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## VARIABLE IMPEDANCE DEVICE

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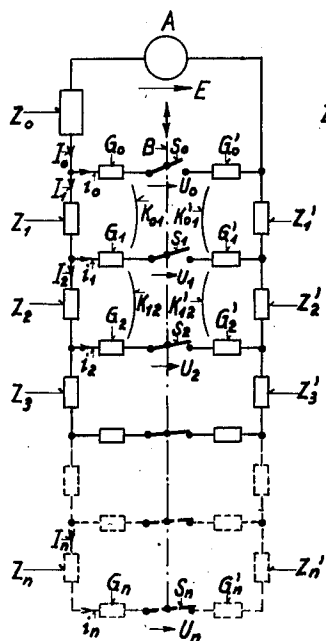


Fig.1

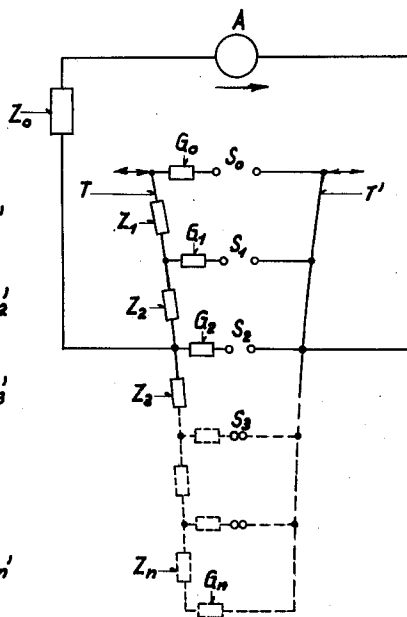


*Fig.2*

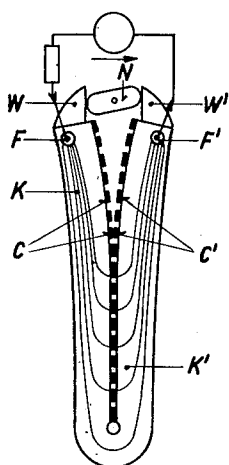


Fig.3

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## UNITED STATES PATENT OFFICE

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## VARIABLE IMPEDANCE DEVICE

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My invention relates to variable impedance devices for controlling or regulating electric circuits.

It is an object of the invention to devise impedance means which afford an extremely rapid yet accurately controllable impedance change under control by minute mechanical movements or/and minute mechanical forces. Another object of the invention is to provide impedance means capable of performing a rapid control in accordance with a predetermined law of impedance change. These and other objects will be apparent from the disclosure of the invention given in the following.

According to the invention I compose a controllable impedance device of a chain-like arrangement, recurrent network or structure of series and shunt impedance members which are joined or meshed together at least partly by means of switching contacts so that in one limit condition all contacts are closed for providing a minimum of total impedance while in the other limit condition the contacts are open for providing maximum impedance.

According to another feature of the invention, the impedance device is symmetrical as regards the chain-like impedance arrangement. The symmetry may be of mirrored character, for instance, relative to a symmetry axis that extends through the switching contacts. The symmetry may also be of the centric or polar type so that impedance members of high value are located at one side and those of low value at the other side of a switching contact, as will be further explained in a later place. For satisfactory switching conditions, the impedance chain may be designed in such a manner that the switched-in contacts, at least those that operate in an immediate sequence, carry currents of the same order of magnitude. The design is then such that the closed contacts establish a parallel connection, in a general sense, of the individual impedances while during the opening of the contacts the chain arrangement is converted substantially into a series arrangement of the individual impedances.

In most cases the current or voltage supply terminals of the device are preferably located at the ends of the impedance chain. By shifting the terminals to other locations relative to the chain arrangement, however, a different current distribution or a different characteristic of the rate of impedance change can be obtained if this is desired for a particular application.

In order to control the change in impedance

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with minimum efforts and within a shortest possible period of time, it is preferable to keep the distance of contact travel, especially of the contact whose opening distance is the largest, as small as possible, for instance, at most about one millimeter.

For certain purposes, for instance, for the rapid insertion of impedance or resistance into a circuit, the traveling distance of the farthest opening contact should be traversed within a period of  $3 \times 10^{-4}$  second or less. There are cases of application, for instance, when interrupting a circuit, where only the minimum and maximum impedance values, of which the latter may be infinite, are of interest, then, practically all switching contacts can simultaneously be opened and closed. In most cases of application, however, it is necessary to open and close the contacts in sequence. This can be obtained, for instance, by having the switching contacts move from closed to fully open position through a predetermined finite path of travel determined by the movement of a spring or by a given overlap. However, it is also possible to design the switching contacts in such a manner that, at least for initiating the opening movement, a predetermined minimum force is required. To this end, the switching contacts may be held closed by a bias provided by a spring or by magnetic means. For some applications it is preferable to design the switching contacts in the manner of instantaneous or snap action switches. The actuation of the contacts is preferably effected by means of a deformable member. In general, elastically deformable actuating members, such as springs or rubber bands are applicable. Especially simple conditions obtain if at least one of the contact carrying structures is designed as an elastic member so that the actuation of the contacts is due to bending or torsional movements of this member. According to another modification of the invention, a plurality of rotatable contact bridges are mounted on an elastic shaft member so that, when the shaft member is subjected to torsional movement, the bridges are sequentially actuated.

In general, a given path of actuating motion of such an elastic body corresponds to an accurately defined value or change of the total impedance value. Under these circumstances, the elastic deformation may be considered to be quasi-stationary, provided the controlling force or torque changes at a moderate rate. For regulating or control purposes which occur at a rapid

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rate of change or which are repetitive at a high frequency, it should be considered that the deformation progresses as an advancing wave, and that it may be desirable to provide for a predetermined damping of the wave-like progression. For certain purposes, for instance for the extremely rapid insertion of resistance, it is advantageous to utilize a propagation of a wave-like deformation which, once initiated, progresses automatically, then, only a fraction of the total mass of the elastically deformable medium is to be moved at the initial moment. As a result, moderate controlling forces or torques suffice for obtaining a very high acceleration.

The above-mentioned elastic deformation in devices according to the invention can be controlled by any suitable forces of mechanical, dynamic, magnetic or electrostatic nature. In addition, such deformation may be controlled by thermal means. For instance, the elongation of solid, liquid or gaseous bodies or the deflection of bimetal bodies or of strips may be used for this purpose.

The chain members of the composite impedance device may be composed of resistances, inductances, capacitances or any combination thereof, and the impedance members are joined together to form the chain by means of ohmic, magnetic or electrostatic links or couplings. However, for most purposes, the individual chain members, or the majority thereof, may be purely ohmic in character. The individual impedances may then consist of resistors whose material is substantially constant, i. e. temperature-independent, although it is sometimes preferable to design these members of a resistance material whose temperature coefficient of resistance is as high as practically possible and, particularly, positive as is the case, for instance, with iron, nickel, or tungsten.

The number of individual impedances joined together to form the chain arrangement may have any desired value. This number may be very high and, in the limit case, may even be infinite. In the latter case, the chain-like impedance arrangement represents substantially a continuous body, such as a single integral body of resistance material. When using only two integral bodies, for instance, of resistance material such as carbon, the number of the contact points may nevertheless be finite. For instance with carbon, a number of highly conductive contact parts of metal may be disposed on the resistance body, for instance, by electrolytic methods. However, it is also possible to design the arrangement in such a manner that the two cooperating resistance bodies are capable of touching each other, at least in theory, in an infinite multiplicity of points. When using resistance structure of the kind last mentioned, it is in most cases desirable that their specific resistance is larger than  $10^{-3} \Omega \text{ cm}$ . In particular,  $10^{-2}$  to  $1 \Omega \text{ cm}$ . and more. In another modification, the specific resistance of the resistance structures or bodies has different values at different respective points along the resistance body, particularly in such a manner that with a progressing increase in impedance a progressively increasing specific resistance becomes effective.

According to another feature of the invention, a resistance body which, at the same time, is a contact carrier consists essentially of a deformable structure whose plastic, elastic or thermic deformation controls the actuation of the contacts.

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In order to secure optimum reliability of impedance devices according to the invention, the switching voltage at the individual contacts should stay below the value at which an arc discharge may occur. That is, when dealing with power currents, impedance values are preferably rated so that the voltage is at most about 10 volts across each interrupting contact gap. A special advantage of the above-mentioned chain arrangement according to the invention, lies in the fact that it is also readily possible to maintain the switching voltage across each interrupting contact gap below the value at which a microscopic transfer of contact material may occur. To this end, it is merely required to maintain the switching voltage across each contact below about 1 volt.

As mentioned in the foregoing, the actuation of the contacts may be effected by any suitable forces. Many purposes render it desirable to control the contacts in dependence upon a physical magnitude to be controlled or regulated by the impedance device. For instance, in dependence upon current, voltage, energy, frequency or temperature. Thus the contact actuation may be controlled by the dynamic, magnetic or thermic effect of the regulated current. Combinations of the mentioned controlling effects are also applicable, for instance, a thermal control for slow regulation and a magnetic or dynamic actuation for rapid control as required for response to short-circuit currents.

The drawing illustrates several embodiments of the invention. Figure 1 shows diagrammatically an impedance chain structure. Fig. 2 represents, in a similar manner, a modified form of such a chain structure. Fig. 3 illustrates an impedance device whose impedance structure and contact carrier consists essentially of an integral elastic body.

In Fig. 1, the references  $Z_1, Z_2 \dots Z_n$  and  $Z'_1, Z'_2, Z'_n$  represent longitudinal or series impedances which, as a rule, represent complex impedance values. Characters  $G_0, G_1, G_2 \dots G_n$  and  $G'_0, G'_2 \dots G'_n$  represent the lateral or shunt impedances. Characters  $K_0, K_{12} \dots$  represent coupling impedances. A plurality of switches denoted by  $S_0, S_1, S_2 \dots S_n$  are connected with one another by means of a control member B. The impedance of the power line or circuit to be controlled is shown as a lumped impedance and denoted by  $Z_0$ . The feeding current source for direct or alternating current is denoted by A and its voltage is denoted by an arrow marked E. The longitudinal currents flowing through the chain members of the device are denoted by  $I_1, I_2 \dots I_n$ , while  $i_0, i_1, i_2 \dots i_n$  denote the cross currents flowing within the impedance device. The arrows marked  $U_0, U_1 \dots U_n$  denote the cross voltages of the device in the closed or open condition of the respective switches.

The operation of the device is as follows: In the condition of minimum impedance all switches S are closed, all cross currents  $i$  have finite values, and neighboring cross currents, such as  $i_0$  and  $i_1$ , are of the same order of magnitude. If the control member B is moved upwardly in the direction of the arrow, and assuming that the member is rigid, all switches S are simultaneously opened. Then, the cross currents  $i_0, i_1 \dots i_{n-1}$  become each equal to zero, and the cross current  $i_n$  becomes equal to the longitudinal current  $I_0$ . The condition then obtaining is that of a series connection of the

longitudinal impedances. Generally, however, the control member B is designed as a deformable, especially as an elastic structure, for instance, as a spring or rubber band. Then, if the free end of the member B is moved upwardly in the direction of the arrow and assuming that for opening of each individual switch a given minimum force is required, the switches S open sequentially to just the extent needed to balance the elastic control force against the opposing biasing force at each switch. During this procedure, the switches open successively (or they close successively when the actuating force declines) so that the number of the switches that are open at any movement depends upon the value of the actuating force obtaining at that moment.

Depending upon whether the switch  $S_n$  is also opened or whether it remains closed, the device operates to completely interrupt the current or to reduce it to a small minimum, respectively. Both possibilities of application are important, depending upon the particular purpose of the device, it being significant that the chain arrangement permits maintaining the individual switch currents below the value at which arcs or a transfer of contact material can occur.

Limit conditions exist if either all cross impedances G are equal to zero or if all longitudinal impedances Z are equal to zero.

Still referring to Fig. 1, it is desirable to electrically dimension the individual members or meshes of the chain network in such a manner that the opening voltage across the individual switches does not exceed given maximum values, for instance, 10 volts or 1 volt. This is especially significant if all members or meshes consist of ohmic resistors. It is of interest, for a proper dimensioning that when, for instance, the switch  $S_0$  is opened, the entire remaining portion of the impedance chain lies in parallel to the switch  $S_0$  and hence has a small impedance or resistance.

As mentioned above, a symmetrical design of the chain-like impedance device offers advantages. A mirrored symmetry exists if  $G_0=G'_1$ , etc.; and if further  $Z_1=Z'_1$ ,  $Z_2=Z'_2$ , etc. A centric or polar symmetry exists if  $G_0=G'_n$ ,  $G_n=G'_{n-1}$ , etc., and if also  $Z_1=Z'_n$ ,  $Z_2=Z'_{n-1}$ , etc.

Fig. 2 illustrates a somewhat modified design of a controllable impedance device according to the invention. In this embodiment, the current source A is connected not to the end points of the impedance chain structure but is attached to intermediate points of the chain network. In each mesh of the chain according to Fig. 2, the series impedances Z and Z' are integrated to a lumped impedance, and the shunt impedances G and G' are similarly shown as lumped impedances. In other respects the reference characters of Fig. 2 correspond to those of Fig. 1. The control of the switches in the device of Fig. 2 is effected by elastically bending the carrier members T and T' away from each other. Otherwise, the control performance of the device is substantially the same as that explained above with reference to Fig. 1.

Fig. 3 exemplifies the above-mentioned limit case in which the number of individual impedances or meshes is infinite. That is, the chain-like impedance network is designed as a single coherent impedance structure. In Fig. 3, K and K' represent electrically conductive bodies that are integral with each other to form a single structure. The two bodies or parts of the structure consist preferably of a resistance material of

a relatively high specific resistance. The current is supplied at electrodes F and F' which are imbedded in the respective parts K and K'. A multiplicity of contacts C and C' are located along the border line of separation of each body. The parts K and K' are elastically deformable. They are joined together so as to have the tendency to move toward each other. A cam member N engaging two projections W and W', of the respective parts K and K', permits moving the two parts away from each other in opposition to their closing bias. When the device is in condition for minimum resistance, all contacts C engage the corresponding contacts C'. Each given or selected angular deflection of the cam member N from the zero position corresponds to a definite number of mutually engaging contacts C and C' and hence to a corresponding and definite value of the effective total impedance. It will be recognized that, depending upon the elastic conditions, very small control movements suffice to completely separate both groups of contacts from each other.

A device according to Fig. 3 may be designed as an inductance regulator by making the two parts K and K' of highly magnetizable material, such as dynamo iron or comminuted magnet cores, and providing each part with a winding which is bare at the points C and C' so that a direct metallic contact between respective turns of the windings is brought about when the two parts K and K' are permitted to touch each other.

Controllable impedance devices according to the invention are applicable for highly diversified purposes. Aside from their application as control and regulating organ, for instance, for automatic regulating purposes, they are also advantageously applicable for remote control and remote measuring. Another field of application is that of starting equipment for electric rotary machinery, for instance, for automatic motor starters. Devices according to the invention are further useful as control components for electric circuits serving to effect complete or partial interruptions of the kind occurring in relays, contactors and other switching equipment for low and high voltage. Relative to the last-mentioned applications, it should be noted that very many cases of application do not require a complete interruption of the circuit to be controlled but can be satisfactorily performed if the current is merely forced down to a small fraction of its rated value. Such current controlling or regulating devices are especially useful in telephone and other electric communication systems, and also of value for the construction of rectifiers, converters, current-chopping devices and the like translating equipment, it being of considerable advantage for power purposes that the individual switching voltages is readily kept below the limits where a coarse or fine transfer of contact material can occur. Controllable impedance devices according to the invention are likewise applicable in amplifiers, microphones, and the like components, especially if advantage is taken of the possibility to obtain large changes in impedance or resistance in accurate accordance with a predetermined law of change while requiring for this purpose a controlling force of extremely low magnitude. As regards the law according to which the change in impedance depends upon the controlling force, the invention facilitates obtaining a linear dependency merely by applying a corresponding rating or dimensioning to the meshes or mem-

bers of the chain-like structure, or by the selection of a corresponding shape or composition of the impedance bodies if devices of the type represented by Fig. 3 are employed. Finally, controllable impedance devices according to the invention can also be designed as selector switches as generally used in automatic telephony. Such selector switches, by virtue of the invention, afford a considerable reduction of the scanning or selector period and permit rendering that period practically independent of the number of selective steps or positions whose number can be increased far beyond the extent heretofore possible.

What I claim is:

1. A variable electric impedance device, comprising two terminals, a recurrent network-like resistance structure connected across said terminals and having a finite plurality of sequentially interconnected impedance sections each having series-arranged and shunt-arranged impedance means, a finite plurality of mutually spaced switch contact means disposed in said respective impedance sections in series relation with said respective shunt-arranged impedance means, said series and shunt arranged impedance means of each of said impedance sections being disposed in symmetry relative to the appertaining switch contact means, and control means movable between different positions for sequentially closing and opening said contact means, a maximum number of said contact means being closed in one of said positions to provide minimum total impedance, a minimum number of said contact means being closed in another one of said positions, and a progressively declining number of said contact means being closed during movement of said control means from said one to said other position.

2. A variable electric impedance device, comprising two terminals, a recurrent network-like structure connected across said terminals and having a finite number of sequentially interconnected impedance sections each having series-arranged and shunt-arranged impedance means, said respective impedance sections having a finite plurality of respective mutually spaced contact means, and control means connected with said impedance sections and movable between given positions for sequentially opening and closing said contact means, a maximum number of said contact means being closed in one of said positions, a minimum number of said contact means being closed in said other position, and a progressively declining number of said contact means being closed during movement of said control means from said one to said other position.

3. A variable electric impedance device, com-

prising two elongated coherent bodies of resistance material extending lengthwise each other, said bodies being joined together at adjacent ends and having current supply terminals at the respective other ends so as to be electrically series connected with each other, each of said bodies having a finite multitude of salient contact points spaced from each other along the body side facing the other body and engageable with the respective contact points of the other body, and each of said bodies having a width larger than the spacing between said contact points, said bodies being deflectable relative to each other substantially about their point of juncture so that the number of contact points mutually engaged at a time depends upon the degree of relative deflection, and means for controlling said deflection.

4. A variable electric impedance device, comprising two elongated coherent bodies of resistance material extending lengthwise and substantially symmetrical to each other, said bodies being joined together at adjacent ends and having current supply terminals at the respective other ends so as to be electrically series connected with each other, each of said bodies having a finite multitude of salient contact points spaced from each other along the body side facing the other body and engageable with the respective contact points of the other body, said bodies being biased toward each other to normally maintain a maximum number of said points in mutual engagement for minimum total resistance, and control means engageable with said two bodies near the terminal ends thereof for progressively disengaging said respective series of contact points in opposition to the bias of said bodies.

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#### REFERENCES CITED

The following references are of record in the file of this patent:

#### UNITED STATES PATENTS

| Number    | Name             | Date           |
|-----------|------------------|----------------|
| 1,073,173 | Ruger            | Sept. 16, 1913 |
| 1,306,085 | Tornblom         | June 10, 1919  |
| 1,364,687 | Bentley          | Jan. 4, 1921   |
| 1,448,681 | Stoeckle         | Mar. 13, 1923  |
| 2,036,084 | Roder            | Mar. 31, 1936  |
| 2,244,958 | Moross           | June 10, 1941  |
| 2,330,569 | Esnault-Pelterie | Sept. 28, 1943 |
| 2,345,409 | Mason            | Mar. 28, 1944  |

#### FOREIGN PATENTS

| Number  | Country     | Date           |
|---------|-------------|----------------|
| 82,335  | Switzerland | Sept. 16, 1919 |
| 562,712 | France      | Sept. 13, 1923 |