TIME-DELAY RELAY

Filed Sept. 22, 1958 4 Sheets-Sheet 1

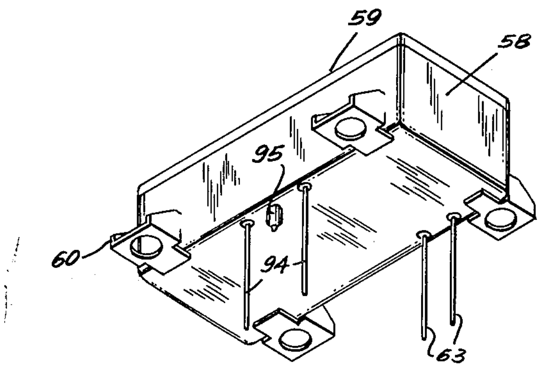
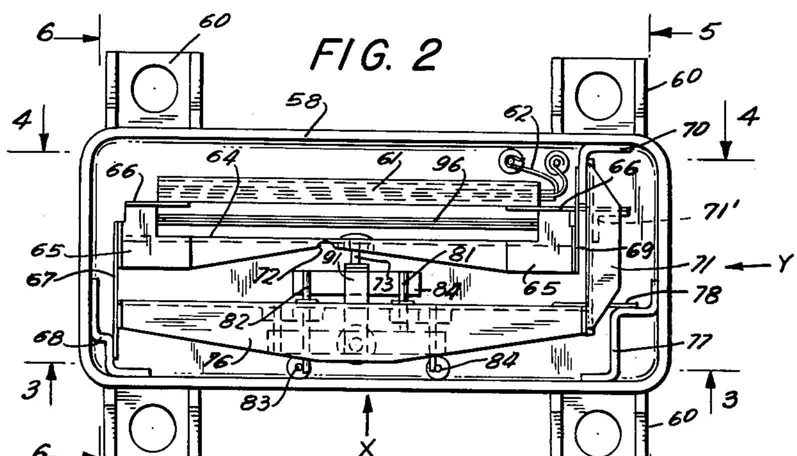


FIG. 1

FIG. 2



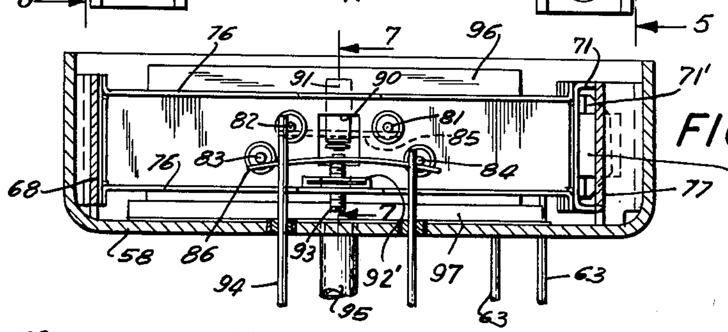


FIG. 3

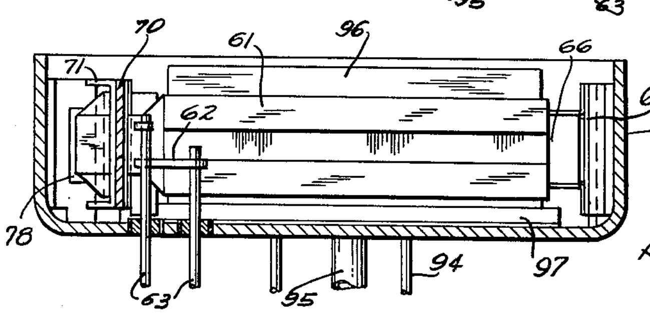


FIG. 4

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FIG. 5

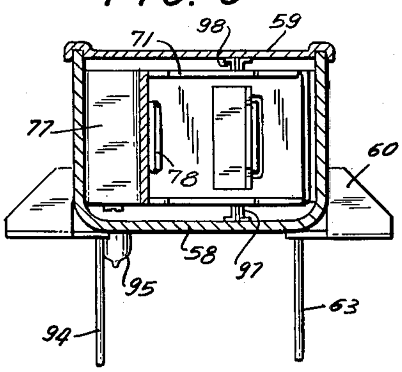

FIG. 6

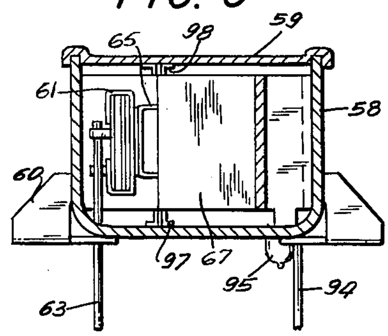

FIG. 7

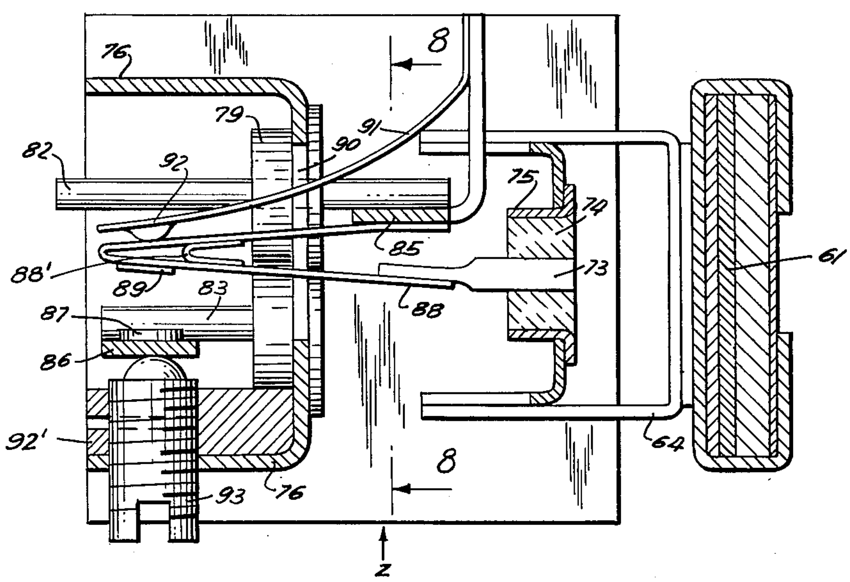

FIG. 8

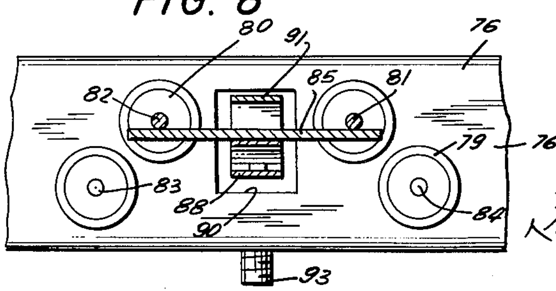

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FIG. 9

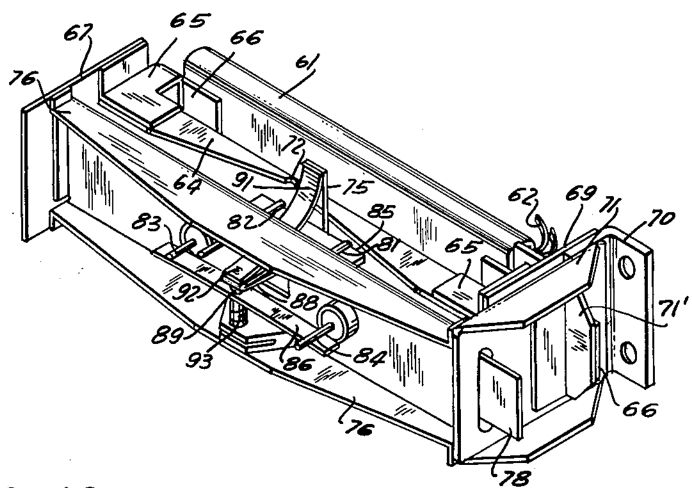

FIG. 10

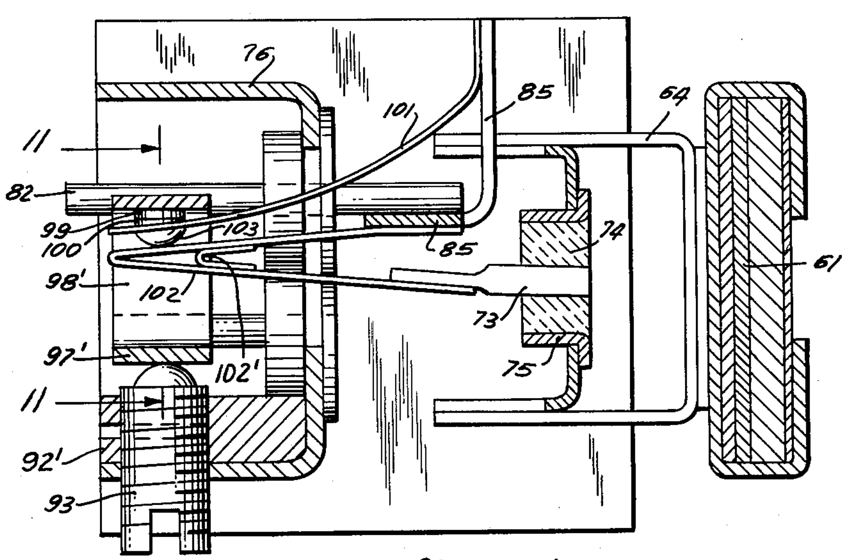

FIG. 11

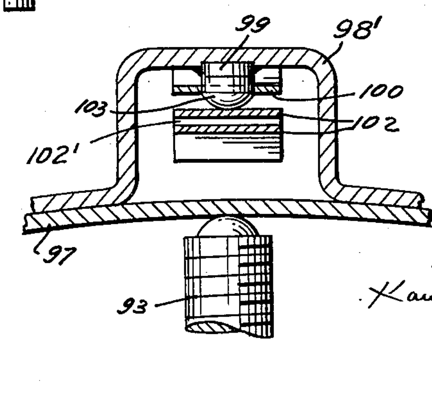

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FIG. 12

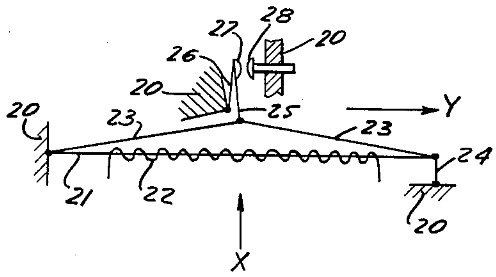


FIG. 13

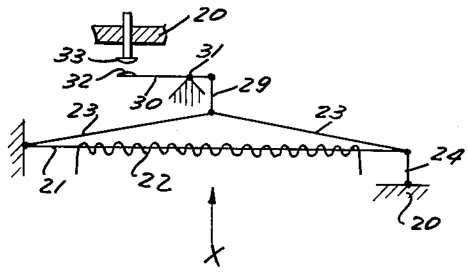


FIG. 14

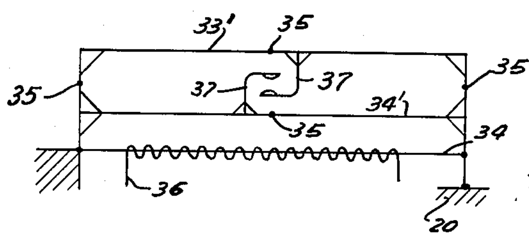


FIG. 15

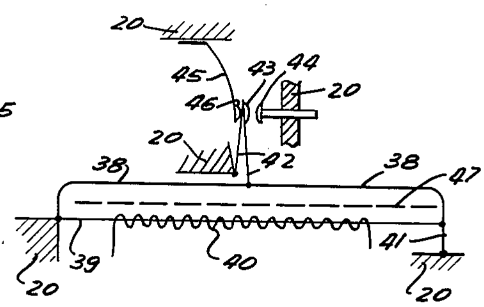
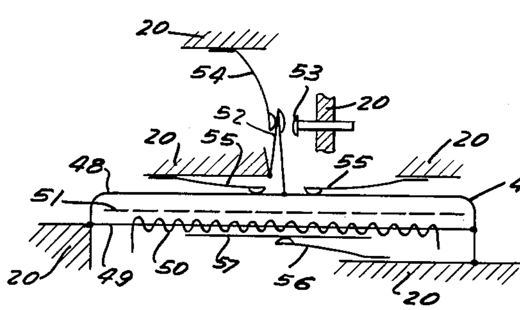


FIG. 16



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United States Patent Office

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3,056,871

TIME-DELAY RELAY

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Filed Sept. 22, 1958, Ser. No. 762,349
23 Claims. (Cl. 200—122)

This invention relates to a functionally and structurally improved electrothermal relay involving a time-delay factor.

By means of the present teachings a unit is provided which may be subjected to a wide range of forces and conditions without impairing its functioning, and which will embody a response of high accuracy. Accordingly, the unit may be included in a missile to control the functioning of the latter under the extremes of conditions encountered in its operation.

The relay will be designed to occupy only a minimum of space, and will embody a relatively simple structure embracing few components, connected to each other to furnish a unit of high accuracy and the performance of which may be relied upon even when the unit is subjected to extremes of acceleration and temperature; the relay embodying an adequate timing range.

With these and other objects in mind, reference is had to the attached sheets of drawings illustrating practical embodiments of the invention and in which:

FIG. 1 is a bottom perspective view of the exterior of the relay casing;

FIG. 2 is a plan view of the relay assembly with the cover removed;

FIGS. 3 and 4 are sectional side views taken respectively along the lines 3—3 and 4—4 in the direction of the arrows as indicated in FIG. 2;

FIGS. 5 and 6 are transverse sectional views taken along the lines 5—5 and 6—6 respectively in the direction of the arrows as also indicated in FIG. 2, with the cover in position;

FIG. 7 is a transverse sectional view in enlarged scale taken along the line 7—7 in the direction of the arrows as indicated in FIG. 3;

FIG. 8 is a sectional view taken along the line 8—8 in the direction of the arrows as indicated in FIG. 7;

FIG. 9 is a perspective view of the main operating mechanism of the relay;

FIG. 10 is a view similar to FIG. 7, but showing an alternative form of structure;

FIG. 11 is a transverse sectional view taken along the line 11—11 in the direction of the arrows as indicated in FIG. 10; and

FIGS. 12 to 16 inclusive are diagrammatic representations of alternative forms of relay mechanisms illustrative of the principles embodied in the design present in the instant application.

The missile time-delay relay embodied in the present teachings is designed to have a minimum response to vibrations up to 2000 cycles per second, even where a force in excess of twenty times gravity is involved. Additionally, it will be highly resistant to shocks in excess of 50 *g* with a duration of as much as 11 milliseconds, and will involve a minimum departure in timing where unidirectional forces as high as 50 *g* are encountered. Moreover, ambient temperature compensation will be present, ranging, for example, from minus 65° C. to plus 125° or even beyond. High accuracy, involving narrow setting tolerance and good repeatability, will be achieved, aside from the fact that there will be minimum sensitivity of the unit regardless of its position. The timing range which may be embraced will be adequate, and the time setting may be adjustable. The adjusting means will

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conveniently be structurally independent of the enclosure.

Hereinafter reference will be made to "tapered" design. By this is meant that the weight of moving parts should decrease very rapidly as the motion is multiplied. In fact, the mass of the motion-multiplying mechanism should change far more rapidly than inversely proportional to the ratio of multiplication. By the present teachings, such a "tapered" design is achieved.

As is well understood, in the case of a high ratio lever (10:1 or higher) it is almost impossible to design that lever and its mounting in a manner such that it will be so rigid as to have a natural period of vibration above 2000 cycles per second. However, an isosceles triangle—even a very low one—when firmly supported at the two ends of its base, will still be very rigid at its apex. This is because its sides are under compressive or tensile stresses, rather than under bending stresses. However, the ratio of multiplication that can be obtained with such a triangular design and with the actuating member as its base is practically limited to 3:1 or 4:1. For substantial contact motion without high energy input and excessive temperature rise of the actuating member, a multiplication of at least 10:1 is needed. To achieve this end result requires two multipliers in cascade, i.e., connected in such manner that the over-all multiplication is the product of the multiplication ratios of the two.

Reference is had primarily to FIGS. 12 to 16 inclusive diagrammatically illustrating structures involving multiple motion-magnifying or multiplying mechanisms arranged in cascade. In FIG. 12 the numeral **20** indicates supporting portions providing points of reference. This structure may be included in the frame of the mechanism. The motion-multiplying mechanisms are of the V type. The first of them embraces a base **21** with which a heater in the form of a resistance wire **22** is associated. Connected to the ends of the base and to each other, are sides or arms **23** which furnish at their juncture the apex of the V. A link **24** is interposed between the point of connection of base **21** and one of the arms **23** and the adjacent surface of the supporting frame. The connections between the several elements may be regarded as pivotal, although in actual practice a flexible coupling zone or part will ordinarily be present. It will be understood that with a design of this type, and in response to the application of heat to base **21**, a multiplication ratio of up to, for example, 4:1 may be obtained at the apex of the V.

The second motion-multiplying mechanism involves a different V design. It will include arms **25** and **26** disposed at an acute angle with respect to each other, with a ratio of height to base of approximately 4:1. A contact **27** is suitably secured adjacent the apex of the V. This contact cooperates with a second contact **28** suitably mounted by frame **20** or any other proper fixed point. The leg or arm **25** is connected in any desired manner adjacent the apex of the V defined by arms **23**. The second arm **26**, connected to arm **25**, is in turn connected to a suitable fixed point of reference, such as the frame **20**. In the diagram, for the sake of clarity, leg **26** is shown shorter than leg **25**, but in actual design these legs are made as nearly equal in length as possible.

Otherwise stated, the second V is of a different nature than the first assembly. It resembles in certain respects a cantilever, of which leg **25** is the long arm; the distance between the ends of **26** and **25** being the short arm. The ratio of these distances is only 3:1 to 4:1, thereby avoiding low resonance. Its legs are more under compression or tension than bending. In that respect it does agree with the first-mentioned V and for this reason can be considered as a closed structure.

With a construction of this type an assembly is furnished which will be rigid enough to give an over-all natural frequency of vibration of more than 2000 c.p.s., and one which will also furnish a motion range adequate for relay purposes. The resonance frequency remains substantially constant from one extreme position to the other. The V embracing arms **23** will be most responsive to vibration along axis X, but substantially non-responsive to vibration along axis Y. The V embracing arms **25** and **26** will be more responsive to vibration along the Y axis. Accordingly, maximum sensitivity to external vibration is reduced.

It is feasible to arrange the second stage lever of the cascade parallel to the first stage. This has been illustrated in FIG. 13, in which the reference numerals **20** to **24** inclusive designate similar or identical parts to those heretofore described. Additionally, in this view it will be observed that the second multiplier includes a link **29** connected to the short arm of a lever **30** pivotally supported as at **31**. The outer end of this lever mounts a contact **32** for cooperation with a contact **33**. The forces generated by the two mechanisms incident to vibration along the axis X will oppose each other in the connecting link **29**. In theory, this could reduce the over-all response to zero. However, to achieve this the forces would have to be equal and 180° out of phase.

As shown in FIG. 14, the motion-multiplying mechanisms may include what might be termed two flat V's **33′** and **34′**, the parts of which are flexibly or rockingly connected at points such as **35**. A heater element **36** is associated with the base or actuating member **34** and serves to control the functioning of the relay. Arms **37** carrying cooperating contacts are mounted in line with, or adjacent the apex of each of assemblies **34′** and **33′**. The relative motion between these contacts is the expansion of the actuating member multiplied by the sum of the multiplications of the two mechanisms, rather than by their product. As far as vibration response is concerned, mechanisms constructed along the lines indicated in FIG. 14 will have characteristics similar to those of the mechanism traversed in FIG. 13.

Employing a structure embodying the design of FIG. 12, a first resonant frequency at the contact **27** as high as 2000 c.p.s. has been obtained; the gap between the contacts being .015″ for normal time settings. With a view to suppressing this first resonance point, it is feasible to resort to the structure schematically shown in FIG. 15. In that view the first motion-multiplying mechanism includes a pair of generally L-shaped arms **38** pivotally or flexibly connected to each other to provide an apex portion, and similarly connected at their outer lower ends to a base member **39**. The latter has the usual heating element **40** associated with it. Thus, a flat V structure similar to one of the units of FIG. 14 is provided. In common with the assemblies of preceding and succeeding figures, an isoceles triangle arrangement is present. Similarly to the structures shown in FIGS. 12, 13 and 14, a link **41** connects one end of the base to have capabilities of controlled movements with respect to the supporting frame **20** or its equivalent. The second motion-multiplying mechanism is preferably identical with that shown in FIG. 12 and includes a pair of arms **42**, one of which is flexibly or pivotally connected adjacent the apex of the arms **38**, with the second arm **42** similarly connected to frame **20**. A contact **43** is disposed adjacent the apex of this second mechanism and cooperates with a contact **44** carried by the frame **20**. Also supported by the frame or a fixed point of reference is a light spring **45** extending at a substantial angle to the arms of the second motion-multiplying mechanism. This spring supports a semi-spherical projection or ball point **46** bearing against the second arm **42**. Due to the disposition of the parts with respect to each other, a pivotal motion of the second multiplying mechanism will cause a rubbing action or friction between the arms carrying contact **43** and the bearing surface **46**. This friction prevents the vibration at contact

43 from building up to a substantial amplitude at or near the resonant frequency. The lower the mass of the second multiplying mechanism embracing the arms **42**, the less pressure will be required between these arms and bearing surface **46**. With this pressure being of low value, the resultant friction does not interfere with the normal motion of the contact body **43** incident to the expansion and contraction of the base member **39**. However, it is adequate to reduce the response to vibration at this first resonant frequency to a negligible factor.

As a result of tests, it was discovered that no matter how rigid the structure involved, the timing of thermal relays generally tends to increase under the influence of unidirectional acceleration. The increase varies with the direction of the acceleration force relative to the relay. Only rarely does the timing decrease or remain constant. The decrease is never very large, but the increase can be in excess of 100%. This is to be attributed not so much to the mechanical effect of the accelerating force, but rather to the increase in thermal convection currents inside the relay enclosure. These increased thermal currents increase thermal coupling between the actuating and compensating members. This is substantiated by the fact that if the relay is evacuated, the effect of unidirectional acceleration is greatly reduced and becomes negative when the direction is such that mechanical compliance would lead one to expect a decrease. In a well-designed structure this mechanical compliance can be reduced to a negligible factor.

However, as a practical matter, evacuation is not the simplest and most effective way to eliminate acceleration sensitivity. Even a small amount of leakage has a pronounced effect on the operation of a relay which was originally adjusted in a substantially complete vacuum. This small leakage can affect the relay to an extent such as to render it inoperative. Therefore, the reliability of the unit is reduced. However, by disposing a partition or baffle as at **47** within what might be termed the "enclosed" structure, an effective coupling by convection currents is prevented between the actuating and compensating members of an assembly. The result obtained by such a structure is almost as effective as with a substantially complete vacuum, without giving rise to the objections inherent to the use of a vacuum. With the arms being of L-shape, they provide the necessary clearance for the baffle, with each arm remaining rigid. Position or orientation sensitivity is simply another manifestation of the effect of convection currents on a smaller scale. It is also effectively eliminated by the use of a baffle or partition, such as **47**.

The heaters **22**, **36** and **40**, heretofore referred to, may be enclosed in members **21** or **39** in a manner corresponding to the disclosure of my prior Patent No. 2,700,084 of January 18, 1955. Where it is desired to have time delays shorter than are achievable by such a member, an externally heated thin strip or ribbon may be employed. However, it then becomes necessary to keep this ribbon under tension at all times. This could be achieved by increasing the pressure of spring **45**, as in FIG. 15. Such increase would result in a substantial increase in the friction between the bearing surface **46** and the arms **42** to a degree which would probably affect the timing accuracy of the relay. Therefore, it is better to use separate springs for biasing and damping. This has been shown diagrammatically in FIG. 16.

In that view, and similarly to FIG. 15, a pair of L-shaped arms **48** are provided which are rockingly connected to each other and to a base **49**. With the latter, a heater **50** is suitably associated. A baffle or barrier **51**, corresponding to unit **47**, is disposed within the space between these arms and base **49**. Connected to a point adjacent the apex or coupling of arms **48** is the second motion-multiplying mechanism **52**, carrying a contact. This mechanism may be in all respects similar to the mechanism heretofore described in FIG. 15. Its contact is engageable with a contact 53, and a spring 54 carrying a suitable bearing surface cooperates with this second mechanism in a manner similar to parts 45 and 46 in FIG. 15.

Additionally, springs 55, conveniently presenting spherical or semispherical bearing surfaces at their free ends, are mounted by the supporting structure 20 and engage the arms 48 providing the V at opposite points beyond its apex. The motion at the outer end of springs 55 is extremely small and occurs incident to the expansion and contraction of the actuating member or base 49. Moreover, springs 55 are placed as nearly parallel to members 48 as is feasible, thereby reducing the relative motion between the tips of springs 55 and members 48 to a minimum. Accordingly, friction at these points is minimized and has negligible effects on the timing accuracy, despite the fact that the pressure of the springs on members 48 may be substantial. It will be understood that while spring 54 is primarily provided to produce a damping effect, it does contribute to a small degree toward tensioning the parts. Also, while springs 55 are provided mainly for the purpose of tensioning, they may exert a slight damping effect.

In this assembly and with the use of a ribbon-type base, this actuating element is likely to have a resonance point below 2000 c.p.s. While this will cause negligible motion at the contact carried by arms 52, it could result in fatigue failure of the ribbon, the heater-connecting leads, etc. This resonance point is conveniently suppressed by the use of a light damping spring 56 carrying a suitable bearing engaging the center of base element 49. An insulating strip 57 is desirably interposed between the heater winding and spring 56.

Thus, in each of the designs shown in FIGS. 12, 15 and 16 there is provided a pair of motion-multiplying mechanisms connected to each other in cascade. The primary mechanism involves rockingly connected and relatively rigid members, of which one provides a base element. That element, when exposed to heat, will expand, carrying with it the adjacent ends of the members connected therewith. Those members provide a central or apex portion to which there is imparted movement of a magnitude substantially greater than the expansive movement of the base element. That element has one end fixedly connected to a supporting frame. The opposite end of the element is movably connected to the frame, preferably by a link, so that its movements are controlled.

The secondary motion-multiplying mechanism involves a pair of rockingly connected members, one of which is coupled for movement with the central or apex portion of the first mechanism. The other member of that secondary mechanism is conveniently rockingly connected to the base, as in FIGS. 12, 15 and 16. This will result in the central zone of connection of the members of that secondary mechanism having movement which will be greatly magnified over the movement of the central or apex portion of the first mechanism.

To this zone there is connected a contact engageable with a second contact to control the circuit. It is a preferred concept of the invention to have the mass of the mechanisms decreasing from the base element through to the part of the second mechanism which has maximum movement and to which is connected the controlling contact. Also, it is preferred to have the axes of maximum sensitivity to shock and vibration of the mechanisms at substantially right angles to each other, so as to minimize these factors.

Moreover, it is in many instances preferred to resort to a damping action effective over the complete range of vibration to which the unit is subjected. This action will, according to the present disclosures, not induce a failure of the assembly. Also, it will in no manner affect sensitivity of control of the relay. In this manner, a unit is provided which will operate with entire satisfaction even when exposed to high frequency vibration.

The relays will be enclosed, and this enclosure conveniently provides the aforementioned supporting frame. The thermal convection currents are preferably deflected in their flow, so that they cannot link the base and compensating members directly when the relay is subjected to varying amounts of unidirectional acceleration.

A practical embodiment of the structure shown in FIG. 15 is illustrated in FIGS. 1 to 8 inclusive. Referring primarily to FIG. 1, a suitable type of casing has been shown at 58, which may have any desired outline and which may be closed by a cover 59. Supporting brackets or foot portions 60 are preferably integral with that casing and may receive securing elements (not shown). Within the casing two multiplying mechanisms arranged in cascade are disposed. As indicated in FIGS. 12 to 16 inclusive, the weight of the moving parts decreases rapidly as the motion is multiplied.

Thus, referring to FIG. 2, the numeral 61 indicates the electrically heated actuating or base member of the initial assembly, to which current is supplied through leads 62. As shown in FIG. 1, these may be continued exteriorly of the casing, in the form of terminals 63. The actuating member conveniently has a construction similar to that disclosed in my afore-mentioned patent, and is preferably made of a material with a high coefficient of expansion, such as stainless steel.

A channel member 64 has L-shaped brackets 65 secured to its ends by, for example, spot welding. Actuating member 61 is supported on brackets 65 by two flat spring members 66, also conveniently by spot welding. The flanges of one of the brackets 65 are secured, for example, again by spot welding, to one end of a wide flat spring 67. This may be similarly attached to a boss or supporting portion 68 extending from the inner face of the casing. A spring 69, similar to spring 67, is secured at one end to the second bracket 65 and at its opposite end is secured to a bracket 70 projecting from the inner face of casing 58. A channel-shaped supporting plate 71 is attached to the underside of bracket 70. An extension of the adjacent spring 66 passes through slots in the spring 69 and plate 71 and is attached to a flange 71′ extending outwardly from the surface of supporting plate 71. Accordingly, springs 66 and 69 furnish for the adjacent bracket 65 a crossed-spring pivot.

The side flanges of channel member 64 are reduced in height toward the center of that member. Adjacent that center zone they are completely eliminated to provide a notch portion, as indicated at 72. In line therewith, the base of channel 64 is preferably formed with an opening. Accordingly, there is created at this point a zone of flexure or swinging connection such that the two end sections of the channel member 64 may rock with respect to each other. To one side of this zone the web of the channel is pierced so as to receive a pin 73. Insulation is interposed between this pin and the adjacent edges of the channel member to electrically isolate pin 73 from the channel member. Conveniently, the structure of the insulating layer comprises a glass bead 74, which, as shown in FIG. 7, is supported by an eyelet 75. It is thus apparent that as the primary motion-multiplying mechanism of the relay functions, pin 73 will be moved along its axis.

It should be noted, however, that as long as base member 61, channel member 64 and brackets 65 are made of the same material, or of materials having the same coefficient of thermal expansion, any change in ambient temperature causing an equal change in temperature of these parts will not cause any axial motion of pin 73. The ambient expansion of member 64 and brackets 65 compensates for the ambient expansion of base member 61.

Extending parallel to and spaced outwardly from channel 64 is a channel member 76. The latter is maintained in position by having one of its ends secured to spring 67 at a point intermediate the attachment of the latter to bracket 65 and support 68. The opposite end of member 76 extends adjacent a corner bracket 77 and is connected to the latter by means of a flat spring 78. That spring extends through a slot in member 71, to the outer end of which channel 76 is rigidly connected.

As shown to best advantage in FIGS. 3, 7 and 8, the web of channel member 76 is pierced at four points and provided with eyelets 79, which preferably receive insulating bodies in the form of glass beads 80, in turn mounting pins 81, 82, 83 and 84. A T-shaped bracket 85 is supported between pins 81 and 82 adjacent one side of channel member 76. A strip 86 is supported between pins 83 and 84 adjacent the opposite side face of the channel. This strip carries a contact 87 at a preferably central point.

Still referring primarily to FIGS. 7 and 8, a flat spring 88, bent into a sharp V to provide a proper unit or assembly, supports adjacent its apex portion a contact 89 in line with contact 87. One leg of this spring is attached to bracket 85, and the opposite end of the same is secured to pin 73. A small V-shaped piece 88′ is preferably inserted between and attached to the legs of the spring assembly 88 near its tip. The purpose of this inner V is to strengthen the tip zone of the spring 88 and to provide a path by which the heat, generated in the zone of the contacts 87 and 89 under heavy current load, can be distributed over both the legs of assembly 88. This will prevent unequal expansion of these legs as a result of this heat. As is apparent, uneven expansion might otherwise interfere with the proper operation of the relay.

The body of spring 88 extends through an opening 90 in the base or web of channel member 76. Also extending through this opening is a leaf or spring strip 91. The inner end of the latter is secured to the upwardly bent shank or leg of bracket 85. Its opposite end carries a bearing member 92, having a spherical contour, which engages the rear surface of the spring assembly 88. With a view to adjusting the position of contact 87, a friction nut 92′ is attached to the inside of channel 76 opposite contact 87, and the flange of channel 76 is provided with an opening in line with the nut. Into this nut is inserted a screw 93 conveniently formed with a glass tip in engagement with the rear face of strip 86. It is apparent that in this manner, strip 86 may be flexed, so that contact 87 assumes a properly adjusted position.

As afore brought out, leads 63 conveniently extend through the base of the casing and connect wires 62 with the coil of actuator 61. Similarly, leads 94 are fused into and insulated from the casing, preferably by glass beads. These leads extend into the body of the casing, and one of them is connected to the end of pin 82. The other is connected to one of the pins 83 and 84. A tube 95 is sealed preferably to the base of the casing and disposed in line with screw 93. Accordingly, after the assembly is completed, it can be tested and adjusted by inserting a screwdriver through the bore of the tube and turning the screw. After the adjustment has been perfected, air may be exhausted through this same tube. Thereafter, and again using the tube, the casing may be filled with a suitable gas, if desired. Otherwise it may be left under vacuum. In any event, the tube is finally pinched off and sealed, in accordance with conventional practice.

A shield 96 in the form of a plate is mounted centrally between actuating member 61 and the compensating assembly. It is preferably made of a material, such as mica, with low heat conductivity and high opacity for heat radiation. A metal shield may also be used, if desired. In any event, the unit is supported between brackets 97 and 98 secured to the casing and cover respectively. This shield acts as a barrier to prevent a change in thermal coupling by convection currents, between the several parts, when current is supplied through wires 62 to operate the actuating member, while the entire relay is subjected to high unidirectional acceleration. As illustrated, the shield extends between brackets 65 through the entire height of the casing and serves to prevent the build-up of strong

convection currents under the influence of such high unidirectional acceleration.

Considering the operation of the assembly as heretofore described in connection with FIGS. 1 to 8 inclusive, it will be understood that with current supplied through leads 63, the heater element of the actuating member 61 will be energized. Accordingly, the latter will expand longitudinally and cause the center of the compensating member, as defined by channel element 64 to move toward the actuating member, incident to a flexing action. Accordingly, pin 73 will exert a thrust on the spring or assembly 88. Such force acting on the leg of the assembly adjacent strip 86, it follows that contact 89 will be shifted toward contact 87 to a point where they finally engage. Therefore, the circuit between pins or leads 94 will be closed, in that a complete current path will be furnished via one of these pins through pin 82, bracket 85, spring assembly 88, contacts 89 and 87, strip or bracket 86 and pin 84 to the second lead or pin 94. The time delay between the application of power to pins 63 and the closing of the circuit depends mainly on the watts input to the actuating member 61, the thermal capacity of the mass of the actuating member and the initial gap between contacts 87 and 89.

The application of power may be continued beyond the time of contact closure. The parts will ordinarily be designed so that they have a range of movement beyond the minimum required to hold contacts 87 and 89 in closed positions. Therefore, with the contacts engaged, further expansion of the actuating member will cause pressure between those contacts to build up. This will create elastic stresses in the structure. Due the extremely low weight of spring assembly or unit 88, this element and its supporting structure (including also channel member 64) can be made sufficiently flexible to keep these stresses within the elastic limit of the material, and yet be sufficiently rigid to prevent mechanical resonance below 2000 c.p.s. When power to pins 63 is removed, the contacts will continue to remain closed until the actuating member has cooled and its length has been reduced to a point where the stresses are reduced to zero. In this connection, it will of course be understood that the several parts of the assembly are conveniently formed of the same metal, so that variations in ambient temperature will not result in differentials of expansion between the components of the assembly.

A comparison of FIGS. 7 and 13 shows that the direction of contact motion in the first figure is along axis Z, while in FIG. 15 it is along axis Y (see FIG. 12). However, since both these axes are at right angles to the axis X (FIG. 2), it will be clear that the maximum sensitivity to vibration is reduced because the V defined by member 64 will be most responsive to vibration along axis X, but substantially non-responsive to vibration along axis Z. The V embracing member 88 will be more responsive to vibration along axis Z.

The entire operating mechanism is supported in the casing at only three points, involving brackets or members 68, 70 and 77. Only the bracket 70 is rigid in all directions. The support on bracket 77 through spring 78 is rigid in directions Y and Z, but permits expansion and contraction of bracket 70 and plate 71 independently of the shell or casing 58, and vice versa. The support on boss or bracket 68 through spring 67 is rigid in directions X and Z, but permits expansion of all parts of the assembly along the axis Y. It also permits of a slight pivoting motion of bracket 65 connected to spring 67, as well as the adjacent end of channel member 64. This will be under the influence of the expansion force exerted by actuating member 61. Springs 66 and 69 allow a similar pivoting motion of the bracket 65, to which they are connected, and of the base portion of channel member 64 attached to this bracket.

From the foregoing, it is apparent that actuating member 61, which involves the heaviest component of the assembly, is rigidly supported in all three axes, conceding that supporting plate 71 is rigid. Its right-hand end is restrained from movement along its axis by spring 66, and from movement at right angles to the axis, in the plane of the drawing, by spring 69. Movement of this end at right angles to the plane of the drawing is prevented by the fact that spring 69 is of substantial width.

Spring 67 being also of substantial width, the left end of base member 61 is restrained from movement at right angles to its axis both in the plane of the drawing and at right angles to it. It is, however, free to move along its axis when member 61 expands or contracts as a result of changes in its temperature.

Consequently, all forces acting on base member 61 due to vibration and shock are transmitted directly from and to the case or frame by springs 66, 67 and 69, permitting no change in their relative positions except for longitudinal expansion of base member 6. Channel member 76, which is the supporting frame and "point of reference" corresponding to part 20 in FIGS. 12 to 16 inclusive, is equally rigidly supported. Both must have sufficient resistance to bending or torsional strain not to be resonant below 2000 c.p.s. in the direction of the X or Z axis.

All parts of the operating structure being made of the same material as actuating member 61, or else of materials with the same coefficient of thermal expansion, a change in ambient temperature will not cause relative motion between contacts 87 and 89. This is true irrespective of the material used to provide the casing. Not only must this expansion member and the channel element 64, or its equivalent, be made of the same metal, but also springs such as 67 and 69, as well as bracket 70, should be made of the same material. Even the coefficient of expansion of pins 73, 81 and 82 is of importance. This is true because any difference in their expansion in comparison with spring 67 and bracket 70 is multiplied by the action of the V spring assembly 88. The entire relay may be mounted on a suitable supporting surface, conveniently by the use of the extensions or foot portions 60. The relay is especially useful in connection with a printed circuit defined on one side of an insulated panel, which latter mounts the relay upon its opposite face. Pins 63 and 94 are, of course, extensible through such a panel for connection to the circuit defined thereon.

In the structures so far reviewed the relay in each instance has included contacts normally spaced from each other so as to provide an open circuit. It is obvious that while following the same teachings, it is entirely feasible to furnish a relay in which the contacts are normally engaged, so that the circuit is closed. However, these contacts will separate after the expiration of a desired time interval. In this connection, attention is invited to FIGS. 10 and 11, in which numerals such as 61, 64, 73–75, 82, 85 and 93 have been employed to designate parts substantially identical with those heretofore designated by those numerals. In this view the frame member 76 also corresponds generally to the member 76 as heretofore described. However, strip 97′, corresponding to strip 86, mounts in FIGS. 10 and 11 a U-shaped bracket 98′. To the inner face of the base of this bracket there is secured a contact 99. A cooperating contact 100 is carried by a spring strip 101, which has its inner end suitably secured to bracket 85. Bracket 85 also mounts the upper arm of a V-shaped spring assembly 102 corresponding to the assembly 88. That strip may also support a small V-shaped piece 102′ corresponding in structure and function to piece 88′ previously described. The lower arm of assembly 102 is attached to pin 73. A bearing member 103, preferably presenting a convex contact surface, is mounted by spring 101 to extend from its side face in a direction opposite to that of contact 100. This bearing member engages with the face of spring assembly 102.

It is obvious that in this form of structure, spring assembly 102 serves only the function of pushing the movable contact 100 in an upward direction, or else of permitting that contact to be lowered. In this connection it will be appreciated that spring strip 101 normally urges the contact in the latter direction. Screw 93 is adjusted so that contact 99 exerts a certain pressure on contact 100 and spring assembly 102 when the relay is not energized. This pressure causes a definite deflection at the tip of the spring assembly 102 from its free position. Therefore, elastic stresses are set up in the structure. When power is now applied to the heater of the actuating member, the initial expansion of the latter gradually neutralizes these stresses until they are eliminated. Thereafter, the contacts 92 and 100 separate.

To modify the structures shown in FIGS. 1 to 11 inclusive in accordance with FIG. 16, it is necessary only to substitute a suitably externally heated ribbon for the base or actuating member of the motion-multiplying mechanism as disclosed, for example, in FIGS. 7 to 10 of my prior application for United States patent on "Electrical Control Device" filed on March 13, 1958 under Serial No. 722,364. Otherwise, the assembly should preferably follow generally an arrangement of mechanism as heretofore disclosed, in which the first motion-multiplying mechanism will involve a base in the form of an actuating member connected to the outer or compensating member in a manner such that movement of the base incident to expansion of the latter will cause a magnified movement on the part of the outer member. The second motion-multiplying mechanism is arranged serially, or in cascade relationship, with the first mechanism by having its operating part connected to the pin 73, or its equivalent, through suitably coupling the free arm of the spring assembly 88 to that pin. Therefore, the actuating part of the second mechanism, which is adjacent the apex of the spring assembly, will have a magnified or multiplied movement with respect to the adjacent contact, in view of the fact that the second arm of the spring assembly is connected to what might be termed a base provided by bracket 85. Additionally, one or two flat leaf springs may be attached to the back of channel 76 adjacent its ends and bearing with their free ends with substantial pressure against compensating member 64 adjacent its center. This will place the actuating member under continuous tension, as heretofore described. Another flat leaf spring may be attached to the inside of casing 58 and made to bear with light tension with its free end against the central portion of the actuating member to suppress resonant vibration, also as previously described.

From the foregoing, it is apparent that a relay assembly is furnished which avoids the difficulties inherent in certain structures, as previously outlined. Preferably a "closed" structure is furnished, and the use of cantilevers is minimized. The weight of moving parts decreases rapidly as the motion is multiplied. This decrease is far more rapid than inversely proportional to the ratio of multiplication. The motion-multiplying mechanisms are arranged in cascade, with their axes of maximum shock and vibration sensitivity at right angles to each other. The damping of vibration is achieved, and the biasing and damping functions are separated, by using different springs for each purpose. Thermal convection currents are blocked. The weight of the outermost motion-multiplying assembly is only a fraction of that of the base or actuating mechanism, so that a properly "tapered" design is achieved.

Thus, among others, the several objects of the invention as specifically aforenoted are achieved. Obviously, numerous changes in construction and rearrangements of the parts might be resorted to without departing from the spirit of the invention as defined in the claims.

I claim:

1. A relay including in combination a base, means for heating said base to cause expansion of the same, a mechanism operatively connected to said base whereby parts of said mechanism will have movements greater

than the expansive movements of said base, a pair of cooperating circuit-controlling contacts, one of said contacts being connected for movement with said mechanism parts, said one contact being subject to vibration transmitted to said relay from a source exteriorly of the same, the connection between said one contact and mechanism parts comprising a further motion-multiplying mechanism and means yieldingly bearing and frictionally rubbing against said further mechanism, thus damping vibratory movements of said one contact.

2. A relay including in combination a base, means for heating said base to cause expansion of the same, a mechanism operatively connected to said base whereby parts of said mechanism will have movements greater than the expansive movements of said base, a pair of cooperating circuit-controlling contacts, one of said contacts being connected for movement with said mechanism parts, a compensating member forming a part of said mechanism for preventing movements of the parts of the latter and said contact when said base expands and contracts due to ambient temperature changes, a shell enclosing said base and said mechanism, and a shield supported within said shell at a point between and spaced from said base and compensating member, said shield substantially dividing the space within said shell into two compartments to the extent that the thermal linkage by convection currents between said base and said compensating member is reduced, even under high unidirectional acceleration of the relay as an entirely, to a magnitude which is small compared to their linkage by thermal conduction and radiation.

3. In a relay as defined in claim 2, said shield extending from a point adjacent one inner face of said shell to an opposed face thereof.

4. A relay including in combination a motion-multiplying mechanism comprising an expansible and contractable base, an outer member and means for connecting said outer member to said base whereby in response to expansive movement of the latter said outer member will have magnified movement, a second motion-multiplying mechanism, an actuating part in such second mechanism connected to said outer member, an operating part also in said second mechanism, a pair of relatively movable contacts, one of which is connected to said actuating part to be moved thereby, heater means cocacting with the base member of said first mechanism for causing expansive movements on the part of such member, a supporting structure, means for securing the base of said first mechanism against movements with respect to said structure in a zone adjacent one of its ends, the opposite end of said base being movable with respect to said supporting structure, and a link interposed between said supporting structure and said last-named end of said base to provide a pivotal connection between the parts.

5. A relay including in combination a base, means for heating said base to cause expansion of the same, a mechanism operatively connected to said base whereby parts of said mechanism will have movements greater than the expansive movements of said base, a pair of cooperating circuit-controlling contacts, one of said contacts being connected for movement with said mechanism parts, said one contact being subject to vibration transmitted to said relay from a source exteriorly of the same, means for damping vibration of said one contact, biasing means cooperating with said mechanism parts for exerting tension on said base, said damping and said biasing means comprising separate springs thrusting against different points of said mechanism parts, and means for mounting said springs independently of said parts and said base.

6. A relay including in combination a primary motion-multiplying mechanism embracing an expansible base and a pair of inflexible arms movably connected to said base at spaced points and to each other to provide an apex portion, heating means acting upon said base to cause expanding movement of the latter and magnified movement of said portion, a second motion-multiplying mechanism embracing a pair of relatively movable arms connected to each other, to a support providing a point of reference and to the apex portion of the first mechanism, the arms of the second mechanism providing an apex portion having magnified movement in comparison with that of the apex portion of the first mechanism, a pair of cooperable circuit-closing contacts, means for mounting one of the same adjacent the other and the other contact of said pair being connected for movement with the apex portion of the second mechanism.

7. In a relay as defined in claim 6, the apex portion of said first mechanism moving in a given direction, and the apex portion of the second mechanism moving in a direction substantially at right angles to the movement of the first apex portion.

8. A relay including in combination a multi-part mechanism comprising a base formed of thermally expansible material, arms connected at spaced points to said base and to each other to provide an apex portion, means adjacent said base to heat and expand the same, the arms causing said apex portion to have a greater range of movement than the expansive movement of the base as it is heated, a second multi-part mechanism connected to said apex portion and having an area shiftable through a greater range of movement than said apex portion as said base is heated, a pair of cooperating contacts, one of said contacts being mounted by said area and the mass of the second mechanism being a fraction of the mass of the first mechanism.

9. In a relay as defined in claim 8, said first mechanism being substantially rigid, the expansion and contraction of said base being multiplied through to said area of the second mechanism and the mass of the mechanisms changing at least as rapidly as inversely proportional to the ratio of multiplication.

10. In a relay as defined in claim 8, a casing enclosing said mechanisms and contacts and means supporting said mechanisms and contacts at a plurality of points within said casing, said supporting means being yielding at not less than all but one of said points.

11. A relay including in combination a base of thermally expansible material, means adjacent said base to heat and expand the same, brackets at opposite ends of said base and rockingly connected thereto, a member extending between said brackets and having its ends rigidly connected one to each of the same, said member having a zone of flexure intermediate its ends, a second member connected to said first member to extend in parallel and spaced relationship thereto, a V-shaped spring strip having one of its legs connected adjacent the zone of flexure of said first member to move therewith, its other leg being substantially fixed, a first contact supported against substantial movement with respect to said second member and a second contact supported for movement with said strip to cooperate with said first contact.

12. In a relay as defined in claim 11, spring means frictionally and slidably bearing against said strip to damp vibrations of the same.

13. In a relay as defined in claim 11, said second contact being secured to said strip adjacent its arch portion, and means for adjusting said contacts toward and away from each other.

14. In a relay as defined in claim 11, the support for said second contact comprising an end of a flexible element, means for fixedly supporting the opposite end of the element against movement with respect to said second member, and said spring strip thrusting against said element to displace the contact carried thereby in a direction aligned with respect to said first contact.

15. In a relay as defined in claim 14, a bracket mounted for limited movement with respect to said second member supporting said first contact, and means carried by said second member and movably bearing against said bracket for adjusting the position of the former.

16. A time-delay relay comprising an element longitudinally expansible by heat, a portion of said element constituting a point of reference; means adjacent said element to heat and expand the same, a first motion multiplier including two joined arms in mutually similar conditions of longitudinal stress operatively connected between the extremities, and motionally responsive at their junction to the length, of said element; a second motion multiplier including two joined arms in mutually opposite conditions of longitudinal stress operatively connected between said junction and a point whose position relative to said point of reference is at least substantially fixed; and circuit control means responsive to the movement of the junction of the arms of said second motion multiplier.

17. In a relay as defined in claim 16, said circuit control means comprising a pair of contacts, one of said contacts being connected for movement with said second motion multiplier to engage and separate from the second of said contacts and means yieldingly bearing and frictionally rubbing against a part adjacent said one contact to thus damp vibratory movements thereof.

18. A time-delay relay comprising in combination a first structure bowable toward and away from a plane containing its extremities to a degree responsive to the separation between these extremities; a second structure operatively connected between an intermediate point on said first structure and a nearby point in said device which is displaced from the line defining the locus of movement of said first-mentioned point, said second structure having a portion extending in a direction at least principally normal to said plane to, and including a region at, a distance from said first-mentioned point large compared with the separation between said points; means forming a part of said first structure for rendering the separation between the extremities of said first structure dependent on temperature variations, means for creating such variations and switch means connected to respond to the movement of said region occurring in the plane defined by that region and said points.

19. A time-delay relay comprising in combination a first structure bowable toward and away from a plane containing its extremities to a degree responsive to the separation between those extremities; a relatively sharply V-shaped structure having its axis disposed in a direction at least principally normal to said plane, having one outer extremity operatively connected to an intermediate point on said first structure, and having its other outer extremity connected to a nearby point in said device; means forming a part of said first structure for rendering the separation between the extremities of said first structure dependent on temperature variations, means for creating such variations and switch means connected to respond to the movement of the apex of said V-shaped structure occurring in the plane defined by that structure.

20. A time-delay relay comprising in combination an element longitudinally expansible by heat, means for creating heat to expand said element; a first motion multiplier, including two arms joined together in serial relationship, operatively connected between the extremities, and motionally responsive at the junction of said arms to the length, of said element; a second motion multiplier, including two arms joined together in serial relationship, operatively connected between said junction and another point in said device, the two arms of one of said multipliers being in mutually similar conditions of stress, and

the two arms of the other of said multipliers being one in tension and the other in compression; and switch means connected to respond to the movement of the junction of the arms of the second motion multiplier.

21. A time-delay relay comprising in combination an element longitudinally expansible by heat, means for creating heat to expand said element; a first motion multiplier, including two arms joined together in serial relationship, operatively connected between the extremities, and motionally responsive at the junction of said arms to the length, of said element; a second motion multiplier, including two arms joined together in serial relationship, operatively connected between said junction and another point in said device, said second motion multiplier being disposed along a plane generally normal to that along which said first multiplier is disposed; and switch means connected to respond to the movement of the junction of the arms of the second motion multiplier occurring in the plane along which said second multiplier is disposed.

22. A time-delay relay comprising in combination an element longitudinally expansible by heat, means for creating heat to expand said element; a structure connected between the extremities of said element and bowable toward and away from said element to a degree responsive to the separation between those extremities; a motion multiplier, including two arms joined together in serial relationship, operatively connected between an intermediate point on said structure and another point in said device, said motion multiplier being disposed along a plane generally normal to that along which said element and structure are disposed; and switch means connected to respond to the movement of the junction of the arms of said motion multiplier occurring in the plane along which said multiplier is disposed.

23. A time-delay relay comprising in combination three arms joined in a closed loop, one of said arms being longitudinally expansible by heat, means for creating heat to expand said one arm whereby to move one of the points of juncture relative to the arm opposite that point; a motion multiplier, including two arms joined together in serial relationship, operatively connected between said point of juncture and another point in said device, said motion multiplier being disposed along a plane generally normal to that along which said loop is disposed; and switch means connected to respond to the movement of the junction of the arms of said motion multiplier occurring in the plane along which said multiplier is disposed.

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