April 27, 1965
J. E. LINDBERG, JR
3,180,956
PRESSURE-ACTUATED ELECTRICAL SWITCH HAVING
FLAT SUPPORT AT CLOSURE FOR PREVENTION
OF OVERPRESSURE DAMAGE
Filed Jan. 26, 1961
8 Sheets-Sheet 1

FIG. 1

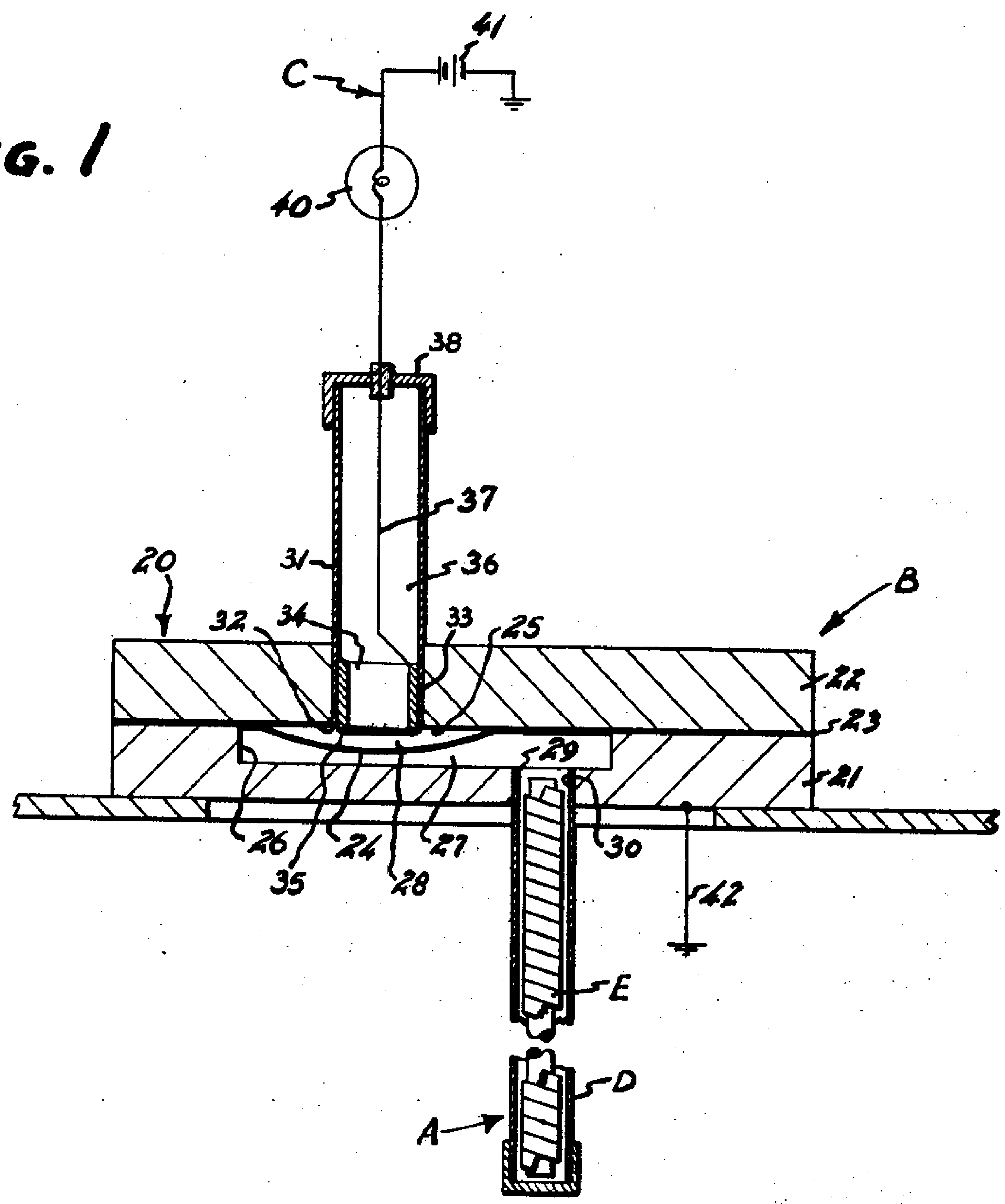

FIG. 2

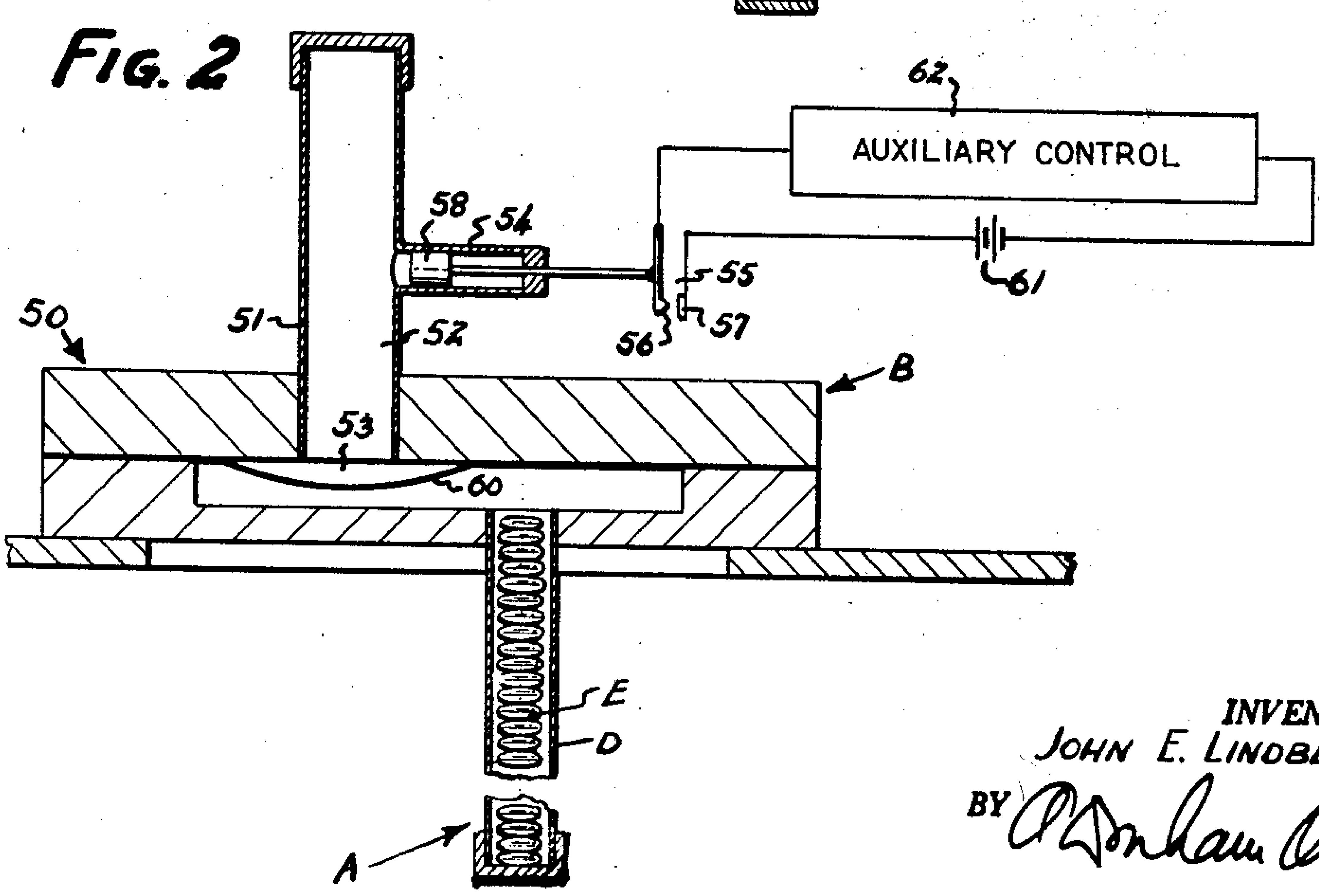

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FIG. 3

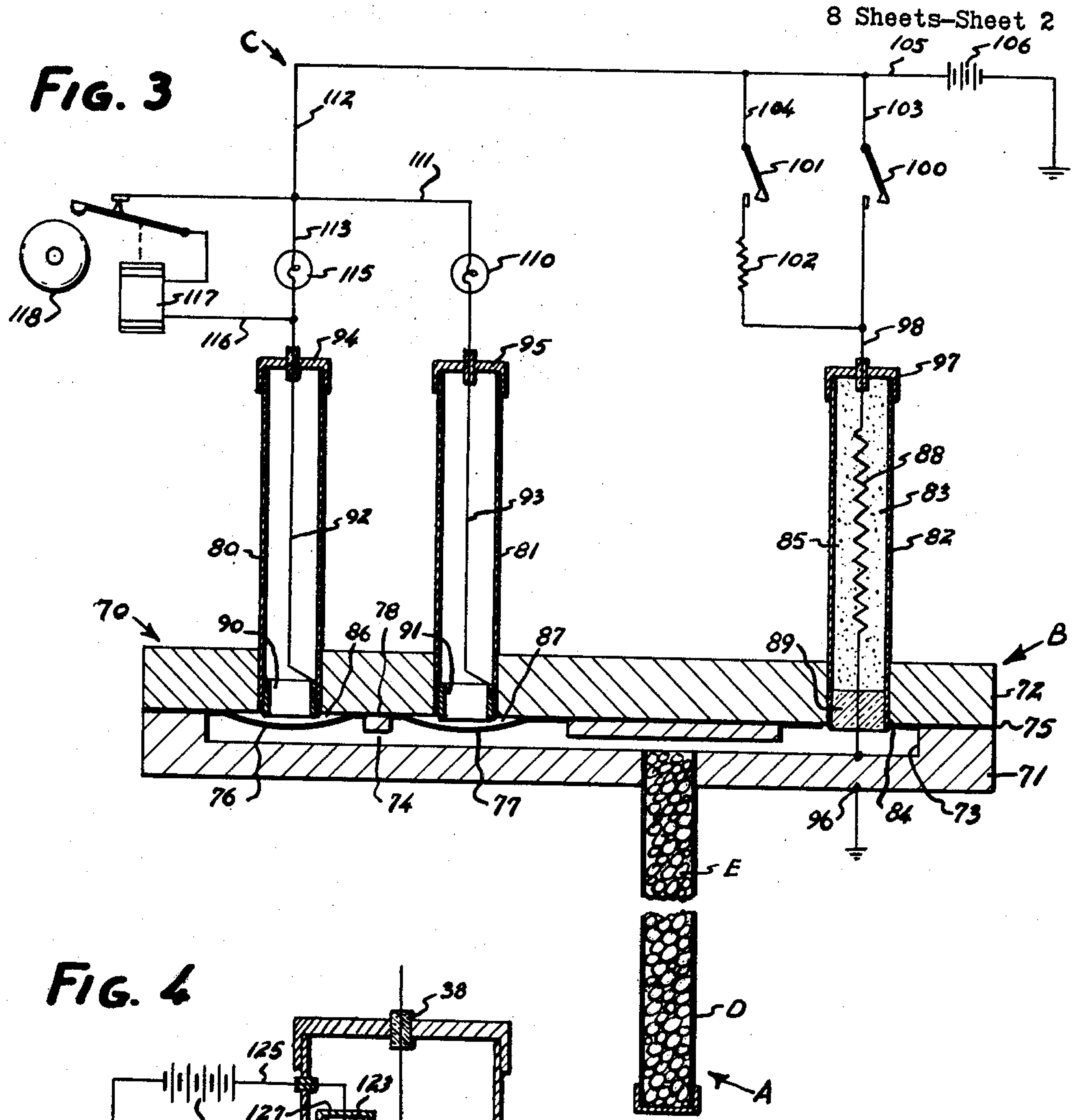
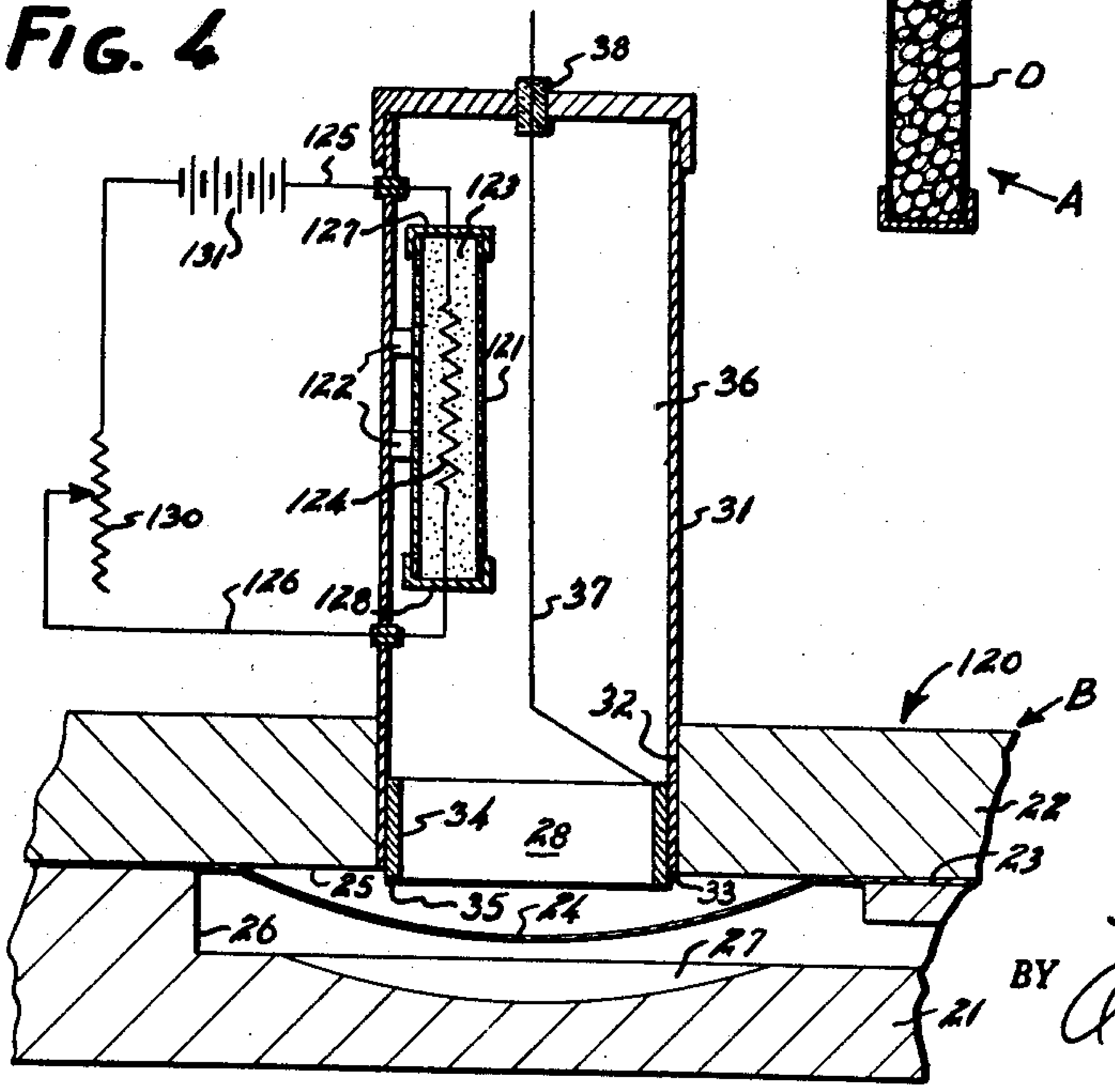


FIG. 4



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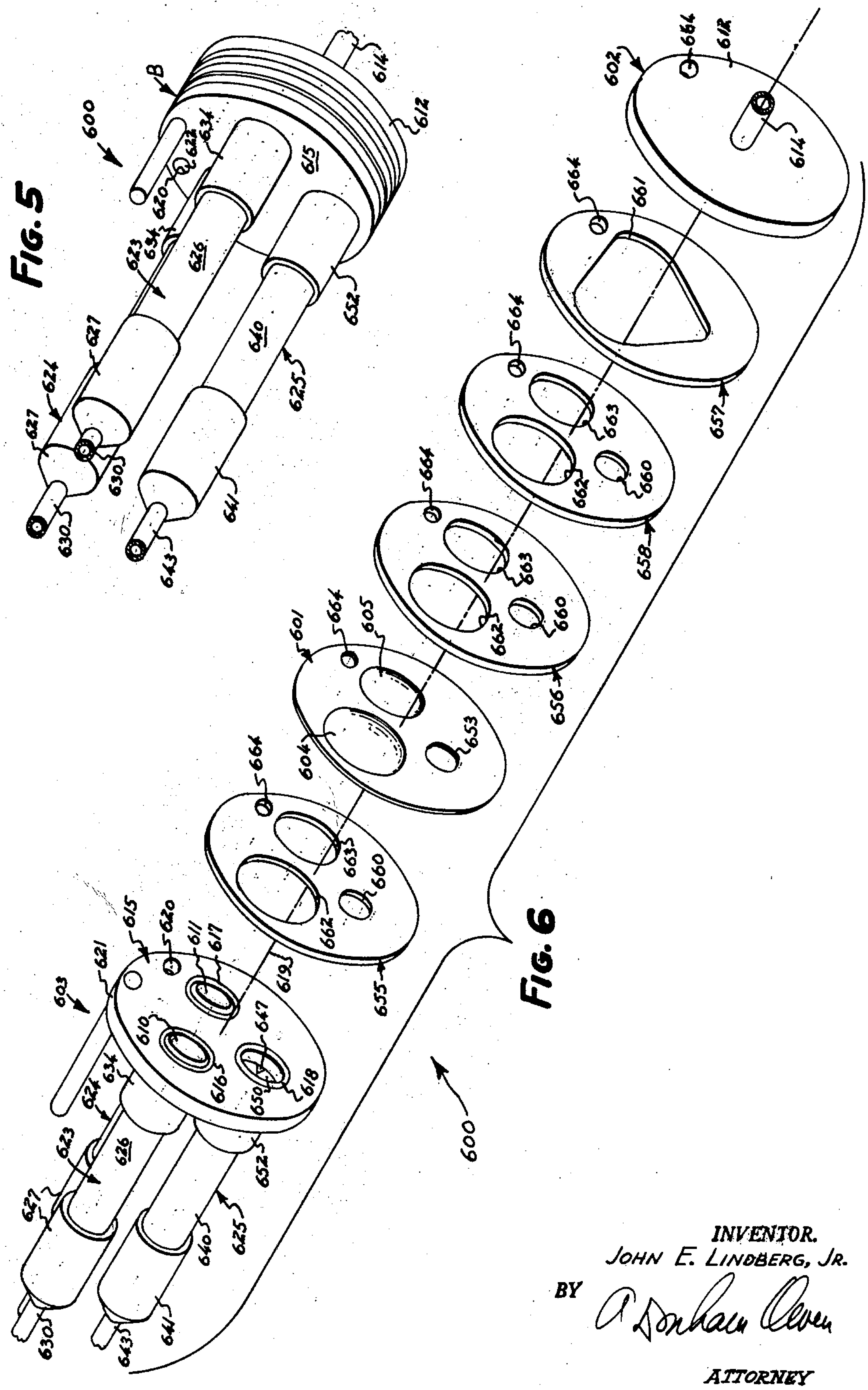
Filed Jan. 26, 1961 8 Sheets-Sheet 3



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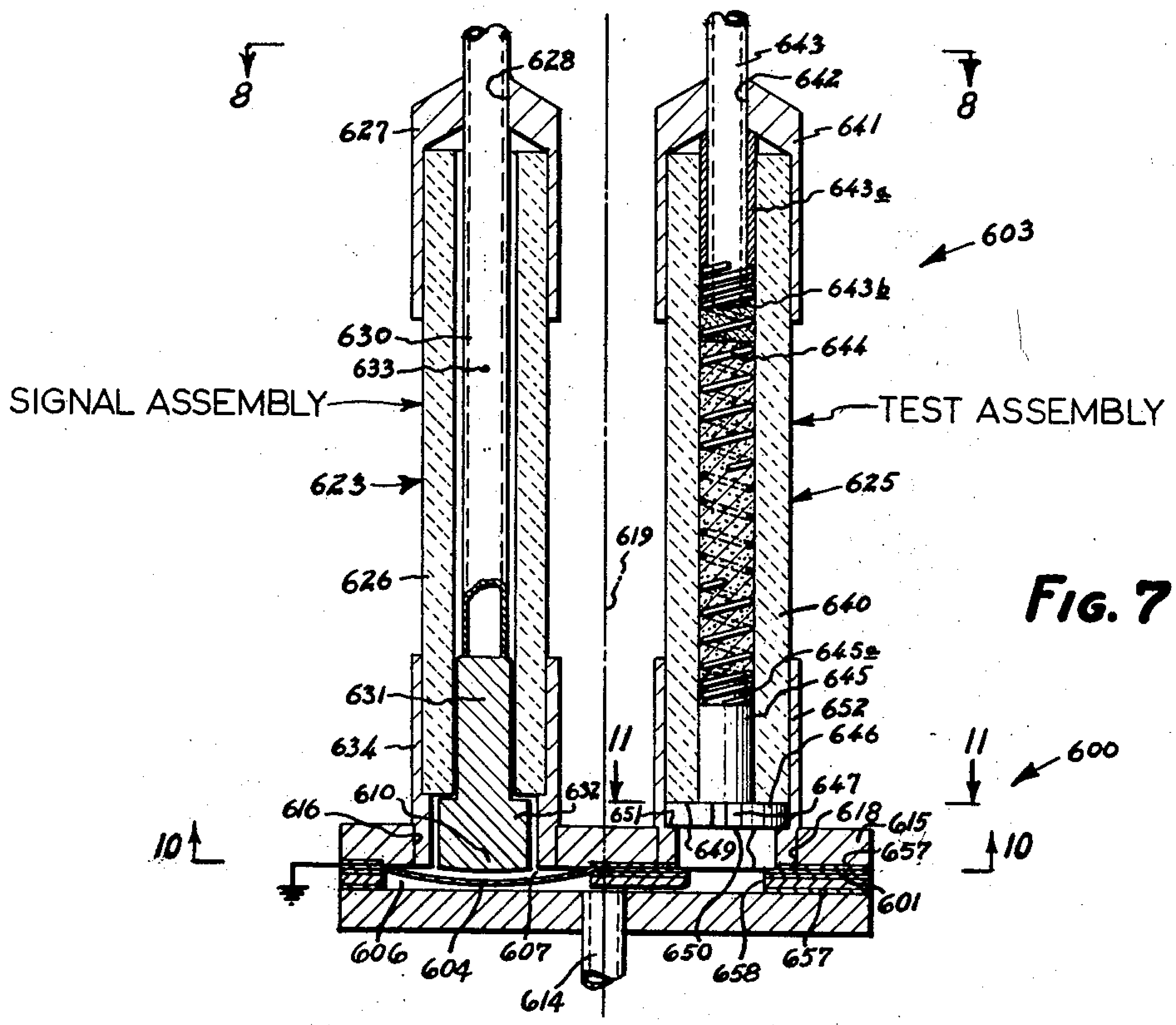

FIG. 7

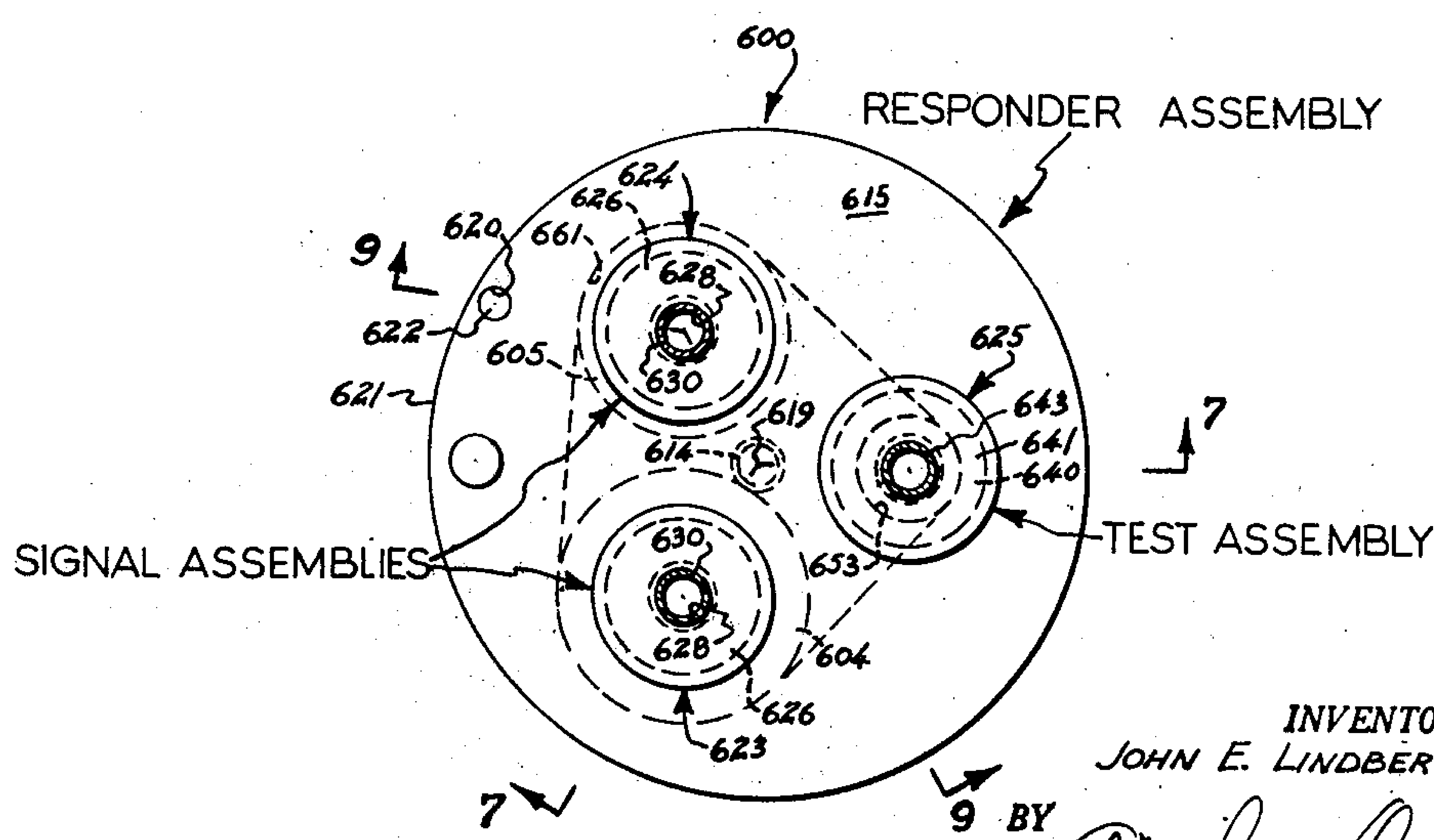

FIG. 8

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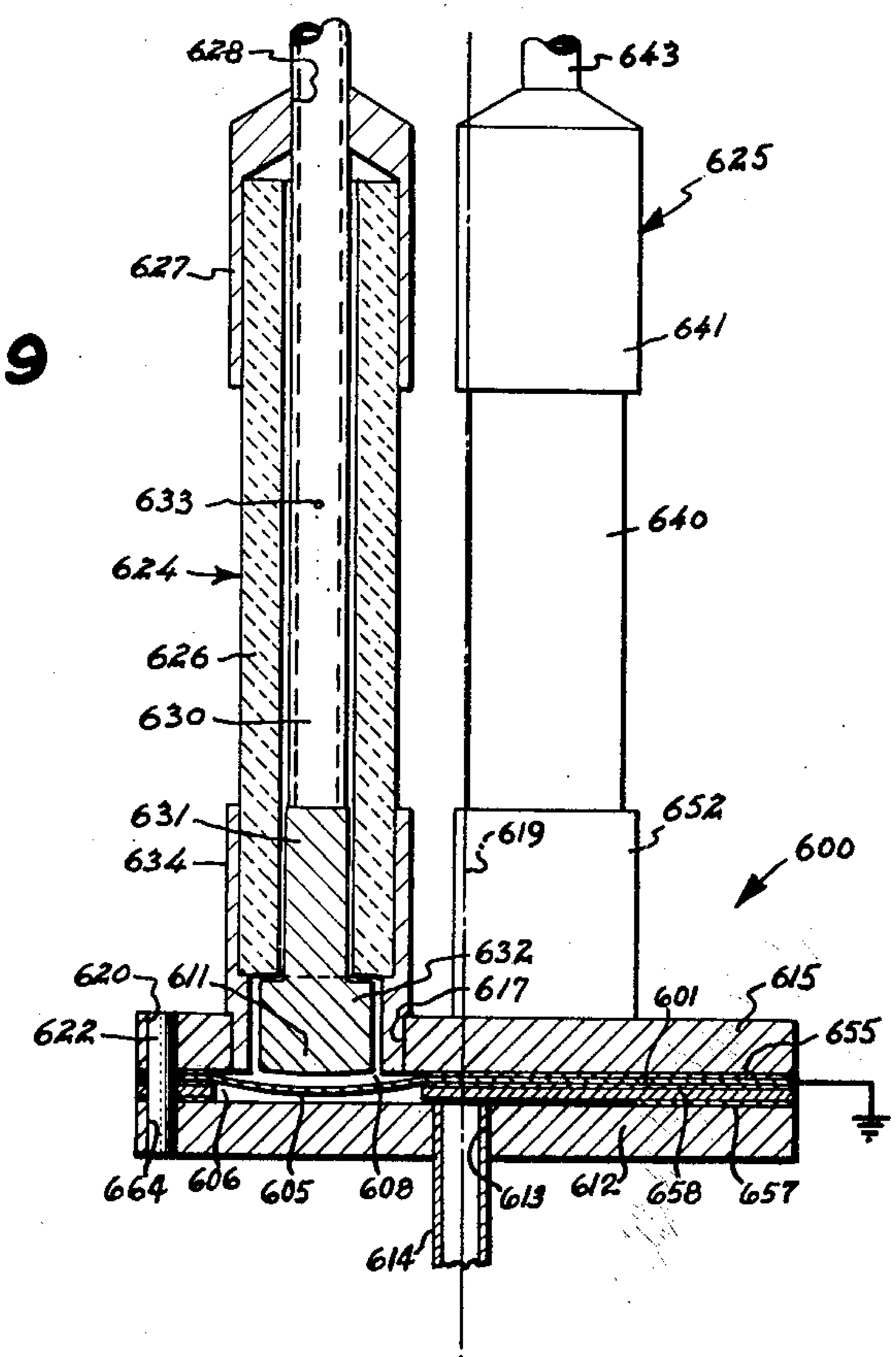
FIG. 9



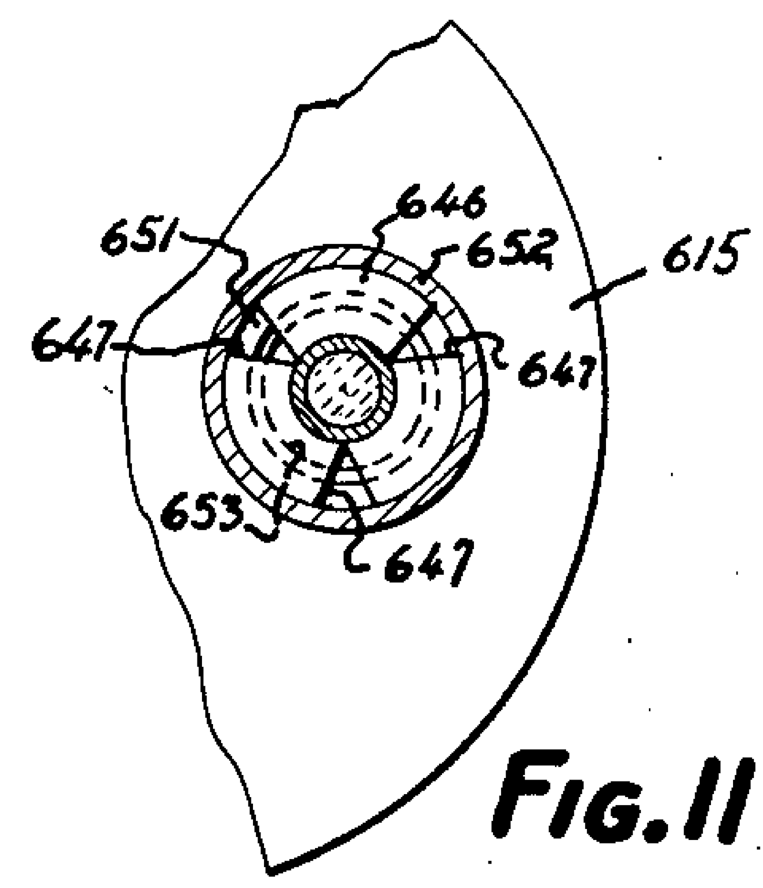


FIG. 11

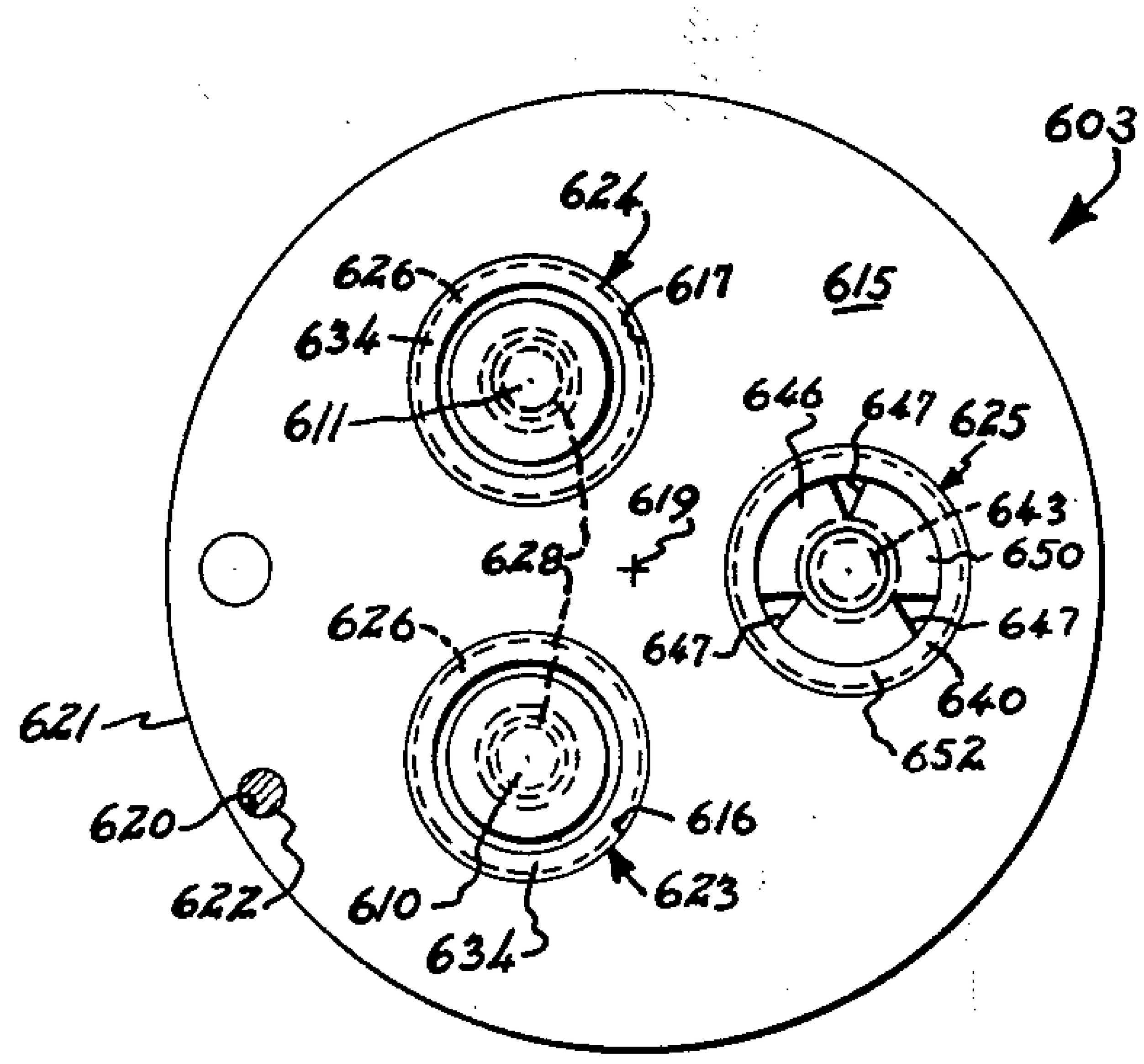


FIG. 10

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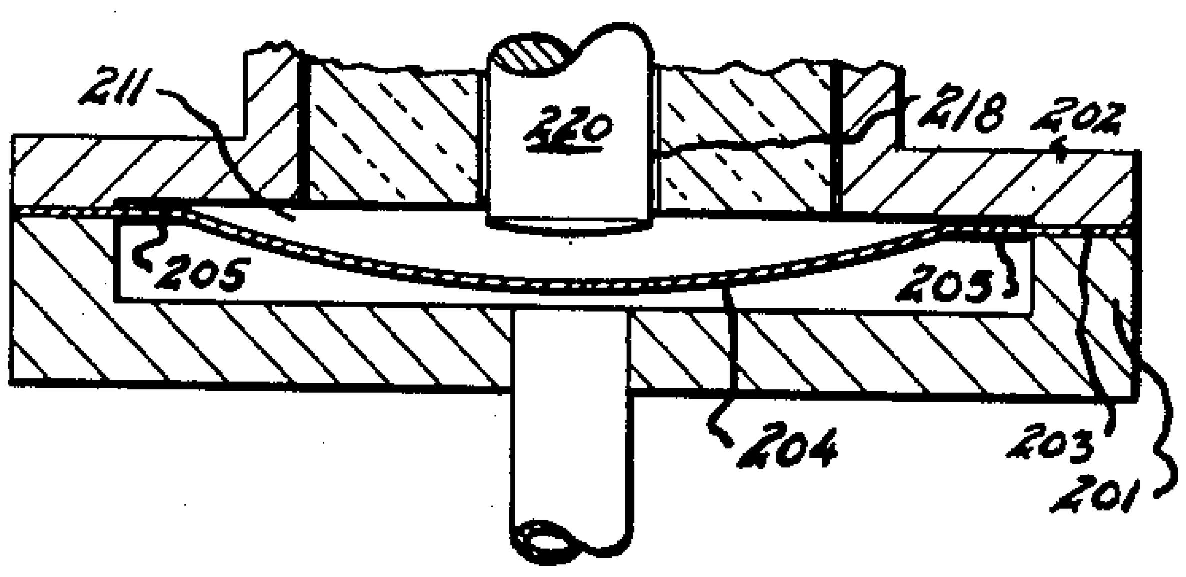

FIG. 15

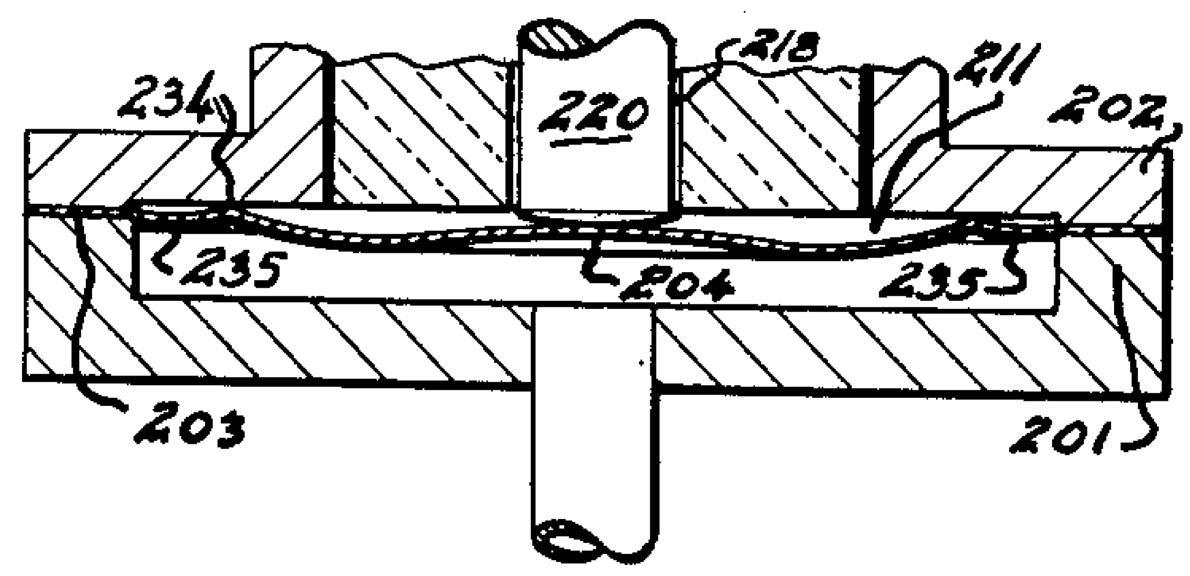

FIG. 16

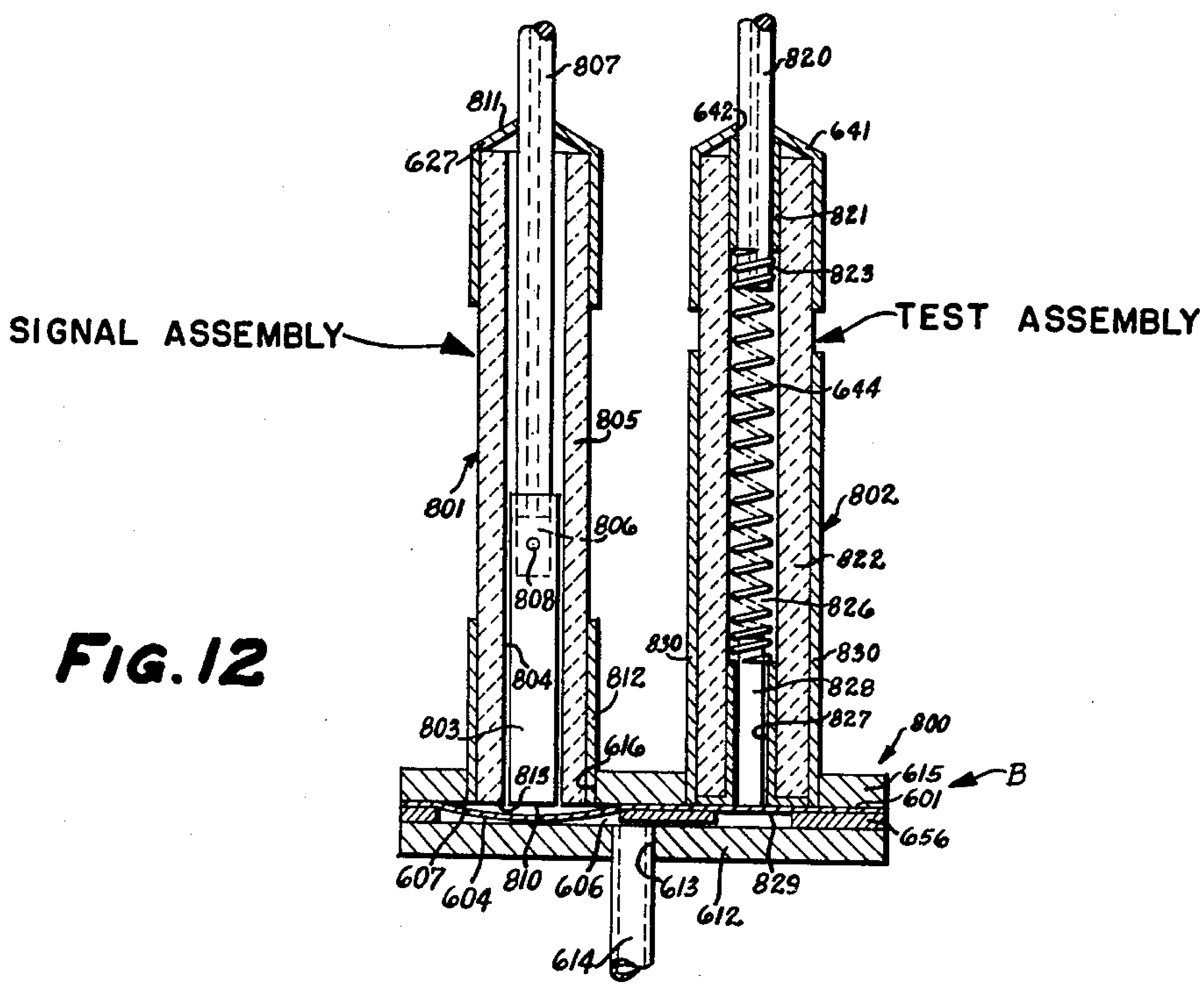

FIG. 12

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PRESSURE-ACTUATED ELECTRICAL SWITCH HAVING FLAT SUPPORT AT CLOSURE FOR PREVENTION OF OVERPRESSURE DAMAGE

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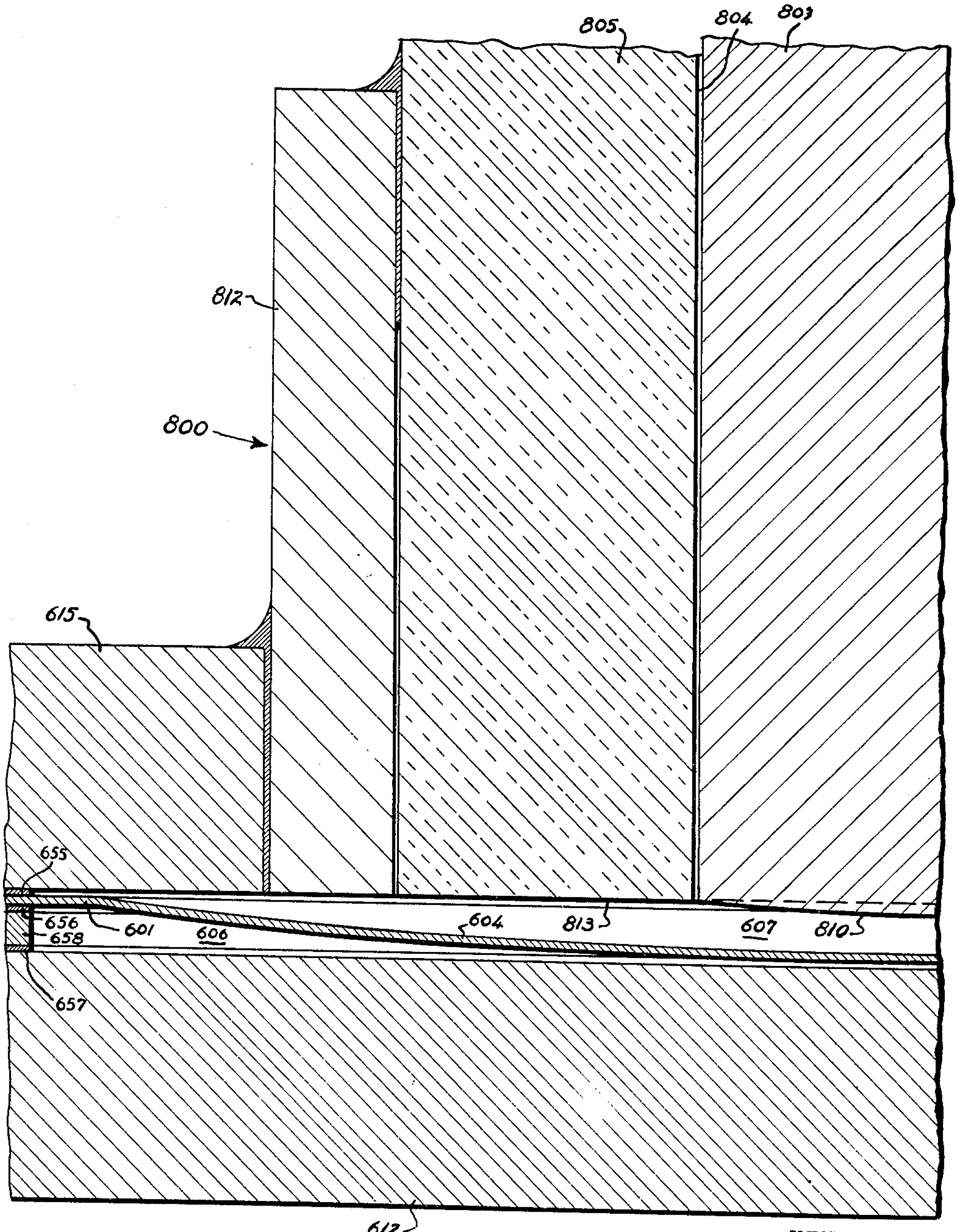

FIG. 13

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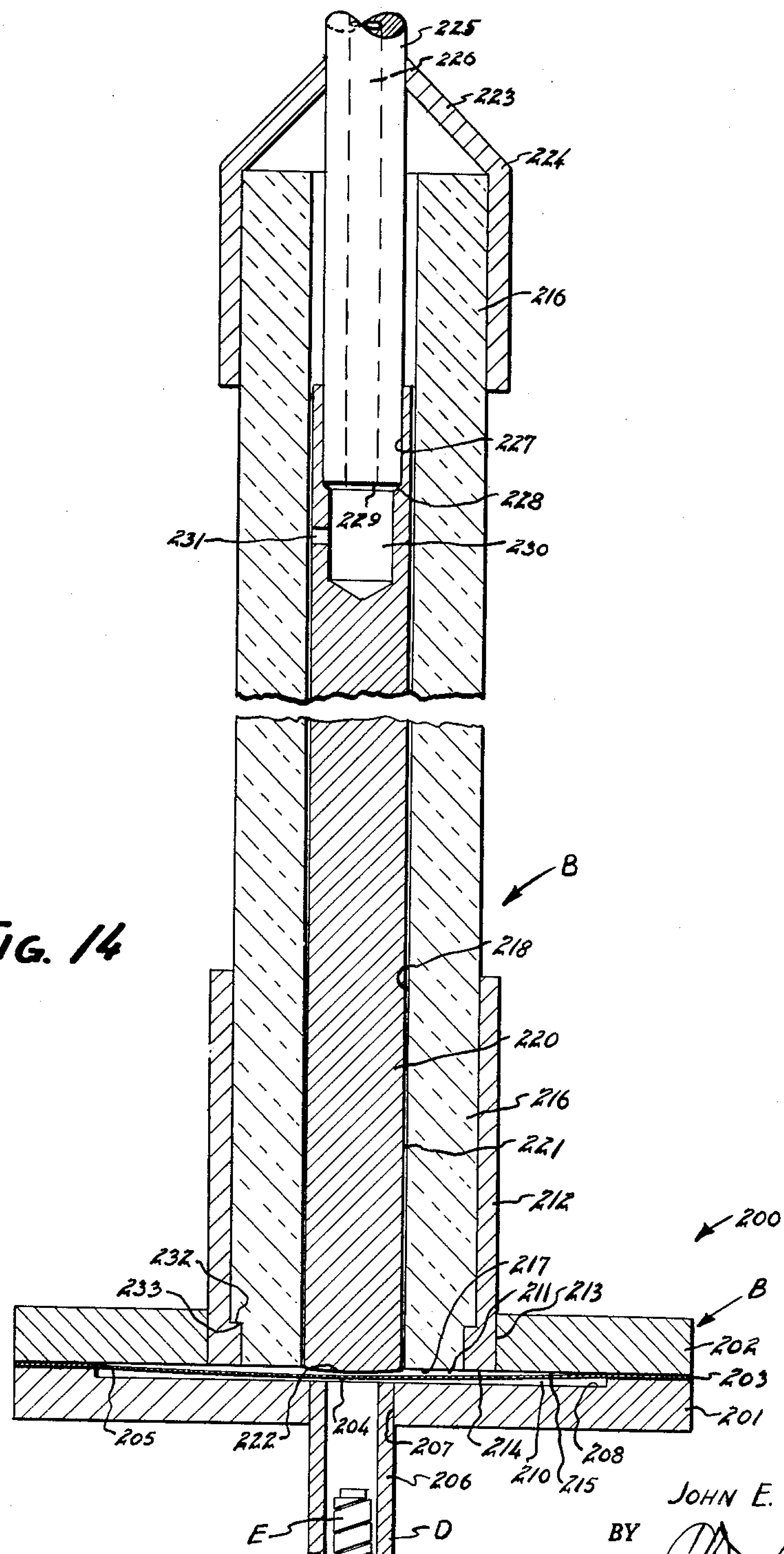

FIG. 14

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United States Patent Office

3,180,956
Patented Apr. 27, 1965

3,180,956
PRESSURE-ACTUATED ELECTRICAL SWITCH HAVING FLAT SUPPORT AT CLOSURE FOR PREVENTION OF OVERPRESSURE DAMAGE

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Filed Jan. 26, 1961, Ser. No. 86,252
16 Claims. (Cl. 200—140)

This invention relates to improvements in pressure-actuated electrical switches and the like and in methods for making them. This application is a continuation-in-part of application Serial Number 815,406, filed May 25, 1959, now Patent No. 3,122,728.

In the parent application I described and claimed a novel non-electric heat-detecting element or sensor, able to detect at any of a wide range of critical temperatures. Only this sensor need be located in the heat-detection zone, and it is connected, preferably outside the zone, to an electrical warning or corrective system by a novel pressure-actuated instrument that I term a "responder," which forms the subject matter of the present application. Combination of this responder with the sensor provides a completely hermetically sealed heat-detection transducer that is completely free from environmental errors that tend to be caused by pressure and altitude changes, moisture condensation, and so on.

One object of this invention is to provide an improved sensitive snap-action pressure-actuated switch. Prior to this invention I was unable to find a sufficiently reliable switch for use with the sensor of my invention. The responder of this invention is fully satisfactory.

Another object is to provide a pressure-actuated electrical switch capable of great miniaturization. Its small size enables it to be sensitive to pressure increases taking place in a sensor having a very small volume.

Another object is to provide a pressure-actuated switch that is reliable under high temperature conditions, in excess of 1000° C.

Another object is to provide a pressure-actuated switch that is readily adjusted to give its snap-action response at any one of several pressures, so that it can accommodate a wide range of effects produced in different sensors.

A further object is to provide a pressure-actuated switch that is substantially unaffected by ambient pressures or temperatures.

An additional object is to provide a switch capable of actuation at high pressures and capable of withstanding rather high pressures without actuation.

Another object is to provide a pressure-operated switch capable of many repeated operations, over an indefinite period and for a large number of times, while giving consistent results.

A further object is to provide a novel and improved method for making a diaphragm for the switch and for making the switch itself.

Other objects and advantages of the invention will appear from the following description of some preferred embodiments.

In the drawings:

FIG. 1 is an enlarged view in elevation and in section of a simplified form of fire-detection system, showing the

responder of this invention used in combination with a heat-detection sensor, which is broken in the middle to conserve space. The electrical circuit is shown diagrammatically.

FIG. 2 is a view similar to FIG. 1, showing a somewhat different responder structure in conjunction with a different type of connection to a different electrical circuit.

FIG. 3 is a view similar to FIG. 1, of another modified form of responder and a modified electrical circuit, in a heat-detection system employing a single sensor to indicate both fire conditions and overheat conditions at a level below the fire level. The system also includes a test mechanism.

FIG. 4 is an enlarged view in elevation and in section of a portion of a responder of this invention, incorporating a modification also utilizing the principles of the invention.

FIG. 5 is a view in perspective of a still further refined form of responder embodying the principles of this invention.

FIG. 6 is an exploded view in perspective of the responder of FIG. 5.

FIG. 7 is an enlarged view in elevation and in section of the responder of FIG. 5 taken along the line 7—7 in FIG. 8.

FIG. 8 is a view in horizontal section taken along the line 8—8 in FIG. 7.

FIG. 9 is a view in elevation and in section taken along the line 9—9 in FIG. 8.

FIG. 10 is a view in horizontal section taken along the line 10—10 in FIG. 7.

FIG. 11 is a fragmentary view in horizontal section taken along the line 11—11 in FIG. 7.

FIG. 12 is a view like FIG. 7 showing a modified form of responder.

FIG. 13 is a very greatly enlarged fragmentary view in elevation and in section of a portion of the responder of FIG. 12.

FIG. 14 is an enlarged view of another modified form of responder, with a portion broken in the middle in order to conserve space.

FIG. 15 is an enlarged fragmentary view of a responder like that of FIG. 14 with its diaphragm in relaxed position.

FIG. 16 is a view similar to FIG. 15 showing the responder of FIG. 15 in stressed position.

A heat-detector employing this invention preferably includes a novel detecting sensor A that is described and claimed in the parent application. The sensor A has an enclosure D, preferably comprising a narrow-diameter metal tube of constant cross-sectional area and of any desired length. Within this enclosure D is means E responsive to the temperature of the enclosure D for varying the pressure inside the enclosure D. This means E may also be referred to as a transducing agent or as a gas-releasing solid, many of which are described in the parent application. For many uses, metallic hydrides are preferred. The enclosure D is gas-tight, and its only opening is connected to a responder B, which itself defines a closed chamber connected to the enclosure D. An alteration of the internal pressure with the enclosure D therefore affects the responder B.

1. *A simple responder* (*FIG. 1*)

FIG. 1 shows a simple form of responder B, comprising a unit 20 with two circular plates 21 and 22, preferably of nonporous metal, between which is bonded (as by brazing) a thin metal flexible disc or diaphragm 23. The plates 21 and 22 are hermetically sealed together and are preferably in electrical contact for their full peripheries and over a substantial margin, but in the center the diaphragm 23 has a generally spherical depression 24 called a "blister," which is free to move relative to the plates 21 and 22 and constitutes the active or movable part of the diaphragm 23. This blister 24 is formed by expanding the diaphragm from a flat plate, preferably in a manner explained later on herein. Use of a diaphragm with a blister 24 makes possible the use of an upper plate 22 with a planar lower surface 25 and gives a more predictable response than do most types of diaphragms.

The lower plate 21 is formed with a recess 26 in its upper surface, and the diaphragm 23 divides the resultant cavity between the plates 21 and 22 into two regions or chambers 27 and 28. Since the lower region 27 communicates with the sensor A, it may be called the "sensor chamber." The other region 28 is located on the opposite side of the diaphragm 23 from the sensor A; so it may be called the "anti-sensor chamber." Of course, either plate 21 or 22 may actually be made by brazing together several thin plates of the desired configuration, and the recess 26 may be provided by using a stack of preformed thin washers over a disc. A preferred material for all the metal elements in the responder 20 is molybdenum, because of its ability to withstand high temperatures and high pressures while retaining the elasticity necessary to snap action. The sensor chamber 27 is usually made as small as possible, so that the pressure effect of the gas liberated in the sensor A is not unduly diluted by a large volume adjacent the diaphragm 23. The present responder is well suited to the provision of a small anti-sensor chamber 28 and to miniaturization of the whole assembly.

One end 29 of the sensor tube D is joined to and sealed to the lower plate 21, fitting within a hole 30. The region 27 is closed and sealed except for its communication with the lumen of the sensor tube D; so the inside of the sensor A and the sensor chamber 27 enjoy a common atmosphere to the exclusion of any other.

A tube 31 of non-porous ceramic material or other nonporous electrically insulating material extends through an opening 32 in the upper plate 22 and is hermetically sealed in place there with its lower end 33 flush with the bottom surface 25 of the plate 22. The hole 32 and tube 31 are preferably centered with respect to the blister 24, on the anti-sensor side thereof. If desired, the responder B may be made with the sensor A also centered with respect to the blister 24 (cf. FIG. 14). A metal electrode 34 is located inside and joined securely to the tube 31 at the end 33 nearest the blister 24, with a portion 35 of the electrode 34 substantially flush with or extending slightly (e.g., less than 0.001") below the lower surface 25 of the plate 22. The amount by which the portion 35 extends below the surface 25 is carefully controlled so as to be uniform in each responder of any particular design. This geometry means that the blister 24 can make electrical contact with the electrode portion 35 when the blister 24 is forced up by pressure in the sensor chamber 27. As shown, the electrode 34 may be annular to give good uniform contact with the blister 24 at that time and also to afford communication between the chamber 28 and the inside 36 of the tube 31. A conducting wire 37 extends from the electrode 34, preferably along the axis of the tube 31, and is brought out of the tube 31 through a hermetic seal at a sealing cap 38. The tube interior 36 and the anti-sensor chamber 28 thus enjoy a common atmosphere to the exclusion of any other.

If sufficient pressure is applied in the sensor chamber 27, the blister 24 will be deflected into contact with the electrode portion 35; and if the deflecting force is removed, the restoring force of the blister 24 will return it to its relaxed position and thus break contact with the electrode portion 35. The force necessary to do this may be chosen by proper design of the blister 24 to accommodate a wide range of values.

The responder B may be connected to an alarm circuit C which, as shown in FIG. 1, is a simple visual indicator consisting of a lamp 40 in series with the conducting wire 37 and a source 41 of electrical current, which may be a battery, as shown, or may be a source of alternating current. A return path for the electrical circuit C may be provided by grounding either one of the plates 21 or 22 and is shown as a ground wire 42 in FIG. 1.

In operation, when the sensor A is exposed to heat at a level high enough to cause the transducing agent E to rise above its threshold temperature, gas is liberated. This gas cannot escape from the sensor tube D except into the sensor chamber 27, where it exerts pressure upon the blister 24. This pressure tends to move the blister 24 upwardly. The pressure in the sensor chamber 27 is a function of the temperature of the sensor A, and in general there will be a one-to-one correspondence between the temperature of the sensor A and the pressure within the sensor chamber 27. This pressure, if great enough, will cause the blister 24 to make contact with the electrode 34, but no contact will be made unless the temperature of the sensor A is at or above a definite level.

When the sensor A is exposed to heat at a level high enough to cause the blister 24 to make contact with the electrode 34, current flows from the battery 41 through the lamp 40, the conductor 37, the electrode 34, and the blister 24, to the plates 21 and 22, and returns to the battery 41 through the ground line 42. This current flow causes the lamp 40 to light and provides a visual indication that the temperature of the sensor A is at or above a certain level. In this sense, the device shown in FIG. 1 functions as a threshold temperature indicator. When heat is removed from the sensor A, the transducing agent E cools and reabsorbs its previously released gas, resulting in reduction of the pressure exerted upon the blister 24. The blister 24 moves away from the electrode 34, breaking the electrical circuit, and the lamp 40 goes out.

2. *Some ways of setting the threshold temperature* (*FIG. 1*)

The force necessary to deflect the blister 24 against the electrode 34 can be chosen to accommodate a wide range of values by a suitable choice of mechanical parameters. Once this force is determined, the dimensions of the sensor tube D and the amount and kind of transducing agent E may be chosen by design to provide the force necessary to obtain contact between the blister 24 and electrode 34 at a certain temperature.

In addition to mechanical design considerations, the necessary deflecting force may also be altered by precharging the anti-sensor chamber 28 with a gas under pressure or by partially evacuating it. To accomplish this, gas is forced into (or withdrawn from) the tube 31 after its attachment to the plate 22 and before it is closed by its cap 38. The required deflecting pressure against the blister 24 becomes greater as more gas is present in the chamber 28.

Alternatively, the deflecting pressure may be effectively lowered by precharging the inside of the sensor tube D and the sensor chamber 27 with gas. In this case, if the ambient pressure in the sensor chamber 27 is greater than normal, less than normal gaseous liberation from the transducing agent E is required to deflect the blister 24 against the electrode 34.

Most gases may be employed for this purpose; however, ideally the gas should not react chemically with its surrounding materials. Particularly suitable are the inert gases, such as helium, argon, neon, and xenon, especially since they do not readily diffuse through most materials. As a consequence, a precharged pressure of argon, for example, may be maintained for an indefinite length of time to retain a desired biasing of the diaphragm 23, as described.

I have found that the amount of pressure necessary in the sensor chamber 27 in order to snap the diaphragm blister 24 against the electrode 34 varies with the temperature of the diaphragm 23. When a molybdenum diaphragm 23 is at room temperature, it takes about 5.4 inches of mercury more pressure to snap its blister 24 against the electrode 34 than when the diaphragm 23 is at 1000° F. The snap action remains and, if anything, even gets sharper as the temperature rises.

I have also found that this change in the actuating pressure may be compensated for by loading the anti-sensor chamber 28 with inert gas in sufficient amount so that the pressure increase in the chamber 28 due to the temperature rise offsets the drop in actuating pressure. In other words, as the temperature of the diaphragm 23 rises, the temperature in the chambers 27 and 28 will be rising, and if there is enough more gas precharge in the chamber 28 than there is in the chamber 27, then the pressure needed to actuate the diaphragm blister will remain nearly constant, for the temperature effect on the metal tending to lower the actuating pressure is offset by the increase in pressure in the chamber 28 that, of course, acts to increase the actuating pressure required. Thus, a balance is achieved giving substantially constant performance.

Also, when the chamber 28 has a precharge of inert gas, there is a returning force that improves the operation of the switch 20 in the off direction. Further, the switch 20 can stand high voltage make-and-break conditions better in an atmosphere of inert gas. Still further, by controlling the precharge of the chamber 28, it becomes possible to regulate the switch 20 to obtain either a positive or negative temperature coefficient on the actuating pressure. Finally, the gas precharges help in obtaining consistency without hysteresis building up.

3. *A modified form of simple responder B and its modified circuit C (FIG. 2)*

The responder B may also be so constructed that the variations in pressure occurring on the anti-sensor side of the daphragm will act indirectly on an auxiliary pressure switch. In this case, the blister does not close against the electrode. In the responder 50 shown in FIG. 2 there is no electrode, but a ceramic tube 51 is inserted in the responder 50 as before, with its interior 52 in direct communication with an anti-sensor chamber 53, and also, via an arm 54 of the tube 51, with a conventional type of pressure switch 55. This switch 55 may be, for example, one whose contacts 56 and 57 close when pressure is applied to a piston 58.

Thus, when the sensor of FIG. 2 is heated, a diaphragm blister 60 is deflected toward the ceramic tube 51 and causes an increase of pressure in the anti-sensor chamber 53 and tube interior 52 which, in turn, is communicated to the pressure switch 55. At the selected pressure, the contacts 56 and 57 of the pressure switch 54 close, and current flows from a battery 61 through an auxiliary control 62. This control 62 may be a lamp like the lamp 40, or it may be a device to perform any other suitable function such as, for example, to operate a fire extinguisher. (Of course, the lamp 40 in FIG. 1 may also be replaced by such a control 62.) When the temperature of the sensor A falls below a certain value, the blister 60 re-deflects toward the sensor A to its normal position and decreases the pressure within the ceramic tube 51, thereby deactivating and opening the pressure switch 55. The auxiliary control 62 then ceases to function.

Alternatively, the pressure switch 55 may be such that its contacts 56 and 57 are normally closed. Then when the pressure in the interior 52 of the ceramic tube 51 is increased beyond a certain value, the applied pressure to

the switch 55 opens its contacts 56 and 57. This action may be used to perform various suitable functions. For example, it may function as a thermostat. It also enables the use of transducing agents such as copper hydride, which ingas as the temperature rises and outgas when the temperature drops.

4. *A more complex form of responder B and its associated circuit C (FIG. 3)*

When one wants to provide an indication of two or more heat levels within the same area, the arrangement shown in FIG. 3 is highly desirable. In addition, FIG. 3 shows a test device that enables the operator to determine whether the unit is functioning properly.

In FIG. 3, a sensor A is joined to a responder 70 at the lower of its two circular metal plates 71 and 72. The lower plate 71 is recessed to provide a cavity 73 for a sensor chamber 74, and a thin, flexible metal diaphragm 75 is sandwiched between the plates 71 and 72 and brazed to them in an hermetic seal. The metal elements 71, 72, and 75 may be molybdenum, Kovar, or Phosphor bronze, for example. The diaphragm 75 is provided with two generally spherical-segment depressions or blisters 76 and 77, isolated from each other by a portion 78 brazed or otherwise hermetically bonded to the plate 72.

Three ceramic or other non-porous and electrically non-conducting tubes 80, 81, and 82 are sealed into and extend through openings in the upper plate 72. The interior 83 of the tube 82 extends through a hole 84 in the diaphragm 75 directly into the sensor chamber 74, while the tubes 80 and 81 are centered directly above their respective blisters 76 and 77 and open into separate anti-sensor chambers 86 and 87. Electrodes 90 and 91 at the lower ends of the tubes 80 and 81 are substantially flush with or extend slightly below the tubes 80 and 81 and the upper plate 72, so that the blisters 75 and 77 can each be deflected into contact with them. Conducting wires 92 and 93 from the electrodes 90 and 91, respectively, extend axially through the tubes 80 and 81 and emerge through sealing caps 94 and 95.

The interior 83 of the tube 82 is filled with a heat dissociable material 85 such as powdered titanium hydride, and a generally axially extending filament 88 is embedded in this material and extends out of the lower end of the tube 82 through a small plug 89 and terminates on the lower plate 71 at a ground point 96. The plug 89 serves to retain the powdered material 85 within the tube 82 but allows any gas that may be released from the material 85 to pass from the tube 82 into the sensor chamber 74. The upper end of the filament 88 is brought out of the tube 82 through a sealing cap 97 and is joined to a conducting wire 98.

The diaphragm 75 and its blisters 76 and 77, together with the peripheral bond 78 between and the bond around the blisters, effectively provides three chambers: the interior 83 of the tube 82 and the interior of the sensor tube D enjoy a common atmosphere with the sensor chamber 74 to the exclusion of any other atmosphere. On the other side of the diaphragm 75 are the two mutually exclusive anti-sensor chambers 86 and 87.

Just as in the device of FIG. 1, the force necessary to deflect the blisters 76 and 77 into contact with the electrodes 90 and 91, respectively, is a function of the mechanical design of the blisters, and may be chosen so that each blister 76 and 77 requires the same or a different deflecting force. In addition, this force may be changed to any desired value by precharging any or all of the chambers 74, 76, and 77 with an inert gas, as explained before.

For example, after charging the sensor A, adjusting the pressure in the sensor chamber 74 to a desired value, and sealing the sensor chamber 74 and the tubes that communicate with it, to provide a sealed system, the tube 80 may be filled with argon at just enough pressure to cause actuation of the blister 76 to close against the electrode 90 when the sensor A is at a temperature of 800° F. Then the tube 80 may be sealed. Next, the temperature of the sensor A may be dropped to, say, 400° F. and the tube 81 charged with argon at a pressure to barely cause actuation of the blister 77 against the electrode 91 at that temperature; then the tube 81 may be sealed closed.

The conducting wires 92, 93, and 98 are part of an alarm circuit C. The conductor 98 passes to two normally open parallel test switches 100 and 101, a resistor 102 being in series with the test switch 101. From the switches 100 and 101 lines 103 and 104 lead to a main line 105, which leads to a suitable A.C. or D.C. current source, such as a battery 106.

The conductor 93 is connected to a signal lamp 110, which is connected by lines 111 and 112 to the main line 105. The conductor 92 is connected to a signal lamp 115, which is connected by lines 113 and 112 to the main line 105. The conductor 92 is also connected by a line 116 to a normally closed bell-ringing circuit 117, which might either be an A.C. or D.C. type, depending upon the current source 106, and is connected to the main line 105. Although a bell 118 is shown in the circuit 117, various other devices may be substituted for it, such as a buzzer or a relay.

5. *Operation of the device of FIG. 3*

Assume, by way of illustration, that the sensor A, the blisters 76 and 77, and other parts, are so constructed that the blister 76 will make contact with its electrode 90 when the sensor A is exposed to a fire temperature, and so that the blister 77 will make contact with the electrode 91 when the sensor A is exposed to an overheat condition substantially lower than fire temperature. For example, the fire temperature may be 450° C. and the overheat temperature may be 200° C.

Then, if the sensor A is exposed to an overheat condition of 200° C. or higher, gas from the sensor A increases the pressure within the sensor chamber 74 and deflects the blister 77 against the electrode 91. However, the blister 76 will not at that time contact the electrode 90. Current thus flows from the battery 106 through the lines 105, 112, and 111, the lamp 110, the conductor 93, the electrode 91, the blister 77, and the plates 72 and 71, to ground through the point 96. The resulting illumination of the lamp 110 provides an indication that the temperature of the area in which the sensor A is located is at or above the critical overheat temperature but is still below the fire temperature.

When the sensor A is exposed to the fire temperature of 450° C., more gas comes from the sensor A and deflects the blister 76 against its electrode 90. The blister 77 is still in contact with its electrode 91 and its lamp 110 is still lighted. But now current from the current source 106 also passes through both the lamp 115 and through the bell circuit 117, ringing the bell 118 and lighting the lamp 115. This provides a visual and audible indication of a fire condition in the area to which the sensor A is exposed.

If the fire is put out and the sensor A is cooled, the pressure on the blisters 76 and 77 is lowered to break their contact with their electrodes 90 and 91, in that order. The current flow then stops, the lamps 115 and 110 go out, in that order, the bell 117 becoming silent at the time the lamp 115 goes out.

6. *The test circuit of FIG. 3 and its operation*

The circuit segment consisting of the parallel arrangement of test switches 100 and 101 in series with the conductor 98 and the filament 88 provides a convenient arrangement for checking the operability of the device. As explained previously, the amount of gas liberated from heat-dissociable material, such as the hydride 83 contained in the tube 82, is a function of its temperature and this, in turn, is a function of the amount of current through the filament 88.

Upon closure of the test switch 101, current flows from the current source 106 through the lines 105 and 104, the switch 101, the current-limiting resistor 102, and the conductor 98, to the filament 88, the plate 71, and thence to the ground point 96. The resultant heating of the hydride 83 frees gas therefrom and, since the gas cannot escape from the sensor chamber 74, it exerts pressure on the sensor side of the blisters 76 and 77. The magnitude of the current-limiting resistor 102 is chosen so that the amount of gas released from the hydride 83 is sufficient to deflect the blister 77 against its electrode 91 but insufficient to deflect the blister 76 against its electrode 90. The result is that the lamp 110 is illuminated, thus providing an indication that the overheat portion of the circuit is functioning correctly and that the sensor A and sensor chamber 74 do not leak.

If, now, the test switch 100 is engaged, a larger current flows through the filament 88, due to the bypassing of the resistor 102 between the current source 106 and the filament 100. The increased current heats the hydride 83 to a higher temperature, with the result that more hydrogen is released. Assuming that the circuit parameters and the amount of hydride are chosen correctly, enough pressure can be exerted upon the blister 76 to deflect it against its electrode 90, ringing the bell 118 and lighting the lamp 115, indicating that the fire portion of the circuit is functioning correctly and also testing the sensor A and chamber 74 against leaks. When the switches 100 and 101 are both disengaged, current flow through the filament 80 ceases, and the hydride 83 cools, re-ingassing its previously released hydrogen. The pressure in the sensor chamber 74 drops and contact between the respective electrodes 90, 91 and their associated blisters 76, 77 is broken, resulting in the extinguishment of the lamps 110 and 115 and silence of the bell 118.

7. *Variation of the pressure in the anti-sensor chamber (FIG. 4)*

As explained before, the force necessary to deflect a blister onto its respective electrode is a function of the pressure in the anti-sensor chamber. A way of changing this pressure is shown in FIG. 4, which is an enlarged view of a portion of a simplified responder 120 generally like the responder 20 shown in FIG. 1, identical numerals being applied to those parts that are identical. In addition, however, the responder 120 has a porous tube 121, which may be of gas-porous ceramic mounted inside the tube 31 by brackets 122. The tube 121 contains a selected amount of a suitable heat-dissociable material 123; for example, powdered vanadium hydride. Embedded in the hydride 123 is a filament 124, and leads 125 and 126 for the filament 124 are brought out of the tube 121 through caps 127 and 128 and then pass through the walls of the tube 31 to a potentiometer 130 and a battery 131. The points where the conductors 125 and 126 are brought out through the tube 31 are sealed so that, as before, the interior 36 of the tube 31 and the anti-sensor chamber 28 enjoy a common atmosphere to the exclusion of any other.

Now, in addition to the mechanical design of the system which includes the design of the blister 24, the effective force necessary to deflect the blister 24 against the electrode 34 may be altered by sending current from the battery 131 to the filament 124 through the potentiometer 130. The magnitude of this current depends upon the setting of the potentiometer 130, and the current through the filament 124 determines the amount of gas released from the hydride 123. This hydrogen passes through the porous tube 121 and increases the pressure in the anti-sensor chamber 28, exerting a force against the blister 24 that tends to counteract the deflecting force due to pressure in the sensor chamber 27. The higher the pressure in the anti-sensor chamber 28, the more the pressure that has to be generated in the sensor chamber 27 to deflect the blister 24 against the electrode 34. By altering the setting of the potentiometer 130, the effective temperature to which the responder 120 as a whole will respond may be continuously altered within the design range of the system, to respond to any of many levels of temperature. For example, suppose that the responder 120 is initially set to respond to a temperature of approximately 1500° F. If it is desired that the responder 120 not respond until the temperature reaches 2000° F., then the resistance of the potentiometer 130 is decreased so that more current flows through the filament 124, and a greater biasing force is applied to the blister 24 in the anti-sensor chamber 28. By means of a calibrated potentiometer 130, the ranges of temperature may be detected.

This design increases the adaptability of the responder to many situations. The responder-sensor combination may be used to monitor a certain temperature within a certain area and, when this is completed, the unit may be removed and, by adjusting the potentiometer 130 to a previously calibrated setting, it may then be inserted into another area to monitor a different temperature level. This design obviously can be employed in either or both tubes of a plural-blister responder like that of FIG. 3. Moreover, when the current through the filament 124 is cut off, the responder 120 functions just like the responder 20 of FIG. 1.

8. *A still further refined form of responder B (FIGS. 5–11)*

FIGS. 5–11 show a responder 600 having some important distinguishing features, and also illustrate how the responder 600 may be made. In the responder 600 a diaphragm 601 is secured between two sub-assemblies 602 and 603. As before, the diaphragm 601 is preferably a thin, circular, non-porous metal disc having two generally spherical-segment depressions or blisters 604 and 605, and separates the responder 600 into three regions or chambers; a sensor chamber 606 and two anti-sensor chambers 607 and 608. The center of each blister 604, 605 is located directly beneath, and does not normally touch, a respective contact 610, 611.

A forebody assembly 602 comprises a non-porous, flat metal forebody disc 612 having an axially located hole 613 to which is brazed a short piece of small-diameter tubing 614 that supports the sensor tube D.

The afterbody assembly 603 comprises a non-porous, flat metal disc or afterbody plate 615 which has three holes 616, 617, and 618, preferably symmetrically located about the central axis 619 of the responder 600 and of the plate 615. Another hole 620 is located near the periphery 621 of the plate 615, and a polarizing pin 622 is brazed in the hole 620 to aid in aligning the responder 600 when the complete unit is assembled and mounted in place.

Two signal assemblies 623 and 624 and one testing assembly 625 are placed in the symmetrically located holes 616, 617, and 618 of the afterbody plate 615. Each signal assembly 623, 624 includes a non-porous insulating tube 626 of such material as non-porous ceramic with a metal contact cap 627 slipped over one end and brazed in place. The cap 627 has an axially located hole 628 through which is passed and brazed an electrically-conductive tube 630 of metal, to which is spot-welded the contact 610 or 611. The contact 610 or 611 is a metal plug having a shank 631, which fits loosely inside the insulator tube 626, and a head 632 larger than the interior of the insulator tube 626. The loose fit of the contact shank 631 inside the insulator tube 626 permits the passage of gas between the contact 610 or 611 and the tube 626. A hole 633 in the side of the conductor tube 630 is used to introduce gas into and to evacuate gas from the interior of the insulator tube 626, via the tube 630. A metal socket 634 for the insulator tube 626 is brazed to the insulator tube 626. Sufficient clearance exists between the contact-head 632 and the socket 634 to allow the passage of gas and to prevent electrical shorting across between them.

The two such signal assemblies 623 and 624, as described, are inserted into the holes 616 and 617 in the afterbody plate 615, and the sockets 634 are brazed to the plate 615.

The testing assembly 625 comprises an insulator tube 640, which may be identical with the tube 626 used in the signal assemblies 623 and 624. To one end of the tube 640 is brazed a cap 641, having an axial hole 642, through which passes a metal tube 643 that projects into the insulator tube 640. A metal sleeve 643*a* fits snugly between the tube 643 and the tube 640, leaving only a short end portion 643*b* of the tube 643 exposed to the inside of the tube 640. One end of a helical filament 644 is wrapped around the end portion 643*b* and brazed there, and the tube 643 is brazed to the cap 641. The filament 644 extends axially down the insulator tube 640, and its other end is wrapped around and brazed to the instepped shank portion 645*a* of a ground stud 645, which (except for the portion 645*a*) fits snugly in the tube 640. The stud 645 has a head 646 whose diameter is equal to the outside diameter of the insulator tube 640; the head 645 has three V-notches 647 equally spaced around its periphery. An upper surface 649 of the head 646 fits snugly against the insulator tube 640, while a lower surface 650 of the head 646 rests on a shoulder 651 of a metal socket 652. The head 646 and the tube 640 are brazed to the socket 652, which in turn is brazed into the hole 618 of the afterbody plate 615. In practice, powdered hydride may be introduced into the tube 640 by shaking it through the filament tube 643, after which the lumen of the tube is sealed. This completes the afterbody assembly 603. The contacts 610 and 611 then lie barely beyond the plate 615, almost flush with it. Good results have been obtained where they extended about 0.0005" to 0.001" beyond the plate 615.

The diaphragm 601 is initially a flat disc with two holes 653 and 664. The blisters 604 and 605 may be formed by placing the diaphragm 601 in a suitable chamber with one side against a sturdy plate with two round holes having diameters the same as is desired for the blisters 604 and 605 and applying high pressure to the other side by means of a suitable gas, such as nitrogen or hydrogen. The higher the gas pressure, the greater the concavity of the blisters 604, 605. Good results have been obtained using about 500 p.s.i.g. gas pressure. The diaphragm 601, along with other parts of the final responder assembly, is sandwiched between the forebody plate 602 and the afterbody plate 615. This procedure for making the diaphragm blister applies to all forms of the diaphragm described in this application.

The sandwiching operation is preferably accomplished with the aid of brazing discs 655, 656, and 657 and a spacer 658, placed as shown in FIG. 6. Each of the brazing discs 655, 656, and 657 is very thin (the scale being shown best in FIG. 13) and has a hole 660 which is placed in line with the hole 653 of the diaphragm 601 and the hole 618 of the plate 615. The holes 660 lie inside the apex of a generally triangular-shaped cut-out 661 of the brazing disc 657. The brazing discs 655 and 656 and the spacer 658 also have two additional holes 662 and 663, each of which is axially in line with a blister 604 or 605 and with one hole 616 or 617 of the plate 615. Each of the discs 601, 612, 655, 656, 657, and 658 has a small dowel-hole 664 located near the periphery 621, through which a dowel-pin 665 is passed to aid in aligning the discs prior to brazing. The sandwich is brazed with the help of suitable stopoff-compound such as chromic oxide, so that portions of the diaphragm 601 which lie directly over the holes 660, 662, and 663 are free from brazing compound. However, the periphery around each hole 660, 662, and 663 is brazed to the periphery around the corresponding holes in the adjacent disc. Many brazing techniques may be applied to the formation of the responder. The technique is standard in industry and will not be described here. The sensor A may then be brazed or welded to the tube support 614, through which gas may pass and exert pressure on the blisters 604 and 605. When the assembly is brazed, the brazing discs 655, 656, and 657 substantially disappear, so thin are they, so that they are omitted from some of the drawings. They are shown in approximately their proper relative size in FIG. 13.

The differential pressure across the diaphragm, necessary for blister deflection against a contact, is a function of the diaphragm material, the blister depth, the blister diameter, and the pre-existing differential pressure, which may be varied by the introduction or withdrawal of a precharged pressure in the sensor chamber 606 or in the antisensor chambers 607 and 608. The blisters 604 and 605 are illustrated as of unequal diameters, so that the differential pressures required for deflection are of unequal magnitude. However, this is not intended to restrict the application and scope of this invention.

One of the features of the responder is that regardless of the magnitude of the pressure applied to the sensor chamber 606 blister deformation or distortion does not occur, because when the blisters 604, 605 are deflected against their contacts 610, 611 they are positioned against an essentially flat surface which provides full support, and the thickness of the brazing disc 655 may be made quite small; 0.001", for example.

An additional feature is that the fractional change in the volume in the sensor chamber 606 due to blister deflection can be made extremely small. Use of this feature gives advantageous results in an average temperature detecting device.

Several responders 600 have been constructed using the same metal for all parts except the insulator tubes 626 and 640, the filament 644, and the very thin brazing discs 655, 656, and 657. In some instances the metal was kovar; in others it was molybdenum. Copper and copper-platinum alloys have been employed as brazing metal, while high-purity alumina has been used for insulator tubes. Kovar possesses excellent brazing properties and, in addition, has an extremely low coefficient of thermal expansion. Molybdenum is even beter. All brazes were gastight.

The use of copper and copper-platinum alloys as brazing material, and of alumina for insulator tubes, permits reliable operation of the responder at low temperatures, as well as at temperatures approximating 1900° F., a very desirable property. In addition, the responder is insensitive to ambient or external pressures and will withstand high rates of vibration or acceleration without affecting its operational properties.

Although the responder may be assembled with the aid of brazing operations, many alternative techniques may be employed. One such method is to employ thermoplastic or thermosetting compounds for the discs 655, 656, and 658. The sandwich is then heated while under pressure, to form the desired bond, while the insulator sockets 634 and 652, the contact caps 627, and the filament caps 641 may be cemented or bonded to the insulator tubes 626, 640 with epoxy-resin, for example. This procedure may be more economical. However, it limits the use of the responder to lower temperature regions of approximately 500° F.

9. *Another form of refined responder B (FIGS. 12 and 13)*

FIGS. 12 and 13 show a modified form of responder 800. The view of FIG. 12 is generally similar to FIG. 7 and some parts which are identical have identical reference numerals, but a signal assembly 801 and a test assembly 802 incorporate some minor but significant changes.

The signal assembly 801 includes a contact member 803 in the form of a metal rod, preferably a cylindrical rod of molybdenum, that fits fairly snugly into the bore 804 of a ceramic tube 805, while still leaving sufficient clearance for gas passage. The contact rod 803 is provided at its upper end with an axially extending cylindrical recess 806 into which a capillary tube 807 of nickel is inserted and brazed. The tube 807 may have an inside diameter of about 0.012". A radial hole 808 extends through the contact 803 into the portion 806 below the end of the tube 807, enabling passage of gas through the capillary tube 807 into the ceramic tube 805.

A lower end 810 of the contact rod 803 extends about 0.0005" below the surface of the afterbody plate 615. The amount of extension may be adjusted somewhat by pressing on the tapered end 811 of the cap 627, after brazing. It is important that the protrusion of the contact portion 810 be maintained accurately during the brazing of the responder assembly 800, when the heat tends to expand the ceramic tube 804 a different amount than the metal parts. For example, relative lengths of the molybdenum and nickel parts may be chosen so that their expansion and contraction exactly cancel those of the ceramic tube 804, whose coefficient of expansion is less than that of nickel and more than that of molybdenum. It may be noted that the contact-capillary assembly 803, 807 is fastened to the responder 800 at only one point, the end cap 627.

A tubular insulator support sleeve 812 is provided and the device is assembled with the lower end 813 of the ceramic tube 805 flush with the lower surface of the afterbody plate 615. This arrangement gives lateral support to the contact rod 803 and also provides a smooth, plane surface against which the blister 604 can rest when deformed.

The test pressure unit 802 includes a tube 820, preferably a nickel capillary tube of about 0.012" inner diameter. A molybdenum sleeve 821 is brazed to the lower end of the capillary tube 820 and fills the volume between the tube 820 and a ceramic tube 822, in order to prevent particles of hydride from getting in between the tubes 820 and 822, where they would not be heated by the filament 644. The upper end of the filament 644 is brazed to a radially instepped lower end portion 823 of the molybdenum sleeve 821 at its lower end, and its lower end is brazed to a support sleeve 825, preferably of molybdenum. The sleeve 825 fits snugly in the bore of the ceramic tube 822. Hydride 826 may be put into the ceramic tube 822 from the bottom through the bore 827 of the support sleeve 825. The bore 827 may then be closed by a quartz or ceramic plug 828, with gas-passage clearance being left. The support sleeve 825 has a flange 829 whose lower surface is flush with the lower surface of the afterbody plate 615.

Preferably, an insulator support sleeve 830 extends up to within about 1/16" of the end cap 641 and serves to carry away the heat generated by the filament 644 and to give more even heating of the hydride 826 by eliminating hot spots. To avoid problems due to differences in the coefficients of thermal expansion of the sleeve 830 and the ceramic tube 822, the sleeve 830 is preferably brazed to the tube 822 only at the lower end.

The sequence of the brazing operations is important. By using a suitable combination of brazing materials, it is possible to maintain the rigidity of the previously-brazed parts when making subsequent brazes. For example, the subassemblies consisting (1) of the contact rods 803 and the nickel capillary tubes 807, (2) the filament 644 and its supports 821 and 825, and (3) the afterbody plate 615 and the insulator supports 812 and 830 are first brazed with Cuplat. Next, the afterbody assembly is brazed together with copper, which melts at a lower temperature than Cuplat. The contact portions

810 are then adjusted and the test pressure unit 802 is filled and closed. Finally, the responder 800 is brazed with Nioro, which melts at a lower temperature than copper.

10. *Another refined responder B (FIGS. 14 to 16)*

FIG. 14 shows a very reliable responder 200 having a lower plate 201, an upper plate 202, and a diaphragm 203 clamped between the plates 201 and 202 in a manner shown in FIGS. 15 and 16, all preferably of molybdenum. The diaphragm 203 has a blister 204 with a margin 205 around the blister 204 coplanar with the flat clamped rim of the diaphragm 203 but free to flex. A sensor tube 206 is centrally located in an opening 207 that lies directly opposite the blister 204. The tube 206 is brazed to the lower plate 201 and opens into a recess 208, which cooperates with the diaphragm 203 to define a sensor chamber 210.

On the other side of the diaphragm 203 is an anti-sensor chamber 211. A tubular support sleeve 212 is brazed into an opening 213 in the upper plate 202 with its lower end 214 flush with the lower surface 215 of the plate 202. The sleeve 212 supports a ceramic tube 216 to which it is hermetically sealed, the lower end 217 of the sleeve 216 lying flush with the surfaces 214 and 215. The sleeve 212 gives lateral support to the ceramic tube 216 and also to a contact rod or electrode 220 which fits inside the bore 218 of the sleeve 216. The clearance 221 between the bore 218 and the rod 220, which is part of the anti-sensor chamber 211, can be quite small because gas passes freely in narrow passages. The lower end 222 of the contact rod 220 is made with its outer periphery substantially flush with the surfaces 214, 215, and 217 and with its central portion slightly convex so as to lie about 0.0005" below the surfaces 214, 215, and 217. The amount of extension may be adjusted as before by pressing on a tapered end 223 of a cap 224 which is brazed to the ceramic tube 216.

The cap 224 is also brazed to a nickel capillary tube 225 having a very small passageway 226 through which the anti-sensor chamber 211 can be filled with an inert gas, such as a noble gas, to achieve the desired pressure in the anti-sensor chamber 211. The tube 225 is brazed into an opening 227 in the contact rod 220. At the lower end of the opening 227 is a shoulder 228 that serves to stop the lower end 229 of the capillary tube 225, and below that is a cavity 230 from which a radially extending passage 231 leads to the clearance 221. The cavity 230 and passage 231 enable passage of the precharging gas from the capillary tube 225, which is sealed after the precharge is introduced, as described before in connection with FIGS. 5 through 12.

The responder 200 is relatively simple. It has no test assembly and so differs in that respect from the responder 800. However, its simplicity is matched by the accuracy with which it can be made. For example, a shoulder 232 on the sleeve 212 and a shoulder 233 on the ceramic sleeve 216 enable exact positioning of the lower surfaces 215 and 217 of these members relative to each other.

FIGS. 15 and 16 are enlarged views, somewhat diagrammatic in nature, illustrating the effect of providing the diaphragm 203 with a margin 205 around the blister 204. In the strained or actuated position, the strains are distributed so that an undue concentration of strain does not occur at the boundary of the blister 204. This is the important thing. Without this provision of a margin, there is a tendency for the blister to shear off sharply at the edge 234. In practice, many blisters without a margin were found to collapse under certain high pressures, but it was found that with the margin 205 of correct size, when the blister 204 snaps through from one position to the other it also tends to flex up at the point shown at 235 in FIG. 16, to relieve the pressure there and therefore to distribute the forces evenly. In all instances the blisters 204 are formed larger than the hole 218 leading out from the anti-sensor chamber 211. Preferably, the blister 204 is considerably larger than the opening 218 as shown in FIGS. 14 through 16. It has been found that as a result of this structure, it is possible to pressurize a diaphragm 203 made in this manner up to 1600 pounds per square inch pressure, without interfering with repeatability.

To those skilled in the arts to which this invention relates, many changes in construction and widely differing embodiments in application of the invention will suggest themselves without departing from the spirit and scope of the invention. The disclosures and the descriptions herein are purely illustrative and are not intended to be in any sense limiting. For example, the blisters need not be true spherical segments, the term "generally spherical" being intended to indicate only their general round shape. They need not necessarily be circular in area, for that matter, though that is generally preferable.

I claim:

1. A very sensitive pressure-responsive device, including in combination: a metal housing; a metal diaphragm in said housing and dividing said housing into a plurality of chambers, said diaphragm having a circular area bounded by a peripheral rim that is rigidly fixed to said housing, said area being deformed beyond the elastic limit of said metal into a generally spherical segment, having a concave side and a convex side, that always tends to resume the spherical shape to which it has been formed and that is flexed toward a flattened condition in response to pressure in said chamber on its convex side, and moving, when it moves, in a snap action, said housing and diaphragm being electrically a single unit; means for applying fluid pressure to the convex side of said diaphragm; and an electrode supported by said housing along substantially the plane of said rim and electrically-insulated from said housing lying directly opposite and centrally located with respect to said spherical segment on the side thereof away from which said segment is normally deflected, whereby deflection of said segment toward said electrode results in electrical and physical contact of said electrode and said segment, said housing being flat on the side facing the concave side of said diaphragm in the plane of said rim and provided with a central opening largely filled by said electrode, which lies substantially in the same plane, to provide a flat support for said diaphragm when the diaphragm is snapped to its actuated position, thereby protecting said diaphragm blister from being pushed beyond its elastic limit and from being deformed during actuation due to pressures greatly exceeding the pressure required for actuation.

2. The device of claim 1 wherein said circular area and said rim are separated by a marginal area coplanar with said rim and free to flex.

3. The device of claim 1 wherein said metal diaphragm tends to require less pressure for actuation as the temperature rises and wherein said concave side is gas-filled so as to increase the pressure opposing actuation as the temperature rises.

4. A very sensitive pressure-responsive device capable of use at high pressures and temperatures, including in combination: a molybdenum two-piece housing; a molybdenum diaphragm in said housing sandwiched between said two pieces and dividing said housing into a plurality of chambers, said diaphragm having a circular area bounded by a peripheral rim that is sealed gas-tight to said housing by a high-temperature braze, said area being deformed from a flat sheet beyond the elastic limit of said molybdenum into a generally spherical segment having a concave side and a convex side that always tends to resume the spherical shape to which it has been formed and that is flexed toward a flattened condiiton in response to pressure in said chamber on its convex side, and moving, when it moves, in a snap action, said housing and diaphragm being electrically a single unit; means for

applying fluid pressure to the convex side of said diaphragm; and an electrode supported by said housing along substantially the plane of said rim and electrically-insulated from said housing, lying directly opposite and centrally located with respect to said spherical segment on the concave side thereof, whereby deflection of said segment toward said electrode results in electrical and physical contact of said electrode and said segment.

5. A very sensitive pressure-responsive device, including in combination: a housing having an upper plate with a flat lower surface and an opening therethrough and a lower plate with a recess larger than and generally coaxial with said opening and having a pressure inlet; a metal diaphragm in said housing sandwiched between said plates to provide in cooperation therewith an upper chamber and a lower chamber, said diaphragm having an area approximately co-extensive with said recess and bounded by a peripheral rim that is rigidly fixed to both said housing plates, said area being deformed beyond the elastic limit of said metal into a segment having a concave side facing said upper plate and a convex side facing said lower plate in said recess, said diaphragm being flexed toward a flattened condition against said upper plate in response to pressure in said lower chamber, moving, when it moves, in a snap action; means for applying fluid pressure to the convex side of said diaphragm; and an electrode supported by said upper plate in said opening along substantially the plane of said lower surface and electrically insulated from said housing, whereby deflection of said area against said electrode results in electrical and physical contact between said electrode and said diaphragm and also provides support for said diaphragm.

6. A very sensitive pressure-responsive device, including in combination a housing and a diaphragm in said housing and dividing said housing into a plurality of chambers, said diaphragm having a plurality of distinct non-overlapping areas, the periphery of each area being rigidly fixed to said housing, each said area being deformed into a convex blister that flexes toward its flat position in response to pressure in said chamber.

7. The device of claim 6 wherein said blisters are of different areas and therefore have different pressure responses.

8. A pressure-responsive switch, including in combination: a first housing member; a second housing member; a metal diaphragm sealed between said housing members and having a plurality of areas, each having a periphery rigidly fixed to said housing members, each said area being deformed to provide a blister normally depressed toward said first housing member, said diaphragm and said first housing member cooperating to provide a first chamber, said diaphragm and said second housing cooperating to provide other chambers, one at each blister; an electrode insulated from said diaphragm and mounted in said second housing directly opposite each said blister; means for applying fluid pressure to the said first chamber; and electrical conduction means for each said electrode and said diaphragm, so that flexure of a said blister due to a pressure differential between said first chamber and one of said other chambers caused by said means for applying fluid pressure causes contact between said blister and a said electrode, which then acts as an electrical switch.

9. A pressure-responsive switch, including in combination: a first metal housing disc having three openings therethrough, generally symmetrically located with respect to the center of said disc; a second metal housing disc having a central opening therethrough; a tube in said central opening extending out one side thereof; a plurality of brazing discs, one being brazed to said first disc and having corresponding openings, the other being brazed to said second disc and having a large, generally central opening; a spacer-disc like said second brazing disc and brazed thereto; a third brazing disc generally like said first brazing disc and brazed to said spacer-disc; a metal diaphragm sealed between and brazed to said first and third brazing discs and having two circular areas whose peripheries are rigidly fixed to said first and third brazing discs, each said area being deformed to provide a blister normally depressed toward said second housing disc, said diaphragm, said second and third brazing discs, said spacer, and said second housing disc cooperating to provide a first chamber, said diaphragm, said first brazing disc, and said first housing cooperating to provide second and third chambers, said diaphragm also having an opening in line with the third opening of said first disc; closed tubes of insulating material secured in each opening of said first disc, directly opposite each said blister and said diaphragm opening; an electrode insulated from said diaphragm and said disc in each of the two tubes directly opposite a said blister and lying flush with the normal plane of said diaphragm; electrical conduction means for each said electrode so that flexure of said blister due to a pressure differential between said first and second or first and third chambers can cause contact between a said blister and a said electrode, which then act as an electrical switch; gas-releasing and re-absorbing means in the third said tube in line with said diaphragm opening; and means for heating said gas-releasing and re-absorbing means.

10. A very sensitive pressure-responsive switch capable of snap type operation at high temperatures, having in combination:

a high-melting-point metal housing comprising a first housing member having a central recess facing a second housing member having a planar face opposite said recess,

a high-melting point metal diaphragm in said housing sandwiched between said housing members and in direct electrical contact with them and dividing said housing into a plurality of chambers,

said diaphragm having an area whoe periphery is rigidly sandwiched and sealed between said housing members, said area being deformed beyond its elastic limit into a smooth blister that dips into said recess and has a convex side and a concave side,

said housing and said diaphragm being electrically a single unit, said diaphragm being fully exposed on both sides and free from encumberances thereon,

means for applying a critical pressure in said chamber on the convex side of said blister to cause a snap-flexure of said blister,

said blister during deflection toward said planar face being supported by said planar face, and

a high-temperature metal electrode supported by said metal housing and electrically insulated therefrom by high-temperature ceramic and directly opposite and centrally located with respect to said blister for contact therewith in one position of said blister.

11. The switch of claim 10 wherein said electrode lies just barely below the plane of said planar face of said housing on the concave side of said blister and helps to support said blister during deflection of said blister against said electrode.

12. The switch of claim 10 wherein the chamber on the opposite side of said diaphragm from said pressure applying means is pre-pressurized to a set value, so that said pre-pressurization opposes the tendency of the diaphragm to become actuable at a lower pressure as its temperature rises.

13. The switch as claimed in claim 12 having means in said pre-pressurized chamber for varying the pressure therein at will so as to change the actuation pressure of said switch.

14. The switch of claim 10 having a test device supported by said housing with its interior in communication with the chamber on the convex side of said blister, said test device containing means for emitting gas under heat in quantities sufficient to actuate said blister and for taking up the emitted gas when cooled and heating means for causing the emission of said gas by said emitting means.

15. The switch of claim 10 wherein the temperature coefficient of expansion of said ceramic lies between the temperature coefficient of expansion of said electrode and that of said housing, said ceramic being sealed to said housing and said electrode being sealed to said ceramic at a point spaced from the seal of the ceramic to said housing, the relative lengths of said electrode, of said ceramic between its said seal points, and of said housing from its inner surface to the seal point with said ceramic being proportioned so that the actual position of the electrode contact relative to the inner surface of said housing remains constant over a very wide range of temperatures.

16. The switch of claim 15 wherein said housing is molybdenum and the major length of said electrode is made from nickel.

References Cited by the Examiner

UNITED STATES PATENTS

2,022,907	12/35	Worley	200—140
2,308,911	1/43	Campodonico	200—140
2,381,582	8/45	Erickson	200—83
2,477,801	8/49	Hathaway	200—83
2,705,270	3/55	Moran	200—140
2,711,459	6/55	Milks	200—140
2,886,885	5/59	Reid	29—421
2,898,418	8/59	Byam	200—83
2,993,268	7/61	Wells	200—83

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