

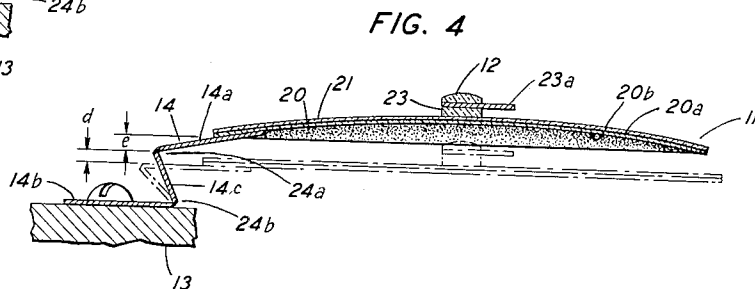
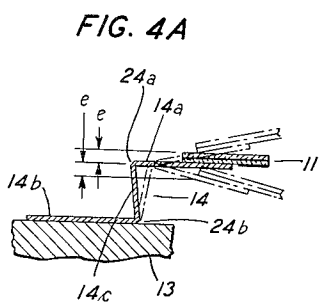
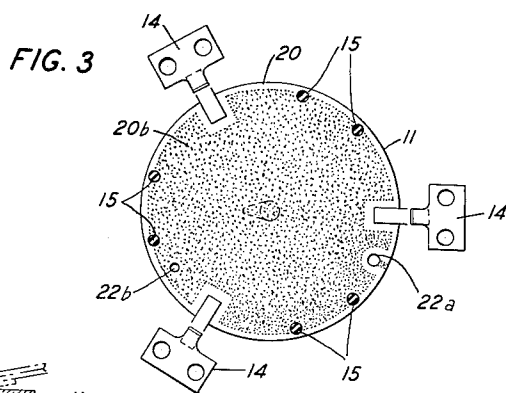
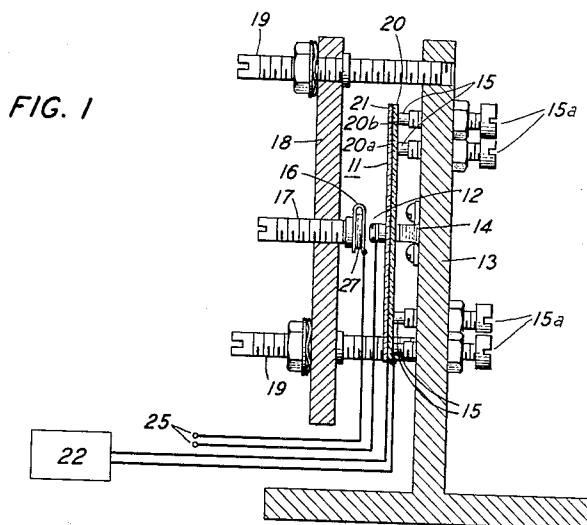
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Filed July 10, 1952

T. G. KINSLEY
HIGH SPEED RELAY OF ELECTROMECHANICAL
TRANSDUCER MATERIAL

2,714,642

3 Sheets-Sheet 1



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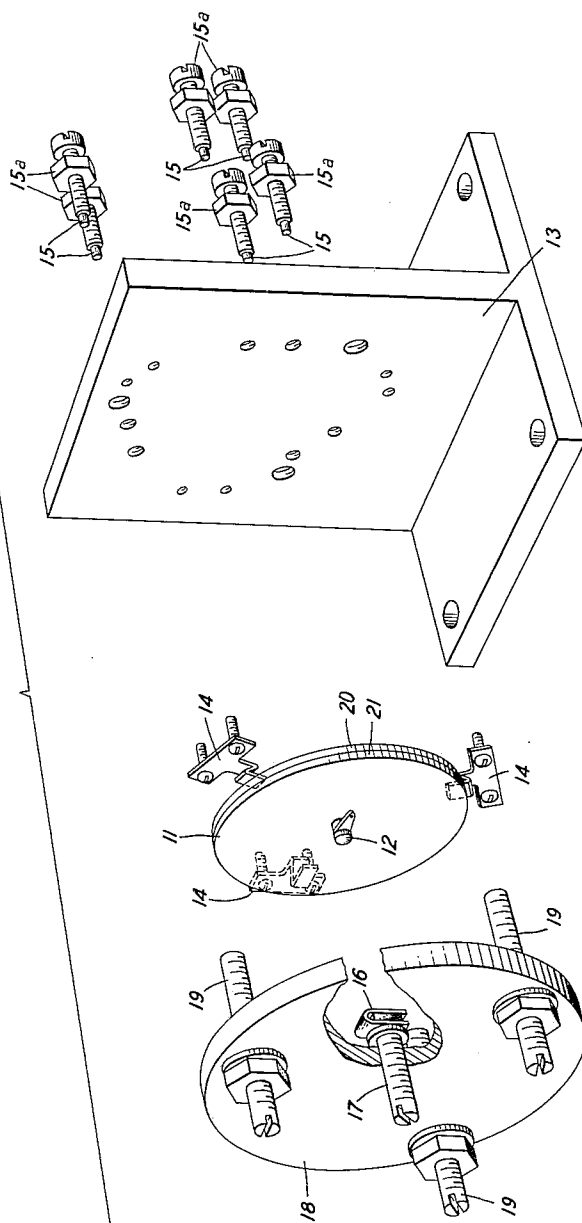
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FIG. 2



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FIG. 5

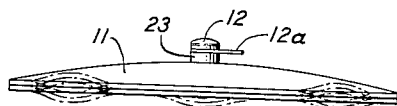


FIG. 6

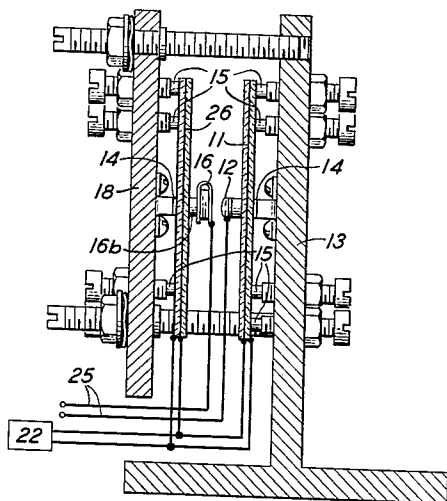


FIG. 7

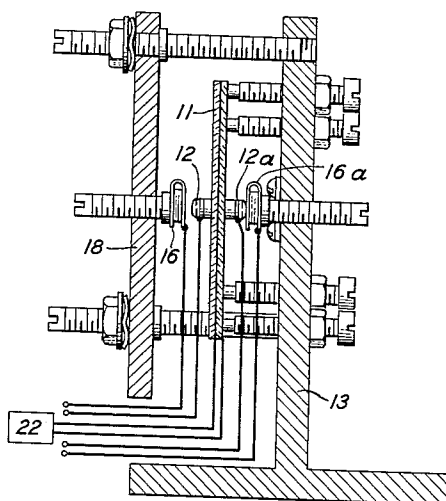


FIG. 9

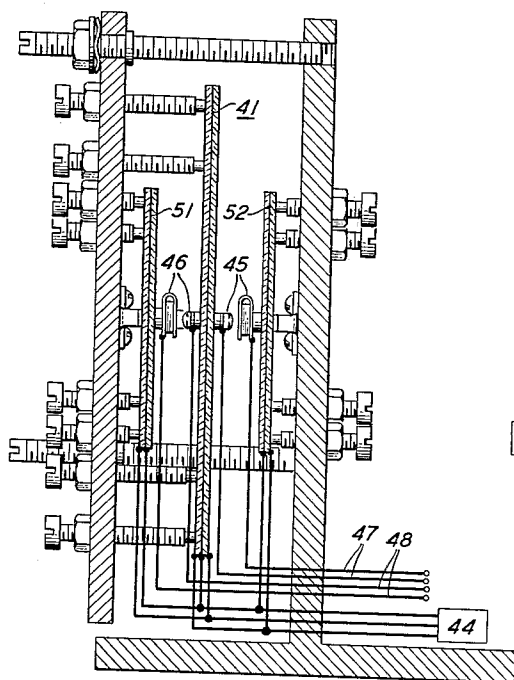
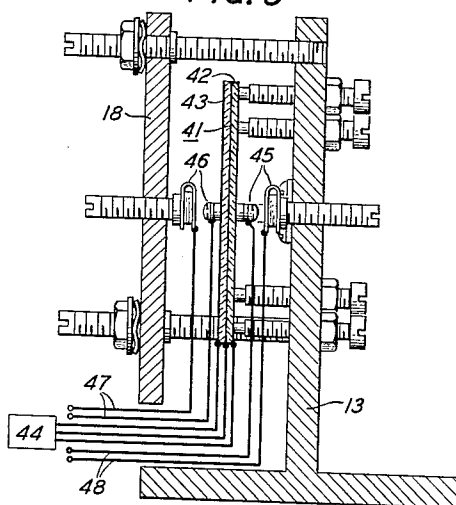


FIG. 8



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HIGH SPEED RELAY OF ELECTROMECHANICAL TRANSDUCER MATERIAL

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5 Claims. (Cl. 200-37)

This invention relates to electromechanical relays and, more particularly, to relays in which movement is dependent upon the electrostrictive or piezoelectric characteristics of an electromechanical transducer element.

One of the objects of the invention is to increase the speed at which the movable element of such a relay responds to the application or removal of the operating voltage.

A further object of this invention is to extend the motion of the transducer elements and to insure high speed operating stability while yet retaining a simple and rugged construction.

Still another object is to provide for operation of such a relay over a broad band of actuating current frequencies.

In accordance with a feature of the invention, a transducer element is mounted on elastic strips which act not only as mounting means and serve to constrain the motion of the element at its edges, but also to actively contribute to the motion of the transducer element.

Another feature of the invention is the critical placement of damping means against the movable element of the relay that absorbs the interference from spurious modes of vibration and adds to the edge stiffness of the movable element.

In accordance with the present invention, a relay is formed of a center flexure plate, with a relay contact of a contact pair on one face of the plate, and a supporting structure for the flexure plate that permits the contacts to close with the flexing of the plate and which structure substantially increases the all too limited motion that can be achieved with the flexure plate alone.

In a specific embodiment of this invention, the flexure plate is a bimorph ceramic disc of two joined polarized electrostrictive transducer elements such as barium titanate. In an instance where each element is 2 inches in diameter and 10 mil inches thick and is polarized in its radial mode, the measured center displacement of the disc is only 1.3 mil inches when 200 volts is applied to one disc. In this invention all of the center displacement motion of the disc is not only preserved but it is substantially contributed to by the mounting means. The disc is attached to a backing plate, which is one extension of the mounting stand, with three elastic shaped mounting strips that are connected to the disc at equally spaced intervals around its edge. The mounting strips are made of a resilient element such as annealed beryllium copper and have two sharp bends which are weakened to permit the bends to serve as elastic hinges about which motion is directed permitting movement of the center flexure disc in limited paths. Further, each strip is so shaped that it selectively resists longitudinal displacement of the periphery of the disc, provides a stable platform for the disc from which all longitudinal center displacement may be measured, and also provides lever arms which, when called into motion by the forces operating near the periphery of the flexing disc, lift the disc in rhythm with

the flexing action to further extend the center of the disc from its neutral position.

For such a bimorph disc of barium titanate as described above, the resonant frequency is found to be near 1600 cycles per second and the center displacement is maximum at that frequency.

Damping means of butyl rubber, for example, placed around the edge of the disc are found to add stiffness to the disc and increase the resonant frequency and also act to control any higher modes of vibration that appear in the disc tending to decrease its center displacement by disrupting the primary mode of vibration. With such damping arrangement the disc is capable of continuous operation at frequencies from zero to seven thousand cycles per second with the exception that some irregularities appear in the operation at the frequencies from 3,000 to 5,000 cycles per second. Additionally, adjustments in the contact spacing for changes in the center displacement of the disc do not have to be made except near the 5,000- to 7,000-cycles-per-second range.

When the spacing between contacts is six tenths of the total disc displacement distance and sufficient contact damping is provided to absorb the remaining disc displacement motion, a contact opening and closing action is had that is smooth and free of any contact chatter resulting from unexpended energy stored in the actuated disc.

As limited by the physical characteristics of the bimorph itself, a center displacement that is six tenths of the total center displacement (at which point the relay contacts are closed) in a disc a resonant frequency of 1600 cycles per second will occur in 100 microseconds after the voltage is applied. In a relay having a single bimorph disc, this operation time may be reduced below 100 microseconds only by varying the contact spacing within the limits dictated at one extreme by the damping required to prevent contact chatter and at the other extreme by the contact spacing required to prevent arcing across the contacts. However, operate time in a relay may be further reduced, for example, by mounting each contact of a contact pair on separate flexure discs that have been linked for synchronous motion.

Below the maximum operate time as limited by the physical characteristics of the bimorph, its mode of motion may be further controlled through the electric charge and discharge characteristics of the disc as influenced by the wave form of the actuating voltage applied to the disc. Hence, an actuating voltage taking the form of a sine wave will tend to cause moderate charge and discharge periods and moderate contact closing and opening speeds, while a rectangular wave will tend to cause fast charge and discharge periods and fast contact close and open speeds. By supplying actuating voltages having different wave forms, other contact closing and opening speeds and combinations of closing and opening speeds may be attained.

The flexure plate may be rectangular, circular or of any number of other geometric shapes, but the flexure motion is found to be greatest and most satisfactory for high speed relay purposes in a thin circular plate having center or "diaphragm" flexure motion. Similarly, while the composition of the plate may be that of a non-elastic restraining plate of metal, plastic, or other material overlaid with and bonded to an electromechanical transducer element which when actuated causes stress in the unit resulting in a flexure motion, the most desirable composition is found to be that of a non-elastic restraining plate of electrostrictive or piezoelectric material identical in physical properties to the electromechanical transducer overlay. A flexure plate of this bimorph disc construction, as described above, has been operated continuously in a relay that has proven to be

substantially insensitive to temperature changes over a range from 55° F. to 100° F. and remained in operating condition for weeks without adjustment.

Polarization enhances the properties of many electro-mechanical transducers and in fact makes electrostrictive materials effectively piezoelectric and responsive to both positive and negative electric fields.

Where a transducer element acts as a restraining element the center displacement can be substantially increased by orienting the restraining plate to actively oppose the motion of the other element. The cumulative effect of such activity is a greater bending, a larger center displacement of the disc, and an increased motion of the mounting lever arms which act to further extend the center of the disc from the neutral position.

Insofar as the components of a disc can be made to grow or shrink in dimensions in response to positive and negative fields, a properly oriented bimorph disc can be made to flex in either of two directions depending upon the nature of the field applied. While this double flexure motion increases the number of modifications and adaptations that might be made in the specific embodiment of the invention, it does not necessitate a modification in the principles of elastic hinge mounting that contributes to the disc displacement and the edge damping of the disc that stabilizes higher order vibrations in the disc.

The invention, its objects and its principles will be more clearly understood as hereinafter described with reference to the accompanying drawings showing different forms of devices suitable for the purpose.

In the drawings:

Fig. 1 is a sectional view of a relay having a transducer element flexure plate in accordance with the invention;

Fig. 2 is an exploded view of the relay device according to Fig. 1 showing the individual parts thereof and the manner in which they are joined together;

Fig. 3 shows a plane view of the flexure plate and the placement of the damping means and supporting means about the flexure plate;

Fig. 4 is a sectional view of the flexure plate and supporting means showing the flexure action of the hinge supporting means and the displacement of the flexure plate where the flexure plate is mounted for flexure in one direction;

Fig. 4A illustrates the flexing action of the hinge supporting means where the flexure plate is mounted for flexure in two directions;

Fig. 5 illustrates the primary and secondary modes of motion that appear in a forced resonating transducer element; and

Figs. 6, 7, 8 and 9 are sectional views of other embodiments of a relay in accordance with the invention.

Referring specifically to the sectional view of Fig. 1, a relay is shown in which a flexure plate 11, having attached thereto an electric conductive contact 12, is connected to a mounting stand 13 by mounting springs 14 and has damping pads 15 in contact with one of its faces. A second electric conductive contact 16 mounted on an adjustable screw 17 which is seated in backing plate 18, is spaced from and placed opposite to the contact 12. The backing plate 18 is connected to the mounting stand 13 by adjustable bolts 19. An exploded view of the same relay is shown in Fig. 2 with a part of its composite parts identified.

The flexure plate 11, by way of example, is made up of two discs 20 and 21 of barium titanate ceramic, each disc being two inches in diameter and ten mil inches thick. Disc 20 is also prepolarized in a direction of its thickness. Electrodes 20a and 20b are, in one example, of aluminum evaporated onto the two faces of disc 20 to within forty mils of the circumference of the disc in order to allow an electrical insulating ring around the disc's edge, as shown in Fig. 3. As can be noted from Fig. 3, other portions of the disc on its outer face are left uncoated to provide space for connecting the

mounting springs 14 and an inner electrode terminal. Such an electrode terminal 22a is provided for the inner electrode 20a by a small strip of evaporated metal which is carried from the circular electrode area across the insulating annulus and over the edge of the disc to its outer face where a small portion of the outer face of said disc is not coated. At the end of this strip, silver paste is fired onto the ceramic to provide a soldering area for connecting an electric conductor to the strip. A suitable silver paste spot on the outer face itself constitutes terminal area 22b for the other electrode 20b to which an electric conductor may also be soldered. The discs 20 and 21 are then cemented together with a thermal cement, the exposed face of disc 20 being that one which is designated the outer face, and the entire unit is cured under pressure.

A power source 22 shown in Fig. 1 is connected between the electrodes 20a and 20b at terminals 22a and 22b so that an electric field is applied in the same direction as the poling of the disc 20 to insure that there will be no loss of polarization with continuous use. The electric conductive contact 12 is connected to a terminal 23a as shown in Fig. 4, and is cemented on and attached to disc 21 of the flexure plate 11 through an electric insulator 23.

The mounting springs 14, of which there are three to assure a flat unstressed plate, are connected to disc 20 of the flexure plate at evenly spaced intervals near the periphery, as shown in Fig. 3. The spring 14, of which an unstressed top view is shown in Fig. 3, and an unstressed side view identified by the broken line with a stressed side view identified by the solid line are shown in Fig. 4, is made in this instance of a long thin strip of annealed beryllium copper bent back upon itself at two points across its longitudinal axis through obtuse angles not greater than 135 degrees, forming two parallel end sections 14a and 14b joined by a middle section 14c. To add resiliency, the shaped strip of beryllium copper is subjected to a hardening heat treatment. The exposed faces of the bends are weakened by milling or filing for example, to form elastic pivot lines 24a and 24b so that when the end sections are stressed along the longitudinal axis of the strip all motion will be restricted to the weakened bends. Pivot line 24a divides portions 14a and 14c, whereas line 24b divides portions 14b and 14c. With the end portion of the spring 14a attached to the flexure plate 11 and the end portion 14b firmly attached to the mounting stand 13, and the plate 11 actuated, the stress set up in the spring as a result of the flexing action of the plate will cause the portions 14a and 14c to rotate around the bend line 24b, and end portion 14a to also rotate around the bend line 24a so that both obtuse angles are made smaller. The rotation of portion 14a about the pivot line 24b increases the displacement of the bend line 24a and the flexure plate supporting portion 14a from the mounting stand 13 over the measurement taken when the plate and spring is unstressed by a distance d . Additionally, the rotation of portion 14a around the bend line 24a increases the displacement of the disc from the bend line 24a by a distance e . Hence, the spring contributes to the displacement of the plate by a distance $d+e$, in this instance, so that the total displacement at the center mounted contact 12 with the plate 11 mounted for diaphragm flexure in one direction is equal to the normal diaphragm flexure displacement plus the displacement distances $d+e$.

In the case where the plate 11 is mounted for diaphragm flexure in two directions, as shown in Figs. 8 and 9, the strip comprising the mounting spring will be bent in two places through obtuse angles only slightly greater than 90 degrees so that when the spring is stressed by a plate flexure in either direction, the rotation of portion 14a around 24b will be such that the distance d will be substantially zero. Hence, in this case the spring 14 contributes to the displacement of contact 12 by a distance e as shown in Fig. 4A.

The damping pads 15 are held against one face of plate 11 at evenly spaced intervals between the mounting springs and near the periphery of plate 11, as shown in Fig. 3, by means of adjustable screws 15a which are seated in the backing plate 13. The pads themselves are made of an energy dissipating material such as butyl rubber to damp and control the higher modes of vibration that appear at the edge of the plate 11 as shown in Fig. 5 and also to add to the edge stiffness of the plate. The pads in so acting tend to increase the resonant frequency of the plate and to eliminate the vibrations that interfere with the primary mode of vibration.

The receiving contact 16 is formed into a shape which permits it to damp the motion between itself and the driving contact 12 to eliminate contact chatter which would otherwise destroy the advantages gained through fast operation. As shown in Fig. 1 this is accomplished in one instance by soldering a six mil inch strip of palladium silver to the adjustable screw 17, bending it over in a U shape, and inserting between the faces of the U a piece of butyl rubber 16a. When the contact spacing is adjusted to six-tenths of the total possible center displacement, the remaining motion compresses the rubber backing and reduces the kinetic energy stored in the driving unit plate 11 so that there is no rebound off of the contact 16. As shown in Fig. 1, electric conductor pairs 25 are connected to the contacts 12 and 16.

Fig. 6 illustrates another embodiment of the invention in which the speed of operation may be increased over that of Fig. 1. Flexure plate 11 is mounted, damped, and has contact 12 attached thereto as shown in Fig. 1; and in addition, in this embodiment contact 16 is mounted at the center of a flexure plate 26 which is a bimorph of the same construction and composition as plate 11. Plate 26 is poled and subjected to an electric field from source 22 connected in parallel with plate 11 so that when the field is applied contacts 12 and 16 are displaced towards one another. In addition, plate 26 is attached to backing plate 18 with mounting springs 14 and damped with pads 15 in the same manner as plate 11. However, in this embodiment inasmuch as two flexure plates are used, if the gap between contacts 12 and 16 is made six tenths of the combined displacements of plates 11 and 26, the distance between said contacts will be approximately double that of the device shown in Fig. 1 but the operate time will remain substantially the same. By decreasing this gap between the contacts to a distance equal to that of the device of Fig. 1, a corresponding increase in operate time of the relay may be had.

Fig. 7 illustrates another embodiment having a single bimorph plate and in which two pairs of contacts are provided for alternate operation. One pair of rear contacts 12a and 16a, of which 12a is centered on the rear surface of plate 11, is placed so that when the plate is unstressed the contacts are closed. The other pair of front contacts 12 and 16, of which 12 is centered on the front face of plate 11, is placed so that for unstressed plate conditions these contacts are open. When the plate is stressed through application of an electric field, the rear contact pair opens and the front contact pair closes. Plate mounting and damping and contact mounting and damping are as described for the device of Fig. 1.

In Fig. 8 another embodiment of the invention is shown in which two pairs of contacts are provided for selective operation. In this instance, plate 41 is composed of two discs 42 and 43 of a ferroelectric ceramic such as 4 per cent lead titanate barium titanate mixture of which both plates are polarized in their thickness direction. Electrodes are evaporated on both sides of each disc and the discs, being oriented so that they are poled in the same direction, are sealed to form a plate according to the method described for the device shown in Fig. 1. The inner electrodes of the two discs are connected as a common electrode which along with the electrodes of the

outside faces of the discs are connected to a multiple power source 44. Two pairs of contacts 45 and 46 are included, both pairs of which are open when the plate 41 is unstressed. The application of a field in one direction causes one pair of contacts to close and a field in the other direction causes the other pair of contacts to close. Conductor pair 47 is connected to contact pair 46 while conductor pair 48 is connected to contact pair 45.

Fig. 9 is a cross sectional view of a modification of the device of Fig. 8 in which the damping contacts of contact pairs 45 and 46 are mounted for movement on flexure plates 51 and 52. A middle flexure plate 41 is of the same construction as the device of Fig. 8. The flexure plates 51 and 52 are of the same construction as plates 26 and 11 of the device of Fig. 6. Flexure plate mounting and damping is as provided in the other devices. The electrodes of plates 41, 51 and 52 are connected to a multiple power source 44 so that plates 41 and 51 will in one instance flex towards one another, closing the contact pair 46, and in another instance plates 41 and 52 will flex towards one another closing contact pair 45.

It is to be understood that the described embodiments are in part illustrative of the invention and that other embodiments not shown may be devised by those skilled in the art without departing either in spirit or scope from the invention herein set forth.

What is claimed is:

1. A relay comprising a mounting stand, a flexure plate, said flexure plate being adapted to flex and change its curvature upon receiving electrical energy, a first conductive electric contact mounted centrally on said flexure plate, a second similar contact mounted on said stand, flexure motion of said plate causing said first contact to move with respect to said second contact along an axis normal to said flexure plate at the center of said plate, a plurality of mounting springs attaching said plate to said stand, said mounting springs being spaced at substantially equal intervals around the periphery of said plate and defining at their points of support on said plate a plane which changes in size and position as said plate flexes, each of said mounting springs comprising a first relatively rigid strip portion attached to the face of said flexure plate and lying substantially in the plane of said plate, second and third relatively rigid strip portions, said second portion being integral with and elastically hinged to said first and said third portions, said third portion being attached to said mounting stand, each of said mounting springs having all three strip portions in alignment with a plane including said axis along which said first contact moves, and means to reduce spurious mode vibrations in said flexure plate comprising damping means pressed against one face of said plate near its edge.

2. A relay comprising a mounting stand, at least one electromechanical transducer bimorph flexure disc, means to attach said disc to said mounting stand at spaced points around the margin of said disc and comprising a mounting spring at each of said points, said mounting spring comprising a rigid first portion attached to the face of said disc and extending radially outward therefrom beyond the periphery of said disc, a rigid second portion that is integral with and elastically hinged to both said first portion and a rigid third portion that is attached to said mounting stand, at least one pair of conductive contacts, one contact of each pair being attached to the center of one face of said disc, the other contact of each said pair being attached to said mounting stand and each said pair so spaced and arranged that the flexure motion of said plate will cause said paired contacts to open and close, and means to reduce spurious mode vibrations in said disc comprising damping element pressed against one face of said plate near its edge.

3. A relay according to claim 2 wherein said mounting spring is a long flat thin elastic element wherein said element is divided into said first, second and third portions by sharp bends, weakened at said bends to provide relative motion for said portions.

4. A relay comprising a mounting stand, at least one electromechanical transducer bimorph flexure disc, means to attach said disc to said mounting stand at three points spaced around the margin of said disc comprising a mounting spring at each of said points, said mounting spring comprising a thin flat element having a rigid first portion attached to the face of said disc and extending radially outward therefrom beyond the periphery of said disc, a rigid second portion that is continuous with and elastically hinged to both said first portion and a rigid third portion at sharp bends where said spring is weakened, said third portion being attached to said mounting stand, at least one pair of conductive contacts, one contact of each pair being attached to the center of one face of each said disc, the other contact of each pair being attached to said mounting stand, each said pair so spaced and arranged that the flexure motion of said disc will cause said contacts to open and close, and means to reduce spurious mode vibrations comprising bodies of mechanically-lossy resilient material spaced around the margin of said disc between said three points and means to hold said bodies compressed against the face of said disc.

5. A relay comprising a mounting stand, at least one bimorph flexure disc of effective piezoelectric elements, means to attach said disc to said mounting stand at spaced points around the margin of said disc comprising a mounting spring at each of said points, said mounting spring comprising a long thin flat element having a first rigid portion attached to the face of said disc and extending radially outward therefrom beyond the periphery of said disc, a rigid second portion that is continuous with and elastically hinged to both said first portion and a rigid

third portion at sharp bends which are weakened, said third portion being attached to said mounting stand, at least one pair of conductive contacts, one contact of each pair being attached to the center of one face of said disc, the other contact of each pair being attached to said mounting stand, each said pair so spaced and arranged that the flexure motion of said disc will cause said contacts to open and close, means to reduce spurious mode vibrations comprising bodies of mechanically-lossy resilient material spaced around the margin of said disc between said three points and means to hold said bodies compressed against one face of said disc, and means to eliminate contact chatter comprising a body of energy dissipating material connected between said mounting stand and each attached contact.

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