June 27, 1939. K. E. SCHIMKUS 2,163,709

MEANS FOR CONTROLLING ELECTRIC CIRCUITS

Original Filed Jan. 30, 1935

Fig. 1.

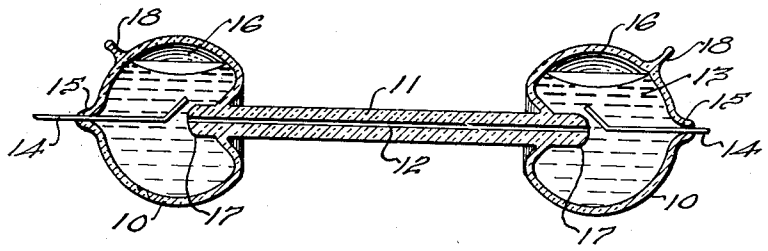


Fig. 2.

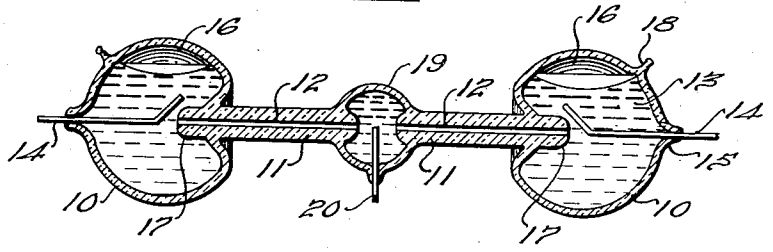


Fig. 3.

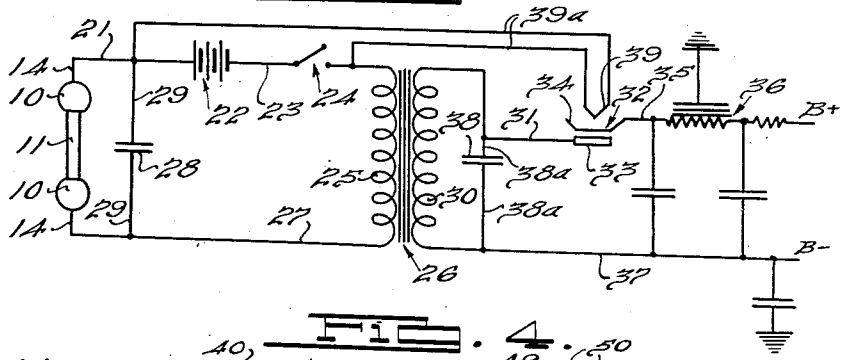
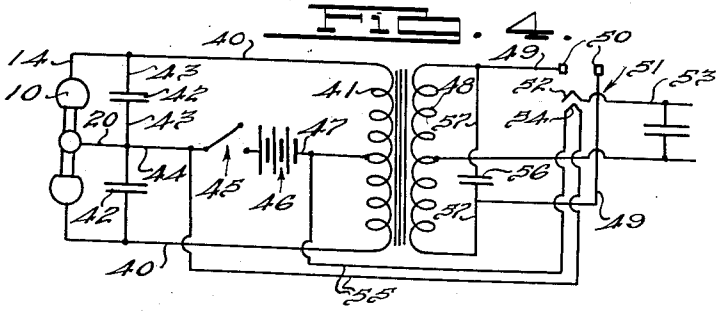


Fig. 4.



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MEANS FOR CONTROLLING ELECTRIC CIRCUITS

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24 Claims. (Cl. 200—113)

The present application is based upon and is a division of application, Serial Number 4,056, filed January 30, 1935, jointly by the present applicant and Willy Dumke, disclosing the same subject matter disclosed herein and claiming subject matter not claimed herein.

The invention relates to devices for increasing and decreasing the flow of current in electric circuits and has as its general aim the provision of a novel means which is simple, substantially free of mechanical noise, practically indestructible from operative causes, and has no moving parts requiring original or subsequent adjustment.

An object of the invention is to provide a novel device of the above class which is capable of producing regular pulsations of current and operates with low current loss and high efficiency.

Another object is to provide a device of this character which embodies novel means for effecting intermittent current pulsations through the recurrent conversion of a current conducting substance from one physical state in which it offers relatively little resistance to current flow into another physical state in which current flow is substantially prevented and thereafter reconverting all or part of the substance to its original state.

A further object is to provide such a device which embodies means for effecting cycles of current pulsations including a conductive material capable of changing its physical state in response to the application of relatively little heat energy arranged to be interposed in the circuit and confined in part to produce a predetermined resistance to current flow, whereby to generate heat energy ample to cause a change in the physical state of said material at some point in the confined part thereof resulting in a "break" of the circuit, the circuit being partially or entirely reestablished immediately thereafter by the return of all or part of said material to its original physical state.

More specifically stated, an object of the invention resides in the provision of a device arranged to be connected in a circuit and including, as a current conducting medium, mercury or mercury amalgam in a container which embodies a constriction, in the nature of a "capillary tube", of such predetermined dimensions as will, when the device is carrying the electrical energy for which it is intended, produce that degree of heat required to volatilize a small portion of the mercury in the constriction, whereupon the gaseous mercury interrupts the continuity of the metallic mercury and not only "breaks" the circuit but entirely stops or minimizes heat generation to permit condensation of all or part of the mercury vapor and partial or entire reestablishment of the circuit.

In conjunction with the foregoing, another object is to provide a novel device embodying means which provides for the expansion and contraction of the mercury or other conducting medium under temperature changes, both internal and external, which means in dimensions is correlated with those of the restricted tube to insure proper operation.

Another object is to provide a device of this character which is not affected by external shocks or vibrations and may be used in any position.

A further object is to provide a novel device in which failure of the device due to the introduction of extraneous matter, such as an air or gas bubble in the constricted portion of the conducting medium, is not possible.

Stated more specifically, another object is to provide, a device embodying a mercury container having a restricted tube opening into a substantially central point of the container, the quantity of mercury in the container being less than the amount required to fill it and more than that required to cover the end of the tube in all positions of the device and at the lowest temperature to which the device may be subjected.

Other objects and advantages will become apparent in the following description and from the accompanying drawing, in which:

Figure 1 is a sectional view of a device embodying the features of the invention.

Fig. 2 is a similar view of such a device modified in form for "full-wave" operation.

Figs. 3 and 4 are wiring diagrams of circuits showing respectively the manner in which the devices illustrated in Figs. 1 and 2 may be connected.

While the invention is susceptible of various modifications and alternative constructions, I have shown in the drawing and will herein describe in detail the preferred embodiment, but it is to be understood that I do not thereby intend to limit the invention to the specific form disclosed, but intend to cover all modifications and alternative constructions falling within the spirit and scope of the invention as expressed in the appended claims.

Briefly stated, the features of the present invention are attained by utilizing the property of certain current conducting substances, of which metallic mercury is an excellent example, to change the physical condition or state thereof, when subjected to heat, temporarily to another physical state in which the substance is either non-conductive or offers such high resistance to current flow as to be substantially non-conductive. With such a substance, and knowing in advance the average current values to be normally encountered by the device, the substance may be arranged to impart a substantially fixed resistance to current flow of such value that the heat energy derived thereby will cause the con-

version of a minute but sufficient quantity of said substance to its non-conductive condition to "break" the circuit and either entirely interrupt or decidedly decrease the current flow. Following the "break", production of heat energy entirely or in large part ceases and the substance which has changed its physical state reverts entirely or in substantial part to its original state and "re-establishes" the circuit. This constitutes one complete operating cycle. In operation the cyclic frequency may be exceedingly high and is entirely independent of mechanical or like limitations. Preferably the predetermined fixed resistance is obtained by forming the substance to provide a current path which is of predetermined dimensions.

The device thus functions to translate the direct current output of a source of electrical supply into a pulsating current, in which the actual current values vary at a predetermined frequency between maximum and minimum values. In certain instances, and depending upon the selection of the material which undergoes the change of state and also depending upon the electrical characteristics of the associated circuit, the current flow may be entirely interrupted at the conclusion of each heating phase, and all of the converted material may revert to its original state during the cooling phase. In other instances, the heating phase may produce only a partial interruption of the current flow and the cooling phase may result in only a partial reconversion of the material. In either event, however, the changes of state are accompanied by and result in periodic variations of the current between well defined maximum and minimum values, and in the illustrated embodiments of the invention, these variations are abrupt and sharp. Throughout the following description and in the appended claims, accordingly, terms such as make, break, interrupt, recondense, reestablish, revert, reconversion, increase, decrease and the like are used in a generic and relative sense. In the claims also, the term "normal" current is utilized to refer to the increased value of current which flows through the substance at the conclusion of each cooling phase, or at the conclusion of each partial or entire reconversion of the substance to its original state, which "normal" value of current again initiates the conversion of the substance to its relatively non-conducting state.

Referring more particularly to the illustrative forms of structure shown in the drawing, what may be termed a pulsator is shown in Fig. 1. Hereinafter mercury or mercury amalgam (both being referred to in the following description and in certain of the claims as mercury) will be considered as exemplary of a suitable substance, the changes in the physical states thereof being from a normal fluid state to a gaseous state, followed by condensation to the fluid state. The device shown in Fig. 1 comprises two mercury containers 10 which may be of any suitable size and shape but are preferably in the form of hollow substantially spherical members. These containers are spaced apart and are connected by a tubular member 11 having a bore 12 oppositely communicating with the interior of each container. Where the device is intended to handle electrical currents of relatively low value, the containers and the tube may well be fashioned of glass, such as that known commercially as Pyrex. For higher values a stronger material may be necessary.

The bore is filled with mercury and the containers are nearly filled as shown, the mercury body being indicated at 13. Connection of the device is an electric circuit so that the mercury in the bore 12 is included in the circuit and may be established by a terminal 14 sealed, as at 15, in each container wall and contacting the body of mercury in each container.

Since in the transmission of electrical energy resistance is inversely proportional to the size of the conductor, the fixed resistance of the mercury may be advantageously predetermined and permanently maintained by properly dimensioning the bore 12. For currents of low potential, such as those drawn from a storage battery, the bore is quite restricted and the tubular members may be in the nature of a capillary tube wherein the bore diameter is a fraction of a millimeter.

Moreover the length of the bore must be properly calculated apparently because of the fact that the mercury vapor produced when the change of physical state occurs has substantially greater volume than the fluid mercury. In capillary tubes or like small diametered bores, the resistance to fluid flow therethrough is relatively great. Hence, if the bore is excessively long the gaseous mercury cannot readily overcome the flow resistance offered with the result that the circuit may not be broken or is not broken sharply and regularly. Conversely, if the bore is too short, expansion of the created gas may cause a greater separation of the mercury column than is necessary to break the circuit. In this case a permanent break in the circuit may result by failure of the broken ends of the column to reunite or an undesirable delay in closing the circuit occurs due to the lag in the flow of the material caused by the resistance to flow. It is, therefore, desirable to predetermine the length of the bore to obtain that intermediate length wherein the circuit is broken sharply, regularly and in which the relationships are so balanced that substantially the initial conversion of mercury from the fluid to the gaseous state will "break" the circuit, immediately followed by a reconversion of gas to fluid which closes the "broken" circuit. When the relationships are of this nature the device is exceedingly sensitive, will start at once upon closing the circuit and will operate at a relatively high frequency.

Since the "break" of the mercury column is the result of change in the physical state of mercury caused by the flow of electrical energy, the average values of the electrical current which is to be interrupted by the device will determine the dimensions of the bore. Generally stated the dimensions will increase as the values of the electrical current increase. As a particular example of dimensions which have been found satisfactory in a device for producing pulsating current from a storage battery in a circuit adapted to energize the primary winding of a transformer, the restricted tube may have an approximate diameter of twenty-two one-hundredths of a millimeter and a length of approximately three and eight-tenths centimeters.

Another factor to be considered is the quantity of mercury in the containers 10 since an opposing force is thereby imposed upon each end of the mercury column in the bore, which force will also affect the sensitivity of the device in operation. Consequently the quantity of fluid in the containers will, if not held within predetermined maximum and minimum limits, have substantially the same effect as a bore 12 which is too long or too short. The quantity of fluid, in general,

increases as the dimensions of the bore 12 increase. In the present instance the mercury in the containers 10 nearly but not quite fills the containers, the bubbles of air or other gas 16 in each container being particularly provided to allow for the expansion and contraction of the mercury as temperature variations occur not only externally but internally as the device passes between inoperative and operative conditions. Such expansion introduces another factor to be considered since the pressure of the gas in the bubbles 16 increases as the mercury expands and thus imposes additional force on the mercury column in the bore which acts thereon in the same manner as does the quantity of the mercury.

However, once the several factors to be taken into consideration are known, it is not difficult to determine the dimensional relationships of the several parts in the fluid confining system of a device intended for operation in connection with current of a known average value. In the specific illustration of container dimensions, a sphere of approximately one and nine-tenths centimeters has been found suitable in connection with a restricted tube of the dimensions above mentioned.

Unless, in a device of this character, some means is provided for preventing the entrance of a bubble of extraneous gas, such as air, from the bubbles 16, the device can be used satisfactorily only in a substantially horizontal position, due to the permanent interruption of the mercury column by the entrance of such a bubble. To this end the present invention preferably embodies means whereby no foreign matter of any kind can enter and become lodged in the bore 12 which arrangement is being claimed in said joint application, Serial No. 4,056. Thus, as shown, each end of the tubular member 11 is extended through the wall of the associated container 10 to a point which is substantially centrally thereof so that the ends of the bore are located approximately on the center points of the containers. The ends of the tubular member 11 are preferably rounded, as indicated at 17, to avoid trapping air bubbles on the ends, as the mercury is introduced into the containers through the filling openings, shown in sealed condition at 18. With this arrangement of parts, and with the containers properly dimensioned, the quantity of mercury in the containers will be more than ample to cover the exposed ends of the bore 12 regardless of the position of the device. Hence, air bubbles, or indeed any foreign matter, such as minute particles of oxide of mercury, cannot possibly enter the bore.

It has been found that the union between the tubular member and each container is stronger and the mercury is better supported if the wall portions of the containers about the tubular member are turned inwardly, as shown, to form a smooth junction. Moreover, to lessen electrical resistance externally of the bore 12 the terminals 14 are extended to points immediately adjacent to the bore ends.

The device shown in Fig. 1 is intended primarily to be used for controlling the simplest type of circuit, such as a circuit for effecting energization of a transformer by a pulsating current. In Fig. 2 a device is shown for controlling a circuit which includes two branches, such as a circuit by which energization of a transformer by current alternating in direction is effected. The construction of the latter device, as well as the correlation and relationship of the parts thereof, is substantially the same as that shown in Fig. 1, as is indicated by the use of the same reference numerals. However, in this form, the tubular member 11 is interrupted between its ends and the interrupted ends communicate with opposite sides of an intermediate contact chamber 19. The casing forming this chamber is preferably smaller than the containers 10 and is filled with mercury. At one side a terminal 20 extends through the casing wall to a point intermediate the opposed ends of the interrupted bore 12. In this device the operation is the same as in the first device except that two restricted bores are provided for controlling the branch circuits. Since it is practically impossible to balance the bore branches exactly, the initial "breaking" of the circuit will occur in one or the other of the bores, after which the circuit through the other bore will be "broken" while the first circuit is being reestablished. Consequently this form of device will be effective to "make" and "break" branch circuits in alternation.

In illustration of circuits embodying these devices and in description of an environment in which these devices have been found particularly suitable, Figs. 3 and 4 show circuits employed in converting low voltage direct current from a storage battery into high voltage direct current for supplying the "B" circuit of a radio receiving set with current having a proper potential. Such circuits are used largely in the so-called "B" battery eliminator devices employed in motor vehicle installations of radio receiving sets.

Fig. 3 shows the device in the capacity of a pulsator. Thus, one terminal 14 is connected through lead 21 with one side of a storage battery 22 which in turn is connected by lead 23 and interposed control switch 24 with one end of the primary winding 25 of a step-up transformer 26. The other end of the primary winding is connected by lead 27 with the other terminal 14. This circuit is effective to energize the primary winding intermittently and always in the same direction, which pulsating current is, however, reflected as an alternating current in the transformer secondary winding. A condenser 28 is connected across the device by leads 29 to the leads 21 and 27 and serves to tune the circuit and reduce the slight electrical noise resulting from the operation of the device. The condenser 28 also appears to affect or control the frequency of the device.

To complete the circuit any suitable means for rectifying the current from the secondary winding 30 may be employed, such as a thermionic valve 32. Herein one end of the secondary winding is connected by lead 31 with the plate element 33 of such a valve, while the cathode element 34 is connected with an output lead 35 to one side of a suitable filter system, generally designated 36. The other end of the secondary winding is connected by lead 37 with the other side of said system. A condenser 38 may be connected by leads 38a across the leads 31 and 37 from the secondary winding. The valve has a heating filament 39 connected by leads 39a directly with the battery 22, although the switch 24 is interposed.

In operation, closing of the switch 24 produces a current flow through the interrupting device, the resistance to which flow almost instantly heats the mercury in the bore and causes a small part of the mercury to volatilize. This change of state through the increased volume occupied by

the gas "breaks" the circuit and immediately thereafter condensation of the gas "reestablishes" the circuit. Repetition of this cycle of operation at a high frequency is effective to energize the primary winding intermittently and produce an alternating current of high voltage in the secondary winding which is rectified to an intermittent direct current by the valve **32**, and smoothed into a substantially even direct current by the filter system for delivery to the proper terminals of a radio receiving set.

With the circuit shown in Fig. 4 energy from a storage battery is translated into pulsating components successively opposite in direction. Thus, the end terminals **14** from the device are connected through leads **40** with the ends of primary winding **41**, condensers **42** of proper value being connected in series across the leads **40** by leads **43**. The intermediate or third terminal **20** of the device is connected by lead **44** with the lead **43** between condensers **42** and with a control switch **45** which, in turn, is connected with one side of the battery **46**, the other side of which is connected with an intermediate or center tap **47** from the primary winding. Each end of the secondary winding **48** is, in this system, connected through a lead **49** with a plate element **50** of a thermionic valve **51** of the full-wave type. A cathode element **52** cooperatively related to said plate elements is connected with an output lead **53** to a suitable filter system which may be of the type shown in Fig. 3 and is generally represented by the first condenser. A heating filament **54** is connected independently with a battery through leads **55** and a condenser **56** is connected across the secondary winding by leads **57**.

The operation of this system is substantially the same as that of the circuit illustrated in Fig. 3. However, in this system the alternate "making" and "breaking" of the circuits in the opposite branches of the bore is effective to energize first one and then the other section of the primary winding, the current flow being in opposite directions. Proper adjustment of the values of the condensers **42** may be employed to synchronize the current pulsations in the two branches of the bores. The resulting alternating current induced in the secondary winding is rectified, filtered and substantially direct current of high potential is delivered to the receiving set. This system is probably more efficient than the first described system.

From the foregoing it will be evident that a novel circuit controlling means has been provided which is unusually simple in construction. The device occupies a closed container. Hence the substance therein is not subject to oxidation or other chemical changes and will remain in its original condition indefinitely. The device is efficient since the only current loss is the result of the relatively low resistance offered by the substance imposed in the circuit. The only change caused by the current flow is one of physical state and the substance, therefore, is not expended or in any manner affected deleteriously by operation. There are no moving parts in the present device, hence accurate adjustment is not required. Upon determination of the proper correlation of dimensions and quantity of substance for a current of average values quantity production of uniform devices may be easily obtained. In addition, the device may be used in any position and under practically all operating conditions without injury thereto or impaired performance. As a result of these several advantageous features devices embodying the present invention are exceedingly practical, efficient, adaptable for many uses and may be economically manufactured.

What is claimed is:

1. In a device for rapidly and recurrently increasing and decreasing current flow in a circuit having a substantially constant voltage applied thereto, the combination of means providing a passageway, current conducting material filling said passageway to provide a conductor for current, said material having the property of changing its physical state when heated to a state in which the material is a substantial non-conductor of the current subjected thereto, said passageway being dimensioned so that the normal quantity of current flowing therethrough produces heat energy sufficient for causing said change of physical state, and means for connecting said material in the circuit.

2. In a device for rapidly and recurrently increasing and decreasing current flow in a circuit, the combination of means defining a bore, fluid material filling said bore and having the property of being a good current conductor when in a fluid state and a poor current conductor when in a gaseous state, said bore being dimensioned according to the average values of electrical energy to be impressed upon the device so that the normal current through the material causes the production of heat energy sufficient to change a part of said material in said bore from its fluid to its gaseous state whereby to reduce the flow of current through said material, and means for establishing said material in the circuit.

3. In a device for rapidly and recurrently increasing and decreasing current flow in a circuit, the combination of means defining a bore, fluid material filling said bore and having the property of being a good current conductor when in a fluid state and a poor current conductor when in a gaseous state, said bore having a length and cross sectional area predetermined according to the normal value of the electrical current to be passed through the device so that said normal current heats said material to a point where a physical change of a portion thereof within said bore to a gaseous state occurs to reduce the current flow until condensation within said bore of the gaseous material reestablishes at least in substantial part the original conductivity of the material, and electrical connections to said material.

4. In a device for rapidly and recurrently increasing and decreasing current flow in a circuit, the combination of means defining a bore, mercury in said bore, and means for passing electric current through said mercury, said bore being dimensioned so that normal current flow produces heat energy sufficient to heat a small portion of said mercury within the bore to a point where vaporization of said portion occurs to sharply reduce the conducting continuity of the mercury.

5. A device for rapidly and recurrently increasing and decreasing current flow in a circuit comprising the combination of a restricted tube containing mercury, and means for connecting said mercury in the circuit, the normal flow of current being sufficient to heat the mercury to its transition point and sharply reduce the current flow in the circuit.

6. A device for rapidly and recurrently increasing and decreasing current flow in a circuit, comprising the combination of a restricted tube containing mercury, means for connecting said mercury in the circuit, the normal flow of current being sufficient to heat the mercury to its

transition point and sharply reduce the current flow in the circuit, and means permitting the expansion and contraction of the mercury without affecting the circuit.

7. In a device for rapidly and recurrently increasing and decreasing current flow in a circuit, the combination of means providing a passageway, current conducting material filling said passageway of a character that applied heat causes a change of physical state to a substantial nonconductor of current, and means for connecting said material in said circuit, said passageway having dimensions predetermined according to the normal value of the current passing through said circuit so that said normal current produces the quantity of heat necessary to cause such change of physical state of a part of the material in said passageway.

8. In a device for rapidly and recurrently increasing and decreasing the flow of electrical energy in a circuit, the combination of a substance which is current conducting in one physical state and substantially non-conducting in another physical state, the transition from one state to the other being produced by heating or cooling, and means for connecting in a circuit having a predetermined normal current flow said substance in such quantity that the normal current flow produces heat energy just sufficient to cause a change of physical state to a substantially non-conducting condition whereupon the subsequent immediate cooling returns the changed substance at least in part to its original state, to thereby entirely or in substantial part reestablish the original conductivity of the circuit.

9. A device for rapidly and recurrently increasing and decreasing current flow in a circuit comprising, in combination, a tube having a passage therethrough of restricted size, a hollow container at each end of said tube, said tube being filled and said containers partially filled with mercury to maintain an unbroken continuity of mercury in said tube, said tube being dimensioned to produce the heat energy required when a normal current passes through the mercury column therein to interrupt the liquid continuity thereof, said containers being filled with mercury to the extent that upon such interruption the increased pressure in the containers causes the interrupted portions of the mercury column to be substantially instantly rejoined, and electrical connections with the mercury in said containers.

10. In a device increasing and decreasing at high frequency the current flow in a circuit, the combination of means defining a restricted bore having mercury therein, said bore being dimensioned so that the mercury column is incapable of carrying the normal quantity of current flow and is broken along its length by the action of such normal current, and means providing a confined gas space communicating with said bore to provide pressure for at least in large part reestablishing the broken mercury column, the pressure exerted being predetermined to permit the mercury column to break instantly and to effect a subsequent substantially instant said reestablishment of the broken column, and means for connecting the mercury in the bore in a circuit.

11. A device of the character described comprising, in combination, an elongated tube of restricted cross sectional dimensions having intermediately of the length thereof and at each end an enlarged closed container, a body of mercury completely filling said tube and intermediate container and partially filling the end containers, and means on each container for establishing electrical connections with said body of mercury.

12. A device of the class described comprising, in combination, an elongated tube having a container at each end, a body of mercury filling said tube and partially filling each container to leave a space therein occupied by a compressible fluid, and means for establishing an electrical circuit from one container to the other through said tube, said tube being dimensioned so that the normal flow of current therethrough will effect an interruption of the liquid continuity of the mercury body, the compressible fluid in said containers having a balanced relation to exert approximately equal forces on each side of the interruption and in oppositon to the interrupting force to effect substantially instant substantial remaking of the continuity of the mercury body after each interruption.

13. In a device for rapidly and recurrently increasing and decreasing current flow in a circuit, the combination of means providing a passageway, current conducting material filling said passageway of a character that applied heat causes a change of physical state to a substantial nonconductor of current, means for connecting said material in said circuit, said passageway having dimensions predetermined according to the normal value of the current passing through said circuit so that said normal current produces the quantity of heat necessary to cause such change of physical state of a part of said material in said passageway, and means for subjecting said part of said material to a pressure tending to cause said part of said material to resume its conducting state within said passageway.

14. In a device for rapidly and recurrently increasing and decreasing current flow in a circuit, the combination of means defining a bore, fluid material filling said bore and having the property of being a good current conductor when in a fluid state and a poor current conductor when in a gaseous state, said bore having dimensions predetermined according to the normal values of the electrical current to be passed through the device so that said normal current is capable of heating said material within the bore to a point where a physical change of a portion thereof within said bore to a gaseous state occurs to reduce the current flow until condensation within the bore of the gaseous material entirely or in substantial part reestablishes the circuit, means for subjecting said material to a pressure tending to cause said condensation and reestablishment, and electrical connections to said material.

15. In a device for rapidly and recurrently increasing and decreasing current flow in a circuit, the combination of means defining a bore, mercury in said bore, means for passing electric current through said mercury, said bore being dimensioned so that the normal current flow through said mercury in the bore produces heat energy sufficient to heat a small portion of said mercury in said bore to a point where vaporization occurs to break the liquid continuity of the mercury, and means for subjecting said mercury to a pressure tending to cause said vaporized mercury to recondense within said bore and reestablish said continuity.

16. A device of the class described for connection to points of different potential comprising, in combination, a tube having a restricted bore therein interrupted intermediate its ends by an

enlarged chamber, closed containers at the ends of said tube in communication with said bore, mercury in said containers and filling said bore and chamber, a terminal indivdual to each end of the tube, a terminal for the chamber and means for connecting said end terminals to one of said points and for connecting said chamber terminal to the other of said points.

17. In a device of the character described for connection to point of different potential, the combination of means providing a pair of similar passageways, current conducting material in said passageways of a character that applied heat causes a change of physical state to a non-conductor of current, said passageways having dimensions predetermined according to the normal value of the current passing through said circuit so that said normal current produces the quantity of heat necessary to cause such change of physical state of a part of the material in said passageways, means for connecting the material at one end of each passageway to one of said points, and means for connecting the material at the other end of each passageway to the other of said points.

18. In a device of the class described for connection to points of different potential, the combination of means providing a pair of passageways communicating with each other at a junction thereof, current conducting material in such passageways of a character that applied heat causes a change of physical state to a substantial non-conductor of current, said passageways having dimensions predetermined according to the normal value of the current passing therethrough so that said normal current produces the quantity of heat necessary to cause such change of physical state, means for connecting the ends of said passageways to one of said points, and means for connecting said junction to the other of said points.

19. In a device of the class described for connection to points of different potential, the combination of means providing a pair of passageways communicating with each other at a junction thereof, current conducting material in such passageways of a character that applied heat causes a change of physical state to a non-conductor of current, said passageways having dimensions predetermined according to the normal value of the current passing therethrough so that said normal current produces the quantity of heat necessary to cause such change of physical state, and means for connecting said material to said points.

20. In a device for rapidly and recurrently increasing and decreasing current flow in a circuit, the combination of means defining a bore, fluid material filling said bore and having the property of being a good current conductor when in a fluid state and a poor current conductor when in a gaseous state, said bore having a length and cross-sectional area predetermined according to the normal value of the current to be passed through the device so that said current is capable of heating said material to a point where a physical change of a portion thereof intermediate the ends of said bore to a gaseous state occurs to reduce the current flow, said gaseous material recondensing at least in part upon the reduction in current flow thereby increasing the conductivity of the device and initiating another heating action, and electrical connections to said material.

21. In a device for rapidly and recurrently increasing and decreasing current flow in a circuit, the combination of means defining a bore, liquid mercury in said bore, and means for passing electric current through said mercury, said bore being dimensioned according to the normal current passed through said mercury so that said normal current produces heat energy sufficient to heat a small portion of said mercury within said bore to a point where vaporization occurs to break the conducting continuity of the liquid mercury, said vaporized mercury being at least in part recondensed within said bore upon said break so as to at least partially restore the original conducting continuity of the mercury.

22. In a device for rapidly and recurrently increasing and decreasing current flow in a circuit, the combination of means providing a passageway, material filling said passageway which in one state is a good conductor and in a second state is a relatively poor conductor, said material being adapted to pass from said one state to said second state upon the application of heat, means for connecting said material in said circuit, said passageway having dimensions predetermined according to the normal value of the current passing through said circuit so that said normal current produces the quantity of heat necessary to cause said change in state of at least a part of the material in said passageway, and means for applying pressure to said material in said passageway so as to confine said part of said material to said passageway and so as to tend to cause said part of said material to revert to said one state.

23. In a device for rapidly and recurrently increasing and decreasing current flow in a circuit, the combination of means defining a bore, fluid material filling said bore having the property of being a good conductor when in a fluid state, and a poor conductor when in a gaseous state, said bore being dimensioned according to the normal value of the current to be passed through the device so that said normal current is capable of heating said material to a point where a physical change of a part thereof intermediate the ends of said bore to a gaseous state occurs to reduce the current flow, and means for applying pressure to the material in said bore so as to confine said gaseous part within said bore and so as to promote recondensation of said gaseous portion.

24. In a device for rapidly and recurrently increasing and decreasing current flow in a circuit, the combination of means defining a bore, fluid material filling said bore having the property of being a good conductor when in a fluid state, and a poor conductor when in a gaseous state, said bore being dimensioned according to the normal value of the current to be passed through the device so that said normal current is capable of heating said material to a point where a physical change of a part thereof intermediate the ends of said bore to a gaseous state occurs to reduce the current flow, and means for applying pressure to said material so that said gaseous part occupies only a small proportion of the length of said bore and so as to promote recondensation of said gaseous portion.

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