Nov. 18, 1952 P. VLAHOS 2,618,724

RHEOSTAT

Filed March 2, 1951 2 SHEETS—SHEET 1

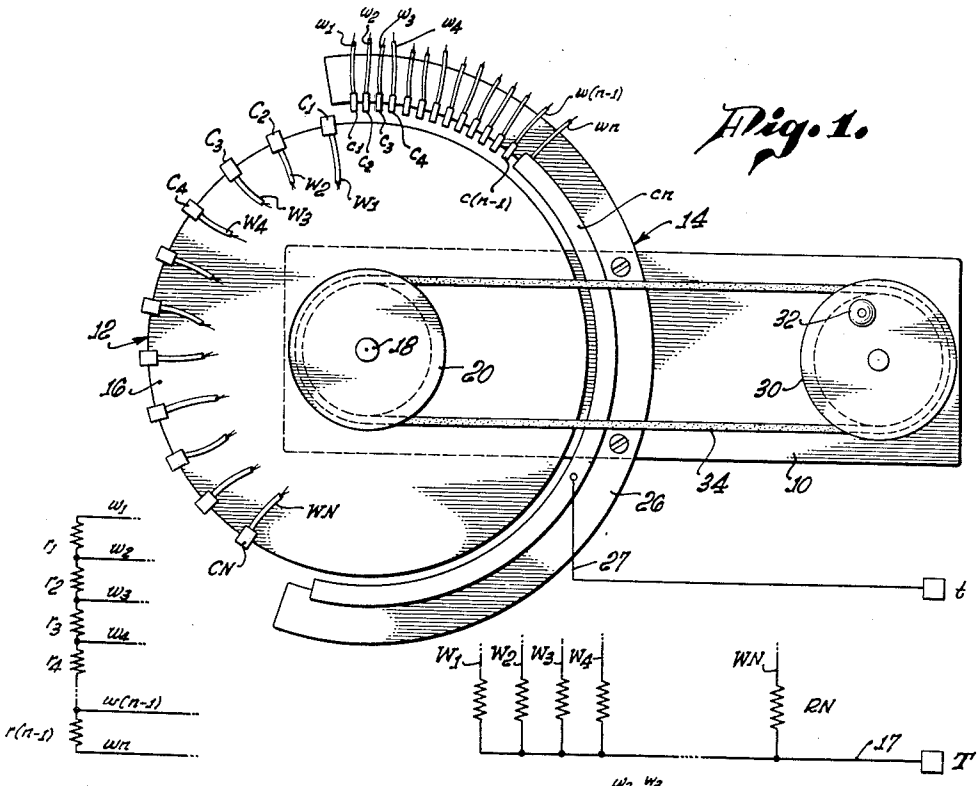


Fig. 1.

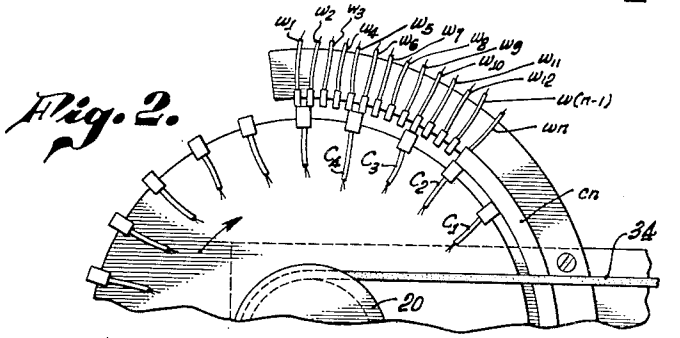


Fig. 2.

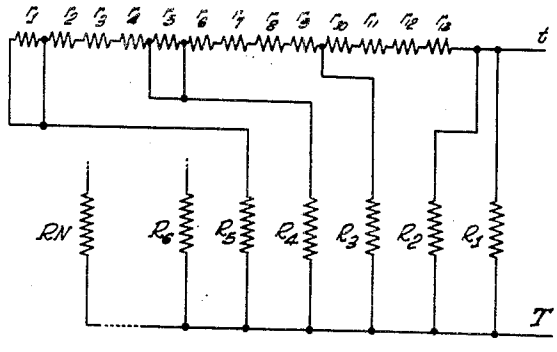


Fig. 3.

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Filed March 2, 1951 2 SHEETS—SHEET 2

Fig. 4.

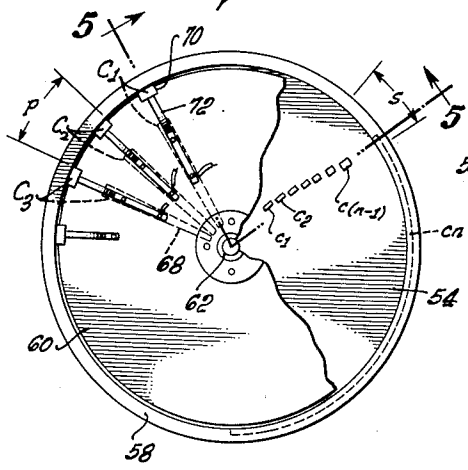


Fig. 5.

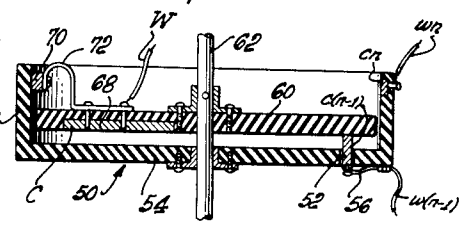


Fig. 6.

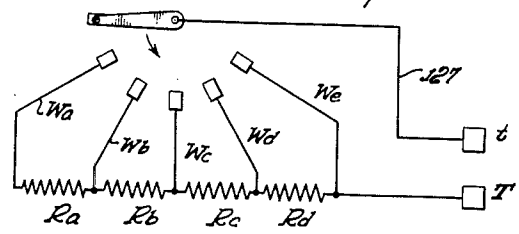


Fig. 8.

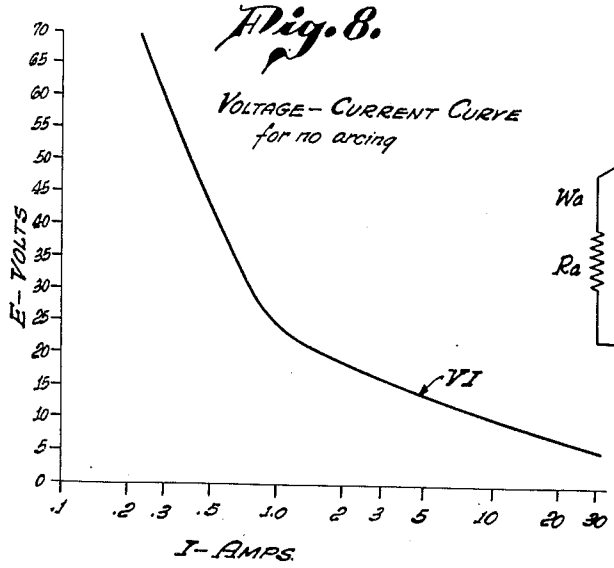
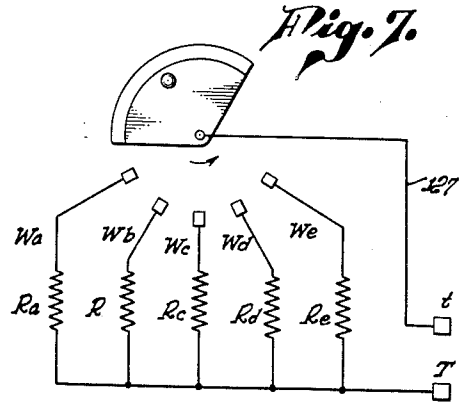


Fig. 7.



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UNITED STATES PATENT OFFICE

2,618,724

RHEOSTAT

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Application March 2, 1951, Serial No. 213,506

4 Claims. (Cl. 201—48)

1

This invention is concerned generally with means for varying the electrical impedance in a circuit, whereby, for example, the current flowing in the circuit, or the voltage between two points of the circuit, may be variably controlled.

The invention is of particular utility in connection with circuits carrying direct current, the variable impedance then being ordinarily essentially resistive in nature. For that reason, and for simplicity and clarity of expression, the following description will be directed primarily to direct current rheostats. However, it will be understood that the invention may be utilized in alternating as well as direct current circuits, and that the resistors of any such rheostat may be replaced by other types of electrical impedances, such for example as inductances and capacitors.

The invention is concerned more particularly with the typical problem of providing a relatively heavy duty rheostat in which the resistance elements may conveniently be spaced from the control mechanism, in which the tendency to arcing at the control contacts is reduced or eliminated, and in which the wire bundle required to interconnect the control mechanism and the resistance elements is much smaller than has previously been required for similar service.

That typical problem is solved in accordance with the present invention by providing an ordered array of resistor elements, switching means for bringing those elements successively into a circuit in parallel, and means for progressively increasing the current through each resistor as it is brought into the circuit.

A full and clear understanding of the invention and of its further objects and advantages will be had from the following description of a specific illustrative embodiment, which is not intended to be limitative on the scope of the invention. The following appended drawings form a part of that description:

Fig. 1 is a diagram illustrating in schematic form a preferred embodiment of the invention in open circuit position;

Fig. 2 is a schematic diagram like Fig. 1, but showing the rheostat in an intermediate position of adjustment;

Fig. 3 is a schematic diagram of the circuit associated with Fig. 2;

Fig. 4 is an axial view, partly broken away, showing an illustrative rheostat switch in accordance with the invention;

Fig. 5 is a section on line 5—5 of Fig. 4;

Figs. 6 and 7 are schematic diagrams of previous types of rheostat; and

2

Fig. 8 is a graph illustrating the general form of the relationship between direct current and voltage in a circuit which may be opened slowly without arcing.

In Figs. 1 and 2, illustrative primary and secondary switch elements 12 and 14 are mounted for relative rotative movement on a rigid support or frame, indicated schematically at 10. Switch element 12 comprises a circular contact-carrying member 16 of insulative material, rotatively fixed on a shaft 18, which carries also driving means such as pulley 20 and is journaled in frame 10 in any suitable manner, not shown in detail. Member 16 carries a number of ordered primary switch contacts C, shown as C1, C2, C3 . . . CN, the exact number of such contacts depending upon the conditions of service for which the apparatus is intended. The number N of primary contacts may, for example, be fourteen. As illustrated, contacts C are spaced uniformly along the periphery of member 16, but any suitable arrangement and type of mounting may be used that provides the proper type of progressive engagement with the secondary contacts to be described.

Primary resistors R1, R2, R3, . . . RN have one terminal of each connected in parallel via line 17 to one main terminal T of the rheostat. The other terminals of resistors R are connected respectively to the corresponding primary switch contacts C1, C2, C3, . . . CN by means of wires W1, W2, W3, . . . WN, which may be flexible over at least a portion of their length to permit limited rotational movement of switch element 12. In the drawing the intermediate portions of wires W are omitted for clarity of representation.

Secondary switch element 14 comprises, as an illustration, an arcuate support 26 of insulative material, mounted rigidly on frame 10 and carrying a number of ordered secondary switch contacts *c*, shown as *c1*, *c2*, *c3* . . . *cn*. The total number *n* of secondary switch contacts depends, as does N, upon detailed design considerations. As an example, *n* may be twenty-two. Contacts *c*, as illustrated, are spaced along the inner circular edge of member 26 in position to make electrical contact with primary contacts C as switch element 12 is rotated. Secondary contacts *c* are preferably relatively closely spaced, and each contact except *cn* is of relatively small angular extent about shaft 18. The last one, *cn*, of the secondary contacts is of relatively great angular extent, or is otherwise so arranged as to be capable of simultaneously engaging all, or substantially all, of the primary contacts C.

A number of secondary resistors *r* (equal to

one less than the number of secondary contacts) are connected between the respective pairs of consecutive secondary contacts by means of secondary wires *w*. The central portions of those wires are omitted in the drawings for clarity of illustration. Thus, resistor *r*1 is connected by wires *w*1 and *w*2 between *c*1 and *c*2; *r*2 is connected by *w*2 and *w*3 between *c*2 and *c*3, etc. The last secondary resistory is designated as *r*(*n*–1) and is connected between the last secondary contact *cn* and the next preceding contact *c*(*n*–1) by conductors *wn* and *w*(*n*–1).

The second main terminal *t* of the rheostat may be connected directly to secondary contact *cn* by a line 27. As is clear from the figures, connections *w* of the secondary resistors *r* may be entirely independent of the main terminals T and *t*. Alternatively, wire *wn* from one terminal of secondary resistor *r*(*n*–1) may be connected directly to main terminal *t*, line 27 then providing connection to *cn*.

Movable switch element 12 may be driven with respect to fixed element 14 in any suitable manner, manually or automatically, as in the operation of any rotary switch. As illustrated, a remote control for the switching means is afforded by a handwheel 30, having the form of a pulley and carrying a handle 32, which is rotatably mounted in any convenient position with relation to frame 10. The endless belt 34 represents an illustrative type of driving linkage between handwheel 30 and shaft 18. It will be understood that either or both of the switch elements may be movable with respect to frame 10, and that their relative movement may be translational rather than rotary. The present showing of one fixed and one rotatable switch element is merely illustrative.

With the switch in the position shown in Fig. 1, there is no electrical contact between primary contacts C and secondary contacts *c*. Hence the circuit between terminals T and *t* is open. By clockwise rotation of switch element 12 (as shown in Figs. 1 and 2) with respect to element 14, primary contact C1 first engages secondary contact *c*1, closing a circuit between T and *t* via lead 17, primary resistor R1, wire W1, the said engaged contacts, wire *w*1, all of the secondary resistors *r* in series and lead 27. Because of the connection of *r*1, *r*2 . . . *r*(*n*–1) in series with R1, a relatively small current is thereby allowed to flow between T and *t*.

As switch element 12 is further rotated clockwise, primary contact C1 engages successively the ordered array of contacts *c*, preferably engaging each contact before leaving the preceding one, eliminating progressively from the circuit one after another of the secondary resistors *r*1, *r*2, and so on. The resistance in series with R1 is thereby progressively decreased, and the current between T and *t* is correspondingly increased. When primary contact C1 reaches the last of the secondary contacts *cn*, the primary resistor R1 is inserted directly across T and *t*. During any further clockwise switch rotation, C1 maintains contact with the circularly elongated contact *cn*, and R1 remains in the circuit.

Primary contact C2 is similarly moved, by clockwise switch rotation, progressively across the ordered array of secondary contacts, first inserting R2 into the circuit in series with all of *r*1, *r*2 . . . *r*(*n*–1), and then progressively removing one after another of the secondary resistances from the circuit. When C2 ultimately reaches *cn*, R2 and R1 are connected in parallel between T and *t*, and that connection is maintained during further switch rotation. The same type of action takes place successively with respect to the remaining contacts C.

As an illustration, when the control switch is in the typical intermediate position shown in Fig. 2, terminals T and *t* are connected by a resistance network of the type illustrated schematically in Fig. 3. Primary resistors R1 and R2 are connected directly in the circuit in parallel, while R3 is connected in parallel with them but in series with secondary resistors *r*10 through *r*13. Similarly, R4 is parallel connected, but with its current limited by series connection with *r*6 through *r*13; and R5 is similarly in series with *r*2–*r*4 and *r*5–*r*13. At the particular switch position of Fig. 2, primary resistors R6, R7 . . . RN remain entirely out of the circuit, while *r*1 and *r*5 are momentarily shorted out by primary contacts C5 and C4, respectively.

As will be seen from the preceding description, a rheostat arrangement in accordance with the invention is capable of providing a relatively large number of discrete voltage or current steps. If the angular interval between each pair of consecutive primary contacts is greater than that between *c*1 and *cn*, for example, the total number of control steps available may equal the product of N by *n*. That product N*n* may readily be made a very large number, for example of the order of 400, thereby giving extremely smooth control while maintaining the relatively large current carrying capacity that results from the use of discrete switch contacts of relatively large area.

Substantially the same smoothness of operation can be obtained with a more compact form of switch by spacing adjacent primary contacts more closely than the total space between *c*1 and *cn*. For example, as shown in Fig. 2, more than one primary contact may engage steps of the secondary rheostat at the same time. When that is the case, the total number of control steps available is at least N*n* divided by the greatest number of primary contacts that may simultaneously engage steps of the secondary rheostat (not counting *cn*). If the interval between adjacent primary contacts C is so related to the interval between adjacent secondary contacts *c* that two primary contacts do not simultaneously make or break their engagement with respective secondary contacts (for example if the said two intervals are incommensurable), then the total number of control steps may approach, or even equal, N*n*, even for the more compact type of arrangement illustrated.

Indexing means may be provided in any usual manner if it is desired to limit the rotary movement of the switch to whatever discrete control steps may be made available by the particular detailed arrangement of the various contacts. However, the described rheostat is particularly well suited to operation without such indexing means, as will be described.

Because of practical considerations, well understood in the art, the actual mechanical mounting and arrangement of the contacts is preferably different from that shown schematically in Figs. 1 and 2. For example, in a preferred mechanical arrangement, the primary and secondary contacts may all lie at the same radius from the axis of shaft 18, and their working faces may lie in a common plane normal to that axis, rather than in a cylindrical surface as indicated in Figs. 1 and 2. Any suitable resilient

means may be employed to provide substantially uniform contact pressure between engaged contacts. All primary contacts, and all secondary contacts, need not be of the same type; and some or all of the contacts may include more than one contact element.

Figs. 4 and 5 show a typical specific embodiment of a switching means which illustrates a few of the great variety of physical features that may be included in an embodiment of the invention. As shown, a cup-shaped member **50** of insulative material supports secondary contacts *c1*, *c2* . . . *c(n−1)* in apertures **52** in its flat base portion **54**, in which they fit movably and are urged upwardly (as seen in Fig. 5) by individual springs **56**. Those springs may also connect the respective contacts to wires *w* which connect to secondary resistors *r* as already described. Secondary contact *cn* is embedded in the inner face of cylindrical rim **58**, extending nearly half way around that rim, as shown in Fig. 4. The relative placement of the contacts *c1* through *c(n−1)* at different radii from the center and their progressive relative angular displacement in a clockwise direction are shown clearly in Fig. 4.

The primary contacts C are mounted on a disk **60** of insulative material, fixed on shaft **62**, which is journalled axially in member **50** as by a bushing **66**. Any suitable means, not shown, may be provided for rotating disk **60** with respect to member **50**. Each of the primary switch contacts C comprises two distinct contact elements, a radially elongated metal insert **68** embedded in disk **60** flush with its inner face in position to engage successively the ordered array of secondary contacts *c1* to *c(n−1)* as disk **60** is rotated clockwise; and a metal shoe **70** resiliently mounted on the outer face of disk **60** as by a spring **72** in position to engage secondary contact *cn* upon further clockwise rotation of disk **60**. Springs **72** may provide electrical connection between the respective shoes **70** and the corresponding inserts **68**. Connection to primary resistors R is made by respective wires W.

As illustrated, the leading edges of both elements **68** and **70** of each secondary contact C lie in the same axial plane. However, their angular relation may be arbitrary, so long as the angular relation between the leading edges of secondary contacts *c(n−1)* and *cn* corresponds, that correspondence being such that, on clockwise rotation of disk **60**, element **70** engages *cn* shortly after element **68** has engaged *c(n−1)*. The angular spacing between consecutive primary contacts C (angle *p* in Fig. 4) is preferably enough greater than the angle between the leading edge of secondary contact *c1* and the trailing edge of *c(n−1)* that one primary contact element leaves *c(n−1)* before the next one engages *c1*. Then only one primary contact is on the secondary rheostat at a time, and it is immaterial that several secondary resistors may be shorted by a primary contact. As illustrated, the secondary contacts *c1* through *c(n−1)* become progressively larger. That is not necessary, but may be advantageous, since the current that those contacts are called upon to carry increases progressively with the number of the contact.

One of the limiting factors in the service capacity of an impedance varying device employing discrete control steps is the tendency to arcing at the contacts as the latter are opened. That is true in both alternating and direct current service, but is particularly troublesome in connection with direct current rheostats. One

method of solving that problem is to provide a very large number of discrete control steps, so that the change in current and voltage at each step is too small to sustain an arc. In power rheostats of previously available types, it is entirely impracticable to provide a large enough number of discrete control steps for that purpose. That is particularly true when, as is ordinarily the case, the resistor elements must be located at a relatively great distance from the control switching mechanism. With a conventional series type rheostat, shown typically in schematic form in Fig. 6, not only line **127**, but also each of the connecting wires W*a* through W*e* must be of sufficient capacity to carry the entire current flowing in the circuit at the time that wire is in use. To provide a large number of contacts with such a system requires a correspondingly large number of wires, each of large size, which is not ordinarily practicable.

A parallel type controller avoids a part of that difficulty. As illustrated in Fig. 7, only lines **117** and **127** are called upon to carry the full circuit current. Each of the wires W*a* through W*e* need carry only that portion of the current passing through its associated resistor. Particularly when a relatively large number of steps is provided, the current through each resistor is ordinarily a small fraction of the total. However, the required wire bundle is still impracticably large if sufficient steps are provided to prevent arcing.

In accordance with the present invention, the values of the various resistors R and *r* may be selected in any appropriate manner, depending upon the service for which the rheostat is intended. Particularly when the resistors and control switch are to be relatively distantly spaced, so that reduction of the size of the bundle of connecting wires is a primary factor, it is preferred to select the values of the various primary resistors R in such a way that each carries approximately the same maximum current. The maximum current through each primary resistor flows when its primary contact has just reached the last secondary contact *cn* as the total current is being increased, or just before it leaves *cn* as the total current is being decreased. If the rheostat is to be connected in series with a substantially constant voltage source and a substantially constant impedance load, the effective voltage across the terminals of the rheostat tends to decrease as the current in the circuit is increased. Under such conditions, the primary resistors preferably decrease successively in resistance value approximately fast enough to compensate for the decreasing applied voltage as they successively reach contact *cn*, so that each will carry substantially the same maximum current. Detailed values for the respective resistances can be calculated from the constants of the circuit, preferably selecting the most severe conditions that may arise. For example, if the circuit includes a motor, the resistance of the motor when stalled may be used as the load impedance.

Values of the various secondary resistors are preferably so selected that the tendency to arc as each secondary contact is opened is kept substantially constant over all of the contacts. A great practical advantage of the invention is that it is ordinarily practicable to keep the values of current and voltage at each contact low enough to avoid arcing even as the contacts are opened slowly. A graph may be plotted from

points obtained experimentally, showing values of current and voltage at which a slowly opened pair of contacts will just fail to maintain an arc. A graph of that type is shown illustratively in Fig. 8. Under the particular experimental conditions represented by that graph, an arc is maintained across opening contacts only if the values of the current carried by the contacts before opening and of the voltage across the contacts after opening correspond to a point of the graph above the line VI. Starting with the last secondary resistor, denoted by $r(n-1)$ in Figs. 1 and 2, and working back toward $r1$, it is possible to compute successively, from such a graph as Fig. 8 and from the other constants of the circuit in which the device is to be used, the maximum value that can be assigned to each resistor without causing arcing at its contact is opened.

In the accompanying table are given illustrative values for primary and secondary resistors that were determined in the manner indicated for a rheostat to be used for controlling a circuit including a source of 120 volts D. C. and a motor having a resistance of about 0.85 ohm when stalled. The calculation assumes primary contacts sufficiently widely spaced that only one at a time can engage second contacts $c1$ to $c(n-1)$.

Primary Resistors		Secondary Resistors		
Number	Ohms	Number	Ohms	Total (Ohms)
1	5.4	21	.46	.46
2	4.6	20	.57	1.03
3	3.9	19	.58	1.61
4	3.4	18	.65	2.26
5	3.0	17	.77	3.03
6	2.7	16	.87	3.9
7	2.5	15	1.0	4.9
8	2.3	14	1.1	6.0
9	2.1	13	1.3	7.3
10	1.8	12	1.5	8.8
11	1.4	11	1.8	10.6
12	1.0	10	2.0	12.6
13	.7	9	2.5	15.1
14	.5	8	2.8	17.9
		7	3.4	21.3
		6	4.0	25.3
		5	4.9	30.2
		4	6.0	36.2
		3	7.0	43.2
		2	8.8	52.0
		1	11.0	63.0

With the values given, there is a possibility of arcing as the control is moved to fully open position, that is, as contacts C1, $c1$ are opened. That can be avoided by connecting a 200 ohm resistor across those contacts, so that the highest available resistance value between T and t is 63 ohms plus 200 ohms instead of infinity Alternatively, two or three additional secondary resistance steps may be provided.

It will be understood that the invention may be embodied in a great variety of specific mechanisms, and that the typical examples that have been described are merely illustrative, the scope of the invention being defined in the appended claims.

I claim:

1. Means for varying the electrical impedance between two terminals, the said means comprising switching means including primary and secondary ordered arrays of mutually spaced and insulated contacts, the said arrays being mounted for relative movement such that the contacts of the primary array are successively engageable in ordered progression with the succcessive contacts of the secondary array, the secondary array including a plurality of preliminary contacts and a final contact that is connected to one terminal and that is sufficiently elongated in the direction of the said movement to engage simultaneously all of the contacts of the primary array, the intervals between corresponding points of pairs of adjacent preliminary contacts of the secondary array being appreciably less than the corresponding intervals for the contacts of the primary array, and the said intervals for the primary array being appreciably less than the sum of the said intervals for the secondary array, a set of primary impedances connected in parallel between the respective contacts of the primary array and the other terminal, and a set of secondary impedances connected between the several pairs of consecutively engaged contacts of the secondary array.

2. Means for varying the electrical impedance between two terminals, the said means comprising switching means including primary and secondary ordered arrays of mutually spaced and insulated contacts, the said arrays being mounted for relative movement such that the contacts of the primary array are successively engageable in ordered progression with the successive contacts of the secondary array until all contacts of the primary array simultaneously engage only the last engaged contact of the secondary array, one terminal being connected to the said last engaged contact of the secondary array, a set of primary impedances of progressively increasing value spaced from the switching means and connected in parallel between the respective contacts of the primary array and the other terminal, the values of the successive primary impedances being such that each primary impedance and its connection to its contact will carry substantially the same current upon first engaging the last engaged contact of the secondary array and means connecting the said last engaged contact of the secondary array to the respective other contacts of the secondary array through respective total impedances that decrease progressively for the successive contacts in the direction of their said successive engagement.

3. Means for varying the electrical impedance between two terminals, the said means comprising primary and secondary ordered arrays of mutually spaced and insulated switching contacts, means for moving one array bodily with respect to the other to produce successive engagement of each of the respective contacts of the primary array in ordered progression with the successive contacts of the secondary array, the last engaged contact of the secondary array being connected to one terminal and being sufficiently elongated in the direction of the said movement to engage simultaneously all of the contacts of the first array, a set of primary impedances connected in parallel between the respective contacts of the primary array and the other terminal, and a set of secondary impedances connected between the several pairs of consecutively engaged contacts of the secondary array, the values of the successively engaged secondary impedances decreasing progressively and having such mutual relation that, as the first engaged contact of the primary array is disengaged by reversed movement from each of the contacts of the secondary array, the current and voltage in each circuit that is thereby broken are insufficient, by approximately the same margin, to maintain an arc.

4. Means for varying the electrical impedance

between two terminals in a circuit having predetermined characteristics, the said means comprising primary and secondary ordered arrays of mutually spaced and insulated switching contacts, means for reversibly moving one array bodily with respect to the other to produce successive engagement of each of the respective contacts of the primary array in ordered progression with the successive contacts of the secondary array, the last engaged contact of the secondary array being connected to one terminal and being sufficiently elongated in the direction of the said movement to engage simultaneously all of the contacts of the first array, a set of primary impedances of progressively increasing value connected between the respective contacts of the primary array and the other terminal, and a set of secondary impedances of progressively decreasing value connected between the several pairs of consecutively engaged contacts of the secondary array, the values of the successive primary impedances being such that each primary impedance will carry substantially the same current upon first engaging the last engaged contact of the secondary array, and the values of the successive secondary impedances being such that, as the first engaged contact of the primary array is disengaged by reversed movement from each of the contacts of the secondary array, the current and voltage in each circuit that is thereby opened are insufficient, by approximately the same margin, to maintain an arc.

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