United States Patent [19]

Barkan et al.

[11] **3,789,174**

[45] **Jan. 29, 1974**

[54] **EARTHQUAKE-PROTECTIVE SUPPORT SYSTEM FOR ELECTRICAL APPARATUS**

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[73] Assignee: **General Electric Company,** New York, N.Y.

[22] Filed: **Mar. 7, 1973**

[21] Appl. No.: **339,025**

[52] **U.S. Cl.** .... **200/168 R,** 52/167, 248/18

[51] **Int. Cl.** **F16f 15/00**

[58] **Field of Search** .... 248/18, 20, 358 R, 370; 52/167; 200/16 BR; 310/91

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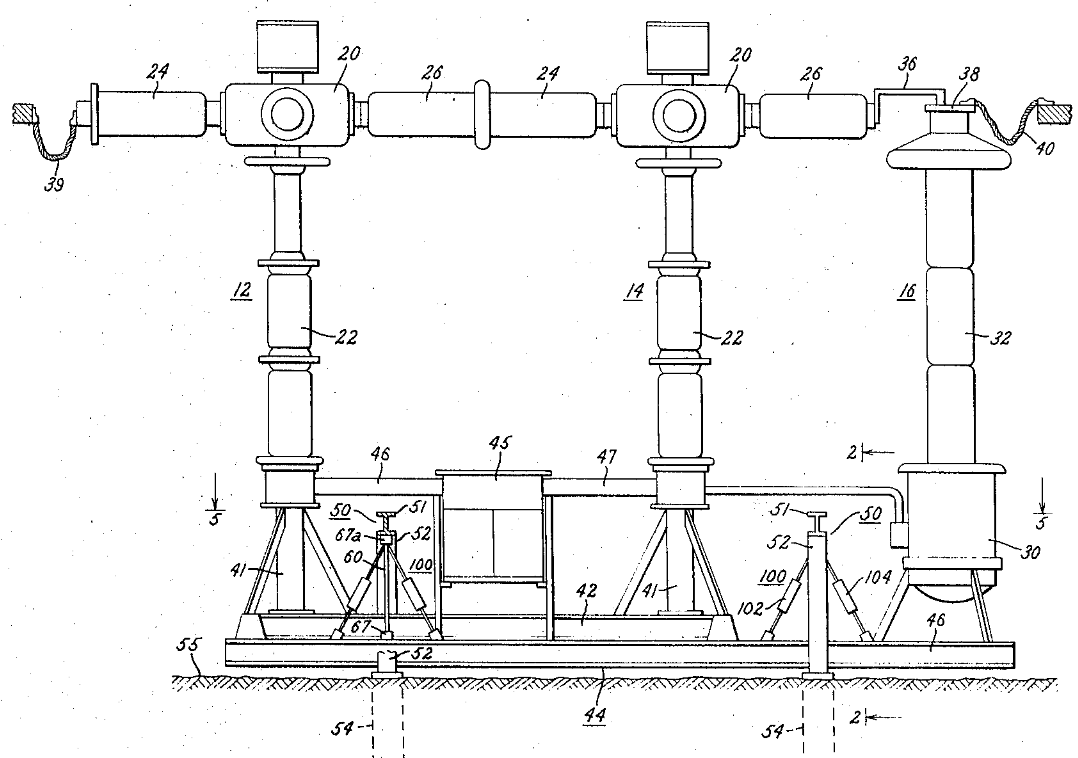
Assistant Examiner—William J. Smith
Attorney, Agent, or Firm—J. Wesley Haubner et al.

[57] **ABSTRACT**

A support system for slender-profile electrical apparatus acts to protect the apparatus against severe earthquakes. The support system comprises: (a) a rigid, horizontally-extending platform on which the apparatus is mounted, (b) a rigid framework anchored in the ground, and (c) four rigid pendulum links with universal joints at opposite ends of each link suspending the platform from the framework. Releasable restraining means normally maintains the platform fixed relative to the framework but is released in response to horizontally-directed acceleration of the ground exceeding a predetermined minimum value. Damping means dissipates the kinetic energy of the suspended mass when it moves relative to the framework.

13 Claims, 9 Drawing Figures



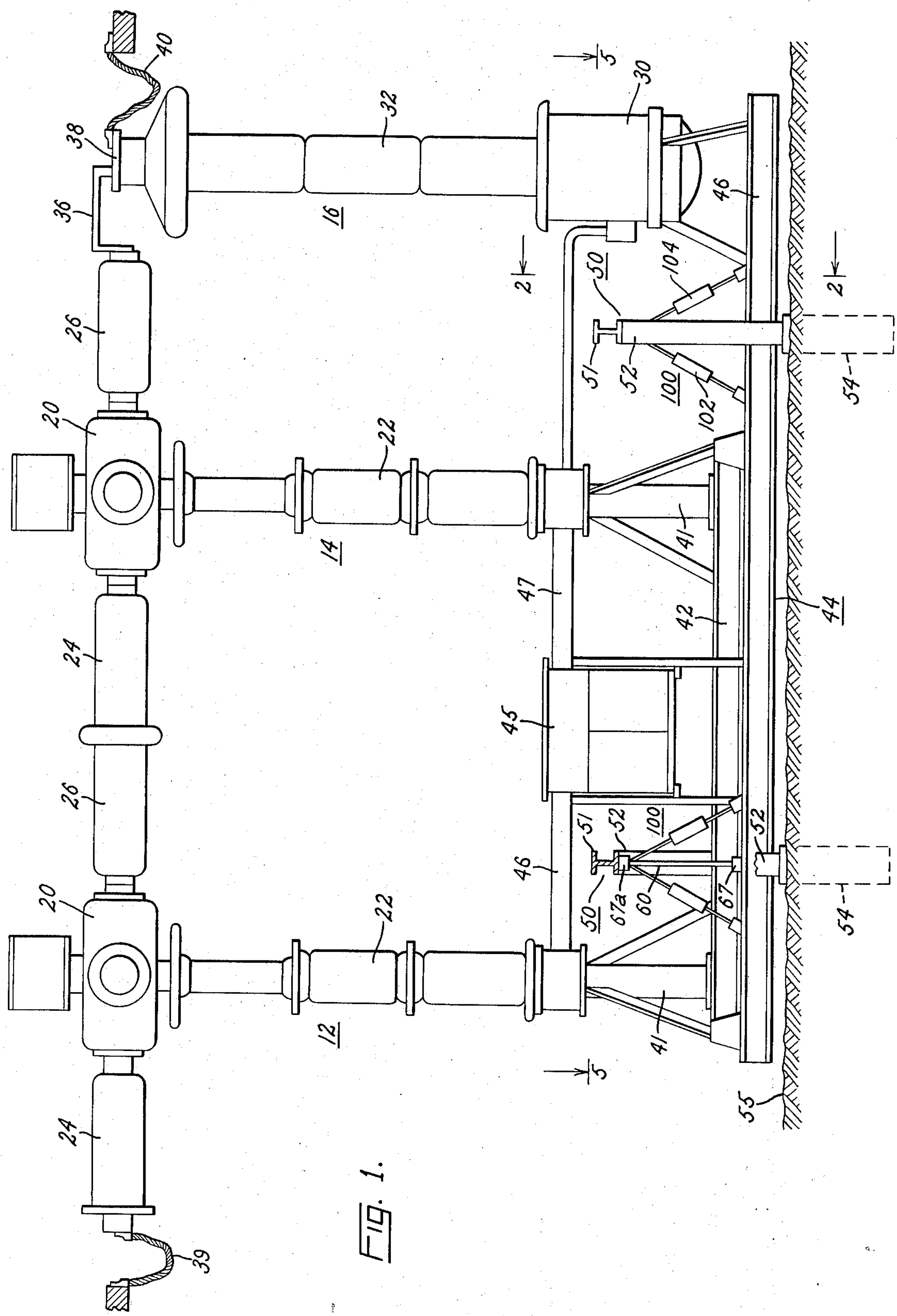

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Fig. 1.

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Fig. 2.

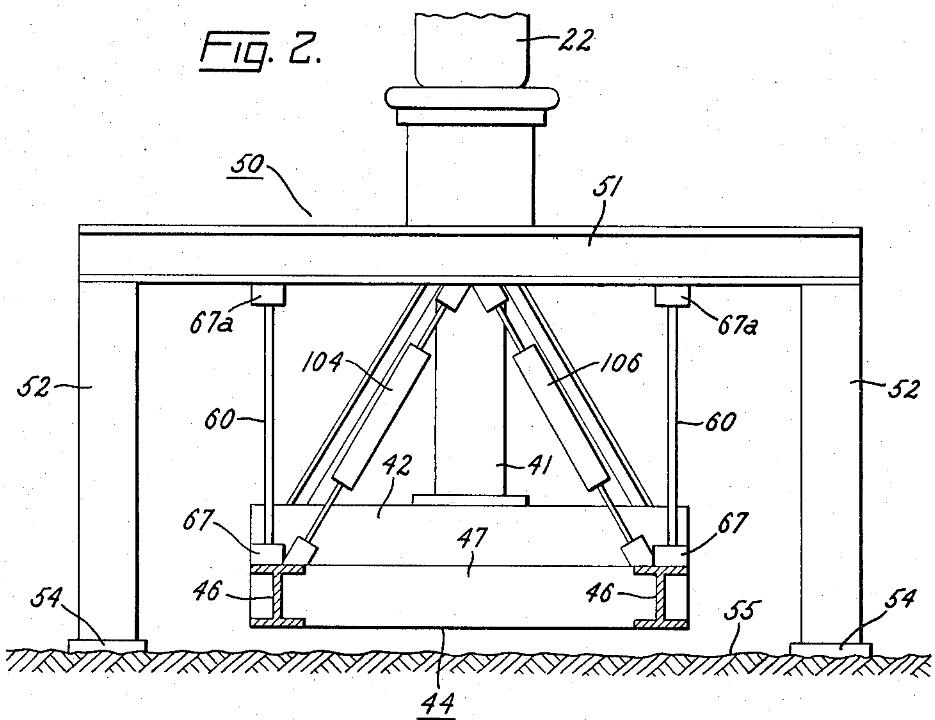


Fig. 3.

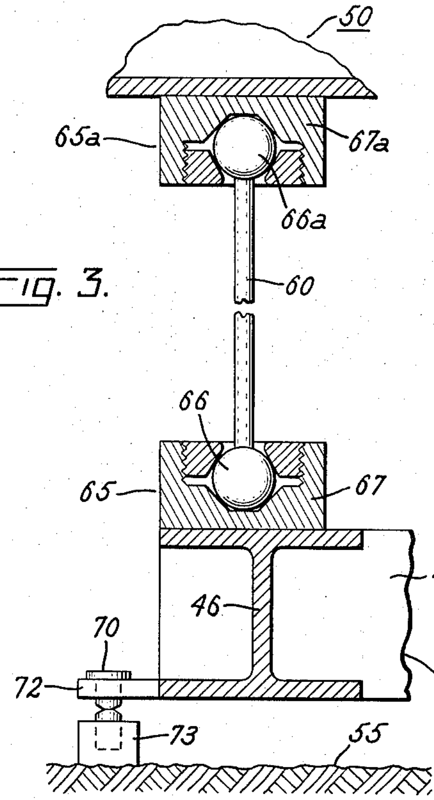


Fig. 3a.

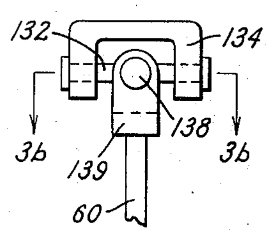


Fig. 3b.

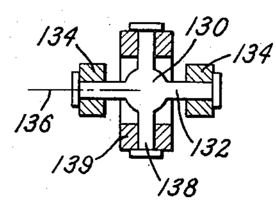


Fig. 4.

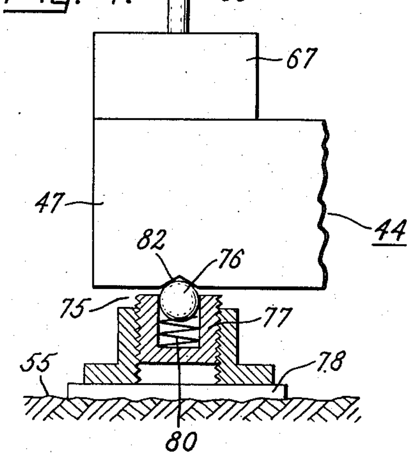


Fig. 5.

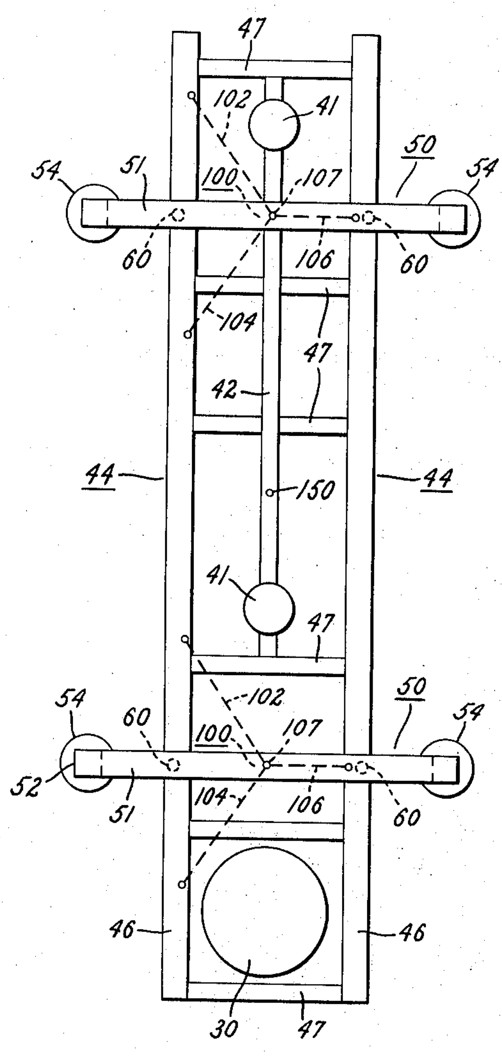


Fig. 6.

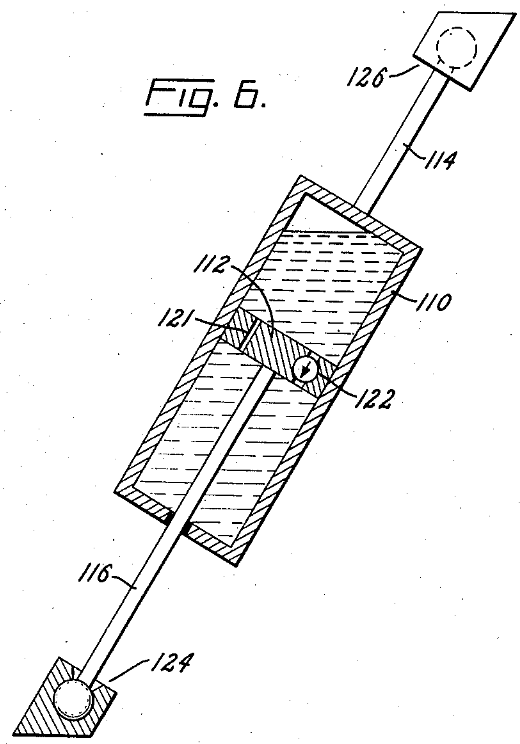
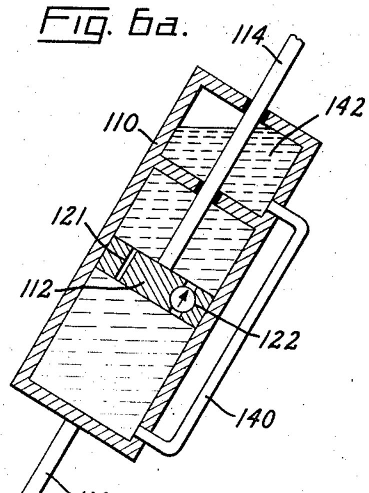


Fig. 6a.



EARTHQUAKE-PROTECTIVE SUPPORT SYSTEM FOR ELECTRICAL APPARATUS

BACKGROUND

This invention relates to a support system for electrical apparatus having a tall, slender profile and, more specifically, relates to a support system of this type that is capable of protecting the apparatus against severe earthquake forces.

Of interest with respect to this application is the following prior art: U.S. Pat. No. 2,711,297-Thiele; U.S. Pat. No. 3,592,422-Paine; and the Shock and Vibration Handbook by Harris and Crede, published by McGraw-Hill Book Co. in 1961, especially Volume 2, pages 32–37 through 32–12.

Some types of electrical apparatus, such as live-tank circuit breakers, are characterized by a tall, slender profile. Prior designs of such apparatus have not been as resistant to damage from earthquake forces as might be desired. One way of increasing this resistance to damage from earthquake forces is to reduce the fundamental natural frequency in the horizontal plane of the apparatus to a level that is significantly lower than the spectrum of frequencies associated with the maximum energy content of any foreseeable earthquake to which the apparatus might be exposed. Such a reduction in natural frequency, by reducing the acceleration of the parts of the apparatus resulting from earthquake ground motion, reduces the forces on the apparatus parts.

We achieve such a reduction in fundamental natural frequency by mounting the apparatus on a pendulum-type suspension that effectively isolates the equipment from horizontal earthquake forces. The fundamental natural frequency in a horizontal direction of such a suspended system for small motions compared to the pendulum length can be expressed by the equation:

$$F = 1/2\pi \quad g/l$$

, where F is the fundamental natural frequency in a horizontal direction of the suspended system (hertz),

g is the acceleration of gravity (in/sec^2), and

l is the length of the pendulum (inches).

By making the pendulum sufficiently long, we can reduce the fundamental natural frequency F to the desired value. It is noted that F is independent of the mass supported.

SUMMARY

An object of our invention is to construct the pendulum suspension system in such a manner that the system can effectively resist the large overturning moments developed by the tall, slender apparatus, which tend to overturn the apparatus about the pendulum pivots, especially at the end of an excursion of the suspended system.

Another object is to mount the apparatus on a pendulaum-suspended platform which remains substantially horizontal during earthquake-produced motion without swinging or oscillating about a horizontal axis in the plane of the platform.

Another object is to permit motion of the apparatus in response to earthquake-produced forces without allowing the apparatus to sway in response to wind and similar forces.

In carrying out our invention in one form, we mount the tall, slender apparatus on a rigid horizontally-extending platform, and we provide a rigid framework anchored in the ground which has portions located above and spaced from the platform. The platform is suspended from said framework portions by means comprising at least three spaced-apart substantially rigid pendulum links and universal joints at opposite ends of each link for respectively connecting the associated link to said framework and said platform. The links are of substantially the same length and substantially parallel to each other so as to form a parallelogram-type linkage that maintains said platform substantially horizontal when moved relative to said framework. Releasable restraining means normally maintains the platform fixed with respect to the framework but is releasable to permit movement of the platform relative to the framework in response to horizontally-directed acceleration of the ground exceeding a predetermined minimum value. Energy dissipating or damping means is also provided both to oppose motion of the platform relative to the framework and to dissipate the kinetic energy of the platform and the apparatus mounted thereon developed by motion of the platform relative to the framework.

BRIEF DESCRIPTION OF DRAWINGS

For a better understanding of our invention, reference may be had to the following description taken in conjunction with the accompanying drawings, wherein:

FIG. **1** is a side elevational view of a high voltage circuit breaker embodying one form of our invention.

FIG. **2** is a sectional view along the line **2—2** of FIG. **1** showing a portion of the pendulum suspension system for the circuit breaker.

FIG. **3** is a detailed view partly in section of one of the pendulums used in the pendulum suspension system of FIG. **2.**

FIG. *3a* shows a modified form of universal joint for use in the pendulum suspension system of FIG. **2.**

FIG. *3b* is a sectional view along the line **36—36** of FIG. *3a.*

FIG. **4** shows a modified form of releasable holding device for use in the system of FIGS. **1–3.**

FIG. **5** is a simplified and schematic plan view of the system of FIG. **1** taken along the line **5—5** of FIG. **1.**

FIG. **6** is an enlarged detailed view of a dashpot assembly constituting a component of the suspension system of FIG. **2.**

FIG. *6a* shows a modified form of dashpot assembly for use in the suspension system of FIG. **2.**

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

Referring now to FIG. **1,** the high voltage circuit breaker shown therein comprises two column units **12** and **14** and a high voltage current transformer **16.** The current carrying parts (not shown) of these three devices are electrically connected in series with each other in a well known manner, as may be seen for example in U.S. Pat. No. 3,612,798—Barton et al., assigned to the assignee of the present invention. Each of the illustrated column units **12** and **14** comprises a metal tank **20** normally at a high voltage, a vertically-extending column **22,** primarily of porcelain, atop which the tank 20 is secured, and horizontally-extending lead-in bushings 24 and 26 mounted on the tank at opposite sides thereof. The vertically extending column 22 serves to support the tank 20 and the bushings 24 and 26 and to electrically isolate these supported parts from ground. Within each tank there are circuit-interrupting elements (not shown) that are electrically connected in series with the usual conductors of the bushings 24 and 26. Column units of this type are conventional, and reference may be had to the aforesaid Barton et al patent or to U.S. Pat. No. 3,336,453—Beatty for more detailed showings of typical column units of this type.

The current transformer 16 is of a conventional design and, in very general terms, comprises a grounded metal tank 30, a hollow porcelain column 32 supported atop the tank, and high voltage terminals 36 and 38 located atop the column and insulated from each other. More details of a typical current transformer of this type are shown and claimed in U.S. Pat. No. 3,456,220—Stewart, assigned to the assignee of the present invention.

The circuit breaker is electrically connected in a high voltage power circuit by flexible conductive means 39 and 40 (soon to be described in more detail) located at its opposite terminals.

The vertical columns 22 of the two column units 12 and 14 are rigidly secured at their lower ends to pedestals 41, which are, in turn, rigidly secured to a common base 42; and this base 42 is rigidly secured to a horizontally-extending platform 44. These parts 41, 42, and 44 are preferably of a suitable steel. The grounded metal tank 30 of the current transformer is also rigidly secured to platform 44. The mechanism for operating the circuit breaker is located within a suitable housing 45 that is also secured to the platform 44. Linkages (not shown) for connecting the mechanism to each column unit extend through tubular housings shown at 46 and 47. In the illustrated embodiment, the platform 44 is a rigid unitary structure comprising a pair of spaced-apart, horizontally-extending I-beams 46, best shown in FIGS. 2 and 5, and suitable cross-beams 47 joining the I-beams.

For supporting the platform 44, we provide two spaced-apart rigid frames 50, each of an inverted U shape, as best seen in FIG. 2. Each of these U-shaped frames 50 comprises a horizontally-extending body 51 and a pair of spaced-apart legs 52, the feet of which are secured to massive concrete piers 54 that are solidly supported within the surrounding ground 55. These two U-shaped frames 50 taken together may be thought of as constituting a rigid framework anchored in the ground. The spaced-apart legs 52 of each frame are disposed at opposite sides of the platform 44 so that each frame, in effect, straddles the platform.

The platform 44 is suspended from the framework 50, 50 by four rigid, pendulum-type links 60, two of which are connected to each of the frames 50 at opposite sides of the platform as seen in FIG. 2. For connecting the lower end of each pendulum link 60 to the platform 44, a ball-and-socket type universal joint 65 is provided, as best seen in FIG. 3. This joint comprises a ball 66 rigidly secured to the lower end of the pendulum link and a socket 67 of conventional form rigidly secured to the platform 44. The ball fits within the socket and is free to rotate with respect to the socket for limited distances in all angular directions. The upper end of each pendulum link is connected to the frame 50 by a corresponding ball-and-socket type universal joint 65*a* comprising a ball 66*a* and a socket 67*a*.

As an alternative to the ball-and-socket type universal joint at each end of each pendulum, we can use a conventional universal joint of the type shown in FIGS. 3*a* and 3*b*. This joint comprises a cross-member 130 including trunnions 132 journalled in a U-shaped bracket 134 secured to frame 50 for mounting the cross-member for pivotal motion about an axis 136. The cross-member also includes another set of trunnions 138 extending perpendicular to trunnions 132. A yoke 139 comprises a pair of spaced-apart arms which are pivotally mounted on trunnions 138 and a hub in which the pendulum link 60 is fixed.

The four pendulum links 60 are of substantially the same length and are substantially parallel to each other so as to form a parallelogram-type support linkage for the platform 44. The parallelogram nature of this linkage, in cooperation with the constant effective length of the pendulums and the rigidity of the platform and framework, assures that the platform will be maintained substantially horizontal during any movement of the platform relative to the framework, such as will soon be described.

For maintaining the platform 44 in a fixed normal position in which the pendulum links extend vertically, we provide releasable restraining, or braking, means such as a pair of shear pin assemblies, each of the form shown at 70–73 in FIG. 3, or a pair of detent devices each of the form shown at 75 in FIG. 4. The shear pin assembly of FIG. 3 comprises a shear pin 70 extending through a lug 72 on the platform 44 and fixed in a support 73 anchored in the earth. Two such shear pin assemblies are preferably provided at spaced-apart locations. The shear pins 70 of the two assemblies, while intact, maintain the platform 44 fixed in its illustrated position against wind forces and similar low level forces acting in a horizontal direction. But in the event of abrupt horizontal ground motion, such as might be produced by a severe earthquake, a much higher force in a horizontal direction can be developed; and this force, upon exceeding a predetermined level, shears the pins 70, thus allowing such ground motion to occur independently of the platform 44. It is to be understood that the magnitude of this earthquake-produced force is directly dependent on the acceleration of the ground in which framework 50 is anchored. The reason for using two spaced-apart shear pin assemblies is to prevent the circuit breaker from being moved by wind loads in a rotational manner about a single shear pin as a central axis.

The detents, one of which is shown at 75 in FIG. 4, act in a manner similar to the shear pin assemblies 70–73 in that they block the platform 44 from moving with respect to the earth against low level forces, such as wind forces, but yield to allow independent movement in response to higher level forces. In each detent device, this blocking is effected by a suitable ball 76 vertically slidable in a socket 77 fixed to a support 78 anchored in the earth. The ball 76 is urged upwardly by a strong spring 80 which seats the ball in a depression 82 in the platform. The spring 80 prevents the ball from moving downwardly when the horizontal force on the platform 44 is relatively low; but when this force exceeds a predetermined value, the ball is forced downwardly by the camming action of the walls of depression 82, thus allowing horizontal ground motion independently of the platform.

Still another form of releasable restraining means usable for this application comprises a plurality of explosive bolts (not shown) connected between the platform and the framework and a suitable sensor (not shown) which effects firing, and resultant release, of the bolts in response to horizontal ground acceleration exceeding a predetermined value.

When the restraining means 70–73 or 75 is released, as above described, the pendulum suspension acts to effectively isolate the circuit breaker from the earth in a horizontal direction and to reduce its fundamental natural frequency in a horizontal plane. As pointed out hereinabove, this fundamental natural frequency varies directly with $\sqrt{g/l}$, where g is the acceleration of gravity and l is the length of the pendulums. Accordingly, by making the pendulums sufficiently long, we can reduce this fundamental natural frequency of the apparatus mounted on the pendulums to the desired value. In one embodiment of the invention, we utilize pendulums about five feet in length for a circuit breaker thirty feet in height, thereby reducing the fundamental natural frequency of the circuit breaker in a horizontal plane to the neighborhood of one-half hertz. This is substantially below the 1 to 10 hertz band of frequencies where earthquakes typically have their peak energy content. A typical circuit breaker such as illustrated when fixed to the ground has a fundamental natural frequency in the horizontal plane of 1-½ to 5 hertz.

With respect to the isolation provided by the pendulum suspension once the restraining device is released, the ground movement accompanying a severe earthquake will cause relative movement between the platform 44 and the framework 50. The platform 44 will, in effect, swing relative to the framework 50, 50 about ball and socket joints 65*a* the specific path followed being defined by the fixed length pendulums 60. During such movement, the platform 44 will remain substantially horizontal because of the parallelogram nature of the pendulum linkage combined with the fixed effective length of the pendulums and the rigid character of the platform 44 and the framework 50, 50. Maintaining this horizontal orientation of the platform prevents the platform from swinging or oscillating about a horizontal axis in its own plane, thus preventing any forces from being developed as a result of such swings or oscillations.

The horizontally-accelerated mass of the circuit breaker in the region of tanks 20, acting through a long moment arm extending from the platform 44 to near the tanks 20, tends to overturn the circuit breaker about the forwardly located pivots 65*a* of the pendulums on the framework 50, 50, especially at the end of any excursion of the pendulums. We are able to effectively resist this overturning moment because the platform and framework are rigid and because our pendulums can take both compressive and tensile loads without appreciable distortion. As a result, the pendulums directly transmit any such overturning forces to the fixed rigid framework 50, 50 thus blocking the overturning action. If these pendulums, instead of being rigid, were spring members, there would be far less resistance to such an overturning moment.

For dissipating the kinetic energy of the suspended circuit breaker when the platform 44 moves relative to the framework 50, 50 so as to limit the maximum displacement of the platform and prevent the moving assembly from impacting against any structure fixed to the framework, damping devices 100 are provided between each of the frames 50 and the platform 44. In one form of the invention, each damping device 100 comprises three separate dashpot assemblies 102, 104, and 106. As shown in FIG. 6, each dashpot assembly comprises a liquid filled cylinder 110, a piston 112 slidable therein, and rods 114 and 116 respectively coupled to the cylinder and piston. The dashpot piston 112 opposes tensile loads on the dashpot assembly (i.e., separation of rod 116 from rod 114) but offers little opposition to compressive loads (i.e., loads moving the rods toward each other). In this connection, separating motion of the rods 114 and 116 must force liquid from the lower to the upper side of the piston via a restricted metering passage 121, thus developing opposition to such separating motion, but during reverse motion a large check-valve 122 opens to permit liquid to freely bypass the metering passage 121, thus effectively eliminating opposition to such reverse movement. By avoiding compressive loads, we are able to employ a more compact dashpot design. Rod 116 is coupled at its lower end to the platform 44 by a suitable universal joint such as ball-and-socket joint 124, and rod 114 is coupled to the frame 50 by a similar joint 126. These universal joints permit the platform 44 to move in any direction relative to the framework 50, 50 without any binding in the joint. As shown in FIG. 5, the three dashpot assemblies of a damping device radiate from a central location on the frame and have lines of action that are angularly displaced by about 120° from each other. Motion of the platform in any direction relative to the frame 50 will load one or more of the dashpot assemblies of each damping device 100 in tension, thereby developing the opposition to such motion which dissipates the kinetic energy of the moving circuit breaker assembly.

Another form of dashpot assembly for use in the damping devices 100 is illustrated in FIG. 6a. In this modified dashpot assembly, the cylinder 110 is fixed to rod 116 and the piston 112 is fixed to rod 114. Check-valve 122 closes to oppose motion of the rods 114 and 116 away from each other but opens to allow the rods to move together with relatively little opposition. For the rods 114 and 116 to move away from each, liquid must be forced through restricted metering passage 121 in the piston 112, thus developing substantial opposition to such separating movement of rods 114 and 116. For accommodating the liquid displaced by piston rod 114 as it enters the cylinder, a bypass 140 is provided extending from the lower end of the cylinder 110 to an auxiliary chamber 142 at the upper end of the cylinder.

To limit the tendency of the suspended circuit breaker to rotate about a vertical axis 150 (FIG. 5) that passes through its center of gravity during earthquake-produced motion of the platform, we locate the pendulums 60 in such positions that they are substantially equidistant from this vertical axis 150. By virtue of this relationship, we can limit to a small value the moment arm through which horizontal forces act to produce such rotational movement. The damping devices 100, of course, oppose such rotational motion.

The reaction forces from damping devices 100 should not produce any substantial twisting or rotating moments about the vertical axis **150** passing through the center of gravity of the suspended circuit breaker. To attain this objective, the damping devices should be provided in pairs located substantially equidistant from axis **150** and at diametrically-opposed sides of axis **150.** In our arrangement, each of the two damping devices **100** may be thought of as being effectively connected to the platform **44** at a point **107** (FIG. **5**) effectively located in vertical alignment with the central location where the lines of action of the three dashpots of each damping device intersect. As seen in FIG. **5**, these locations **107** of the effective points of connection of the two damping devices are substantially equidistant from axis **150** and in substantially diametrically-opposed relationship with respect to axis **150.**

While our pendulum-type suspension is very effective in isolating the circuit breaker from horizontally-directed, earthquake-produced forces, it is not effective in isolating the circuit breaker from vertically-directed forces. This, however, is not a significant disadvantage because the vertically-directed forces produced by an earthquake are typically only about two-thirds to three-fourths as high as the horizontally-directed forces produced by the earthquake and, more importantly, because the circuit breaker is inherently strong in a vertical direction in view of the high compression strength of the porcelain in its vertically-extending columns, and in view of the always present need, even without earthquake considerations, to design to withstand forces of 1 g. Also, there is no amplification of accelerations in the vertical direction because the natural frequency of the breaker in a vertical direction is much higher than the spectrum of frequencies associated with the maximum energy content of earthquakes.

To prevent any significant interference with the above-described motion of the platform **44** in response to earthquake-produced forces, it is important that the terminal connectors **39, 40** have sufficient flexibility to accommodate without becoming taut the full required movement of the suspended circuit breaker relative to the earth. Unless such flexibiltiy is present, damaging high loads can be developed on the circuit breaker components and the connectors during the above-described movement of platform **44.**

While we prefer to employ four pendulum links in our suspension, it is feasible to use three and, in certain cases, more than four. The use of four instead of three pendulums results in more effective resistance to twisting of the platform about a horizontal axis, thus reducing the rigidity requirements imposed on the platform.

Irrespective of the number of pendulums used, it is highly desirable that they all be located substantially equidistant from the vertical axis **150** passing through the center of gravity of the suspended circuit breaker, thus facilitating rotational movement of the platform about such vertical axis in response to earthquake-produced forces tending to produce such rotational movement.

While we have shown and described particular embodiments of our invention, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from our invention in its broader aspects; and we, therefore, intend in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of our invention.

We claim:

1. A support system for electrical apparatus having a tall, slender profile that is capable of protecting the apparatus against severe earthquake forces, comprising:

a. a rigid substantially horizontally-extending platform on which said apparatus is mounted,

b. a rigid framework supported on and rigidly anchored in the ground, said framework having portions located above and spaced from said platform,

c. means for suspending said platform from said framework portions comprising: at least three spaced-apart substantially rigid pendulum links and universal joints at opposite ends of said links for respectively connecting the associated link to said framework and said platform, said links being of substantially the same length, of a constant effective length, and substantially parallel to each other so as to form a parallelogram type linkage that maintains said platform substantially horizontal when moved relative to said framework,

d. releasable restraining means for normally maintaining said platform fixed with respect to said framework but releasable to permit movement of the platform relative to the framework in response to horizontally-directed acceleration exceeding a predetermined minimum value of the ground in which said framework is anchored,

e. damping means opposing motion of said platform relative to said framework for dissipating the kinetic energy of the platform and the apparatus mounted thereon developed by motion of said platform relative to said framework.

2. The support system of claim **1** in combination with conductive means for electrically connecting said apparatus in a circuit, said conductive means having sufficient flexibility to accommodate the full range of earthquake-produced motion of said apparatus without losing its flexibility.

3. The support system of claim **1** in which said damping means comprises a plurality of dashpot assemblies connected between said platform and said framework for opposing motion of said platform relative to said framework in all horizontal directions.

4. The suspension system of claim **3** in which said dashpot assemblies are connected to said platform and said framework through joints capable of accommodating motion of said platform in all horizontal directions without binding.

5. The suspension system of claim **3** in which said damping means comprises a plurality of damping devices respectively connected to said platform at spaced-apart locations, each damping device comprising dashpot assemblies having lines of action radiating from a central region and angularly spaced from each other.

6. The support system of claim **1** in which said damping means comprises a pair of damping devices effectively connected to said platform at spaced points have effective locations substantially equidistant from a vertical axis passing through the center of gravity of the suspended mass of said support system and generally diametrically-opposed with respect to said vertical axis.

7. The support system of claim 1 in which said pendulum links are connected to said platform at points substantially equidistant from a vertical axis passing through the center of gravity of the suspended mass of said support system.

8. The support system of claim 1 in which said pendulum links are connected to said platform at points substantially equidistant from a vertical axis passing through the center of gravity of the suspended mass of said support system and in which said damping means comprises a pair of damping devices connected to said platform at spaced points having effective locations substantially equidistant from said vertical axis and substantially diametrically-opposed relative to said vertical axis.

9. The support system of claim 1 in which said means for suspending the platform includes four pendulum links as defined in claim 1.

10. The support system of claim 9 in which a first pair of said pendulums are connected between said framework and said platform adjacent opposite sides of said platform in a first region at one side of a vertical axis passing through the center of gravity of the suspended mass of said support system and a second pair of said pendulums are connected between said framework and said platform adjacent opposite sides of said platform in a second region at an opposite side of said vertical axis from said first region.

11. The support system of claim 9 in which said framework comprises a pair of frames of inverted U form, each straddling said platform, two of said pendulums being connected between one of said frames and said platform adjacent opposite sides of said platform and two other of said pendulums being connected between the other of said frames and said platform adjacent opposite sides of said platform.

12. The support system of claim 11 in which said damping means comprises a plurality of energy-absorbing devices, one connected between one of said frames and said platform and the other connected between the other of said frames and said platform.

13. The equipment of claim 9 in which said electrical apparatus is a high voltage circuit breaker comprising vertically-extending insulating columns and circuit-interrupting means mounted atop said columns.

* * * * *

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,789,174 Dated January 29, 1974

Inventor(s) P. Barkan, R. S. Barton, K. M. Skreiner, U.R. Tognella

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 42, change "36-36" to -- 3b-3b --

Column 5, line 38, after "65a" add a comma (,)

Column 7, line 58, change "facilitating" to -- minimizing --

Column 7, line 59, change "such" to -- a --

Column 7, lines 60 & 61, cancel "tending to produce such rotational movement."

Signed and sealed this 3rd day of September 1974.

(SEAL)
Attest:

McCOY M. GIBSON, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents