

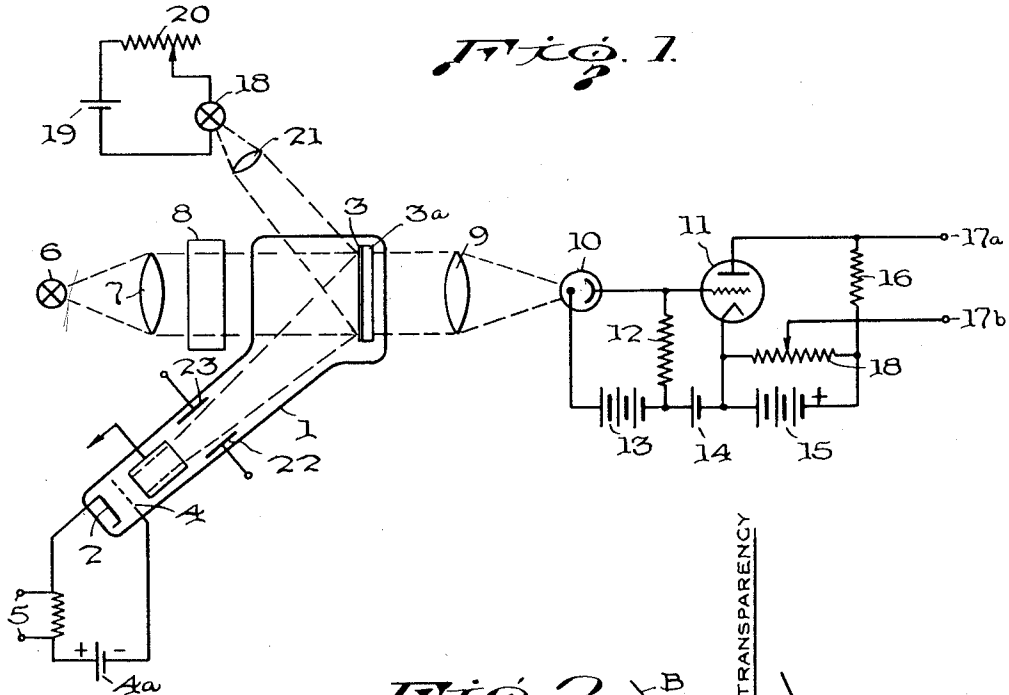
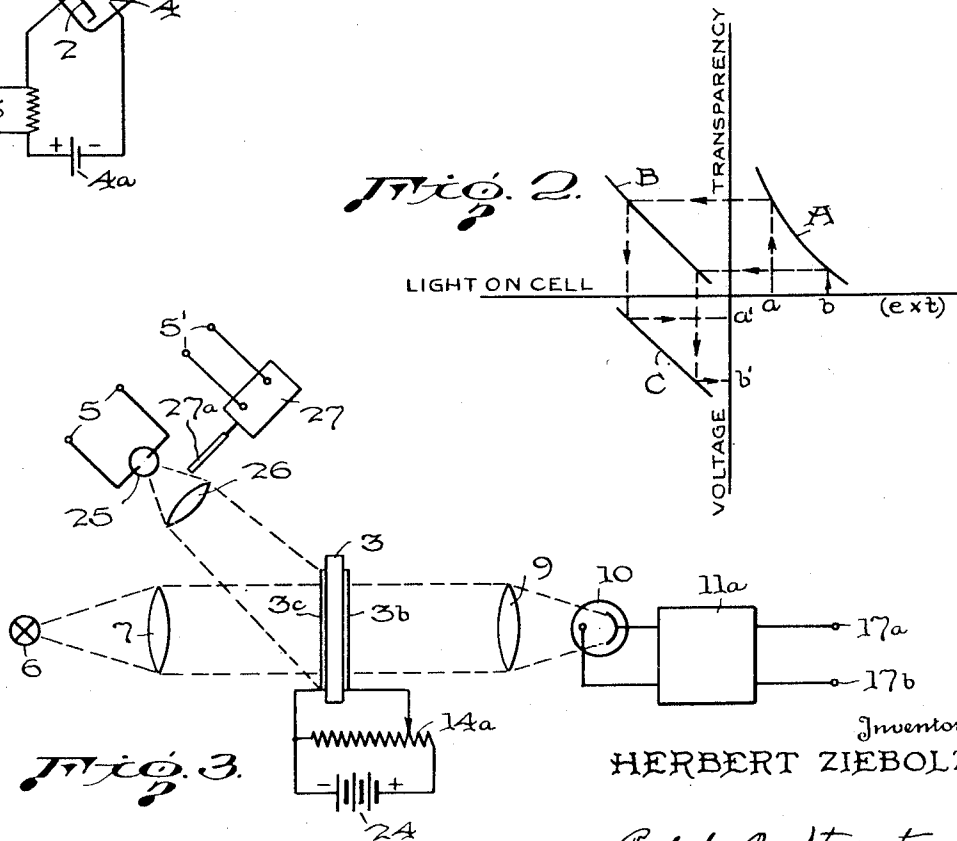
Oct. 2, 1951

H. ZIEBOLZ
SIGNAL STORING DEVICE AND PROPORTIONAL
CONTROL CIRCUITS THEREFOR

2,569,911

Filed Dec. 18, 1944

2 Sheets-Sheet 1



Inventor
HERBERT ZIEBOLZ

Ralph B. Stewart

Attorney

Oct. 2, 1951

H. ZIEBOLZ
SIGNAL STORING DEVICE AND PROPORTIONAL
CONTROL CIRCUITS THEREFOR

2,569,911

Filed Dec. 18, 1944

2 Sheets-Sheet 2

Fig. 4.

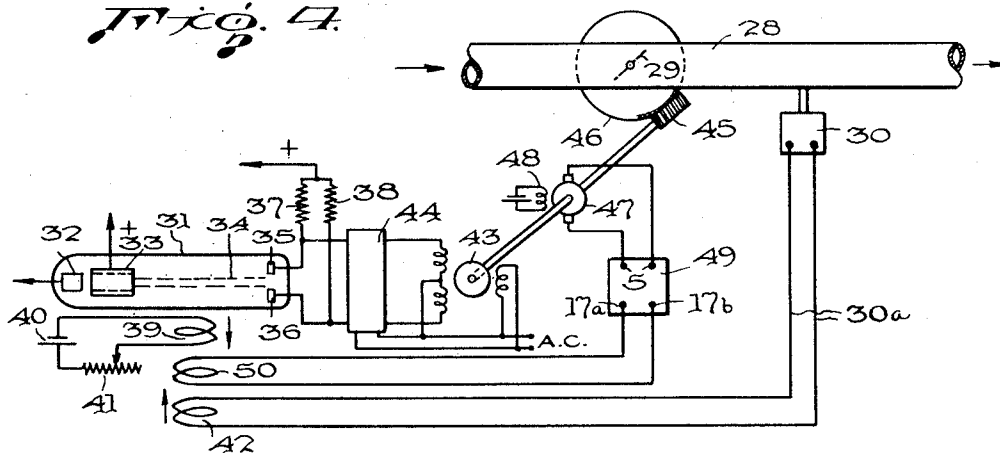
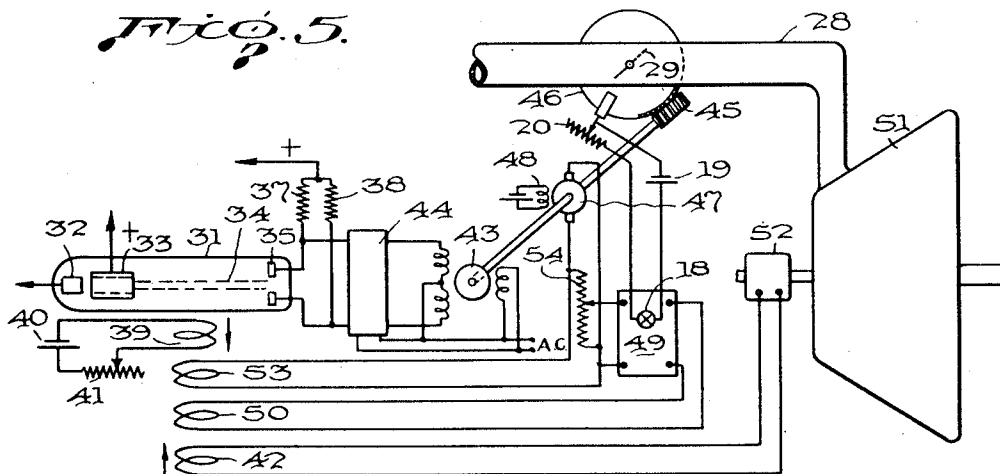


Fig. 5.



Inventor
HERBERT ZIEBOLZ

By *Ralph B. Stewart*

Attorney

UNITED STATES PATENT OFFICE

2,569,911

SIGNAL STORING DEVICE AND PROPORTIONAL-CONTROL CIRCUITS THEREFOR

Herbert Ziebolz, Chicago, Ill., assignor to Electronbeam, Ltd., Chicago, Ill., a partnership of Illinois

Application December 18, 1944, Serial No. 568,751

15 Claims. (Cl. 137-158)

1

This invention relates to signal storing devices by which signals may be stored or recorded, and to regulating systems of the proportional control type incorporating such signal storing devices.

The signal storing device of my invention is also useful as a time delay circuit.

Another use for the invention is for integrating the effect of a signal or force acting over a certain time.

My invention involves a photocell circuit which receives light from a normally constant source, and a light modulating device interposed between the cell and the source to vary the light transmitted to the cell in accordance with a controlling signal or force. The light modulating device is formed of a normally transparent substance which when subjected to certain forms of radiant energy from the signal source becomes opaque or clouded to a varying degree depending upon the intensity of the radiant energy and the time during which the radiant energy is acting on the substance. The invention also involves a source of radiant energy for acting on the substance of the light valve to erase the opacity or to restore the substance to its original condition.

In certain respects my signal storage device acts in the same manner as an electric condenser in being charged through a resistance, that is, when an input signal of a given value is applied to the device, the output voltage increases with time and in proportion to the value of the input signal, in a manner similar to the increase in voltage across a condenser which is being charged through a resistance by a given current. When the restoring energy is applied to the storage device, the action is somewhat like a condenser being discharged through a resistance circuit. The time required for the output current or voltage to drop to zero is dependent upon the intensity of the restoring energy and on the time during which the energy is applied.

My signal storing devices are capable of many uses but are especially useful in regulating systems of the proportional control type, as will appear hereinafter.

The invention is illustrated in the accompanying drawing in which

Figure 1 is a diagrammatic showing of one form of the storage device;

Figure 2 is a set of curves illustrating the operation of Figure 1;

Figure 3 is a diagram illustrating a modified form of the storage device;

2

Figure 4 is a diagrammatic showing of a pressure regulator system of my invention employing the storage device; and

Figure 5 is a diagrammatic showing of a speed regulating system using the storage device, which constitutes another embodiment of my invention.

Referring to the drawing, 1 indicates an electron discharge tube which embodies a suitable electrode arrangement for producing a beam of electrons originating at cathode 2 and being directed upon an electron sensitive layer 3 formed on the front face of a transparent plate 3a. The intensity of the electron beam is controlled by a grid 4 the potential of which is varied in accordance with signals applied to input terminals 5. In the absence of input signals the electron beam is cut off by a negative potential applied to the grid from a suitable biasing source 4a.

The electron sensitive layer 3 is formed of a crystalline substance selected from the alkali and alkali earth halides, such as the chlorides, bromides and iodides of sodium and potassium, lithium bromide, calcium fluoride, strontium fluoride and strontium chloride. Preferably a mixture of potassium bromide and potassium hydride is employed in proportions of 1000 to 1. This mixture becomes black or dark blue under the influence of fast electrons.

The light sensitive element may be formed of a single flat crystal, in which case there will be no need for the plate 3a, or it may be formed as a mosaic of small crystals or as a micro-crystalline layer.

6 indicates a source of normally constant light from which a beam of rays is collected by an optical condenser 7 and directed through a suitable heat filter 8 onto the electron sensitive layer 3. The rays which pass through the light valve are collected by a condenser 9 and are directed upon a photocell 10 which is included in the input circuit of a vacuum tube amplifier 11. The photocell is connected in the input circuit of the amplifier by means of a coupling resistance 12 which is connected in series with the cell through a battery 13. A source of biasing voltage 14 is also inserted between the cathode and the grid of tube 11. The plate circuit of tube 11 includes a source of potential 15 and a coupling resistance 16 in series. One output terminal 17a is connected to the plate of tube 11 and the other terminal 17b is connected to a movable contact on potentiometer 18 connected in shunt to source 15. With full light on cell 10 and no signal applied to input terminals 5, potentiometer 18 is adjusted until there is no output voltage across terminals 17a-17b.

Operation of Figure 1 is as follows: Normally the layer 3 is transparent and the maximum light falls on cell 10 which results in zero output voltage at terminals 17a—17b. When a signal of predetermined intensity is applied to input terminals 5, the layer 3 will be bombarded by electrons of an intensity determined by the value of the signal. This bombardment causes the layer to become increasingly opaque in accordance with the intensity of the electron bombardment and the time during which the bombardment acts. Thus, the output voltage of the amplifier will increase with time and in proportion to the value of the input signal.

The set of curves shown in Figure 2 will illustrate the operation of Figure 1. The horizontal axis to the right of the origin is expressed in terms of $e \times t$ where e is the value of applied signal and t is the time during which the signal acts. The vertical axis above the origin is calibrated in terms of transparency of the layer 3. The horizontal axis to the left of the origin is calibrated in terms of light falling on the cell 10, and the vertical axis below the origin is calibrated in terms of voltage at the output terminals of the storage device. Curve A shows the relation between the et value and the transparency of the layer 3. Curve B shows the relation between the transparency of the layer 3 and the light received by the cell 10, while curve C indicates the relation between the light acting on cell 10 and the voltage at the output terminals. Thus, where the et product has a value equal to a , the output voltage has a value equal to a' and may be determined by drawing the dotted lines through the three curves as shown in Figure 2 starting from the point a . In a like manner, where the et product has a value b , the output voltage will have a value b' . From Figure 2 it will be seen that as the et product increases, the output voltage also increases.

The layer 3 will retain its semi-transparent or opaque condition even after the signal ceases to act, and the voltage at the output terminals will continue to be effective unless the transparency of the layer is restored. Depending on the nature of the layer 3, the transparency may be restored by heating the layer or by subjecting it to the action of radiant energy of a different wave length from that of source 6. In Figure 1 I have shown a source of infra-red radiation represented by the electric light 18 energized from a suitable source 19 through an adjustable resistance 20. Rays from the source 18 are collected by an optical system 21 and projected upon the layer 3. The time required to restore transparency of the layer will be dependent upon the intensity of the erasing rays. Thus, the time required for the output voltage to die down to zero after discontinuance of the input signal will depend upon the value of the erasing energy and may be varied by changing the value of this energy.

Instead of controlling the intensity of the electron beam bombarding the layer 3, suitable beam deflecting means such as deflecting plates 22 and 23 may be energized normally to deflect the beam to one side of the layer 3, and the input signal would be impressed upon the deflecting means to deflect the beam onto a varying portion of the layer 3 depending on the strength of the signal.

Instead of arranging the cathode ray tube so that the beam is cut off in the absence of a signal, the grid 4 may be biased normally to a potential such that the beam has an intensity

of a given value and input signals of one polarity will increase the intensity of the beam while signals of opposite polarity will decrease the intensity of the beam. In this case also, the output potentiometer will be adjusted to produce zero output voltage in the absence of signals, and the output voltage will vary in polarity in accordance with the polarity of the input signal.

In most cases, and especially where the material is in the form of a single crystal, the opacity of the material seems to be due to an opaque deposit within the crystal structure which can be caused to move within the crystal by the application of an electric field. Furthermore the opaque deposit can be made to disappear by subjecting the crystals to an electric field at a suitable temperature, the deposit being drawn through the crystal towards the positive pole producing the field and it thereupon disappears leaving the crystal substantially transparent. The speed of movement of the deposit depends upon the strength of the electric field and upon the temperature of the crystal, and this speed may be varied by varying either the field or the temperature. For a given strength of field, the movement increases with increase in temperature of the crystal.

In Figure 3 I have shown an arrangement in which the opaque deposit is erased or removed by means of an electric field instead of by infra-red rays as in Figure 1. In this arrangement, the light valve consists of a flat crystal 3 formed of an alkali halide such as potassium chloride and is provided with a pair of thin metallic electrodes 3b and 3c on opposite faces thereof. These electrodes are formed of thin transparent metallic layers deposited in any suitable manner, but they may also be formed of fine wire netting or mesh. The electrodes 3b and 3c are maintained at a difference of potential from a suitable source represented by the battery 24. This potential may be adjusted by means of a potentiometer 14a.

Figure 3 also illustrates a further variation of Figure 1 in that instead of using electrons to produce the opaque deposit within the crystal, light rays of a different wave length from the source 6 are employed for this purpose. For example, a vapor lamp 25 is employed to provide a source of light of lower wave length than the source 6, which might conveniently be formed of an incandescent lamp producing a longer wave length than the source 25, and if necessary, suitable filters may be interposed between the two sources to limit the radiations to the desired separated bands. The lamp 25 may be suitably energized or modulated by applying the input signal to the terminals 5. A lens system 26 collects rays from the source 25 and directs them against the front face of crystal 3 which causes the opaque deposit to be formed on the front face of the crystal in accordance with the intensity of the rays from the source 25. The voltage applied between transparent plates 3b and 3c causes this deposit to travel through the crystal towards the plate 3b, and the time required to pass through the crystal is dependent upon the potential difference maintained between the two plates and on the temperature of the crystal. As soon as the deposit reaches the positive pole 3b it disappears and the crystal is restored to its original transparency, assuming that no signal is impressed on terminals 5. The operation of the photocell circuit is the same as in the case of Figure 1.

Instead of energizing the lamp 25 in accordance with the applied signals, this lamp may be energized continuously, and the amount of light transmitted to the crystal 3 may be varied by any suitable light valve represented at 27 and having a movable shutter 27a which cuts off a varying amount of the rays which fall upon the crystal 3 from the source 25. The shutter 27a may be positioned normally so that for zero signal it either shuts off the light from source 25 or admits the light fully. In either case, potentiometer 18 of the amplifier would be adjusted to obtain a condition of no output voltage for no input signal.

From the foregoing it is clear that the arrangements shown in Figures 1 and 3 are useful in various applications requiring delayed action of a relay, or in situations requiring a storage effect such as that obtained in an ordinary condenser. Also, these devices will be useful in certain applications in the control field where it is desirable to have the stored signal disappear as a function of time.

In Figure 4 I have shown one application of devices of the type shown in Figures 1 and 3 as applied to a system for regulating the flow of fluids in a conduit. In this arrangement, 28 indicates a supply pipe for supplying fluid, such as gas or liquid, under pressure to any suitable apparatus which requires a constant pressure of the fluid supply. It will be understood that the fluid pressure supplied to the apparatus is subject to change, either by reason of changes in the pressure of the source of fluid or by changes in the consuming apparatus, and the problem is to maintain a constant pressure at the intake of the apparatus. For the purpose of regulating the pressure a control valve 29 is positioned in the pipe 28 and a suitable pressure responsive device 30 is connected to the pipe 28 between the valve 29 and the consuming apparatus. The device 30 responds to the pressure in the pipe 28 and produces a direct current or voltage in its output circuit 30a proportional to the pressure applied to the device. Such devices are well known and the details need not be described. The current produced by device 30 is employed to control the deflection of the beam of the cathode ray tube.

The cathode ray tube may be of any known construction but for the purpose of illustration it consists of an insulating envelope 31 enclosing an electron gun structure represented at 32 which supplies an electron beam which passes through a perforated anode 33 which is maintained at a positive potential with respect to the gun. The cathode ray beam is represented by the dotted lines 34 and is directed towards target anodes 35 and 36 positioned in the opposite end of the tube from the gun 32. Anodes 35 and 36 are maintained at a positive potential by connections to a suitable source through coupling resistances 37 and 38. Beam deflecting means represented by coil 39 is provided for fixing the initial position of the beam, and this coil is energized by an adjustable current from a suitable source represented by battery 40 through resistance 41. The output of pressure responsive device 30 is connected to energize a second beam deflecting means represented by the coil 42, and this coil tends to deflect the beam in the opposite direction from coil 39. It will be understood that both

deflecting means tend to shift the beam 34 from one target anode towards the other, and vice versa.

So long as the electron beam falls between the target anodes, or where the beam falls upon the two anodes in equal amounts, there will be no difference of potential between the two anodes. If, however, one target anode intercepts more electrons from the beam than the other, then a difference of potential develops between the anodes, and the polarity of the output voltage will depend upon which anode receives the greatest number of electrons.

The output voltage of the cathode ray relay is employed to control the direction of rotation of a reversible motor 43 through a suitable reversing relay circuit represented at 44. Such relay circuits are known to those skilled in the art, and one suitable example is disclosed in my co-pending application Serial No. 511,332, filed November 22, 1943, now Patent No. 2,453,563, granted November 9, 1948. It will be understood that the relay 44 controls the motor for operation in one direction for one polarity of output signal and in the opposite direction for a signal of opposite polarity, and the speed of the motor will be proportional to the value of the signal.

Motor 43 is connected to operate the control valve 29 through any suitable driving mechanism such as that represented by a worm 45 mounted on the motor shaft and serving to drive a worm-wheel 46 carried by the shaft of valve 29. A small pilot generator 47 having a field winding 48 is also driven by motor 43. The generator 47 is connected to the input terminals 5 of a signal storage device like that shown in Figures 1 or 3 and represented by the rectangle 49. The output terminals of the storage device are connected to energize a deflecting coil 50 associated with the cathode ray tube. The storage device is adjusted to receive signals of either polarity as described above.

Operation of Figure 4 is as follows: Resistance 41 is adjusted to determine the value of the pressure to be maintained at the inlet of the consuming apparatus. Coil 39 tends to deflect the electron beam in a direction to operate motor 43 to open the valve 29. As the pressure supplied to the consuming apparatus builds up, the current in deflecting coil 42 produced by device 30 increases and tends to deflect the electron beam in an opposite direction. As soon as the pressure reaches the desired point, the beam 34 has been deflected back to its central or normal position. The beam will remain in this position so long as the pressure remains at the desired value, but if the pressure varies from this value for any cause, there will be a change in current supplied to coil 42, and the beam will be deflected in a direction to energize motor 43 and operate valve 29 in a direction to restore the pressure to the desired value. As motor 43 begins to operate, pilot generator 47 generates a voltage of a value proportional to the speed of the motor and of a polarity determined by the direction of rotation. This voltage is repeated through storage device 49 and energizes deflecting coil 50 in a direction tending to restore the beam 34 to its neutral position. The operation of motor 43, through the action of valve 29 and pressure responsive device 30, changes the amount of current supplied to coil 42 in a direction tending to restore the beam to its normal or neutral position. As the motor continues to operate, and as the pressure approaches the desired value, the speed of the mo-

tor will slow down, thus reducing the value of the control potential applied to the input of storage device 49, but due to the time delay action of this device, the change is not immediately effective in coil 50. Accordingly, the motor speed will be relatively high at the beginning of the adjustment for any given departure of the condition from its normal value, and the speed will decrease as the value of the condition approaches the normal value. The current in coil 50 tends to restore the beam to its neutral position and it tends to stop the motor 43 earlier than it would be stopped by the action of coil 42 acting alone. This action tends to prevent overshooting of the regulator. Furthermore, the current supplied to coil 50 is proportional to the speed of motor 43 and to the time of operation of the motor; in other words, the current in coil 50 will be proportional to the amount of movement of the valve 29 from an initial position. This current, however, will decrease to zero in a predetermined time after the motor stops depending upon the strength of the restoring energy applied to the storing device 49. The gradual reduction in the value of the current in coil 50 also tends to stabilize the action of the regulator system and prevents "droop" in the regulation as well as preventing hunting.

In case the pressure at the inlet of the consuming device should change in an opposite direction from that described above, the motor 43 will be driven in an opposite direction, and the voltage supplied to deflecting coil 50 will also be reversed in direction, and the regulating action will be the same as that described above.

The regulator system shown in Figure 5 is generally like that shown in Figure 4, and like parts are represented by the same reference numerals. In this case the conduit 28 is a steam supply pipe for a steam turbine 51 the speed of which is to be maintained constant. For this purpose the counter-deflecting coil 42 is energized from a pilot generator 52 driven by the turbine 51. An additional deflecting coil 53 is provided and is energized directly from pilot generator 47. The deflecting coil 50 is energized from storage device 49 which has its input terminals connected to generator 47 through potentiometer 54. In this case also, the storage device 49 is adjusted to receive signals of both polarity. Coil 53 provides a restoring action directly proportional to the speed of motor 43, while coil 50 provides a restoring action proportional to the product of motor speed and time.

The operation of Figure 5 will be clear from the foregoing description of operation of Figure 4. Coil 53 is responsive directly and instantaneously to the voltage generated by pilot generator 47, and acts in a direction tending to restore the electron beam to its neutral position. The current supplied to coil 53 is proportional to the speed of motor 43. Coil 50 is energized in the same manner as for Figure 4; that is, the current in this coil is proportional to the amount of movement of the valve 29 from its initial position, but the current in this coil dies down to zero value in a predetermined time after stopping of the motor. It may be noted that the current in coil 53 ceases flowing as soon as the motor stops running, but the current in coil 50 continues for a time after the motor stops.

An additional feature which may be embodied in the regulator systems of Figures 4 and 5 is the control of the rate of restoring action within the storage device in accordance with the position of the controlling valve. For example, as shown in

Figure 5, the intensity of the erasing or restoring energy supplied by source 18 may be varied in accordance with the position of the valve by placing the movable contact for resistance 20 on the driving gear 46 for the valve 29. Since the position of valve 29 forms a rough indication of the value of the load, the arrangement just described will provide means for varying the restoring rate of storage device 49 in accordance with the value of the load.

I claim:

1. A signal storing and integrating device comprising a light sensitive circuit including a light sensitive cell, a source of light for energizing said cell, a light transmitting element interposed between said source of light and said cell and comprising a substance which under the influence of radiant energy is rendered opaque to a degree in proportion to the intensity of the radiant energy and the time the energy acts on said substance, a source of radiant energy for clouding said substance, and signal responsive means for varying the amount of clouding radiant energy acting on said substance.

2. A device according to claim 1 wherein said signal responsive means includes intensity control means responsive to said received signal to vary the intensity of energy from said clouding source acting on said light transmitting substance.

3. A device according to claim 1 wherein said signal responsive means includes direction control means responsive to said received signal to direct clouding radiant energy from said clouding source over a variable portion of said light transmitting substance.

4. A device according to claim 1 and including means constantly acting on said light transmitting substance and tending to restore the transparency of said substance at a predetermined rate.

5. A device according to claim 1 and including a source of radiant energy constantly acting upon said light transmitting substance and serving to restore the transparency of said substance in proportion to the intensity of said restoring energy and the time of action thereof.

6. A signal translating device for producing an electric current of a value proportional to the product of the magnitude of an input signal and the duration of the signal comprising, in combination, a light sensitive circuit including a light sensitive cell, a source of light for energizing said cell, a light transmitting element interposed between said source of light and said cell and comprising a substance which under the influence of radiant energy is clouded to a degree in proportion to the intensity of the radiant energy and the time the energy acts on said substance, a source of radiant energy for clouding said substance, an input circuit for said device including signal responsive means for varying the amount of clouding radiant energy acting on said substance, and an output circuit connected to spaced points of said light sensitive circuit having the same potential at no-signal condition.

7. In a regulator system, the combination of a movable control element for varying the magnitude of a condition to be regulated, means for operating said control element including an electron beam relay having beam deflecting means operable to deflect the beam of said relay to one side or the other of a normal position for said beam at which said condition has a predetermined value, and means responsive to said de-

deflection to move said control element in one direction or the other to increase or decrease the magnitude of said condition, means responsive to variation of said condition from said predetermined value for actuating said beam deflecting means in a direction to restore said condition to said predetermined value, means responsive to movement of said control element for applying an opposing beam-deflecting force proportional to the amount of movement of said control element from its initial position, and means for reducing said opposing force to zero at a predetermined rate after said element stops moving.

8. In a regulator system, the combination of a movable control element for varying the magnitude of a condition to be regulated, means for operating said control element including an electron beam relay having beam deflecting means operable to deflect the beam of said relay to one side or the other of a normal position for said beam at which said condition has a predetermined value, and means responsive to said deflection to move said control element in one direction or the other to increase or decrease the magnitude of said condition, means responsive to variation of said condition from said predetermined value for actuating said beam deflecting means in a direction to restore said condition to said predetermined value, and means for applying to said beam relay an opposing deflecting force proportional to the product of the speed of movement of said element and the duration of movement, including means for continuing said opposing force after movement of said element has stopped but at a continuously decreasing value.

9. In a regulator system, the combination of a movable control element for varying the magnitude of a condition to be regulated, means for operating said control element including an electron beam relay having beam deflecting means operable to deflect the beam of said relay to one side or the other of a normal position for said beam at which said condition has a predetermined value, and means responsive to said deflection to move said control element in one direction or the other to increase or decrease the magnitude of said condition, means responsive to variation of said condition from said predetermined value for actuating said beam deflecting means in a direction to restore said condition to said predetermined value, means responsive to the speed of movement of said control element tending to oppose the deflection of said beam by said condition responsive means, and means for applying to said beam relay an opposing deflecting force proportional to the product of the speed of movement of said element and the duration of movement, including means for continuing said opposing force after movement of said element has stopped but at a continuously decreasing value.

10. In a regulator system, the combination of a movable control element for varying the magnitude of a condition to be regulated, means for operating said control element including an electron beam relay having beam deflecting means operable to deflect the beam of said relay to one side or the other of a normal position for said beam at which said condition has a predetermined value, and means responsive to said deflection to move said control element in one direction or the other to increase or decrease the magnitude of said condition, adjustable magnitude setting means for energizing said beam de-

fecting means so as to urge it to move in a direction along a line passing through said normal position such as to increase the magnitude of such condition, adjustment of said means serving to set the predetermined value, means responsive to the value of said condition and tending to deflect said beam along said line in the opposite direction for the purpose of limiting the increase in magnitude of said condition, means responsive to the speed of movement of said control element tending to oppose the deflection of said beam by said condition responsive means, and means for applying to said beam relay a deflecting force proportional to the product of the speed of movement of said element and the duration of movement and in a direction tending to reduce the deflection of said beam from its normal position, including means for continuing said opposing force after movement of said element has stopped but at a continuously decreasing value.

11. In a regulator system, the combination of a movable control element for varying the magnitude of a condition to be regulated, means for operating said control element including an electron beam relay having beam deflecting means operable to deflect the beam of said relay to one side or the other of a normal position for said beam at which said condition has a predetermined value, and means responsive to said deflection to move said control element in one direction or the other to increase or decrease the magnitude of said condition, means responsive to variation of said condition from said predetermined value for actuating said beam deflecting means in a direction to restore said condition to said predetermined value, a light sensitive circuit including a light sensitive cell, a source of light for energizing said cell, a light transmitting element interposed between said source of light and said cell and comprising a substance which under the influence of radiant energy is clouded to a degree in proportion to the intensity of the radiant energy and the time the energy acts on said substance, a source of radiant energy for clouding said substance, means operated by said control element for varying the amount of clouding energy acting on said substance in accordance with the speed of said element and means energized by the current in said light sensitive circuit for opposing the deflection of said beam by said condition responsive means.

12. A regulator system according to claim 11 and including means acting on said light transmitting element tending to restore the transparency of said element at a predetermined rate.

13. In a regulator system embodying a movable control element for varying the magnitude of a condition to be regulated and including condition responsive means responsive to variation in said condition from a predetermined value, the combination of means for operating said movable control element by said condition responsive means comprising, an electron beam tube having beam deflecting means controlled by said condition responsive means to deflect the beam of said tube to one side or the other of a normal position in response to variation of said condition above or below a predetermined value, and including means responding to said deflection to operate said control element in a direction tending to restore said condition to said predetermined value, and means for applying to said beam tube an opposing deflecting force propor-

tional to the product of the speed of movement of said element and the duration of movement thereof and tending to oppose deflection of said beam from its normal position.

14. In a regulator system embodying a movable control element for varying the magnitude of a condition to be regulated and including condition responsive means responsive to variation in said condition from a predetermined value, the combination of means for operating said movable control element by said condition responsive means comprising, an electron beam tube having beam deflecting means energized by said condition responsive means, means responsive to the speed of movement of said control element tending to oppose the deflection of said beam by said condition responsive means, and means for applying to said beam tube an opposing deflecting force proportional to the product of the speed of movement of said element and the duration of movement thereof and tending to oppose deflection of said beam from its normal position.

15. In a regulator system embodying a movable control element for varying the magnitude of a condition to be regulated and including condition responsive means responsive to variation in said condition from a predetermined value, the combination of means for operating said movable control element by said condition responsive means comprising, an electron beam tube having beam deflecting means energized by said condition responsive means, a light sensitive circuit including a light sensitive cell, a source of light for energizing said cell, a light transmitting element interposed between said source of

light and said cell and comprising a substance which under the influence of radiant energy is clouded to a degree in proportion to the intensity of the radiant energy and the time the energy acts on said substance, a source of radiant energy for clouding said substance, means operated by said control element for varying the amount of clouding energy acting on said substance in accordance with the speed of said element and means energized by the current in said light sensitive circuit for opposing the deflection of said beam by said condition responsive means.

HERBERT ZIEBOLZ.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
Re. 22,628	Rosenthal	Apr. 10, 1945
1,671,463	Boddie	May 29, 1928
1,743,545	Helpbringer	Jan. 14, 1930
1,860,821	Smoot	May 31, 1932
2,050,020	Schmidt	Aug. 4, 1936
2,080,465	Ells	May 18, 1937
2,096,986	Ardenne	Oct. 26, 1937
2,163,918	Schwartz	June 27, 1939
2,199,066	Bernstein	Apr. 30, 1940
2,228,064	Runge et al.	Jan. 7, 1941
2,262,173	Fischer	Nov. 11, 1941
2,294,209	Roder	Aug. 25, 1942
2,330,171	Rosenthal	Sept. 21, 1943
2,330,172	Rosenthal	Sept. 21, 1943
2,351,079	Strobel	June 13, 1944
2,351,889	Strubig	June 20, 1944