Aug. 2, 1966 J. C. MARTIN ETAL 3,264,436

ELECTRICAL SWITCH HAVING A TRIGGER ELECTRODE WHOSE SHARP EDGES ARE SEALED TO SUPPRESS THE FORMATION OF CORONA

Filed Dec. 23, 1964

3 Sheets-Sheet 1

FIG.1.

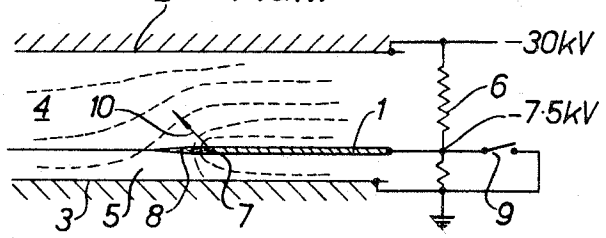


FIG.2.

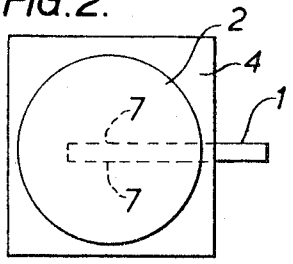


FIG.3.

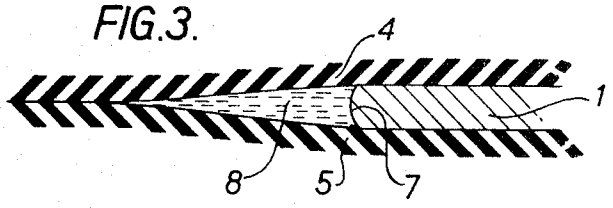
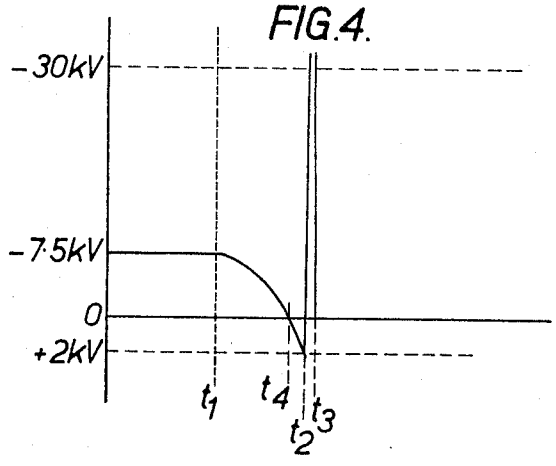


FIG.4.



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FIG.5.

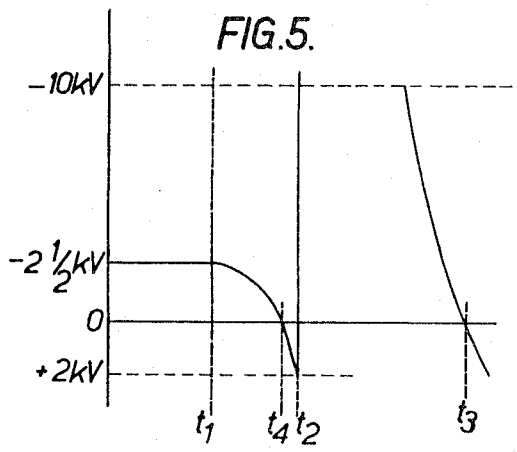


FIG.6.

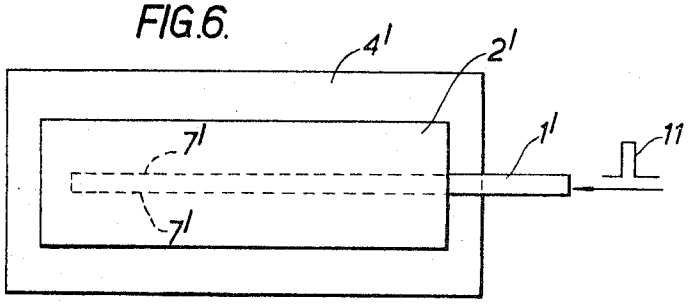
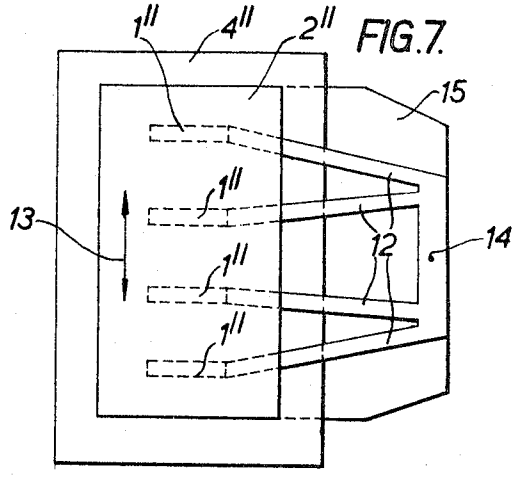
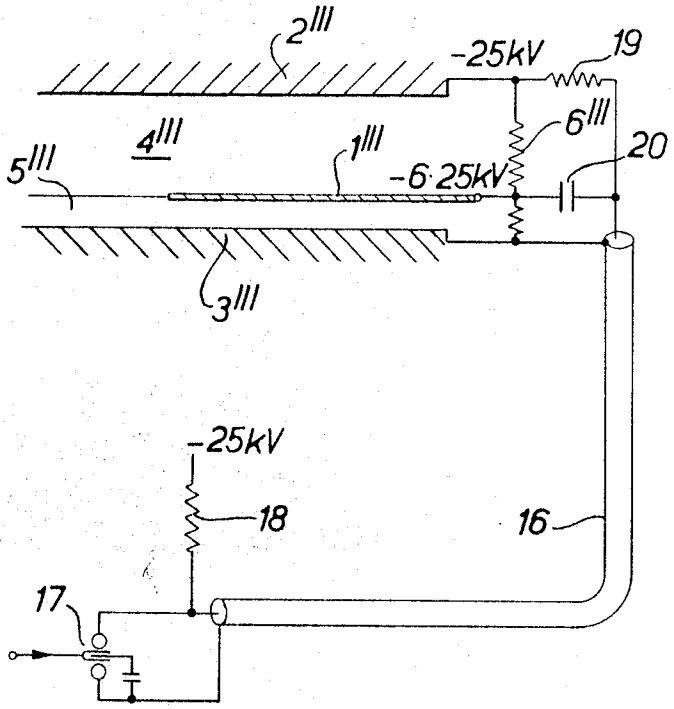


FIG.7.



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FIG.8.



United States Patent Office 3,264,436 Patented August 2, 1966

3,264,436

ELECTRICAL SWITCH HAVING A TRIGGER ELECTRODE WHOSE SHARP EDGES ARE SEALED TO SUPPRESS THE FORMATION OF CORONA

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8 Claims. (Cl. 200—118)

This invention relates to switches of the kind in which a trigger electrode of sheet form is insulatedly sandwiched by solid dielectric material between two further electrodes, the switch being closed by a change in voltage of the trigger electrode which leads to rupture of the dielectric material between the two further electrodes. A switch of this kind is described, for example, in the specification of our copending U.S. application Serial No. 249,853 filed 7th January 1963.

It is one object of the present invention to produce a switch in which the uncertainty as to the instant of "closure" after triggering, known as the "jitter," is reduced to a minimum. This is especially important where it is desired to close several switches as simultaneously as possible.

According to the present invention a switch comprises a thin conducting sheet constituting a trigger electrode insulatedly sandwiched by solid dielectric material between two further electrodes and having a sharp edge located therebetween, at least a substantial proportion of said edge being sealed to said material by a substance of high dielectric strength and resistivity which in operation suppresses the formation of corona at the edge and allows an intense local electric field to form thereat.

Preferably the trigger electrode is a sheet whose length exceeds its width to provide a large edge-to-area ratio.

The dielectric material between the trigger electrode and one said further electrode may be thicker than that between the trigger electrode and the other said further electrode. The thickness ratio may be approximately 3:1, and the switch may include potentiometer means for holding the trigger electrode at such a potential between those of said further electrodes that the static electric field in the dielectric material between said further electrodes is substantially uniform.

The trigger electrode may be made of aluminium foil, the sealing substance may be a silicone grease, and the dielectric material may be polyethylene terephthalate.

To enable the nature of the invention to be more readily understood, and the manner in which it is believed to operate, attention is directed by way of example to the accompanying drawings wherein

FIGURE 1 is a cross-sectional elevation of a switch illustrating the principle of the invention.

FIGURE 2 is a plan view of the switch of FIGURE 1.

FIGURE 3 shows part of the switch of FIGURE 1 to an enlarged scale.

FIGURES 4 and 5 are graphs illustrating the operation and performance of such switches.

FIGURE 6 is a plan view of an alternative form of the invention of FIGURES 1–3.

FIGURE 7 is a plan view of a further alternative form of the invention.

FIGURE 8 is a circuit diagram illustrating a method of triggering.

FIGURE 1 shows a trigger electrode 1, made of 0.00025 inch aluminium foil, sandwiched between two circular copper electrodes 2 and 3 (see FIGURE 2) and insulated therefrom by upper and lower Mylar (R.T.M.) polyethylene terephthalate sheets 4 and 5 respectively constituting solid dielectric material. Typically electrode 1 may be about 0.15–0.2 inch wide and extend about 1 inch between electrodes 2 and 3, although electrodes as narrow as 0.05 inch have been used to reduce the capacitance. The upper sheet 4 is 0.003 inch thick and the lower sheet 5 is 0.001 inch thick. A high impedance potentiometer chain 6 applies to the trigger electrode 1 a potential, —7.5 kv., which is ¼ of the standing potential, —30 kv., between electrodes 2 and 3. Sheets 4 and 5 are thus equally stressed in the static condition.

FIGURE 3 shows an edge 7 of the sheet 1 to a larger scale. It will be seen that, when the sandwich is formed, a space 8 is formed adjacent the edges where sheets 4 and 5 diverge to embrace the electrode 1. In the present switch this space contains silicone grease sealed to the edge of electrode 1. Silicone grease has high dielectric strength and resistivity. Filling is effected by smearing the sheets with grease before forming the sandwich, and then applying pressure to the sandwich with a roller. It is desirable that as much air as possible be excluded from the space adjacent edges 7.

The switch can be operated by connecting electrode 1 to electrode 3 via a switch 9 which will normally be a gas spark-gap or a further switch of the present kind, although a mechanical switch can be used. Because of the capacitance between electrodes 1 and 3 and the inductance of the connections to switch 9, the voltage on electrode 1 falls to zero and then overswings slightly positive. FIGURE 4 shows the variation of potential of electrode 1 with time, switch 9 being closed at time t_1. At time t_2, when the overswing voltage has reached about +2 kv., the equipotential field lines in sheets 4 and 5 are as shown by the dashed lines in FIGURE 1. (Initially, of course, in the static condition, the field was uniform and these lines were equispaced and parallel to the electrodes.) It will be seen that as a result of the sharp edge of electrode 1, and because the mean field across sheet 4 is now greater than across sheet 5, the field lines concentrate around the upper portion of edge 7 to produce an intense local field. In the absence of a solid or liquid sealing substance this field would be relieved by the formation of gaseous corona, but where the edge is effectively sealed to the Mylar by the grease corona cannot for, and a field of sufficient local intensity is created in these regions which is beyond the intrinsic dielectric strength of the Mylar to withstand. The resulting rupture of the Mylar propagates in the direction shown by arrow 10 towards the upper electrode 2, and electrode 1 becomes effectively connected to electrode 2 at time t_2 in FIGURE 4. As a result, the potential of electrode 1 rises rapidly to —30 kv. which is beyond the breakdown voltage (approximately 18 kv.) of sheet 5. Sheet 5 therefore ruptures (at a number of points, owing to the rapid rise of electrode 1), and electrodes 1 and 2 fall rapidly to earth potential at time t_3. As the multichannel ruptures in sheet 5 carry enough energy to vapourise corresponding points on electrode 1, intense shock waves are formed which propagate through sheet 4 and produce multi-channel ruptures therein. Thus the final situation is that multi-channel ruptures exist in both sheets 4 and 5.

The time-scale in FIGURE 4 is of the following order. If the switch 9 is a spark-gap, the time interval between t_1 and t_2 will be about 10 ns.; if the switch 9 is a further switch of the present kind, this interval may be reduced to about 1 ns. The jitter arises from variations in the interval t_4–t_2, owing to imprecision in the precise overswing voltage at which the upper Mylar sheet 4 ruptures. Typically the jitter might be about ¼ ns. when the interval t_1–t_2 is about 1 ns. The actual breakdown time, t_2–t_3, is about $\frac{1}{10}$ ns.

An approximate indication of the order of magnitude of the local field F obtainable at the upper portion of edge **7** is given by

$$F=\frac{V}{a \log b/a}$$

where

V=the overswing voltage between electrodes **1** and **3**
a=radius of edge **7** (taken as half the thickness of sheet **1**)
b=radius of the earth potential field line relative to edge **7** (taken as the thickness of sheet **5**)

Thus putting $V=3$ kv., $a=3\times10^{-4}$ cm. and

$$b=2.5\times10^{-3} \text{ cm.}$$

gives $F=5\times10^{6}$ volts/cm., which is of the same order as the intrinsic breakdown strength of Mylar. In practice the edge **7** is not smoothly rounded but ragged and spiky, so that very much higher field values will be obtained at many points.

Sufficient field enhancement to rupture sheet **4** is sometimes obtained before electrode **1** has gone positive with respect to electrode **3**.

FIGURE 5 shows another mode of operation in which the potential of electrode **2** is only —10 kv., electrode **1** being, as before, at ¼ of this potential, viz. —2.5 kv. In this case rupture of the upper Mylar sheet **4** occurs, as before, when electrode **1** has overswung by about 2 kv. However in this case the potential to which electrode **1** rises, —10 kv., is insufficient to cause immediate rupture of sheet **5** at time t_2. Under these conditions rupture of sheet **5** does take place, but by a shock-wave mechanism caused by partial vapourisation of the aluminium of electrode **1**. This shock-wave rupture is a much slower process than the breakdown of sheet **5** by overvolting as in FIGURE 4, and the interval t_2–t_3 in FIGURE 5 is typically about $\frac{1}{10}$ μsec. i.e. 1000 times longer than in FIGURE 4.

The intense local field necessary to break down the Mylar is only obtainable where the field is not relieved by corona formed at the edge of electrode **1**. It is therefore desirable, for two reasons, that as much as possible of the edge should be sealed to the Mylar sheets by grease **8**, and air excluded therefrom. Firstly, as mentioned above, neither the sharpness of the electrode edge nor the strength of the Mylar are uniform, and the initial breakdown channel occurs at some point where the local breakdown value of the field is first achieved. The more of the edge is sealed, the larger the number of such points and hence the less the jitter. In this connection the use of a long, narrow trigger electrode giving a large edge-to-area ratio is advantageous. Secondly, if much of the edge is unsealed, corona will cause the effective value of the electrode capacitance to increase with time. This acts as a resistive term and may cause damping of the trigger pulse, leading to a reduced rate of rise of trigger voltage and hence to increased jitter. To achieve good sealing, it has been found advantageous to apply the grease (Midland Silicones Type MS4) as a strong solution dissolved in Evostick Cleaner (made by Messrs. Evode Ltd, Stafford, England). The solution is painted on the Mylar sheets and the solvent allowed to evaporate, leaving a film of grease. Other sealing substances have also been used, for example glycerine and unpolymerised araldite.

It will be realised that it is not essential to use switch **9** to trigger the present switch. Triggering can be effected by applying a voltage pulse of the correct polarity to electrode **1**. In the switch of FIGURE 6, which is particularly adapted for pulse triggering, the trigger electrode **1** is a long narrow electrode forming with the adjacent electrodes a parallel strip transmission line to which a steep-fronted triggering pulse **11** is applied. It is found that as the pulse-front travels down the electrode, the phenomena described above take place progressively at the lateral edges of the electrode, causing a plurality of

individual ruptures to occur along its length in a very short time. The plurality of ruptures, and hence of current paths, results in a switch of exceptionally low inductance. Theoretically, 1000 individual paths would give an inductance of only 10^{-14} h.

Unlike the mode of operation described with reference to FIGURE 1, which can be triggered by a pulse having a fairly slow rise-time of the order of a few micro seconds, this transmission-line mode requires a pulse having a fast rise-time of the order of a few nanoseconds for efficient working. Otherwise the damping effect of the successive ruptures rapidly attenuates the travelling wave-front. Similarly, to prevent excessive resistive attenuation very narrow trigger electrodes are less suitable for this mode.

In one example of such a switch, electrode **1'** was 2 ft. long and about 0.25 inch wide. Electrodes **2'** and **5'** were further sheets of 0.00025 aluminium about 2 in. wide stuck to the Mylar sheets, the whole being sandwiched between two solid metal electrodes contacting sheets **2'** and **5'**. This form of construction was used because of the difficulty of providing adequately flat solid electrodes of such length. The fast trigger pulse was provided by a single-unit parallel-strip pulse-generating circuit of the kind shown in FIGURE 1 of copending U.S. application Serial No. 249,873 filed 7th January 1963.

In other embodiments of the present switch, several trigger electrodes **1** may be used rather than the single electrode **1** of FIGURES 1–3. Thus four such electrodes have been used, as shown in FIGURE 7, arranged parallel to one other and connected by strip connectors **12** to a common point **14** at which a mechanical switch (not shown), corresponding to switch **9** in FIGURE 1, is used to make contact with a broad sheet connector **15** connected to the lower electrode (not shown). This four-channel form of switch, which gives a correspondingly lower impedance than a single channel, is only made possible by the present speed of operation, the variation in breakdown times (jitter) at the four electrodes **1''** being less than the propagation time of the corresponding potential changes along the electrode **2''** (in the direction of arrow **13**) between breakdown points.

The form of switch described with reference to FIGURE 1 has been used as the single common shorting switch in a multiunit parallel-strip pulse-generator of the kind shown in FIGURE 2 of copending application Serial No. 249,873, now U.S. Patent 3,225,223. This switch, as shown diagrammatically in FIGURE 8, is triggered by a pulse generated by short circuiting a charged coaxial line **16** at the end remote from the switch, using a spark-gap switch **17**. The line **16** is also used to charge the switch (and the pulse-generator strip-lines (not shown) which electrodes **2'''** and **3'''** are connected to short-circuit), via high-value charging resistors **18** and **19**. On firing switch **17** a positive wave-front of 25 kv. is propagated down line **16** and applied to electrode **1'''** via capacitor **20**. The applied potential is reduced by the capacity-divider effect of capacitor **20** in series with the capacitance between electrodes **1'''** and **3'''**, but is still ample to trigger the switch.

Instead of using switch **17** to generate the positive trigger pulse, such a pulse can be applied to the line **16** from a suitable source via a further capacitor.

In the described embodiments only a thickness ratio of 3:1 between sheets **4** and **5** has been mentioned. This ratio can be varied however, over a wide range, ratios of 3:1 or 4:1 merely being approximately correct to optimise the range of standing voltages over which the switch will operate, without altering the thickness of the sheets. Such switches can be used over a 2:1 variation of voltage retaining fast operation (as described with reference to FIG. 4), and a 3:1 variation if some delay can be tolerated (as described with reference to FIG. 5). The limitation is that the thinner sheet (sheet **5**) must be thin enough to be ruptured by the increase in voltage

between electrodes **1** and **3** when the former rises to the voltage of electrode **2**, without being ruptured by the trigger pulse itself. Sheets **4** and **5** need not be of different thickness, however, and satisfactory operation has been obtained with a switch of the kind shown in FIGURE 7 using equal thickness sheets of Mylar (0.001 inch), with an applied voltage of —10 kv., the four 0.0002 inch aluminium trigger electrodes **1** being held at —5 kv. by a high-resistance potential divider; each of these electrodes was 3 in. long and ¼ in. wide.

Switches using different thickness of dielectric sheet have been used from 3 kv. up to 1 mv. At the high-voltage end of the range polyethylene was used instead of Mylar because of the availability of thicker sheet in this material, and pulse charging was employed to avoid flash-over difficulties. Methylmethacrylate (Perspex) sheet has also been used, and different materials have been used for the two sheets **4** and **5**.

The switch could be assembled by moulding the electrode **1** between sheets of thermosetting dielectric material. In this case the dielectric material would itself contact the edges of the electrode and constitute the sealing substance.

It should also be noted that it is not necessary that there should be a potential difference between the two outer electrodes, i.e. the electrodes other than the trigger electrode, and the switch can thus be used as a clamp switch. In this case the thicknesses of sheets **4** and **5** are made equal. As there is no voltage across the outer electrodes in the static condition, a more powerful triggering source is necessary to provide a positive pulse of sufficient energy to rupture both sheets.

In all the embodiments, the described results are only achieved by using a positive triggering pulse. In FIGURE 1, for example, the switch does not operate if the polarities shown are reversed. However, it is normally possible to arrange the external circuit so that the desired polarity across the switch is obtained.

The foregoing theory of operation is put forward as an explanation of the results obtained, but the inventors do not wish to be bound thereby.

We claim:

1. A switch comprising a thin sheet of conducting material constituting a trigger electrode, two further electrodes sandwiching said trigger electrode in face-to-face relationship therewith and overlapping an edge-portion thereof, said further electrodes being insulatedly spaced from said trigger electrode by solid dielectric material, a connection to said trigger electrode extending beyond said solid dielectric material, said edge-portion of the trigger electrode being sharp therearound, and a substance of high dielectric strength and resistivity sealing said sharp-edge-portion to said dielectric material to suppress the formation of corona at said edge-portion and to allow an intense local electric field to form at said edge-portion when the switch is in operation.

2. A switch as claimed in claim **1** wherein the trigger electrode is a sheet whose length exceeds its width to provide a large edge-to-area ratio.

3. A switch as claimed in claim **1** wherein the dielectric material between the trigger electrode and one said further electrode is thicker than that between the trigger electrode and the other said further electrode.

4. A switch as claimed in claim **3** wherein the thickness ratio is approximately 3:1.

5. A switch as claimed in claim **1** wherein the trigger electrode is made of aluminium foil.

6. A switch as claimed in claim **1** wherein the sealing substance is a silicone grease.

7. A switch as claimed in claim **1** wherein the dielectric material is polyethylene terephthalate.

8. A switch as claimed in claim **1** wherein the dielectric material between the trigger electrode and each of the further electrodes is of equal thickness.

References Cited by the Examiner

UNITED STATES PATENTS

1,155,415	10/1915	Greene	313—243
2,050,364	8/1936	Morton	200—118
2,198,101	3/1940	Young et al.	200—118
2,295,379	9/1942	Beck et al.	313—268
2,695,348	11/1954	Matthysse et al.	200—121
2,724,793	11/1955	Fisher	200—118
2,750,470	6/1956	McBride	200—127
2,936,390	5/1960	Melhart	313—306 X
3,046,436	7/1962	Cavalconte	313—268
3,149,263	9/1964	Rabus	315—36 X
3,225,223	12/1965	Martin.	

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