig. 3A. Experimentally it has been found that the value of  $L_2$  should be such that the initial rate of current rise does not exceed 25 amperes per microsecond. Then  $di/dt=25 \times 10^6$ .

Taking  $E_0$  as the maximum voltage which may occur on the condenser 31,

$$L_2 di/dt = E_0 \text{ or } L_2 = \frac{E_0}{25} \text{ microhenries} \quad (3)$$

This is the minimum value which may be safely used. In certain cases a higher value may be advantageous.

Consideration of the functioning of the three elements  $Z_1$ , shown as inductance 33,  $C_1$  shown as condenser 31, and  $L_2$  shown as inductance 32, in combination, shows that the interactions which occur in two of the three combinations are not detrimental. The third combination involves the inductance 32 at a contact opening. In this situation  $L_2$  is located next to the contact and beyond the protective influence of the condenser 31. If prior to contact opening  $L_2$  was carrying a current  $I_0$ , the energy stored in its magnetic field was  $L_2 I_0^2/2$ . The only outlet for this energy on opening of the contact is in discharge across the opening gap. It has been found that this discharge is relatively innocuous and may be tolerated providing the inductively stored energy does not exceed about  $40 \times 10^{-6}$  joule. A maximum value of inductance is thus established.

$$L_2 \text{ max} = \frac{80}{I_0^2} \text{ microhenries} \quad (4)$$

Where  $L_2$  does not exceed this value, opening of the contact results in a weak "glow discharge" of rapidly dwindling current at about 30 volts. Its duration is usually less than one microsecond.

Upon the closure of contacts 16 and 20 the condenser 31 will discharge through the neck of mercury formed, as shown in sketches A, B and C of Fig. 2. Fig. 4 is a graphic illustration of the effect of the inductance 32. Without this inductance the current rise, particularly for the initial period, is very high as shown by graph 34. With the inductance 32 in the circuit, however, this characteristic condenser discharge curve is modified in accordance with the graph 35 so that it will be readily apparent that the inductance 32 will hold the current value down to a reasonable value during the period when the mercury neck is small.

When contacts of more than one relay are functioning in a system, it is possible that switching surges of a given contact under certain conditions may reach a contact of another relay during a critical period, thus subjecting the latter to severe transitory conditions. To avoid this difficulty, it has been found desirable in a circuit utilizing more than one relay to isolate the contacts from each other by means of low Q choke coils. This arrangement is illustrated in Fig. 3B where a typical contact system is shown. While the value of these coils does not appear to be at all critical, it is evident that the value of  $L_3$ , coil 36 by way of example, must be large with respect to  $L_2$ , inductance 37 by way of example, and may be small with regard to  $L_1$ , the inductance value of  $Z_1$ , element 38. A value per winding of  $L_3$  which appears to be satisfactory is

$$L_3 = \sqrt{L_1 L_2} \quad (5)$$

Coupling between the windings of the pairs of  $L_3$  may be desirable in some cases. For example,

the coupling between the  $L_3$  windings indicated in Fig. 3B has been found to be satisfactory.

Isolation of contact electrodes for the band of prominent surge frequencies by use of  $L_3$  coils accomplishes a two-fold result: (a) a contact is permitted to cope with its own transient conditions without detrimental effects of surges introduced from other circuits, and (b) localization of the transient surges to the immediate vicinity of their origin may reduce interference in associated apparatus.

In some cases it may be desirable to utilize resistance 39 ( $R_3$ ) and a capacitance 40 ( $C_3$ ) connected in series, forming a shunt across the load terminals as shown dotted in Fig. 3B. In absence of  $L_3$  coils this shunt may be of value in reducing sparking at the relay contacts when the load is inductive. The value of the resistance may be in the order of the load resistance component or lower. The condenser value should be such that the impedance presented to the relay circuit is low for the important switching surge frequencies, but the value should not be larger than  $C_1$  in any case. Where the  $L_3$  coils are used, the importance of this shunt as a protective device is greatly reduced, although the combination may be useful as a filter section for suppressing the contact surges at the load circuit terminals.

It will thus be seen that contact protection for that type of contact where a momentary connection of comparatively high resistance is made on both the opening and the closing of the contacts and particularly where this comparatively high resistance connection is in the form of a thread of mercury, may be provided by a condenser bridged about the contacts and an inductance in series therewith. The inductance will operate on closing of the contacts to limit the high rate of discharge of the condenser and the condenser will operate on opening of the contacts to dissipate the energy inductively stored in the inductance coil.

What is claimed is:

1. In combination, contacts for making and breaking an electrical circuit, a pool of mercury, means leading from said pool of mercury to one of said contacts for supplying mercury to said contacts, the surfaces of said contacts being formed to retain mercury thereon, means for moving said contacts toward and away from each other whereby the resistance between said contacts while in contact with each other is extremely low due to the thickness of the column of mercury formed therebetween but which varies through a wide range to a comparatively high value during the movement apart of said contacts due to the drawing out of a fine thread of mercury before a complete break in contacts between said contacts, and an electrical network providing means for transiently limiting the flow of current through said contacts during the said transient high resistance periods of the operation of said contacts, said network including an inductance element in series with said contacts, and a capacitor bridged about the said series combination of contacts and inductance element.

2. In combination, contacts for making and breaking an electrical circuit, a pool of mercury, means leading from said pool of mercury to one of said contacts for supplying mercury to said contacts, the surfaces of said contacts being formed to retain mercury thereon, means for moving said contacts toward and away from each other whereby the resistance between said contacts while in contact with each other is extremely

low due to the thickness of the column of mercury formed therebetween but which varies through a wide range to a comparatively high value during the movement apart of said contacts due to the drawing out of a fine thread of mercury before a complete break in contact between said contacts and which varies from a comparatively high value to said extremely low value during the movement together of said contacts due to the substantially spherical contour of the mercury on said contacts before contact is made therebetween and the fact that the first contact between two such spherical surfaces is a point contact and an electrical network providing means for transiently limiting the flow of current through said contacts during the said transient high resistance periods of the operation of said contacts, said network including an inductance element of substantially zero resistance in series with said contacts and a capacitor bridged about said series combination of contacts and inductance element.

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