

Sept. 8, 1942.

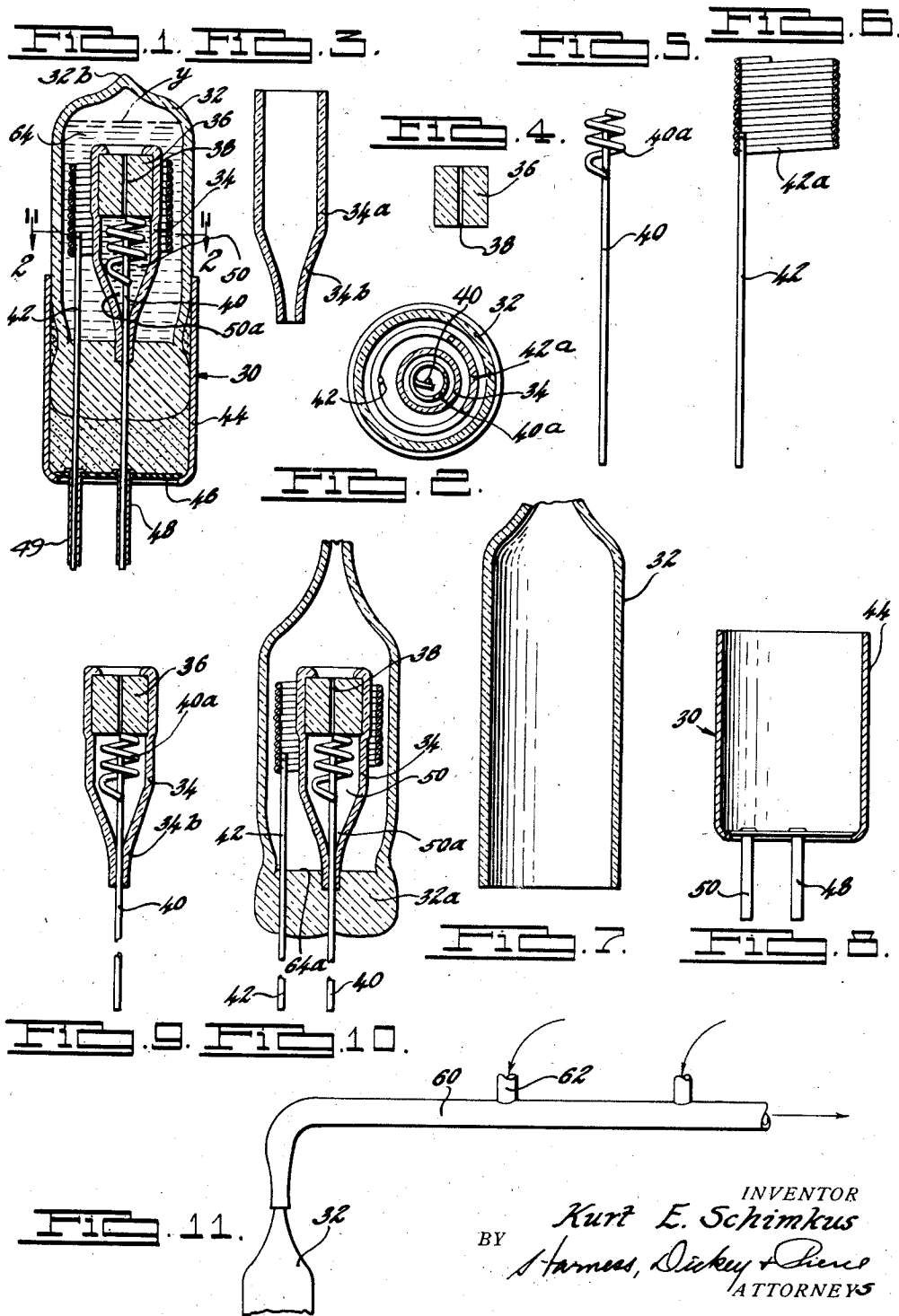
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2,295,295

CIRCUIT CONTROLLING APPARATUS

Filed April 12, 1939

2 Sheets-Sheet 1



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2,295,295

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2 Sheets-Sheet 2

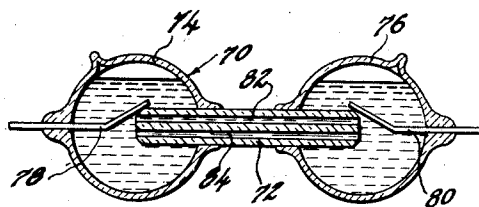


FIG. 12.

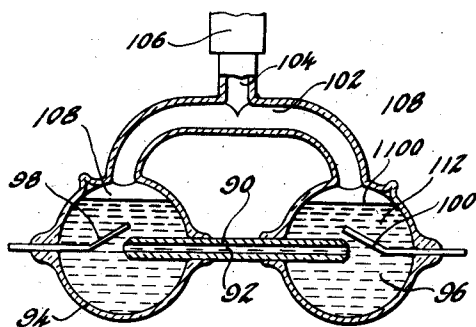


FIG. 13.

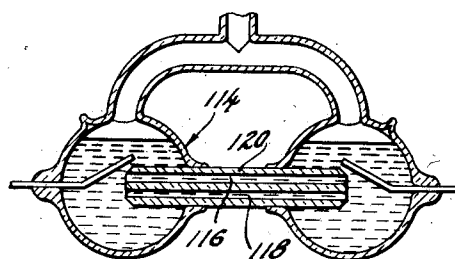


FIG. 14.

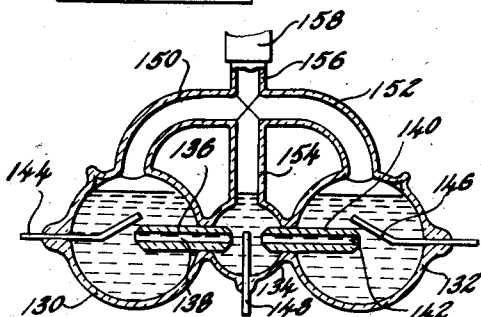


FIG. 15.

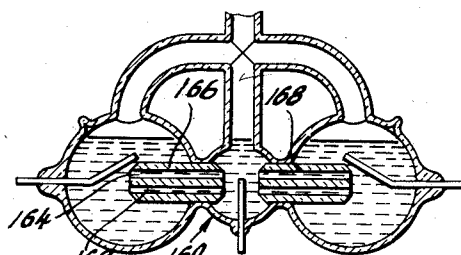


FIG. 16.

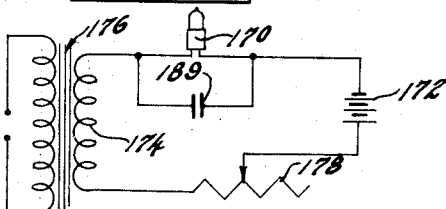


FIG. 17.

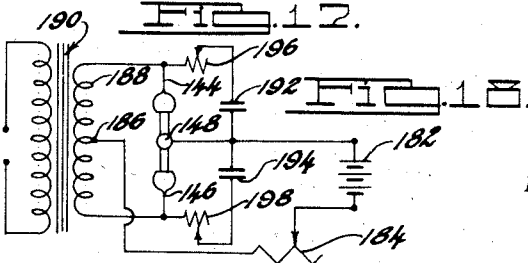


FIG. 18.

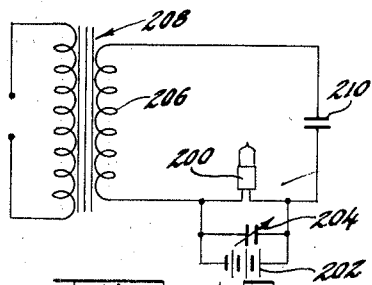


FIG. 19.

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CIRCUIT CONTROLLING APPARATUS

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Application April 12, 1939, Serial No. 267,457

11 Claims. (Cl. 200—113)

The present invention relates to methods of and apparatus for rapidly and recurrently modifying current flow in electric circuits, and in particular is directed to improvements in or relating to the methods and apparatus disclosed and claimed in the co-pending application of the present applicant and W. Dumke, Serial No. 4056, filed January 30, 1935, and in the co-pending application of the present applicant, Serial No. 179,893, filed December 15, 1937, now Patents Nos. 2,163,708 and 2,163,709, respectively.

The principal objects of the present invention are to provide improved devices of the above indicated character, as well as improved methods of assembling, regulating, and utilizing the same; and to provide such devices of simplified mechanical construction, and embodying improved features of control.

Further objects of the present invention are to provide an improved device of the above indicated character, comprising generally inner and outer envelopes having contact terminals projecting thereinto, respectively, and disposed to be connected together through an element having a relatively fine tubular bore; to provide such a structure which is operative in all rotative or tilted positions thereof; and to provide such a structure which is extremely simple and durable in construction.

Further objects of the present invention are to provide improved devices of the above generally indicated character embodying an improved means for balancing the pressures acting upon the ends of the thread of conducting material, to provide such structures embodying threads of conducting material arranged in multiple, so as to increase the capacity of the device; and to provide such structures selectively arranged so as to apply varying degrees of pressure to the ends of the thread of conducting material.

Further objects of the present invention are to provide improved circuit connections for controlling the performance of the unit, characterized as embodying means which may be selectively regulated so as to vary the frequency and output of the unit.

With the above and other objects in view, which appear in the following description and in the appended claims, preferred but illustrative embodiments of the invention are shown in the accompanying drawings, throughout the several views of which corresponding reference characters are used to designate corresponding parts, and in which:

Figure 1 is a view in vertical transverse section of a preferred embodiment of the invention;

Fig. 2 is a view in horizontal section, taken along the line 2—2 of Fig. 1;

Figs. 3, 4, 5, 6, 7, and 8 are detailed views of the individual elements utilized in the structure of Figs. 1 and 2;

Figs. 9 and 10 are views illustrative of the preferred method of assembly of the structure of Figs. 1 and 2;

Fig. 11 is a diagrammatic view illustrative of suitable evacuating and charging apparatus used in the process of assembling the structure of Figs. 1 and 2;

Figs. 12, 13, 14, 15, and 16 are diagrammatic structural views of modified embodiments of the invention; and

Figs. 17, 18, and 19 are diagrammatic views, illustrative of preferred circuit relationship for use in the practice of the invention.

Considering first the embodiment of Figs. 1 through 10, the device comprises generally a plug type base 30, an outer envelope 32, an inner envelope 34, a tubular member having a relatively fine bore 38, and inner and outer terminal members 40 and 42, respectively. The outer and inner envelopes 32 and 34, as well as the tubular member 38, may be, and preferably are, formed from a refractory material capable of withstanding substantial changes in operating temperature, such as the glass sold commercially under the name "Pyrex."

The base 30 may be, and preferably is, formed of a cylindrical metal body 44, having an enclosing insulating base 46 provided with conducting ferrules 48 and 49, into which the lower ends of the terminals 40 and 42 project, for connection to the associated circuit. The outer envelope, which houses the inner envelope, preferably has an outer diameter adjacent its lower portion substantially equal to the inside diameter of the metal case 44. The lower end of the outer envelope is sealed within the base 30 in any suitable way, as by introducing a quantity of paste-like phenolic condensate, such as that known commercially as "Bakelite," and thereafter heating the unit so as to bake the paste into a hard form. The resulting unit is relatively small in size, and is extremely rugged and durable in operation, as well as being extremely simple of assembly.

The inner envelope 34 is preferably formed of an initially tubular section of stock 34a (Fig. 3) having the lower end thereof constricted as indicated at 34b. The initial assembly step prefer-

ably consists in introducing the inner terminal 40 into the inner envelope 34, thereafter introducing the tubular member 36 into the end of the envelope 34, sealing off the lower end 34b of the envelope 34, and finally forming a seal between the envelope and the member 36 which entirely surrounds the member 36. In performing this assembly operation, it is preferred to position the member 36 axially of the envelope 34, by permitting its lower end to rest upon the upper and coiled end 40a of the inner terminal 40. During such operation, a predetermined axial relation is, of course, maintained between the terminal 40 and the envelope 34.

The just described resultant inner structure thus constitutes an inner chamber 50 which is completely sealed off and to which access is afforded only through the relatively fine bore 38 formed in the tubular member 36.

Following the just above described assembly of the inner envelope structure, it is preferred to introduce the inner envelope structure and the outer terminal 42 into the outer envelope 32 through the lower end thereof, bringing these inner parts to substantially the axial position shown in Fig. 10, in which position the inner envelope 34 is completely surrounded but radially spaced from the upper coiled end 42a of the outer terminal 42. With the parts thus positioned, the outer envelope, the outer terminal 42, and the inner envelope structure, may be fitted into a suitable heating fixture and while retained therein, the lower end of the outer envelope 32 may be pinched upon itself, as indicated at 32a, thus completely sealing such lower end.

Either before or after, but preferably after, the inner envelope structure is secured within the base 30, the unit is connected to a pumping system, represented by the tube 60 of Fig. 11, and both the inner and outer chambers are evacuated, to a suitable degree, such as two to three millimeters of mercury. If desired, the unit may be internally rinsed as by introducing an inert gas, such as argon or neon, and thereafter again evacuating the unit. After treating the unit in the just specified way, so as to insure that the interior of the inner chamber 50, as well as the interior of the outer envelope 32, is substantially free of foreign gaseous content, a suitable quantity of conducting material is preferably introduced into the unit through the just mentioned tube 60, which may be provided with a filler branch 62 for this purpose. As is described in detail in the above identified copending application, the conducting material is selected as one which is a relatively good conductor in a liquid phase, and which becomes, at least in a relative sense, a substantial non-conductor when in the gaseous or vapor phase. Mercury, or mercury amalgam, both being hereinafter referred to by the generic term mercury, is a preferred material. During the filling stage, the conducting material is preferably introduced into the outer envelope to a point somewhat above the top of the inner envelope 34. The weight of the mercury, or other material, above the top of the bore 38, assisted by the partial vacuum within the chamber 50, causes a relatively rapid flow of the mercury through the bore 38 into chamber 50, ultimately completely filling the latter, so that the inner terminal 40 is thus in continuous conducting relation, through the mercury in the completely filled chamber 50, with the mercury in the tubular bore 38. The flow of mercury into the chamber 50 serves to lower the level therein in the

outer envelope 32 to substantially the point represented by the line y in Fig. 1.

Dependent upon considerations which are discussed in more detail below, the sealing off of the upper end 32b of the outer envelope 32 may take place while the interior thereof is partially evacuated, or this operation may be postponed until an inert gas, such as argon, neon, or the like, is introduced into the upper end of the outer envelope, either to a subatmospheric, atmospheric, or greater than atmospheric pressure. In any event, following sealing off the upper end 32b of the outer envelope, it will be appreciated that the structure defines an outer container or chamber 64 which is substantially filled with conducting material, an inner chamber 50 which is entirely filled with conducting material, and a single communicating passage 38 between the two. The terminal 42 projects into the outer chamber 64 and is in continuous electrical contact with the material within the bore 38 through the material contained in such outer chamber 64. The inner terminal 40 projects into the chamber 50 and is also in continuous electrical contact with the material in the bore 38 through the material in such chamber 50.

It will be noted that the normal level y of the conducting material within the chamber 64 is substantially above the level of the upper end of the bore 38. The outer envelope, as well as the inner structure, are preferably so proportioned that even though the unit is turned upon its side or at an intermediate angle, the resultant gas bubble occupies a space above the then position of the bore 38, so that such tilting does not interrupt the otherwise complete electrical continuity between the terminals 40 and 42 through the bore 38. It will also be noted that the lower end 50a of the inner chamber 50 is positioned a substantial distance above the lower end 64a of the chamber 64. With this relation, if the unit is inverted, the resultant gas bubble assumes a position adjacent the end 64a but above the end 50a of the inner chamber 50. Accordingly, no tendency whatever results, even when the unit is in the just mentioned inverted position, for any of the conducting material to flow outwardly of the chamber 50. In all positions of the device, accordingly, the relation is one in which the inner and outer terminals 40 and 42 are in continuous electrical contact with each other through the material contained within the tubular bore 38.

Subject to the above considerations concerning the tiltability of the device, it will be appreciated that the volumes of the inner and outer envelopes, as well as the volume and pressure of the gas bubble, and the diameter and length of the bore 38, are determined on the same basis as is described in detail in the above identified copending patents. That is to say, the dimensioning of the device is such that at the normal expected load currents, the heat generated in the conducting material within the bore 38, converts a portion of such material into the vapor phase, partially or entirely interrupting the electrical continuity between the terminals 40 and 42 and correspondingly partially or entirely interrupting the heating action. The interruption of the heating action permits the material within the bore 38 to recondense wholly or in part into its initial conducting condition, thus "recompleting" the circuit. The proper dimensioning of the above mentioned elements thus causes the successive increases and decreases in current to oc-

cur at a frequency which can be readily regulated between relatively wide limits.

The unit described, with reference to Figs. 1 to 11, is characterized, of course, as utilizing only a single column (bore 38) of conducting material, so that all the power transmitted through the device is required to be passed through such single column of conducting material. As previously pointed out, the diameter and length of the just mentioned single column serves to control both the frequency, as well as the current output, of the device. It has been observed that increases in the voltage applied across the device, while having the effect of increasing the frequency thereof, and of increasing the instantaneous current values, do not result in proportionate increases in average values of the current passed through the device. This appears to be for the reason that such increase in voltage, other conditions remaining the same, shortens the ratio of the "conducting" periods to the "non-conducting" periods in each cycle.

It has been observed, however, that for a given operating voltage, and a given desired frequency, the output of a device may be materially increased by providing a plurality of the conducting columns, and this arrangement is shown in Fig. 12. In Fig. 12, the device 70 follows generally the construction described in the above identified copending application, and comprises a tubular member 72, and containers 74 and 76, and terminals 78 and 80 which project into the end containers, respectively. The tubular member 72 is provided with a plurality of relatively fine bores 82 and 84, of substantially identical dimensions. The dimensioning of each bore is such that, considered alone, the device will be operative to produce a predetermined frequency of modulating action and a predetermined average current flow, in response to the application of a normal or expected voltage across the terminals 78 and 80, all as described in the above identified copending application and as also described with reference to Figs. 1 through 11. In operation, however, identical current flows and "interrupting" actions occur in each of the tubular bores 82 and 84, so that the average value of the current flow through the device is equal to the sum of the average values of the currents in the individual bores 82 and 84. For a given voltage and frequency, accordingly, the average current output or power capacity of the multiple bore unit of Fig. 12 is substantially twice that of a corresponding unit having only a single bore. It will be appreciated that particular care must be observed in the manufacture of a unit of the type shown in Fig. 12, to ensure substantial uniformity between the several bores such as 82 and 84, so as to ensure that the interruptions in the two bores will occur in synchronism with each other.

The arrangements of Figures 13, 14, 15, and 16 are illustrative of further improvements in the structures shown in the above identified copending applications, the improvements being directed primarily to the provision of means to maintain a predetermined balance between the pressures existing in the several end containers for the conducting material. In Fig. 13, the device comprises a connecting tubular member 90, having a bore 92, proportioned according to the teachings of said copending application, and containers 94 and 96, and terminal members 98 and 100 which project into the end containers, respectively. In addition, the two end containers 94 and 96 are interconnected by a balancing con-

duit 102, having a branch 104 which may be closed off by a suitable valve 106.

Subject to the considerations discussed below, with respect to the pressures within the devices, it will be appreciated that the spaces 108 and 110 above the conducting material 112 in the end containers may be suitably evacuated or positively charged preferably with a suitable relatively inert gas, through the valve 106 and the conduits 104 and 102. These conduits also serve to maintain the pressures within the end containers at substantially uniform values at all times. This uniformity of pressure is found to improve the operation of units of the type shown in Fig. 13 in certain instances, apparently for the reason that the balanced pressure tends to maintain the intermittently formed bubble of non-conducting vapor within the bore 92 in substantially fixed position intermediate the ends of the bore. The arrangement of Fig. 14 duplicates that of Fig. 13 with the exception that the unit 114 in this figure is provided with multiple bores 116 and 118 in the member 120 thereof, in accordance with the disclosure of Fig. 12.

The embodiments of Figs. 15 and 16 are of the so-called double-wave type described in detail in the above identified copending applications. The arrangement of Fig. 15 comprises end containers 130 and 132 and an intermediate container 134. A connecting member 136, having a bore 138, forms a connection between containers 130 and 134, and a corresponding member 140, having a bore 142, forms a corresponding connection between the end container 132 and the intermediate container 134. Terminals 144 and 146 project into the end containers, respectively, and a central terminal 148 extends into the intermediate container 134. As is described in the above identified copending application, and as is also described below with reference to Fig. 19, the unit in Fig. 15 may be suitably connected to a source of power so as to provide double or full wave operation. The unit of Fig. 15 is provided with pressure balancing conduits 150, 152, 154, which lead, respectively, into the end containers 130, 132, and the intermediate container 134, and which also are connected to a branch conduit 156 leading, through a valve 158, to a suitable pressure or vacuum system (not shown). It will be appreciated that the balancing conduits in Fig. 15 maintain an exact balance between the pressures existing in the various containers for the conducting material. The arrangement of Fig. 16 corresponds to that of Fig. 15, with the exception that the device thereof is provided with multiple bores such as 162 and 164 in each of the connecting members 166 and 168, for the purposes and to produce the improvements described above in more detail with reference to Fig. 12.

In general, it may be said that the operation of the devices shown in Figs. 1 through 16 depends primarily upon alternative heating and cooling of the normally conducting material contained in the connecting bores thereof. The heating action results in the transformation of a quantity of the conducting material into a substantially non-conducting vapor phase, and the cooling action results in the recondensing of all or part of the vaporized component to the liquid phase. The "conducting" interval in each cycle of operation of the device appears to be primarily determined by the time required for what may be called the normal current through the device to heat the conducting material sufficiently to

transform it to the vapor phase. The "non-conducting" interval in each cycle, conversely, appears to be primarily controlled by the interval required for the vaporized bubble to partially or entirely recondense to the liquid phase, thus permitting the current value to rise to the above mentioned normal value and initiate another heating cycle.

The frequency of the just mentioned conversions from "conducting" to "non-conducting" relations, and vice versa, appears to be, as has previously been noted, a definite function of the diameter and length of the connecting bore, and also appears to be a definite function of the pressures to which the conducting material is subjected, and of the electrical characteristics of the associated circuits.

With respect to the pressures to which the conducting material is subjected, it appears that the pressures within the end containers of the devices in Figs. 12 through 16, and within the chamber 54 in the devices in Figs. 1 through 11, have a definite control of the frequency and the output of the associated device. This appears to be due primarily to the fact that the pressures control the duration of each "non-conducting" interval, it being appreciated that the "non-conducting" interval results from the formation of a substantially non-conducting vapor bubble, which is required to be condensed in whole or in part to the liquid phase in order to terminate the "non-conducting" interval. The temperature at which the vapor bubble recondenses is, of course, a function of the pressure to which the bubble is subjected. Accordingly, a relatively high pressure within the unit is found to be accompanied by a decrease in the length of each non-conducting interval, and a relatively low pressure within the device is found to be accompanied by an increase in the length of each non-conducting interval. In each case, the vapor bubble is subjected to a mechanical force represented by the gravity head of the conducting material above it, tending to cause a recondensing action. In the case of a relatively low pressure within the end containers, it would appear that this gravity head is a dominant force in producing recondensation, and in the case of relatively high pressures, it would appear that the gravity component is relatively unimportant. The reduction in the length of each non-conducting period serves to increase the output frequency of the device and also appears to produce an increase in the average current values, since the ratio of conducting to non-conducting periods is increased.

In the case of the device of Figs. 1 through 11, the pressures existing within the device are, of course, determined at the time of manufacture, since the outer envelope 32 is sealed at the port 32b as the final step to manufacture thereof. Depending upon expected service conditions, accordingly, the initial pressure within the device may be varied between relatively low or partial vacuum values and relatively high or substantial pressure values. The arrangements of Figs. 13 through 16 are particularly advantageous with respect to control by pressure, in view of the fact that the devices, in service, may be connected to suitable pumping systems, through the valves 106, 158, etc., associated therewith, so as to permit a variation of the pressure during operation, thereby affording a means of varying the frequency and output of the device.

With respect to the electrical characteristics

of the circuit, including the device, it will be appreciated that each conducting interval of the device involves the building up of the instantaneous current through the device from a zero or substantially zero value to a maximum value, and also involves a falling off of the current from the maximum value to a substantially zero value. The inductive, capacitive, and resistive components of any electrical circuit serve to control the rate of build-up and drop-off of current flows through the corresponding circuits, as will be appreciated. In addition, the inductive component of an electrical circuit is determinative of the quantity of electrical energy stored in the circuit, which must be dissipated when the circuit is interrupted. The stored energy in a circuit normally appears as an arc drawn between the contacts of the switch utilized to open the circuit. In the case of a device of the present type, the opening or separating action occurs within the tubular connecting bore. The transition from heat conducting to heat non-conducting interval of the device, accordingly, may be expected to involve some tendency for the formation of an arc passing between the two ends of the conducting material which are separated by the substantially non-conducting bubble. As is described in the above identified co-pending application, the tendency for the formation of such an arc may be reduced and in some cases substantially eliminated by interposing a capacitance in parallel with the device, which may be charged by the energy stored within the system. A control of this character appears to alter the frequency of operation of the device in that the otherwise existing tendency to form an arc tends to prolong the conducting interval and so tends to decrease the overall frequency of the device.

In addition, it has been discovered that a definite control of the frequency of the device may be effected by suitably adjusting and varying the relative values of the inductive, reactive, and capacitive components of the associated circuits. In Fig. 17, for example, the device 170, which may, and preferably does, follow the construction described with reference to Figs. 1 through 11, is connected to a suitable source of power represented as a battery 172, in series with the primary winding of a transformer 176 and a regulating control resistor 178. A condenser 180 is connected in parallel with the device 170. The associated circuit thus contains predeterminable components of resistance, reactance, and capacitance, and the device itself also includes predeterminable components of resistance and reactance. By suitably varying the effective value of the resistor 178 in the associated circuit, it has been found that a corresponding variation in frequency results, increases in the resistive component of the circuit per unit of voltage across the device 170 having been found to increase the frequency of the device, and decreases in the resistive component per unit of voltage across the device having been found to decrease the frequency of the device.

Fig. 18 is illustrative of a suitable regulating circuit for a device of the double-wave type, such as shown in Figs. 15 and 16. In Fig. 18, the intermediate contact 148 of the device is connected to one terminal of a suitable source of power represented as a battery 182. The other terminal of the battery 182 is connected through a regulating resistor 184 to a center tap 186 on the primary winding 188 of a suitable transformer 190. The end terminals 144 and 146 are connected,

respectively, to the end turns of the winding 198. Condensers 192 and 194 are connected in parallel with the separate halves of the device, in series with regulating resistors 196 and 198 respectively. It will be appreciated, accordingly, that the primary regulating resistor 194 is connected in series with each separate half of the interrupting device, and that the secondary regulating resistors 196 and 198 are connected in parallel with the tuning or discharge circuits associated with said halves. In accordance with the description of Fig. 17, it is found that variations in the effective values of the regulating resistors are accompanied by corresponding variations in the frequency and output current of the unit.

It has been found in practice that the device of the present invention is also applicable for use in circuits of the so-called Poulsen arc type. In Fig. 19, a device 200, which may, and preferably does, follow the construction described with reference to Figs. 1 through 11, is connected to a suitable source of power represented by the battery 202, and is also provided with a tuning condenser 204. The usual Poulsen oscillating circuit, including the primary transformer winding 206 and a condenser 210 are connected in parallel with the device 200. With this relationship, it will be appreciated that the device rapidly and recurrently interrupts the supply circuit, as well as the oscillating circuit, at a rate determined by the electrical characteristics of the supply circuit and of the oscillating circuit, and produces an oscillating action in the oscillating circuit in accordance with the usual principles of operation of the Poulsen arc circuit.

Although specific embodiments of the invention have been described in detail, it will be appreciated that various modifications of the form, number, and arrangement of parts, as well as the specific methods of assembly and of utilizing the same, may be made within the spirit and scope of the invention.

What is claimed is:

1. A device for rapidly and recurrently modifying current flow in electric circuits, comprising in combination an outer sealed envelope, an inner sealed envelope positioned within said outer envelope, an element having a relatively fine bore forming a connection between the interior of said outer envelope and the interior of said inner envelope, terminal means projecting into said outer and inner envelopes respectively, and material contained in said envelope forming an electrical connection between said terminals through said bore, said material having the property of being relatively freely conducting in one state and having the property of being transformed to a relatively non-conducting state in response to the heat generated by the passage of an electric current therethrough between said terminals.

2. A device for rapidly and recurrently modifying current flow in electric circuits, comprising in combination an outer sealed envelope, an inner sealed envelope positioned within said outer envelope, an element having a relatively fine bore forming a connection between the interior of said outer envelope and the interior of said inner envelope, terminal means projecting into said outer and inner envelopes respectively, and material contained in said envelope forming an electrical connection between said terminals through said bore, said material having the property of being relatively freely conducting in one state and having the property of being transformed to a relatively non-conducting state in response to the

heat generated by the passage of a current therethrough between said terminals, said material acting to completely fill said inner envelope and to partially fill said outer envelope.

3. In a device for rapidly and recurrently modifying current flow in electric circuits, comprising in combination an outer sealed envelope, an inner sealed envelope positioned within said outer envelope, an element having a relatively fine bore forming a connection between the interior of said outer envelope and the interior of said inner envelope, terminal means projecting into said outer and inner envelopes respectively, and material contained in said envelopes forming an electrical connection between said terminals through said bore, said material having the property of being relatively freely conducting in one state and having the property of being transformed to a relatively non-conducting state in response to the heat generated by the passage of a current therethrough between said terminals, said material acting to completely fill said inner envelope and to partially fill said outer envelope, the portion of said outer envelope not filled by said material being charged to a predetermined pressure with an inert gas.

4. In a device for rapidly and recurrently modifying current flow in electric circuits, comprising in combination an outer sealed envelope, an inner sealed envelope positioned within said outer envelope, an element having a relatively fine bore forming a connection between the interior of said outer envelope and the interior of said inner envelope, terminal means projecting into said outer and inner envelopes respectively, and material contained in said envelope forming an electrical connection between said terminals through said bore, said material having the property of being relatively freely conducting in one state and having the property of being transformed to a relatively non-conducting state in response to the heat generated by the passage of a current therethrough between said terminals, said material acting to completely fill said inner envelope and to partially fill said outer envelope, the portion of said outer envelope not filled by said material being under a partial vacuum.

5. In a device for rapidly and recurrently modifying current flow in electric circuits, comprising in combination, an outer sealed envelope, an inner sealed envelope positioned within said outer envelope, an element having a relatively fine bore forming a connection between the interior of said outer envelope and the interior of said inner envelope, terminal means projecting into said outer and inner envelopes respectively, and material contained in said envelope forming an electrical connection between said terminals through said bore, said material having the property of being relatively freely conducting in one state and having the property of being transformed in a relatively non-conducting state in response to the heat generated by the passage of a current therethrough between said terminals, said material acting to completely fill said inner envelope and to partially fill said outer envelope, the portion of said envelope not filled by said material being charged with an inert gas to a pressure substantially in excess of one atmosphere.

6. In a device for rapidly and recurrently modifying current flow in electric circuits, the combination of a base structure, an outer envelope, an inner envelope supported within said outer envelope, an element having a relatively fine bore extending therethrough forming a communica-

tion between said inner and outer envelopes, terminal means projecting through said base into said inner and outer envelopes respectively, and a normally conducting material contained within said outer and inner envelopes and forming a normally conducting thread between said terminals through said bore.

7. The method of assembling a device having an outer envelope, an inner envelope contained within said outer envelope, a member having a relatively fine bore forming a connection between said envelope, and terminal members extending into said inner and outer envelopes respectively, which includes the steps of introducing said element and one of said terminals into said inner envelope, forming a seal between said element and said inner envelope and between said terminal and said inner envelope so as to form closures for the ends of said envelope, introducing said element, inner envelope, and one terminal and said other terminal into one end of said outer envelope, sealing said one end of said outer envelope so as to support said inner envelope therein, and finally sealing the other end of said outer envelope.

8. In a device for rapidly and recurrently modifying 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 non-conductor 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 to cause the resistance offered by the material in said passageway to produce the quantity of heat necessary to cause such change of physical state, means including containers for said material for enclosing the ends of said passageway, and means supplemental to said passageway for balancing the pressures within said containers.

9. In a device for rapidly and recurrently modifying 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 non-conductor 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 to cause the resistance offered by the material in said passageway to produce the quantity of heat necessary to cause such change of physical state, means including containers for said material for enclosing the ends of said passageway, said containers being subjected to balanced pressures substantially in excess of one atmosphere.

10. In a device for rapidly and recurrently modifying 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 non-conductor 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 to cause the resistance offered by the material in said passageway to produce the quantity of heat necessary to cause such change of physical state, means including containers for said material for enclosing the ends of said passageway, said containers being maintained at balanced partial vacuums.

11. In a device for rapidly and recurrently modifying 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 non-conductor 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 to cause the resistance offered by the material in said passageway to produce the quantity of heat necessary to cause such change of physical state, means for subjecting said material to a pressure tending to cause said material to resume its conducting state, and means for varying said pressure to thereby effect a variation in the frequency of said device.

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