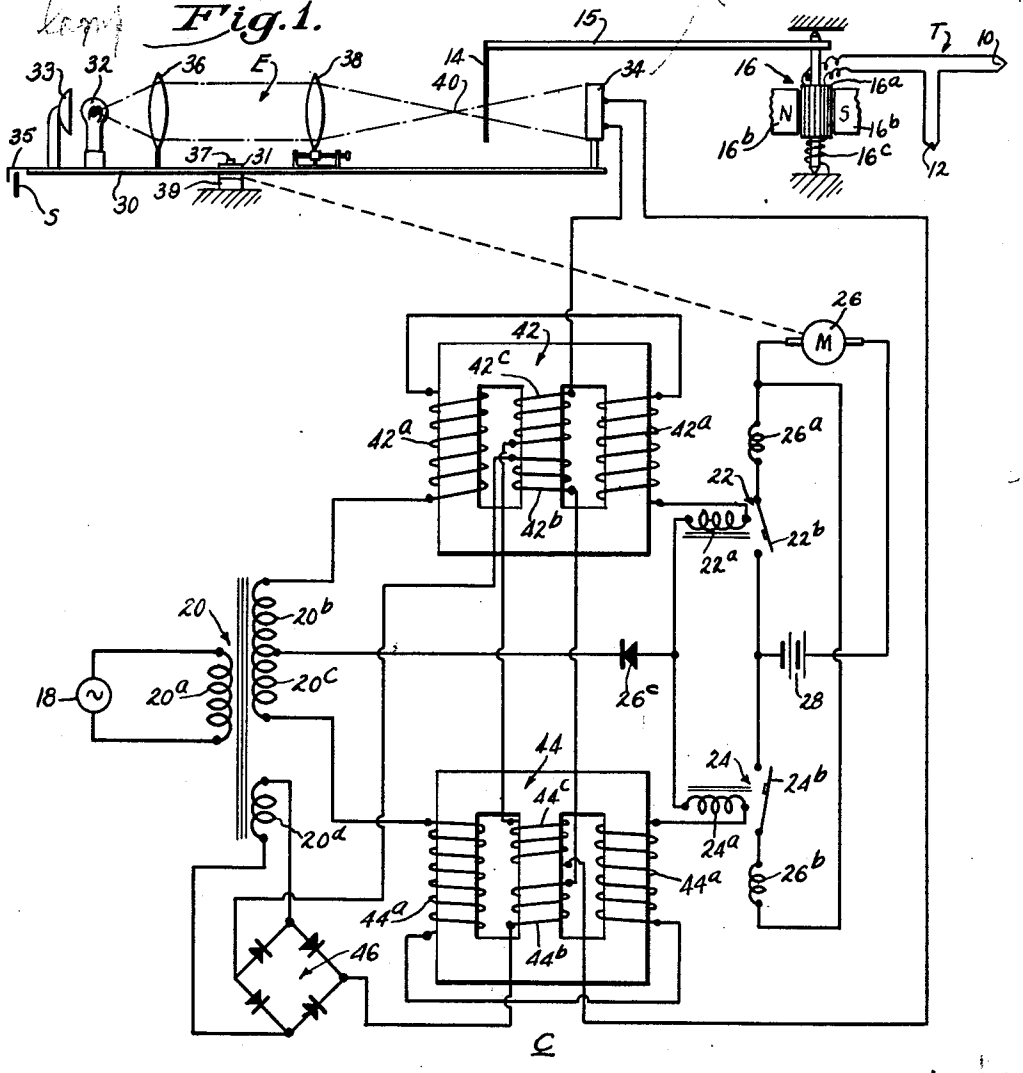
Sept. 1, 1953 P. T. SEMM 2,650,986

VARIABLE SENSITIVITY CONTROL DEVICE AND CIRCUIT FOR USE THEREIN

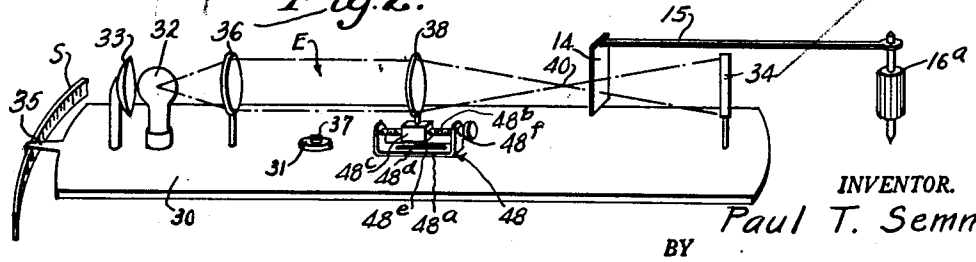
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Fig. 1.



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Fig. 2.



INVENTOR.
Paul T. Semm

BY

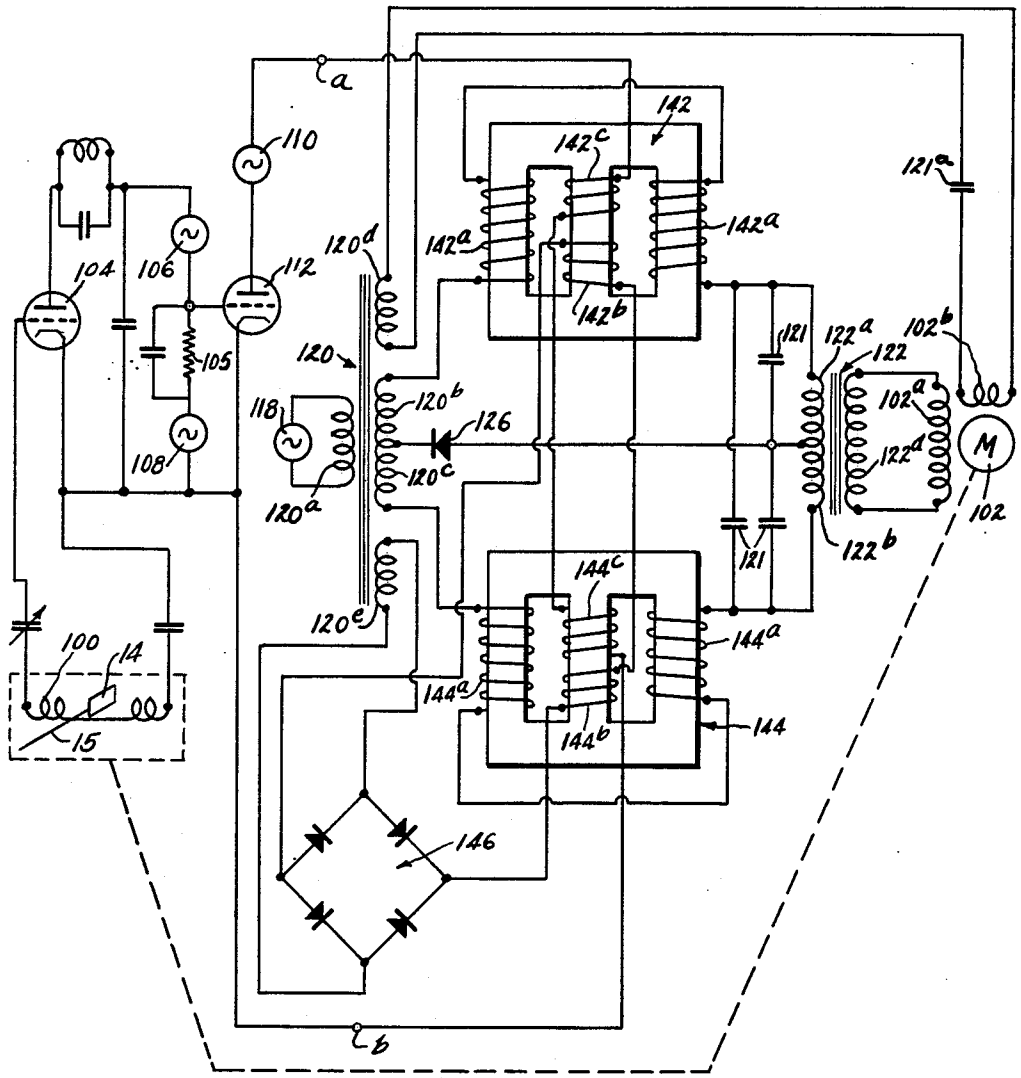
Carlson, Pitzner, Hubbard & Wolfe
ATTORNEYS

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Fig. 3.



INVENTOR.
Paul T. Semm
BY
Carlson, Pitzner, Hubbard & Wolfe
ATTORNEYS

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2,650,986

VARIABLE SENSITIVITY CONTROL DEVICE AND CIRCUIT FOR USE THEREIN

Paul T. Semm, Chicago, Ill., assignor, by mesne assignments, to Barber-Colman Company, Rockford, Ill., a corporation of Illinois

Application June 1, 1950, Serial No. 165,473

4 Claims. (Cl. 250—203)

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My invention relates to an improved control device having adjustable sensitivity, together with a circuit for use therein.

In control or follow-up mechanism it is desirable to provide low-friction means having great sensitivity to small relative motions and yet adjustable with respect to sensitivity so that varying degrees of inertia, dead band, friction, and other effects in the associated follow-up or control system and varying requirements as to hunting may be taken into account by convenient adjustments after the system is built.

In accordance with the present invention an improved light operated sensing element is provided. This element includes adjustable mechanism which, in one condition of adjustment, gives a high degree of sensitivity limited only by the physical facts that the opaque vane that interrupts the light beam has depth, the light undergoes some unavoidable dispersion, and the lens system can never produce a perfect focal point. As the adjustable element is moved away from this critical position, the sensitivity decreases in accord with the departure from critical.

Further in accordance with the present invention a magnetic amplifier control circuit is provided for use with the sensing mechanism. This control is responsive to the direction and amount of the departure of the control current from a reference value and is characterized by an ability to accommodate itself to slow variations in the control current and may be designed to accommodate control currents of widely varying magnitudes. The control circuit is further characterized by ability to operate effectively with only a single response element (such as a photocell) on the sensing mechanism.

It is therefore a general object of the present invention to provide an improved sensing mechanism imposing small load on the controlling device and having an adjustable sensitivity up to a very high value.

Another object of the present invention is to provide an improved sensing mechanism suitable for use with a follow-up type system.

A further object of the present invention is to provide an improved control circuit responsive to deviations of a control current from a reference value.

Yet another object of the present invention is to provide an improved control circuit responsive to the direction and magnitude of the deviations of a control current from a reference value and using magnetic amplifiers.

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The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawing, in which:

Figure 1 is a schematic diagram illustrating a follow-up mechanism incorporating the features of the present invention;

Figure 2 is a view in perspective of the sensing mechanism of the present invention; and,

Figure 3 is a schematic diagram of the control circuit of the present invention as applied to a different type sensing unit and adapted to drive a two phase alternating current motor.

Referring now to Figure 1, there is shown a follow-up control mechanism operative to produce an indication on the scale S in accord with the temperature differential between the junctions 10 and 12 of the thermocouple T. Briefly, this mechanism includes a sensing element, indicated generally at E, which is driven by the control mechanism C in response to movements of the opaque vane 14 which itself moves in response to the current flow in D'Arsenval movement 16 associated with the temperature differential between thermocouples 10 and 12.

The control mechanism C derives energy from an A.-C. voltage source 18 connected to the primary 20*a* of the transformer 20. This transformer has a pair of like secondaries, 20*b* and 20*c*, which feed the relay windings 22*a* and 24*a* of the relays 22 and 24, respectively. The windings 22*a* and 24*a* have a common return circuit to the windings 20*b* and 20*c* through the rectifier 26*c*.

The relays 22 and 24, when energized, close their respective contacts 22*b* and 24*b* to cause current flow through the respective field windings 26*a* and 26*b* of the D.-C. series motor 26, this current being derived from the battery 28. When relay 22 is energized the motor 26 is driven in one direction and when relay 24 is energized, motor 26 is driven in the opposite direction.

The sensing device, indicated generally at E, includes a rotatable carriage 30 upon which is mounted a point source lamp 32 and a photoelectric cell 34. The lamp 32 may be any one of many types well known in the art, a small size, high intensity tungsten filament type lamp being particularly suitable for this purpose. The

photo-electric cell likewise may be any one of many well known types, the selenium or "barrier layer" cell being especially suitable.

A pair of lenses 36 and 38 are mounted on the carriage 30 to direct the portion of the total light emanating through a preset solid angle area from lamp 32 on the cell 34. These lenses define a focal point 40 which is substantially in the line of travel of the vane 14. At this point the rays of light that eventually reach the photo cell 34 converge at a single point. As pointed out hereafter, the position of this focal point is adjustable relative to the line of travel of vane 14 to adjust the sensitivity of the sensing mechanism.

A mirror 33 is mounted behind the lamp 32 to direct illumination therefrom in the forward direction to lens 36.

The motor 26 is mechanically connected to rotate the carriage 30 in accord with its own rotations. This drive mechanism, shown diagrammatically in Figure 1, may, for example, include a gear train connecting these elements and having a motion step down so that the available torque of motor 26 is stepped up for application to the carriage. Chain, belt, or other drive may be employed.

When the relay 22 is energized and motor 26 rotated in one direction, the carriage 30 rotates in a corresponding direction. When relay 24 is energized, motor 26 rotates oppositely and the carriage 30 rotates in the reverse direction.

The relays 22 and 24 are separately energized in response to the quantity of light incident on photocell 34 by the circuits including magnetic amplifiers 42 and 44. These magnetic amplifiers or saturable reactors each comprise a rectangular magnetic core with a pair of windows defining three legs. Each has a controlled winding (42*a* and 44*a*, respectively) wound on the outside legs, the two parts of each winding being wound in cumulative sense. The center or control leg of each magnetic amplifier carries a pair of windings, one winding of each pair (42*b* and 44*b* of amplifiers 42 and 44, respectively) is a biasing winding to carry relatively constant biasing current. The other winding of each pair (42*c* and 44*c* of amplifiers 42 and 44, respectively) is a control winding and carries the control current from the photocell 34.

The biasing windings 42*b* and 44*b* are connected in a series circuit to the D.-C. output terminals of the bridge rectifier 46, the A.-C. input terminals of this rectifier being connected to the tertiary winding 20*d* of the transformer 20.

The control windings 42*c* and 44*c* are similarly connected in a series circuit with the photocell 34. However, this circuit is poled so that in magnetic amplifier 42 the magnetomotive force of the winding 42*c* reinforces that of winding 42*b* while the magnetomotive force of the winding 44*c* opposes that of the winding 44*b* when current flows in one direction in the circuit. For opposite current flow, the M. M. F. of winding 42*c* opposes that of winding 42*b* and the M. M. F. of winding 44*c* reinforces that of the winding 44*b*.

Operation

Operation of the system of Figure 1 is as follows. When the temperature differential between thermocouples 10 and 12 changes from an initial condition where relays 22 and 24 are not picked up and vane 14 interrupts part of the light rays, the current flow in the D'Arsenval movement 16 accordingly changes. This current

flow in the coil 16*a* gives rise to a change in torque (since the magnetic field between poles 16*b* does not change) and causes the movement to rotate until the restoring torque of spring 16*c* again equals the torque due to current flow. As the movement rotates, the vane 14 (attached to the rotor by the arm 15) swings into or out of the path of the light from lamp 32 and thereby increases or decreases the illumination of the photocell 34.

As the illumination of photocell 34 changes, the output voltage thereof varies and the current flow through the control windings 42C and 44*c* is altered. This current flow change causes relays 22*a* or 24*a* to be more or less energized in accord with the direction of departure from the neutral or predetermined initial value. However, the relay that is more energized does not pick up until this departure from the neutral current reaches a predetermined quantity determined by the friction and lost motion inherent in the relay units.

When the energized relay picks up the motor 26 is driven in the corresponding direction and the carriage 30 executes rotation in unison therewith. The direction of rotation imparted to the carriage (due to the orientation of field windings 26*a* and 26*b*, the arrangement of the drive between motor 26 and the carriage 30, and to the orientation of control windings 42*c* and 44*c*) is such as to drive the carriage in direction to restore the predetermined reference light value on the photocell 34, thereby rotating the carriage in amount corresponding to the initial movement of the opaque vane 14. The amount of the vane movement (and hence the temperature change) can then be read from the position of the pointer 35 on the scale S.

Sensitivity adjustment

The foregoing mechanism, as a follow-up or closed cycle control, inherently deviates slightly from true response as the departure from reference or neutral condition increases. The amount of this departure is determined by the quantity of movement imparted to the carriage 30 for a given movement of the vane 14. However, inherent time delays, lost motion, and other unavoidable attributes of a physical system place an upper limit on the allowable sensitivity, since they cause undesirable hunting and perhaps even self-excited oscillations.

The sensing mechanism of the present invention, shown in detail in Figure 2, is particularly effective in that it can be adjusted to achieve a wide range of sensitivities to accommodate the unit to a great range of operating conditions. This is accomplished by the movable mount, indicated generally at 48, which provides convenient manual adjustment of the position of the lens 38 along the axis between light 32 and photocell 34. When the lens is shifted to position vane 14 exactly at the focal point 40 (as shown in Figure 2), the change in illumination of the photocell 34 with a small vane movement is very great and is limited only by the physical facts that the vane 14 has some thickness, the focal point defined by the lenses cannot be perfect, and dispersion is inherent in the optical system. When the lens 38 is shifted to move the focal point 40 away from the path of travel of vane 14, as shown in Figure 1, the amount of light change upon vane movement is reduced, since the cone of light has substantial cross-sectional area in the path of vane travel. The sensitivity

of the sensing element is accordingly reduced in accord with the amount of the departure of the focal point from the path of vane travel.

The lens adjusting mechanism **48** comprises a U-shaped support **48***a* mounted on carriage **30** and carrying a horizontal screw thread shaft **48***b*, this shaft being rotatably supported by bearings on support **48***a*. The lens **38** is mounted on a rider **48***c* which threadedly receives the shaft **48***b* and has a depending pin **48***d* extending through the elongated slot **48***e* on the support **48***a*. As the handle **48***f* is rotated to rotate shaft **48***b*, the rider **48C** shifts in response to the screw thread engagement and shifts the lens **38**. The rider **48***c* is held against rotation by the pin **48***d*.

The carriage **30**, Figures 1 and 2, is supported for rotation about the axis of the fixed vertical shaft **37**. As seen in Figure 1, a fixed bushing **39** is mounted on the bottom of this shaft and defines an annular bearing surface upon which rests the bushing **31** (formed unitarily with carriage **30**), thus supporting the carriage for rotation about the shaft **37**.

The electrical elements on the carriage **30** are energized through loose flexible leads (not shown) which permit free rotation of the carriage over the length of the fixed scale S.

A.-C. motor follow-up

Figure 3 shows the circuit of the present invention as applied to an A.-C. motor driven follow-up system. In this device the sensing mechanism shown in Lang and Cross application S. N. 786,678, now Patent Number 2,576,611, entitled "Measuring Apparatus" and assigned to the same assignee as the present invention, is used. Briefly, this apparatus includes a split inductor **100** mounted on a movable carriage driven by the two-phase induction motor **102**. A vane or flag **14** (which may, for example, be a D'Arsonval movement responsive to the temperature difference between a pair of thermocouples) is of metal and moves relative to this coil, thus altering the impedance thereof.

The motion of the vane **14** and the incident impedance change of the inductor **100** detunes the tuned plate-tuned grid type oscillator defined by the election tube **104** and thereby alters the magnitude of oscillations of the oscillator and the value of the unidirectional space current flow in the tube **104**. This unidirectional space current flow is in the form of pulses of low frequency (i. e. 60 cycles), since the cathode-anode space path voltage of tube **104** is obtained from the synchronized A.-C. voltage sources **106** and **108**.

The quantity of the unidirectional space current flow in the tube **104** varies the voltage drop across the resistance **105** and thereby controls the cathode-control electrode voltage of the electron tube **112**. The electron tube **112** conducts unidirectional space current in low frequency pulses each of magnitude determined by the detuning of the oscillator defined by the tube **104** and hence by the position of vane **14** relative to the inductor **100**. The resultant voltage pulses appear across terminals *a*—*b*.

The control circuit of Figure 3 embodies a pair of magnetic amplifiers **142** and **144** of construction like reactors **42** and **44**, Figure 1. The control windings **142***c* and **144***c* of these reactors are connected in series across terminals *a* and *b* and thus carry current of magnitude determined by the position of vane **14**.

The controlled windings **142***a* and **144***a* of the magnetic amplifiers **142** and **144** are connected in series circuit with the winding **120***b*—**120***c* of transformer **120** and the winding **122***a*—**122***b* of the transformer **122**. A connection including rectifier **126** extends between the common terminal of windings **122***a* and **122***b* and the common terminal of windings **120***b* and **120***c*.

The primary winding **120***a* of the transformer **120** is energized from alternating voltage source **118** which is synchronized with the sources **106**, **108**, and **110** to produce a current wave through each of windings **142***a* and **144***a* synchronized in phase and frequency with the control current in windings **142***c* and **144***c*. The bias windings **142***b* and **144***b* are energized from the bridge rectifier **146** which is fed from the secondary winding **120***e*.

The secondary winding **122***d* of the transformer **122** is connected to one phase winding **102***a* of the two-phase induction motor **102**. The other phase winding **102***b* is connected to the additional winding **120***d* of the transformer **120** through the phasing capacitor **121***a*. This capacitor is of such value that current flow through the winding **102***b* is substantially 90 degrees out of phase with the source **118** and the current flow in winding **102***a*.

In the device of Figure 3, the voltage induced in winding **122***d* (and the current flow in the winding **102***a*) depends on the relative impedances of the windings **142***a* and **144***a* because the magnetomotive forces of the windings **122***a* and **122***b* are in opposition.

The series circuit formed by the control windings **144***c* and **142***c* is so poled that current flow therethrough produces magnetomotive force opposing that of one bias winding (**142***b* or **144***b*) and reinforces that of the other bias winding. As described above in connection with Figure 1, this causes the impedance of one of windings **142***a* and **144***a* to increase relative to the impedance of the other, thereby causing the magnetomotive force of one of windings **122***a* and **122***b* to overpower that of the other and produce a corresponding voltage in winding **122***d*. Moreover, when the current flow in winding **122***a* exceeds that of winding **122***b*, the current flow is 180° out of phase with the current produced in winding **102***a* when the opposite condition exists. The direction of rotation of motor **102** accordingly varies in accord with which of the windings **122***a* and **122***b* creates the predominant magnetomotive force.

The capacitors **121** serve to tune the windings **122***a* and **122***b* to convert the half wave current flow otherwise created by the rectifier **126** to a current which has a more nearly sinusoidal wave form.

The windings **142***c* and **144***c*, **122***a* and **122***b*, and **102***a* and **102***b*, and the drive between motor **102** and the inductor **100** are so arranged that when the vane **14** moves into the inductor **100** the corresponding movement imparted to the inductor is in direction to pull the inductor away from the vane. Consequently, the inductor **100** follows the motion of the vane and the amount of vane movement may be indicated by a suitable fixed scale between the inductor and the support mechanism (not shown).

The vane **14** may be mounted on any control device whose movement is desired to be recorded. The D'Arsenval galvanometer movement shown in Figure 1 is only one of many devices that may be used for this purpose. Others include pres-

sure responsive bellows, a Bourdon tube, and so forth.

Moreover, in any of the follow-up systems shown and described herein, anticipation may be used to improve stability of operation without reducing the sensitivity.

It will be apparent that while the transformer windings 20*b* and 20*c*, Figure 1, and 120*b* and 120*c*, Figure 3, derive energy from the same source of alternating E. M. F., these windings in fact as separate sources of alternating E. M. F. synchronized in phase and frequency.

Each of the magnetic amplifiers or saturable reactors 42, 44, 142, and 144 acts to produce a net inductance (or inductive impedance) in the controlled winding (i. e. 42*a*) determined by the net M. M. F. of the control and bias windings (i. e. 42*c* and 42*b*, respectively). When this net M. M. F. increases, the resultant flux in the middle leg of the magnetic amplifier returns by way of the outer legs and thereby saturates these legs. The resultant saturation reduces the inductance of the controlled winding. The controlled winding does not cause induced voltage in the controlling or bias windings, since the central leg of each core extends between points of like magnetic potential with respect to the magnetizing effects of the controlled windings.

While I have shown a specific mechanism including a shiftable lens to alter the position of the focal point 40 relative to the path of travel of vane 14, it will be understood that other arrangements will work. Specifically, the means may be provided to shift the carriage as a unit and thereby alter the position of the focal point relative to the path of vane travel.

While I have shown and described specific embodiments of the present invention, it will of course be understood that I do not wish to be limited thereto and that many modifications and alternative constructions may be made without departing from the true spirit and scope of the invention. I therefore intend by the appended claims to cover all such modifications and alternative constructions falling within the true spirit and scope thereof.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a follow-up system operative to follow the movements of an opaque vane along a predetermined path and having an adjustable sensitivity, the improvement comprising a movable carriage, a light source and a photo sensitive device on the carriage, means on the carriage operable to direct light from the source to the device, the means directing the light to a focal point substantially in the path of movement of the vane, said means including elements adjustably positioned on the carriage and operative to shift the position of the focal point to provide controlled sensitivity to vane motion, and mechanism responsive to the output of the photo sensitive device operative to move the carriage in the direction of vane movement.

2. In a follow-up system operative to follow the movements of an opaque vane along a predetermined path and having adjustable sensitvity, the improvement comprising a movable carriage, a light source and photosensitive device on the carriage, lens elements on the carriage operable

to direct light from the source to the device, the lens elements directing the light to a focal point substantially in the path of movement of the vane, at least one lens element being adjustably positioned on the carriage to vary the location of the focal point in relation to the path of vane movement to control the sensitivity to vane motion.

3. A follow-up mechanism responsive to the movements of an opaque vane along a predetermined path comprising a movable carriage, a light source and light sensitive device on the carriage, means on the carriage directing light from the source to a focal point substantially in the path of movement of the vane and operable to direct light from the source to the device, a pair of magnetic amplifiers each having a bias winding, a control winding and a controlled winding, a pair of synchronized sources of alternating E. M. F., means having a pair of energizing circuits and operative when one circuit is energized to move the carriage in one direction and when the other circuit is energized to move the carriage in the opposite direction, means defining a pair of circuits each including one source, one of the controlled windings and one energizing circuit, means defining a circuit through the bias windings, and means defining a circuit from the light sensitive device through the control windings, the last circuit being poled to cause one control winding to oppose the M. M. F. of its associated bias winding and the other control winding to reinforce the M. M. F. of its associated bias winding.

4. In a follow-up system operative to follow the movements of an opaque vane along a predetermined path and having an adjustable sensitivity, the improvement comprising a movable carriage, a light source and a photo sensitive device on the carriage, means on the carriage operable to direct light from the source to the device, the means directing the light to a focal point substantially in the path of movement of the vane, elements operable to adjust the position of the focal point relative to the path of travel of the vane to provide controlled sensitivity to vane motion, and mechanism responsive to the output of the photo sensitive device operative to move the carriage in the direction of vane movement.

PAUL T. SEMM.

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