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ELECTRIC CONTACT DEVICE FOR VARIABLE CURRENTS

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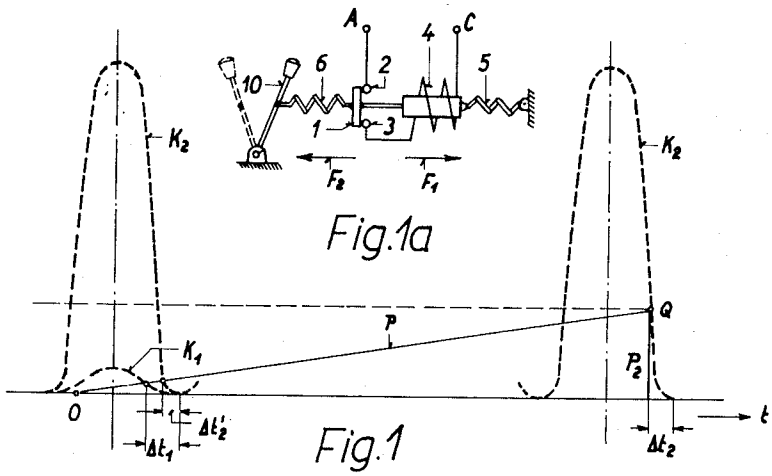


Fig.1a

Fig.1

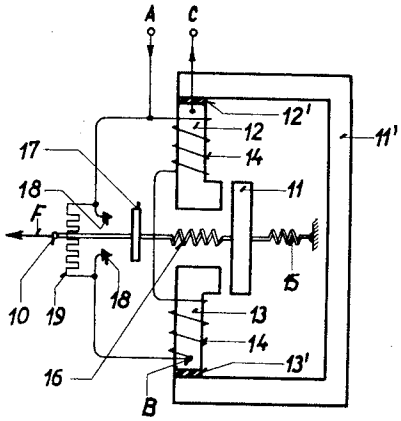


Fig.2

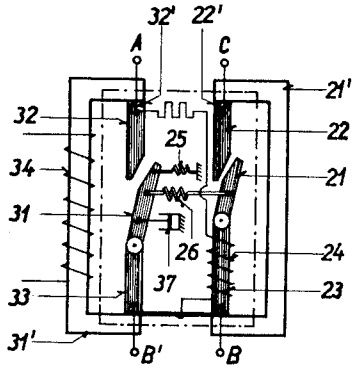


Fig.3

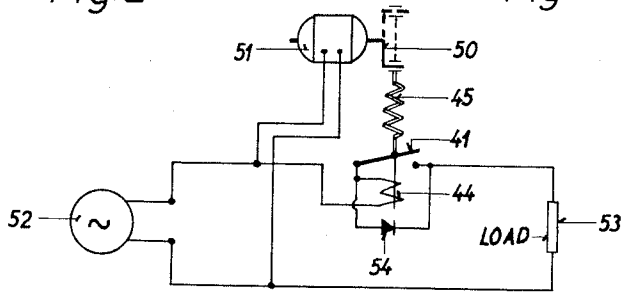


Fig.4

INVENTOR:

FRITZ KESSELRING

BY: Curt M. Avery

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ELECTRIC CONTACT DEVICE FOR VARIABLE CURRENTS

Fritz Kesselring, Zollikon-Zurich, Switzerland, assignor to FKG Fritz Kesselring Gerätebau Aktiengesellschaft, Bachtobel-Weinfelden, a Swiss company

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My invention relates to electric contact devices, such as circuit breakers, relays, contactors, synchronous switches, contact rectifiers, and the like apparatus in which a movable contact controls a variable current by opening or closing a circuit in a given time relation to the occurrence of a predetermined condition of that current.

It has been proposed to control such devices so that the opening and closing movements of the contact take place within intervals of time, relative to the period of the variable current, in which the transmission of electric energy through the contact is a minimum. The known solutions of this problem, however, are either far from accurate or require sensing apparatus too intricate and delicate for reliable performance.

It is an object of my invention to devise electric contact devices, of the kind mentioned, which afford a greatly improved solution of the stated problem by securing a high accuracy of contact control even for switching intervals of less than one millisecond while eliminating or considerably reducing the necessity of using additional relays or other extraneous control apparatus.

Another more specific object of the invention is to provide an alternating-current contactor which combines the advantage of a relatively simple design with reliable assurance that the circuit opening movement of the contact will occur during a switching interval beginning shortly but sufficiently ahead of a current zero passage.

These and further objects and advantages of the invention will be apparent from the following disclosure and explanations, as well as from the description of the illustrated embodiments given hereinafter.

According to a feature of my inevntion, a contact device of the above-mentioned kind is designed in such a manner that the movable contact element, when switching from one to its other position, is under control by the resultant effect of two variable component forces. One of these forces (hereinafter called "main force" for conveniently distinguishing it from the other, "auxiliary force") is provided by first control means which, in turn, are directly or indirectly under control by the current to be switched so that the variations of the main force are dependent upon those of the current. The other, auxiliary force, is provided by second control means, preferably so as to vary in a predetermined manner and within a predetermined period of time, although the second control means

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may also be controlled in dependence upon a magnitude or condition of the controlled current.

Referring more specifically to the first control means for providing the main force component, a variety of current-responsive sources of mechanical power are applicable depending upon the requirements of each particular purpose. For instance, the first control means may consist of a dynamometric system directly controlled by the current to be switched. Then, the main force imposed on the movable armature or contact element is proportional to the square of that current. Of course, the system may also be energized by partial currents, for instance, by applying resistance shunts or by deriving the control current for the first control means from the secondary of a transformer. If desired, the main force may be produced or controlled by a current which is modified by a control valve or rectifier. If the first control means are designed as a moving-coil system, having a movable conductor traversed by variable current and subjected to a magnetic field not produced by that current, the main force imposed on the conductor and on the contact element associated therewith is linearly proportional to the current and changes its direction together with the directional change of current flow. In electromagnets, also applicable as first control means for the purpose of the invention, the main force imposed on the magnet armature and controlled by the variable current flowing through the magnet coil is not strictly proportional to the controlling current but is determined by the magnetic induction which may differ from the current variations in rate of change and phase condition. Some applications of the invention make it advantageous to derive the main force from the voltage peak which the current to be controlled causes to appear across the winding of a saturated iron core due to the steepness of the flux change occurring in such a core.

Referring now to the second control means for imposing the auxiliary force component on the movable contact element, it is also possible to employ a variety of designs. According to a preferred feature of the invention, the second control means are equipped with springs or other elastic means which are attached to the movable switching element or armature of the first control means and are caused, by a movable control member, to vary the auxiliary force as the control member moves from one to the other limit or control position. The control member may be actuated manually or with the aid of generally

available drive means, such as electromagnetic or compressed-air drives. It is, as a rule, advantageous to provide for a monotonous variation of the auxiliary force between the respective initial and end values of the individual periods of variation. With "monotonous" I mean to say, in accordance with mathematical terminology, that the change of the auxiliary force between initial and end values is always either in the increasing or decreasing sense, although the change need not be steady. For instance, combinations of springs, when progressively stressed, result in broken or unsteady force-time characteristics while maintaining a monotonous force variation in the meaning here intended, and it will be understood that characteristics with jumps or steps are applicable. The initial or end value of the auxiliary force may be zero. According to another feature of the invention, however, the elastic or spring means are designed and controlled to reverse the direction of the auxiliary force so that, while monotonously varying between initial value and end value, this force passes through the zero value. This directional change can be obtained, for instance, by providing a spring which is deformable in opposing directions and controlled to press the movable contact element toward contact closing position before the spring force passes through the zero value and reverses into a pulling force in order to switch the contact element to its opening position.

The foregoing and other features of the invention are hereinafter explained more in detail with reference to the drawings, in which Figure 1 is an explanatory force-time diagram and Fig. 1*a* is a rudimentary and schematic showing of a contact device related to the diagram of Fig. 1, while Figs. 2, 3 and 4 represent three respective embodiments of contact devices according to the invention.

The contact device according to Fig. 1*a* includes a circuit, with terminals A and C, to be traversed by variable current to be controlled. The circuit extends through a movable contact element 1 which, when in closed position, bridges two stationary contacts 2 and 3 and is associated with an electromagnetic first control means whose energizing coil 4 is connected in the controlled circuit. For the purpose of the following explanation, it is assumed that contact element 1 is in the illustrated closed position and that then a variable current is flowing through coil 4 which causes the coil to impose a correspondingly variable holding or sealing force (main force) on the contact element 1 in the direction of the arrow F_1. The current may be undulating or alternating and may vary between low and high values i_1 and i_2 respectively, thus producing a corresponding main force which may vary between corresponding low and high values K_1 and K_2 respectively. These forces are represented in Fig. 1 by correspondingly denoted curves.

The device according to Fig. 1*a* may be equipped with a spring 5 for imposing on element 1 a substantially constant bias in the closing direction. The second control means for providing the auxiliary force comprise a spring 6 and a control member 10. Member 10 is movable between two control positions. In the position shown, the auxiliary force imposed by spring 6 on the contact element 1 is assumed to be negligible or zero. As member 10 moves to the dotted-line position, the auxiliary force increases from zero to a finite end value and acts in the direction of the arrow F_2. The auxiliary force is represented in Fig. 1 by the line P and shown to vary from the zero value at time point O to the end value P_2 at time point Q. When member 10 is being moved to the dotted-line position, the contact element 1 switches to the open position at the moment when the steadily increasing auxiliary force overcomes the periodically variable holding or main force. Before explaining this more in detail, it should be understood that, in general, devices according to the invention are to perform their switching operations during intervals of small instantaneous current values, especially in the neighborhood of current zero passages. It is also preferred to design the devices so that the movable contact element completes its individual movements during intervals in which the change in current amplitude remains small even at the expected steepest rate of change.

According to another feature of the invention, relating especially to switching devices for alternating current, the second control means are designed for varying the auxiliary force in such a manner that the time required for one period or cycle of variation, for instance, from an initial zero value to a given finite end value of the force, is larger than the half-wave period of the alternating current to be controlled. As a result, the current interruption occurs always in the immediate vicinity of a current zero passage within a wide range of current values, as will now be explained with reference to the diagram of Fig. 1.

In Fig. 1, the scale of representation is chosen so that at the moment when the illustrated amplitudes of main force and auxiliary force are equal, the resultant force passes through zero. It will be recognized that, relative to current i_1 and force K_1, this already happens near the end of the first half-wave at a moment an interval Δt_1 ahead of the first zero passage. In principle, this occurs also with the high current i_2 and corresponding high main force K_2 except that then the remaining period $\Delta t'_2$ is so small that the contact element cannot open. Hence, an interruption at high currents occurs only when the remaining interval becomes large enough. Such a sufficient interval Δt_2 occurs only after the auxiliary force P has become large enough, and this is assumed to happen at the moment Q. Consequently, the switching operation occurs earlier at low currents than at high currents, and is automatically controlled to start only after force and time conditions have become suitable. In comparison, if the auxiliary force were kept constant, for instance, at the value P_2, a synchronous or properly phased switching would be impossible for currents whose corresponding main force is smaller than P_2.

While Fig. 1 shows a linear time-proportional change of the auxiliary force P, a different rate of change may be provided for, for instance, according to the above-mentioned square law of progression. For certain applications, for instance, in contact rectifiers, converters or other commutating equipment, the auxiliary force may preferably be controlled to traverse an extreme value while passing from the initial to the end value of its variation. The second control means may also be designed so that the auxiliary force at least temporarily assists the main force especially during the switching-in performance and in the closed condition of the contact element.

In order to reduce the size of the device and especially also the heat developed in the apparatus, the main force can be controlled to become weaker or zero at the moment or shortly before

the auxiliary force reaches its end value. To this end, the energizing coil of the first control means may be deenergized at the proper moment, for instance, by short-circuiting or interrupting contacts controlled by the second control device. The embodiment shown in Fig. 2 and explained presently exemplifies the just-mentioned features.

According to Fig. 2, the movable contact element 11 consists of the armature of an electromagnetic device whose pole pieces 12 and 13 serve also as the stationary contacts of the appertaining electric circuit and are equipped with a holding coil 14. The pole pieces 12, 13 are electrically insulated at 12' and 13' from the magnetic yoke structure 11' of the device. Element 11 is biased toward the illustrated open position by a biasing spring 15. A movable control member 10 is connected to element 11 through a spring 16. In the illustrated position of member 10, the spring 16 is compressed and pushes against element 11, thus supporting the opening bias of spring 15. When member 10 is moved in the direction of the arrow F, the spring 16 relaxes and is then forced to expand so that the auxiliary force imposed on element 11 reverses and exerts a pull in the closing direction. An auxiliary contact 17 is attached to member 10 to cooperate with stationary contacts 18 which are connected across the holding coil 14.

The device operates as follows. When control member 10 is moved to the left, the contact element 11, under the pull of spring 16, moves into engagement with pole pieces 12 and 13. From this moment on, current flows from terminal A through holding coil 14 to point B and thence through pole piece 13, contact element 11 and pole piece 12 to terminal C. This condition continues until contact 17 touches the contacts 18. From then on, the current flows directly from terminal A through contact 17 to point B and thence through elements 13, 11 and 12 to terminal C. Hence, when control member 10 reaches its end position, the coil 14 is shorted and deenergized so that current and heat losses are at a minimum as long as the contact device remains in closed condition. The force for holding the contact element in the closed position is then provided by the auxiliary force P, i. e. by the pull of the expanded spring 16. When control member 10 is moved back to the right, the auxiliary force P is reduced. In the initial portion of this movement, the contact 17 is opened so that the coil 14 is again energized. As a result, the magnetic main force is now effective and holds the element 11 in closed position except during the zero passages. As the member 10 passes through a given position, the mechanical force acting on the element 11 is zero, i. e. the forces of springs 5 and 6 are just balanced. If member 10 moves farther to the right, the mechanical force imposed on element 11 acts in the opening direction. After this force has become large enough, the contact element is switched to the opening position and interrupts the circuit shortly before a current zero passage, as explained above with reference to Fig. 1.

If required, an impedance circuit, such as the resistor 19, may be connected across contacts 18 in order to suppress sparking at contact 17. The resistance value of resistor 19 should be large as compared with the resistance of holding coil 4. Depending upon the requirements of particular operating conditions, it may be desirable to provide for a small time constant of the holding coil circuit relative to the half-wave period of the

alternating current to be controlled, in order to obtain a rapid building-up of the holding flux.

The auxiliary force, or the operation of the means that control the auxiliary force, may be made dependent upon an electric quantity. Significant in this respect are embodiments in which the auxiliary force is produced by an auxiliary current, for instance, under control by a relay. Of particular importance are designs in which the auxiliary force is dependent upon an electric condition of the circuit to be controlled. For instance, the auxiliary force may be produced by the controlled current itself, especially in response to an overload current, provided, of course, the auxiliary force is controlled so as to vary in accordance with the above-explained principles of the invention. A device controlled by relay-type equipment in response to an electric quantity and suitable for the just-mentioned purposes is exemplified by the embodiment of Fig. 3. The movable contact element 21 consists of the armature of an electromagnetic system (first control means) whose pole pieces 22 and 23 are magnetically bridged by a yoke 21'. At least one pole piece is electrically insulated from yoke 21', as shown at 22'. Contact element 21 is pivoted to pole piece 23. Pole piece 22 serves also as a stationary contact and is electrically connected to a terminal C. A holding coil inductively associated with the magnetic system is denoted by 24, a biasing or kick-out spring by 25. The second control means, for imposing variable auxiliary force on the contact element 21, comprise a spring 26 which connects the element 21 to the armature 31 of a relay system with a yoke or field structure 31' and two pole pieces 32, 33 of which at least one is electrically insulated from yoke 31', as shown at 32'. Pole pieces 32 and 33 serve also as electric conductors. Pole piece 32 is connected to a terminal A, and pole piece 33 is electrically connected to pole piece 23, the connection extending between points B' and B. A control coil 34 is disposed on yoke 31'. Connected to armature 31 is a dash pot 37 or equivalent damping device which delays the armature movement only in the opening direction. The parts enclosed by a dot-and-dash line (excluding the yokes 21' and 31') may be combined to a cartridge-type unit, as disclosed in the copending application Serial No. 757,860, filed June 28, 1947, and assigned to the assignee of the present invention.

The device operates as follows. When control coil 34 is energized, armature 31 is magnetically moved in the counterclockwise direction in opposition to the bias of spring 25. Spring 26 is stressed and pulls the contact element 21 toward closing position. As soon as element 21 touches the pole piece 22, the current to be controlled flows from terminal A through coil 24, pole piece 23, element 21 and pole piece 22 to terminal C. Hence, coil 24 is energized and a holding force is imposed on the element 21. This continues only until armature 31 contacts the pole piece 32 and short-circuits the coil 34. Now the current flows from terminal A to B', thence to B and back to terminal C. When control coil 34 is deenergized, the armature 31 moves slowly clockwise back to the open position due to the bias of spring 25. Initially the coil 24 becomes energized and causes the variable main force (holding force) to act on element 21. During the first portion of movement of armature 31, the previously expanded spring 26 relaxes until it is placed under compression and opposes the

main force to effect opening of element 41 shortly before a current zero passage, as explained above with reference to Fig. 1. The damping device 37 takes care that the auxiliary force reaches its end value only after a timed period, for instance, longer than the half-wave period of the controlled current.

When applying the invention to periodically operating contact devices, such as rectifiers, inverters and the like translating or commutating equipment, provision may be made to vary the auxiliary force in dependence upon the voltage of the circuit to be controlled, especially in order to secure a desired switching-in performance. For synchronous switches and other synchronously controlled apparatus such as those just mentioned, it is also of importance to control the variation of the auxiliary force in such a manner that it is larger than the main force at a predetermined moment preceding the current zero passage; and it is then also desired that the end value of the auxiliary force be small at small currents and correspondingly large at large currents so that the switching movement is always initiated at about the same time point ahead of the current zero passage. In cases of this kind, it may be essential that the auxiliary force reach the required end value during periods smaller than the half-wave period of the controlled current. An additional improvement, applicable for synchronously operating as well as for other devices according to the invention, can be obtained by controlling the main force in such a manner that it reaches its zero passages at phase points earlier than the zero passages of the current controlling the main force, for instance, by means of devices as disclosed in the copending application Serial No. 778,439, filed October 7, 1947, now Patent No. 2,499,394, March 7, 1950, and assigned to the assignee of the present invention.

In order to elucidate devices of the just-mentioned synchronous type, the embodiment shown in Fig. 4 will now be referred to. This embodiment is especially suitable for rectifying purposes. The movable contact element 41 is magnetically controlled by a main force controlled by a coil 44. The auxiliary force is provided by a spring 45 which has one end attached to element 41 while the other end is actuated by a control member 50 which is formed by a crank mounted on the shaft of a synchronous motor 51. A source of alternating current is denoted by 52, a direct-current load by 53, and an auxiliary valve by 54. Motor 51 is energized by voltage from source 52, and crank member 50 is adjusted to an angular position, relative to the motor shaft, which corresponds to the desired phase relation of the auxiliary force variation to the variation of the magnetic main force.

At the moment of the voltage zero passage, the crank 50 is in the position shown in full lines so that the spring 45 has minimum tension. Hence, a very small current in coil 44 suffices for moving the contact element 41 and shorting the valve 54. For the switching-out performance, however, a relatively large tension of spring 45 is desired to accelerate element 41 sufficiently for reaching the required opening distance at the moment of the current zero passage. Such an increased tension of spring 45 is secured by the fact that, during switching-out, the crank turns to the dotted-line position. It will be recognized that the auxiliary force is periodically varied between a minimum value obtaining when crank 50 is in the lowest position and a maximum value obtaining at the highest crank position. Since motor 51 runs synchronously with the alternating-current voltage, the auxiliary force depends not only on time but also on the voltage of the circuit to be controlled.

Aside from the embodiments specifically described, the invention is applicable for various other purposes, for instance, for relays, load switches, energy switches, safety devices, control or regulating equipment. It should also be understood, that the invention is not limited to application for alternating current but is likewise suitable for direct-current circuits in which the current is variable due to switching phenomena of any kind, for instance, when forward current changes to back current or regenerative current.

Devices according to the invention offer the advantage of dispensing with the highly sensitive relays and the like accessories heretofore required for equipment of this kind, and that the actuation, even with synchronous switches, may be effected manually or with the aid of known and available drives not subject to specialized or exacting requirements, thus combining simplicity of design with highly reliable operation.

I claim as my invention:

1. An electric contact device, comprising an alternating-current circuit having a contact element movable between two positions for respectively opening and closing said circuit, biasing means connected with said element for biasing it toward opening position, control means electromagnetically connected with said element and having a magnet coil electrically connected with said circuit for imposing on said element a main force varying in accordance with said current and biasing said element toward closing position, a control member movable between two control positions, elastic structure deformable in opposing directions and disposed between said member and said element for imposing on said element an auxiliary force in the direction of said main force when said member is in one of said control positions and in opposition to said main force direction when said member is being moved to said other position, and electrically operable actuating means associated with said member for controlling it to move between said control positions during a period longer than the period of said alternating current.

2. An electric contact device, comprising an alternating-current circuit having a contact element movable between two positions for respectively opening and closing said circuit, control means electromagnetically connected with said element and having a magnet coil electrically connected with said circuit for imposing on said element a main force varying in accordance with said current and biasing said element toward closing position, a biasing spring attached to said element for imposing thereon a biasing force toward the opening position, a control member movable between two control positions, and spring means connecting said member with said element for imposing on said element an auxiliary force variable in dependence upon movement of said member so that said element is in said opening and closing positions when said member is in said respective control positions, whereby said element is moved from closing to opening position at a moment when, during the corresponding movement of said member, said main force drops below a given value.

3. An electric contact device, comprising an alternating-current circuit having a contact element movable between two positions for respectively opening and closing said circuit, control means electromagnetically connected with said element and having a magnet coil electrically connected with said circuit for imposing on said element a main force varying in accordance with said current and biasing said element toward closing position, an electromagnet having an armature movable between two control positions and biasing means tending to hold said armature in one of said control positions, said magnet having a control coil for causing said armature to move to said other control position during a period of long duration as compared with the half-wave period of said current, and spring means connecting said armature with said element for imposing on said element an auxiliary force variable in dependence upon movement of said armature for placing said element in said opening and closing positions when said armature is in said respective control positions so that said element is moved from opening to closing position when, during corresponding movement of said armature, the resultant of said main and auxiliary forces passes through a given condition.

4. An electric contact device, comprising an electromagnet having an armature normally biased toward magnetically open position and a magnetizing coil for imposing on said armature a variable magnetic holding force when said coil is energized while said armature is in magnetically closed position, a circuit for variable current to be controlled having contact means engageable with said armature for closing and opening said circuit when said armature is in closing and opening positions respectively, a control member movable between two control positions, spring means interconnecting said member and said armature for moving said armature against its bias to closing position when said member is moving from one to the other control position, said coil being connected with said circuit under control by said contact means to be energized when, during movement of said member, said circuit becomes closed, and auxiliary contact means associated with said member and connected to said coil for deenergizing said coil when said member, during said movement, approaches said other control position whereby, during reverse movement of said member, said coil is reenergized and thereafter said armature moved to opening position at a moment when the resultant of said holding force and of the variable force imposed by said spring means on said armature passes through a given condition.

5. An electric contact device, comprising an electromagnet having an armature normally biased toward magnetically open position and a magnetizing coil for imposing on said armature a variable magnetic holding force when said coil is energized while said armature is in magnetically closed position, a circuit for variable current to be controlled having contact means associated with said armature for closing and opening said circuit when said armature is in closing and opening positions respectively, a control member movable between two control positions, spring means interconnecting said member and said armature for moving said armature against its bias to closing position when said member is moving from one to the other control position, and auxiliary contact means engageable with said member and connected to said coil for energizing said coil when said member starts moving from the other to said one control position so that said armature is caused to move to its opening position at a moment when the resultant of said holding force and of the variable force imposed by said spring means on said armature passes through a given condition.

6. A contact device for alternating current, comprising a circuit for current to be controlled, an electromagnetic contactor having a contact element disposed in said circuit and movable between two positions to open and close said circuit, said contactor having a control coil connected to said circuit for biasing said element to move in the closing direction by a variable first force controlled by said current, spring means attached to said element for imposing thereon a second force in the opening direction, a synchronous motor electrically connected to said circuit and mechanically connected to said spring means for varying said second force in synchronism with said current to effect opening movement of said element in a given phase relation to said current.

7. An electric contact device for switching periods below one millisecond, comprising circuit means for periodic current, a contact element forming part of said circuit means and being movable between two positions for respectively opening and closing said circuit, biasing means connected with said element for biasing it to one of said positions, actuating means operatively connected with said element for imposing thereon a moving force in opposition to said biasing means to move said element to said other position, said actuating means having simultaneously operable first and second control means to jointly produce said moving force, said two control means having respective variable component forces opposing each other at the opening moment of said contact element, said first control means being electrically series-connected with said circuit means and having its component force controlled by the magnitude of said current and variable with the period of said current, and said second control means being independent of said current magnitude and of said first control means and having a period of force variation other than said current period.

8. An electric contact device for switching periods below one millisecond, comprising a circuit for periodic current, an electromagnetic contact device having a contact element series-connected in said circuit and being movable between two positions for respectively opening and closing said circuit, a biasing spring connected with said element for normally holding it in the opening position, said contact device having a control coil for imposing on said element a first component force in opposition to said spring to move said element to the closing position, said coil being series-connected in said circuit so that said component force is dependent upon the magnitude of said current and variable with the period of said current, and control means connected with said element and operable simultaneously with said coil for imposing on said element another variable component force in opposition to said first component force, said control means having a monotonous force variation between different given values and having a period of force variation longer than said current period.

9. An electric contact device for switching periods below one millisecond, comprising circuit means for periodic current, a contact element forming part of said circuit means and be-

ing movable between two positions for controlling said current, biasing spring means connected with said element for biasing it to one of said positions, actuating means operatively connected with said element for imposing thereon a moving force in opposition to said biasing means to move said element to said other position, said actuating means having current-responsive first control means electrically connected with said circuit means for providing a variable component force synchronous with and dependent upon the magnitude of said current, and second control means having an electric driving device with a movable drive member for providing mechanical power and a coupling spring connecting said drive member with said element for imposing on said element another variable component force independent of said current magnitude, said moving force being the resultant of said two variable component forces.

10. An electric contact device, comprising a circuit for periodically variable current, a contact element forming part of said circuit and being movable between two positions for respectively opening and closing said circuit, first control means electrically connected to said circuit and operatively connected with said element for imposing on said element a force directed toward one of said positions and variable in dependence upon said current, and second control means operable simultaneously with said first control means and operatively connected with said element for imposing a reversible force on said element, said second control means having an electromagnetic device with an armature member movable between two positions, and a spring connected between said member and said element so as to be stressed in opposing directions respective when said member is in its respective positions for controlling said reversible force to vary through the zero value, said member having a period of movement longer than that of the variation of said current.

11. In an electric contact device according to claim 10, said first control means having said variable force directed toward the circuit closing position of said element, and said reversible force being normally cumulative to said variable force when said element is in said closing position.

12. An electric contact device, comprising an alternating-current circuit, a contact element series-connected in said circuit and being movable between circuit opening and closing positions, first control means having a current-responsive electromagnet electrically connected with said circuit and magnetically joined with said element for imposing thereon a force variable in accordance with the instantaneous magnitude of the alternating current, second control means having a movable member connected with said element for imposing thereon another variable force so that the movement of said element depends upon the resultant of said two forces, and condition-responsive electric actuating means independent of said current magnitude and connected with said member for controlling said member to vary said other force between an initial value and an end value, said member having a period of movement longer than the half-wave period of the alternating current.

FRITZ KESSELRING.

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