April 23, 1963 H. G. KEOGH, JR 3,087,066

CONTROL CIRCUIT

Filed Oct. 24, 1960

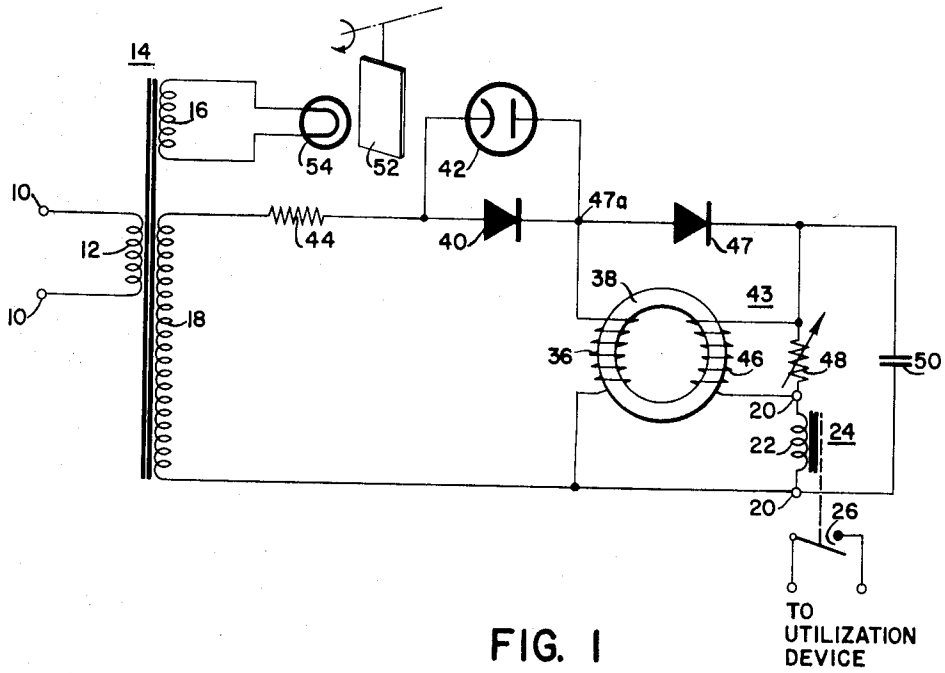


FIG. 1

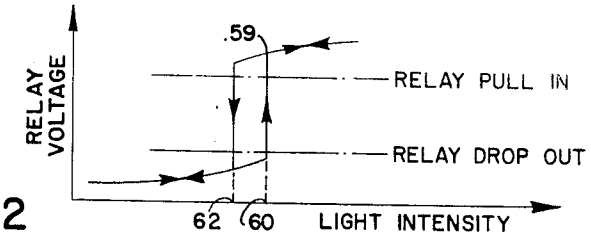


FIG. 2

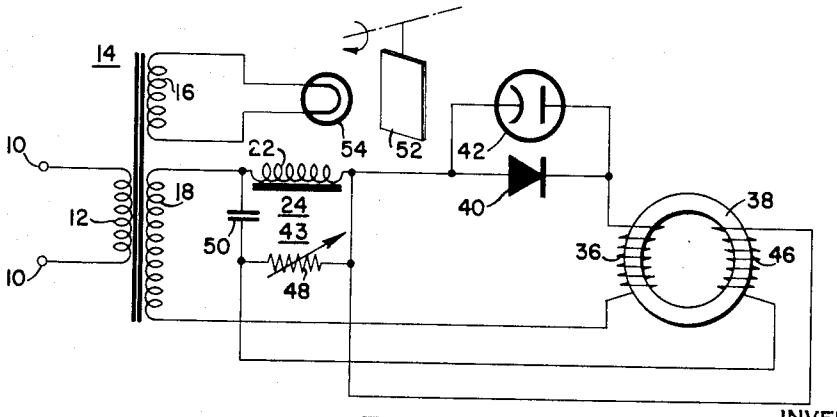


FIG. 3

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CONTROL CIRCUIT

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This invention relates to a radiation responsive control circuit and, more particularly, in a preferred embodiment of this invention, to a self-saturating magnetic amplifier controlled in response to the intensity of radiated light.

Many control systems have been developed in the past using D'Arsonval microampers movements in conjunction with an optical feedback system incorporating photosensitive elements.

These prior art systems include contactless type of indicating controls utilizing a vane attached to the pointer of a microampere movement. This vane passes in the path of a light beam to block the light from a detecting photocell. The action of the photocell actuates a sensitive relay which in turn operates through a secondary control element such as a power relay to control; for example, the heat applied to a furnace.

Many control circuits have been developed which are capable of detecting the vane movement, or position. One such circuit is described in United States Patent No. 2,892,092, issued June 23, 1959, to Joseph L. Behr. The Behr patent describes a light-responsive self-saturating magnetic amplifier wherein the light-sensitive element, instead of being in circuit with a separate control winding, is connected in a current path which shunts the saturating rectifier and supplies the reactor power winding with desaturating current. Also in the Behr circuit, the resistance of the light-sensitive element is employed to control the desaturating current and consequently the output of the amplifier.

Such control systems find use in various industrial processes wherein physical conditions, such as temperature, percentage of hydrogen ion concentration, voltage, or current have to be maintained constant or limited to specific values. These prior art circuits have many advantages; but unfortunately, also have certain disadvantages. Because of the nature of the process involved, any automatic control circuit used, desirably should perform with the highest degree of reliability, sensitivity and stability over relatively long periods of time.

Among the disadvantages of the prior art circuits are the unwanted relay chatter due to the relay contacts failing to achieve a firm make or break contact. Also, the speed of response of these prior circuits was often so fast that it tended to cause unwanted relay action due to vibration of the pointer and vane of the meter movement. Also, in order to achieve a stable operation, there was a certain amount of dependency upon the line voltage. To prevent this, some of these prior circuits required relatively expensive relays having a small pull-in to drop-out ratio as well as relatively high quality magnetic cores. Both of these requirements often led to costlier units than is desired.

It is, therefore, an object of this invention to overcome many of the disadvantages of the prior art control circuits.

Another object of this invention is to accurately control an output relay in response to light.

In accordance with the present invention, an improved light-responsive, self-saturating magnetic amplifier has a light-sensitive element connected in a current path that shunts the saturating rectifier and supplies the main reactor winding with desaturating current. The light-responsive resistance of the light-sensitive element is employed to control the desaturating current and hence, the output of the amplifier. The output of the amplifier is the voltage developed across the main reactor winding, and hence, approaches zero when the reactor is saturated; and, conversely, approaches line voltage when the reactor is desaturated (in the presence of light).

In one embodiment of the invention, to improve the amplifier response, a serially connected feedback winding on the reactor and a unidirectional conducting device are connected in shunt with the main reactor winding. The feedback winding is paralleled by a storage capacitor to store the voltage developed across the main reactor winding. The winding of an output relay is serially connected to the feedback winding.

The action of the feedback winding is such as to cause a hysteresis type action of the control circuit. With an increase in light applied to the light-sensitive device, some point is reached at which the relay is actuated. On the other hand, as the light is decreased, the relay does not drop out with the same amount of light with which it was actuated. Instead, the light intensity must decrease below the intensity at which the relay originally was actuated in order to cause a relay to again drop out.

This hysteresis action improves the stability of the control circuit for line voltages and insures "snap action" of the output relay.

Further advantages and features of this invention will become apparent upon consideration of the following description read in conjunction with the drawing wherein:

FIGURE 1 is a circuit diagram of light-responsive control circuit utilizing a self-saturating magnetic amplifier in accordance with one embodiment of this invention;

FIGURE 2 is a graph of the control voltage, developed from the control circuit illustrated in FIGURE 1, plotted as the ordinate versus the light intensity applied to the light-sensitive device in the control circuit plotted as the abscissa; and

FIGURE 3 is a circuit diagram of a light-responsive control circuit utilizing a self-saturating magnetic amplifier in accordance with another embodiment of this invention.

The term "self-saturating magnetic amplifier" has an accepted meaning in the art and refers to a circuit in which the main reactor winding of a saturable cone reactor is always in series with a switching device having recurring active and inactive periods. The switching device, which may be, for example, a unilateral conducting device, allows periodic, unidirectional, current pulses to flow in the main reactor winding during the conductive or active periods of the switching device and little or no current to flow therein during the inactive periods of the switching device. Hence, the reactor is driven into magnetic saturation during the active periods of the switching device. This magnetic saturation is most commonly known as "self-saturation."

Hereinafter, current flowing through the main reactor winding in the direction which provides or aids the magnetization will be referred to as saturating current, and the direction of such flow shall be referred to as the saturating direction. On the other hand, current which flows through the main reactor winding in a direction to oppose the magnetization will be referred to as desaturating current; and the direction of its flow, the desaturating direction. The cyclic switching device, whether it be an asymmetric conductor, mechanical means or other, may be referred to as the unilateral conducting device, or diode, because it provides the pulsed unidirectional current for self-saturation.

In the amplifier illustrated in FIG. 1 are included a pair of power input terminals **10** which are coupled to the primary winding **12** of a transformer **14** having a step-down secondary **16** and an output secondary winding **18**. The input terminals **10** may be connected to a source of alternating current power supplying, for example, 117 volts at 60 cycles. The magnetic amplifier illustrated in FIG. 1 also has a pair of output terminals **20** across which may be connected the winding **22** of a control relay **24** which closes a pair of control contacts **26**. Connected between the input terminals **10** and the output terminals **20** is the magnetic amplifier constructed in accordance with this invention.

The magnetic amplifier includes a main reactor, or power winding **36**, on a saturable core reactor **38**, connected in series with a unilateral conducting device **40**, and also, a light-sensitive device **42**. The unilateral conducting device **40** and the photocell **42** are connected in parallel with each other in a circuit between the secondary **18** of the transformer **14**, which provides the input to the magnetic amplifier through a current limiting resistor **44**, and the output circuit **43** of the amplifier. The output circuit **43** is connected across the power winding **36**, i.e., between the output terminals **20** and the junction **47** between the diode **40** and the power winding **36**.

The output circuit **43** includes a feedback winding **46** on the saturable reactor **38** that is connected in series with a second unilateral conducting device **47**, which also may be a diode or mechanical switch. Shunted immediately across the feedback winding **46** is a resistor **48** which may be adjustable. Connected in parallel with the series combination of the feedback winding **46** and the output terminals **20** (relay winding **22**) is a storage capacitor **50**. Thus, the voltage developed in the output circuit **43** of the magnetic amplifier is dependent upon the impedance presented by the power winding **36** to the input voltage derived from the secondary winding **18**.

The unidirectional conducting devices **40** and **47** are poled in the same direction and may be any suitable device; such as, a silicon diode that is capable of allowing current flow substantially in one direction only. The light-sensitive device **42** may be of any type whose resistivity is responsive to the intensity or the wave length or both of light radiation. A photocell, for example, employing a light-sensitive material such as cadmium selenide or other well-known materials whose resistivity changes in response to light is suitable. The term light is employed herein in its broadest sense to include all forms of detectable radiation. Characteristics and structural details of light-sensitive cells of various types are well-known and a further description thereof is believed unnecessary.

The resistance of a light-sensitive element, such as the device **42**, usually varies from a high to a low value as the intensity of light is increased from a low to a high value or as a particular wave length to which the cell is most responsive is approached. For purposes of illustration, the present magnetic amplifier is illustrated in a pyromillivoltmeter type circuit in which a vane **52** is attached to the needle (not shown) of a D'Arsonval type meter movement and so positioned as to be interposed in the light path between a source of light **54** and the light-sensitive element **42**. The light source **54** may, for example, be an incandescent lamp energized by the secondary **16** of the transformer **14**. Both the light-sensitive device **42** and the light source **54** may be enclosed by a light-proof enclosure (not shown) to prevent extraneous light from affecting the light-sensitive element **42**.

The operation of the control circuit of this invention may be explained as follows. When the controlled variable, for example, the temperature of an electric furnace, which may be controlled by the opening or closure of the relay contacts **26**, is below some predetermined set point, as is determined by the physical position of the vane **52** with respect to the light source **54** and photocell **42**, the vane **52** allows light from the light source **54** to fall on the photocell **42**. The resistance of the photocell **42** drops to a lower value. Therefore, on the negative going, or reset half-cycle portion of the alternating current signal derived from the source **10**, desaturating current flows through the photocell **42** and the saturable reactor **38** desaturates. The reactor **38** is now said to be reset.

Thus reset, the saturable reactor **38** presents a relatively high impedance to the flow of saturating current through the power winding **36** during the positive-going portion of the input voltage. Saturating current passing in the forward conducting direction through the first diode **40** develops a voltage across the power winding **36**. This voltage also appears across the output circuit **43**. This voltage, which is transmitted through the second diode **47** to the storage capacitor **50** and the feedback winding **46** each reset half-cycle, increases in the voltage developed across the capacitor and the output terminals **20**. Discharge current from the capacitor **50** during each reset half-cycle passes through the feedback winding **46** due to the blocking action of the second diode **47**. This discharge current is in such direction as to aid in desaturating or resetting the saturable reactor **38**. A point is finally reached of which the two resetting currents, i.e., that in the power winding **36** and that in the feedback winding **46** are sufficient to develop enough voltage across the power winding **36** during the positive-going half-cycle such that the relay **24** pulls in and closes the contacts **26**. In the assumed illustration, the closure of the contacts **26** causes more heat to be applied to the furnace.

Now, as the temperature of the furance increases and the vane **52** again starts to cover the photocell and block the flow of light thereto, the resistance of the photocell **42** increases. This increase in resistance decreases the reset, or desaturating, current that flows through the power winding **36**. The discharge current from the storage capacitor **50**, however, continues to flow for several cycles, during the reset half-cycle, in such a direction as to desaturate the saturable reactor **38**. The saturable reactor **38**, therefore, is prevented for a short period of time from becoming saturated during each positive half-cycle of the power supply voltage. A point is finally reached at which the discharge current from the capacitor is insufficient to prevent saturation of the saturable reactor **38** and the voltage developed across the power winding **36** in sufficient to maintain the relay **24** actuated. Hence, the relay **24** drops out, disengaging the contacts **26**.

It may be pointed out that due to the unique feedback circuit of this invention, a differential exists between the relay pull-in and drop-out points. That is, although the relay pulls-in, as illustrated in the graph of FIG. 2 by the rapid increase in relay voltage to the point **59** with a certain amount of light, illustrated by the point **60**, impinging on the photocell **42**, once "pulled in," the relay **24** resists "dropping out" until a lesser amount of light is present on the photocell **42**. This lesser amount of light is illustrated by the point **62** in FIG. 2, which it may be noted is to the left of (closer to zero light intensity) the pull-in point **60**.

This difference between the relay pull-in and drop-out points **60** and **62**, respectively, may be termed a hysteresis type action which aids in giving the magnetic amplifier a more positive, or snap-type action, that is relatively insensitive to line voltage variations or extraneous light variations such as might be caused by vibration of the vane **52**. The amount of hysteresis may be adjusted by varying the resistor **48** or the capacitor **50**.

As a result of this invention, a relatively inexpensive relay **24** may be employed due to the "snap-action" provided by the feedback circuit. In addition, the material

selected for the saturable reactor **38** may be of lower quality as it is not required to have a substantially rectangular hysteresis loop as was often required in the prior art. Also, the circuit of FIG. 1 is fail-safe in that, in the event of power failure, the relay drops out.

The circuit of FIG. 3 illustrates an alternative embodiment of this invention in which the feedback or output circuit **43** is connected in series with the power winding **36** of the magnetic amplifier rather than in parallel as illustrated in FIG. 1. Since the elements of FIG. 3 are, for the most part, identical to those employed by FIG. 1, the same reference numerals have been employed. The primary difference between these two embodiments is that in FIG. 3 the relay winding **22** of the relay **24** replaces the resistor **44** (FIG. 1) and is connected in series with the power winding **36**. The feedback winding **46** is connected in shunt with the relay winding **22** through the storage capacitor **50**. The feedback winding **46** is shunted by the adjustable resistor **48** as before. The relay contacts **26** (FIG. 1) are not shown in FIG. 3. The remaining circuit connections in the embodiment of FIG. 2 are the same as in FIG. 1, and accordingly no further description herein will be made.

The operation of the embodiment of FIG. 3 is substantially the same as that of FIG. 1 except that its response to light is the opposite. Initially, in the presence of light, such as caused by the vane **52** allowing light to fall on the photocell **42**, equal saturating and desaturating currents flow through the power winding **36** during each half-cycle of the power supply voltage. Hence, the reactor **38** is not saturated and the power winding **36** presents a high impedance to the current flow. The resulting decreased current flow through the relay winding **22** is insufficient to pull-in the relay **24**. Now, as the vane **52** moves between the light source **54** and the photocell **42**, the amount of light falling on the photocell **42** decreases, thereby decreasing the desaturating current in the power winding **36**. The reactor **38** begins to saturate resulting in an increased voltage drop across the relay winding **22**. The capacitor **50** charges through the feedback winding **46** in such a direction as to oppose the saturating current and aid the desaturating current (which is now decreasing in magnitude). This feedback action delays the saturation of the reactor **38** until the light intensity of the photocell **42** decreases still further. After several cycles of the input alternating current from the source **10**, in the presence of decreasing light intensity, the reactor **38** gradually is driven to saturation due to the decreased desaturating current. When the light intensity decreases to a predetermined value, the saturating current flow is sufficient to pull-in the relay **24** and close the contacts **26** (not shown).

With the reactor **38** saturated, the majority of the voltage drop occurs across the relay winding **22** instead of the power winding **36**. The capacitor **50** stores this voltage such as to maintain the relay winding **22** energized during the desaturating portion of the cycle (there is little or no current flow to the power winding **36** since the photocell **42** is a high impedance).

Conversely, with an increase in light intensity on the photocell **42**, the reactor **38** begins to desaturate. With desaturation of the reactor **38**, the magnitude of the saturating current decreases due to the higher impedance of the power winding **36**. The resulting decreased voltage drop across the relay winding **22** causes a discharge current from the capacitor **50** which passes through the feedback winding **46** in such a direction as to aid the saturating current in saturating the reactor **38** and to oppose the desaturating current. The action is cumulative and the reactor **38** quickly desaturates such that the power winding **36** again presents a relatively high impedance. With the resulting reduced current flow through the relay winding **22**, relay **24** drops out.

The functioning of the feedback winding **46**, which aids and opposes saturating and desaturating, respectively,

the reactor **38** of the magnetic amplifier, causes the hysteresis type action similar to that described in the embodiment of FIG. 1. This hysteresis action results in the relay **24** dropping out with a greater light intensity impinging on the photocell **42** than is required to cause the relay **24** to again pull-in with decreasing light intensity.

There has thus been described a relatively simple control circuit using a light-responsive, self-saturating type magnetic amplifier having hysteresis type action. The hysteresis action provides a "snap action" type of output and allows the use of less expensive output relays. Further, the circuit may be adjusted such that it is relatively insensitive to line voltage variations or extraneous vibrations; for example, of the vane attached to a D'Arsonval type meter movement. Further, in one of the embodiments of this invention, the circuit is fail-safe; in the event of power failure, the relay drops-out.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. In a self-saturating magnetic amplifier including a reactor with a magnetically saturable core having a power winding and a feedback winding on said core, unidirectional conducting means connected in series with said power winding for passing intermittent unidirectional current through said power winding in a particular direction thereby to saturate said core, means having light-responsive conductivity connected in series with said power winding and effectively in shunt with said unidirectional conducting means for creating a voltage drop across said power winding in response to light, the combination comprising capacitance means and a second unidirectional conducting means connected in series with each other and in parallel with said power winding, said feedback winding being connected in parallel with said capacitance means whereby the voltage developed across said capacitance means changes differentially with increasing or decreasing light and said amplifier provides a hysteresis type response to light impinging on said light responsive means.

2. A self-saturating magnetic amplifier comprising a reactor with a saturable core having a power winding and a feedback winding on said core, a source of current alternatively having a first polarity and a second polarity, first means connecting said current source to said power winding for allowing current of one of said polarities to flow through said power winding in a direction to saturate said core, second means coupled between said current source and said power winding for selective passing current of said second polarity through said power winding in a direction to reduce the saturation of said core, and storage means connected in parallel across said power winding for storing the voltage of said one polarity developed across said power winding when said core is unsaturated, said feedback winding being coupled across said storage means for opposing the saturation of said core and aiding the desaturation of said core, thereby to provide a rapid differential response to variations of said second means.

3. A self-saturating magnetic amplifier comprising a reactor with a saturable core having a power winding and a feedback winding on said core, means connected in series with said power winding for passing intermittent unidirectional current through said power winding in a particular direction, means having light-responsive conductivity connected in series with said power winding and effectively in shunt with said unidirectional current means for passing current through said power winding in the opposite direction in response to light, an output circuit

connected in series with said power winding, and a capacitor, said capacitor and said feedback winding being connected in series with each other and in parallel with said output circuit, thereby to provide a differential response to increasing and decreasing amounts of light.

4. A self-saturating magnetic amplifier as set forth in claim 3 wherein a variable resistor is coupled in parallel with said feedback winding thereby to control the amount of differential response of said amplifier.

5. A self-saturating magnetic amplifier comprising a reactor with a saturable core having a power winding and a feedback winding on said core, means connected in series with said power winding for passing intermittent unidirectional current through said power winding in a particular direction, means having light responsive conductivity connected in series with said power winding and effectively in shunt with said unidirectional current means for passing current through said power winding in direction opposite said particular direction in response to light, and a second means connected in parallel with said power winding for passing intermittent unidirectional current,

and capacitance means connected in series with said second unidirectional current means, said feedback winding being connected in parallel with said capacitance means and in series with said second unidirectional current means.

6. The combination set forth in claim 5 which also includes an impedance means connected in parallel with said feedback winding.

7. The combination set forth in claim 6 which also includes an output circuit connected in series with said feedback winding whereby the current supplied to said output circuit varies differentially in response to increasing and decreasing light intensity impinging on said light responsive means and hence is less sensitive to the receipt of undesired variations of said light intensity.

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