

April 20, 1954

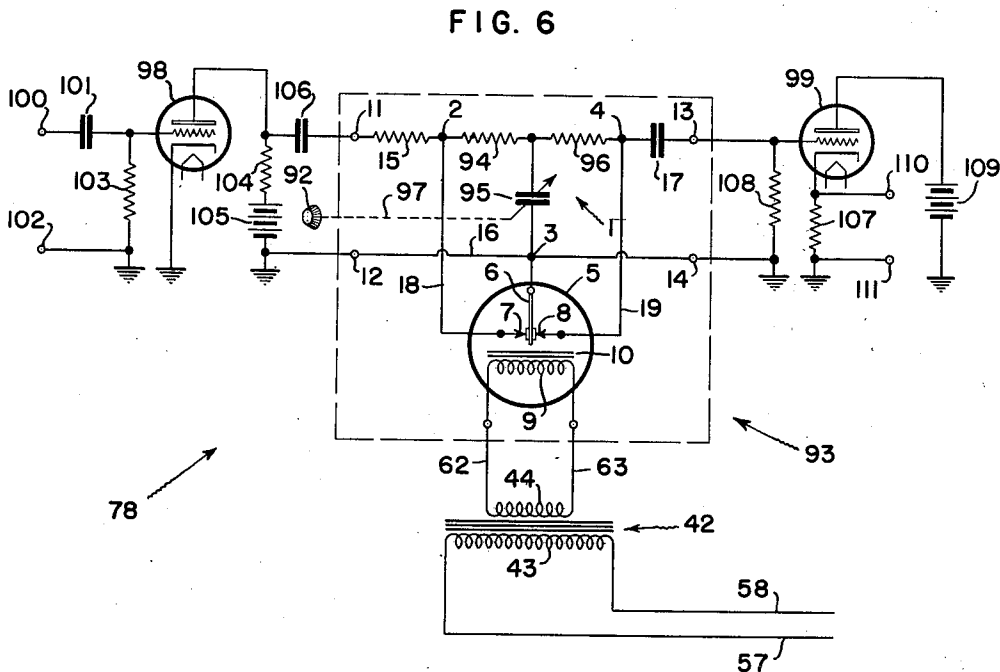
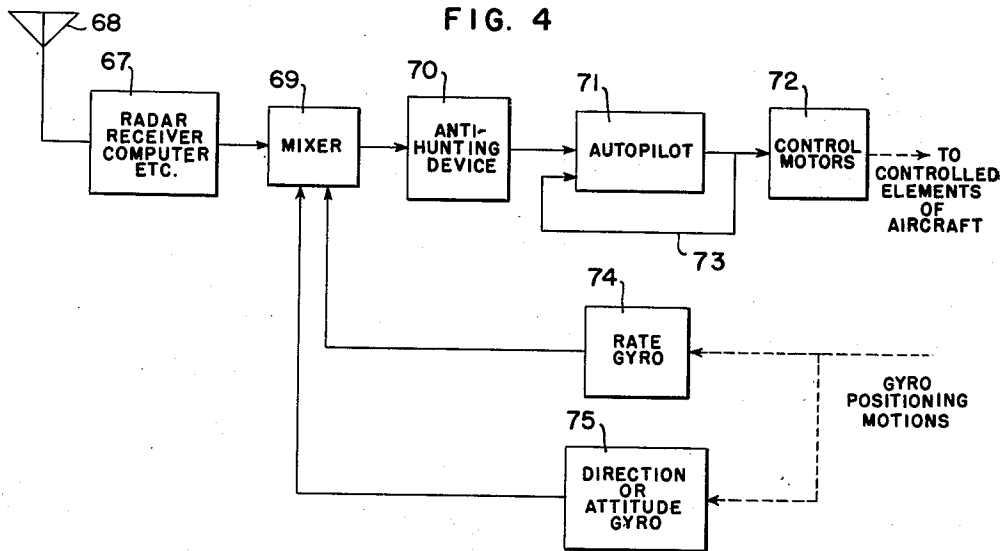
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PHASE SHIFTING ANTICIPATION IN AUTOMATIC CONTROL SYSTEMS

Filed Sept. 25, 1950

3 Sheets-Sheet 2



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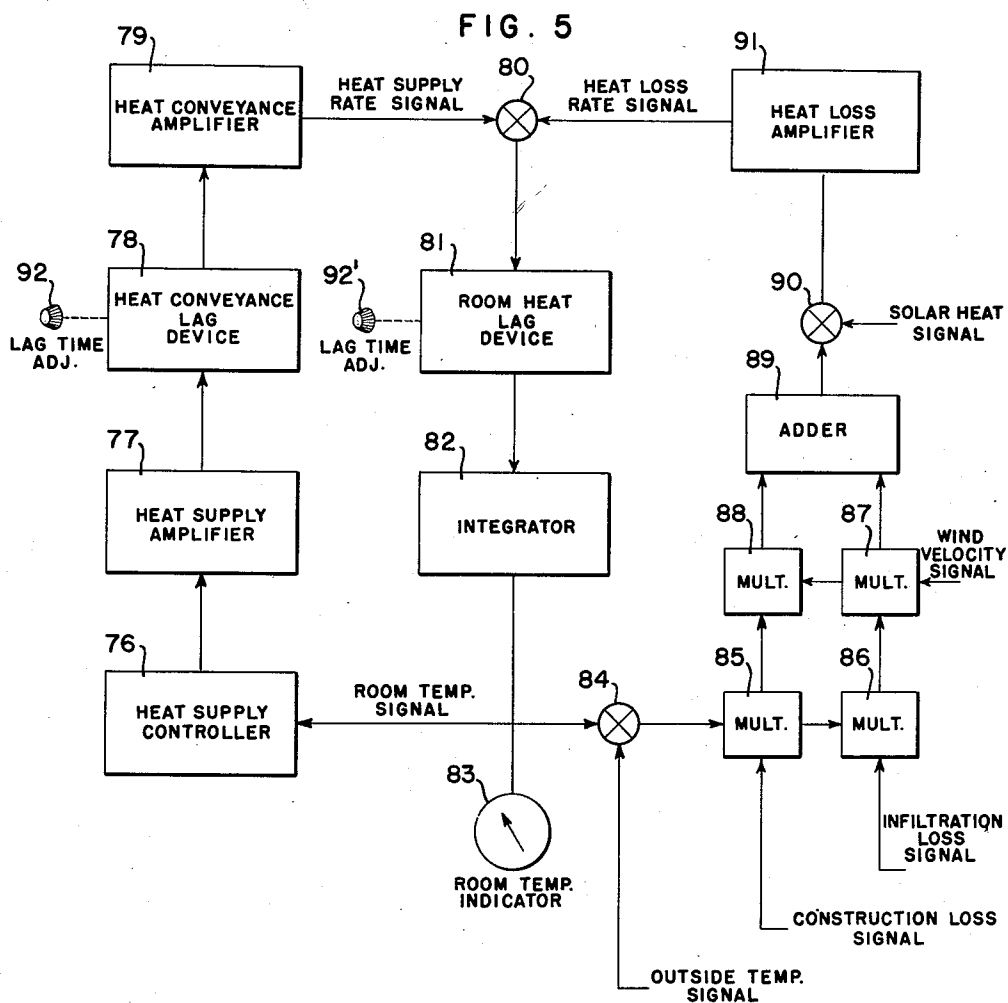
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PHASE SHIFTING ANTICIPATION IN AUTOMATIC CONTROL SYSTEMS

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Application September 25, 1950, Serial No. 186,524

13 Claims. (Cl. 318—29)

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The present invention relates generally to apparatus employed for automatic control purposes, and relates specifically to a novel shifting device for shifting with respect to time the effects of amplitude variations in an alternating current control signal. More specifically, the invention relates to a novel shifting device of the type specified which is useful to provide anti-hunting effects in one type of electric control apparatus, and to provide time delay effects in another type of such apparatus.

A general object of the present invention is to provide an improvement in automatic control apparatus whereby desirable shifting effects are obtained in such apparatus in a novel and simplified manner. A more specific object of the invention is to provide a novel shifting device well adapted for use with automatic electric control apparatus and operative to shift with respect to time the effects of amplitude variations in an alternating current signal.

More specifically, an object of the present invention is to provide a novel shifting device of the type specified which is operative in a first form to produce an alternating current output signal exhibiting amplitude variations which are advanced with respect to time relative to corresponding variations in an alternating current input signal, and which is operative in a second form to produce an alternating current output signal exhibiting amplitude variations which are retarded with respect to time relative to corresponding alternating current input signal variations.

A still more specific object of the invention is to provide a shifting device of the type specified which is well adapted in the aforementioned first form to produce advanced or anticipatory output signals useful in providing anti-hunting effects in automatic control devices of the self-balancing electric type. A different but equally specific object of the invention is to provide a shifting device of the specified type which is well adapted in the aforementioned second form to produce retarded or delayed output signals useful in providing lag effects in automatic control devices of the electrical analogue type.

An even more specific object of the present invention is to provide a novel shifting device of the type specified which is characterized by its simplicity and use of only a small number of components. To this end, the present invention provides a novel shifting device wherein a single synchronous switching device having a single movable contact performs both the rectifying and the modulating functions required in a shifting device of the type specified.

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An additional specific object of the invention is to provide a shifting device of the type specified wherein the shifting function provided thereby is controllable in a simple and effective manner in both the signal advancing and signal retarding forms of the device. To this end, the invention provides a suitable variable condenser included in the novel shifting device thereof.

To the end of fulfilling the above enumerated objects, the novel shifting device of the invention comprises a shifting circuit having an input portion, an output portion, and electrical shifting components, including a condenser, connected between said portions. The condenser may be fixed or variable, depending upon whether fixed or variable shifting effects are desired. The shifting device further comprises a pair of input terminals adapted to have applied therebetween an alternating current input signal exhibiting amplitude variations which occur at rates substantially lower than the frequency of the input signal. When the input signal is, for example, the output voltage of an alternating current bridge circuit, these signal amplitude variations will correspond to excursions of the bridge circuit from and toward the balanced condition.

Also included in the described shifting device is a synchronous switching device having a rectifying portion including a movable contact and a first cooperating stationary contact, having a modulating portion including the movable contact and a second cooperating stationary contact, and having a driving portion operative, when supplied with energizing current, to move the movable contact into and out of engagement with each of the stationary contacts, alternately, at a rate corresponding to the frequency of the current supplied to the driving portion. Means are provided for connecting the driving portion of the switching device to a suitable source of energizing current which is in synchronism with the input signal. In practice, the frequency of the input signal and energizing current is usually sixty cycles per second or four hundred cycles per second.

Included further in the shifting device being described are connections between the aforementioned input terminals and input portion which include the rectifying portion of the switching device, whereby the rectified form of the input signal is applied to the input portion. Also included in the shifting device are a pair of output terminals and connections between the latter and the aforementioned output portion which include the modulating portion of the switching device, whereby there appears between

the output terminals an alternating current output signal exhibiting variations in amplitude corresponding to input signal amplitude variations but shifted in time with respect to the last mentioned variations.

In the form of the shifting device where the output signal variations are caused to be advanced, the values and connections of the shifting circuit components are so chosen as to accomplish this, and the resulting output signal is an anticipatory one, well adapted for providing anti-hunting or damping effects in control apparatus including, for example, the aforementioned bridge circuit and means under the control of the shifting device output signal for maintaining the bridge circuit balanced under varying bridge circuit conditions.

In the form of the shifting device where the output signal variations are caused to be retarded, the values and connections of the shifting circuit components are again so chosen as to accomplish the desired result, and the resulting output signal is a lagging or delayed one, well adapted to provide lag effects in an electrical analogue device including the shifting device connected between a simulated source of heat energy, for example, and a simulated load.

In each of the above forms and examples, the condenser included in the shifting circuit may be made variable if desired, whereby the anti-hunting action of the first example will be controllable, as will the time lag action of the second example.

As will be brought out hereinafter, the inclusion in the described shifting device of a single switching device having a single movable contact for accomplishing both the required rectifying and modulating functions provides a novel device exhibiting outstanding features of simplicity, reliability, compactness, and economy which, nevertheless, functions to produce results which are equal, if not superior, to those heretofore obtained from much more highly complicated, bulkier, and costlier apparatus. The importance of this fact is particularly significant in instances where the shifting device is employed in conjunction with automatic aircraft control apparatus carried by the aircraft and matched to the characteristics thereof by the shifting device.

The various features of novelty which characterize my invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, however, its advantages and specific objects obtained with its use, reference should be had to the accompanying drawings and descriptive matter in which are illustrated and described preferred embodiments of the invention.

Of the drawings:

Fig. 1 is a circuit diagram broadly illustrating the shifting device of the present invention;

Fig. 2 is a circuit diagram of a typical self-balancing bridge circuit control apparatus embodying the shifting device of Fig. 1 in its signal advancing form for anti-hunting purposes;

Fig. 3 is a circuit diagram of a modification of the shifting device of Fig. 2;

Fig. 4 is a block diagram of a typical aircraft control apparatus of the autopilot type embodying the shifting device of Fig. 2 or 3;

Fig. 5 is a block diagram of a typical electronic analogue apparatus embodying the shifting device of Fig. 1 in its signal retarding form in two

portions, both of which simulate heat lags in a simulated heating system; and

Fig. 6 is a circuit diagram showing in detail one of the heat lag simulating portions of the apparatus of Fig. 5.

In Fig. 1, I have illustrated diagrammatically the novel shifting device of the present invention in its broad, general form. As shown, the shifting device of Fig. 1 comprises a shifting circuit 1, shown in block form, having an input portion connected internally between an input terminal 2 and a common terminal 3, and having an output portion connected internally between an output terminal 4 and the common terminal 3. Included also in the Fig. 1 device is a synchronous switching device 5 which includes a movable contact member 6, a first stationary contact 7, a second stationary contact 8, and a driving portion consisting of an operating winding 9 and a permanent magnet 10. The switching device 5 is of a conventional and well known form, and may well be of the type disclosed in the Side Patent 2,423,524. Since the switching device 5 is fully described in said Side patent, and is well known as to both construction and operation in the art, it appears to be sufficient to state herein merely that, when the operating winding 9 is supplied with alternating energizing current, the winding 9 and permanent magnet 10 cooperate to cause the movable contact 6 to move in synchronism with the alternating energizing current between a first position, in which the contact 6 engages only the stationary contact 7, and a second position, in which the contact 6 engages only the stationary contact 8. Accordingly, when the device 5 is in operation, the movable contact 6 is moved into and out of engagement with each of the stationary contacts 7 and 8, alternately, at a rate corresponding to the frequency of the alternating energizing current.

The Fig. 1 shifting device of the present invention also includes a first input terminal 11, a second input terminal 12, a first output terminal 13, and a second output terminal 14. The input terminal 11 is connected through a resistor 15 to the input terminal 2 of the shifting circuit 1, while the input terminal 12 is directly connected by a common conductor 16 to the output terminal 14 and to the common terminal 3 of the circuit 1. The movable contact 6 of the switching device 5 is also connected to the conductor 16. The output terminal 4 of the circuit 1 is connected through a blocking condenser 17 to the output terminal 13 of the apparatus.

The contacts 6 and 7 of the device 5 constitute a rectifying portion of the latter. To this end, the contact 7 is connected by a conductor 18 to the input terminal 2 of the circuit 1. Accordingly, it can be seen that the contacts 6 and 7 are connected across the input portion of the circuit 1 which in turn is connected internally between the terminals 2 and 3.

The contacts 6 and 8 of the device 5 constitute a modulating portion thereof, and, to this end, the contact 8 is connected by a conductor 19 to the output terminal 4 of the circuit 1. It is apparent, therefore, that the contacts 6 and 8 are connected across the output portion of the circuit 1 which in turn is internally connected between the terminals 3 and 4.

As will be more fully described in detail hereinafter in connection with the preferred embodiments of the shifting device of Fig. 1, the latter is operative to produce between the output termi-

nals 13 and 14 and alternating current output signal which exhibits amplitude variations corresponding to amplitude variations in an input signal applied between the terminals 11 and 12. Due to the action of the shifting circuit 1, however, the output signal variations are shifted with respect to time relative to the corresponding input signal variations. That is, a change in the magnitude of the input signal between the terminals 11 and 12 causes a change to take place in the magnitude of the output signal between the terminals 13 and 14 at some other predetermined time. Accordingly, the effect of the Fig. 1 shifting device on input signals applied thereto is to convert the signals into output signals exhibiting effects which are advanced or retarded as to their time of occurrence with respect to corresponding effects appearing in the input signals.

In general operation, the operating winding 9 of the device 5 is supplied with alternating energizing current which is of the same frequency as the input signal applied between the terminals 11 and 12, and which is in synchronism with this input signal. Accordingly, there is provided between the terminals 2 and 3, and across the input portion of the circuit 1, a pulsating unidirectional signal which is the half-wave rectified form of the input signal applied between the terminals 11 and 12. The unidirectional signal produced between the terminals 2 and 3 is acted on and modified by the components included in the shifting circuit 1, and the resulting modified form of the unidirectional signal appears between the terminals 3 and 4, across the output portion of the circuit 1.

The modulating action of the synchronously operated contacts 6 and 8 of the device 5 imparts an alternating current component to the unidirectional signal appearing between the terminals 3 and 4. Due to the action of the blocking condenser 17, it is this alternating component only which appears between the output terminals 13 and 14 of the apparatus as the alternating current output signal thereof.

Because of the synchronous operation of the device 5, the alternating current output signal so produced is of the same frequency as the input signal impressed between the terminals 11 and 12. The relatively rapid variations or alternations in the input signal which impart to the latter its alternating characteristics are not significantly affected by the operation of the shifting device. Instead, these alternations may conveniently be thought of as those of a carrier frequency, and it is only the relatively lower frequency or slower variations in the input signal which have their effects significantly advanced or retarded by the apparatus. This is true since the values of the components of the shifting circuit 1 are so chosen as to be operative to shift effectively and significantly only input signal variations which occur at rates substantially lower than the carrier frequency of the input signal. The resistor 15 prevents excessive loading of the source providing the input signal between the terminals 11 and 12.

From the above description it is evident that the contacts 6 and 7 constitute a synchronous rectifying device which removes the alternating current carrier frequency from the input signal between the terminals 11 and 12 before the unidirectional or rectified form of this signal is applied to the circuit 1. Similarly, it can be seen that the contacts 6 and 8 constitute a synchronous modulator operative to restore the alternat-

ing current carrier frequency to the modified output of the circuit 1. Accordingly, the switching device 5 serves as both a synchronous rectifier and a synchronous modulator in the apparatus of Fig. 1.

The novel device of Fig. 1 has been termed a shifting device since it is operative either to advance or retard the effects of input signal variations, depending on the values and connections of the components constituting the shifting circuit 1. The broad shifting device of Fig. 1 will be described in detail in its signal advancing form in connection with the apparatus of Fig. 2 and that of Fig. 4, and will be described in detail in its signal retarding form in connection with the analogue apparatus of Figs. 5 and 6.

In Fig. 2, I have illustrated in partial block diagram form a preferred embodiment of the novel shifting circuit of Fig. 1. The arrangement illustrated in Fig. 2 is an automatic control device of the well-known electronic self-balancing Wheatstone bridge form, and is shown as being of the type illustrated and described in the Wills Patent 2,423,540. The novel signal shifting device of Fig. 1 has been embodied in its signal advancing or anticipatory form in the self-balancing Wheatstone bridge control arrangement for the purpose of providing desirable anti-hunting effect therein. Since the electronic self-balancing control arrangement per se is now well known in the art, and is more than adequately described in the aforementioned Wills patent, only a brief description of this apparatus appears to be required herein.

The apparatus of Fig. 2 comprises a Wheatstone bridge circuit, generally designated at 20, including a temperature-sensitive resistance thermometer element 21, a bridge arm resistor 22, and a rebalancing slidewire resistor 23. The latter has a movable contact 24 which constitutes one output terminal of the bridge 20. One end of the resistance thermometer element 21 is connected to one end of the resistor 22 to form the second output terminal 25 of the bridge 20. The remaining end of the element 21 is connected to one end of the slidewire resistor 23 to form a bridge input terminal 26, and the remaining end of the resistor 22 is connected to the other end of the resistor 23 at a second bridge input terminal 27.

In addition to the shifting device to be described in detail hereinafter, the Fig. 2 apparatus also includes an electronic amplifier and motor drive device 28 having input terminals 29 and 30, output terminals 31 and 32, and energizing terminals 33 and 34. The apparatus further includes a reversible electric motor, generally designated at 35, having a control winding 36, a power winding 37, and a rotor 38. Finally, the Fig. 2 arrangement includes a bridge energizing transformer 39 having a primary winding 40 and a secondary winding 41, and a transformer 42 operative to energize the shifting device and including a primary winding 43 and secondary winding 44. The elements 20, 28, 35, and 39 are of the same types as the corresponding elements shown and described in the aforementioned Wills patent, and function and cooperate exactly as do the corresponding elements in the last mentioned patent.

The shifting device of Fig. 1 is included in the Fig. 2 apparatus and is generally designated at 45 therein. As shown, the device 45 includes all of the elements 1 through 19 of the Fig. 1 device,

and in addition includes various shifting components constituting the shifting circuit 1. Specifically, the shifting circuit 1 of Fig. 2 includes a resistor 46, a resistor 47, and a condenser 48 connected between the terminals 2, 3, and 4 of the shifting circuit 1. The values and connections of the components 46, 47, and 48 are so chosen, as will be explained hereinafter, that the device 45 provides desirable anticipatory output signals for the purpose of securing the aforementioned anti-hunting effects in the Fig. 2 control arrangement.

The various above-described elements are interconnected in the following manner. The input terminal 26 of the bridge 20 is connected by a conductor 49 to one end terminal of the secondary winding 41 of the transformer 39, while the other bridge input terminal 27 is connected by a conductor 50 to the remaining end terminal of the winding 41. The output terminal of the bridge 20 which is formed by the slidewire contact 24 is connected by a conductor 51 to the input terminal 11 of the shifting device 45, while the remaining bridge output terminal 25 is connected by a conductor 52 to the remaining input terminal 12 of the device 45. The output terminal 13 of the latter is connected to the input terminal 29 of the electronic device 28 by means of a conductor 53, and the remaining output terminal 14 of the device 45 is connected by a conductor 54 to the remaining input terminal 30 of the device 28.

The power winding 35 of the motor 35 is connected between the output terminals 31 and 32 of the electronic device 28, and the energizing terminals 33 and 34 of the latter are connected by respective conductors 55 and 56 to respective electrical supply conductors 57 and 58. The latter two conductors are operative to supply to the apparatus alternating energizing current of conventional voltage and frequency. The motor power winding 37 is connected across the supply conductors 57 and 58 in series with a suitable condenser 59 as in the aforementioned Wills patent.

The rotor 38 of the motor 35 is connected by a suitable mechanical linkage 60 to the movable contact 24 of the slidewire resistor 23 of the bridge 20, whereby rotation of the rotor 38 provides corresponding adjustments of the contact 24 along the length of the resistor 23. The linkage 60 has a control portion 61 which is operative to transmit suitable motions to a control device, not shown, whereby the control device is actuated in the known manner in accordance with the position of the slidewire contact 24 as determined by operation of the motor 35. Since the aforementioned Wills patent illustrates such a typical control device controlled by apparatus substantially identical, except for the device 45, to the apparatus disclosed in Fig. 2 herein, it is believed to be unnecessary to show such a control device in detail herein.

The operating winding 9 of the synchronous switching device 5 of the shifting device 45 is supplied with alternating energizing current from the transformer 42. To this end, the winding 9 is connected by conductors 62 and 63 across the secondary winding 44 of the transformer 42. The primary winding 43 of the latter, as well as the primary winding 40 of the transformer 39, is connected across the supply conductors 57 and 58.

In the operation of the Fig. 2 apparatus, momentarily neglecting the anti-hunting action provided by the shifting device 45, the tempera-

ture to which the resistance thermometer element 21 is subjected determines the resistance of the latter and hence controls the state of balance of the bridge circuit 20. When the latter is balanced, the contact 24 will be at a position along the slidewire resistor 23 corresponding to the then-existing temperature measured by the element 21, and no bridge output signal will appear between the conductors 51 and 52. Under this condition, no input signal will be applied to the input terminals 29 and 30 of the electronic amplifier and motor drive device 28, whereby, as is described in detail in the aforementioned Wills patent, the rotor 38 of the motor 35, and hence the contact 24, will not be urged to move in either direction, but will be maintained stationary. This condition will prevail until a change occurs in the temperature measured by the element 21.

By way of illustration, it may be assumed that the temperature measured by the element 21 is the temperature of a furnace or similar device, not shown, to which fuel is supplied at a rate determined by the control means actuated in turn by the linkage 61 and the motor 35. In such a control arrangement, for the balanced bridge condition just described, the motor 35 and linkage 61 will have adjusted the rate of fuel supply to the furnace or other device to the value necessary to maintain the measured temperature at some predetermined value.

Upon the occurrence of a change in the temperature measured by the element 21, the bridge circuit 20 will become momentarily unbalanced, and a corresponding unbalance bridge output signal of suitable phase and magnitude will appear between the conductors 51 and 52. Again momentarily neglecting the action of the shifting device 45, the bridge output signal will be applied in unmodified form as an input signal between the terminals 29 and 30 of the device 28, and the latter will then be operative to supply to the motor control winding 36 a control signal operative to cause rotation of the rotor 38 in the direction and to the extent required to move the slidewire contact 24 along the slidewire resistor 23 to a new position in which the bridge 20 is once again balanced. The motion thus given to the contact 24 will also be imparted to the control device through the linkage 61, whereby the aforementioned fuel supply rate will be changed as necessary to return the measured temperature to the initial, predetermined value.

When control apparatus of the type shown in Fig. 2 operates in the manner just described, the high sensitivity of the electronic apparatus and the high speed with which rebalancing and control actions are effected often cause undesirable hunting or overshooting actions to occur. That is, while moving the contact 24 into a new balance position following unbalance of the bridge 20, the motor 35 may tend to coast subsequent to its deenergization, thereby causing the contact 24 to be driven further along the resistor 23 than is actually necessary. This then produces reverse rotation of the rotor 38 and tends to establish a cyclic, hunting action which may continue for some time, and which usually is highly undesirable, inasmuch as the oscillatory movements of the contact 24 are also imparted to the control means through the linkage 61. Accordingly, it has been found highly desirable, and in a number of cases imperative, to include in apparatus of the type shown in Fig. 2 suitable damping or anti-hunting means for eliminating or at least substantially reducing the occurrence

of overshooting and consequent hunting with its disadvantageous results.

It is for the purpose of providing such an anti-hunting action that the novel shifting device 45 of the present invention is included in the control apparatus of Fig. 2. As shown, the output signal from the bridge 20 is applied to the input of the device 28 through the shifting device 45 so that the latter can modify the input signal to the device 28 as necessary to provide the desired anti-hunting function.

The manner in which the shifting device 45 is operative to shift with respect to time effects of changes in the bridge output signal so as to provide an anticipatory output signal for application to the device 28 will now be described. As shown in Fig. 2, the resistor 46 is connected between the input terminal 2 and the output terminal 4 of the shifting circuit 1, while the condenser 48 is connected in parallel with the resistor 46 between the last mentioned terminals. In addition, the resistor 47 is connected between the output terminal 4 and the common terminal 3 of the circuit 1. For purposes of illustration, let it first be assumed that the bridge 20 is in the balanced condition and that the measured temperature is at the desired, predetermined value. As noted previously, there will be no input signal to the device 45 under this condition, and, consequently, there will be no input signal applied to the device 28. Assuming that this condition has prevailed for a sufficient length of time, it can be seen that there will be no significant charge on the condenser 48, and that there will be no significant current flow through the resistors 15, 46, and 47. Since the condenser 17 is merely a blocking condenser, no attention need be paid to its charging and discharging in the present analysis. The absence of any current flow through, or voltage drop across, the resistor 47 dictates, therefore, that there is no output signal applied to the input of the device 28 under the assumed balanced condition.

Let it now be assumed for illustrative purposes that the temperature measured by the element 21 starts to change at a rate which exceeds the maximum rebalancing rate of the apparatus, whereby unbalance of the bridge 20 occurs. Immediately upon such unbalance, a corresponding input signal will be applied between the terminals 11 and 12, this signal increasing in magnitude as the extent of bridge unbalance increases. Since the condenser 48 is uncharged at first, it will momentarily appear, in effect, to be a short-circuit across the resistor 46, whereby substantially the entire signal applied between the input terminals 11 and 12 will appear between the output terminals 13 and 14. The signal between the last mentioned two terminals will, of course, be applied between the input terminals 29 and 30 of the device 28, whereby the latter will be actuated as necessary to produce a large motor drive signal which in turn will be effective in getting the motor 35 into operation for the purpose of rebalancing the bridge circuit.

However, the condenser 48 will start to charge at the instant that the input signal is applied between the terminals 11 and 12, whereby the short-circuiting effect of the condenser 48 on the resistor 46 will start to decrease as the condenser charges. As this occurs, a voltage drop will build up across the condenser 48 and resistor 46 which will have the effect of reducing the magnitude of the portion of the input signal 75

which appears across the resistor 47 and between the output terminals 13 and 14. The condenser 48 is able to be charged in this manner because of the fact that the signal between the terminals 2 and 3 is a unidirectional one, due to the aforementioned synchronous rectifying action of the contacts 6 and 7 of the switching device 5. Similarly, the voltage drop across the resistor 47 is provided with an alternating current component of the same frequency and phase as the alternating current input signal by virtue of the aforementioned synchronous modulating action of the switch contacts 6 and 8. As noted above, it is this alternating component which constitutes the output signal from the device 45 which is applied between the input terminals 29 and 30 of the device 28.

As noted above, the magnitude of the output signal from the device 45, as applied to the input of the device 28, will be decreased progressively as the condenser 48 becomes charged, even though the input signal to the device 45 may still be increasing. Finally, however, an equilibrium condition will be reached momentarily wherein the magnitude of the bridge output signal will level off at some finite value, due either to the rate of the rebalancing operation produced by the motor 35 and slidewire resistor 23 having reached the rate of temperature change, or to a decrease in the last mentioned rate. In any event, the magnitude of the input signal applied to the device 28 will at this time be significantly lower than the magnitude of the bridge output signal, due to the voltage drop which will have developed across the resistor 46.

An analysis of the above described operation clearly shows that the device 45 functions to produce an alternating current output signal exhibiting amplitude variations which are advanced with respect to time relative to corresponding variations in an applied alternating current input signal. Specifically, it can be seen from the above description that the output signal of the device 45 is made to have its maximum amplitude at an appreciable time before the corresponding input signal reaches its maximum amplitude. In other words, the effect of the input signal increase above described is shifted ahead or advanced with respect to time so that the output signal is subjected to a variation which causes this signal to reach its maximum value earlier than does the input signal. Although such an advanced signal is not strictly an anti-hunting signal as applied to the completion of a rebalancing operation, such a signal is, nevertheless, an anticipatory signal, and serves the important function of providing a so-called "rate action," whereby the rebalancing motor in apparatus of the type being described is subjected to a maximum driving effect at a time before an unbalance signal has had the opportunity to increase to its maximum value. Such operation is of especial advantage in control apparatus of the type disclosed herein, since it functions to prevent the changing value of a controlled condition from getting ahead of the necessary control action required to return the condition to its predetermined value.

Although in practice the changes which occur in controlled variables such as the temperature measured by the element 21 do not necessarily occur in the extensive manner outlined in the above illustrative description, the latter does serve to illustrate the basic operation of the device 45, and shows that anticipatory effects are

produced by the device 45. It is equally true, however, that other, different rates and extents of temperature change will also cause the device 45 to produce desirable anticipatory output signals which in each case will be commensurate with the input signals producing them.

Continuing the description of the operation of the shifting device 45, let it now be assumed that the temperature measured by the element 21 has reached some constant value, but that the bridge circuit 20 is still substantially unbalanced due to the aforementioned temperature change. The bridge output signal caused by bridge unbalance will be producing an input signal to the device 28, and the latter will be causing the rebalancing motor 35 to drive the slidewire contact 24 toward the new bridge balance position. A suitable voltage drop will be present across the resistor 46, due to the charged condition of the condenser 48.

Under the condition being considered, the rebalancing action effected by the motor 35 and contact 24 will be operating to bring the bridge circuit 20 back into the balanced condition, and will, therefore, be causing the bridge output signal to decrease at some rate. Because of the charged condition of the condenser 48, the output signal from the device 45 will be decreasing at a more rapid rate than that at which the input signal is decreasing, as can readily be seen by noting that the output signal will reach its zero value at a time substantially before the instant at which the bridge output signal will be decreased to its zero value as bridge balance is finally reached. An inspection of the circuit of the device 45 clearly shows that the voltage drop across the resistor 46 will cause the signal applied to the input of the device 28 to reach zero while the bridge output signal is still of some finite value. Here again it is evident that the shifting device 45 provides an output signal of anticipatory nature exhibiting amplitude variations which are advanced in time with respect to corresponding input signal variations.

The manner in which the anticipatory nature of the output signal of the device 45 provides a desirable anti-hunting effect is believed to be obvious. Suffice it to say that the reduction to zero of the input signal to the device 28 prior to the attainment of balance in the bridge circuit 20 prematurely deenergizes the rebalancing motor 35 so that the inherent inertia of the motor rotor 38 and associated linkages and elements is then operative to cause the slidewire contact 24 to coast into the position necessary for bridge balance without the occurrence of overshooting and consequent hunting which would otherwise occur if the motor 35 were not deenergized until bridge balance was actually reached. Viewing the situation from another angle, it can be seen that the anticipatory action of the device 45 provides an anticipatory balance point at a time before actual bridge balance is reached, whereby the inertia of the rebalancing mechanism is then operative to bring the bridge into the true balance point instead of causing this point to be overshoot.

In addition to the operation just described, under certain conditions of unbalance, the voltage drop across the resistor 46 will be operative actually to reverse the instantaneous polarity of the input signal to the device 28 with respect to the bridge output signal. This will occur when the magnitude of the voltage drop across the resistor 46 exceeds the magnitude of the bridge output signal, due to the charge-storing action of the

condenser 48. Such a signal of reversed polarity will, of course, appear to the device 28 to be a signal indicative of bridge unbalance in the opposite direction. Such a signal will, therefore, cause the device 28 to energize the motor 35 for rotation in the direction opposite to that in which the motor is already rotating in the then-existing rebalancing operation. Such reverse energization of the motor 35 will obviously assist the normal frictional losses in the rebalancing mechanism to bring the movement of that mechanism to a suitable stop more quickly than when the input signal to the device 28 is merely reduced to zero but is not reversed.

Since the operation just described generally takes place in the presence of a rapidly decreasing bridge unbalance output signal, the additional restraining force exerted on the rebalancing mechanism is produced at a time when it is most needed. This naturally contributes substantially to the effectiveness of the anti-hunting function obtained by virtue of the operation of the shifting device 45.

From the above, it should be readily apparent that the novel shifting device of the present invention in its signal advancing, anti-hunting form 45 provides a highly desirable operative effect in the control apparatus of Fig. 2 while embodying but a minimum of components connected in a relatively simple circuit arrangement. The inclusion in the device 45 of only one switching device for accomplishing both the signal rectifying and modulating functions by means of but a single movable contact member and two cooperating stationary contact members provides a highly useful device of novel form which exhibits outstanding features of simplicity, reliability, compactness, and economy. As should be readily apparent, the device 45 is one which can easily and conveniently be connected into an existing alternating current type control apparatus circuit so as to provide in the latter anti-hunting effects heretofore obtainable only from much more highly complicated, bulkier, and costlier apparatus. Thus the novel shifting device of the present invention in its signal advancing form provides anti-hunting functions in alternating current energized control circuits in a novel, simplified manner requiring the use of a minimum of components connected in a simplified and easily constructed, compact unit.

An additional feature of the shifting device 45 is that the condenser 48 may be made adjustable or variable, if desired, to provide a means for adjusting the magnitude of the signal advancing or anticipatory effect produced by the device. By utilizing a condenser 48 which is capable of adjustment, the shifting device 45 can be adjusted to have the necessary characteristics corresponding to the characteristics of the particular control apparatus with which the device 45 is to be used. Suitable elements of the circuit 1, other than the condenser 48, may be made variable if desired.

There is illustrated in Fig. 3 a modification of the shifting device 45 of Fig. 2 which includes a filtering circuit not included in the Fig. 2 apparatus. Specifically, the device of Fig. 3 has been designated by the reference character 64 and includes a filter reactance or choke 65 which is inserted in the connection between the end of the resistor 15 connected to the conductor 18 and the input terminal 2 of the circuit 1. A filter condenser 66 is connected in Fig. 3 between the terminals 2 and 3 of the circuit 1, and this con-

condenser cooperates with the filter choke 65 to provide a filtering action on the pulsating unidirectional current which results from the operation of the rectifying contacts 6 and 7 of the switching device 5 on the alternating current input signal supplied between the input terminals 11 and 12. The modified circuit shown in Fig. 3 contains all of the elements 1 through 19, 46, 47, and 48 of the Fig. 2 apparatus in addition to the filter components 65 and 66 just described. The filtering action provided by these filter components in the Fig. 3 apparatus provides a unidirectional signal for application to the shifting circuit 1 which contains substantially less alternating current ripple than the corresponding signal in the apparatus of Fig. 2. The use of a well-filtered signal for application to the condenser 48 in the Fig. 3 arrangement leads to somewhat better over-all performance of the apparatus than is obtained with the Fig. 2 arrangement, since the wave form of the output signal appearing between the output terminals 13 and 14 of the Fig. 3 apparatus is of more suitable form than that obtainable with the arrangement of Fig. 2.

In Fig. 4, I have illustrated in block diagram form a typical aircraft control apparatus of the autopilot type as an example of an automatic control apparatus for use with which the novel shifting device of the present invention in its anti-hunting form has especial utility. Since the control arrangement per se shown in Fig. 4 is of a conventional design well known in the art, and forms no part of the present invention, no detailed explanation of the construction or operation of this arrangement appears to be necessary herein. Suffice it to say that the arrangement of Fig. 4 includes a device 67 which functions as a radar receiver, computer, and/or other similar devices, and which receives and transmits suitable radio signals by means of an antenna array 63. The output of the device 67 is an alternating current signal which is applied to the input of a mixer device 69, the latter also having applied to its input circuits the output signals of other apparatus shortly to be described. The output of the mixer 69 is again an alternating current signal which is applied to the input of an anti-hunting device 70 of the type disclosed in either Fig. 2 or Fig. 3. Thus, the device 70 may take the form of the shifting device 45 of Fig. 2, or it may take the form of the improved shifting device 64 of Fig. 3.

The output of the anti-hunting device 70 of Fig. 4 is a modified alternating current signal which bears the same relation to the corresponding input signal as exists between the input and output signals of the device 45 of the Fig. 2 apparatus as described hereinbefore. The output signal from the device 70 is applied to the input of an autopilot device 71, the output of which is applied to the necessary control motors which are generally designated at 72. These motors are mechanically coupled in the well known manner to the corresponding various control elements of the aircraft, not shown, in which the apparatus of Fig. 4 is installed. A conventional follow-up signal is fed from the output of the autopilot unit 71 to the input thereof by means of a feedback path 73.

The Fig. 4 apparatus also includes a rate gyro 74 and a direction or attitude gyro 75. These two gyros are actuated in accordance with the positions and/or motions of the associated aircraft, and their outputs are applied to corresponding inputs of the mixer 69. The latter is operative,

therefore, to mix the gyro output signals with the output signal of the device 67, whereby the mixer output signal is representative of the actual flying condition and course of the aircraft as well as the desired or required condition and course thereof.

It is of course understood that conventional means, not shown, are incorporated to prevent undesirable interaction between the directional gyroscope signal and the computer signal. This may be done, for example, by mechanically or electrically changing the direction of the stabilized axis of the directional gyroscope in accordance with the radio signal.

As to the operation of Fig. 4 apparatus, it need be stated here only that the alternating current output signal of the mixer 69 is operative to control the autopilot unit 71 as necessary to cause the latter to energize the control motors 72 as required to adjust the various controlled elements of the aircraft in the manner necessary to maintain the flight of the latter along a desired course. Departures from this course are detected by the device 67 by means of either radio beacon or radar or both, and such departures cause energization of the autopilot unit 71 which then in turn energizes the control motors 72 as necessary to return the aircraft to said course. The resulting changes in flight characteristics of the aircraft produce suitable reactions on the gyros 74 and 75, and the output signals of the latter operate through the mixer 69 to control the autopilot unit 71 in a follow-up manner so that the control actions of the motors 72 will be in the proper direction and of the correct magnitude. When the aircraft has subsequently been returned to its proper course as determined by the device 67, further adjustments of the controlled elements by the control motors may be made if necessary to maintain thereafter the proper course for the aircraft.

The anti-hunting device 70 of the Fig. 4 apparatus provides an anti-hunting action in this apparatus which is analogous to the action provided by the device 45 in the apparatus of Fig. 2. Specifically, the device 70 of Fig. 4 supplies to the autopilot unit 71 advanced or anticipatory signals which are operative to stabilize the control actions effected by the control motors 72. For example, when a turn is being made, the device 70 will cause the control motors 72 to be deenergized just prior to the completion of the necessary adjustments of the controlled elements utilized in making the turn, whereby those elements will be brought into their correct positions by the inertia of the moving mechanisms. From this it can readily be seen that unstable, hunting operation of the control apparatus of Fig. 4 is avoided by the use of the device 70 in the same manner as the device 45 of Fig. 2 renders the control apparatus thereof free from hunting effects.

From the above it is evident that the device 70 of Fig. 4 constitutes what may well be called a response corrector for use with automatic aircraft control equipment. In other words, the device 70 constitutes means which can be properly designed to coordinate the inherent characteristics of a given automatic control system with the inherent flying characteristics of a given aircraft. Further, by making the condenser 48 adjustable or variable in the device 70, there is obtained a compensating or coordinating device which can be utilized for coordinating a given control apparatus to any one of a number of different aircraft having different flying characteristics, the

coordination of the apparatus with each of the different forms of aircraft being effected in a simple, straight-forward manner by the suitable adjustment of the condenser 48 in the device 70.

It should be readily apparent that the features of simplicity, reliability, compactness, and light weight exhibited by the novel shifting device of the present invention make this device highly advantageous for use in aircraft in the manner described above where apparatus must be as simple, reliable, compact, and light in weight as possible without sacrificing the quality of the operation obtained.

Fig. 5 illustrates in block diagram form a typical electronic analogue apparatus useful for the analysis of various heating systems. The Fig. 5 arrangement is illustrated herein as one in which the novel shifting device of the present invention is operative in its signal retarding form to provide desirable time delay effects. In electronic heating system analogue apparatus, it is customary to employ suitable devices for simulating the heat lags encountered in practice in the systems being analyzed, and the signal retarding form of the shifting device of Fig. 1 is well adapted for use as such a heat lag simulating device.

Fig. 5 includes a heat supply controller 76 which is analogous to a controlled boiler and burner combination or other similar source of controlled heat energy. The alternating current output signal of the device 76 is applied to the input of a heat supply amplifier 77 wherein the signal is amplified and applied to the input of a heat conveyance lag device 78 which is employed to simulate the lag which occurs in practice in the transfer or conveyance of heat from the heat source to the heated space or room. The device 78, which will be described in detail in connection with its illustration in Fig. 6, includes the shifting device of Fig. 1 in its signal retarding, time delay or time lag form. For the present, let it be stated merely that the alternating current output signal of the device 78 is applied to the input of a heat conveyance amplifier 79, wherein the signal is amplified and applied to a mixing device 80.

This input signal applied to the mixer 80 is a heat supply rate signal, and is representative of the rate of heat supply to the heated space or room of the system being simulated. Applied also to the input of the mixer 80 is an alternating current heat loss rate signal provided by apparatus to be described hereinafter. The alternating current output signal of the mixer 80 is the algebraic summation of the heat supply rate and heat loss rate signals, and is applied to the input of a room heat lag device 81. The latter is employed to simulate heat lags associated with the particular heated space of the simulated system and with the particular type of heating system being considered. The device 81 includes apparatus which may well be identical to the apparatus included in the device 78 and, therefore, includes a signal retarding form of the shifting circuit of Fig. 1. Since the device 81 may be assumed to be identical to the device 78, the subsequent description of the latter in connection with its illustration in Fig. 6 will serve also to describe the details of the device 81.

For the present, let it merely be stated that the alternating current output signal from the device 81 is applied to an integrator 82 which integrates the modified heat summation signal from the mixer 80 so as to provide an output signal which is representative of the temperature of the

heated space or room of the simulated system. This room temperature signal is utilized to actuate a room temperature indicator 83, and is also utilized to control the rate of heat output of the device 76. Accordingly, the room temperature signal controls the device 76 in a manner analogous to that in which the temperature of an actual room actuates a thermostat to control the heat output of an associated burner and boiler or equivalent combination.

In addition to the elements described above, the analogue apparatus of Fig. 5 also includes various devices for introducing into the apparatus various signals which are representative of corresponding conditions which, in practice, affect the operation of the heating system being simulated. To this end, the Fig. 5 apparatus includes an outside temperature mixer 84, a construction loss signal multiplier 85, an infiltration loss signal multiplier 86, wind velocity signal multipliers 87 and 88, a heat loss signal adder 89, a solar heat signal mixer 90, and a heat loss amplifier 91.

To the input of the mixer 84 is applied an outside temperature signal the magnitude of which is adjusted to conform to that of the outside temperature of the simulated system. Also applied to the input of the mixer 84 is the aforementioned room temperature signal, and the mixer 84 is operative to provide an output signal which is the algebraic difference of the room temperature and outside temperature signals. The output signal of the mixer 84 is applied to the input of the multiplier 85 to which is also applied a construction loss signal the magnitude of which corresponds to the contemplated heat loss due to the particular type of construction of the structure containing the heated space of the simulated system. The output signal of the multiplier 85 represents the mathematical product of the output signal of the mixer 84 and the construction loss signal.

An infiltration loss signal is applied to the input of the multiplier 86, the magnitude of this signal being made to correspond to the expected infiltration heat loss present in the simulated system. To the input of the multiplier 86 is supplied also the output signal of the mixer 84, whereby the output signal of the multiplier 86 is representative of the mathematical product of the infiltration loss signal and the output signal of the mixer 84.

To the input of the multiplier 87 is supplied a wind velocity signal the magnitude of which is made to correspond to the wind velocity associated with the structure of the simulated system. To the input of the multiplier 87 is applied also the output signal of the multiplier 86, and the output signal of the multiplier 87 is therefore representative of the mathematical product of the wind velocity signal and the output signal of the multiplier 86. Similarly, the wind velocity signal is applied to the input of the multiplier 88 along with the output signal of the multiplier 85. The output signal of the multiplier 88 is representative of the mathematical product of the wind velocity signal and the output signal of the multiplier 85.

The output signals of the multipliers 87 and 88 are applied to the input of the adder 89, the output signal of which represents the algebraic summation of the two input signals. The output signal of the adder 89 is applied to the input of the mixer 90 to which is applied also a solar heat signal the magnitude of which is made to

correspond to the solar heat expected to be associated with the structure of the simulated apparatus. The output of the mixer 90 is representative of the algebraic summation of the solar heat signal and the output signal of the adder 89, and the output signal of the mixer 90 is applied to the input of the heat loss amplifier 91, the output of which is the aforementioned heat loss rate signal which is applied to the input of the mixer 90.

Summarizing the above, it is seen from Fig. 5 that the signal representing the difference between the room and outside temperatures is effectively multiplied by the construction and infiltration loss signals, each resulting product being multiplied by the wind velocity signal. The resulting signal products are added together and to the solar heat signal, and the resultant signal is amplified in the heat loss amplifier 91 and applied to the input of the mixer 90.

As to the operation of the apparatus of Fig. 5, it is believed to be sufficient to state herein that the analogue apparatus is set up to simulate a given, desired heating system by adjusting the magnitudes of the various input signals to correspond to the magnitudes of the actual physical conditions being simulated. As shown in Fig. 5, the lag devices 78 and 81 are provided with adjusting knobs 92 and 92', respectively. By adjusting the knob 92 of the device 78, the magnitude of the time lag introduced by the device 78 can be controlled, whereby the device 78 can be adjusted to provide the correct degree of simulated heat conveyance lag for the particular system being studied. Similarly, adjustment of the lag device 81 by its knob 92' permits the device 81 to be adjusted so as to provide the correct amount of simulated room heat lag for the simulated heating system.

After the signals representing the various effects on the simulated system have been adjusted to desired values, and after the lag devices 78 and 81 have been adjusted to provide the desired simulated heat lags, the operation of the actual heating system under actual operating conditions can be studied by observing the operation of the analogue apparatus under the corresponding conditions. Also, the various signals and adjustments of the analogue apparatus can be changed as desired so that a study can be made of the operation of the actual heating system under various, changing conditions.

In Fig. 6 there is shown the circuit of the heat conveyance lag device 78 of Fig. 5 which includes the novel signal retarding or time delay form of the shifting device of Fig. 1. The Fig. 6 arrangement could also represent the room heat lag device 81 of Fig. 5, since the devices 78 and 81 may be identical. However, I have chosen to illustrate in Fig. 6 the device 78, and the Fig. 6 arrangement is therefore so identified.

With reference to Fig. 6, it can be seen that the heat lag device 78 includes a signal retarding or time delay circuit 93 which, as noted above, is the shifting device of Fig. 1 in its time delay form. The device 93 includes all of the elements 1 through 19 of the Fig. 1 device, and in addition includes in the shifting circuit 1 a resistor 94, a variable condenser 95, and a resistor 96. The resistors 94 and 96 are connected in series between the terminals 2 and 4 of the circuit 1, and the condenser 95 is connected between the terminal 3 and the junction between the resistors 94 and 96. The knob 92 of Fig. 5 is shown connected by a suitable linkage 97 to the variable

condenser 95, whereby adjustments given to the knob 92 adjust the capacity of the condenser 95 and hence adjust the degree of time delay to be introduced by the device 93.

The Fig. 6 arrangement also includes an input amplifier including an electron tube 98 of the triode type having an anode, a control grid, a cathode, and a cathode heater. Also included in the Fig. 6 arrangement is a coupling circuit including an electron tube 99 of the triode type having an anode, a control grid, a cathode, and a cathode heater. The input amplifier and coupling circuit also include various other components to be described hereinafter. Finally, the Fig. 6 heat lag device 78 includes the transformer 42 of Fig. 2 which supplies alternating energizing current to the switching device 5 of the device 93 from the supply conductors 57 and 58 in the same manner as for the Fig. 2 arrangement.

In the input amplifier of the Fig. 6 apparatus, an input terminal 100 is connected through a coupling condenser 101 to the control grid of the triode 98. A second input terminal 102 is connected to a common ground point in the apparatus, as is the cathode of the triode 98. A grid resistor 103 is connected between the control grid and cathode of the triode 98 in the usual manner.

The anode of the triode 98 is connected through an anode load resistor 104 to the positive terminal of a source of anode supply voltage, shown in Fig. 6 as a battery 105. The negative terminal of the latter is connected to ground. A coupling condenser 106 connects the anode of the triode 98 to the input terminal 11 of the lag device 93, the input terminal 12 of which is connected to ground and hence to the cathode of the triode 98.

The output terminal 13 of the device 93 is connected to the control grid of the triode 99, the cathode of which is connected to ground through a cathode resistor 107. A grid resistor 108 is connected between the control grid of the triode 99 and ground. The anode of the triode 99 is connected to the positive terminal of a source of anode supply voltage, shown in Fig. 6 as a battery 109. The negative terminal of the latter is connected to ground.

The output of the device of Fig. 6 is taken from across the cathode resistor 107, whereby the coupling circuit functions as a cathode follower. To this end, an output terminal 110 is connected to the cathode of the triode 99, while an output terminal 111 is connected to the grounded end of the resistor 107. The cathode heaters of the triodes 98 and 99 are supplied with suitable energizing current from a suitable source, not shown in the drawing.

In the use of the Fig. 6 heat lag device in the analogue apparatus of Fig. 5, the alternating current output signal of the heat supply amplifier 77 is applied between the input terminals 100 and 102 of the device 78. The resulting alternating current output signal from the device 78 appears between the terminals 110 and 111 and is applied to the input of the heat conveyance amplifier 79 of Fig. 5.

In the operation of the heat conveyance lag device 78, the input amplifier including the triode 98 functions in the usual manner to apply between the terminals 11 and 12 an amplified form of the input signal impressed between the input terminals 100 and 102. By way of illustration and example, let it be assumed that a signal of a

given, constant magnitude is impressed on the input terminals 100 and 102, whereby a signal of constant magnitude appears between the terminals 11 and 12. Assuming also that this condition has prevailed for a sufficient length of time, it can readily be seen that the condenser 95 will have thereon a definite charge, determined by the values of the circuit components and the magnitude of the input signal. The latter, through an alternating current signal, is able to so charge the condenser 95 by virtue of the above described synchronous rectifying action provided by the switch contacts 6 and 7.

The aforementioned modulating action of the switch contacts 6 and 8 impart an alternating current component to the voltage appearing across the condenser 95, which voltage is determined by the magnitude of the charge on the condenser. The blocking condenser 17 passes to the output terminals 13 and 14 only the alternating current signal component just mentioned, and the latter is passed from the terminals 13 and 14 through the coupling circuit to the output terminals 110 and 111. When the input signal to the apparatus is at a constant value as just assumed, the output signal will also have a constant value which can be made to be equal to the input signal value by arranging the input amplifier to have sufficient gain to make up for signal transmission loss through the device 93.

The device 93 of Fig. 6 imposes no appreciable phase shifting effects on the individual alternations which constitute the normal alternating current input signal impressed on the device. As in the case of the shifting arrangement of Fig. 2, the values of the components of the device 93 of Fig. 6 are so chosen as to cause the device to have appreciable phase shifting effects on only relatively slow variations in the applied input signal.

It should be mentioned herein that either or both of the input amplifier and coupling circuit portions of the Fig. 6 apparatus may be omitted under appropriate conditions without affecting the basic time lag or time delay operation of the device 93.

Let it now be assumed that a sudden, appreciable change takes place in the input signal impressed between the terminals 100 and 102, whereby this signal increases rapidly to a new, higher value at which it thereafter remains constant. Because of the charge on the condenser 95 and the electrical inertia of the condenser, the magnitude of the output signal developed between the terminals 110 and 111 cannot follow the input signal change, but can only start to increase at a relatively slow rate, this rate being determined by the adjusted capacity of the condenser 95, other values remaining constant. After a certain time, however, the magnitude of the output signal will have increased to its maximum value, corresponding to the new, higher value of the input signal. Since the time required for the output signal to reach its maximum value is a function of the rate of change of this signal, it is apparent that the time required for the effect of a change in the input signal to appear in the output signal is determined by the adjustment of the condenser 95. Accordingly, the device 93 is operative to produce an alternating current output signal exhibiting amplitude variations which are retarded or delayed with respect to time relative to corresponding alternating current input signal variations. The manner in which such retarding or delaying of the effects of input signal

changes serves in the analogue apparatus of Fig. 5 to simulate heat lags or delays in heat conveyance is believed to be obvious.

From the above it should be clearly apparent that the device 93 of Fig. 6 constitutes a simple and highly effective means for producing adjustable delay effects of desired magnitude in an alternating current signal. It should also be noted that elements other than the condenser 95 may be made variable if desired for the purpose of adjusting the time constant of the shifting circuit 1 for varying the magnitude of the time delay effect produced thereby. It should be noted further that the filter arrangement illustrated in Fig. 3 may be employed in the Fig. 6 shifting circuit if desired.

While, in accordance with the provisions of the statutes, I have illustrated and described the best forms of my invention now known to me, it will be apparent to those skilled in the art that changes may be made in the forms of the apparatus disclosed without departing from the spirit of my invention as set forth in the appended claims, and that in some cases certain features of my invention may sometimes be used to advantage without a corresponding use of other features.

Having now described my invention, what I claim as new and desire to secure by Letters Patent, is as follows:

1. A device for shifting with respect to time the effects of amplitude variations in an alternating current signal comprising a shifting circuit having an input portion, an output portion, and electrical shifting components connected between said portions and including a condenser, a pair of input terminals adapted to have applied therebetween an alternating current input signal exhibiting variations in amplitude, said variations occurring at rates substantially lower than the frequency of said signal, a synchronous switching device having a rectifying portion including a movable contact and a first cooperating stationary contact, having a modulating portion including said movable contact and a second cooperating stationary contact, and having a driving portion operative, when supplied with energizing current, to move said movable contact into and out of engagement with each of said stationary contacts, alternately, at a rate corresponding to the frequency of said energizing current, means adapted to connect said driving portion to a source supplying energizing current which is in synchronism with said input signal, connections between said input terminals and said input portion including said rectifying portion, whereby the rectified form of said input signal is applied to said input portion, a pair of output terminals, and connections between said output portion and said output terminals including said modulating portion, the values and connections of said components of said shifting circuit being so chosen that the latter is operative to apply between said output terminals an alternating current output signal exhibiting variations in amplitude corresponding to the amplitude variations in said input signal but shifted in time with respect to the last mentioned variations.

2. A device as specified in claim 1, wherein said input portion includes a first terminal and a common terminal between which said rectified form of said input signal is applied, wherein said output portion includes a second terminal and said common terminal between which said shift-

ing circuit impresses a unidirectional output signal, and wherein said condenser is connected between said first and second terminals, whereby said output signal amplitude variations are shifted ahead or advanced in time with respect to the corresponding input signal amplitude variations.

3. A device as specified in claim 2, wherein one of said shifting components is a first resistor, wherein another of said shifting components is a second resistor, and wherein said first resistor is connected in parallel with said condenser, and said second resistor is connected between said second and common terminals.

4. A device as specified in claim 3, wherein there is included a filter circuit connected between said input terminals and said input portion, whereby the rectified form of said input signal is subjected to a filtering action before application to said input portion.

5. A device as specified in claim 4, wherein said filter circuit includes a filter reactance connected between one of said input terminals and said first terminal, and includes a filter condenser connected between said first and common terminals.

6. A device as specified in claim 1, wherein said input portion includes a first terminal and a common terminal between which said rectified form of said input signal is applied, wherein said output portion includes a second terminal and said common terminal between which said shifting circuit impresses a unidirectional output signal, and wherein said condenser is connected between said second and common terminals, whereby said output signal amplitude variations are shifted behind or delayed in time with respect to the corresponding input signal amplitude variations.

7. A device as specified in claim 6, wherein one of said shifting components is a first resistor, wherein another of said shifting components is a second resistor, and wherein said first resistor is connected in series between one terminal of said condenser and said first terminal, and said second resistor is connected between said one terminal and said second terminal, the remaining terminal of said condenser being directly connected to said common terminal.

8. A device as specified in claim 7, wherein there is included a filter circuit connected between said input terminals and said input portion, whereby the rectified form of said input signal is subjected to a filtering action before application to said input portion.

9. A device as specified in claim 8, wherein said filter circuit includes a filter reactance connected between one of said input terminals and said first terminal, and includes a filter condenser connected between said first and common terminals.

10. A device for shifting with respect to time the effects of amplitude variations in an alternating current signal comprising a shifting circuit having an input portion including a first terminal and a common terminal, having an output portion including a second terminal and said common terminal, and having electrical shifting components connected between said portions and including a condenser, a pair of input terminals adapted to have applied therebetween an alternating current input signal exhibiting variations in amplitude, said variations occurring at rates substantially lower than the frequency of said signal, a synchronous switching device having a rectifying portion including a movable contact and a first cooperating stationary contact, 75

having a modulating portion including said movable contact and a second cooperating stationary contact, and having a driving portion operative, when supplied with energizing current, to move said movable contact into and out of engagement with each of said stationary contacts, alternately, at a rate corresponding to the frequency of said energizing current, means adapted to connect said driving portion to a source supplying energizing current which is in synchronism with said input signal, a connection between one of said input terminals, said first terminal, and said first contact, a connection between the other of said input terminals, said common terminal, and said movable contact, whereby the rectified form of said input signal is applied to said input portion, a connection between said second terminal, one of said output terminals, and said second contact, and a connection between said common terminal and the other of said output terminals, the values and connections of said components of said shifting circuit being so chosen that the latter is operative to apply between said output terminals an alternating current output signal exhibiting variations in amplitude corresponding to the amplitude variations in said input signal but shifted in time with respect to the last mentioned variations.

11. A device as specified in claim 10, wherein one of said shifting components is a first resistor, wherein another of said shifting components is a second resistor, and wherein said condenser and said first resistor are connected together in parallel between said first and second terminals, and said second resistor is connected between said second and common terminals, whereby said output signal amplitude variations are shifted ahead or advanced in time with respect to the corresponding input signal amplitude variations.

12. A device as specified in claim 10, wherein one of said shifting components is a first resistor, wherein another of said shifting components is a second resistor, and wherein said first and second resistors are connected in series between said first and second terminals, and said condenser is connected between said common terminal and the junction between said first and second resistors, whereby said output signal amplitude variations are shifted behind or delayed in time with respect to the corresponding input signal amplitude variations.

13. In control apparatus of the self-balancing electronic type including a balanceable alternating current network operative to be unbalanced by changes in the value of a variable condition and operative, when unbalanced, to produce an alternating current output signal having a magnitude and phase respectively dependent upon the extent and direction of network unbalance, electronic amplifying and motor control means having an input portion to which said output signal is applied and having an output portion operative to supply actuating current to a reversible electric motor for operation of the latter to an extent and in a direction respectively dependent upon the magnitude and phase of said output signal, and network rebalancing means controlled by said motor and operative to utilize said motor operation to rebalance said network when the latter is unbalanced, the improvement comprising an anti-hunting signal shifting device electrically connected in series between said network and the input portion of said amplifying and motor control means, said device comprising a pair of input terminals between which said out-

put signal is applied, a pair of output terminals connected to the input portion of said amplifying and motor control means, a first resistor connected between one of said input terminals and a first junction, a shifting condenser connected between said first junction and a second junction, a blocking condenser connected between said second junction and one of said output terminals, a second resistor connected between said first and second junctions, a third resistor connected between said second junction and a common connection between the other of said input terminals and the other of said output terminals, a synchronous switching device having a movable contact, first and second cooperating relatively stationary contacts, and a driving portion operative, when supplied with energizing current, to move said movable contact into and out of engagement with each of said stationary contacts,

alternately, at a rate corresponding to the frequency of said energizing current, means adapted to connect said driving portion to a source supplying energizing current which is in synchronism with said output signal, a connection between said first contact and said first junction, a connection between said second contact and said second junction, and a connection between said movable contact and said common connection, whereby said anti-hunting device is operative to effect anticipatory, anti-hunting actions in said apparatus.

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