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(54) PRESSURE-ELECTRICAL SIGNAL CONVERSION DEVICE

(71) We, MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD., a Japanese Body Corporate, of 1006, Oaza Kadoma, Kadoma-shi, Osaka-fu, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a device for the conversion of pressure signals to electrical signals. More particularly the invention relates to a pressure-electrical signal conversion device which has a simple and rugged construction but which is also sensitive to small pressure changes.

According to the present invention there is provided a pressure-electrical signal conversion device comprising:

a housing enclosing an interior space and having an inlet port leading to said interior space for admitting thereto fluid at a pressure to be measured;

a diaphragm which extends across said interior space so as to divide it into two separate compartments, said inlet port communicating with only a first of said compartments so that a difference in pressure in said two compartments can produce corresponding movement of the diaphragm, said diaphragm including a centrally located plate-like portion and a flexible diaphragm member which surrounds the central plate-like portion and which is attached to the walls of the interior space;

biassing means disposed in said interior space and arranged such that, when there is a finite pressure differential between said two compartments, said biassing means applies to said central plate-like portion of the diaphragm a force acting in a direction tending to vary the volume ratio of said two compartments, the magnitude of the said force being proportional to the position within the interior space of said central plate-like portion of the diaphragm;

and means for determining the instantaneous position within the interior space of said central plate-like portion of the diaphragm, said position determining means being located in one of said two compartments and including a light source for emitting light, a photosensitive unit for converting light incident thereon to a corresponding electrical output and light image forming means for receiving the light emitted by said light source and forming a light image on said photosensitive unit, either the light image forming means or said photosensitive unit being connected to said central plate-like portion of the diaphragm for movement therewith relative to said photosensitive unit or said light image forming means respectively, so that the position of a light image formed on said photosensitive unit by said light image forming means moves in correspondence to the movement of said central plate-like portion of the diaphragm, the photosensitive unit comprising a pair of adjacent photosensitive elements of the same photosensitive material, the photosensitive elements being such that the respective areas thereof illuminated by a light image formed thereon vary in a complementary fashion in a direction parallel to the path of movement of said light image so that the electrical output of the photosensitive unit varies in proportion to the location of a light image formed thereon and hence to the position in the interior space of said central plate-like portion of the diaphragm.

Thus, in a device according to preferred embodiments of the invention light from a light source is caused to illuminate different portions of a photosensitive unit in accordance with the difference in the pressure of fluid in two compartments defined in main housing portions of the means. These two compartments are connected to different sources of fluid, and separated by a diaphragm comprising a diaphragm member and displacement plates which are fixed to the central portion of the diaphragm member. The photosensitive unit is constituted by two identical elements of which each has a wide end and decreases evenly in width to a narrow end. These elements are disposed adjacent to one another in a manner such that the increasingly wide portion of one element is in line with the increasingly narrow portion of the other element. These elements are connected to a common electrode and to independent electrodes, these electrodes being connected to an output circuit which is suitably external to the main housing.

Except when the central portion of the photosensitive unit is illuminated, the illuminated area of one constituent element thereof is greater than the illuminated area of the other constituent elements, and the output circuit produces a signal which is proportional to this difference of illuminated areas. In other words, the output signal is proportional to the difference in pressure of the fluid from the different sources.

Since the photosensitive unit is constituted by identical, symmetrical disposed elements, variation of the characteristics of these elements or of other elements of the conversion means which may be caused due to variation in ambient conditions cancel one another, and good linearity of response is achieved in varying working conditions.

Further, while the main elements of the device of the invention are simple and rugged the output signal obtained is a DC signal of the order of 0.3 V per 1 mmAq change in pressure difference, and is easily stepped up to a level for actuation of a servo-control means, for example, without use of complex amplification or frequency modulation circuits.

Reference is now made to the accompanying drawings, which illustrate, by way of example, various embodiments of the invention, in which like reference numerals refer to like parts, and of which:

Figure 1 is a cross-sectional view showing the main features of construction of a first embodiment of a device according to the invention;

Figure 2 is a schematic drawing showing the principles of construction of the photosensitive unit employed in the device of the invention;

Figure 3 is a graph plotting the characteristics of the unit of Figure 2;

Figure 4 is a graph plotting the performance of the device of Figure 1;

Figures 5 and 6 are schematic drawings showing modifications of the photosensitive unit according to the invention:

Figures 7 and 8 are explanatory drawings of alternative methods of illumination of the photosensitive unit;

Figures 9, 10 and 11 are cross-sectional views of other embodiments of the invention;

Figures 12 and 13 are graphs respectively illustrating the output characteristics of the photosensitive unit and the performance curves relating to the means of Figure 11;

Figure 14 is a cross-sectional view of another embodiment of the invention;

Figure 15 is a schematic drawing showing the construction of a slit plate employed in the device of Figure 14;

Figures 16, 17 and 18 are cross-sectional views of other embodiments of the invention;

Figure 19 is a graph plotting the characteristics of the device of Figure 18;

Figures 20 and 21 are cross-sectional views of other embodiments of the invention;

Figures 22 and 23 are graphs relating to the means of Figure 21 and respectively illustrating the output characteristics of the photosensitive element employed in the device and the performance of the device;

Figures 24 and 25 are cross-sectional views of other embodiments of the invention;

Figure 26 is a graph showing performance of the device of Figure 25;

Figures 27 and 28 are cross-sectional views of other embodiments of the invention;

Figure 29 is a graph showing the performance of the device of Figure 28;

Figure 30 is a cross-sectional view of another embodiment of the invention;

Figure 31 is a detail view of elements of the device of Figure 30;

Figure 32 is a graph of the characteristics of the device of Figure 30;

Figures 33 and 34 are cross-sectional views of other embodiments of the invention;

Figure 35 schematically illustrates the construction of and the configuration of an electric circuit employed in a pressure control system employing the device of the invention;

Figure 36 is a time chart illustrating the operation of the circuit of Figure 35; and

Figure 37 is a cross-sectional view of the pressure-electric signal conversion device employed in the control system of Figure 35.

Referring initially to Figure 1 there is shown in cross-section a pressure-electrical signal conversion device according to a first embodiment of the invention comprising a high-pressure side casing 1 and a low-pressure side casing 2. The casings 1 and 2 comprise the outer walls of the first embodiment, are in a facing relationship to one another, casing 1 being above casing 2, have peripheral portions which are joined to one another, and together define an interior space (1, 2) in which are accommodated various elements of the means described below. The joint between the casings 1 and 2 is made impervious to the particular fluid whose pressure variations the device is required to detect. In the high pressure side casing 1 there is a high pressure port 3, through which high pressure fluid may enter the upper portion of the interior space (1, 2). The low pressure side casing 2 similarly has a low pressure port 4 through which low pressure fluid may enter the lower portion of the interior space (1, 2). The interior space (1, 2) is enclosed apart from the access thereto provided by the ports 3 and 4. It will be understood the terms 'high-pressure fluid' and 'low pressure fluid' refer simply to relative values of pressure of fluid entering the ports 3 and 4, and that the pressure of fluid entering one port may in fact be very close to that of fluid entering the other port.

The interior space (1, 2) is divided into a high pressure compartment 1*a* and a low pressure compartment 2*a* by a diaphragm member 5 and displacement plates 6 and 7. These determine the range of response of the conversion device to pressure differences in a manner described below. The diaphragm member 5 extends between the joint portions of the casings 1 and 2, over the entire area defining the boundary between the high pressure compartment 1*a* and low pressure compartment 2*a*. A generally central portion of diaphragm member 5 is clamped between the plates 6 and 7 which are fixed in flat relationship to one another by a fixed stud 8 provided at the central portions thereof. The plate 6 is uppermost and has an upper surface constituting a portion of the lower boundary of the high pressure compartment 1*a*, and the plate 7 being lowermost and having a lower surface constituting a portion of the upper boundary of the low pressure compartment 2*a*. That portion of the diaphragm member 5 which extends between the clamped central portion thereof and the joint portions of the casings 1 and 2 dips and is sufficiently large to permit unhindered upward and downward movement of the plates 6 and 7 in an action described below. Edge portions 6*a* of the upper plate 6 are upturned and may come into contact with the inner surface of the high-pressure casing 1 and so prevent more than a certain amount of upward movement of the plates 6 and 7.

Affixed to the inner surface of the low pressure side casing 2 there is a mounting block 14, which extends upwards to approximately the centre of the interior area (1, 2). A generally central portion of mounting block 14 defines a vertically disposed slot 14*s*, which is closed at the bottom and open at the top. A plate 9 whose upper end is fixedly attached to the stud 8 is slidably accommodated in slot 14*s*, and in a generally central portion of plate 9 there is defined a rectangular slit 17 whose long axis is horizontal. A limit to the downward movement of plates 6, 7 and 9 is imposed by stud 8 coming into contact with block 14. The mounting block 14 defines a small central open area at one side of which there is provided a small light source 13 which is mounted in an opening 14*o* in the block 14, and at the other side of which there is provided a photosensitive unit 12 which is suitably constituted by photoconductive elements. The photosensitive unit 12 has a construction which is described in greater detail below and the centre of which is effectively in a horizontal line with the light source 13, the unit 12 and source 13 being very close to one another. The slide plate 9 lies between the light source 13 and the photosensitive unit 12 and is almost flush with the light-receiving surface of the unit 12, whereby the unit 12 may be illuminated only by light which passes through the slit 17 defined in the plate 9. Leads 16 which pass through the low-pressure side connect the light source 13 to an external actuation circuit not shown. Leads 15*a*, 15*b* and 15*c* supply the output from the photosensitive unit 12 to an external element not shown which is desired to be actuated in response to changes in the difference between the pressure of the fluid entering port 3 and that of the fluid entering port 4.

Inner wall portions of the low-pressure side casing 2 located around the mounting block 14 define a slot 11 which accommodates the lower end portion of a compression coil spring 10 whose upper end is attached to peripheral portions of the lower surface of the plate 7.

Action of the above described device in one set of operating conditions described by way of example is as follows. The fluid employed is air, and the low pressure port 4 is left open, whereby the pressure in the low pressure compartment 2*a* is equal to atmospheric pressure P*o*. Air under pressure P*s* is introduced into the high pressure compartment 1*a* via port 3. This causes plates 6 and 7, and hence plate 9, to be moved downwards in the low pressure direction by an amount which depends on the difference $Ps—Po$ of pressure in compartments 1*a* and 2*a* and on the force exerted by compression spring 10. Movement of plate 9 causes a corresponding displacement of slit 17 defined therein. In other words when light source 13 is actuated the portion of photosensitive unit 12 which is illuminated through slit 17 depends on the pressure difference $Ps—Po$ and the force of spring 10. The range of displacement of the slit 17 is determined by the distance between the edge portions 6*a* and the high pressure casing 1 and the distance between the lower surface of the stud 8 and the upper surface of the mounting block 14 when the pressure is equal in compartments 1*a* and 2*a*.

Referring now to Fig. 2, the photosensitive unit 12 is basically constituted by a pair of identical photoconductive elements 18 and 19, for example C*d*S, C*d*S*e*, or silicon elements. Each element 18, 19 has a regularly varying width, the elements being mounted next to one another so that the broadest part of one element is in line with the narrowest part of the other. The elements 18 and 19 in the example shown in the drawing are triangular and are placed together to define a rectangle. Element 18 is provided with an independent electrode 20 which is connected through the lead 15*a* to the positive terminal of a voltage source Vi, element 19 with an independent electrode 22 which is connected through lead 15*c* to the negative terminal of voltage source Vi, and there is a further electrode 21 which is common to both elements 18 and 19 and is connected to lead 15*b*. The output of the unit 12 is the potential difference Vo across leads 15*b* and 15*c*. Unit 12 is illuminated by a band of light L which has passed through the above mentioned slit 17 and extends over the entire width of unit 12. If slit 17 is located centrally with respect to unit 12, in the position X=0 shown in Figure 2, the size of area *a* of element 18 illuminated by the light L is equal to that of illuminated area *b* of element 19. In any other position of slit 17 areas *a* and *b* differ in size and the values of resistance presented by elements 18 and 19 are therefore different. A varying output Vo is therefore obtained which increases as the band of light L moves upwards, to increase the illuminated area *a* of element 18 and to decrease the illuminated area *b* of element 19. In the description below, upward or downward movement of the band of light 17 from the central position X=0 is measured in millimetres and defined as positive or negative displacement respectively.

Needless to say, as long as it is centred on the long axis of the photosensitive unit 12 the slit 17 may have a shape other than rectangular, and the neutral position of the slit 17 determined by the spring 10 when there is equal pressure in compartments 1*a* and 2*a* is not necessarily such that the illuminated areas *a* and *b* are equal.

Referring to the assembly of plates 6 and 7 and diaphragm member 5 as diaphragm 5′ for simplicity, if the effective area S of diaphragm 5′ is 32 cm^2, the spring constant k of compression spring 10 is 16 g/mm, and the displacement range l of the band of light L is 4 mm, and for each 1 mmAq of pressure difference $P=Ps—Po$, and assuming that the stress relative to the diaphragm 5′ can be ignored as being insignificantly small compared to the stress built up by the spring 10, the pressure force f (in grams per millimetre of water i.e. g/mmAq) imposed on the diaphragm 5′ is given by:

$$f=1/10\ S=3.2\ \text{g/mmAq}.$$

As the spring constant k of spring 10 is 16 g/mm, there is a 0.2 mm displacement of the band of light L for each 1 mmAq of pressure different P. The relative disposition and dimensions of plate 9, slit 17, spring 10 and photosensitive unit 12 are such that when the pressure difference P=10 mmAq., the band of light L is located at the position X=0, as shown in Figure 2. In this condition, when light source 13 is actuated and a voltage $Vi=10$ V is imposed across electrodes 20 and 22 of unit 12, the output voltage Vo is 5 V, as plotted both in Figure 3 and in Figure 4. If the pressure difference P is now varied, there is positive or negative displacement of the band of light L according to whether the pressure difference P increases or decreases, and since the displacement is 0.2 mm/mmAq, the displacement range l of 4 mm, i.e., from X=+2 mm to X=−2 mm, corresponds to a variation of pressure difference P over the range of from P=0 mmAq to P=20 mmAq. The output voltage Vo over this range of displacement of the band of light L varies linearly, as shown in Figure 4, and covers the comparatively wide range of from 2 V to 8 V.

Advantages offered by the above described device may be summarized as follows.

(1) There is good response to small changes in pressure and the variation of voltage output with respect to variation of pressure is linear. Further, the proportional response of the device i.e., the amount of change of output voltage for a given change in pressure, may be varied by simply selecting compression coil springs having different spring constants, and the detection range may be altered by varying the dimensions of the spring and the dimensions of the interior portion of the conversion

device between the block 14 and the low-pressure casing 1. Thus, the conversion device is easily adaptable for use for different types of measurement or detection of pressure over different ranges.

(2) Since the photosensitive unit 12 is constituted by two identical elements and the output is determined by the relative size of the illuminated areas of these elements, any variation in physical properties of these elements which may occur due to variation in ambient conditions cancel out, and a faithful response is achieved over the whole range of temperatures, etc., encountered in normal working conditions. This symmetry of construction of the unit 12 also ensures a fidelity of response despite a fall in light-emission efficiency of the light source 13, since both photosensitive elements 18 and 19 are illuminated by the same source, and the conversion device of the invention thus offers the advantage of reliable response over a long period of service. If the photosensitive unit 12 is constituted by a hermetically sealed photoconductive cell and the light source 13 by a photoemissive diode, a service life of more than 100,000 hours may be achieved.

(3) When, for example, photoconductive cells are employed to constitute the unit 12, as shown in Figure 3, a sufficiently large DC voltage V_o is obtained as the output without there being any need for complex frequency modulation or phase modulation circuits such as are required in conventional devices.

Also, if the output impedance in the output signal circuit is high, i.e., 100 K or more, the output is easily detectable by means of a single transistor forming an emitter follower circuit, and there is no need for the employment of costly or complex circuit elements.

Since, in addition, the other elements of the conversion device, the diaphragm member, compression coil spring, etc., are inexpensive, the whole unit may be produced at very low cost.

(4) In contrast to conventional devices, which normally demand employment of very delicate, and hence easily breakable, elements to detect small values or small changes of pressure, the device according to the invention permits this detection using only rugged elements such as described above, and is therefore much more adapted for use in rough working conditions and does not require especially careful handling, during manufacture, transportation, or installation.

There are of course many possible modifications of the device of Figure 1 which will be apparent to those skilled in the art; examples of such modifications are as follows:

(1) Instead of a compression spring, there may be a tension coil spring or plate spring means mounted in the high pressure compartment 1*a*.

(2) Instead of being provided in the low pressure compartment 2*a*, the light source 13 and photosensitive unit 12 may be provided in the high pressure compartment 1*a*.

(3) For measurement of particularly small pressures, to give improved temperature characteristics, etc., the portion of the diaphragm member 5 which extends between the plates 6 and 7 and the casings 1 and 2 should be almost flat, the dip of this portion of the diaphragm member being suitably of the order of 0.1 to 0.2 times the thickness of the diaphragm member, if the diaphragm member is made of rubber material.

Selection of the material of the diaphragm member is of course made in reference to the type of fluid whose pressure changes are to be detected, silicone rubber being a suitable material if the fluid is air, for example. Also, instead of a sheet diaphragm member such as is shown in Figure 1, there may be employed a bellows element or an undulated diaphragm member.

(4) There may be employed an undulated metallic element which serves both as a diaphragm member and as a spring element to assist positioning of the slit plate 9.

(5) Instead of being fixedly attached to the stud 8, the slit plate 9 may be attached thereto by a hinge or rotary ball element, which permits the plate 9 to pivot slightly about its upper end and move slightly to the left and right as seen in the drawing while being guided in a slot defined in the mounting block 14. In this case, the plates 6 and 7 need not be perfectly horizontal when they are moved due to a difference of pressure between the compartments 1*a* and 2*a*, since the plate 9 naturally swings into a vertical alignment, so avoiding frictional contact with the block 14 and ensuring maintenance of accurate control of illumination of the photosensitive unit 12, even if the plates 6 and 7 are slightly tilted.

(6) To further ensure that exposure of the photosensitive unit 12 is limited to exposure by light passing through the slit 17 defined in the plate 9, as well as ensuring that the plate 9 remains very close to the unit 12, it is also advantageous to impart a matt, black surface to portions of the plate 9 and block 14 which are adjacent to or in line with the slit 7, in order to keep the passage of reflected light through the slit 17 to a minimum.

(7) To increase the effective range over which the band of light L may be displaced, while maintaining a linear relationship

between pressure changes and output of the conversion means, the distance between the plate 9 and the photosensitive unit 12 may be made smaller and the distance between the plate 9 and the light source 13 may be made larger, and also as far as possible the light source may be made a point source, which may be achieved by employed a glass or resin encapsulated photoemissive diode.

(8) The photosensitive unit 12 may be constituted by C*d*S or C*d*S*e* photoconductive cells or silicon cells, as noted above, and in addition to elements whose resistance varies in response to incident light, there may also be employed selenium photovoltaic elements which produce varying amounts of electromotive force in response to incident light.

(9) The elements 18 and 19 constituting the photosensitive unit 12 may each be a triangular block of uniform material as shown in Figure 5, or may each be constituted by grid elements of varying length which project from an independent straight-bar electrode constituting the short side of the unit 12. In this latter case the common electrode is defined by an N-shaped base element whose outer sides define the long sides of the unit 12, grid elements which extend between the grid elements of the elements 18 and 19, as shown in Figure 6, being attached to the cross portion of the N-shaped base element. The construction of Figure 6 has the advantage that the impedance of the unit is less and the processing of output signals is therefore easier, but it should be noted that since the elements 18 and 19 do not actually contact the common electrode, the width of the slit 17 must be very large compared with the clearance between the elements 18 and 19 and the cross-bar portion of the common electrode, and that there is liable to be poor linearity of response if the slit 17 is made too narrow.

Referring to Figure 7, instead of slit plate 9 there may be employed a frame 9′ which supports a square or rectangular opaque board in a generally central location. In this case, as shown in Figure 8, the unit 12 is constituted by elements 18′ and 19′ which are in the form of straight strips of material and are respectively sandwiched between an independent electrode 20′ and a common electrode 21′, and between an independent electrode 22′ and the common electrode 21′, and which extend downwards and upwards to the level of the centre of the unit 12, whereby a greater area *a*′ of the element 18 and a smaller area *b*′ of the element 19 are illuminated by bands of light L1 and L2 passing above and below the opaque portion of the frame 9′ as the frame 9′ moves downwards, and vice-versa. With this construction, the effective displacement range of the frame 9′ is one half the height of the opaque portion thereof.

The description continues below in reference to other embodiments of the invention.

Referring to Figure 9, according to a second embodiment of the invention, instead of being mounted in the block 14, light source 13 is fixed to one arm 23*a* of a generally U-shaped bracket 23, whose base is fixedly attached to the lower surface of the displacement plate 7 by the stud 8 and whose other arm is in a parallel facing relationship to the arm 23*a* and in effect defines the plate 9 having a slit 17 defined therein, the slit 17 being in a horizontal line with the light source 13. In this case, when the plates 6 and 7 are moved, both the source 13 and the slit 17 are displaced by identical amounts and different portions of the fixedly mounted photosensitive unit 12 are illuminated dependent on the amount of this displacement. With this arrangement, elimination of reflected light may be achieved by providing an opaque sleeve element, not shown, which extends between the light source 13 and the slit 17. The leads 16 inside the conversion device are of course made sufficiently long and flexible to permit unhindered upward or downward movement of the bracket 23.

In Figure 10, the light source 13 is mounted in and enclosed by an outer wall portion 14*b* of the mounting block 14. The slit 17 is not movable but is defined in the block 14 in line with the light source 13 and extends from the location of the light source 13 in wall portion 14*b* to the surface of the wall portion 14*b* which faces the opposite wall portion 14*a* of the block 14. The upper end of the photosensitive unit 12 is attached to an angle piece 24 which is fixed to the central portion of the lower surface of the displacement plate 7 by the stud 8, and which holds the photosensitive unit 12 close to the wall portion 14*b* of the block 14 and causes the unit to be moved up and down as the plates 6 and 7 are moved up and down. This embodiment gives the same general advantages as the embodiment of Figure 9.

Referring now to Figure 11, there is shown a pressure-electrical signal conversion device which has the same general construction as that described in reference to Figure 1. The difference is that the inner surface of the low pressure side casing 1 above the plate 6 has a downwardly extending ridge portion which is disposed symmetrically with respect to the centre plate 6 and constitutes a stop 25 for preventing of more than a certain amount of upward movement of the plates 6 and 7, and hence of the slit 17 in the plate 9, and the upper surface of the mounting block 14 below the plate 7 defines an upwardly extending ridge portion which is disposed symmetrically with respect to the centre of the plate 7 and constitutes a stop 26 for prevention of more than a certain amount of downward movement of the plates 6 and 7. The dimensions of the stops 25 and 26 are such that the permitted amount of displacement of the slit 17 from the abovementioned neutral position X=0 is +2 mm or −2 mm. The reason for this, is that, as shown in Figure 12, over the range of displacement of the slit 17 wherein there is a parity between the size of the illuminated area a of the element 18 and that of the illuminated area b of the element 19 (see Figure 2) there is a good linear relationship between displacement of the slit 17 and output signal voltage Vo, but outside this range, when practically no portion of the unit 12 is illuminated, it is practically impossible to achieve linearity of response. For the abovenoted dimensions of the various elements of the conversion device, the range of displacement of the slit 17 in which good response is achieved is X±2 mm. Thus, if the position X=—2 mm of the slit 17 is the position in which the area a is almost zero, the stops 25 and 26, by preventing movement of the slit 17 outside a range of 4 mm, ensure that only reliable values of output are produced. As shown in Figure 13, the range of output values in this case is from 2 V to 6 V, and the corresponding range of difference of pressure P is from P=0 mmAq, which is a practical required limit of a pressure detection device, to P=20 mmAq. Needless to say, the linear response range is easily varied by changing the neutral setting of the slit 17 and/or the dimensions of the photosensitive unit 12.

In Figures 14 and 15, with the photosensitive element 12 and light source 13 fixed, the range of displacement of the slit 17 may be controlled by providing in an upper portion of the plate 9 an elliptical slot 28 whose major axis is perpendicular and which encloses a rod 27 which is fixedly attached to the mounting block 14 and extends across an upper portion of the slit defined in the block 14 in which the plate 9 may slide up and down. With this construction, after a certain degree of upward movement of the plate 9 the lower end of the slot 28 comes into contact with the rod 27 and prevents further upward movement of the plate 9. Downward movement of the plate 9 through more than a certain distance is prevented by the upper end of the slot 28 coming into contact with the rod 27.

In the embodiment shown in Figure 16, the slit plate 9 is fixed or integrally attached to a bracket 9″ having a horizontal portion attached to the lower surface of the displacement plate 7 by means of the stud 8, the plate 9 being out of vertical line with the stud 8 and being close to the photosensitive unit 12. The upper end of a vertically disposed rod 29 is attached to the stud 8 or a fixed extension thereof. The rod 29 is slidable in a rod guide 30 which permits movement of the rod 29 in a vertical line only. Thus, even if there is uneven distribution of pressure in either or both the compartments 1a and 2a, the plates 6 and 7 are maintained horizontal and the slit plate 9 is maintained vertical and remains accurately positioned with respect to the unit 12.

In the embodiment of Figure 17, the light source 13 and photosensitive unit 12 are fixed, and the slit plate 9 is defined by the vertical plate of a right-angle piece 35 having a horizontal plate attached by means of a holder element 35a to a vertical rod 31. The upper end of rod 31 is connected to the stud 8 and passes through and is slidable in holes defined in the upper horizontal wall and lower horizontal wall of a rod guide element 32, which permits the rod 31 to move only along a vertical line and defines a central open space. The right-angle piece 35 is attached to a portion of the rod 31 which is below the upper horizontal wall of the guide 32. In this conversion device the abovementioned compression spring 10 is not employed, but instead there is provided around the rod 31 a much smaller compression spring 33 which is held between spring retainer elements 34a and 34b which are attached to the lower surface of the horizontal plate of the right-angle piece 35 and the upper surface of the lower horizontal wall of the rod guide 32 respectively. The spring 33 is smaller than the spring 10 and it is possible to increase the sensitivity of the conversion device, since it is comparatively easy to employ a spring which exerts only a small tensile or compressive force.

Referring now to Figure 18, there is shown an embodiment of the invention which further permits detection of negative values of pressure difference, and in which, in addition to the compression spring 10, comprises a compression coil spring 36, whose spring constant is equal to that of spring 10 and which extends between and is held by spring retainer portions defined by the upper surface of the displacement plate 6 and the lower surface of the high pressure side casing 1. The main features of construction of the conversion device are otherwise the same as described in reference to Figure 1.

Referring also to Figure 19 the size and disposition of the elements of the device of Figure 18 are such that when the pressure difference P is zero, the output signal voltage V_o is 5 V. If the pressure in compartment 1*a* increases while the pressure in compartment 2*a* remains constant, the plates 6 and 7 are moved downwards, spring 36 is expanded and the force exerted thereby on the plate 6 becomes less while the spring 10 is compressed and the force exerted thereby becomes correspondingly greater, with the result that the output voltage from the photosensitive unit is increased linearly as the pressure increases. The reverse action takes place if the pressure in compartment 1*a* falls below that in compartment 2*a* and a linearly decreasing output voltage V_o is produced by the photosensitive unit 12. The output voltage V_o of the device of Figure 18 ranges from 2 V to 8 V for the pressure difference range of 0±20 mmAq.

In the embodiment shown in Figure 20, the light source 13 and photosensitive unit 12 are fixed, and the slit plate 9 is fixed to the stud 8 and may be freely moved up and down in a comparatively wide slit defined in the mounting block 14. Horizontality of the displacement plates 6 and 7 and verticality of the slit plate 9 are maintained by a bracket element 37 in the general shape of a square U. The bracket element 37 has an upper horizontal side having one end attached to the stud 8, a lower horizontal side having one end attached to the lower end of the slit plate 9, and a vertical side which joins the horizontal sides and is slidably mounted in a pair of slide support elements 38 and 39 which are mounted in vertical alignment with one another on an inner mounting wall portion in the low pressure side casing 2.

In Figure 21 there is shown a device which is particularly suited to applications in which it is required to keep the signal output unchanged over a certain range of pressure difference, such as for example automatic control systems, in which it is wished to avoid actuation of feedback elements in response to small fluctuations of fluid pressure.

The device of Figure 21 has the same basic construction as the device of Figure 1, with the addition of an expansion coil spring 41, a spring force transmission element 41, and a spring retainer 42. The spring retainer 42 is attached to the inner surface of the low pressure casing 2, surrounds and extends upwards to higher than the mounting block 14, and has an upper end portion having a hook or retainer portion 42*a*. The spring force transmission element 41 comprises a lower end step portion which is hooked onto, but not attached to, the hook portion 42*a*, and a straight portion which joins the lower end step portion to an upper end step portion. The spring 40 is provided around the mounting block 14 and between the block 14 and retainer 42. The lower end of the spring 40 is mounted in a spring mount portion defined by the lower end of the retainer 42 and an upwardly projecting portion of the inner surface of the casing 2, and the upper end thereof is attached to or simply presses against the upper stepped portion of the transmission element 41.

Still referring to Figure 21, and also referring to Figures 22 and 23, with this construction when the pressure difference P is zero, the spring 10 pushes the plates 6 and 7 upwards so that a part of plate 6 contacts the casing 1 and exerts thereon a pressure force F1. Spring 40 pushes the transmission element 41 as far upwards as is permitted by the retainer element 42, the upper stepped portion of the transmission element 41 being out of contact with and a certain distance below the plate 7 at this time. Spring 40 exerts ar upward force F2 on the transmission element 41.

When the pressure difference P becomes positive, downward pressure is exerted on the plates 6 and 7 but the plates 6 and 7 are not moved until the downward pressure becomes greater than the upwardly acting force F1 exerted by spring 10. Once the pressure difference P exceeds the force F1, plates 6 and 7 are moved downwards and the output V_o varies proportionally as pressure difference P increases, until plate 7 is brought into contact with the upper stepped portion of transmission element 41. When this happens, any further increase of pressure difference P is temporarily ineffective in causing further downward movement of plates 6 and 7, since it is first necessary to overcome the upwardly acting force F2 exerted by spring 40, and the output V_o therefore remains constant for a certain time. When the pressure difference P increases further to and beyond the point at which force F2 also is overcome, the spring force transmission element 41 pivots about the hook portion 42*a* of the retainer element 42, the plates 6 and 7 begin to move downwards again, and the output V_o changes accordingly. In this second stage of downward movement of plates 6 and 7, although linearity of response is maintained a given increase of pressure difference P results in less displacement of plates 6 and 7, resulting in a change of slope of portions I and II of the plots of Figures 22 and 23. Depending on the application, the slopes of the portions I and II in Figures 22 and 23 may be different, or may be made constant by changing the geometry of the elements 18 and 19 constituting unit 12, e.g., by providing elements 18 and 19 of which the widths do not change evenly.

Referring to Figure 24, the same results as achieved by the device of Figure 21 may be achieved by employing the device of Figure

1 with the addition of a spring plate element 43, spring plate element 43, which has one end portion attached by means of a bolt or bolts 44 to a side portion of the high pressure compartment 1*a*, extends into compartment 1*a* above displacement plate 7 so that the free end portion 43*a* thereof is approximately above stud 8. The mounting of spring plate element 43 is such that the spring force thereof is exerted upwards, the spring plate element 43 being prevented from moving upwards beyond the horizontal position illustrated in Figure 24 by a downwardly projecting portion 46 integrally attached to the inner surface of casing 1, and a channel-shaped element 45 which has one side attached to stud 8 and one side projecting to above and engageable by the free end portion 43*a* of plate spring 43. In this embodiment, for a certain time during which the pressure difference P increases, the element 45 comes into contact with and presses downwards on the free end 43*a* of spring plate element 43 and the pressure difference P is opposed by the spring force of spring plate element 43 as well as by the spring force of spring 10, resulting in a stepped characteristic curve similar to those of Figures 22 and 23.

Needless to say, for the embodiments of both Figure 21 and Figure 24 the extent and location of the stepped portions of the characteristic curves may be altered as required by suitable selection of the spring constant values of the spring 10 and spring 41 or spring plate element 43 and of distance of the transmission elements from the plate 7 or of the distance between element 45 and the free end 43*a* of spring plate element 43 when the pressure difference P is zero, or another reference value.

In Figure 25 there is shown an embodiment in which port 3 is made the low pressure or reference pressure port and port 4 is employed for input of the fluid whose variations of pressure are to be detected. An expansion coil spring 47 is provided between casing 1 and displacement plate 6 and a circular weight element 48 is suspended above plate 6 by a flexible element 49 attached to casing 1 by a screw 50, other elements being mounted in the manner described in reference to Figure 1.

Referring to Figures 25 and 26, in this embodiment, as pressure difference P increases from a reference value, at first there is no displacement of plates 6 and 7, and hence no change of the output V_o, because of the force produced by spring 47 which must be overcome before the plates 6 and 7 are displaced in proportion to the increase in the pressure difference P. Then when the plate 6 comes into contact with weight element 48, the output V_o remains unchanged until the increase of force due to the pressure difference P exceeds the downward force exerted by weight element 48, and then output V_o again increases linearly with the increasing pressure difference P.

Depending on the application of the pressure-electrical signal conversion device it may be desired to position the slit 7 in line with different portions of the photosensitive unit 12 when the device is in a neutral position. This is achievable by the device of Figure 27, in which light source 13 and unit 12 are mounted in mounting block 14 and block 14 is not attached to casing 2 but is slidably mounted in internal slide bearing portions (not shown) of the conversion device. The block 14 may be moved towards or away from casing 2 by means of a screw element 52 which passes through casing 2. The screw element 52 has an inner end which is rotatable but not slidable in a lower portion of block 14, a central threaded portion which may engage a correspondingly threaded portion of casing 2 through which screw element 52 passes, and an outer end portion attached to an externally actuable adjustment knob 53. A stem portion of the adjustment knob 53 is set in casing 2 and is surrounded by an O ring 54 or similar seal means for preventing leakage of fluid. Between mounting block 14 and casing 2 there is provided a compression coil spring 51 which is disposed symmetrically with respect to screw 52 and has opposite ends attached to block 14 and casing 2. Displacement plates 6 and 7 and slit plate 9 are completely independent of block 14 and are moved only in accordance with the relative value of force exerted by the pressure difference P and spring 10. To change the neutral setting of the conversion device, it is simply necessary to turn knob 53 to cause block 14 to move towards or away from the high pressure compartment 1*a*, which action, presuming slit plate 9 is stationary, has the effect of bringing slit 17 into line with a different portion of photosensitive unit 12. Knob 53 is itself or has associated therewith dial means, not shown, which indicate the relevant neutral position values of pressure or output, for example, for different settings of knob 53.

Referring now to Figure 28 there is shown a device which causes the output V_o to change in proportion to the pressure difference P at selected rates of change. The device shown has the same construction as that of Figure 1 with the addition of a plate spring 55, connector 56, adjustment screw 57, and compensation screw 58. Plate spring 55, whose spring force acts upwardly, has one end portion fixedly attached to a side wall portion of the high pressure side casing 1, and extends horizontally into high pressure compartment 1*a* a distance such that the free end portion 55*a* thereof is above stud 8. This free end portion 55*a* is connected to stud 8 by connector 56. Adjustment screw 57 is disposed parallel to plate spring 55, passes through casing 1 and extends into the high pressure compartment 1*a* below plate spring 55. The adjustment screw 57 has an outer end which is externally contactable and permits screw 57 to be advanced further towards or be withdrawn from the centre of compartment 1*a*, and a head portion 57*a* which contacts the lower surface of plate spring 55. Compensation stud 58 is externally contactable and extends downwards through the upper wall of casing 1. The lower end of compensation stud 58 contacts the upper surface of plate spring 55 at a point between the fixed end of plate spring 58 and the portion contacted by the head portion 57*a* of adjustment screw 57. With this construction, displacement of plates 6 and 7 depends on the balance of the forces exerted by the pressure difference P and the springs 55 and 10, and hence is dependent on the spring constants of springs 55 and 10. The spring constant of spring 10 remains unchanged, but by moving adjustment screw 57 inwards or outwards the effective length of plate spring 55, i.e., the distance between the free end portion 55*a* of spring 55 and the portion thereof contacted by the head portion 57*a* of screw 57, is changed, and hence the spring constant of spring 55 is changed. Thus a given change in pressure difference P results in a different amount of displacement of plates 6 and 7. This is illustrated in Figure 29 which plots the output V*o* versus the pressure difference P for different settings of adjustment screw 57. When the setting of screw 57 is such that the spring constant of plate spring 55 is comparatively small the output V*o* increases comparatively rapidly with increasing pressure difference P, as indicated by the steep curve K1. If however screw 57 is adjusted inwards, the spring constant of spring 55 is increased, and the output V*o* therefore increases less rapidly with increasing pressure difference P, as indicated by the curve K2. Compensation screw 58 is employed to make adjustment to achieve a required output for a particular reference value of pressure difference P, both screws 57 and 58 having associated therewith suitable indication means not shown.

Referring now to Figures 30 and 31, according to another embodiment of the invention, in addition to being loaded by spring 10, the displacement plates 6 and 7 are loaded by a coil spring 60 which has a lower end connected to the central portion of the upper surface of plate 6 and an upper end connected to the lower surface of an externally contactable adjustment plug 61. The plug 61 is mounted in an upward extension portion of the upper wall portion of casing 1. The plug 61 may be moved downwards or upwards to increase or decrease the spring constant of spring 60, and so alter the rate at which the output V*o* changes with changing pressure difference P. The photosensitive unit 12 in this embodiment is supported in the fixed block 14 in a manner such that it may rotate about a horizontal axis but may not otherwise move with respect to block 14. Unit 12 may be caused to rotate by means of an externally contactable adjustment screw 59 which extends upwards through casing 2 and has a notched end portion 59*a* in which is engaged a small projection 62 which is attached to the periphery of the rear mount portion of unit 12. At any given setting of slit 17, upward or downward movement of adjustment screw 59 causes the photosensitive surface to pivot clockwise or anticlockwise as seen in Figure 2, while remaining parallel to plate 9, whereby the dimensions of illuminated areas *a* and *b* of elements 18 and 19 are changed. By suitable adjustment of the settings of screw 59 and plug 61 therefore it is possible to achieve an output which changes at varying rates with the displacement of plates 6 and 7, and to bring the output to the same value in all cases when plates 6 and 7 are at the neutral position X=0, as illustrated in Figure 32.

The devices of Figures 28 and 31 offer particular advantages when employed in automatic control systems, since the output can be easily matched to the control of other circuits to be actuated in response to a pressure change, and one conversion device may therefore be employed in different control systems, and may be rapidly adjusted to meet different requirements in any one control system.

Figures 33 and 34 show pressure-electrical signal conversion devices according to the invention which allow greater freedom in location of the constituent parts thereof.

In Figure 33, the light path from light source 13 to photosensitive unit 12 is longer than the light path in the device of Figure 1. Unit 12 is positioned in the same manner in block 14 but source 13 is mounted in casing 2 in such a manner that light is directed upwards through an internal space defined by block 14, impinges on a fixed reflector 63 which is mounted at an angle of 45° to the horizontal on an internal wall portion of block 14, and is reflected through 90° by reflector 63 and directed thereby through slit 17 to unit 12, plate 9 and slit 17 being movable in response to pressure changes as described above.

In Figure 34, plate 9 is dispensed with, and there is affixed to the lower end of stud

8 a plate 64 which carries a strip 64*a* of downwardly facing reflector material which is parallel to plates 6 and 7. Light source 13 is mounted in a lower portion of block 14 and the light emitted thereby is directed upwards through an inclined slit 65 defined by block 14 and onto reflector strip 64*a* which directs the light downwards along a path inclined to the vertical to photosensitive unit 12 which is mounted in a lower portion of block 14 and so disposed that the photosensitive surface thereof is normal to the path of light reflected from strip 64*a*. With this construction, as the plates 6 and 7 move downwards or upwards, the light reflected by strip 64*a* illuminates increasingly leftward or rightward portions of unit 12 as seen in the drawing, thus resulting in an output V*o* which varies with variations of pressure.

Needless to say, since the pressure P′ exerted by a fluid is related to the rate of flow Q thereof by the equation Q=A . P′, A being a constant, the various embodiments of the invention described above may be employed to detect rate of flow by providing in the casings 1 and 2 suitable ports which permit fluid to flow through the device. Also, of course, it is not essential that pressure in one compartment remain constant but pressure may vary in both compartments.

An example of an application of a conversion device according to the invention is illustrated in Figures 35 and 36, to which reference is now had. In this application, the device is associated with a central heating control installation, for example of a furnace, which has a plurality of hot or cold air ports and which is required to maintain outflow at some ports constant even if other ports are closed, pressure in the wind box of the installation being maintained constant in order to achieve this, whereby heating or cooling of associated devices is effected in an optimum manner.

The device of the invention permits this control to be effected with maximum precision, but also prevents hunting or other instability of the control system as a whole.

In Figure 35, a motor 102 drives a blower B which drives air into a wind storage box C having a plurality of outlet ports D connecting to ducts, not shown, which are to be supplied with air from wind box C. One compartment of a pressure-electrical signal conversion device F, such as described above with reference to Figures 1 to 34, is connected to the interior of wind box L by duct E, the pressure in the other compartment of the conversion device being maintained constant.

The electric power required to actuate motor 102 is controlled by a triac 103 associated with a diode 104, a capacitor 105, zener diodes 106 and 107 and a resistance 108 constituting a DC power supply circuit. This circuit is connected to a pressure detection circuit which is constituted by variable resistors 109*a* and 109*b* which are the elements 18 and 19 constituting the photosensitive unit 12 of conversion device F, a photoemissive diode 110, a transistor 112, and resistors 111, 113 and 114. The power supply is stepped up by a DC amplification circuit constituted by resistors 115, 117, 118, 119, 120, 121 and 125, transistors 116 and 122, and a capacitor 124. The gate input to the triac 103 is supplied by a trigger circuit which is constituted by a capacitor 125, and a switching element 126, and synchronization with the commercial power supply is effected by a synchronization circuit constituted by resistors 127, 128, 132, 134, 136 and 138, diodes 129 and 130, a zener diode 131, and transistors 133, 135, and 137. These various circuits, i.e., the DC power supply circuit, pressure detection circuit, DC amplification circuit, trigger circuit, and synchronization circuit, together constitute a phase control circuit for the triac 103.

Referring also to Figure 36, the control circuit of Figure 35 functions as follows. Supposing first that triac 103 is in a conducting state, current flows in motor 102 and at time t_0 of sequence I of Figure 36, the load current I_L flowing in motor 102 is not zero even though the voltage V*s* of the commercial supply is zero, because the load current I_L lags voltage V*s* in phase, as shown in sequence II of Figure 36. During the succeeding half-cycle of voltage V*s*, in which voltage V*s* is negative as seen in the drawing, at time t_1 the load current I_L becomes zero, triac 103 becomes non-conductive, and voltage V_L across opposite terminals of the motor 102 becomes zero. At this time, as shown in Sequence I of Figure 36, a voltage V_T is imposed across opposite terminals of triac 103. Taking the potential at terminal T1 of triac 103 as the reference, the potential at terminal T2 is negative. This polarity is the requisite polarity for conduction of diode 129 of the synchronization circuit, and if voltage V_T is more than several volts, current flows through resistor 128, diode 129, and resistor 127, transistor 135 becomes fully conductive, and transistor 137 is therefore turned off.

The zener diode 131 is selected so that the zener voltage thereof is slightly greater than the DC power supply voltage of the DC power supply circuit. Therefore, during the time that the potential at terminal T2 of triac 103 is in the range of from zero to the value of the DC supply voltage with respect to the potential at terminal T1 of triac 103, the current flow is stopped by zener diode 131 and transistor 133 remains non-conductive, current flow being stopped by diode 130 and the same effect achieved when the terminal T1 — terminal T2 potential is lower than this range. In other words, when the potential at terminal T1 is more than several volts negative with respect to terminal T2 of triac 103, transistor 135 conducts, transistor 133 does not conduct, and so transistor 137 is made non-conductive, as shown in sequence III of Figure 36.

When transistor 137 is non-conductive, the difference between the detection signal of the pressure detection circuit and voltage corresponding to the set pressure is amplified by the DC amplification circuit, capacitor 125 starts to be charged as current flows through transistor 122 and resistor 123, and as shown in sequence IV of Figure 36, there is a linear increase of voltage *Vc* across opposite plates of capacitor 125. When at time t_2, the voltage *Vc* reaches the set switching voltage of switching element 126, element 126 is rendered momentarily conductive, resulting in the application of a voltage V_G to the gate of triac 103, as shown in sequence V of Figure 36, and triac 103 becomes conductive, after which the voltage V_L is applied across motor 102 and the voltage V_T across terminals T1 and T2 of triac 103 becomes more or less equal to zero, as indicated in sequence I and sequence II of Figure 36.

With the voltage V_T across triac 103 close to zero, current stops flowing in resistor 128, diode 129 and resistor 127, and, since transistor 133 is not conducting, transistor 135 becomes non-conductive, and transistor 137 is turned on. Therefore, current which up to this point had been flowing through transistor 122 and resistor 123 and charging capacitor 125 now flows to transistor 137, with the result that capacitor 125 is no longer charged, and the voltage V_C across capacitor 125 becomes practically zero.

Thus at time t_2, triac 103 becomes conductive, the voltage V_L is applied across motor 102, and the load current I_L flows, but at time t_3, even though the voltage of the commercial supply 101 leaves a negative half-cycle to enter a positive half-cycle, the load current I_L, which lags as noted before, becomes zero at time t_4, and triac 103 becomes non-conductive, the voltage V_T appears, and the voltage V_L across opposite terminals of motor 102 becomes zero. Then, terminal T2 of triac 103 becomes positive with respect to terminal T1, and when it becomes more than several volts positive, conditions no longer permit diode 129 to conduct, and at the same time a voltage exceeding the zener voltage of zener diode 131 is applied to zener diode 131, and so current flows through resistor 127, diode 130, zener diode 131, and resistor 132, and transistor 133 is made conductive. This results in current flow through resistors 128 and 134 and consequent turn-on of transistor 135, and turn-off of transistor 137. Therefore a charging current flows into capacitor 125, and the previously described action is continuously repeated, whereby motor 102 forces air into wind box C at a rate to maintain pressure in wind box C equal to a set value.

Considering in more detail the action of the conversion device F, the resistance of the resistors 109*a* and 109*b* constituted by elements 18 and 19 of photosensitive unit 12 vary inversely to one another as pressure in wind box C varies, and voltage at the junction of resistors 109*a* and 109*b* varies accordingly. As the impedance of these elements also varies greatly depending on the degree of illumination and ambient temperature, as well as on the position of the slit 17, the transistor 112 and resistor 113 are provided as an emitter-follower for impedance matching with the next stage, a voltage corresponding to the voltage at the junction of resistors 109*a* and 109*b* being obtained at the emitter of transistor 112.

This voltage is supplied through resistors 114 and 115 to the base of transistor 116 whose emitter receives an input of set value which is supplied through resistor 117 provided for setting the degree of amplification from the junction of a voltage divider constituted by resistors 118 and 119 and which compares this set input with the value of voltage at the junction of resistors 109*a* and 109*b*, and produces an amplified output indicative of this comparison.

The collector of transistor 116 supplies voltage through a voltage divider constituted by resistors 120 and 121 to a constant current circuit constituted by transistor 122 and resistor 114. The base of transistor 122 is connected to the junction of resistors 120 and 121 and the emitter thereof is connected to resistor 114 through a feedback capacitor 124.

Supposing now that pressure in the wind box C becomes low, the base voltage *e*1 of transistor 112 is lowered, the voltage at the emitter of transistor 112 becomes lower, and therefore there is greater current flow through the collector of transistor 116, the voltage at the junction of resistors 120 and 121 rises, and transistor 122 supplies an increased charging current to capacitor 125. As a result of the increased charging current supplied to capacitor 125, the switching voltage of switching element 126 is achieved in a shorter time, triac 103 is therefore switched from a non-conductive to a conductive state in a shorter time, the voltage applied to motor 102 is increased, and blower B causes an increased supply of air into, and hence raised pressure in, wind box C.

If the pressure in wind box C increases, the action is the reverse of that described above, and the pressure in wind box C is therefore constantly maintained within a narrow range of values centering on a set value of pressure.

Momentary variations of pressure in wind box C are of course liable to occur even if the operation of blower B is very stable and all ports D are open, and it is therefore desirable to avoid actuation of the control system in response to such fluctuations, since such actuation would result in oscillations in motor 102 or the control system as a whole. Such a phenomenon is avoided by inclusion of feedback capacitor 124 in the circuit of Figure 35. If pressure in wind box C becomes low momentarily, the voltage at the junction of resistors 114 and 115 tends to become low, and so the collector current of transistor 116 and the emitter voltage of transistor 122 should rise. However, by making the resistor 114 comparatively large, the charging of capacitor 124 proceeds slowly. In other words, there is practically no change of charge on capacitor 124 in response to a momentary fluctuation in the preceding stages of the circuit, and so the voltage at the junction of resistors 114 and 115 rises in accordance with the rise of the emitter voltage of transistor 122, i.e., feedback capacitor 124 prevents the junction voltage of resistors 114 and 115 from becoming low for other reasons. Thus, even if output signals from the device F contain irregular alternating components, the circuit action is generally unaffected, and stable triggering of triac 103 and control of motor 102 are achieved.

It is also possible to smooth pressure detection signals by including a narrow portion in duct E. However, this has the disadvantage that any blockage of duct E may occur more easily and control is therefore best achieved by use of capacitor 124 and resistor 114, and selection of suitable values of capacity and resistance thereof.

In addition of course there may be employed a device such as described in reference to Figure 21, which has an output of stepped form, and the dimensions and electrical or physical properties of elements are so selected that the output remains unchanged during variations of pressure in wind-box C over a small range centering on the standard pressure required to be maintained in wind-box C.

To limit the action of the conversion device F to a certain range of pressure variation there may be employed a device such as that described in reference to Figure 11 or a device such as that shown in Figure 37, which comprises a high pressure side casing 139 having a port 141 which is connected to duct E, a low pressure side casing 140 having a port 142, and a diaphragm dividing the interior of the conversion device into two compartments. The diaphragm is constituted by a diaphragm member 143 and displacement plates 144 and 145, the latter being held together by a stud 146 and loaded by a spring 149. A mounting block 150, which has mounted therein a light source 110 and a photosensitive unit 109, is seated through spring 153 on casing 140, and is movable upwards or downwards to alter the neutral setting of the conversion device by the turning of an externally contactable knob 152 connected to block 150 by a screw 151. Mounting block 150 has a slot in which a vertically disposed slit plate 147 can slide, the upper end of the slit plate 147 being attached to the stud 8. The slit plate 147 is disposed between light source 110 and unit 109, and has, in a generally central portion thereof, a slit 148 through which light from light source 110 may pass to illuminate unit 109. In an upper portion of the slit plate 147 is formed a slot 156 with a vertically disposed long axis which encloses a stop rod 157 which is fixed across the upper end of a slot defined in block 140, whereby plate 147 may move upwards and downwards only over a certain range.

The main advantages of the invention may be summarized as follows.

(1) The conversion device is easily and rapidly adjustable to respond to different conditions in different heating, cooling or ventilation systems.

(2) Good linearity and sensitivity of response is achieved, but there are no problems of oscillation or unnecessary response to momentary fluctuations.

(3) Although the device can respond to small pressures of the order of only a few millimetres of water (i.e. mmAq), the component parts of the device are all sturdy elements, thereby ensuring a long service life and greatly facilitating handling of the conversion device.

(4) Being constituted by simple elements the conversion device can be manufactured cheaply as individual units. In addition since the device of the invention is settable to meet different conditions it is not necessary to provide different conversion devices in different compartments, line segments, etc. of a control system, but the same type of conversion device may be employed in all parts of the control system, whose installation and maintenance are therefore made much easier as well as less costly.

WHAT WE CLAIM IS:—

1. A pressure-electrical signal conversion device comprising:

a housing enclosing an interior space and having an inlet port leading to said interior space for admitting thereto fluid at a pressure to be measured;

a diaphragm which extends across said interior space so as to divide it into two separate compartments, said inlet port communicating with only a first of said compartments so that a difference in pressure in said two compartments can produce corresponding movement of the diaphragm, said diaphragm including a centrally located plate-like portion and a flexible diaphragm member which surrounds the central plate-like portion and which is attached to the walls of the interior space;

biassing means disposed in said interior space and arranged such that, when there is a finite pressure differential between said two compartments, said biassing means applies to said central plate-like portion of the diaphragm a force acting in a direction tending to vary the volume ratio of said two compartments, the magnitude of the said force being proportional to the position within the interior space of said central plate-like portion of the diaphragm;

and means for determining the instantaneous position within the interior space of said central plate-like portion of the diaphragm, said position determining means being located in one of said two compartments and including a light source for emitting light, a photosensitive unit for converting light incident thereon to a corresponding electrical output and light image forming means for receiving the light emitted by said light source and forming a light image on said photosensitive unit, either the light image forming means or said photosensitive unit being connected to said central plate-like portion of the diaphragm for movement therewith relative to said photosensitive unit or said light image forming means respectively, so that the position of a light image formed on said photosensitive unit by said light image forming means moves in correspondence to the movement of said central plate-like portion of the diaphragm, the photosensitive unit comprising a pair of adjacent photosensitive elements of the same photosensitive material, the photosensitive elements being such that the respective areas thereof illuminated by a light image formed thereon vary in a complementary fashion in a direction parallel to the path of movement of said light image so that the electrical output of the photosensitive unit varies in proportion to the location of a light image formed thereon and hence to the position in the interior space of said central plate-like portion of the diaphragm.

2. A device as claimed in Claim 1, in which said central plate-like portion of the diaphragm comprises a plate element to which the flexible diaphragm member is connected.

3. A device as claimed in Claim 1 or Claim 2, in which the diaphragm member comprises a flexible sheet element.

4. A device as claimed in any of Claims 1 to 3, in which the second of said two compartments is provided with a second inlet port in communication therewith so that the pressure in the second compartment can be held constant.

5. A device as claimed in any of Claims 1 to 4, in which the position detecting means is located in the second of said two compartments.

6. A device as claimed in any of Claims 1 to 5, further comprising means for limiting the range of relative movement between said photosensitive unit and said light image forming means, whereby said electrical output is produced only in response to variation of said pressure difference in a certain range.

7. A device as claimed in any of Claims 1 to 5, in which said light image forming means comprises a slit plate disposed adjacent said photosensitive unit and having a slit formed therein for the passage through said slit plate towards said photosensitive unit of at least a part of the light emitted from said light source.

8. A device as claimed in Claim 7, in which said light source and said photosensitive unit are stationary relative to said housing, the photosensitive surface of said photosensitive unit faces and is generally normal to the optical path of light emitted by said light source, and in which said slit plate is attached to and movable together with said central platelike portion of the diaphragm, is disposed between said light source and said photosensitive unit close to said photosensitive unit so that light emitted by said light source can pass to impinge on said photosensitive unit.

9. A device as claimed in Claim 8, in which said slit plate further has formed therein a slot having a long axis generally parallel to the line of movement of said slit plate, there being a stop rod which is stationary relative to the housing and which passes through said slot in said slit plate so that the range of movement of said slit plate is limited.

10. A device as claimed in Claim 8, in which stop elements are provided which limit the range of movement of said central platelike portion of the diaphragm.

11. A device as claimed in any of Claims 8

to 10, further comprising slit plate guide means in which said slit plate can slide as it moves, and with said central platelike portion of the diaphragm, said slit plate guide means being adapted to permit any rectilinear movement of said slit plate, whereby displacement of said slit plate due to uneven distribution of pressure in the compartments of said device is inhibited.

12. A device as claimed in any of Claims 8 to 10, further comprising guide means connected to said central plate like portion of said diaphragm for permitting any rectilinear movement of said central platelike portion.

13. A device as claimed in Claim 12, wherein said guide means comprises a rod which is attached at one end to said central plate like portion of said diaphragm and extends perpendicularly away therefrom, said rod being accommodated in a guide for longitudinal sliding movement therein.

14. A device as claimed in Claim 13, in which said rod is biassed with a compression spring which is compressed when said central plate like portion of said diaphragm is moved in one direction due to said pressure difference.

15. A device as claimed in Claim 12, wherein said biassing means comprises two springs which apply force to said central plate like portion in opposed directions.

16. A device as claimed in Claim 12, in which said biassing means is constituted by a plate spring which applies a force to said central plate like portion of said diaphragm whatever the direction of movement of said central plate like portion.

17. A device as claimed in any of Claims 1 to 8, further comprising range elements which prevent movement of said central plate like portion of said diaphragm in response to certain ranges of variation of said pressure difference.

18. A device as claimed in Claim 17, in which said biassing means comprises two springs, at least one of which applies force to said central plate like portion of said diaphragm in response to a certain range of variation of said pressure difference.

19. A device as claimed in Claim 17, in which said biassing means comprises at least one spring, and a weight element whose weight opposes movement of said central plate like portion of said diaphragm during movement of said central plate like portion in one direction.

20. A device as claimed in any of Claims 1 to 8, further comprising adjustment means actuable to adjust the relationship between said electrical output and said pressure difference.

21. A device as claimed in Claim 20, in which said adjustment means is arranged to permit adjustment of the mounting position of at least said photosensitive unit, or said photosensitive unit and said light source together, thereby to cause different portions of said photosensitive unit to be illuminated by said light image forming means when said light image forming means is in a given position relative to said photosensitive unit.

22. A device as claimed in Claim 20, in which said adjustment means is connected to said biassing means and is arranged to permit adjustment of the force applied by said biassing means to said central plate like portion of said diaphragm.

23. A device as claimed in Claim 20, in which said biassing means includes at least one plate spring and said adjustment means is arranged to permit adjustment of the effective length of said plate spring whereby a given variation of said pressure difference results in a different amount of displacement of said central plate like portion of said diaphragm.

24. A device as claimed in any of Claims 1 to 7, in which said light image forming means includes reflection or refraction means which changes the direction of light emitted by said light source.

25. A device as claimed in any of Claims 1 to 7, in which said photosensitive unit is stationary relative to the housing, and said light source and said light image forming means are connected to and move together with said central plate like portion of said diaphragm.

26. A device as claimed in any of Claims 1 to 7, in which said light source and said light image forming means are stationary relative to the housing, and said photosensitive unit is connected to and moves together with said central plate like portion of the diaphragm.

27. A pressure-electrical signal conversion device substantially as hereinbefore described with reference to and as illustrated in any of the accompanying drawings.

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FIG. 1

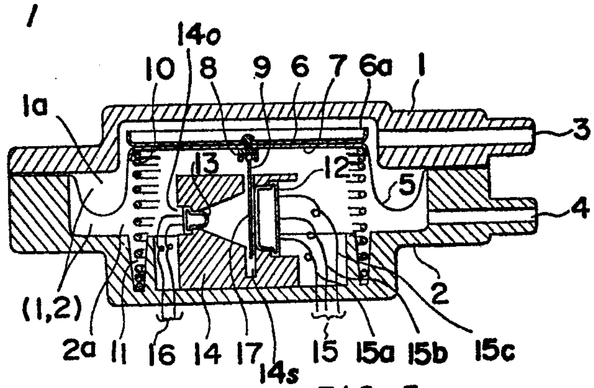


FIG. 2

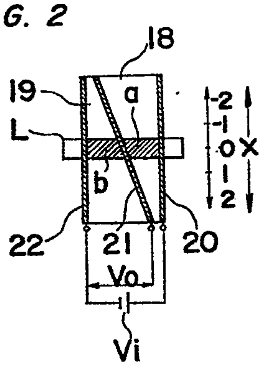


FIG. 3

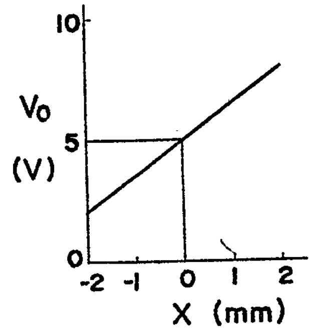


FIG. 4

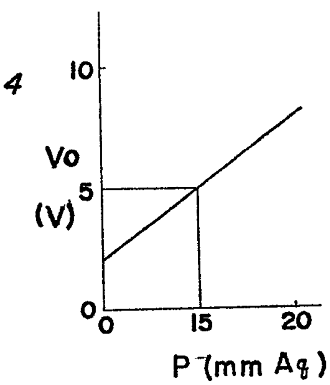


FIG. 5

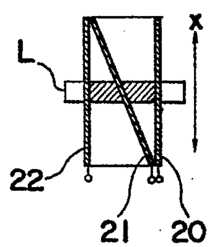


FIG. 6

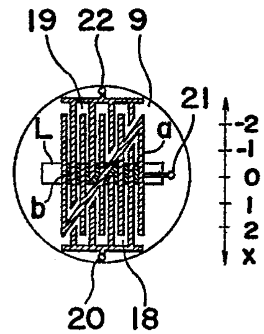


FIG. 7

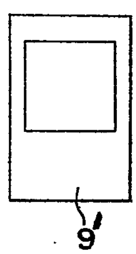
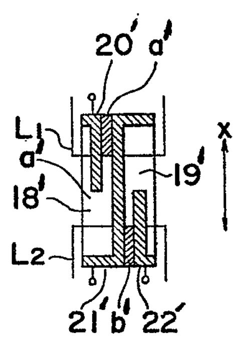


FIG. 8



1569360 COMPLETE SPECIFICATION

13 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

FIG. 9

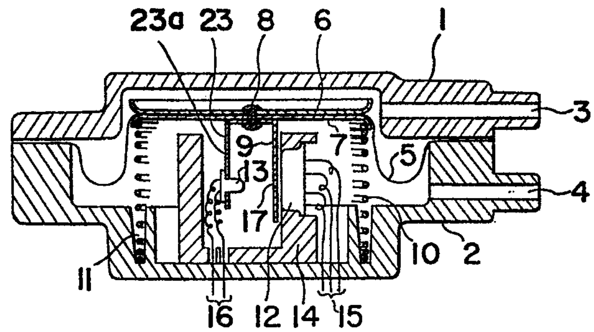


FIG. 10

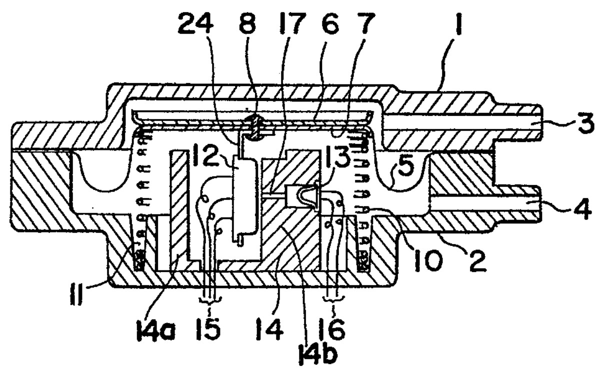


FIG. 11

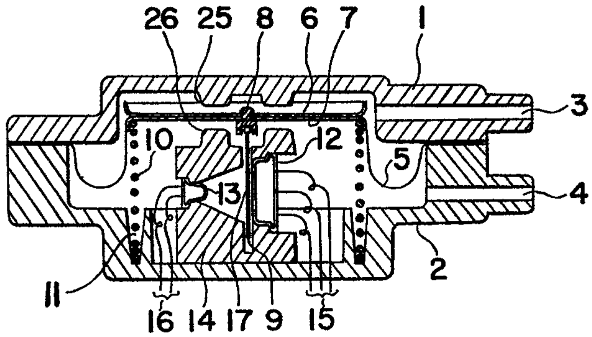


FIG. 12

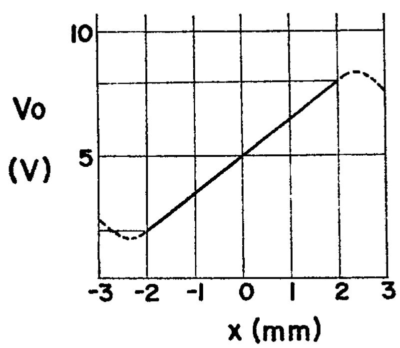


FIG. 13

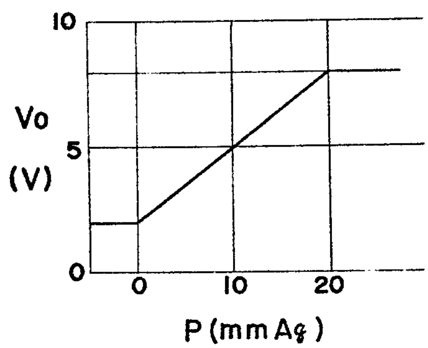


FIG. 14

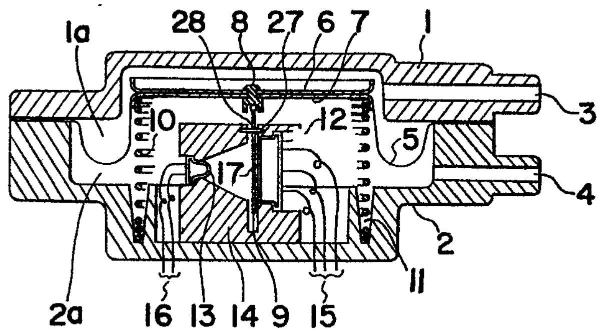


FIG. 15

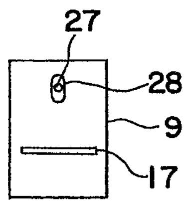


FIG. 16

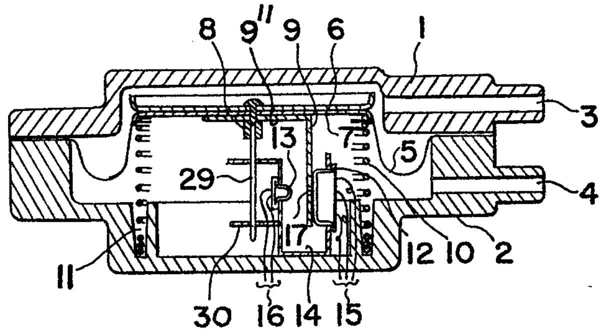


FIG. 17

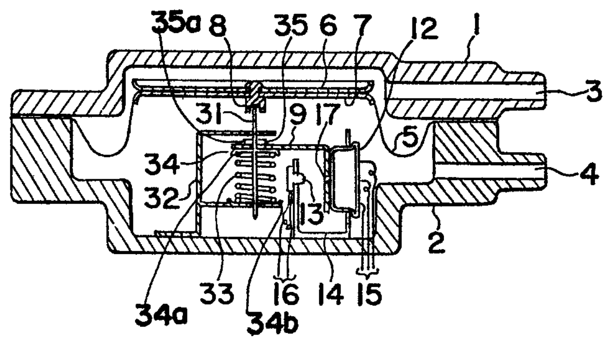


FIG. 18

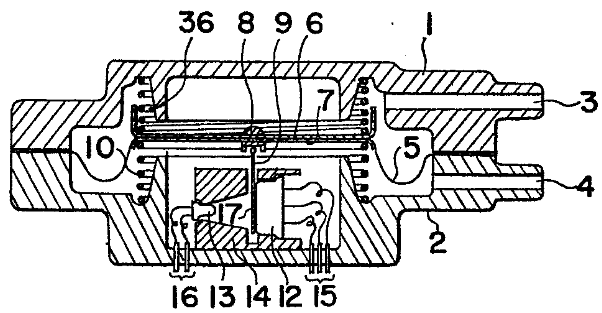


FIG. 19

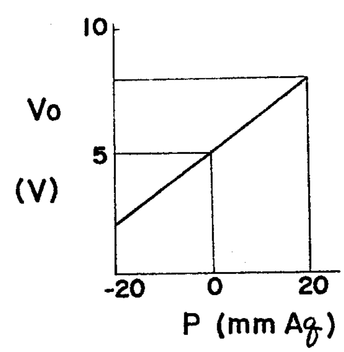


FIG. 20

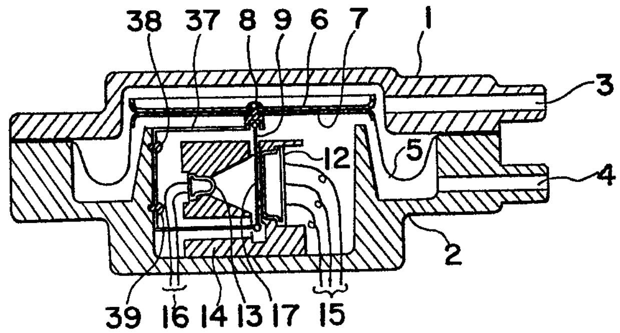


FIG. 21

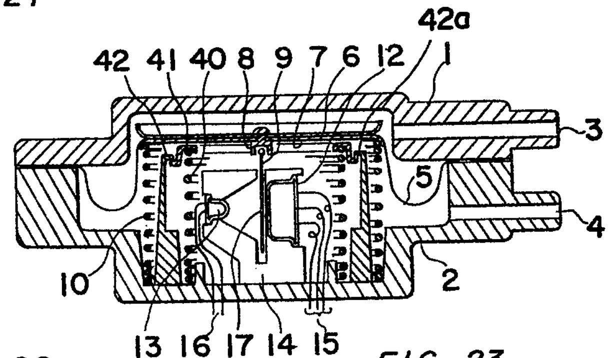


FIG. 22

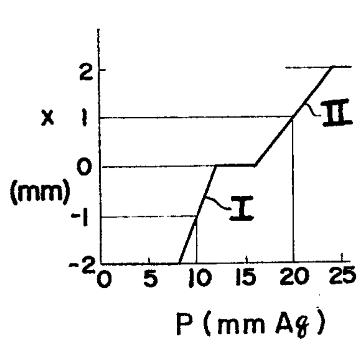


FIG. 23

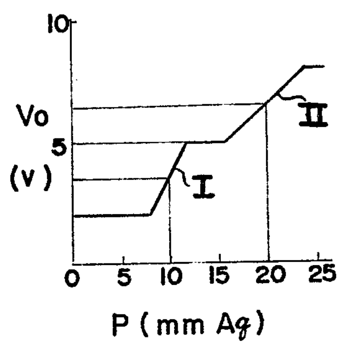


FIG. 24

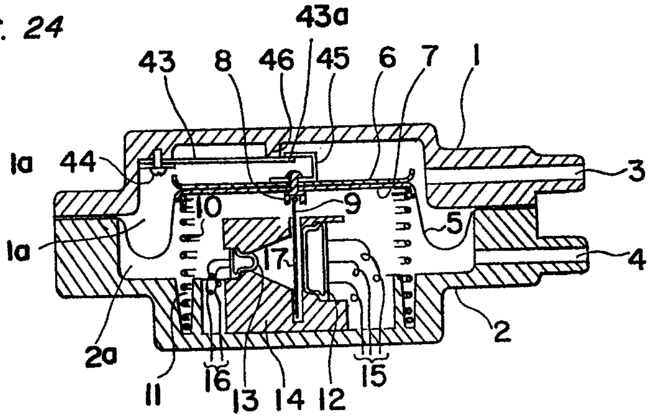


FIG. 25

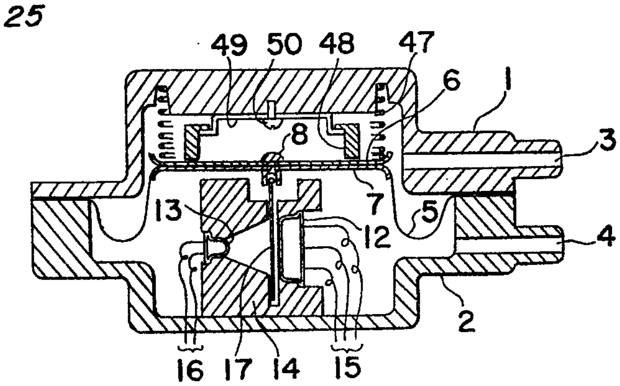


FIG. 26

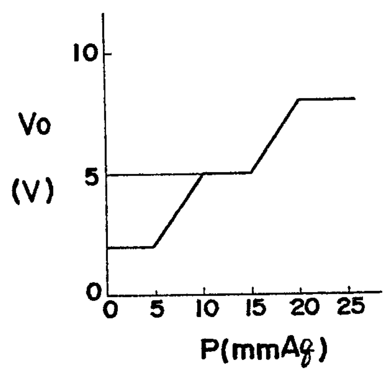


FIG. 27

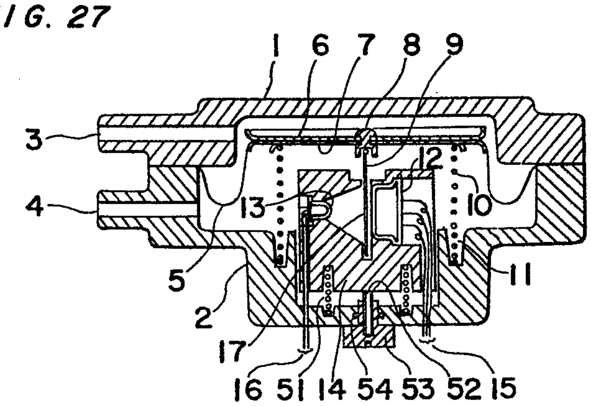


FIG. 28

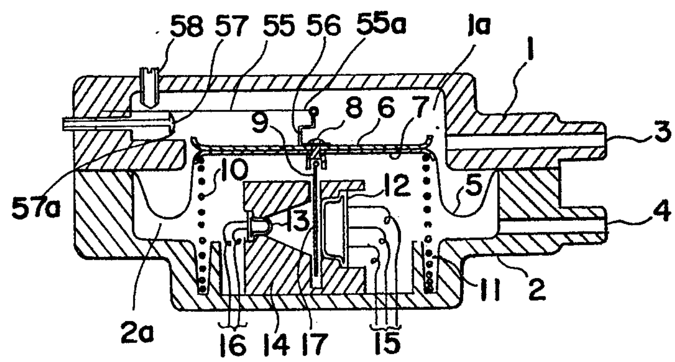


FIG. 29

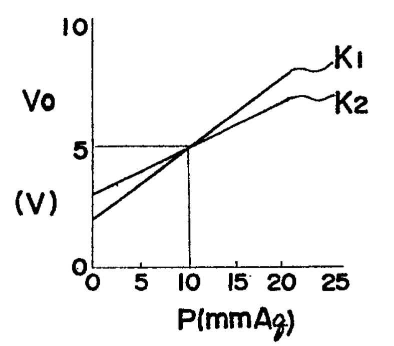


FIG. 30

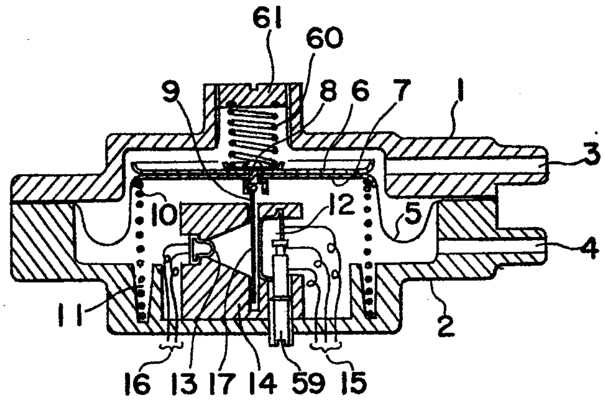


FIG. 31

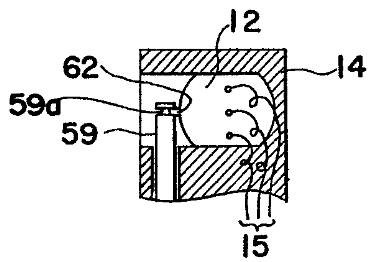


FIG. 32

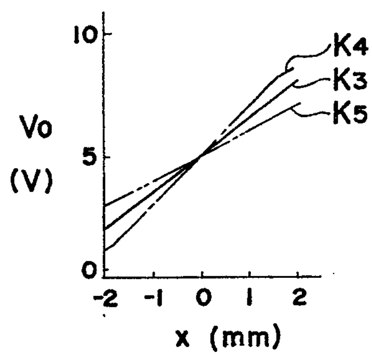
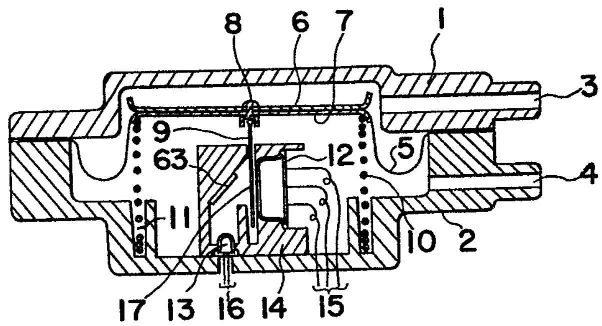


FIG. 33


8
6
7
1
3
9
63
12
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4
11
10
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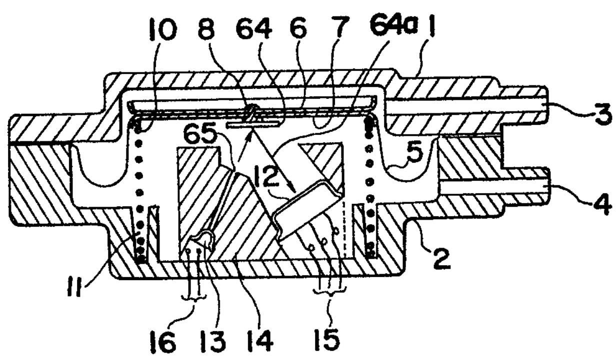
15

FIG. 34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4
2
11
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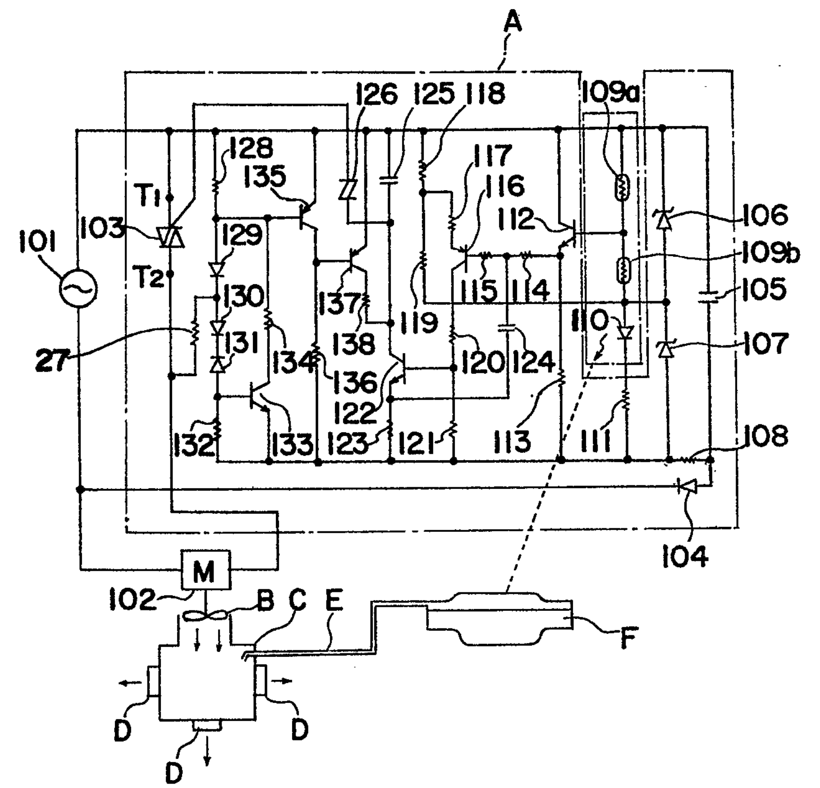
14
15

FIG. 35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125
118
109a
128
135
117
116
112
T1
103
101
106
129
109b
T2
130
115
114
105
137
119
110
27
131
138
134
120
124
107
136
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123
121
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111
108
104
M
102
B
C
E
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D
D
D

FIG. 36

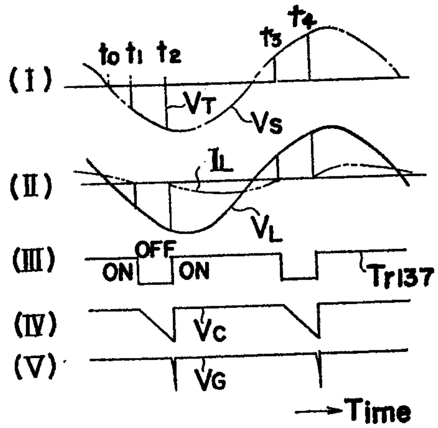
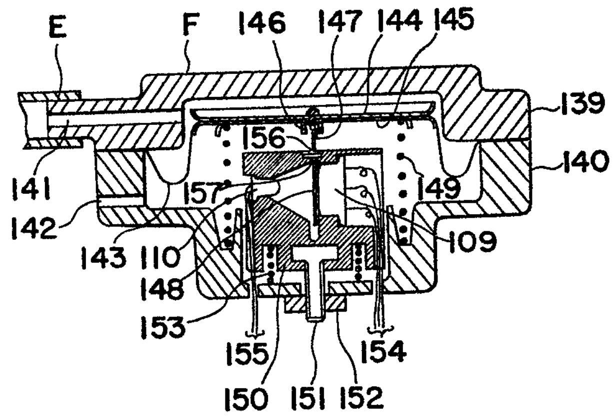

t0 t1 t2
t3 t4
(I)
VT
Vs
(II)
IL
VL
(III)
ON
OFF
ON
Tr137
(IV)
Vc
(V)
VG
Time

FIG. 37


E
F
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147
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151
152