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Edwards et al.

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[54] **PHOTOSENSITIVE CONTROL APPARATUS WITH MOVABLE LIGHT CONTROL MEMBER**

[75] Inventors: **Harrison F. Edwards**, Norwich, N.Y.; **Stewart F. Bottorf**, Waterbury, Conn.

[73] Assignee: **The Lewis Engineering Company**, Naugatuck, Conn.

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[21] Appl. No.: **249,411**

[52] **U.S. Cl.** **250/201,** 250/231, 250/237
[51] **Int. Cl.** **G01j 1/20**
[58] **Field of Search** 250/201, 231, 237

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Primary Examiner—Harold A. Dixon
Attorney—H. Gibner Lehmann et al.

[57] **ABSTRACT**

A novel control device for use in a servo apparatus of the type employing a galvanometer movement connected in a servo feedback loop arrangement. The device comprises a photosensitive transducer having an expansive sensing surface, means providing a beam of light to strike said surface, and a movable, tapered light-control member disposed in the path of the light beam to produce illuminated areas disposed on either side of an elongate shadowed area on the sensing surface. The relative size of the illuminated and shadowed areas changes in response to movement of the member, thus varying the transducer response. The control device is employed in a servo apparatus comprising a bridge circuit, one leg of which includes the photosensitive transducer and the other leg of which contains a condition-responsive transducer. Amplifying means are provided, having input terminals connected with the bridge to receive signals therefrom and having output terminals connected to a galvanometer to drive the latter. The light control member is directly carried by the galvanometer movement. Any change in the output of the condition-responsive transducer is sensed by the amplifiers, which drive the glavanometer upscale (or downscale), thus changing the position of the light control member in such a way as to direct more (or less) light on the photosensitive transducer and thereby reestablish balance of the bridge. In this way, changes of the condition-responsive transducer are reflected by a corresponding change in the position of the galvanometer, which can be calibrated in convenient units intended to form the basis for the particular measurement desired.

14 Claims, 21 Drawing Figures

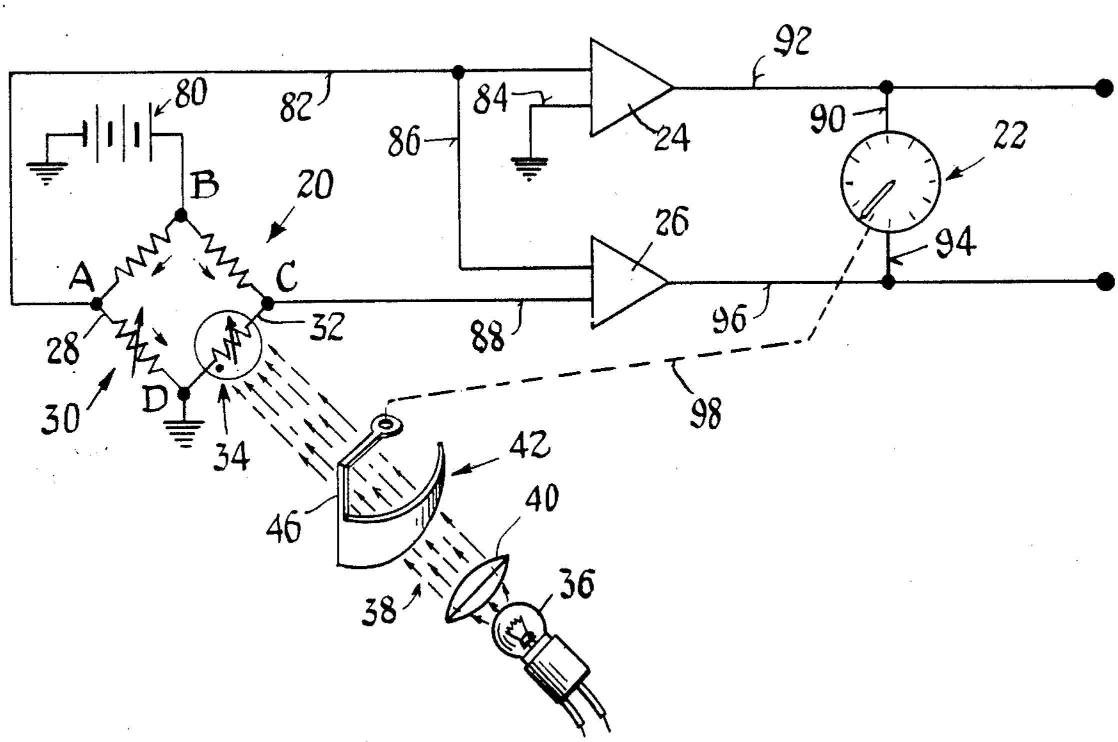


Fig: 1

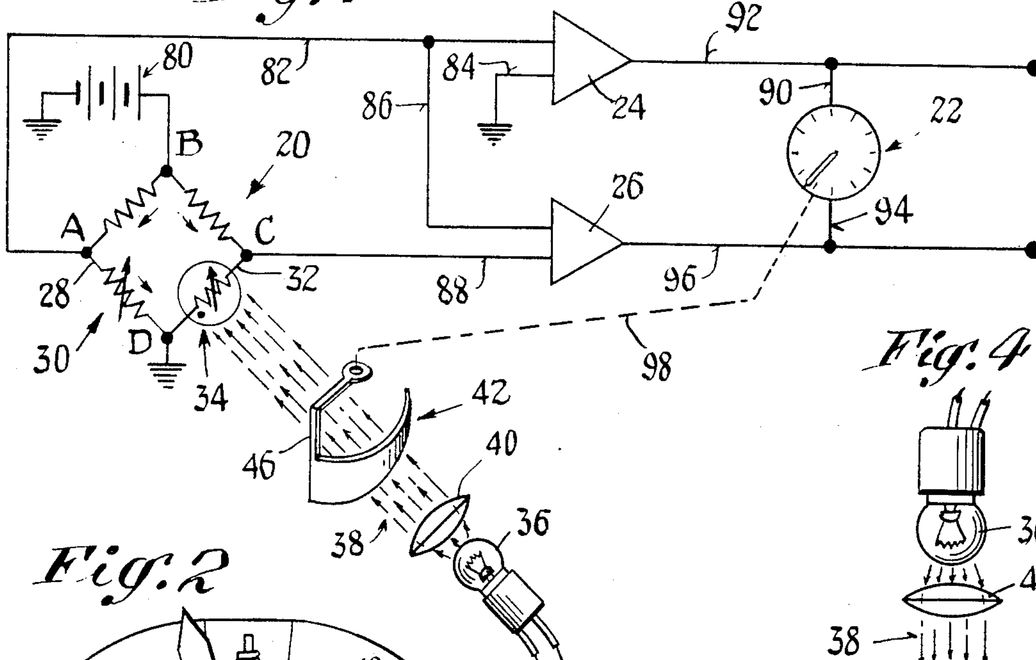


Fig: 4

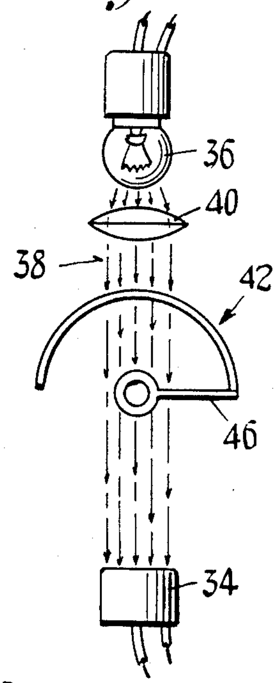


Fig: 2

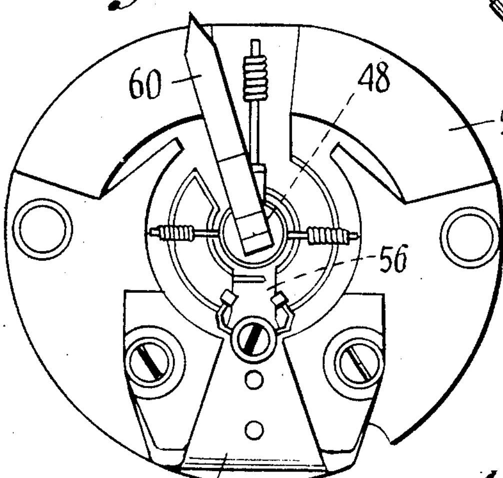


Fig: 3

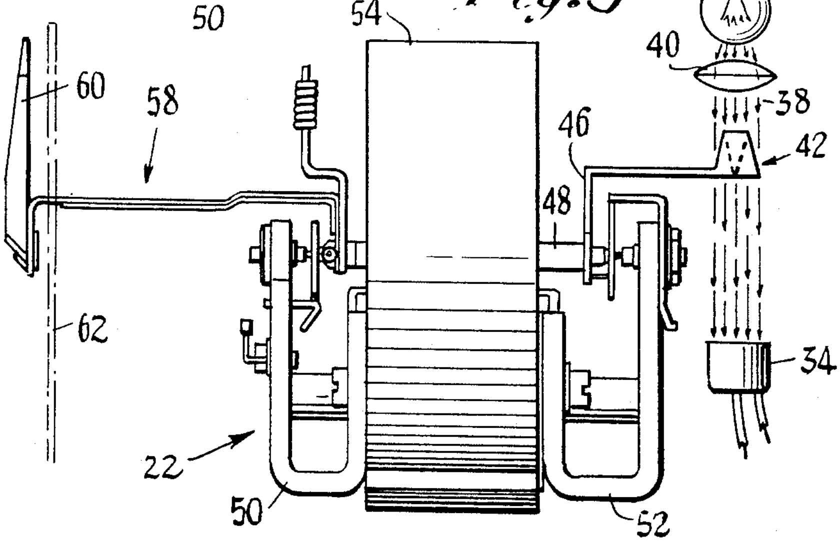


Fig: 5

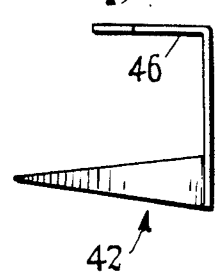


Fig: 6

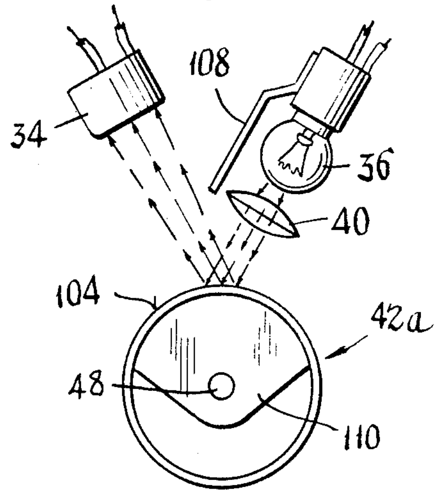


Fig: 8

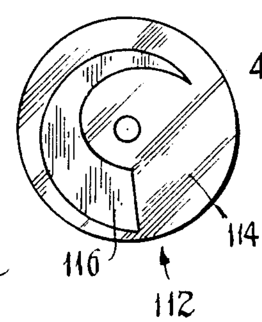


Fig: 9

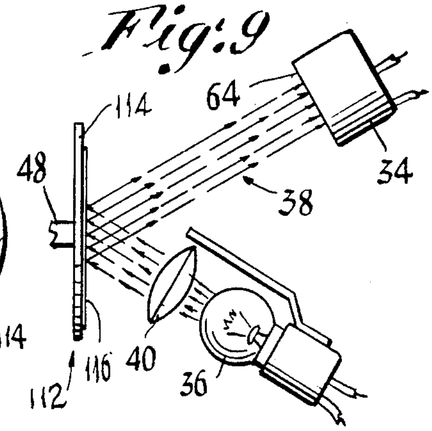


Fig: 7

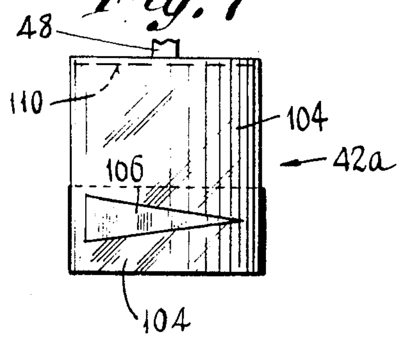


Fig: 10

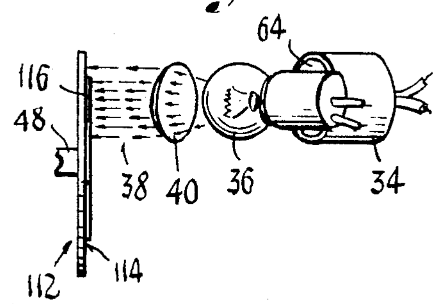


Fig. 11

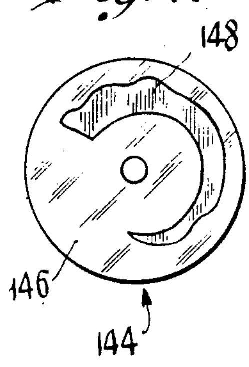


Fig: 12

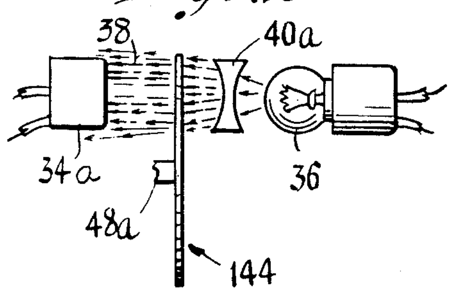


Fig: 14

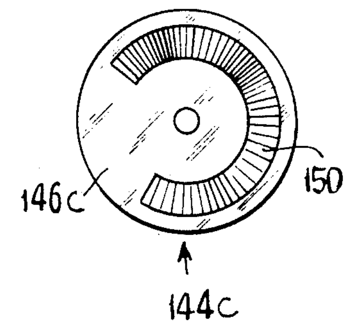


Fig: 13

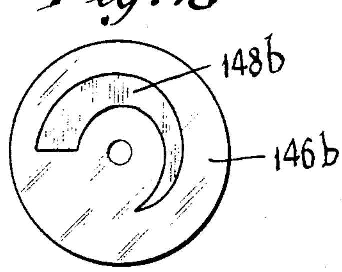


Fig: 15

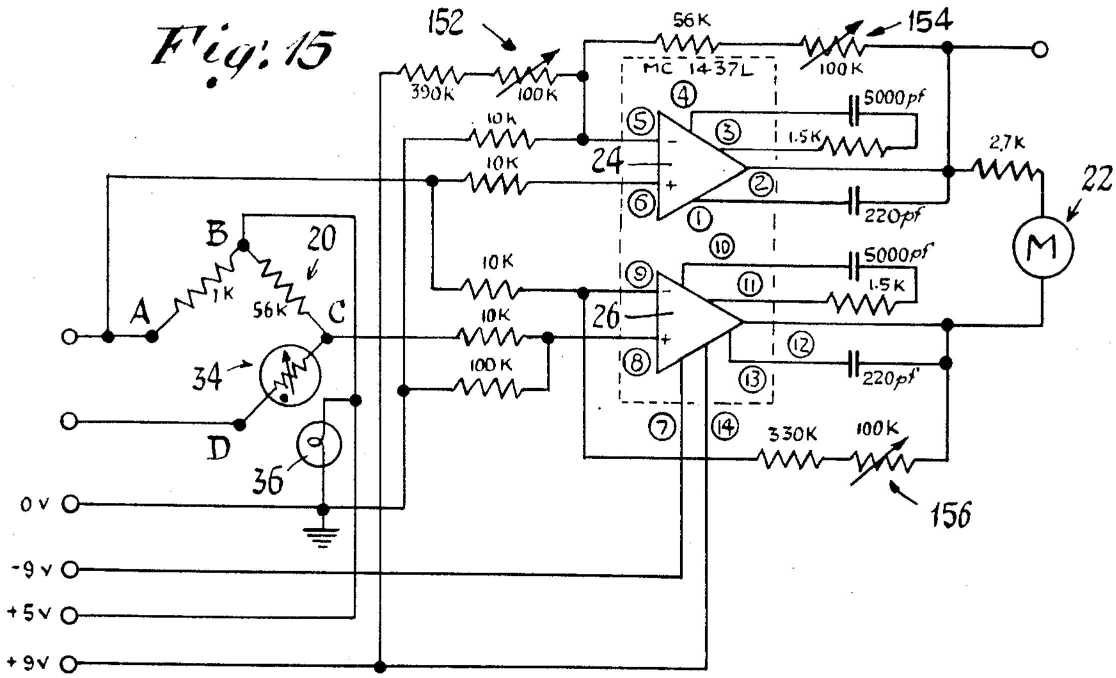


Fig: 16

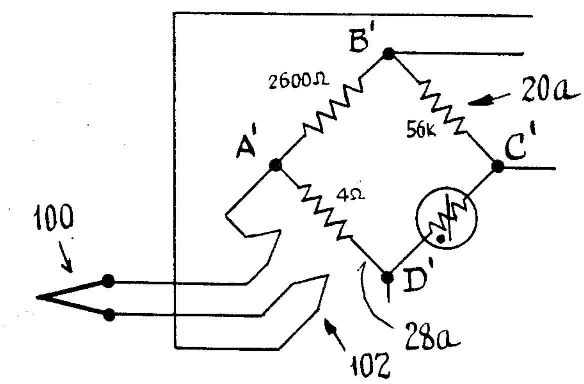


Fig: 17

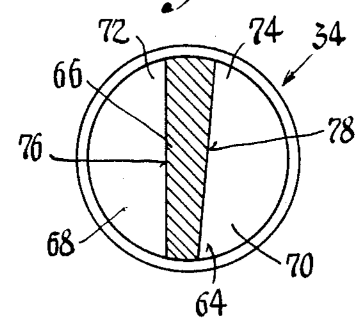


Fig: 18

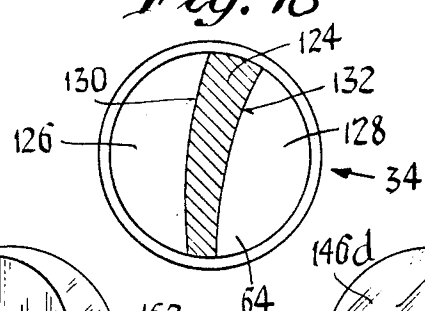
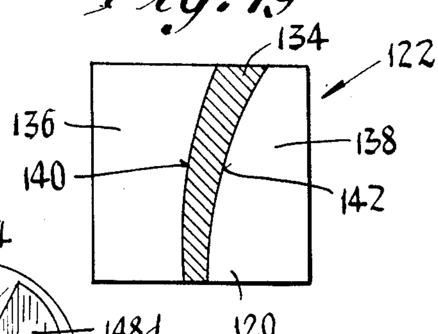


Fig: 19



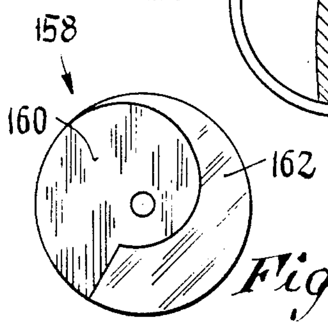


Fig. 20

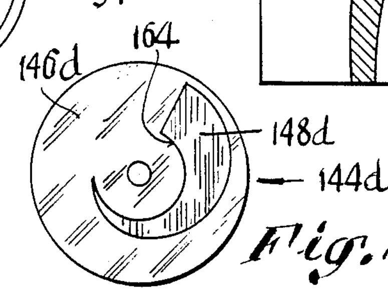


Fig. 21

PHOTOSENSITIVE CONTROL APPARATUS WITH MOVABLE LIGHT CONTROL MEMBER

CROSS REFERENCES TO RELATED APPLICATIONS

Copending application of Harrison F. Edwards, et al entitled "Servo Apparatus", Ser. No. 173,748, filed Aug. 23, 1971, and having the same ownership as the present application.

BACKGROUND

This invention relates to servo-indicator control devices, and more particularly to systems of this type that involve transducers which respond to heat, pressure, strain or other conditions to be measured. Heretofore, servo-indicator devices utilized reversible motors and systems of gears to provide the desired indications and controls. Frequently in servo feedback loops the servo motor would be employed to drive a movable pointer over a calibrated dial, and to simultaneously drive a potentiometer of some kind, wherein the change in resistance between the potentiometer terminal pairs would be used to provide a feedback signal to the amplifier stage which was driving the servo motor. In many cases the potentiometer had substantial friction and thus required a relatively large driving torque to be supplied by the servo motor. Also, the linearity of the potentiometer had to be sufficiently good in order to render accurate scale measurements. Many problems were encountered with noisy potentiometers which suffered from discontinuities as the wiper arm was driven. This led to erratic operation, and in many cases unsatisfactory performance. In addition, the prior devices required appreciable power and involved a multiplicity of moving parts, as well as being quite costly to produce and expensive with respect to maintenance. The prior devices were also relatively complicated and tended to be physically large, all of which made their use prohibitive, for many applications.

SUMMARY

The above disadvantages and drawbacks of prior, servo-type devices are obviated by the present invention, which has for one of its objects the provision of a novel and improved low power yet sensitive servo-type instrument wherein the number of moving parts is reduced to an absolute minimum, and wherein the fabrication and maintenance costs are also appreciably reduced, thereby expanding considerably the field of usefulness of the device. Related objects are to provide an improved servo device as above set forth, wherein standard components already available on the market can be largely utilized, with relatively few special parts being needed, and wherein the entire device is relatively small and compact, completely portable, and operable on minute currents such as are obtainable from batteries if this should be desired.

A further object is the provision of a novel control device for use with a servo indicator apparatus, said device comprising a unique and advantageous, movable light-control member which can very accurately modify a light beam passing from a light source to a photosensitive device without involving critical adjustments or tolerances.

The above objects are accomplished by the provision of a novel control comprising a source of light, a photosensitive device having an expansive sensing surface to be illuminated by said light, and a unique light-control member having a tapered or otherwise non-monotonous configuration, disposed in the path of the light beam and adapted to produce an elongate shadowed area bounded or straddled by lighted areas on the expansive sensing surface of the photosenstive device. The control is preferably employed in a servo indicator, in conjunction with a Wheatstone bridge and galvanometer with interposed solid-state amplifiers so arranged as to increase the energy to the galvanometer when a bridge unbalance occurs. Under such circumstances, the galvanometer movement can directly carry the light-control member, in addition to carrying the conventional indicator apparatus such as pointers, mirrors, etc. commonly used in galvanometers. In one bridge leg is a condition-sensitive transducer, and in another leg the photosensitive device. Unbalance of the bridge occasioned by a change in the condition sensed by the transducer deflects the galvanometer which in turn effects a movement of the light-control member to change the size of the elongate shadowed area on the photosensitive device sensing surface so as to reestablish the bridge balance. The new, deflected position of the galvanometer thus indicates the new condition affecting the transducer, whereby the galvanometer position is a function of the condition monitored by the transducer. The galvanometer movable element constitutes the single moving part of the device, and all components can be small, compact and lightweight, thus requiring little power.

Still other features and advantages will hereinafter appear.

In the accompanying drawings showing a number of different embodiments of the invention:

FIG. **1** is a part diagrammatic part block diagram representation of the servo device of the invention, this figure illustrating one embodiment thereof.

FIG. **2** is a front elevational view of an instrument movement of the D'Arsonval or galvanometer type as used with the servo system of the invention.

FIG. **3** is a side elevational view of the instrument movement of FIG. **2**, showing in addition to other details the light beam control associated therewith.

FIG. **4** is a diagrammatic representation constituting a fragmentary rear view of the light beam control of FIGS. **1** and **3**.

FIG. **5** is a top plan view of the light-control member of the light beam control of FIG. **4**.

FIG. **6** is a rear elevational view of a light beam control somewhat similar to that of FIG. **4**, but illustrating another embodiment of the invention involving a reflector-type beam modifying device.

FIG. **7** is a top plan view of the light-control member of the light beam control of FIG. **6**.

FIG. **8** is a rear elevational view of another type of light-control member, constituting yet another embodiment of the invention.

FIG. **9** is a diagrammatic representation of a light-beam control incorporating the member of FIG. **8**.

FIG. **10** is a diagrammatic representation in the form of a side elevational view of the light beam control of FIGS. **8** and **9**.

FIG. **11** is a rear elevational view of a light-control member constituting yet another embodiment of the invention.

FIG. **12** is a diagrammatic representation of a light-beam type control utilizing the member of FIG. **11**.

FIG. 13 is a rear elevational view of a light-control member constituting still another embodiment of the invention.

FIG. 14 is a rear elevational view of a light-control member constituting still another embodiment of the invention.

FIG. 15 is a schematic circuit diagram of the novel Wheatstone bridge, amplifier system and galvanometer combination as provided by the invention.

FIG. 16 is a schematic bridge circuit diagram showing a different type of transducer to be used with the diagram of FIG. 1 in place of the bridge circuit shown therein.

FIG. 17 is an enlarged view of the sensing surface of the photosensitive device or transducer, showing the illuminated and shadowed areas produced thereon by the light-control member of FIGS. 3–5.

FIG. 18 is an enlarged view of the sensing surface of the photosensitive device showing the illuminated and shadowed areas produced thereon by the light-control member of FIG. 8.

FIG. 19 is an enlarged view of a photosensitive device sensing surface having a substantially rectangular configuration, showing the illuminated and shadowed areas produced thereon by a light-control member similar to that of FIG. 13.

FIG. 20 is a rear elevational view of a light-control member constituting still another embodiment of the invention.

FIG. 21 is a rear elevational view of another light-control member constituting yet another embodiment of the invention.

Considering first FIGS. 1–5, there is illustrated a Wheatstone bridge designated generally by the numeral **20**, and a galvanometer **22** with interposed amplifiers **24, 26** respectively, the amplifiers being so arranged as to increase the energy to the galvanometer when a bridge unbalance occurs.

In one bridge leg **28** there is interposed a condition-responsive transducer **30** which can, for example, be a resistance thermometer bulb, and as provided by the invention in another symmetrically disposed bridge leg **32** there is connected a light sensitive cell or photosensitive device **34** which is shown as being of the variable conductance type. A small incandescent electric lamp **36** constituting electrically energized means providing a source of light supplies a light beam **38**, arranged to strike the photosensitive device **34**. A condensing lens **40** is shown as concentrating the beam **38** in the well known manner.

In accordance with the present invention, according to one embodiment thereof, there is provided an elongate, opaque movable light-control member **42** having a tapered or otherwise non-monotonous configuration and comprising a segment of the lateral surface of a cylinder. The member is supported by an arm **46** which can be coupled directly to the movable portion or spindle **48** of the instrument movement or galvanometer **22**, the arm thus constituting means turnably mounting the light-control member for movement across the path of the light beam **38**. The instrument movement **22** can in large part be of conventional construction, having front and rear bearing or pivot support members **50, 52** respectively, a permanent magnet field structure **54**, a moving coil **56** carried by the spindle **48**, and a pointer assemblage **58** including a pointer **60**. Associated with the pointer **60** is a dial **62**. The arrangement is such that deflection of the movable coil system of the galvanometer **22** results in corresponding deflecting movement of the light-control member **42** about the axis of the instrument movement.

In FIG. 3 the photosensitive cell **34** is shown below the light-control member **42**, with the lamp **36** and condensing lens **40** above the element. The arrangement is such that a portion of the light beam **38** striking the sensing surface of the photosensitive device **34** is intercepted by the movable member **42**. Depending on the rotative position of the galvanometer moving assemblage, either more or less light will strike the cell **34** since the beam **38** is more or less cut off due to the tapered shape of the movable member **42**.

Referring now to FIG. 17, there is illustrated an enlarged view of the expansive sensing surface **64** of the photosensitive device **34**. It will be understood that the response of the device depends not only upon the intensity of the light striking this surface but also upon the portion of the entire area of the surface which is illuminated at any particular time. As best understood by referring to FIG. 3, when the movable member **42** is rotated about the axis of the galvanometer spindle **48**, to an intermediate position, the member will intercept a portion of the beam **38** and thus produce a defined elongate shadowed area **66** (FIG. 17) on the sensing surface **64**, the area being bounded on both sides by illuminated areas **68** and **70** respectively. The illuminated areas comprise a pair of spaced apart marginal border portions **72** and **74** respectively, the distance between the latter varying in accordance with a predetermined pattern which in turn is dependent upon the particular configuration or taper of the member **42**. The border portions **72** and **74** are thus characterized by spaced apart lines of separation **76** and **78** respectively, between the shadowed area **66** and the illuminated areas **68** and **70** on the sensing surface **64**. The movable member **42** blocks out the light which would normally fall between the spaced apart lines of separation **76** and **78**. By this arrangement, the expanse of the illuminated areas **68** and **70** on the sensing surface varies as the movable member **42** is turned about the axis of the galvanometer spindle **48**, due to the tapered shape of the member **42**. Lines **76** and **78** are not parallel, but rather are convergent, in FIG. 17. Further, in accordance with the present invention, the member **42** is disposed for movement along a path in which the shadowed area **66** produced thereby will be roughly centralized with respect to the sensing surface **64**. By this arrangement wherein the illuminated areas **68** and **70** are co-extensive with each other, undesirable variation in the photodevice response due to inadvertent lateral shifting of the shadowed area **66** with respect to the sensing surface **64** is minimized, since a small shift in a lateral direction of the shadowed area **66** will have minimal effect on the relative size of the illuminated and shadowed areas, said relative size being the major factor establishing the photosensitive device response.

Considering again FIG. 1, one set of opposite corners B, D of the bridge **20** is energized from a battery **80** having one terminal grounded. A corner terminal A of the bridge **20** is connected by a line **82** to what I term a "positioning amplifier", constituting the amplifier **24** whose other input lead **84** is grounded. Thus, the positioning amplifier **24** will be responsive to the potential across the leg **28** of the bridge **20**, and it will be seen that the condition-responsive transducer **30** comprises the said leg whereby voltage variations across the transducer will also be present at the input of the positioning amplifier 24.

Further, in accordance with the invention, the amplifier 26 which I term herein a "null" amplifier has one input lead 86 connected to the input lead 82 of the amplifier 24 and has its other input lead 88 connected to the bridge corner C which is opposite the corner A. Thus, the input to the null amplifier 26 will be taken from the opposite bridge corners A, C, and will be subjected to voltage differences between the said bridge corners.

The positioning amplifier 24 is so arranged as to drive the galvanometer 22. In effecting this, the galvanometer has a lead 90 connected to an output line 92 of the positioning amplifier 24 and has a second lead 94 connected to an output line 96 of the null amplifier 26.

The null amplifier 26 provides an output which is opposite in polarity to that of the positioning amplifier and therefore drives the meter or galvanometer 22 even more rapidly when an unbalanced condition of the bridge 20 exists. For a balanced condition of the bridge 20, the null amplifier 26 has zero output, and the galvanometer 22 indicates the difference between the amplifier outputs.

In FIG. 1 the mechanical connection between the movable system of the galvanometer 22 and the light-control member 42 is indicated by the broken line 98. The operation of the bridge-galvanometer light-control servo device of the present invention can now be understood. Referring to FIG. 1, assuming a balanced condition of the bridge, the output of the amplifier 26 would be zero, and the galvanometer 22 will have a predetermined position by which a certain amount of light from the lamp 36 is allowed to strike the sensing surface 64 of the photosensitive device 34 so as to balance out the transducer 30 which is subjected to a condition such as heat, cold, etc. Since the galvanometer 22 is at rest, the pointer 60 thereof will have a definite indicating position, and the dial 62 can be graduated in various units depending on the use to which the servo system is put. The indication of the pointer 60 on the dial 62 accordingly can be an indication of the condition to which the transducer 30 responds. For example, the dial 62 can be calibrated in degrees temperature or various other units, as is well understood. Upon a change in the condition influencing the transducer 30, the latter will change its electrical characteristic or response and effect an unbalance of the bridge 20. This will result in the amplifiers 24, 26 driving the galvanometer either upscale or downscale, depending on the direction of change of the condition.

Deflection of the galvanometer will result in the light beam 38 being modified by the light-control member 42 so as to allow either more or less light to strike the photosensitive device 34. The change in the amount of light striking the sensing surface 64 thus varies the response of the photosensitive device 34 in such a manner as to re-establish the balance of the bridge; the galvanometer will deflect the required extent to supply the necessary amount of light to the cell for effecting such balance. Upon the bridge again becoming balanced, the galvanometer needle 60 will now have a new position, indicating a new value on the dial 62 which corresponds to the new value of the condition being monitored by the transducer 30.

Accordingly, the response of the galvanometer 22 is seen to be a function of the changes in the condition which influences the transducer. The galvanometer thus can function as a position transducer for angular or even for linear values, since conversion from angular to straight line motion can be readily effected either optically or by other suitable means. The present servo system can also operate as a basic function generator, giving an electrical as well as a mechanical output. For example, the output of the photosensitive device 34 can be utilized to excite other electronic equipment. Instead of the cell being of the conductive type, it can be of the generative type, whereby a voltage is generated as a result of light striking the cell.

Also, the transducer 30 can be in the form of a thermocouple 100 as illustrated in FIG. 16, such thermocouple being connected by a cold junction arrangement 102 to a leg 28*a* of a bridge circuit 20a which is substitutable for the bridge 20 in FIG. 1. The four corners of the bridge in FIG. 1 have been labelled A, B, C, and D, and in FIG. 16 the corresponding four corners of the bridge therein have been labelled A', B', C' and D' respectively, thereby to indicate the proper connections to be followed in substituting the bridge 20*a* in FIG. 16 for the bridge 20 of FIG. 1.

The amplifiers 24, 26 can be of the solid state variety, both incorporated in a single chip of miniature size. Likewise, the Wheatstone bridge 20 requires but little space and the same is true of the lamp 36 and optical system involving the lens 40, light-control member 42 and photosensitive device 34. Also, instrument movements of the D'Arsonval type are currently manufactured so as to require relatively little space, whereby the entire servo unit can be especially small and compact, and of light weight. Further, the electrical energization needed can be supplied from small batteries whereby the entire unit is readily portable. Servicing is kept to a minimum inasmuch as but a single movable part is involved, that comprising the movable system of the galvanometer which carries the light-control member. A high degree of accuracy and reliability is had in the servo system, and the fabrication cost can be relatively low.

Another embodiment of the invention is illustrated in FIGS. 6 and 7. In these figures the light-control member 42*a* comprises a segment of a cylinder having an expansive mirrored or silvered reflecting cylindrical wall surface 104 and a non-reflecting opaque portion 106 of tapered configuration. As seen in FIG. 6, the photosensitive device 34 and the incandescent lamp 36 are both located at the exterior of the member 42*a*, together with the condensing lens 40. An opaque light shield 108 prevents stray light from the lamp 36 from striking the photosensitive cell 34. Accordingly, the cell 34 receives its light by reflection from the reflecting surface 104 of the member 42*a*. As the member 42*a* is arcuately shifted, either a greater or a smaller reflective area of the reflecting surface 104 is available for directing light from the lamp 36 against the sensing surface 64 of the photosensitive device 34. Accordingly, the position of the control member 42*a* determines the amount of light which is received by the cell 34. The member 42*a* has a sector-shaped transverse wall 110 by which it can be mounted on the spindle 48 of the galvanometer 22. It will be readily understood that the light-control member 42 will give rise to shadowed and illuminated areas on the sensing surface 64 of the photosensitive device **34** of the same character as those depicted in FIG. **17** and discussed above in connection with the first-mentioned embodiment of the invention. In the embodiment of FIGS. **6** and **7**, the configuration of the opaque portion **106** will determine the shape of the shadowed area **66** in FIG. **17**, which will have a direct bearing on the response of the photosensitive device **34** as the member **42** is rotated about the axis of the galvanometer spindle **48**. There is one difference, however. Due to the fact the reflecting surface **104** is cylindrical, the reflected portion of the beam **38** will be somewhat divergent (after reflection) as shown in FIG. **6** and this will give rise to axially expanded illuminated areas and an axially expanded shadowed area on the sensing surface **64** in FIG. **17**.

Still another embodiment of the invention is illustrated in FIGS. **8–10**, in which a light-control member **112** comprises a substantially flat, disk-shaped sheet, having an expansive silvered or mirrored reflective portion **114**, and an elongate light-absorbing opaque portion **116**. The opaque portion **116** may take the form of an overlay on the reflective portion **114**, and can have a wedge-like configuration as illustrated in FIG.**8**, wherein the width of the opaque portion varies circumferentially according to a predetermined pattern. The light-control member **112** can be mounted on the galvanometer spindle **48** in place of either the members **42** or **42***a*. As seen in FIGS. **9** and **10**, the incandescent lamp **36** directs light through a lens **40** against the reflective portion **114**, from which the light beam is directed to the sensing surface **64** of the photosensitive device **34**. The action of the light beam control shown in FIGS. **8–10** is accordingly seen to be similar to that illustrated in FIGS. **6** and **7**, with the exception that the control member **112** comprises merely a flat disk, whereas the control member **42***a* in FIGS. **6** and **7** comprises a segment of a cylinder. FIGS. **18** and **19** illustrate circular and substantially rectangular configurations respectively of sensing surfaces **64** and **120** of photosensitive devices **34** and **122**. The arrangement of the light-control member **112** in FIGS. **8–10** will produce an elongate shadowed area **124** and illuminated areas **126** and **128** on the surface **64** of the photocell **34** in FIG. **18**. The spaced apart lines of separation **130** and **132** in this case are curved, due to the configuration of the opaque portion **116** of the light-control member **112**, and are also convergent as illustrated in FIG. **18**. Similarly, when the photosensitive device **122** having the rectangular sensing surface **120** is employed in the arrangement of FIGS. **8–10**, the light-control member **112** will produce an elongate shadowed area **134**, and substantially coextensive illuminated areas **136** and **138**. In this case also, the lines of separation **140** and **142** between the shadowed area and the illuminated areas are curved and convergent, due to the configuration of the opaque portion **116** of the light-control member **112**.

Yet another embodiment of the invention is illustrated in FIGS. **11** and **12**. In these figures, a light-control member **144** having the form of a substantially flat sheet is adapted for mounting on the galvanometer spindle **48***a*. The member **144** has an expansive transparent portion **146** through which light can pass and an elongate opaque portion **148** having a generally tapered configuration, wherein the taper is not regular but instead non-monotonous and irregular, this being intended to modify the light beam according to a predetermined pattern or plan. As seen in FIG. **12**, the incandescent lamp **36** and a diffusing lens **40**a are disposed on one side of the light-control member **144**, whereas the photosensitive device **34***a* having a rectangular sensing surface is disposed on the opposite side. Light passing through the transparent portion **146** and striking the sensing surface of the photosensitive device will determine the response of the latter; the response will be varied as the light-control member **144** is rotated due to the tapered configuration of the opaque portion **148** of the member. By modifying the configuration of the opaque portion **148**, various characteristics can be built into the light beam control to suit particular conditions of use. It will be understood that the opaque portion **106** of FIG. **7**, or **116** of FIG. **8** can also be given an irregular or specific contour different from that shown, to impart the desired control characteristics thereto.

Yet another embodiment of the invention is illustrated in FIG. **14**, wherein a light-control member **144***c* has a transparent portion **146***c* on which there is disposed a translucent film **150** having a graduated opacity, with some intermediate portions made purposely less translucent to provide a desired, non-uniform characteristic. By properly laying out the translucency of the film, many varied characteristics can be obtained. The member **144***c* could be used in place of the member **144** shown in FIG. **12**, as can be understood. Also, the irregular taper of the opaque portion **148** of the member **144** in FIG. **11** can have a uniform characteristic as illustrated in FIG. **13**, wherein the transparent portion is designated **146***b*, and the opaque portion is designated **148***b*.

Another embodiment of the invention is illustrated in FIG. **20**, showing a light-control member **158** having an opaque portion **160** and a transparent portion **162**. The member **158** can be substituted for the member **144** in FIG. **12**. It will be readily understood that the member **158** will give rise to a single shadowed area and a single illuminated area on the sensing surface of the photosensitive device **34***a*. As the member is rotated, the relative size of the illuminated and shadowed areas on the sensing surface will vary according to the specific contour of the opaque portion **160**, and will thus cause the output response of the device to change according to a predetermined pattern.

Still another embodiment of the invention is illustrated in FIG. **21**, wherein a light-control member **144***d* is shown having a transparent portion **146***d* and an opaque portion **148***d*. The opaque portion is in the form of a curved wedge, the inner border portion **164** thereof lying along an arc of constant radius with respect to the axis of rotation of the member. The member **144***d* can be substituted for the member **144** in FIG. **12**, and the operation thereof is analogous to that of the latter.

FIG. **15** provides more details of the circuitry involving the Wheatstone bridge **20** and positioning and null amplifiers **24, 26**. The lamp **36** is shown as provided with a potential of 5 volts, and thus has a constant tight output intensity, and 9 volt potentials of opposite polarity are provided for the amplifiers **24, 26**. The potential applied to the Wheatstone bridge **20** is also seen to be 5 volts. The galvanometer **22** can be of a sensitivity which provides full scale deflection for from 0 to 2 milliamperes or other sensitivities as desired. The various values of resistors and capacitors associated with the amplifiers, bridge and galvanometer are indicated on the circuit, together with the connections of the various components. One skilled in solid state circuitry will be able to readily produce the system illustrated in FIG. **15** from the information given. The amplifiers **24, 26,** both on a single chip, are commercially available products, identified by the number MC1437L. In place of the exact amplifier chip designated, equivalent amplifier chips can be utilized, either with or without alteration of the circuitry depending on the various requirements. In FIG. **15,** the pin numbers of the MC1437L are given beside the respective leads, and one possible arrangement of the amplifier input polarities is given in the interest of making a complete disclosure. However, the invention is not intended to be restricted by this disclosure of a typical circuit arrangement.

It will now be seen from the foregoing that we have provided a novel and improved control apparatus which can be employed in a servo device characterized by a Wheatstone bridge, galvanometer, and energy boosting amplifiers which provide outputs of opposite polarity, connected to the galvanometer to drive the same at an increased rate. The movable system of the galvanometer, comprising the only movable part of the servo apparatus, actuates a light-control member including a photosensitive device which is incorporated in one leg of the Wheatstone bridge. Another leg of the Wheatstone bridge incorporates the condition-sensitive or condition-responsive transducer with which the servo apparatus is to be used. As already mentioned, the different positions of the galvanometer to effect a balance of the bridge for changes in the condition being monitored constitute an indication of the condition, whereby the galvanometer serves as a function generator or as a position transducer, with either angular or linear output values. Either an electrical or mechanical output can be obtained from the galvanometer **22.** Calibration of the system is possible to obtain an initial setting depending on the particular brilliance of the lamp **36** at any time. This can be effected by the variable resistor **152** shown in FIG. **15.** Variable resistors **154** and **156** associated respectively with the amplifiers **24, 26** enable adjustment of the outputs of these to be effected.

Variations and modifications are possible without departing from the spirit of the invention.

We claim:

1. A control apparatus comprising in combination:

a. a photosensitive device having an expansive sensing surface,

b. electrically energized means providing a beam of constant light to strike said sensing surface and illuminate the same,

c. movable means interposed in the path of said beam for producing a defined elongate shadowed area on said sensing surface bounded on both sides by illuminated areas of said surface,

d. said movable means producing a pair of spaced apart lines of separation between the shadowed area and the illuminated areas the spacing of which varies in accordance with a predetermined pattern whereby the expanse of the illuminated areas on the sensing surface continuously varies in response to gradual movement of said movable means, thus altering the response of the photosensitive device as the movable member changes its position with respect thereto.

2. A control apparatus as in claim **1,** wherein:

a. said movable means comprises an elongate opaque member for blocking a portion of the light beam passing from said electrically energized means to said photosensitive device, and

b. means turnably mounting said opaque member for movement across the path of said beam of light.

3. A control apparatus as in claim **2,** wherein:

a. said opaque member comprises a segment of the lateral surface of a cylinder.

4. A control apparatus as in claim **2,** wherein:

a. said opaque member is substantially crescent-shaped.

5. A control apparatus as in claim **1,** wherein:

a. the illuminated areas on the sensing surface are substantially coextensive with each other.

6. A control apparatus as in claim **1,** wherein:

a. said movable member comprises a substantially flat sheet having a transparent portion through which light can pass, and an elongate opaque portion located in said transparent portion, and

b. means mounting said member for rotation about an axis perpendicular to the plane of the sheet.

7. A control apparatus as in claim **6,** wherein:

a. said opaque portion has a wedge-like configuration.

8. A control apparatus as in claim **7,** wherein:

a. the width of the opaque portion varies according to a predetermined pattern.

9. A control apparatus as in claim **1,** wherein:

a. said movable member comprises a substantially flat sheet having a light reflecting portion and an elongate light-absorbing portion,

b. said light reflecting portion producing illumination on said sensing surface, and

c. means mounting said member for rotation about an axis perpendicular to the plane of the sheet.

10. A control apparatus as in claim **9,** wherein:

a. said light-absorbing portion has a wedge-like configuration disposed within said reflecting portion.

11. A control apparatus as in claim **1,** and further including:

a. a bridge having four legs which constitute interrelated circuits,

b. condition-responsive means connected with one leg of said bridge for effecting an unbalance of the latter in response to changes in a condition,

c. said bridge having terminals comprising output means connected to said legs,

d. amplifying means having input and output circuitry, said input circuitry being connected to said output means to receive energy therefrom,

e. said photosensitive device being connected with said bridge output means,

f. a galvanometer connected to the output circuitry of the amplifying means to be operated thereby,

g. said movable means comprising a light-control member coupled to the galvanometer to be actuated thereby, whereby any change in said condition which causes an unbalance of the bridge results in a deflection of the galvanometer to alter the light striking said photosensitive device in a manner that causes reestablishment of the bridge balance.

12. A control apparatus as in claim **11,** wherein:

a. the light-control member is carried directly by the moving system of the galvanometer and has arcuate movement.

13. A control apparatus comprising in combination:

a. a photosensitive device having an expansive sensing surface,

b. electrically energized means providing a beam of constant light to strike said sensing surface and illuminate the same,

c. movable means interposed in the path of said beam for producing a defined elongate shadowed area on said sensing surface bounded on both sides by illuminated areas of said surface,

d. said movable means producing a pair of spaced apart lines of separation between the shadowed area and the illuminated areas the spacing of which varies in accordance with a predetermined pattern whereby the expanse of the illuminated areas on the sensing surface continuously varies in response to gradual movement of said movable means, thus altering the response of the photosensitive device as the movable member changes its position with respect thereto,

e. a bridge having four legs which constitute interrelated circuits,

f. condition-responsive means connected with one leg of said bridge for effecting an unbalance of the latter in response to changes in a condition,

g. said bridge having terminals comprising output means connected to said legs,

h. amplifying means having input and output circuitry, said input circuitry being connected to said output means to receive energy therefrom,

i. said amplifying means comprising a positioning amplifier and a null amplifier,

j. a galvanometer connected to the output circuitry of said amplifiers to be energized and actuated therefrom,

k. said movable means comprising a light-control member coupled to the galvanometer to be actuated thereby, whereby any change in said condition which causes an unbalance of the bridge results in a deflection of the galvanometer to alter the light striking said photosensitive device in a manner that causes reestablishment of the bridge balance.

14. A control apparatus as in claim **13,** wherein:

a. the light control member is carried directly by the moving system of the galvanometer and has arcuate movement.

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