

April 22, 1952

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2,594,022

MAGNETIC AMPLIFIER RELAY CIRCUITS

Filed Aug. 5, 1950

2 SHEETS—SHEET 1

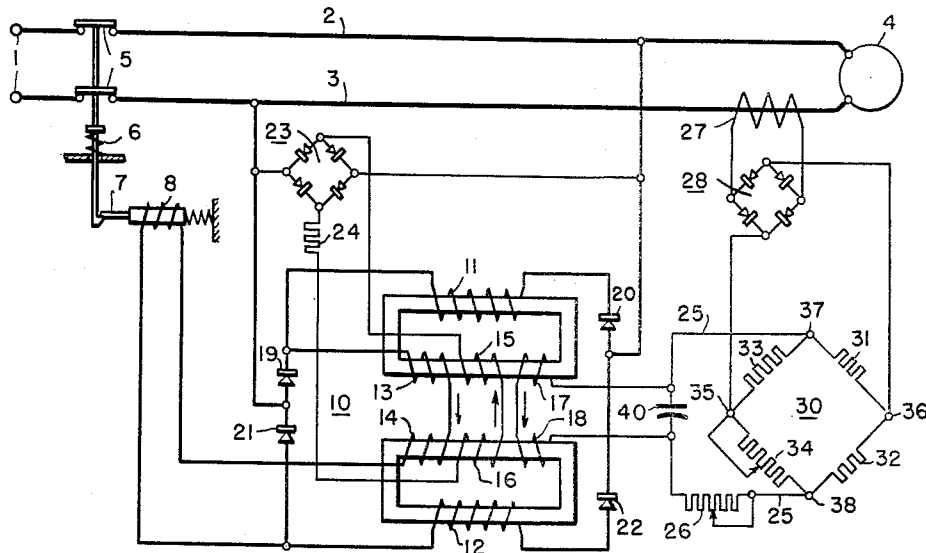


Fig. 1.

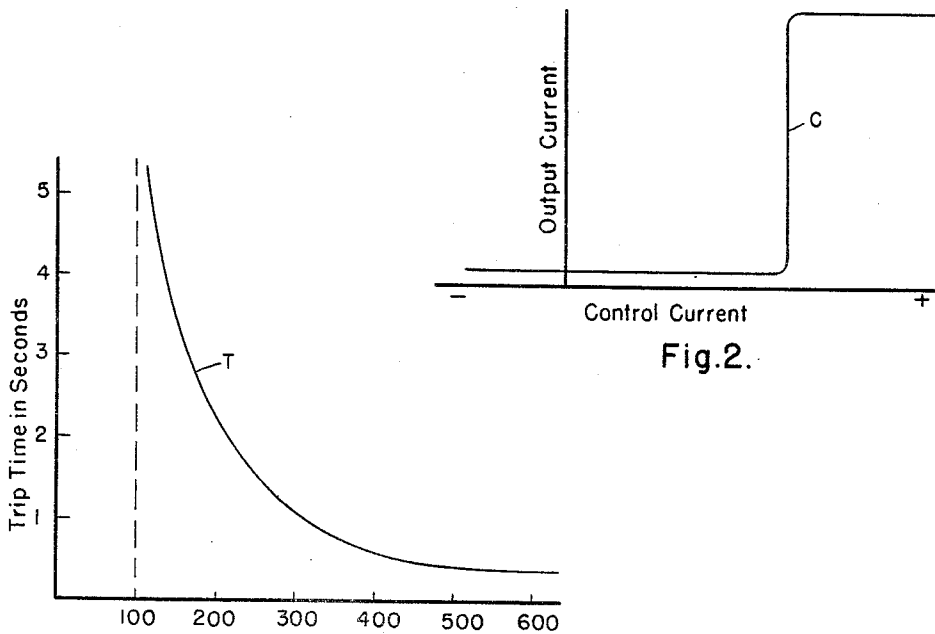


Fig. 2.

Fig. 3.

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2 SHEETS—SHEET 2

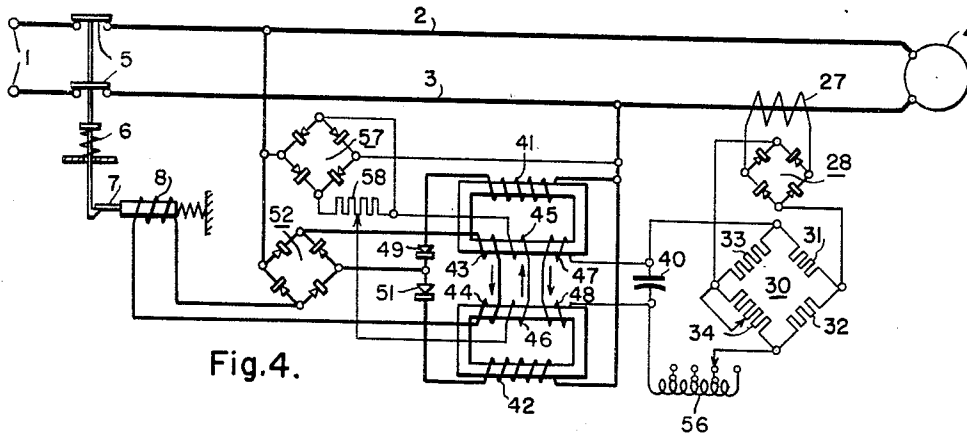


Fig. 4.

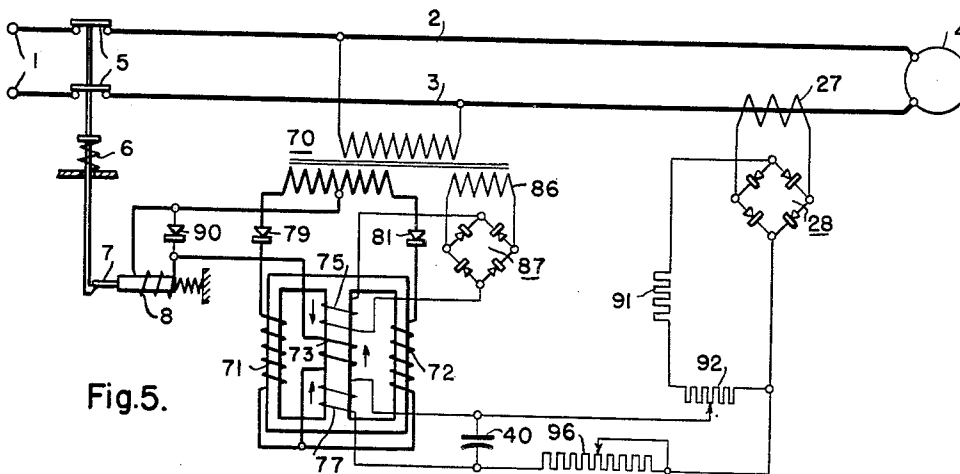


Fig. 5.

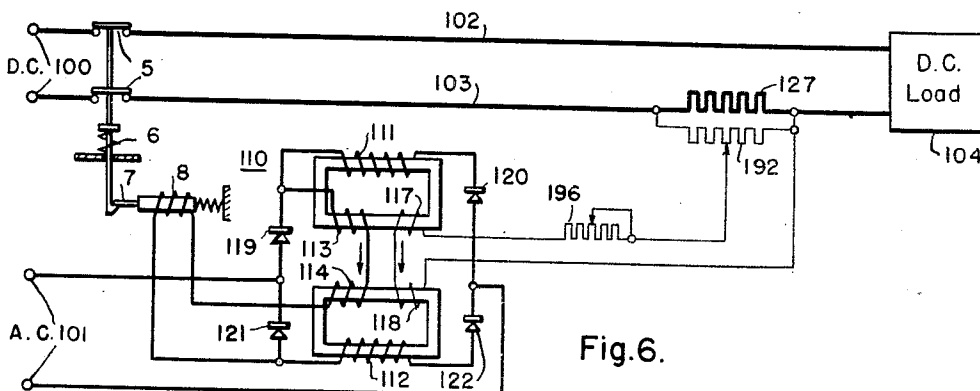


Fig. 6.

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MAGNETIC AMPLIFIER RELAY CIRCUITS

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Application August 5, 1950, Serial No. 177,867

11 Claims. (Cl. 175—294)

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My invention relates to relay apparatus which trigger a load or relay circuit by abruptly changing a circuit condition when a controlling condition passes through a predetermined critical value.

In one of its more specific aspects, my invention concerns overload relays and other relay apparatus of an inverse time delay characteristic which actuate a contact device a period of time after the controlling condition has passed through the critical value, the delay period being longer at small departures of the triggering control condition from the critical value than at larger departures so that the response of an overload relay, for instance, is more delayed at small overload currents than at higher currents.

It is an object of my invention to devise relay apparatus of the above-mentioned kind that affords a wide-range selection of the tripping conditions as well as an inverse time delay performance of high accuracy and stability while eliminating the need for producing or controlling the time delay by movable armatures or other mechanisms customary in known adjustable time delay relays.

Another object of my invention is to provide relay apparatus suitable for time delayed operation of any standard solenoid or other electromagnetic contact relay.

Still another object of my invention, in conjunction with those mentioned, is the provision of a readily and accurately adjustable timing relay of sturdy design and long useful life virtually without maintenance requirements.

Another object of my invention is the provision of a condition-responsive, adjustable time delay device of only static components, which is capable by adjustable and delayed trigger performance of directly controlling an electromagnetic contactor or circuit breaker of a power circuit without requiring the intermediate electromagnetic relay heretofore customary for such purposes.

I secure the desired objects of my invention with the aid of an overexcited magnetic amplifier in combination with condition-responsive saturation control and circuit means as set forth in the annexed claims and the following description in conjunction with the drawings, in which:

Figure 1 shows the circuit diagram of relay apparatus according to the invention for the protection of a load from excessive overloads;

Fig. 2 shows the input-output current characteristic or transfer curve of the magnetic amplifier appertaining to the apparatus according to Fig. 1; and

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Fig. 3 shows schematically the timing characteristic of the same apparatus, and

Figs. 4, 5 and 6 are diagrammatic showings of three modifications of my invention having performance characteristics similar to the embodiment illustrated in Fig. 1.

According to Fig. 1, the load 4 is shown connected to the alternating current supply terminals 1 by leads 2 and 3 through the main contacts 5 of a circuit breaker. The contacts 5 are biased by a spring 6 to the circuit opening position but are secured in the circuit closing position by means of a latch 7 controllable by a magnet coil 8.

The control circuit of coil 8 is energized from a magnetic amplifier, denoted as a whole by 10, which has two saturable reactors with respective main windings 11 and 12. The saturable magnet cores of these reactors are each equipped with three direct-current saturation coils denoted by 13 through 18. The reactor main windings 11 and 12 are connected with rectifiers 19 through 22 in a bridge circuit which is energized from leads 2 and 3 and provides its output circuit with rectified current to be applied to the contactor control coil 8. The saturation coils 13 and 14 are series-connected in the output circuit and poled to magnetize each reactor core in the direction of the self-saturation due to the rectified current that traverses the main winding 11 or 12 of the reactor through the series-connected rectifiers. In this manner the reactors are magnetically overexcited, that is, they have more than 100% feed-back excitation. The coils 15 and 16 receive normally constant excitation from a rectifier 23 through a calibrating resistor 24, in order to provide the reactors with a desired bias. Coils 17 and 18 represent the amplifier control coils proper and are energized in dependence upon the load current flowing through the leads 2 and 3. To this end, the circuit 25 of coils 17 and 18, which represents the direct-current input circuit of the amplifier, is connected in series with an adjusting rheostat 26 to a current transformer 27 through a rectifier 28. Interposed between rectifiers 28 and the amplifier input circuit is a resistance bridge 30 composed of four resistors 31 through 34. The diagonal points of the bridge are denoted by 35, 36, 37 and 38. Resistors 31 and 32 have each a relatively low resistance value which may be the same for both resistors. Resistors 33 and 34 have a relatively high resistance value. The resistance relation, for instance, is such that if resistors 31 and 32 each have a value

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of 10 ohms, the resistors 33 and 34 each have a value of about 1,000 or more ohms. Resistor 34 is adjustable, thus permitting any desired degree of bridge unbalance so that a corresponding proportion of the current responsive voltage from rectifier 28 can be imposed on the amplifier input circuit of control coils 17 and 18.

The resistor arrangement of bridge 30 is such that the low ohmic resistors 31 and 32 lie in series across the amplifier input circuit. Consequently, the input circuit faces always a low total bridge resistance whose value is virtually not affected by changes in adjustment of resistor 34. The rheostat 26 has a total resistance in the order of magnitude of the high-resistant bridge resistors, for instance equal to 1,000 ohms. A capacitor 40 is provided across coils 17 and 18 as a shunt path for harmonics generated in the control windings.

A typical transfer curve of an overexcited magnetic amplifier of the type shown in Fig. 1 is schematically represented by the curve C in the coordinate diagram of Fig. 2. The abscissa in Fig. 2 represents the control current applied across the control windings 17 and 18, while the ordinate represents the rectified output current passing through the contactor control coil 8 and the feed-back windings 13 and 14. The effect of the bias imposed on the amplifier by means of the constant excitation coils 15 and 16 is to shift the transfer curve C toward higher positive values of control current so that the trip current of the amplifier can be adjusted to a desired value. Due to the overexcitation of the amplifier, the output current in the contactor coil 8 rises from a negligible amount to its full value with no intermediate stable values as soon as the critical trip current is exceeded. Consequently, the contactor or relay controlled by the amplifier is forced to operate with positive action, or substantially a trigger action.

The typical time characteristic of the amplifier operation is represented in the coordinate diagram of Fig. 3 by the curve T. The abscissa denotes the per cent of trip current, while the ordinate indicates the time in seconds elapsing from the currents of the trip current to the actuation of the controlled relay or contactor. At values of load responsive control current just below 100% of the adjusted trip value, no relay action occurs. When the overload exceeds the adjusted trip value, the relay operation follows with more delay at lower overload values than at higher values, thus securing the desired reverse time characteristic. For instance, in the example represented by Fig. 3, at a particular value of control circuit resistance, about 5 seconds will elapse when the apparatus is tripped by overload current slightly higher than the trip value, while about 2 seconds will elapse when the overload current is 200% of the critical value.

The current applied to the control windings 17 and 18 of the magnetic amplifier is a function of the resistance adjusted at rheostat 26 and of the resistance setting of the bridge circuit 30. The resistance values of the bridge circuit can be chosen so that the amplifier input current through control windings 17 and 18 can be controlled over a wide range while the resistance of the control circuit from the control coils 17 and 18 is approximately constant. The time delay characteristic of the device can be shifted toward smaller or higher trip current values by adjustment of the rheostat 34, while adjusting the rheostat 26 jointly with rheostat 34 will shift

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the characteristic up and down, thus permitting a selection of the period of time delay.

Apparatus according to the invention permits a direct control of the contactor or circuit breaker of a power circuit without need for an intermediate relay in the contactor or breaker control circuit. It will be understood, however, that if desired, such an intermediate relay may be provided.

For increasing the range of adjustable delay periods, the rheostat 26 may be replaced by an inductive device, such as the tapped inductance coil shown in Fig. 4. Fig. 4 also illustrates a different design of the magnetic amplifying devices.

According to Fig. 4, alternating current supplied from terminals 1 through leads 2, 3 to a load 4 is controlled by the contacts 5 of a contactor whose control coil 8 is energized from a magnetic amplifying device designed as follows.

The amplifier has two saturable reactors with respective main windings 41 and 42 connected in parallel relation to each other and in series with a full-wave rectifier 52 across the leads 2 and 3. Each reactor has a feed-back coil 43 or 44, a bias coil 45 or 46, and a control coil 47 or 48. Series-connected with the reactor main windings 41 and 42 are respective half-wave rectifiers 49 and 51 of mutually opposed poling. The input terminals of rectifier 52 are supplied with alternating current through the alternately conductive rectifier-reactor circuits, and the output voltage of rectifier 52 is applied to the contactor control coil 8 in series with the feed-back coils 43 and 44. The feed-back excitation of coils 43 and 44 is cumulative to the self-saturation due to the presence of rectifiers 49 and 51. Consequently, the two reactors of the amplifier are overexcited, and have a performance typified by Figs. 2 and 3.

Time excitation for coils 45 and 46 is supplied from a rectifier 57 and a rheostat 58 which permits selecting a desired bias. The control coils 47 and 48 are energized from a current transformer 27, rectifier 28, and a resistance bridge 30 in the same manner as explained above with reference to Fig. 1, except that, as mentioned, the tapped inductance coil 56 is provided in the amplifier control circuit for securing an increased range of timing adjustment.

In the embodiment according to Fig. 5, the magnetic amplifier for controlling the control coil 8 of a contactor in the circuit 1, 2, 3 of an alternating-current load 4 is designed in the following manner.

A transformer 70 energized from leads 2 and 3 has a midtapped secondary, which forms part of a full-wave rectifier circuit. The ends of the secondary are connected to the respective main windings 71 and 72 of a saturable reactor in series with respective half-wave rectifiers 79 and 81. The reactor is shown to have a three-legged saturable coil whose center leg is provided with a feed-back coil 73, a bias coil 75 and a control coil 77. The feed-back coil 73 is series-connected with the reactor control coil 8 between the midtap of the transformer secondary and a circuit point between the reactor main windings 71 and 72. Feed-back coil 73 is poled so that it provides magnetization cumulative to that due to the rectified current flowing through the main windings 71 and 72. Consequently, this amplifier is also overexcited to provide operating characteristics of the type shown in Figs. 2 and 3. The bias coil receives constant excitation from another secondary 86 of transformer 70 through a recti-

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fier 87. A commutating rectifier 90 is connected across coil 8 and poled to short circuit the self-induced current of the coil.

The load responsive control circuit for coil 77 is energized from a current transformer 27 through a rectifier 28 in the same manner as in the preceding embodiments. However, the resistance circuit interposed between rectifier 28 and control coil 77 has a simplified design which is satisfactory for many applications connected across the output terminals of rectifier 28 and a resistor 91 for a potentiometric rheostat 92. The control coil 77 is connected across a selectively tapped-off portion of rheostat 92 through an adjustable series rheostat 96. The total resistance values of resistors 91 and 92 are relatively small, for instance, 100 ohms in comparison with the resistance value of rheostat 96 in the order of 1,000 ohms. Consequently, a change in the adjustments of rheostats 92 and 96 does not appreciably vary the effective total resistance seen from the control coil 77. Consequently, sufficiently stable operating conditions will prevail if the setting of rheostat 96 is changed, in order to select the trip current and timing period within the available range. The embodiment of Fig. 6 exemplifies the application of the invention for overload protection of a direct-current load. The direct current is supplied at terminals 100 through leads 102, 103 to the load 104, under control by the contacts 5 of a contactor or circuit breaker whose control coil is denoted by 8. Series-connected with the load 104 is a resistor 127 to provide a voltage drop proportional to the load current.

Coil 8 is controlled by a magnetic amplifier 110 which is designed and functions in the same manner as the amplifier 10 shown in Fig. 1. The individual circuit elements 111 through 122 of amplifier 110 are similar to respective elements 11 through 22 of the amplifier shown in Fig. 1. The amplifier 110 is normally equipped with bias windings corresponding to the windings 15 and 16 in Fig. 1, but these windings are not illustrated in Fig. 6. Amplifier 110 is energized from alternating-current terminals 101. Its feed-back saturation windings 113 and 114 are series-connected with coil 8 in the amplifier output circuit. The current responsive control windings 117 and 118 are series-connected with an adjustable rheostat 196 across a tapped-off portion of a rheostat 192 which is parallel connected to the above-mentioned series resistor 127. As regards arrangement, resistance, rating and function, resistors 192 and 196 are similar to resistors 92 and 96, respectively, of the embodiment shown in Fig. 5.

It will be apparent to those skilled in the art upon a study of this disclosure that relay apparatus according to the invention can be modified in various respects and may be embodied in designs and circuits other than those specifically shown and illustrated, without departing from the objects and essence of the invention and within the scope of the claims annexed hereto.

I claim as my invention:

1. Load responsive relay apparatus, comprising an alternating-current supply circuit, contactor means having normally closed contacts in said supply circuit and having a control coil for controlling said contacts to open, a magnetic amplifier having an output circuit connected to said control coil and having saturable reactor means including main coil means and valve means con-

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nected in series with each other to said supply circuit to be energized therefrom, said reactor means having saturation controlling direct-current coil means having a part interconnected with said output circuit and poled to provide feed-back saturation cumulative to saturation due to current flowing through said main coil means, and current-responsive voltage supply means interconnected with said supply circuit through another part of said direct-current coil means for triggering said amplifier when the current of said supply circuit exceeds a given value.

2. Load responsive relay apparatus, comprising an alternating-current supply circuit, contactor means having normal closed contacts in said supply circuit and having a control coil for controlling said contacts to open, a magnetic amplifier having an output circuit connected to said control coil and including a saturable reactor having a main coil and a valve connected in series with each other to said supply circuit to be energized therefrom, said reactor having direct-current saturation coils, one of said saturation coils being connected in series with said output circuit and poled to provide feed-back saturation cumulative to saturation due to flow of current through said valve and main coil, current-responsive direct-current voltage supply means connected with said supply circuit and having an output voltage dependent upon the current of said supply circuit, another one of said saturation coils being connected to said direct-current voltage supply means to trigger said amplifier when said current exceeds a given value.

3. Load responsive relay apparatus, comprising an alternating-current supply circuit, contactor means having normally closed contacts in said supply circuit and having a control coil for controlling said contacts to open, a magnetic amplifier having an output circuit connected to said control coil and including a saturable reactor having a main coil and a valve connected in series with each other to said supply circuit to be energized therefrom, said reactor having direct-current saturation coils, one of said saturation coils being connected in series with said output circuit and poled to provide feed-back saturation cumulative to saturation due to said main coil, current-responsive direct-current voltage supply means connected with said supply circuit, adjustable resistance means connected with said direct-current voltage supply means to provide a voltage varying in accordance with the current in said supply circuit, a control circuit having a resistance higher than that of said resistance means and connecting another one of said saturation coils across said resistance means for triggering said amplifier when the current in said supply circuit exceeds a given value determined by the adjustment of said resistance means.

4. Load responsive relay apparatus, comprising an alternating-current supply circuit, contactor means having normally closed contacts in said supply circuit and having a control coil for controlling said contacts to open, a magnetic amplifier having an output circuit connected to said control coil and including a saturable reactor having a main coil and a valve connected in series with each other to said supply circuit to be energized therefrom, said reactor having direct-current saturation coils, one of said saturation coils being interconnected with said output circuit and poled to provide feed-back saturation cumulative to saturation due to said main

coil, current-responsive direct-current voltage supply means connected with said supply circuit, a control circuit connected with another one of said saturation control coils to trigger said amplifier when said control circuit is sufficiently excited, a resistance bridge having four loop-connected resistors and having four diagonal points between said resistors, said voltage supply means being connected across two mutually opposite ones of said points, said control circuit being connected across said other two points, two of said four bridge resistors having a resistance lower than that of the other two resistors and lower than the resistance of said control circuit, said two low-resistance resistors being series-connected with each other across said other two points, at least one of said resistors being adjustable for adjusting the unbalance of said bridge in accordance with a desired trigger value of current in said supply circuit.

5. Load responsive relay apparatus, comprising an alternating-current supply circuit, contactor means having normally closed contacts in said supply circuit and having a control coil for controlling said contacts to open, a magnetic amplifier having an output circuit connected with said control coil and including a saturable reactor having a main coil and a valve connected in series with each other to said supply circuit to be energized therefrom, said reactor having direct-current saturation coils, one of said saturation coils being connected with said output circuit and poled to provide feed-back saturation cumulative to saturation due to said main coil, current-responsive direct-current voltage supply means connected with said supply circuit, a control circuit connected with another one of said saturation control coils to trigger said amplifier when said control circuit is sufficiently excited, an adjustable series resistor connected in said control circuit, a resistance bridge having four loop-connected resistors and having four diagonal points between said resistors, said voltage supply means being connected across two mutually opposite ones of said points, said control circuit being connected across said other two points, two of said four bridge resistors having a resistance lower than that of the other two bridge resistors and lower than the resistance of said series resistor, said two low-resistance bridge resistors being series-connected across said other two points, and one of said other two bridge resistors being adjustable for adjusting the unbalance of said bridge in accordance with a desired trigger value of current in said supply circuit.

6. A magnetic amplifier circuit, comprising alternating-current supply leads, a device to be controlled, a magnetic amplifier including a saturable reactor, and a main coil and valve means connected with each other between said leads and said device, said reactor having a direct-current saturation control coil, condition-responsive voltage supply means, a control circuit connected to said control coil and having an adjustable series resistor, a resistance bridge having four loop-connected resistors and having four diagonal points between said resistors, said voltage supply means being connected across two mutually opposite ones of said points, said control circuit being connected across said other two points, two of said four bridge resistors having a resistance lower than that of the other two bridge resistors and lower than the resistance of said series resistor, said two low-resistance bridge re-

sistors being series-connected across said other two points, and one of said other two bridge resistors being adjustable for adjusting the unbalance of said bridge in accordance with a desired trigger value of the voltage of said supply means.

7. A magnetic amplifier circuit, comprising alternating-current supply leads, a device to be controlled, a magnetic amplifier including a saturable reactor having a main coil and valve connected in series with each other across said leads and having a direct-current output circuit connected to said device, said reactor having a direct-current feed-back coil and a direct-current saturation control coil, said feed-back coil being connected in circuit with said output circuit and poled to provide saturation cumulative to that due to said main coil, condition-responsive voltage supply means, a control circuit connected to said control coil and having an adjustable series resistor, a resistance bridge having four loop-connected resistors and having four diagonal points between said resistors, said voltage supply means being connected across two mutually opposite ones of said points, said control circuit being connected across said other two points, two of said four bridge resistors having a resistance lower than that of the other two bridge resistors and lower than the resistance of said series resistor, said two low-resistance bridge resistors being series-connected across said other two points, and one of said other two bridge resistors being adjustable for adjusting the unbalance of said bridge in accordance with a desired trigger value of the voltage of said supply means.

8. In a system of control, in combination, alternating current supply terminals, and magnetic amplifying means including, a reactor core, a main winding on said core supplied with current from said terminals, a half-wave rectifier in the circuit of the main winding for causing the main winding to be energized by pulses of current in the same direction during alternate half cycles of the alternating current, further rectifying means and a direct-current positive feed-back coil on the core and interconnected with said further rectifying means and the main coil to provide a cumulative magnetizing effect in the core proportional to the current in the main coil, a direct-current bias coil on the core acting in opposition to the main coil, a direct-current control coil, responsive to some control function, for controlling the output current of the magnetic amplifying means, and an output circuit connected in series with the positive feed-back coil.

9. In a system of control, in combination, alternating current supply terminals, and magnetic amplifying means including, a reactor core, a main winding on said core supplied with current from said terminals, a half-wave rectifier in the circuit of the main winding for causing the main winding to be energized by pulses of current in the same direction during alternate half cycles of the alternating current, further rectifying means and a direct-current positive feed-back coil on the core and interconnected with said further rectifying means and the main coil to provide a cumulative magnetizing effect in the core proportional to the current in the main coil, a direct-current bias coil on the core acting in opposition to the main coil, means for adjusting the magnetizing effect of the bias coil, a direct-current control coil, responsive to some control function, for controlling the output current of the magnetic amplifying means, and an out-

put circuit connected in series with the positive feed-back coil.

10. In a system of control for controlling the output of a magnetic amplifier, in combination, alternating current supply terminals, a magnetic amplifier including magnetic circuit means, a main coil for energizing the magnetic circuit means, a half-wave rectifier in series with the main coil, both the main coil and the rectifying means being connected to said terminals to thus effect energization of said main coil with pulses of unidirectional current during alternate half-cycles of alternating current supplied to said main coil from said terminals, an output circuit interconnected with said main coil, said output circuit including a load unit and a positive feed-back coil and rectifying means for cumulatively energizing said magnetic circuit means with substantially continuous direct current proportional to the current supplied to the load unit, a bias coil energized with direct current of a selected value and wound on the magnetic circuit means to act in a sense opposite to the magnetizing effect of the feed-back coil to thus shift the saturation point with reference to the output current, and a control coil energized with direct current as a function of an electric circuit the operation of which is to be controlled, wound on the magnetic circuit means to produce an effect in the same sense as the effect produced by the feed-back coil.

11. In a system of control for controlling the output of a magnetic amplifier, in combination, alternating current supply terminals, a magnetic amplifier including magnetic circuit means having a very steep saturation curve, a main coil for energizing the magnetic circuit means, a half-wave rectifier in series with the main coil, both

the main coil and the rectifying means being connected to said terminals to thus effect energization of said main coil with pulses of unidirectional current during alternate half-cycles of alternating current supplied to said main coil from said terminals, an output circuit interconnected with said main coil, said output circuit including a load unit and a positive feed-back coil and rectifying means for cumulatively energizing said magnetic circuit means with substantially continuous direct current proportional to the current supplied to the load unit, a bias coil energized with direct current of a selected value and wound on the magnetic circuit means to act in a sense opposite to the magnetizing effect of the feed-back coil to thus shift the steep portion of the saturation curve with reference to the output current, and a control coil energized with direct current as a function of an electric circuit the operation of which is to be controlled, wound on the magnetic circuit means to produce an effect in the same sense as the effect produced by the feed-back coil, whereby the output current will rise sharply when the current in the control coil rises above a selected value.

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