March 19, 1957 P. B. REED, JR 2,786,111

ELECTROSTATIC RELAY

Filed Dec. 16, 1952

Fig. 1.

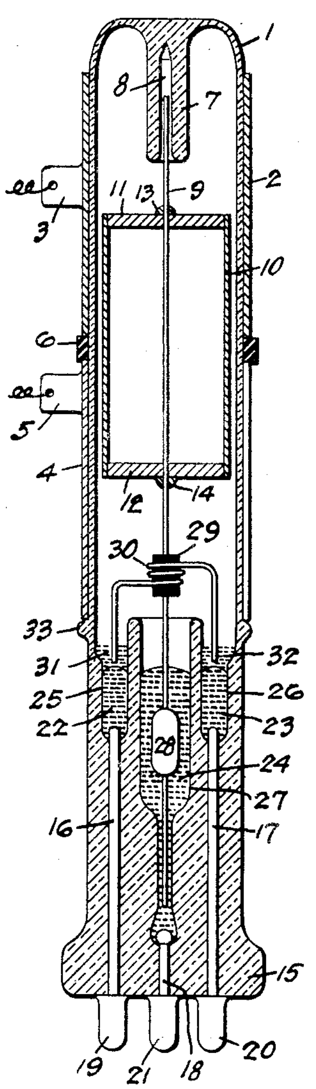


Fig. 3.

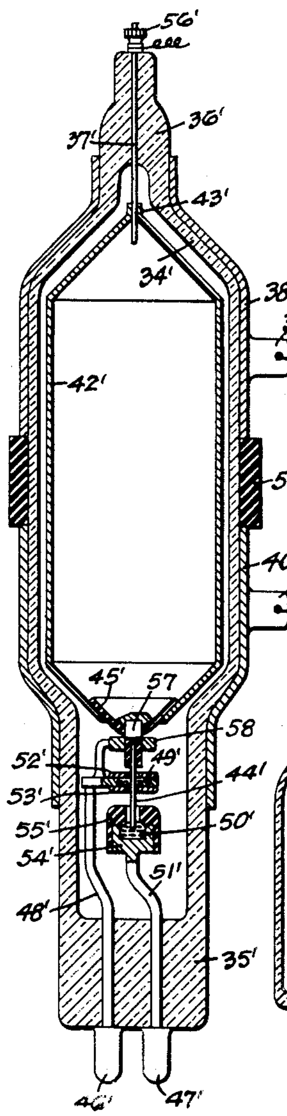


Fig. 2.

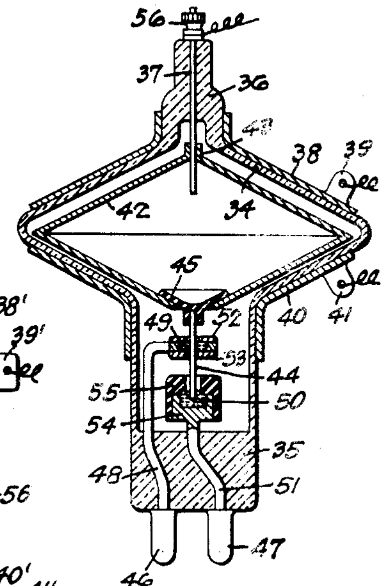
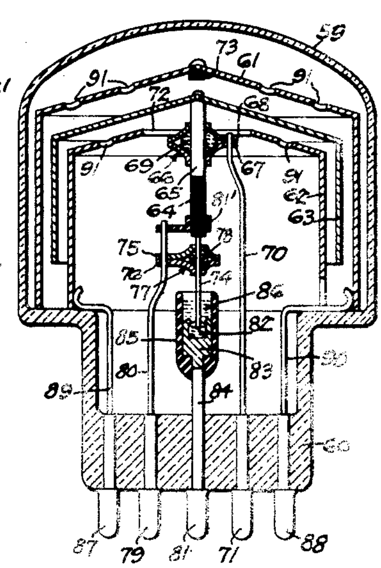


Fig. 4.



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ELECTROSTATIC RELAY

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8 Claims. (Cl. 200—87)

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The invention described herein may be manufactured and used by or for the Government for governmental purposes without the payment to me of any royalty thereon.

The present invention relates to a new and improved, high-speed relay, which is economical and reliable in operation. More particularly the present invention relates to a novel, high-speed, electrostatic relay, wherein an actuator plate is positioned in an electrostatic field whereby contact is made or broken by movement of the actuator plate depending on the charge applied thereto.

Accordingly it is an object of the present invention to provide a novel, high-speed relay which is reliable in operation.

Another object of the present invention is to provide a high-speed relay which eliminates the need for a cathode heater element, and the consequence, large current supply ordinarily required for vacuum tubes.

A further object of the present invention resides in the sturdiness of structure and ease of manufacture of the high-speed relay in accordance with the present invention.

Another object of the present invention is to provide a single-unit, high-speed relay which can be used as both open and closed contact relay, which is faster in action than a solenoid relay, and which is more reliable and longer-lived than either solenoid relay or vacuum tube relay.

A further object of the present invention is to provide a fast-acting, electrostatic relay which is comparatively inexpensive, and which possesses negligible inductance and exhibits only very small capacitance.

A still further object of the present invention is to provide a high-speed relay, which utilizes the forces exerted on a charged plate in an electrostatic field to make or break the contacts thereof, and wherein a short-circuit of the elements is virtually impossible.

These and other objects and advantages of my invention will become obvious from the following description when taken together with the drawing which shows for purposes of illustration only several preferred embodiments of the relay in accordance with the present invention, and wherein:

Figure 1 is a cross sectional view of one embodiment of the relay in accordance with the present invention having a cylindrical actuator plate;

Figure 2 is a cross sectional view of a modified form of the relay of Figure 1 having a double-cone actuator plate in accordance with the present invention;

Figure 3 is a cross sectional view of still another modification of the relay of Figure 2;

Figure 4 is a cross sectional view of a further modification of the relay of Figure 3 in accordance with the present invention.

The requirement for relays which operate reliably for use with digital computers, for example, is well-known. Conventional solenoid relays are relatively slow in operation, and have the additional disadvantage of consuming current. Vaccum-tube relays also consume current, pro-

duce heat, and are of finite life and reliability. The disadvantages and shortcomings of the aforementioned types of relays are eliminated by the electrostatic relays in accordance with the present invention wherein an actuator plate is moved between two charge plates producing an electrostatic field by placing appropriate charges on the charge plates whereby the motion of the actuator plate makes or breaks the contacts.

Referring now more particularly to the drawing wherein like reference numerals are used to designate like elements in the various figures thereof, numeral **1** designates the glass envelope of the electrostatic relay of Figure 1 in accordance with the present invention. Affixed to or supported by the outside of glass envelope **1** is upper charge plate **2** having an upper charge plate connector **3**. Lower charge plate **4** having a lower charge plate connector **5** is affixed to or supported by the outside of glass envelope **1** below upper charge plate **2** from which it is separated by insulating spacer **6**. Glass envelope **1** is formed at its top with an inwardly protruding extension **7** having a substantially central bore **8** in which the upper portion of axial shaft **9** is guided during movement thereof. Cylindrical actuator plate **10** is secured to axial shaft **9** by means of upper and lower spacer discs **11** and **12** which are mechanically and electrically connected to plate **10** and which comprise each a central bore to receive axial shaft **9**. Spacer discs **11** and **12** are secured to axial shaft in any conventional manner as by solder joints **13** and **14** which assure mechanical as well as electrical connections therebetween. Since spacer discs **11** and **12** as well as axial shaft **9** and actuator plate **10** are made of material which is an electrical conductor, a continuous, electrical circuit is established between axial shaft **9** and cylindrical actuator plate **10**.

The lower part of glass envelope **1** is provided with a base **15** and includes three bores sufficiently large to receive connecting wires **16**, **17** and **18** for connecting contact pins **19**, **20** and **21** with mercury pools **22**, **23** and **24** respectively, which are stored in appropriate counterbore portions **25**, **26** and **27**. A float **28** immersed in mercury pool **24** is attached to the lower end of axial shaft **9**. Intermediate float **28** and actuator plate **10**, axial shaft **9** is provided with a cylindrical insulator **29** fastened thereto for axial movement therewith. Contact filament wire **30** is wound over insulator **29** and is shaped in such a way as to establish an electrical circuit betwen mercury pools **22** and **23** when the actuator plate **10** moves downward, whereby contact pins **19** and **20** are electrically connected. Spark-quenching oils **31** and **32** may be provided on top of mercury pools **22** and **23** to quench arcing during breaking of contact when actuator plate **10** moves upward. The glass envelope **1** may be further provided with a supporting bulge **33** against which charge plate **4** may rest. The interior of the tube may be partially evacuated or be filled optionally with an inert gas.

In the operation of the electrostatic relay of Figure 1 which is similar to the principle of the electroscope the cylindrical actuator plate **10**, which is centered between the upper charge plate **2** and lower charge plate **4** having opposite, high voltages applied thereto through terminals **3** and **5**, moves axially when a charge is placed on it through actuator contact pin **21**, via central mercury pool **24** and axial shaft **9**.

Such axial motion is also imparted to insulator **29** and therewith to filament wire **30**, which makes or breaks the electrical contact between mercury pools **22** and **23**, thereby effectively connecting or disconnecting contact pins **19** and **20**. Any arcing is suppressed by spark-quench oil pools **31** and **32**. The weight of the moving parts is carried by float **28** immersed in mercury pool **24**. Since float **28** carries the exact weight of the moving parts, it thereby permits the relatively small electrostatic forces produced by the charges on charge plates **2** and **4** and actuator plate **10** to produce relatively large movements. If axial shaft **9** is made of small diametric dimension at the point of contact with mercury pool **24**, it produces the effect of suspending the entire system as by a very weak spring. And since the mass of the moving parts may be made relatively small, the operation of the electrostatic relay in accordance with the present invention can be made to close and open its contacts in a relatively short time.

The modification of the electrostatic relay shown in Figure 2 comprises a glass envelope **34** in the form of a doube-cone having a base portion **35** and an upwardly extending apex portion **36** having a central bore to receive fixed axial shaft **37**. Upper actuator charge plate **38** which comprises a connecting terminal **39** is conical in shape and follows the outer contours of the upper portion of glass envelope **34** by which it is supported; lower actuator charge plate **40** which comprises a connecting terminal **41** is also conical in shape and follows the outer contours of the lower portion of glass envelope **34** by which it is also supported. The actuator plate **42** consists of two cones, base-to-base, and is slidably supported at its upper end by fixed axial shaft or pin **37** over which the actuator plate **42** slides while maintaining electrical continuity therebetween by means of the small cylindrical section **43** formed by the apex of the upper cone of actuator plate **42** and extending upwardly therefrom. The apex of the lower cone of actuator plate **42** is supported by means of contact filament **44** which is secured to actuator plate **42** by means of a small cup **45** made of insulating material to which it is fastened in any conventional manner so that contact filament **44** moves in unison with actuator plate **42**. Cup **45** may be also secured to actuator plate in any conventional manner as by gluing or cementing. An electric circuit is established between contact pins **46** and **47** in base **35** over wire **48**, upper mercury contact **49**, contact filament **44**, lower mercury contact **50**, and wire **51**, wherein wire **48** connects contact pin **46** with mercury contact **49**, and wire **51** connects mercury contact **50** with contact pin **47**. The upper mercury contact **49** consists of a small droplet of mercury housed between two retaining discs **52** and **53** each having a central bore which are adequate to confine the mercury droplet because of its high surface tension, and yet permit movement of contact filament **44** through these bores while making contact with the mercury. The lower mercury contact **50** comprises a lower contact cup **54** which contains the mercury and an insulating retainer **55** fitting over contact cup **54** which includes a central bore of large enough diametric dimension to permit passage therethrough of contact filament **44** and to receive the arc-quenching oil.

In the operation of the electrostatic relay of Figure 2, opposite high voltages are applied to charge plates **38** and **40** via terminals **39** and **41**. As different charges are applied to double-cone, actuator plate **42** via terminal **56**, fixed axial shaft **37** and cylindrical section **43**, the actuator plate together with cup **45** and contact filament **44** move in a vertical direction thereby making or breaking the electrical circuit between contact pins **46** and **47**.

Figure 3 shows a further modified form of an electrostatic relay in accordance with the present invention, similar to that of Figure 2 wherein similar parts are designated by primed reference numerals but containing further refinements. Glass envelope **34'** is in the form of two cones having a cylindrical section joining the two bases thereof, and includes an upwardly extending apex portion **36'** and a base portion **35'**. The upper and lower charge plates **38'** and **40'** which conform to the contours of the glass envelope **34'** and include terminals **39'** and **41'**, are separated from one another by insulating disc **56**. Actuator plate **42'** consists of two cones, joined at their respective bases by a cylindrical section, and is slidably supported at its upper end by a fixed axial shaft or pin **37'** over which the actuator plate **42'** slides while maintaining electrical continuity therebetween by means of the small cylindrical section **43'** formed by the apex of the upper cone of actuator plate **42'** and extending upwardly therefrom. The apex of the lower cone of actuator plate **42'** is supported by means of an insulating cup **45'** fastened to actuator plate in any conventional manner, as by gluing or cementing. An insulating rod **57** is secured substantially centrally thereof to cup **45'** in any conventional manner and carries contact filament **44'** fastened thereto so that contact filament **44'** moves in unison with actuator plate **42'**. A bearing member **58** having a central bore to receive freely insulating rod **57** serves to keep the moving parts in alignment. The parts forming the actual electrical circuits including the contacts are identical with those shown and described with respect to Figure 2, and have been designated by identical, primed reference numerals. However a detailed description thereof is not deemed necessary.

The operation of the electrostatic relay of Figure 3 is identical to that of the relay shown in Figure 2, with the added feature of an alignment bearing **58** which assures axial movement of acuator plate **42'** and contact assembly **45'**, **57** and **44'** when a voltage is applied to actuator plate **42'** via terminal **56'**, shaft **37'**, and cylindrical contact section **43'**. Actuator plate **42'** will tend to move axially due to the forces produced by the interaction of the electric fields set up by application of opposite voltages to charge plates **38'** and **40'** respectively and by application of predetermined voltage to actuator plate **42'**.

Figure 4 shows a still further modified form of an electrostatic relay in accordance with the present invention which has low capacitance, and which comprises a glass envelope **59** having a base **60**. Within glass envelope **59** is the actual electrostatic relay which comprises an outer charge plate **61**, an inner charge plate **62**, and an actuator plate **63** intermediate the outer and inner charge plates **61** and **62**. Charge plates **61** and **62**, which are supported by envelope **59**, and actuator plate **63** have an inverted U-shape with two tapered members replacing the conventional straight crossbar thereof as illustrated in the cross-sectional view of Figure 4. Thus charge plates **61** and **62** and actuator plate **63** each comprise a cylindrical section represented by the two vertical sides and a shallow conical section crowning the cylindrical section represented by the two tapered top members. This arrangement permits better utilization of the space within glass envelope **59** by providing larger surface areas of charge plates **61** and **62** and actuator plate **63**.

An insulating support rod **64** having a conducting surface **65** applied to its upper part, as for instance by metal coating is secured to actuator plate **63** in any conventional manner. Insulator rod **64** is mechanically supported by and makes electrical contact through its conducting surface **65** with the mechanical-support, mercury contact assembly **66** which consists of two flat strips **67** and **68** held together in any conventional manner, each strip having a small conical detent, made for instance with the 120° cone of the rear end of a twist drill and a small central bore through the apex of each cone, and a droplet of mercury **69** which is safely retained between strips **67** and **68** owing to its surface tension as described above. Contact assembly **66** is supported by supporting wire **70** which establishes a continuous electrical circuit between connecting pin **71** and actuator plate **63** via wire **70**, contact assembly **66** and conducting surface **65** of insulating rod **64**. In order to provide free movement inner charge plate **62** is provided with a central, spherical cut-out portion **72**, and in order to prevent a short-circuit between outer charge plate **61** and actuator plate **63** when the latter moves upwardly, outer charge plate **61** is provided with a centrally disposed, insulating limit stop **73** against which the uppermost part of the conducting surface 65 will come to bear when the actuator plate 63 is moving upwardly. A contact filament 74 is carried by insulating rod 64 for movement therewith which projects downwardly substantially centrally of the insulating rod 64. Contact filament 74 passes through the central bores at the apices of the conical indentations made into metallic strips 75 and 76 of the mercury contact assembly 77 which is similar to the mercury contact assembly 66 except for the smaller central bores because of the smaller diametric dimension of contact filament 74 as compared to insulating rod 64. A droplet of mercury 78 is contained within the space formed by the conical indentations, base-to-base, in flat strips 75 and 76, which establishes a continuous electric circuit between contact pin 79 and contact filament 74 over connecting wire 80 which serves simultaneously as mechanical support for mercury contact assembly 77 and for alignment bearing 81′ made of insulating material which is supported by the upward extension of wire 80. The electrical circuit of the relay between contact pin 79 and contact pin 81 is closed with contact filament 74 in actual contact with the mercury pool 82, which is contained in contact cup 83, which in turn is connected to contact pin 81 over wire 84. Insulating cup 85 fits around contact cup 83 and houses the quenching oil 86. Appropriate voltages may be applied to outer and inner charge plates 61 and 62 via connecting pins 87 and 88 and connecting wires 89 and 90 respectively. Charge plates 61 and 62 may be provided optionally with holes 91.

In the operation of the electrostatic relay shown in Figure 4, an electric circuit is closed and opened between contact pins 79 and 81 by movement of actuator plate 63 together with insulating rod 64 and contact filament 74 upon application of predetermined voltages to actuator plate 63 over connecting pin 71, mercury contact assembly 66, and conducting surface 65 of insulating rod 64, which interacts with the electrostatic field produced by opposite, high voltages applied to charge plates 61 and 62 over connecting pins 87 and 88 and wires 89 and 90 respectively.

While I have shown and described several preferred embodiments of my invention, it will be obvious to those skilled in the art that it is not so limited but is susceptible of various changes and modfications without departing from the spirit thereof, as, for example, foils may be used as actuator plates to decrease the mass of the moving parts, the charge plates may be placed within the glass envelopes, or electrets may be substituted for the charge plates, and one or more mercury contacts may be added to permit more than one circuit to be controlled. The envelopes may be made of any suitable material other than glass, and the insides thereof evacuated or filled with inert gas, and conventional metal "cat whisker" contacts may be substituted for the mercury contacts. Delay networks consisting of L-C or R-C networks may be connected to the input circuits of the actuator plates so as to provide accurate time delays in the operation of the relay, and may be built into the relay itself as by placing appropriate circuit diameters or elements within the glass envelopes or base thereof and by connecting them directly into the input circuits of the actuator plates. I desire, therefore, that only such limitations be placed thereupon as are imposed by the prior art or as are specifically set forth in the appended claims.

What I claim is:

1. A polarized electrostatic relay comprising an evacuated dielectric envelope, a pair of open ended cylindrical charge plates supported by said envelope and having an insulated spacer separating said charge plates in axial spaced relation, means for applying a polarizing voltage of opposite polarity to said charge plates, a cylindrical actuator mounted for reciprocal movement along the longitudinal axis of said charge plates and spaced therefrom, means to guide said actuator and to apply a polarizing voltage of predetermined magnitude and polarity to said cylindrical actuator, contact means fastened to said actu-

ator for movement therewith, terminal means in said envelope, an electric circuit connecting said terminals, said contact means opening and closing said circuit in response to voltages applied to said actuator.

2. A polarized electrostatic relay comprising an evacuated dielectric envelope of generally double-conical configuration, a pair of generally cone shaped charge plates supported by the conical portions of said envelope, means for applying a polarizing voltage of opposite polarity to said charge plates, an actuator member of a double-conical form concentric with said charge plates and mounted for reciprocal movement therebetween, bearing means to guide said actuator member, means to supply said actuator member with a polarizing voltage of predetermined magnitude and polarity, contact means fastened to said actuator for movement therewith, terminal means in said envelope, an electric circuit connecting said terminals, said contact means opening and closing said circuit in response to voltages applied to said actuator.

3. A polarized electrostatic relay comprising an evacuated dielectric envelope, a pair of spaced concentric cup shaped charge plates, a cup shaped actuator member concentric with said charge plates and mounted for reciprocal movement therebetween, bearing means to guide said actuator member, means for applying a polarizing voltage of opposite polarity to said charge plates, means to supply a polarizing voltage of predetermined magnitude and polarity to said actuator member, movable contact means fastened to said actuator member for movement therewith, terminal means in said envelope, an electric circuit connecting said terminals, said contact means opening and closing said circuit in response to voltages appled to said actuator.

4. A polarized electrostatic relay comprising in combination a dielectric envelope, a pair of open ended cylindrical charge plates supported by said envelope and having an insulated spacer separating said charge plates in axial spaced relation, means for applying voltages of opposite polarity to said charge plates, a cylindrical actuator plate mounted for reciprocal movement along the longitudinal axis of said charge plates and spaced therefrom, bearing means to guide said actuator and supply a polarizing voltage of predetermined magnitude and polarity to said cylindrical actuator plate, contact means fastened to said actuator plate for movement therewith, a plurality of contact bores formed in one end of said envelope and operatively associated with said actuator contact means, terminal means in said envelope integral with said contact bores, and mercury contact and oil quench means within said contact bores.

5. A polarized electrostatic relay comprising in combination within a dielectric envelope a pair of open ended cylindrical charge plates having one end of a generally conical shape supported by said envelope and having an insulated spacer separating said charge plates in axial spaced relation, means for applying voltages of opposite polarity to said charge plates, a cylindrical actuator member having conically formed ends thereon mounted for reciprocal movement along the longitudinal axis of said charge plates and spaced therefrom, means to supply a polarizing voltage of predetermined magnitude and polarity to said cylindrical actuator member, bearing means to guide said actuator member at each end thereof, movable contact means fastened to said actuator member for movement therewith, fixed mercury contact and oil quench means operatively associated with said movable contact means, an electric circuit operatively associated with said fixed and movable contacts including a mercury contact assembly having a droplet of mercury housed between a pair of centrally bored retaining strips and outlet terminals for said electric circuit in one end of said envelope.

6. The modification with the device of claim 5 in which said charge plates and said actuator member are in the form of a generally base to base double cone.

7. A polarized electrostatic relay comprising in com-

bination within a dielectric envelope, a pair of spaced concentric cup shaped charge plates, a cup shaped actuator member concentric with said charge plates and mounted for reciprocal movement therebetween, bearing means to guide said actuator member, means for applying a polarizing voltage of opposite polarity to said charge plates, means to supply a polarizing voltage of predetermined magnitude and polarity to said actuator member, movable contact means fastened to said actuator member for movement therewith, a fixed mercury contact and oil quench means operatively associated with said movable contact means, and an electric circuit operatively associated with said fixed and movable contacts including a mercury contact assembly having a droplet of mercury housed between a pair of conducting centrally bored retaining strips.

8. A polarized electrostatic relay comprising in combination within a dielectric envelope, a pair of spaced concentric cup shaped charge plates fixedly supported within said envelope, means for applying a polarizing voltage of opposite polarity to said charge plates, a cup shaped actuator member concentric with said charge plates and mounted for reciprocal movement therebetween, an insulated support rod having a conducting surface on a portion of its length attached to said actuator and extending along the longitudinal axis thereof, bearing means at one end of said rod, means to supply a polarizing voltage of predetermined magnitude and polarity to said actuator member including a mercury contact assembly having a droplet of mercury housed between a pair of conducting centrally bored retaining strips, said conducting portion of said rod passing through said bore of said assembly, movable contact means fastened to said actuator for movement therewith, a fixed mercury contact and oil quench means operatively associated with said movable contact means and an electric circuit operatively associated with said fixed and movable contacts including a second mercury contact assembly having a droplet of mercury housed between a pair of conducting centrally bored retaining strips.

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