

Oct. 21, 1969

C. P. G. RIOUX

3,474,339

ELECTRIC SWITCHES FOR HIGH CURRENTS

Filed Oct. 9, 1967

2 Sheets-Sheet 1

Fig. 1.

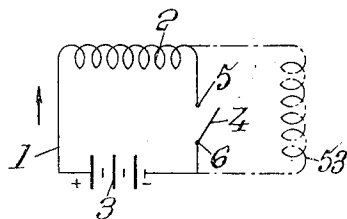


Fig. 2.

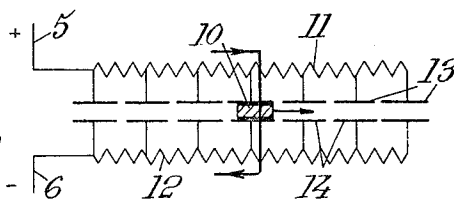


Fig. 3.

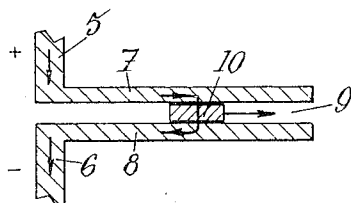


Fig. 4.

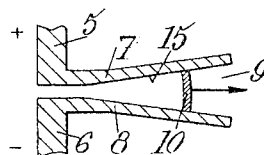


Fig. 5.

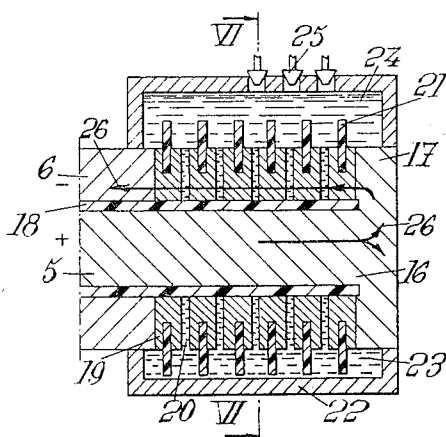
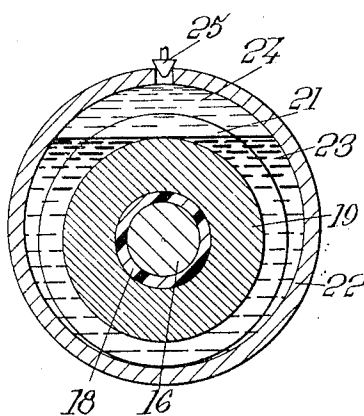


Fig. 6.



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Fig. 7.

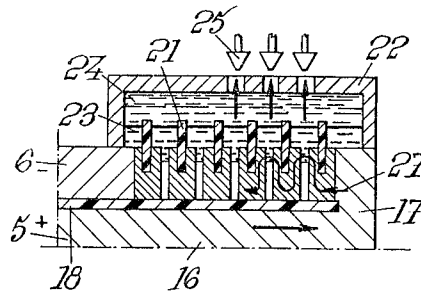


Fig. 8.

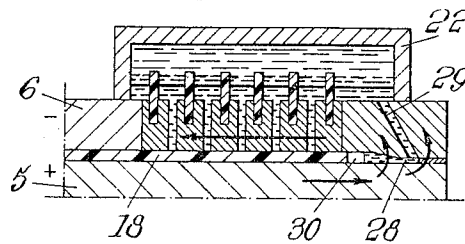
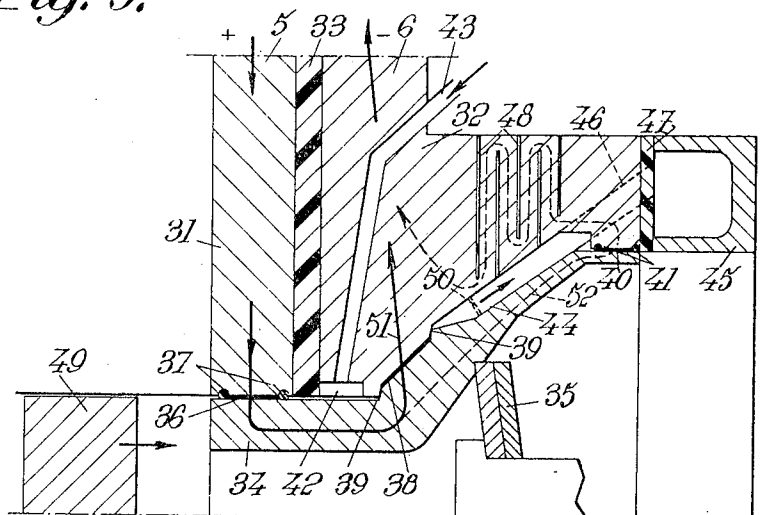


Fig. 9.



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ELECTRIC SWITCHES FOR HIGH CURRENTS
Christian Paul Gilbert Rioux, Antony, France, assignor
to Centre National de la Recherche Scientifique, Paris,
France, a French Government administration
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79,533

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U.S. Cl. 335—47

12 Claims

ABSTRACT OF THE DISCLOSURE

The electric circuit is made in this switch through a conductive fluid maintained in an interval in spite of the Laplace forces on the fluid due to the current flow. To break the circuit, an evacuation opening is cleared to allow the Laplace forces to eject the fluid abruptly out of this interval, towards the exterior of the switch.

This invention relates to electric switches intended to cut off in a very short time (less than a millisecond) electric currents of very high intensity (preferably greater than a million amperes) preferably generated in electric circuits having high self impedance.

An object of the invention is to provide a switch of this type which is able to fulfill the various requirements of practice better than prior switches, in particular with respect to the brevity of the cut off and robustness.

According to the present invention, a switch of the type in question comprises principally: two conductive pieces electrically connected respectively to the two terminals of the switch and electrically separated one from the other by an interval of small width, this interval being adapted to contain a conductive fluid to establish electric contact between the two conductive pieces; means for maintaining this conductive fluid in the interval during flow through this conductive fluid of the intense current to be cut off, in spite of the action of Laplace forces on this conductive fluid; and means for rapidly clearing an appropriate evacuation opening in communication with said interval to permit the action of these Laplace forces to eject abruptly this fluid out of the interval, towards the exterior of the switch; and, should the need arise, means for helping the ejection action of these forces by driving this fluid towards the opening with the air of another fluid which is compressed and non-conductive.

The invention includes, apart from this principal feature, certain other features which are preferably used at the same time and which will be more explicitly mentioned hereafter.

In particular, a second feature comprises giving the interval which separates the two conductive pieces an increasing width in the direction of the evacuation of the fluid, this width being counted parallel to the direction of passage of the current in this interval for the normal closed state of the switch.

A third feature comprises providing baffles of electrically insulating material in the part, of at least one of the two conductive pieces, which delimits the downstream part (with respect to the direction of evacuation of the fluid) of the interval which separates these two pieces.

The invention is particularly suitable for abruptly cutting off high currents flowing in self inductances with a view to creating very intense current impulses usable in particular for the formation of plasmas.

The invention will be easily understood from the following specific description, given merely by way of example, with reference to the accompanying drawings.

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In these drawings:

FIGURE 1 is a schematic diagram of an electric circuit equipped with a switch according to the invention; FIGURE 2 is a schematic model diagram of such a switch;

FIGURES 3 and 4 show schematically two such switches;

FIGURES 5 and 6 show, respectively, in axial section and in transverse section along VI—VI of FIGURE 5, a switch arranged according to one embodiment of the present invention, in its closed state;

FIGURE 7 is an axial half-section of this same switch, in its open state;

FIGURE 8 is an axial half-section of a modification of such a switch, also arranged according to the present invention; and

FIGURE 9 is an axial half-section of another embodiment of a switch according to the invention.

Referring first of all to FIGURE 1, an electric circuit 1 has been shown having a self inductance 2 in which a current generator 3 generates a high current; a switch 4, arranged according to the present invention, is inserted in the circuit 1 to cut or interrupt the high current in a very short time, in a manner, in particular, to generate a current impulse of considerable intensity.

The two terminals 5 and 6 of this switch 4 are connected respectively to two conductive pieces or members 7 and 8 separated one from the other by an interval or gap 9 (FIGURE 3) of small thickness. A fluid conductor 10 is introduced into this interval assuring the electrical connection between the two pieces. And means are provided for ejecting abruptly at the desired instant this fluid out of the interval towards the exterior of the switch so as to cut this connection at that instant.

Instead of filling the interval 9, the fluid conductor 10 can be in the form of a simple finger initially interconnecting (that is to say for the "closed" state of the switch) the parts, of the pieces 7 and 8, that are the nearest to the terminals 5 and 6.

In this manner, during its ejection, the conductive finger 10 progressively interconnects parts of these pieces 7 and 8 that are more and more remote from these terminals, which increases the resistance interposed between these terminals. It should be recalled that, in practice, the current cut off is considered to be sufficient when this resistance reaches a value about 1000 times greater than its initial value.

In FIGURE 2, each of the piece 7 and 8 has been schematically represented by a series of resistances 11 and 12 of which certain corresponding points are respectively connected to conductive plates 13 and 14 insulated from one another, each plate 13 being disposed opposite to a plate 14 and being able to be electrically connected to this plate 14 by the fluid finger 10. It will be easily understood from this schematic diagram that the abrupt ejection of the finger (towards the right in FIGURE 2) rapidly increases the total resistance of the switch by adding successive resistance between its terminals 5 and 6.

In order to eject abruptly the fluid finger from its initial position, use is made of the electric forces, often called "Laplace forces," that the electric current passing through this finger exerts thereon.

As these forces are greater as the thickness of the finger (that is to say its dimension parallel to the direction of the current flow) is greater, and besides, as it is appropriate to reduce the mass of fluid to be ejected as much as possible, it can be advantageous to arrange the profile of the interval 9 to widen towards the downstream (with respect to the direction of ejection), as illustrated schematically at 15 in FIGURE 4. With such a profile, the cross section offered by the finger to the current flow remains sufficient for this finger to assure correctly the

transfer of current in the closed state of the switch (that is to say without the risk of excessive calorific dissipation in this finger, which dissipation would lead to vaporization of the finger and deterioration of the adjacent solid contact surfaces), and nevertheless the mass of this finger remains small and its thickness quickly becomes large during its ejection.

In the following, two preferred embodiments of the present invention will be described with reference to the drawings. In these embodiments the switch has a general shape of revolution about an axis, and the current cut off is obtained by centrifugal ejection (that is to say, away from the centre) of the conductive liquid out of an annular chamber.

In the first embodiment, illustrated in FIGURES 5 to 7 (with an improvement in FIGURE 8), the switch comprises a central cylindrical conductive core 16 terminated by a conductive disc 17 and surrounded successively by an insulating sleeve 18 and conductive rings 19 axially separated from each other by annular intervals 20. Insulating rings 21 overlap with the peripheral parts of the conductive rings. The core 16 and the conductive ring farthest from the terminal disc 17 are connected respectively to the two terminals 5 and 6 of the switch. This unit is mounted in a tank 22 filled on the one hand with a conductive liquid 23 (such as mercury, sodium, potassium or another metal or alloy having a low melting point, such as the sodium-potassium eutectic or the mercury-indium eutectic), up to the level of the tops of the rings 19, and on the other hand with a liquid 24 which is lighter and insulating (such as water or alcohol) and which floats on the surface of the conductive liquid 23. Quick-opening gates 25 are provided in the top of the tank 22. Although the construction of gates 25 forms no part of the invention, in a preferred embodiment gates 25 are of a conventional "differential" type in which the internal pressure of the conductive liquid normally urges a movable member against the seat therefor. In gates of this type, a short pressure pulse (impact) applied to the movable member in the direction in which the movable member moves away from its seat will provide sudden opening of gates 25 through an "avalanche" effect, the internal pressure itself acting increasingly on the movable member in a manner such as to further the opening of the gates 25.

The operation of this switch is the following.

Initially, the liquids 23 and 24 occupy their respective positions of FIGURES 5 and 6, the switch is closed and the electric current flows according to the arrows 26. The total resistance r of the system is then small due to the short length of the lines of current and the large flow cross section of the conductors.

The flow of current in the liquid exerts considerable forces (called "Laplace forces") on this liquid which tend to eject radially the liquid towards the exterior out of the intervals 20, but such an ejection is impossible as long as the gates 25 are closed, due to the incompressibility of the liquids.

To cut off the current, the gates 25 are abruptly opened.

Immediately, the action of the Laplace forces results in an extremely rapid evacuation of the liquid through these gates. During its evacuation, the liquid undergoes dilation.

It is advantageous to limit this evacuation, for example by receiving the liquid ejected through the gates in a non-deformable enclosure of limited volume, so that the conductive liquid still remains in contact with the discs 19 (FIGURE 7) at the end of the evacuation. The total resistance of the system will then have a value of the order of $1000r$, for example, due to the increase of the length of the lines of current schematically represented at 27 in FIGURE 7 (lines which are obliged to follow a path by going around the baffles formed by the insulating rings 21 and the volumes emptied from the annular intervals 20), and due to the decrease of the flow cross section.

The role of the light and insulating liquid 24 is double: its lightness facilitates its ejection under the push of the heavier conductive liquid; its insulating nature prevents the direct closing of the electric circuit across this insulating liquid.

The multiplicity of the conductive rings permits the number of annular intervals to be multiplied, and thus the unit thickness of these intervals to be reduced as well as the quantity of calories dissipated in each of them. In other words, the percentage of the calories dissipated in the solid pieces is thus increased, and the risk of deterioration of the surfaces of these pieces bordering the liquid is correspondingly reduced.

It is appropriate that all the annular intervals 20 remain filled with the conductive liquid as long as the switch remains closed, that is to say as long as the gates 25 are not open, in spite of the tendency of this liquid to move away from the bottom of these intervals under the effect of the Laplace forces.

For this purpose, it is advantageous to use the improvement shown schematically in FIGURE 8, which comprises making a longitudinal recess 28 formed in the axial extension of the insulating sleeve 18 communicate with the internal volume of the tank 22. This communication is established by at least one conduit 29, from the axial end of the recess that is the farthest from the sleeve. The recess 28 and the conduit 29 are thus filled with the conductive liquid.

Thus, when the current flows in the system, the hydrostatic ejection pressure exerted axially on the liquid contained in the recess 28 by the Laplace forces is greater than the pressure exerted radially on the liquid contained in the annular intervals 20. This pressure thus automatically makes up for any possible faults of filling of these intervals by forming a pocket 30 emptied of liquid in the recess 28 in the neighbourhood of the sleeve.

It is not indifferent to dispose the series of rings at the exterior of the sleeve 18 rather than at the interior of the sleeve: indeed, it is only in the former case (which corresponds to a centrifugal ejection of the conductive liquid) that the differences between the speeds of emptying of the various annular intervals are automatically compensated, the ejection force decreasing automatically for the intervals which empty themselves more quickly, which avoids any unbalance of the explosive type during operation of the switch.

In order to regulate the speed of ejection of the conductive liquid, it can be advantageous to eject it through at least one opening calibrated in an appropriate manner.

In the second embodiment schematically shown in FIGURE 9, the switch comprises essentially two pieces of revolution adapted to be abruptly displaced axially with respect to one another, namely:

A first piece comprising two conductive masses 31 and 32 connected respectively to the two terminals 5 and 6 and electrically insulated from one another by a disc 33 of insulating material, and

A second piece 34 of conductive material generally in the form of a cone housed at the interior of the first piece.

In the normal position (switch closed) the second piece is strongly applied against the first in the axial direction, for example by means of springs 35, and it is electrically connected to the first piece, on the one hand by a cylindrical liquid conductive sleeve 36, sealed by two rings 37, inside the mass 31, and on the other hand by two liquid conductive sleeves inside the mass 32, one of these latter two sleeves 38 being tronconical and limited by two tronconical journals 39 belonging to less sharply pointed cones than that of the sleeve 38, and the other 40 being conical and relatively remote from the sleeve 36 and sealed by two rings 41.

Upstream of the journal 39 nearest to the disc 33, that is to say on the same side of this journal as this disc, is located a chamber 42 in which can be injected a gas under pressure through a conduit 43.

Downstream of the downstream journal 39 is disposed a tronconical chamber 44 which widens out and which is connected to an annular collector gutter 45 by at least one conduit 46 passing through an insulating ring 47 interposed between the piece 32 and the gutter 45.

The part of the piece 32 bordering the downstream part of the chamber 44 is provided with transverse baffles 48 of insulating material which oblige the electric current to travel along a long path in order to go around these baffles.

The switch thus formed operates as follows.

For the closed position of the switch, the current follows the path indicated by the arrows 51, which is short and corresponds to large flow cross sections, by crossing successively the two liquid sleeves 36 and 38.

In order to cut off this current, a mass 49 is projected axially against the piece 34. Under the effect of the shock, the piece 34 moves towards the right.

Immediately, the journals 39 separate and the Laplace forces, preferably aided by the push of the compressed gas introduced into the chamber 42, ejects the liquid of the sleeve 38 towards the chamber 44 and the gutter 45 by forming a finger 50 of this liquid which becomes narrower and narrower in the direction of its ejection and wider and wider in the direction of the current flow.

The enormous quantity of heat then applied to this finger partially or totally gasifies the finger and brings it in a very small fraction of a second to a high temperature. At this temperature the latent heat of vaporization or the latent heat of ionization of the finger is very high so that, in spite of its small mass, it can absorb large calorific energies due to the successive electric commutation of the different layers of the mass 32, separated by the baffles 48.

The high disruptive force which appears just upstream of the finger 50 is contained by the pressure of the gas injected at 42. In order that this gas can fulfill this role and follow the finger, it is appropriate that it is light, difficult to ionize, highly compressed and possibly preheated. For example, this gas can be constituted by hydrogen or helium at 1000-1500° C. and compressed at 100 or 200 kg./cm.².

At the end of the ejection of the finger, the current is obliged to follow the path indicated by the arrows 52, this path being long and of small flow cross section. The corresponding resistance is sufficient so that the switch can then be considered as being open.

To re-set the device, it is sufficient to again apply the piece 34 against the piece 32 and to re-inject some conductive liquid into the tronconical sleeve 38.

As a result, and whatever embodiment is adopted, a switch is provided which permits of cutting off in a very small fraction of a second (that is to say less than one millisecond, and sometimes as low as 10 milliseconds or even less) a very intense electric current (for example of intensity greater than 1 million amperes) such as for example those generated by the dynamos described in U.S. Patent No. 3,270,228, filed by the present applicant on Mar. 15, 1963, granted Aug. 30, 1966, and entitled "Machines and Methods for Producing Very High Intensity Electric Currents."

Such a switch can be used for many purposes, for example to make a large fraction of the energy stored in the self inductance 2 of FIGURE 1 pass abruptly into a self inductance 53 (FIGURE 1) mounted in parallel with the switch. This is especially advantageous when creating the intense electric current envisaged in the previous paragraph, the magnetic field then generated in the self inductance 53 being able to be much greater than that generated in the self inductance 2.

Various modifications of the embodiments described above are possible, such as a modification in which the progressive increase of the resistance put in circuit by the finger is obtained, not by the successive addition of resistances mounted in series, but by the discontinuous modification of resistance mounted in parallel. In this

case, the finger comes, for example, successively into contact with parallel plates whose ends facing the finger are insulated from one another whereas their other ends are interconnected, these plates being of different thicknesses and/or natures.

Although the invention has been described with reference to specific embodiments, it should be understood that the invention is in no way limited thereto; various modifications are possible without departing from the spirit or scope of the present invention.

What I claim is:

1. An electric switch for interrupting high currents in a very short time, comprising: a first conductive member electrically connected to a first terminal of the switch; a second conductive member electrically connected to a second terminal of the switch, said second conductive member being electrically separated from said first conductive member by at least one gap; a conductive fluid located within said gap for establishing electric contact between said first and second conductive members; means for maintaining said conductive fluid in said gap during the flow through said conductive fluid of the high current to be interrupted despite the action of the Laplace forces on said conductive fluid; at least one evacuation opening in communication with said gap to permit displacement of said conductive fluid in said gap; and means for rapidly opening said at least one evacuation opening to permit the action of said Laplace forces to eject said conductive fluid abruptly along said gap towards the exterior of the switch to increase the electrical resistance between said first and second terminals.

2. A switch according to claim 1 in which said fluid is a liquid, said switch having a general form of revolution and including an annular chamber in communication with said gap, said evacuation opening being provided in an external wall of said annular chamber whereby the current interruption is obtained by centrifugal ejection of said conductive liquid out of said annular chamber.

3. A switch according to claim 2 in which one of said conductive members comprises a conductive core extending substantially axially of said annular chamber, the electric current to be interrupted flowing through said core.

4. A switch according to claim 3 in which a plurality of gaps are provided, said gaps being annular in shape and co-axial with each other, and defined by a plurality of co-axial, annular, parallel conductive rings which said gaps separate from one another, said conductive rings being mounted on an insulating sleeve surrounding said conductive core, said core having two ends one of which is connected to one of said terminals of the switch and the other of which is connected to one of said conductive rings, each said conductive ring carrying at its periphery an insulating ring embedded into said conductive ring a predetermined distance and extending outwards from said conductive ring into said annular chamber, an exterior enclosure being provided outside said annular chamber in communication with said evacuation opening to receive the conductive liquid that is ejected through said opening.

5. A switch according to claim 4 in which said exterior enclosure is of limited, constant volume to limit the quantity of liquid evacuated from said annular chamber so that some liquid remains in said intervals in the vicinity of the peripheries of said conductive rings whereby the current is not completely interrupted.

6. A switch according to claim 5 in which a recess is provided axially in line with said insulating sleeve, said recess communicating with said annular chamber through at least one conduit connected to the end of said recess remote from said insulating sleeve.

7. A switch according to claim 1 in which said conductive fluid is a liquid at least when said switch is in its normal closed state, and in which said gap is generally tronconical in shape, one of said two conductive members being adapted to be abruptly separated from the other

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conductive member in the direction of the axis of said trunconical gap to open said evacuation opening.

8. A switch according to claim 7 in which said gap is delimited by said two conductive members and comprises an upstream portion and a downstream portion with respect to the direction of ejection of said fluid, said two conductive members completely enclosing said upstream portion when said switch is in its normal closed state to maintain said conductive fluid in said upstream portion, and said two conductive members, on separation, putting said upstream portion in communication with said downstream portion to allow ejection of said fluid through said downstream portion.

9. A switch according to claim 8 in which said downstream portion of said gap has an increasing width in the downstream direction, said width being counted parallel to the direction of the current flow through said gap in the normal closed state of the switch.

10. A switch according to claim 8 in which said first conductive member is electrically connected to said second conductive member downstream of said gap both in the normal closed state of the switch and in the open state of the switch whereby the current is not completely interrupted, there being baffles of insulating material provided in a part of at least one of said two conductive

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members, said part delimiting at least partially said downstream portion of said gap, said insulating baffles providing an increased resistance in the switch in its open state.

11. A switch according to claim 1 in which means are provided for driving said conductive fluid towards said evacuation opening by another fluid which is compressed and non-conductive, to aid the ejection action of the Laplace forces.

12. A switch according to claim 1 in which said gap has an increasing width in the direction of the ejection of said fluid, said width being measured parallel to the direction of the current flow through said gap in the normal closed state of the switch.

References Cited

UNITED STATES PATENTS

1,660,407 2/1928 Bainbridge.
2,936,711 5/1960 Watt.

BERNARD A. GILHEANY, Primary Examiner

H. BROOME, Assistant Examiner

U.S. Cl. X.R.

103—1; 310—11