April 9, 1968 E. LANGBERG ETAL 3,377,576

GALLIUM-WETTED MOVABLE ELECTRODE SWITCH

Filed May 3, 1965

2 Sheets-Sheet 1

Fig. 3.

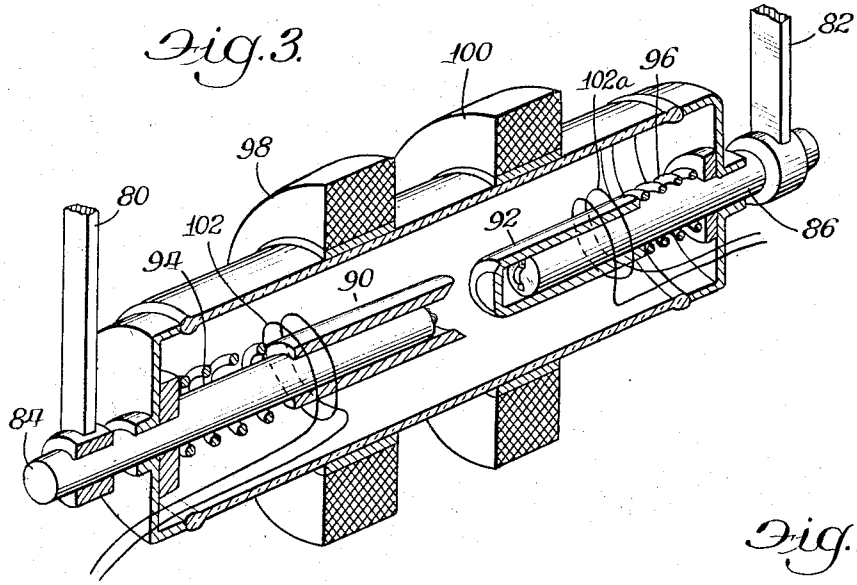


Fig. 2.

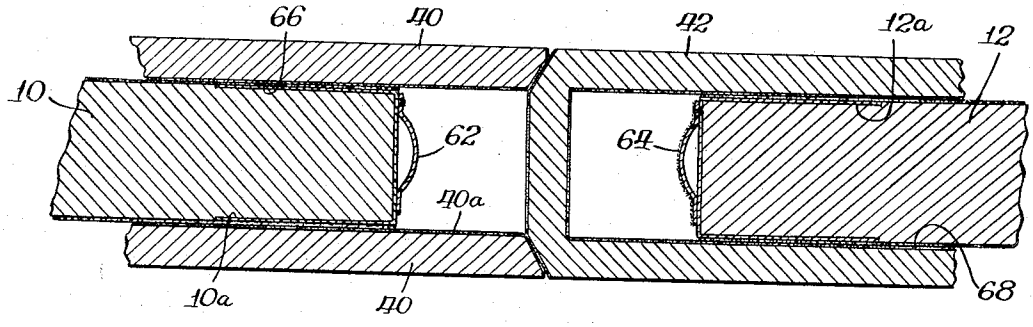
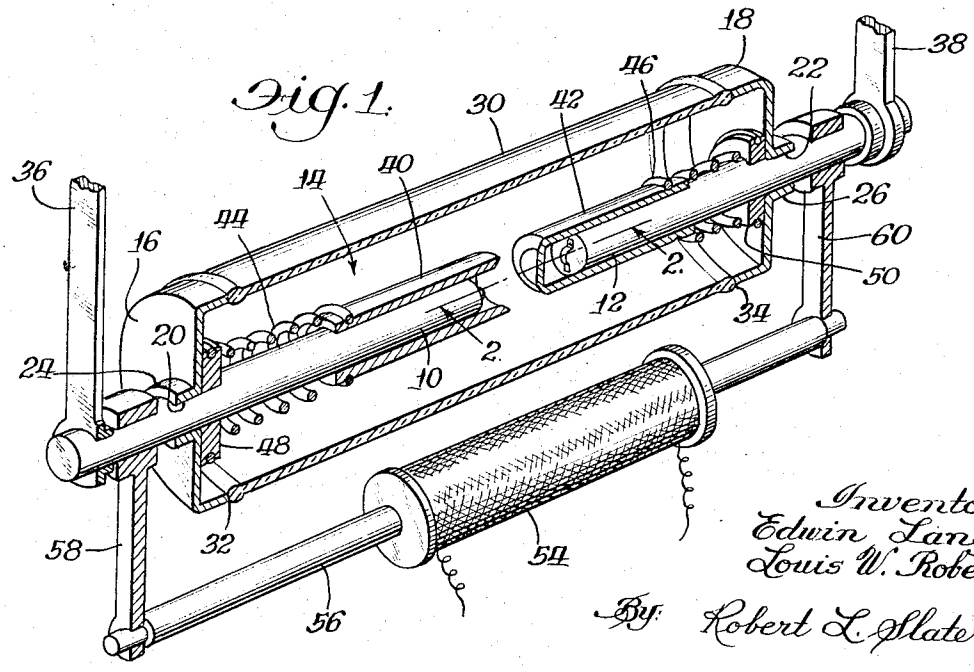


Fig. 1.



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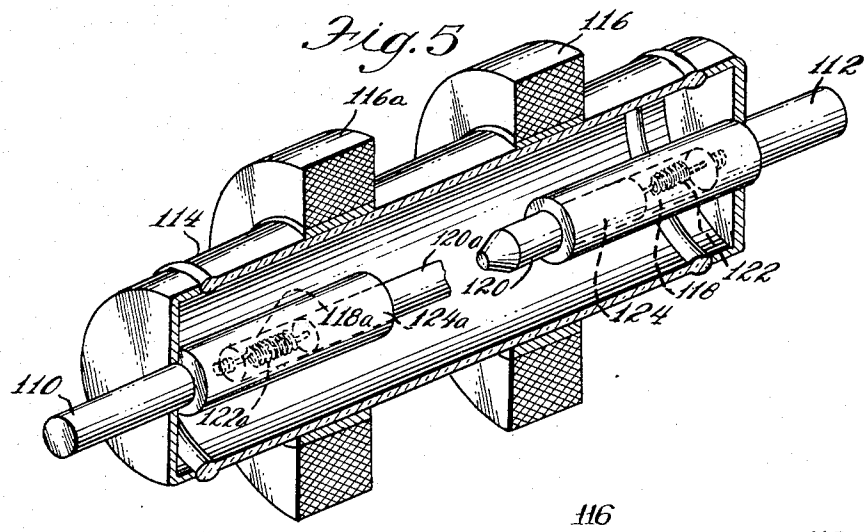
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GALLIUM-WETTED MOVABLE ELECTRODE SWITCH

Filed May 3, 1965 2 Sheets-Sheet 2

Fig. 5



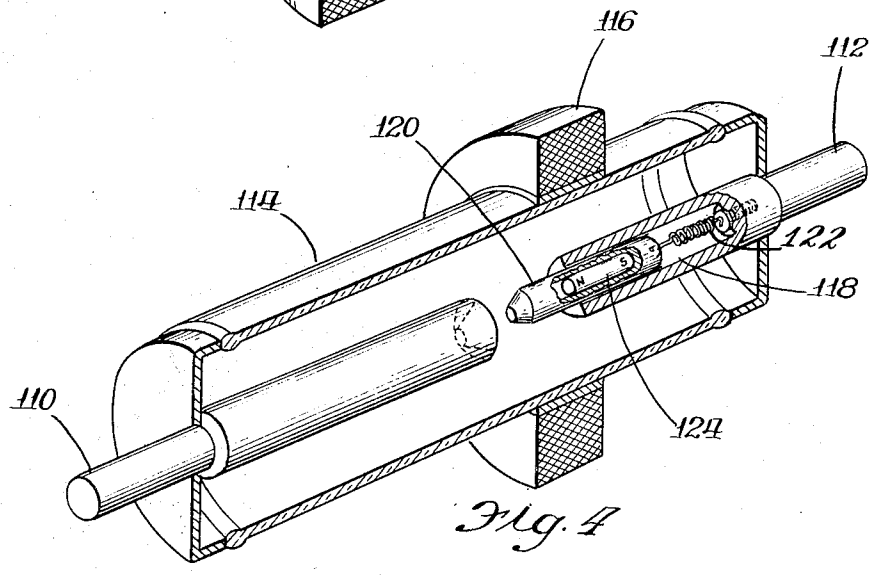


Fig. 4

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GALLIUM-WETTED MOVABLE ELECTRODE SWITCH

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6 Claims. (Cl. 335—196)

This invention pertains to electrical switching devices; more particularly, it pertains to large power capacity switches which embody arc suppressing features.

Switches in high voltage large current capacity service are subject to arcing between the open switch electrodes. Such arcing phenomenon itself causes undesired RF signals, increases switching time, disturbs line balance heightening undesired line transients, and is destructive of the switching equipment per se.

The "hold-off" voltage of a switch is defined as the voltage which the switch is capable of withstanding without breakdown or arcing between electrodes when the switch is in an open position. The breakdown phenomenon is caused primarily by ionization of gas molecules in the electric field between the electrodes. A second breakdown phenomenon, which may be described as electron field emission from the cathode switch eledtrode, occurs at higher voltages and also acts to limit switch hold-off voltage.

At the instant of the contact electrode's separating or closing, when the separation distances are 10^{-4} cm. or less, a very large valued electric field is created. The cathode, whether it be a solid or liquid electrode, emits some ionized metal vapor along with substantial thermionic and field emission electron flow sufficient to initiate arcing. If the vapor pressure of the electrode metal is high enough, the arc initiated by the breaking of the contacts will continue even after the electrodes are separated to their full distances.

Switch arcing pits solid metal electrodes by melting small regions of the electrode surfaces and vaporizing or splattering the molten electrode material. The pitted contact electrodes exhibit during switching action increased field electron emission due to regions of intense concentration in the electrical field above the roughened pitted electrode surfaces. The pitted contact electrodes have higher junction resistance because of the reduced area of contact. Excessive electrode pitting renders switches useless due to heightened electron emission, overheating and increasingly inefficient switching action.

Liquid metal or self-healing switch electrodes offer some advantage over solid metal electrodes in that electrode pitting and consequent electrode deterioration are avoided. Heretofore, mercury has by far been the preferred liquid metal electrode substance for switch applications. While mercury is normally in the liquid state through the range of ambient temperatures, the vapor pressure of mercury is much too high for use with high voltage systems. The presence of mercury vapor increases arcing due to gas ionization between the electrodes. Despite the apparent advantage of liquid metal electrodes or self-healing electrode switches, earlier workers in high power capacity switch technology have not disclosed practical self-healing electrode switches for high voltage, large current capacity service.

One technique extensively employed to increase switch hold-off voltage and to suppress switch arcing is to encase the contact electrodes and the region therebetween in an evacuated envelope. The contact electrodes are moved into and out of contact by mechanical linkages which interconnect through the vacuum seal. A remarkably reduced arcing between contact electrodes may be achieved by reducing the presence of ionizable gas in the envelope

to a pressure below 10^{-6} mm. of Hg. As a result, gas ionization breakdown is greatly reduced, however, the field emission arcing effects remain unchanged or may even increase in an evacuated environment. Thus, solid electrode pitting is not controlled by use of vacuum alone.

Although operation of a high power switch in vacuum achieves a marked reduction in electrode arcing, the mechanical motion of the electrodes in vacuum introduces heretofore unsolved mechanical problems. Mechanical linkages interconnected through vacuum seals are notoriously troublesome. Previously available mechanical linkages operated through vacuum seals exhibit only short useful life expectancy.

Still another problem exists in actuating mechanical linkages to close or to open vacuum encased power switches. The mechanical movement of one metallic member against another in high vacuum under conditions of large current flow through the moving parts has been a continuous source of switch malfunction. Lubrication of the moving parts in a vacuum is restricted to very low vapor pressure substances. The configuration of the switch linkages often requires that the lubricant be conductive for the switch to function properly. Heretofore, none of the earlier high voltage large capacity vacuum switches has satisfactorily avoided, with practical inexpensive mechanical means, the disadvantage of dry non-lubricated sliding junctions between current conducting switch linkage elements.

There remains, then, an unfulfilled need for a large current capacity, high hold-off voltage switch which simultaneously embodies the advantages of self-healing electrodes, high vacuum environment suppression of ionized gas arcing and fully lubricated mechanical motion of the switch electrodes.

Accordingly, one object of the present invention is to provide an improved high hold-off voltage, large current capacity switch.

Another object of this invention is to provide a high voltage vacuum switch with self-healing contact electrodes.

Still another object of this invention is to provide a large power capacity, high voltage vacuum switch having lubricated sliding mechanical contacts.

Another object of this invention is to provide in a high voltage vacuum switch system an improved means of communicating switch motion through a vacuum seal.

Another object of this invention is to provide a high voltage, large power capacity switch with a superior arc suppression capability.

Still another object of this invention is to provide a long-life, highly reliable high voltage, high power capacity switch.

These and other objects and advantages of our invention will be evident from the following illustrations, specification and claims.

FIGURE 1 is a partly cut away view of a first preferred embodiment of our invention.

FIGURE 2 is a cross section view of a fragment of the embodiment of our invention shown in FIGURE 1.

FIGURE 3 is a partially cut away view of a second preferred embodiment of our invention.

FIGURE 4 is a partially cut away view of a variation of the embodiment of our invention illustrated in FIGURE 3.

FIGURE 5 is a partially cut away view similar to FIGURE 4 but showing two sliding electrodes.

Referring now to the figures, a first preferred embodiment of our invention illustrated in FIGURES 1 and 2 is adapted for interruption of high voltage, large current capacity power mains. Stationary switch electrodes **10** and **12** are mounted coaxially in a spaced relationship within a gas tight electrically insulating envelope **14**. The

envelope is comprised of metal end caps **16** and **18**, each having a central aperture **20** and **22** through which the stationary electrodes **10** and **12**, respectively, are mounted. The apertures **20** and **22** are each provided with a flange **24** and **26** that provides a surface suitable for metallurgically bonding to the respective stationary electrodes **10** and **12**.

A high dielectric material cylindrical tube **30** is sealed to the edges **32** and **34**, respectively, of the end caps **16** and **18** and provides the side walls of the gas tight envelope.

The electrical power main bus bars **36** and **38** are connected, respectively, by conventional mechanical means to the portion of the stationary electrodes **10** and **12** which extend outside the gas tight envelope **14**. In the embodiment shown in FIGURE 1, the stationary electrodes **10** and **12** are inserted through close fitting apertures in the bus bars **36** and **38**.

Movable electrodes **40** and **42**, comprised of high relative magnetic permeability metallic cylinders, are each respectively mounted coaxially over the stationary electrodes **10** and **12**. The movable electrodes **40** and **42** are sized to readily slide coaxially along the stationary electrodes with only a small clearance. In addition, the movable electrodes are sufficiently long so that when extended coaxially beyond the respective stationary electrodes **10** and **12**, the two movable electrodes **40** and **42** will readily make contact with one another in the space between the stationary electrodes without slipping off the supporting stationary electrodes; and when the movable electrodes are retracted from the ends of the stationary electrodes, a substantial space exists between the two ends thereof. The relative position of the two movable electrodes **40** and **42** in the closed switch position is illustrated in FIGURE 2, and the open switch position is illustrated in FIGURE 1.

The movable electrodes **40** and **42** are normally held in the open switch positions, such as illustrated in FIGURE 1, by means of two tension springs **44** and **46** respectively mounted coaxially over the stationary electrodes **10** and **12**. The spring **44** is connected at a first end to the moving electrode **40** and at the second end rigidly connects by means of a collar **48** to the end cap **16**. A groove is provided in the movable electrode **12** and in the collar **48** into which one coil at each end of spring **44** rests for purposes of securing the spring at either end. Similarly, the moving electrode **42** is normally held in a retracted or open switch position by means of the spring **46** one end of which is fixed by a groove, shown in the illustrations, to the end cap **18** by means of rigidly mounted collar **50**.

FIGURE 2 illustrates the detailed structure of the movable electrodes **40** and **42**. The fixed electrodes **10** and **12** are made of copper and have at the forward tips a flame spray tungsten coating **10***a* and **12***a*. The movable electrodes **40** and **42** are made of ferromagnetic material such as 420 stainless steel, a high magnetic permeable stainless steel. The movable electrodes are similarly provided with flame spray tungsten coatings **40***a* and **42***a* on those surfaces through which current may be required to pass. The tungsten coating furnishes a high wear resistant surface to the underlying copper electrode. The electrical resistivity of tungsten is much greater than that of copper, however the flame spray coating may be as shallow as a few thousandths of an inch. Hence, in the arrangement shown in the illustrations, a relatively large area of the tungsten coating is available through which the current passes and only negligible resistances losses are encountered.

A solenoid **54** is mounted exterior of the envelope **14** about a high magnetic flux capacity core **56**. The core **56** is in turn mounted between two magnetic flux conductors **58** and **60** which in turn are connected respectively to the stationary electrodes **10** and **12**. When a direct current is passed through the solenoid coil **54**, a magnetic flux is

induced in the core **56** and transmitted through the magnetic flux conductors **58** and **60** to the stationary electrodes **10** and **12** and finally to the movable electrodes **40** and **42**. The polarity of the magnetic field transmitted to the first movable electrode **40**, by the above-described arrangement, will always be opposite to that transmitted to the second movable electrode **42**; thus, a strong magnetic field of opposite polarity may be induced between the two movable electrodes. A magnetic field of suitable strength will draw the movable electrodes together, overcoming the spring tension which holds the two electrodes in normally separated position.

With the application of a large current to the solenoid **54**, the movable electrodes **40** and **42** may be brought together with considerable force. To prevent damage to the stationary electrode mountings, cushion springs **62** and **64** are mounted at the ends of the stationary electrodes **10** and **12** to absorb the impact momentum incurred by the magnetic field force closing and the spring loaded opening of the movable electrodes.

Large current at high voltage must pass through the stationary electrodes **10** and **12** and the moving electrodes **40** and **42**. By placing a film **66** and **68** of liquid gallium metal over the stationary electrodes, a low viscosity, low vapor pressure, high conductivity contact surface is maintained between the sliding metal electrodes. The gallium metal film provides a low friction lubricant having high conductivity and readily "healed" electrode action. Moreover, the vapor pressure of liquid gallium metal is lower than that of solid silver and compares favorably with copper alloys. Accordingly, vacuum of 10^{-6} mm. Hg or better may be readily maintained within the envelope **14**. The physical properties of gallium metal will not be described in detail here, but the reader is referred to the numerous places in the literature which set forth the full physical data.

By the above-described switch, large current at high voltages may be readily and economically interrupted without appreciable arcing between electrodes or without excessive wear between sliding electrode members.

Gallium melts at 30° C. Only a small quantity of heat need be applied to the switch before start-up to assure that the gallium metal is melted and is lubricating the moving electrode parts. After being in high voltage, large current service for a short period of time, ample heat is normally generated within the electrodes to assure liquification of the metallic gallium lubricant and electrode surfaces.

Referring now to FIGURE 3, a variation of our invention shown in FIGURES 1 and 2 is illustrated. The actuation of the movable electrodes in the embodiment shown in FIGURE 3 is controlled by solenoidal magnetic fields applied directly to the movable electrodes, as will be readily understood from the following description.

Power main bus bars **80** and **82** terminate on fixed electrodes **84** and **86**. The fixed electrodes are elongated and mounted in spaced relationship but in coaxial alignment. A vacuum tight envelope **88** is hermetically sealed about an intermediate point on fixed electrodes **84** and **86** so that a portion of each electrode extends into the interior of the envelope **88**, which is made of high dielectric, nonmagnetic material. The electrodes may be made of any low resistance metal, copper being preferred. Movable electrodes **90** and **92**, comprised of hollow cylindrical tubes, are fitted over the fixed electrodes respectively and adapted to readily slide therealong. The movable electrodes are made of a ferromagnetic, electrically conductive metal such as magnetic stainless steel. Coil springs **94** and **96** are mounted over the respective fixed electrodes and secured at each first end of the respective springs to a movable electrode and at the respective second ends of the springs to the respective fixed electrodes. The coil springs **94** and **96** will normally hold the movable electrodes **90** and **92** in retracted positions; that is, out of contact with one another.

Solenoids **98** and **100** are positioned exterior of the

envelope **88** and transversally about the portion of the fixed electrodes **84** and **86** which extend into the interior of the envelope **88**.

A film of liquid gallium metal is coated onto the fixed electrodes **84** and **86** and onto the surfaces of the movable electrodes **90** and **92**. The gallium metal readily wets other metal surfaces and liquefies at 30° C. A small quantity of heat from an external source or from a heating element **102**, inserted permanently within the envelope, may be required to liquefy the gallium metal electrode surfaces and lubricant prior to use of the switch.

The solenoids **98** and **100** are powered by direct current, the polarity of which determines the polarity of the resultant magnetic field. If the polarity of the solenoid magnetic fields from coils **98** and **100** are opposite in sign, the two movable electrodes **90** and **92** will have induced therein magnetic fields of opposite polarity and exert a strong attraction upon one another. Such attraction between the movable electrodes will abruptly close the switch. The coil springs **94** and **96** separate the movable electrodes, thereby opening the switch upon the removal of the solenoidal magnetic fields.

FIGURE 4 illustrates still another embodiment of our invention. Two nonmagnetic, fixed electrodes **110** and **112** are mounted to extend into a high dielectric nonmagnetic material envelope **114**. The fixed electrodes are mounted in coaxial alignment but in a spaced arrangement so that a space is provided between the fixed electrodes within the envelope. The envelope is preferably vacuum tight and capable of maintaining vacuum of 10^{-6} mm. Hg or greater.

A solenoid **116** is mounted on the exterior of the envelope **114** and when energized is positioned to induce a magnetic field within the envelope having a fixed polarity.

The fixed electrode **112** is provided with a cylindrical hollow recess **118** into which a movable electrode **120** may be inserted. A coil tension spring **122** secured at the end of the recess **118** is inserted into the recess **118** beneath the movable electrode **120**. The second end of the spring **122** is secured to the end of the movable electrode as shown in the illustration.

The movable electrode **120** is hollow and made of a nonmagnetic conducting metal such as copper. Sealed mechanically within the electrode **120** is a permanent elongated maget **124** positioned so that the permanent magnet field is coaxial with the movable electrode **120**. The permanent magnet may be made of any "hard" ferromagnetic material.

A film of gallium metal applied to the movable electrode **120** wets the exterior of the electrode **120** and the surfaces of the recess **118**. The gallium film when liquefied provides a low friction lubricant suitable for relatively high vacuum environment between the moving electrode **120** and the surfaces of the fixed electrode **112**. Moreover, the liquid gallium film provides a highly conductive self-healing interelectrode contact surface between the moving electrode parts.

When the solenoid **116** is energized, the resulting magnetic field reacts on the permanent magnet **124** causing the movable electrode **120** to slide partially out of the recess **118** and make contact with the first fixed electrode **110**. This action closes the switch. When the solenoid **116** is de-energized, the movable electrode **120** is abruptly retracted by the coil spring **122**. This latter action opens the switch. A variation of FIGURE 4 is set forth in FIGURE 5. As shown, FIGURE 5 illustrates a second sliding electrode controlled by a second solenoid, the parts of which are designated by the same numerals as the sliding electrode and solenoid in FIGURE 4 but with a suffix *a*. The structure and function of each of the two sliding electrodes in FIGURE 5 are similar to the structure and function of the single sliding electrode assembly shown in FIGURE 4.

As a variant of this embodiment, the fixed electrode

110 can be replaced with a second sliding electrode assembly including a solenoid, such assembly being similar to the single assembly illustrated. The tips of the two sliding electrodes will preferably be formed into complementary shapes for proper physical contact. In the resulting switch, the two movable electrodes will readily make contact with one another in the space between the stationary electrodes without slipping out of the recesses therein; and when the movable electrodes are retracted from the ends of the stationary electrodes, a substantial space exists between the two ends thereof.

Numerous variations and alternative combinations of the detailed construction of embodiments of our invention fall within the scope of our invention. The above-described and illustrated preferred embodiments of our invention are intended as merely illustrative of our invention, the scope of which is set forth in the following claims.

We claim:

1. An electrical switch comprised of an evacuated high dielectric material envelope; a first and a second elongated fixed electrode mounted in coaxially aligned spaced relationship within the envelope; a first and a second hollow cylindrical sliding electrode mounted, respectively, coaxially about the first and second fixed electrodes, the sliding electrodes being made of relatively high magnetically permeable material; a lubricating self-healing film of gallium metal wetting the electrode surfaces; and solenoids mounted exterior to the envelope and transversally of the fixed electrodes; whereby, electrical contact between the fixed electrodes may be made and broken by alternately axially moving the sliding electrodes into and out of contact in the space between the fixed electrodes.

2. An electrical switch comprised of an evacuated high dielectric material envelope; a first and a second elongated fixed electrode mounted in coaxially aligned spaced relationship within the envelope; a first and a second sliding electrode mounted, respectively, to and coaxially with the first and second fixed electrodes, the sliding electrodes having means for mounting a permanent magnetic polarity; a lubricating self-healing film of gallium metal wetting the electrode surfaces; heating means for liquefying the gallium metal mounted within the envelope; and magnetic means mounted exterior of the envelope for positioning the sliding electrodes along the fixed electrodes; whereby, electrical contact between the fixed electrodes may be made and broken by moving the sliding electrodes into and out of contact in the space between the fixed electrodes.

3. An electrical switch comprised of an evacuated high dielectric material envelope; a first and a second elongated fixed electrode mounted in coaxially aligned spaced relationship within the envelope, the first such fixed electrode being characterized by having a hollow central recess having an aperture opening into the space between the fixed electrodes; a sliding cylindrical electrode slidably mounted within the recess, such sliding electrode being of relatively high magnetically permeable material; a lubricating self-healing film of gallium metal wetting the electrode surfaces; and magnetic means for positioning the sliding electrode along the first fixed electrode and relative to the second fixed electrode, being mounted to the envelope; whereby electrical contact between the fixed electrodes may be made and broken by alternately moving the sliding electrode into and out of contact with the second fixed electrode.

4. An electrical switch comprised of an evacuated high dielectric material envelope; a first and a second elongated fixed electrode mounted in coaxially aligned spaced relationship within the envelope; a first and a second sliding electrode having a hollow tubular configuration mounted respectively coaxially on the first and second fixed electrodes, the sliding electrodes being made of relatively high magnetically permeable material; a lubricating self-heal-

ing film of gallium metal wetting the electrode surfaces; and magnetic means for positioning the sliding electrodes along the fixed electrodes; whereby, electrical contact between the fixed electrodes may be made and broken by alternately axially moving the sliding electrodes into and out of contact in the space between the fixed electrodes.

5. An electrical switch comprised of an evacuated high dielectric material envelope; a first and a second elongated fixed electrode being mounted in coaxially aligned spaced relationship within the envelope and having each a hollow central recess with an aperture opening into the space between the fixed electrodes; a first and a second sliding electrode having cylindrical rod configuration, the first and second sliding electrodes being mounted respectively coaxially within the first and second fixed electrodes, the sliding electrodes being made of relatively high magnetically permeable material; a lubricating self-healing film of gallium metal wetting the electrode surfaces; and magnetic means for positioning the sliding electrodes along the fixed electrodes; whereby, electrical contact between the fixed electrodes may be made and broken by alternately axially moving the sliding electrodes into and out of contact in the space between the fixed electrodes.

6. An electrical switch comprised of an evacuated high dielectric material envelope; a first fixed electrode, and a second fixed electrode, the second fixed electrode having

hollow cylindrical tubular configuration, the first and second fixed electrodes being mounted in coaxially aligned spaced relationship within the envelope; a sliding electrode mounted coaxially within the second fixed electrode, the sliding electrode being made of relatively high magnetically permeable material; a lubricating self-healing film of gallium metal wetting the electrode surfaces; and magnetic means for positioning the sliding electrode along the second fixed electrode; whereby electrical contact may be made and broken by alternately axially moving the sliding electrode into and out of contact with the first fixed electrode in the space between the fixed electrodes.

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