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SYNCHRONOUSLY OPERATED REGULATOR

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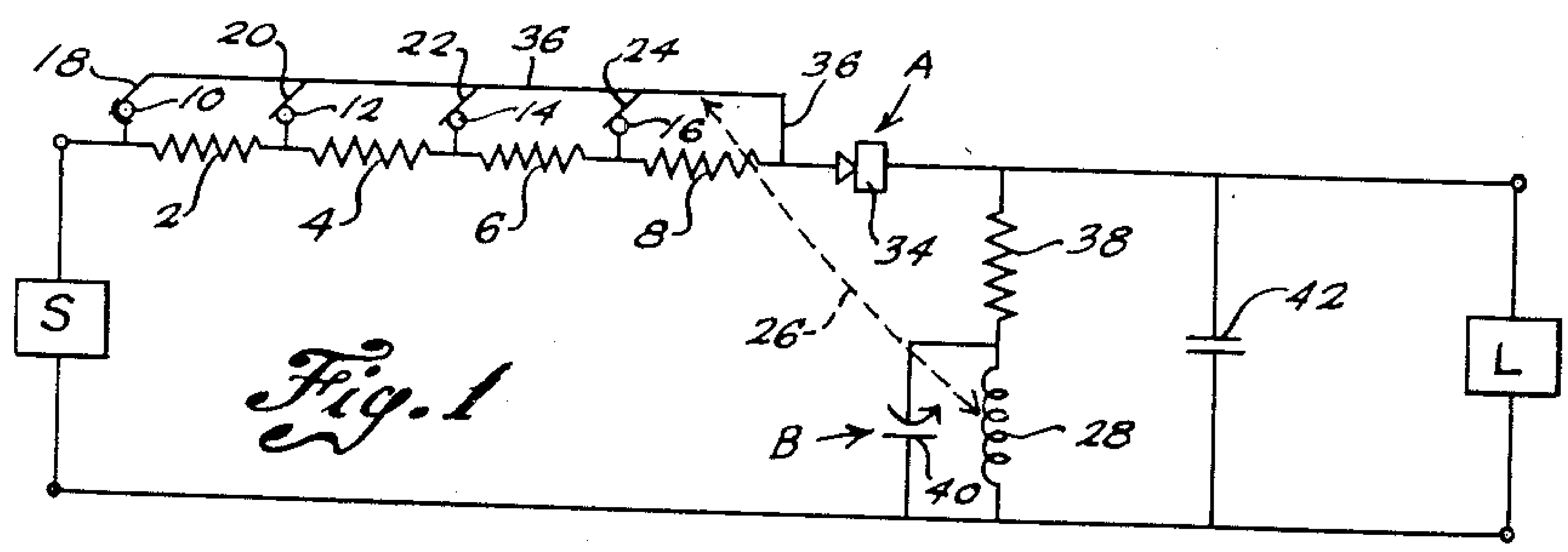

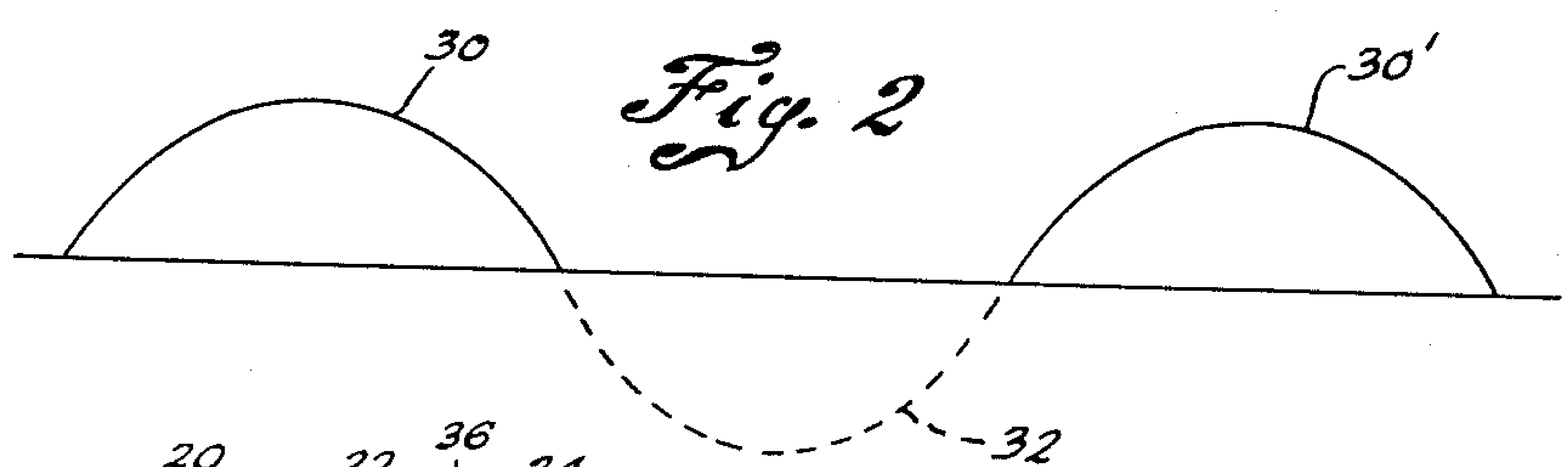

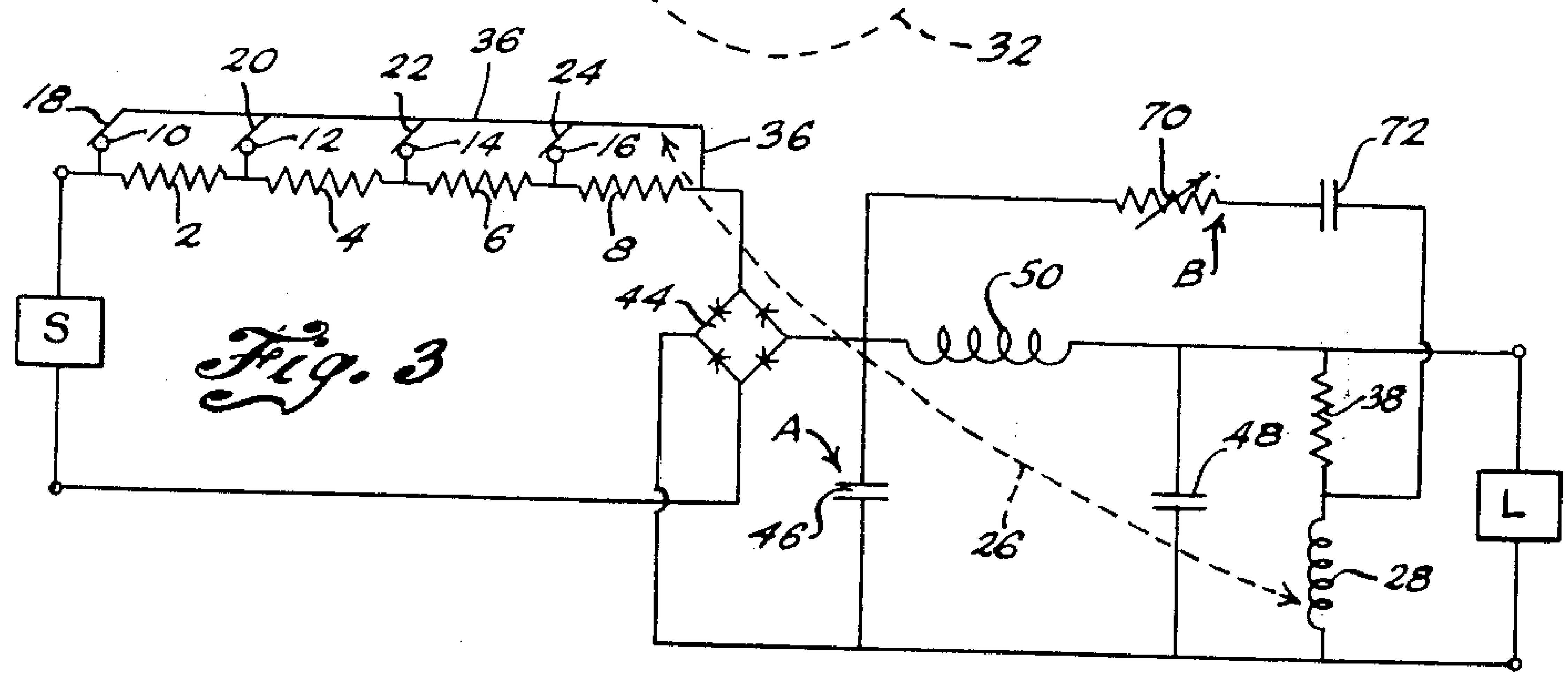

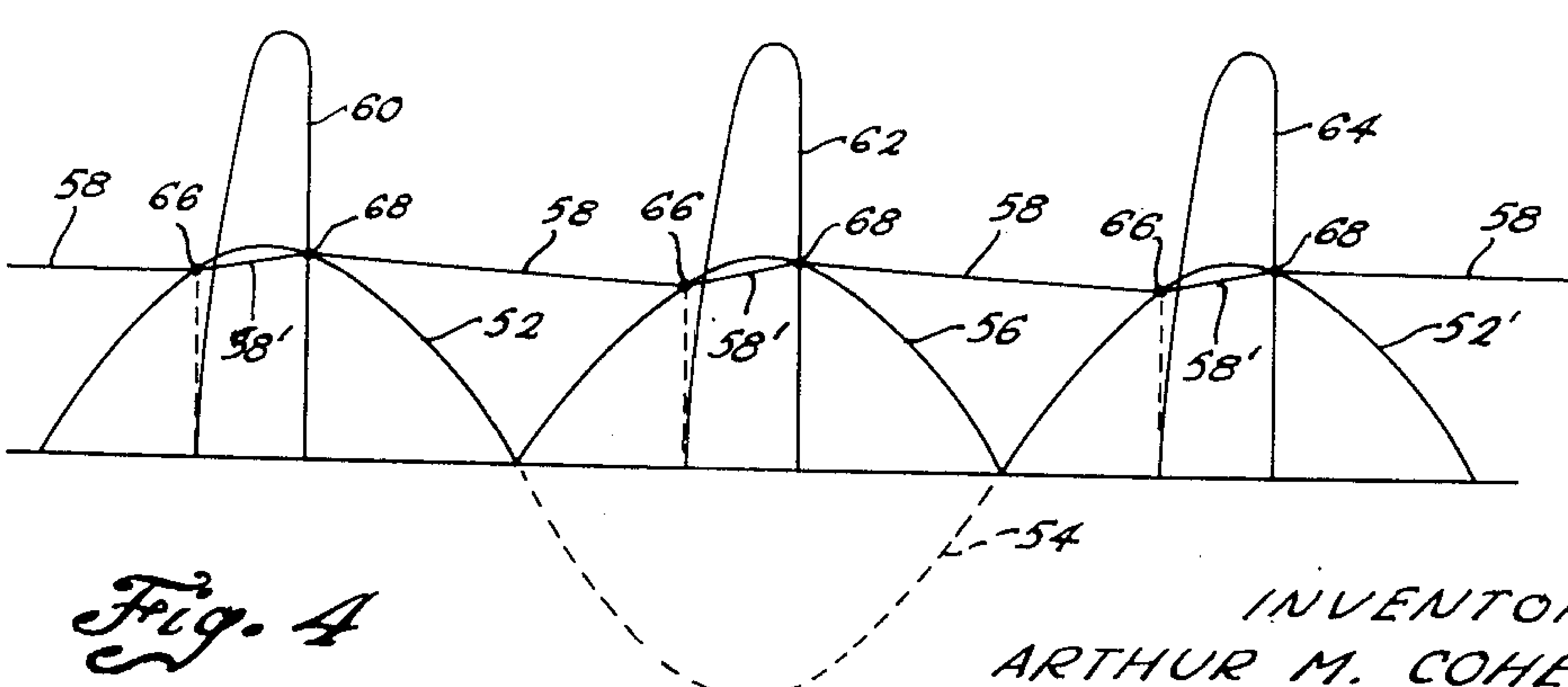

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SYNCHRONOUSLY OPERATED REGULATOR

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19 Claims. (Cl. 321—16)

The present invention relates to the connection and operation of a regulator adapted to control intermittently supplied electrical energy and to a method of increasing the current carrying capacity of such a regulator.

The type of regulator to which the present invention is particularly adapted for use and with respect to which the invention is herein illustrated is the so-called "finger type," which is constituted of a plurality of regulatory circuit elements such as resistances and a plurality of contact pairs, one member of each pair being carried by a movable finger. The fingers may be moved in any desired manner so as to successively open and close the contact pairs and thereby successively connect and disconnect the regulatory circuit elements in the circuit, thereby varying the energy loss in said elements and hence inversely varying the energy available to the load. In this manner, the load voltage, for example, may be rendered constant despite limited variations in the source voltage, the contacts being opened and closed according to the voltage at the load so that as that voltage tends to increase, more resistance is inserted into the circuit, thus maintaining the voltage at the load substantially constant.

One of the primary limiting factors in the use of regulators of this type has been their current carrying capacity. Most critical in this respect are the contact pairs themselves, since those contact pairs, or at least one of them at any given time, carry substantially the full current supplied to the load. When any given contact pair is separated by appropriate movement of the finger which carries one of the contacts, the current is interrupted and, if its magnitude is sufficient, an arc will tend to form between the separating contacts. This not only causes excessive heating of the contacts themselves but also results in the well known phenomena of pitting and metal transfer. As the magnitude of the current increases, the importance of these effects also increases and if the current exceeds a certain critical value, the arcing and attendant self-destruction of the contacts will soon render the regulator undependable if not absolutely unuseable.

The above disadvantages have in the past not proved of material significance because the regulators in use were sufficiently massive so that they were adequate for almost all applications. Moreover, by reason of their massive construction, the moving parts thereof had such great inertia as to be relatively insensitive to rapid fluctuations in current. A recent development in this field has been the fabrication of exceedingly small and light finger type regulators the moving parts of which are extremely sensitive. With respect to such regulators, the considerations above described become of prime and limiting importance, since the construction is compact and the contacts themselves are small. By reason of the compact construction, adequate cooling and ventilating of the contacts is rendered difficult. By reason of the small size of the contacts themselves, a much smaller degree of overheating or of pitting or of metal transfer will suffice to render faulty the functioning of the regulator.

It is the prime object of the present invention to devise a regulator system which has a greater current carrying capacity than has been attainable heretofore. By the present invention, the contacts themselves, which formerly were the determining factor insofar as current carrying capacity is concerned, no longer limit said capacity in any way.

Another object of the present invention is to devise a method of employing finger type voltage regulators, and in particular such regulators of small size, so as to render them capable of regulating currents of high magnitude.

A more specific object of the present invention is to so connect a finger type regulator into a circuit in which current is only intermittently supplied to a load as to synchronize the opening of any given contact pair with the intermittent passage of current therethrough, to the end that the maximum amplitude of current and even the average amplitude thereof, no matter how high, has no deleterious or destructive effect upon the contacts.

The above generalized objects are achieved by opening a given contact pair only during the period between the intermittent current supplying periods. By so doing, no arcing whatsoever will take place at the contacts, since no current is being carried by them as they are opened. As a result, a given regulator may carry currents greatly exceeding those capable of being carried by regulators connected in the circuit in conventional manner. The timing and control of the opening of the contacts is in turn achieved by energizing the contact opening mechanism from the intermittently supplied current and by varying the phase of the energizing current so as to compensate for the mechanical stiffness or inertia of the contact opening mechanism.

To the accomplishment of the above objects and such other objects as may hereinafter appear, the present invention relates to an improvement in the method of connecting a voltage regulator in a circuit in which electrical energy is intermittently supplied to a load and to an improvement in a regulation system as defined in the appended claims and as set forth in this specification, taken together with the accompanying drawings, in which:

Fig. 1 is a schematic circuit representation of one application of the present invention in which half wave rectified direct current is supplied to a load from an alternating current source;

Fig. 2 is a graphical representation of the current and voltages present in the circuit of Fig. 1;

Fig. 3 is a schematic circuit diagram illustrating another application of the present invention in which full wave rectified direct current is supplied to a load from an alternating current source but in which a blocking condenser is employed to periodically interrupt the full wave rectified direct current; and

Fig. 4 is a graphical representation of various of the currents and voltages active in the circuit of Fig. 3.

My invention is here illustrated as applied to a finger type regulator having a plurality of resistors 2, 4, 6 and 8 constituting regulatory circuit components (Four resistances are shown by way of example only. The number may be increased at will.), a plurality of fixed contacts 10, 12, 14 and 16, a plurality of movable fingers 18, 20, 22 and 24 each adapted to make and break electrical connection with the fixed contacts 10, 12, 14 and 16 respectively and defining contact pairs therewith, an actuator 26 for moving said contacts so as to successively open and close the contact pairs, the actuator 26 being shown schematically by means of a broken line, and an actuator-moving electrically energized element such as the coil 28 for controlling the movement of the actuator 26 and hence the opening and closing of the contact pairs. This regulator is connected into a circuit comprising a current source generally designated S and the load L. The actuator-moving electrically energized coil 28 is connected in the circuit so as to be energized by the interrupted current and a phase shifting circuit generally designated B is employed in conjunction with the coil 28 so as to controllably vary the phase of the current active therein in a manner to be described more fully hereinafter.

As illustrated in Fig. 1, the source S supplies an alternating voltage illustrated in Fig. 2 by means of the solid lines 30, 30' and the broken line 32. The regulator circuit components, the resistors 2, 4, 6 and 8, are connected in series between the source S and a half wave rectifier 34, which may take the form of a selenium cell rectifier or any other half wave rectifier known to the art. A short-circuiting connector 36, in conjunction with the fingers 18, 20, 22 and 24 to which it is electrically connected, serves to shunt or short-circuit the resistors 2, 4, 6 and 8 out of the circuit. The coil 28, which constitutes the actuator-moving electrically energized element, is connected across the load on the opposite side of the rectifier 34 from the resistors 2, 4, 6 and 8 and may be provided with a series connected protective resistance 38. An adjustable condenser 40 is connected in shunt across the coil 28, the condenser 40 constituting the phase shifting component or circuit B. A filter condenser 42 may be connected in shunt across the load in order to smooth the current impulses supplied by the source S through the rectifier 34 so that the load L may ultimately be provided with a more constant current supply.

Since the rectifier 34 is of the half wave type, it will be apparent that, although the voltage from the source S will continuously pass through a complete sinusoid as illustrated by the broken and solid lines in Fig. 2, the current supplied by the source S, and hence the current passing through the regulator, will be periodically interrupted and will take the form illustrated by the solid lines 30, 30' of Fig. 2. Hence, current will flow only during half of each cycle of the alternating voltage.

Regulators of the finger type normally function in the following manner. When the voltage at the source S is of the proper value, all of the fingers 18, 20, 22 and 24 will be in electrical connection with their respective fixed contacts 10, 12, 14 and 16. In this condition, all of the resistors 2, 4, 6 and 8 are short-circuited and in effect are not in the circuit at all. If the source voltage should tend to rise, the voltage at the load will also tend to rise and since the coil 28 is connected across the load, an increased current will flow through it. It will therefore move the actuator 26 and will, for the circuit shown in Fig. 1, break electrical connection between the finger 18 and the fixed contact 10. When this has been accomplished, the resistor 2 will be in series in the circuit and hence a voltage loss will take place in it, thus reducing the voltage at the load. If the source voltage continues to rise, increased current in the coil 28 will cause the breaking of electrical connection between the finger 20 and the fixed contact 12 so that the resistors 2 and 4 will be in series in the circuit, thus further reducing the voltage at the load and so on.

It will be noted that with the fingers in their position shown in Fig. 1, in which all of them are in electrical connection with their respective fixed contacts, substantially all of the current passes through the contact pair 10, 18. If this pair be opened while current is flowing, substantially the entire current supply to the load must be broken between the contacts 10 and 18, and similarly with each of the other contact pairs as they are successively opened.

The coil 28 which controls the motion of the fingers 18, 20, 22 and 24 via the actuator 26 will, in the circuit of Fig. 1, be energized by the pulsating or intermittent current which the rectifier 34 permits to pass. It therefore will, if the voltage should increase, tend to move the actuator 26 in accordance with those surges of current. The actuator 26 and fingers 18, 20, 22 and 24 are naturally possessed of some inertia and consequently will not move instantaneously in response to the intermittent surges imparted to them by the coil 28 but, if the actuator 26 and the fingers 18, 20, 22 and 24 be of sufficiently small size, they nevertheless will tend to move in an intermittent manner. If then the phase of the current flowing through the coil 28 be properly related to the phase of the current passing from the source S through the contact pairs and be also properly related to the inertia of the actuator 26 and the fingers 18, 20, 22 and 24, so as to ensure that the initial separating movement of each of the contact pairs will take place, or at least commence, only during the period between pulses or surges of current, then opening of a given contact pair will not result in arcing and hence the life of the contacts and fingers will be greatly increased.

While it may accidentally happen, in a given installation, that the circuit constants are such that such synchronous opening of the contact pairs is accomplished, that situation is exceedingly rare and completely unpredictable. Moreover, as the circuit ages or as it is exposed to varying temperatures or the like, its circuit constants will probably vary sufficiently so that synchronous operation will no longer take place. I therefore provide the adjustable condenser 40 connected in shunt across the coil 28, this condenser having the effect of shifting the phase of the current in the coil 28. It is contemplated that, after a given installation has been accomplished, the condenser 40 will be manually adjusted until no sparking is observed at the contact pairs as the source voltage varies, this being indicative of the fact that the contact pairs are opening when no current is passing through them. For more accurate adjustment, a test oscilloscope may be used. Once this adjustment has been made, the regulator, even one of exceedingly small size, may carry line currents of very great magnitude, since the contacts are not affected thereby. Should the synchronous adjustment shift, either because of variations in temperature, deterioration of a circuit element or the like, the circuit may be easily readjusted for synchronous regulation merely by readjusting the condenser 40.

The desired phase relationship may also be achieved mechanically, by so varying the mechanical constants of the moving parts of the regulator, and in particular their weights, the rate of response of the dash pot, if one is employed, and the resistance to flexing of the fingers 18, 20, 22 and 24, as to give to the regulator an inertia of proper value. Additional elements may be added to the mechanical system for the same purpose.

The circuit of Fig. 3 discloses another method of utilizing the same regulator as illustrated in Fig. 1 but in a different circuit. In Fig. 3, a selenium cell rectifier bridge 44 is employed to give full wave rectification and a blocking condenser 46 is connected across the line before the filter comprising the shunt condenser 48 and the series inductance 50, the blocking condenser acting as the current interrupter A in the manner illustrated in Fig. 4. The alternating current voltage supplied by the source S is represented by the solid lines 52, 52′ and the broken line 54. The full wave rectified voltage applied across the blocking condenser 46 is represented by the lines 52, 52′ and the line 56. The voltage at the blocking condenser 46 is represented by the line 58 and the current surges or pulses passing through the circuit are represented by the lines 60, 62 and 64. The blocking condenser 46 is, after the circuit has been in operation, charged to a value illustrated by the beginning of the line 58, which value is for a considerable period of time greater than the instantaneous rectified voltage supplied by the source S. However, the voltage supplied by the source is increasing at the same time that the voltage of the blocking condenser 46 is decreasing because of its discharge and at the point 66 the rectified voltage 52, 56 or 52′ exceeds the blocking voltage of the condenser 46. It is at this point that the current starts to flow. The magnitude of the current increases until the magnitude of the rectified voltage reaches its maximum and then the current starts to decrease along with the voltage. During the period of current flow, the condenser 46 is recharged as indicated by the upward slope of the portions 58′ of the line 58. At the point 68, the rectified voltage 52, 56 or 52′ becomes less than the voltage 58 of the blocking condenser 46 and hence at this point the current falls off. The rectified voltage decreases at a greater rate than the condenser 46 discharges so it is not until the next point 66 is reached that any current again flows. Consequently, although the voltage from the source S is constantly alternating, current flows in the circuit only during discrete surge periods.

It will therefore be apparent that if the phase of the current in the actuator-moving electrically energized coil 28 be properly related to the other electrical and physical constants of the system, once again the contact pairs will be opened only during periods of no current flow and hence the current carrying capacity of the regulator can be increased. In Fig. 3, the coil 28 is connected across the load after the filter and hence the pulsations are somewhat smoothened before they directly affect the coil 28. Consequently, the phase shifting circuit, here illustrated as an adjustable resistor 70 in series with a fixed capacitance 72, is connected between the coil 28 and the line before the filter. By suitable adjustment of the resistor 70, the phase and amplitude of the pulsations in the coil 28 can be so controlled as to achieve the desired results.

The two illustrated circuits are merely exemplary of the myriad of applications to which my invention is susceptible. While both full and half wave rectifications have been here illustrated, it is not necessary that any rectification at all take place so long as the current is, in some way, periodically interrupted. The specific phase shifting circuits B here illustrated and the specific manners of connection are capable of an almost infinite number of variations all within the skill of those versed in the art. Many ways of phase shifting are known and the precise manner of phase shifting is not of significance insofar as this invention is concerned. Mechanical as well as electrical phase shifting may be employed to achieve the desired results.

The fact of significance is that the contact pairs are connected into a circuit the current in which is intermittent and the actuator for the contact pairs is moved in timed or synchronous relation to the intermittent pulses or surges of current, the synchronization being such that the actuator is moved to open the contacts only during those periods of time when no current is flowing in the circuit. While it is desirable that the closing of the contacts occur during the same periods of no current flow, this is not considered a necessary feature, since it has been noted that practically no damage occurs to the contacts when they close on large currents, whereas exceedingly great damage is done to the contacts, particularly in small regulators, when they open while carrying large currents.

By the invention herein described it is possible, by means of a simple adjustment of a circuit element which forms a part of a phase shifting circuit, to so synchronize the operation of the regulator with the intermittent surges or pulses of current carried thereby as to render even the smallest regulator capable of carrying exceedingly large currents over extended periods of time without malfunctioning. This characteristic is of exceedingly great importance, particularly since the space and weight requirements of aircraft-carried and military equipment are very rigorous, making small size regulators exceedingly useful. Moreover, by means of this invention, exceedingly small finger type regulators are enabled to do the work of previously used much larger and more massive regulators the cost of which are from ten to one hundred times that of the small regulator.

It will be apparent that many detailed changes may be made in my invention within the spirit thereof as defined in the appended claims.

I claim:

1. A regulation system comprising a current source, a current interrupter, and a load connected in sequence, a plurality of regulatory circuit components in said circuit, a plurality of contacts electrically connected to said regulatory components and successively movable between open and closed positions so as to successively connect and disconnect said components in said circuit, an actuator operatively connected to said contacts and positionable over a range of movement so as to open and close said contacts, an electrically energized element connected in said circuit after said interrupter and active on said actuator to control its position and thus determine which of said contacts are opened or closed, and phase shifting components in said circuit active on said element for controlling the phase of the current in said element relative to the phase of current flowing through said contacts so that said contacts are opened only during the periods when said circuit is interrupted.

2. A regulation system comprising an alternating current source, a current interrupter, and a load connected in sequence, a plurality of regulatory circuit components in said circuit, a plurality of contacts electrically connected to said regulatory components and successively movable between open and closed positions so as to successively connect and disconnect said components in said circuit, an actuator operatively connected to said contacts and positionable over a range of movement so as to open and close said contacts, an electrically energized element connected across said load after said interrupter and active on said actuator to control its position and thus determine which of said contacts are opened or closed, and phase shifting components in said circuit active on said element for controlling the phase of current in said element relative to the phase of current flowing through said contacts so that said contacts are opened only during the periods when said circuit is interrupted.

3. A regulation system comprising an alternating current source, a rectification circuit capable of producing pulsating direct current, and a load connected in sequence, a plurality of regulatory circuit components in said circuit, a plurality of contacts electrically connected to said regulatory components and successively movable between open and closed positions so as to successively connect and disconnect said components in said circuit, an actuator operatively connected to said contacts and positionable over a range of movement so as to open and close said contacts, an electrically energized element connected across said load after said rectification circuit and active on said actuator to control its position and thus determine which of said contacts are opened or closed, and phase shifting components in said circuit active on said element for controlling the phase of current in said element relative to the phase of current flowing through said contacts so that said contacts are opened only during the periods between the pulses of direct current.

4. A regulation system comprising an alternating current source, a half wave rectifier and a load connected in sequence, a plurality of regulatory circuit components in said circuit before said rectifier, a plurality of contacts electrically connected to said regulatory components and successively movable between open and closed positions so as to successively connect and disconnect said components in said circuit, an actuator operatively connected to said contacts and positionable over a range of movement so as to open and close said contacts, an electrically energized element connected across said load after said rectifier and active on said actuator to control its position and thus determine which of said contacts are opened or closed, and phase shifting components in said circuit active on said element for controlling the phase of the current in said element relative to the phase of current flowing through said contacts so that said contacts are opened only during the periods between the surges of direct current.

5. A regulation system comprising an alternating current source, a full wave rectifier and a load connected in sequence, a condenser connected across said load and effective to periodically interrupt the current supplied by said source, a plurality of regulatory circuit components in said circuit before said rectifier, a plurality of contacts electrically connected to said regulatory components and successively movable between open and closed positions so as to successively connect and disconnect said components in said circuit, an actuator operatively connected to said contacts and positionable over a range of movement so as to open and close said contacts, an electrically energized element connected across said load after said rectifier and active on said actuator to control its position and thus determine which of said contacts are opened or closed, and phase shifting components in said circuit active on said element for controlling the phase of the current in said element relative to the phase of current flowing through said contacts so that said contacts are opened only during the periods when the current from said source is interrupted.

6. A regulation system comprising an alternating current source, a half wave rectifier and a load connected in sequence, a plurality of resistors connected in series in the alternating current portion of the circuit, a plurality of contacts electrically connected to said resistors, successively movable between open and closed positions, and active to successively short-circuit said resistors and thus remove them from said circuit, an actuator operatively connected to said contacts and positionable over a range of movement so as to open and close said contacts, a coil connected across said load in the rectified portion of the circuit and active on said actuator to control its position and thus determine which of said contacts are opened or closed, and a capacitance connected in shunt across said coil, the value of said capacitance being so chosen as to control the phase of current in said coil relative to the phase of current flowing through said contacts so that said actuator opens said contacts only during the periods between the surges of direct current.

7. A regulation system comprising an alternating current source, a full wave rectifier and a load connected in sequence, a blocking condenser connected across said load and effective to periodically interrupt the current supplied by

said source, a plurality of resistors connected in series in the alternating current portion of the circuit, a plurality of contacts electrically connected to said resistors, successively movable between open and closed positions, and active to successively short-circuit said resistors and thus remove them from said circuit, an actuator operatively connected to said contacts and positionable over a range of movement so as to open and close said contacts, a coil connected across said load and active on said actuator to control its position and thus determine which of said contacts are opened or closed, and a phase shifting circuit connected between one end of said coil and a portion of the direct current part of said circuit having pulsating current flowing therethrough, the value of the circuit components of said phase shifting circuit being so chosen as to control the phase of the current in said coil relative to the phase of current flowing through said contacts so that said actuator opens said contacts only during the periods when the current from said source is interrupted.

8. A regulation system comprising a current source, a current interrupter, and a load connected in sequence, a plurality of regulatory circuit components in said circuit before said interrupter, a plurality of contacts electrically connected to said regulatory components and successively movable between open and closed positions so as to successively connect and disconnect said components in said circuit, an actuator operatively connected to said contacts and positionable over a range of movement so as to open and close said contacts, an electrically energized element connected in said circuit after said interrupter and active on said actuator to control its position and thus determine which of said contacts are opened or closed, and means for varying the inertia of the actuator-contacts combination so that said contacts are opened only during the periods when said circuit is interrupted.

9. The regulation system comprising a circuit, means in said circuit for periodically interrupting the current therein, regulating means in said circuit comprising regulatory circuit components and circuit-breaking elements operatively connected thereto so as to connect or disconnect said components in said circuit, operating means operatively connected to said circuit-breaking elements to open or close the latter, and means to actuate said operating means in synchronism with the periodical interruption of current in said circuit so as to open said elements only when said circuit is interrupted.

10. The regulation system comprising a circuit, means for supplying said circuit with intermittent current, regulating means in said circuit comprising regulatory circuit components and circuit-breaking elements operatively connected thereto so as to connect or disconnect said components in said circuit, operating means operatively connected to said circuit-breaking elements to open or close the latter, and means to actuate said operating means in synchronism with the current in said circuit so as to open said elements only when said current is flowing.

11. The regulation system comprising a circuit, means for supplying said circuit with rectified pulsating direct current, regulating means in said circuit comprising regulatory circuit components and circuit-breaking elements operatively connected thereto so as to connect or disconnect said components in said circuit, operating means operatively connected to said circuit-breaking elements to open or close the latter, and means to actuate said operating means in synchronism with the current in said circuit so as to open said elements only during the periods between said direct current pulses.

12. A regulation system comprising a circuit, means for supplying said circuit with half-wave rectified direct current, regulating means in said circuit comprising regulatory circuit components and circuit-breaking elements operatively connected thereto so as to connect or disconnect said components in said circuit, operating means operatively connected to said circuit-breaking elements to open or close the latter, and means to actuate said operating means in synchronism with the current in said circuit so as to open said elements only during the periods between said direct current pulses.

13. A regulation system comprising a circuit, means for supplying said circuit with pulsating full wave rectified current, regulating means in said circuit comprising regulatory circuit components and circuit-breaking elements operatively connected thereto so as to connect or disconnect said components in said circuit, operating means operatively connected to said circuit-breaking elements to open or close the latter, and means to actuate said operating means in synchronism with the current in said circuit so as to open said elements only during the periods between said direct current pulses.

14. In the regulation system of claim 9, electrical connections between said circuit and said actuating means so as to energize the latter from the former, said connections including means to control the phase of the energizing current supplied to said actuating means relative to the phase of the interrupted current in said circuit.

15. In the regulation system of claim 10, electrical connections between said circuit and said actuating means so as to energize the latter from the former, said connections including means to control the phase of the energizing current supplied to said actuating means relative to the phase of the intermediate current in said circuit.

16. In the regulation system of claim 11, electrical connections between said circuit and said actuating means so as to energize the latter from the former, said connections including means to control the phase of the energizing current supplied to said actuating means relative to the phase of the pulsating current in said circuit.

17. In the regulation system of claim 12, electrical connections between said circuit and said actuating means so as to energize the latter from the former, said connections including means to control the phase of the energizing current supplied to said actuating means relative to the phase of the pulsating current in said circuit.

18. In the regulation system of claim 13, electrical connections between said circuit and said actuating means so as to energize the latter from the former, said connections including means to control the phase of the energizing current supplied to said actuating means relative to the phase of the pulsating current in said circuit.

19. In the regulation system of claim 9, electrical connections between said circuit and said actuating means so as to energize the latter from the former, and means for controlling the inertia of the mechanical moving parts of the system including said circuit-breaking elements.

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