March 7, 1967 M. KRAKINOWSKI 3,308,253

DIAPHRAGM SWITCH HAVING A DIAPHRAGM SUPPORTED ON AN INCOMPRESSIBLE LAYER AND AN ELASTOMER OVERLAYING THE DIAPHRAGM

Filed March 25, 1965

FIG. 1

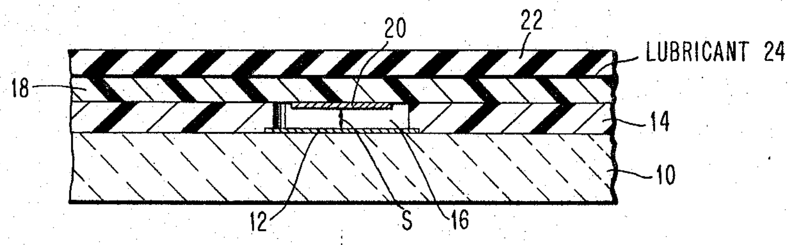
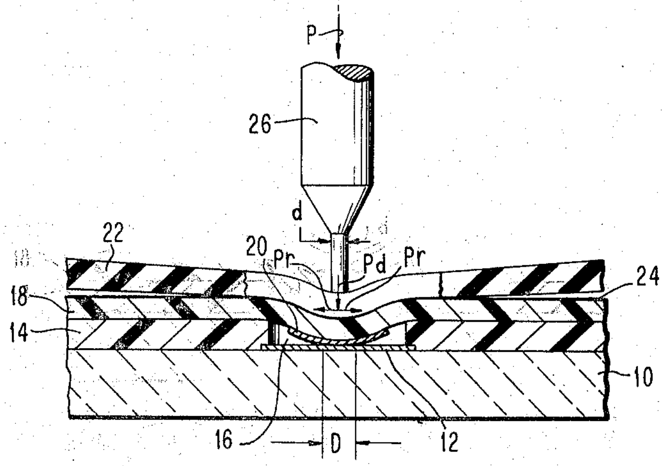


FIG. 2



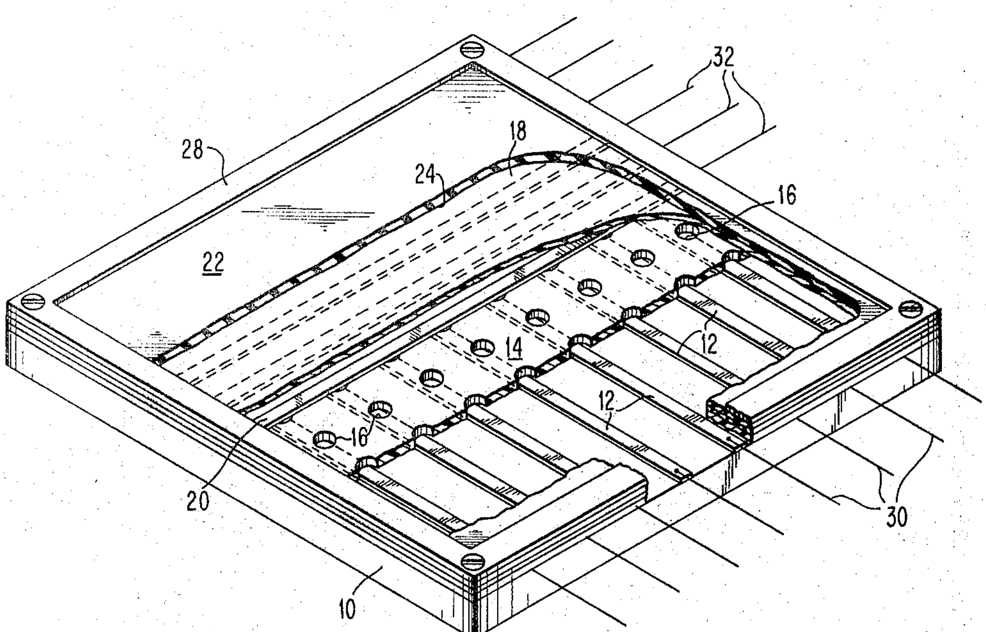


FIG. 3

INVENTOR.
MORRIS KRAKINOWSKI

BY Ronald J. Kransdorf
ATTORNEY

United States Patent Office

3,308,253
Patented Mar. 7, 1967

3,308,253

DIAPHRAGM SWITCH HAVING A DIAPHRAGM SUPPORTED ON AN INCOMPRESSIBLE LAYER AND AN ELASTOMER OVERLAYING THE DIAPHRAGM

Morris Krakinowski, Ossining, N.Y., assignor to International Business Machines Corporation, Armonk, N.Y., a corporation of New York

Filed Mar. 25, 1965, Ser. No. 442,758
8 Claims. (Cl. 200—46)

This invention relates to electrical switching elements and more particularly to pressure-sensitive diaphragm switching elements.

While pressure-sensitive switches have been in existence for some time, their field of application has been limited by such factors as their size, cost, and lack of sensitivity to very slight pressures. One way in which such limitations have been overcome is to form the switch by use of thin film techniques. In doing this, a first conducting segment or strip is laid down on a substrate, a non-conductive spacer layer placed over this with an opening over the conducting segment, and a diaphragm having a conducting segment positioned adjacent to the conducting segment on the substrate positioned over the spacer layer. With such an arrangement, the conducting segments are brought into contact with each other by applying pressure to deform the diaphragm.

Since thin film techniques are employed in constructing these switches, the size of the switch may be made quite small and their cost kept low. However, there are still practical limitations on their usefulness. One disadvantage is that if a fairly pointed stylus such as a pencil or a pen is being used as the actuating element, as would often be the case in many applications of such switches, a thin diaphragm tends to puncture or to at least sustain permanent deformation on the point where pressure is applied due to the high stress concentration. The deformation may occur in the diaphragm itself and/or in the conducting segment attached to the diaphragm, and may occur after only a short number of switching cycles. This problem may be overcome to some extent by using a thicker diaphragm. However, when this is done, the permissible switch density (i.e. switches per unit area) is severely restricted. In applications of such switches, such as in a punched card reader, an embossed card reader, or a constrained handwriting recording device, the limitation on the switch density becomes a serious problem. Also, with a thick diaphragm, the amount of force required to energize the switch is increased.

In addition to the shortcomings mentioned above, most diaphragm switches have a limited contact area which is largely determined by the surface area of the actuating device and its alignment with the plane of the switch. The contact resistance and the current density at the point of contact between the two conducting segments is inversely proportional to the area of contact between these two segments. Heating at this junction is directly proportional to both the current density and the resistance, and therefore the smaller the contact area, the greater the heating at the junction. This causes evaporation of contact material and material transfer, which ultimately results in a failure of the switch. The limited contact area and the resulting heating problem therefore seriously reduces the current carrying capacity of the switch.

Another problem with diaphragm switches is contamination of the conducting surfaces by organic molecules and other dirt in the atmosphere which causes a thin film to form over the contacts. Such a film, unless broken, prevents good contact from being made, lead-

ing to erroneous indications from the switch. It is therefore important that the switch be designed to prevent contamination of the contacts as much as possible and to pierce such film as may exist in order to establish good contact in every instance.

A diaphragm switch should also be designed to have a minimum stroke so as to have a short response time and to be capable of being stacked so as to provide multi-pole isolated switching elements that can be activated by a single actuator.

It is therefore a primary object of this invention to provide an improved pressure responsive electrical switching element.

A more specific object of this invention is to provide an improved diaphragm, pressure-responsive switching element.

Another object of this invention is to provide a diaphragm switching element which is capable of operating for a very large number of switching cycles, even with a relatively pointed actuating element, without having the diaphragm puncture or become permanently deformed.

A further object of this invention is to provide a diaphragm switching element which provides a larger contact area at the terminals than the area of the pressure-applying element.

Still another object of this invention is to provide a pressure-responsive diaphragm switch which is capable of switching relatively large currents.

A still further object of this invention is to provide a pressure-responsive diaphragm switch which allows a very dense array of switching points to be constructed.

Another object of this invention is to provide a pressure-responsive diaphragm switch which requires a minimum actuating force to cause contact closure.

Another object of this invention is to provide a pressure-responsive diaphragm switching element, several of which may be stacked together to provide multi-pole isolated switching elements that can be activated by a single actuator.

Still another object of this invention is to provide a pressure-responsive diaphragm switch with a very small stroke and therefore very short response time.

A still further object of this invention is to provide a pressure-responsive diaphragm switch which is easy and inexpensive to fabricate.

Another object of this invention is to provide a pressure-responsive diaphragm switch which is nearly maintenance free and therefore extremely inexpensive to operate.

A feature of this invention is the provision of a pressure-responsive diaphragm switch, the terminals of which open and close with an inherent rolling action which helps penetrate any contaminant film on the contacting surfaces.

Another feature of this invention is the provision of a pressure-responsive diaphragm switch which is inherently sealed and which may easily be hermetically sealed so as to be capable of operating under adverse environmental conditions.

In accordance with these objects, this invention provides a switching element which includes a first terminal which is fixed on a substrate, a diaphragm-carried second terminal which is adjacent to the first terminal, a spacer for normally separating the terminals, and a layer of elastomeric material over the diaphragm. The spacer has an opening in it so that when pressure is applied to the elastomeric material, the elastomeric material and the diaphragm are deformed to bring the terminals into contact with each other. The individual switching elements may be arranged in an array for performing any desired function.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of a preferred embodiment of the invention, as illustrated in the accompanying drawings.

In the drawings:

FIG. 1 is a sectional side view of a single switching element of this invention in its open condition.

FIG. 2 is a sectional side view of the switching element shown in FIG. 1 in its closed condition.

FIG. 3 is a partially cutaway perspective view of an array of switching elements of the type shown in FIGS. 1 and 2.

Referring now to FIGS. 1 and 2, it is seen that the preferred embodiment of the switching element of this invention has a laminar structure. The individual lamina of this structure are (1) a substrate **10**, having a segment of conductive material **12** plated on its upper surface; (2) a layer of insulating material **14** overlaying or plated on substrate **10**, the insulating material being incompressible and having an opening **16** in it in the area of conducting segment **12**; (3) a diaphragm **18** positioned on top of the insulating material **14**; (4) a segment **20** of conducting material fixed to the underside of diaphragm **18** in the area of opening **16**; (5) a layer **22** of elastomeric material resting on diaphragm **18**; and (6) a layer of lubricant **24** between diaphragm **18** and elastomeric material **22**. While the particular materials employed for the various layers shown in FIGS. 1 and 2 and the relative thicknesses of these layers are a matter of choice and will vary with the application to which the switch is being put, the following materials and relative dimensions have been found to give satisfactory results:

The substrate is of copper-clad glass or paper-filled epoxy laminate and is 0.060″ thick, with 1 oz. copper. Separator **14** is of Mylar[1] and is 0.001 to 0.005″ thick. Diaphragm **18** is of a Mylar-copper laminate and is 0.003 to 0.006″ thick with one-half to 1 oz. copper. Contacts **12** and **20** are of gold and are 25 to 30×10^{-6}″ thick. Cover sheet **22** is of neoprene, Hypalon, Viton film rubber, a urethane synthetic rubber, or of any other elastomer and may vary in thickness from 0.005 to 0.030″, depending on the application to which the switch is being put. In the discussion to follow, cover sheet **22** will be referred to as being made of either an elastomer or an elastomeric material. Lubricant **24** is a silicone grease.

Referring now to FIG. 2, it is seen that when pressure is applied to the upper surface of elastomer cover sheet **22**, the single component of pressure P in the downward direction is converted by the elastomer into a component of pressure P*d* in the downward direction and components of pressure P*r* which radiate out in all directions in a plane parallel to that of substrate **10**. This effectively widens the area over which pressure is applied to diaphragm **18**, causing a larger area, D, of conductive segment **20** to be brought in contact with conductive segment **12**, then the area, *d*, of actuating stylus **26**. The relatively large contact area, D, reduces the contact resistance and the current density so that the switch is capable of handling relatively large currents of a magnitude approaching 1 amp. without overheating. With lower currents of a magnitude in the milliamp range, the switch is capable of operating for an almost unlimited number of cycles without breakdown. The contact-making ability of the switch is further enhanced by the inherent rolling action which occurs as the center of segment **20** first touches segment **12** followed by adjacent sections of this segment making contact until contact is made over the entire area D. A reverse unrolling action occurs when contact is broken. The initial point contact causes a high pressure to be momentarily applied over a small area to physically puncture any contaminant film which may have accumulated on the conducting segment surfaces and also causes a high contact resistance and current density to exist for a short period of time. This latter condition exists long enough for any contaminant film to be burned away but not long enough to do any damage to the conducting surfaces.

From FIG. 1, it can be seen also that the stroke(s) of the switch is very small (0.003 to 0.030″ with the illustrative dimensions previously stated) so that the response time of the switch is good and the force required to activate it low. The silicone grease **24** between diaphragm **18** and cover sheet **22** reduces the friction which would otherwise occur as these two sheets move relative to each other, thereby further reducing the energizing force required and improving the response time of the switch. The fact that only the relatively thin diaphragm **18** must move into opening **16** permits opening **16** to be relatively small and therefore allows a relatively dense array of switching points to be constructed.

In order to provide a fuller understanding of the invention, the physical sequence of events which occurs when pressure is applied to a small area, having a diameter *d*, near the center of the switch will now be described in detail. The pressure P applied to the elastomeric layer **22** is initially transmitted through the elastomeric layer to deform the diaphragm with a very small radius of curvature, resulting in a point contact between conducting segments **12** and **20**. The small radius of curvature of the diaphragm results from the fact that it is being rigidly supported at the walls of the opening as it is being poked and stretched into the opening by the pressure applied to it. Once contact is made, additional pressure applied to the switch results in a flattening of the elastomer material. However, since an elastomer is substantially incompressible, the flattening of the elastomer causes material to be forced out all around the periphery of the actuator. Lubricant **24** provides low friction between diaphragm **18** and elastomer **22** which permits the forced-out material to move freely. Since the elastomer is, at this time, wedged into the deformation in the diaphragm, the elastomer material forced out around the periphery by the flattening thereof, causes radial pressures P*r* to be applied to the diaphragm which further deform the diaphragm toward the walls of the opening. This further deformation of the diaphragm increases the radius of curvature thereof, and therefore increases the contact area between segments **12** and **20**. The rolling action described above is in this manner achieved.

FIG. 3 is a partially cutaway view of an array of the pressure-responsive diaphragm switches of this invention. This array may, for example, be used as part of a punched card reader or to give a series of *x–y* coordinates when used as part of a curve or character reading device. In this array, the layers **10**, **12**, **14**, **18**, **20** and **22** are clamped in a frame **28** to avoid gross relative shift of the separate layers. For purpose of illustration, segments **12** have been shown as being continuous strips oriented in one direction, and segments **20** have been shown as continuous strips oriented in a direction perpendicular to that of the strip **12**. A line **30** is connected to each of the strips **12** and a line **32** to each of the strips **20**.

As an example of how the array shown in FIG. 3 may be operated, assume that a stylus is moved across the top of sheet **22**. As the stylus comes over each opening **16**, diaphragm **18** and an associate strip **20** are forced through the opening into contact with a strip **12**. By succeedingly applying a signal to the lines **30** and sensing on which of the lines **32** an output occurs, it is possible to determine which of the openings **16** the stylus is positioned over at any given time.

It can be seen that the array shown in FIG. 3 may be easily fabricated by use of known thin film techniques

[1] A trademark of the Du Pont Corporation.

such as photo-etching and that the cost per switching point for a switching array may be made extremely low by use of such techniques. Such techniques also provide an extremely thin switching array as may be observed from the illustrative layer thickness previously stated. Further, the frame **28** forcing the various layers together, provides an inherent sealing action which enables the array to operate under adverse conditions of temperature, humidity and contamination without ill effect. Should further security against adverse environmental conditions be desired, the entire array may be hermetically sealed. Any contamination of the contacts which still exists is taken care of by the inherent rolling action previously described. It should also be noted that a sheet of paper or similar material may be placed over layer **22** and written on without in any way hampering the switching action of the array so that a visual record of what is being recorded may be obtained at the same time that it is being electrically recorded.

While in FIG. 3, segments **12** and **20** have been shown as being strips of conducting material oriented perpendicular to each other and the switching points oriented in a matrix array, the array may also be constructed by, for example, coating the entire underside of diaphragm **18** with conducting material or using a diaphragm of conducting material and providing an individual conducting segment **12** for each index position. A single lead would be connected to the conducting layer under the diaphragm and an individual output lead would be provided for each of the segments **12**. The array could then be laid out in any desired fashion.

Where it is desired to provide a multi-pole isolated switching element which may be activated by a single actuator, segment **12** is mounted on the upper surface of a second diaphragm with the underside of the diaphragm having a conducting segment **20**. This second conducting segment **20** has a separator layer **14**, a conductor segment **12**, and a substrate **10** associated with it, thereby providing a two-layer stacked diaphragm switch, the upper layer of which closes first and opens last when pressure is applied to cover sheet **22**. A third and possibly a fourth layer of stacked switch could likewise be provided in this manner.

While the invention has been particularly shown and described with reference to a preferred embodiment thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and detail may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A switch which is activated by pressure applied to a small area near the center thereof comprising:
- a base assembly having a first conductive contact element;
- a substantially incompressible insulating layer overlaying said base assembly, said insulating layer having an opening therethrough which is aligned with said first conductive contact element;
- a diaphragm assembly overlaying said insulating layer, said diaphragm assembly having a second conductive contact element which is aligned with said first conductive contact element but is normally separated therefrom by a gap formed by said opening;
- and an elastomer layer in contact with the upper surface of said diaphragm assembly and having a low coefficient of friction therewith, said elastomer layer coacting with the walls of said opening to deform said diaphragm assembly into said opening with a small radius of curvature as pressure is initially applied to said small area to cause an initial point contact to be established between said contact elements, and further coacting with the walls of said opening to further deform said diaphragm assembly to increase the radius of curvature of the lower surface thereof, as the pressure applied to said small area is increased, to cause the area of contact between said contact elements to be increased.

2. A switch of the type described in claim **1** including a layer of lubricant between said elastomer layer and said diaphragm which provides said low coefficient of friction.

3. A switch of the type described in claim **1** wherein said first and second conductive contact elements are plated onto said base and diaphragm assemblies respectively;
- and wherein said insulating layer is plated on said base assembly.

4. A switching array, each element of which is activated by pressure applied to a small area of the array near the center of the element, comprising:
- a base assembly having at least one first conductive contact element, and a diaphragm assembly having at least one second conductive contact element, where at least one of said assemblies has a plurality of conductive contact elements which are electrically isolated from each other;
- a substantially incompressible insulating layer separating said base and diaphragm assemblies from each other, said insulating layer having an opening therethrough at each point which is between a first contact element, or a portion thereof, and a second contact element, or a portion thereof, which contact elements it is desired to have make switching contact with each other;
- an elastomer layer in contact with the upper surface of said diaphragm assembly and having a low coefficient of friction therewith, said elastomer layer coacting with the walls of said opening, when pressure is applied to a small area of said switch above a point near the center of one of said openings, to deform said diaphragm assembly into said opening with a small radius of curvature to cause a point contact to be established between the conductive contact elements on either side of said opening, and coacting with the walls of said opening, as the pressure applied to said small area of the switch is increased, to further deform said diaphragm assembly to increase the radius of curvature of the lower surface thereof to cause the area of contact between said conductive contact elements to be increased;
- and means adapted to indicate which two of said conductive contact elements have been brought into contact with each other.

5. A switching array of the type described in claim **4** including a layer of lubricating material between said elastomer layer and said diaphragm assembly to provide said low coefficient of friction.

6. A switching array of the type described in claim **4** wherein said based assembly includes a substrate having conductive material selectively plated thereon to form said first conductive contact elements;
- wherein said diaphragm assembly includes an elastic sheet having conducting material selectively plated thereon to form said second conductive contact elements;
- and wherein said insulating layer is plated onto said base assembly.

7. A switching array of the type described in claim **4** including a frame holding said base and diaphragm assemblies, said insulating layer, and said layer of elasmeric material together.

8. A switching array of the type described in claim **4** wherein said first conductive contact elements are parallel strips;
- wherein said second conductive contact elements are parallel strips oriented at right angles to the strips forming said first conductive contact elements;
- and wherein the openings in said separating means are at each intersection of a first and second conductive contact element.

(References on following page)

References Cited by the Examiner

UNITED STATES PATENTS

2,843,695	7/1958	Osuch et al.	200—86
3,056,005	9/1962	Larson	200—96
3,230,325	1/1965	Parkinson	200—86 X

FOREIGN PATENTS

342,157	1/1931	Great Britain.
406,285	2/1934	Great Britain.
27,422	11/1916	Norway.

References Cited by the Applicant

UNITED STATES PATENTS

2,734,954	2/1956	Kidd.

OTHER REFERENCES

Electro Mechanical Design, November 1962, pages 40–41.

BERNARD A. GILHEANY, *Primary Examiner.*

H. A. LEWITTER, *Assistant Examiner.*