United States Patent [19]

Stuhler

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[54] **REACTIVE ATTITUDE STABILIZATION SYSTEM**

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[51] **Int. Cl.**[4] **H01Q 1/18;** F16F 7/10

[52] **U.S. Cl.** **188/378;** 343/765; 343/709; 248/184; 114/191

[58] **Field of Search** .... 343/757, 759, 763, 765, 343/766, 880, 882, 709; 248/182, 184, 284, 286, 292.1, 291, 559, 562, 564, 565, 567, 581, 582, 280.1, 288.1; 74/1 R, 5.22, 5.41, 5.6, 5.44, 574; 188/378-380; 267/136, 140.1, 140.5; 114/191, 193, 195

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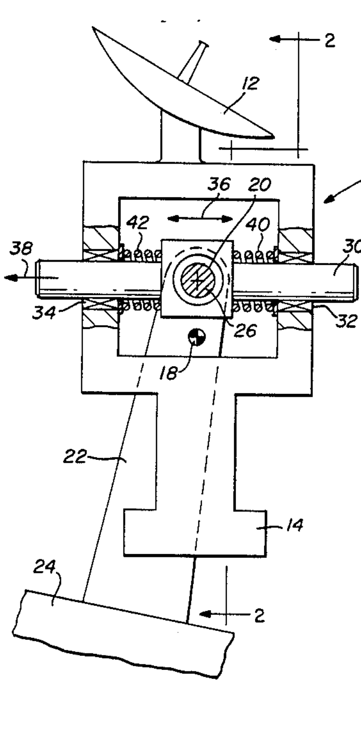
Attorney, Agent, or Firm—Richards, Harris, Medlock & Andrews

[57] **ABSTRACT**

A reactive attitude stabilization system to be carried by a vehicle is provided where a first shaft is pivotally mounted on the vehicle in a normally horizontal relation. A second shaft is supported in horizontal relation at its midpoint by the first shaft and oriented perpendicular to the first shaft. Nonrotating slide bearings support a platform on the second shaft for translation of said second shaft relative to the platform. Resilient members oppose translation of the second shaft relative to the platform in either direction and normally maintain the intersection of the axes of the first and second shafts vertically above the center of gravity of the platform. An acceleration induced shift of the second shaft axially and horizontally relative to said platform causes a torque due to gravity to counteract the acceleration dependent torque.

7 Claims, 5 Drawing Figures



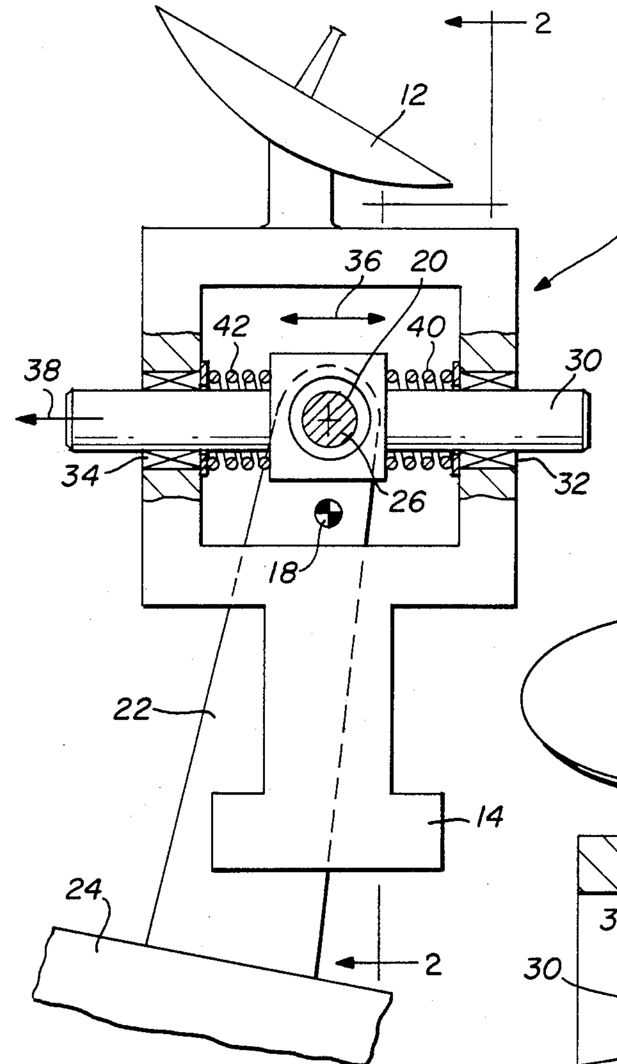

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FIG. 1

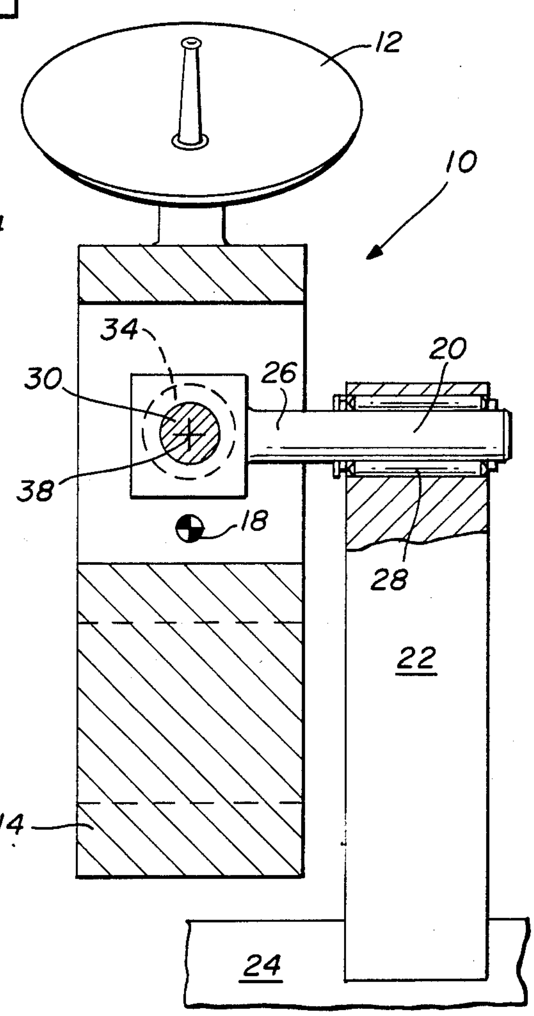
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FIG. 2

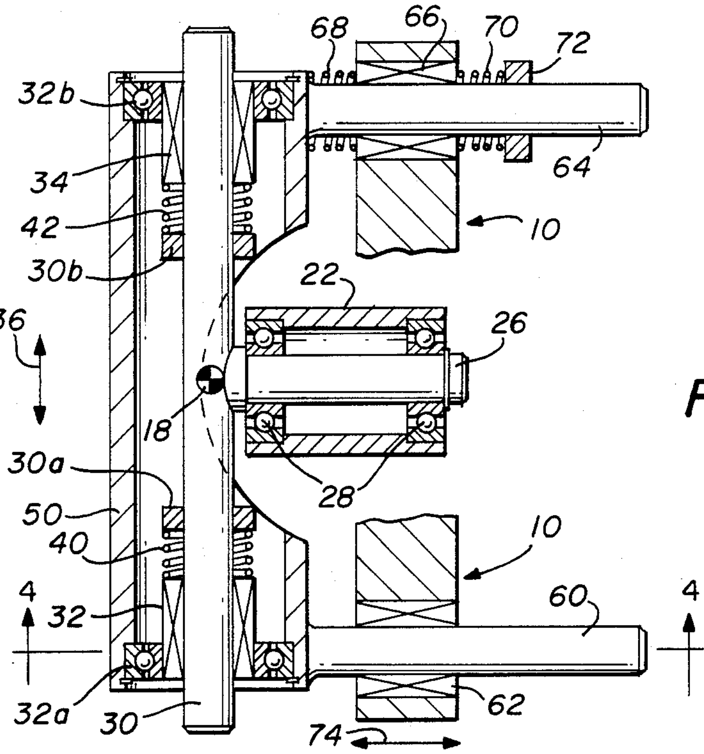

FIG. 3

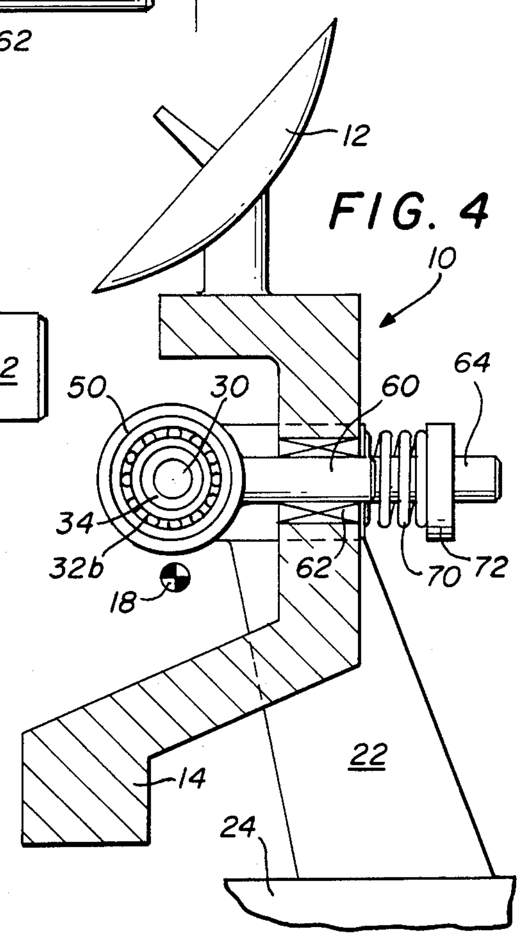

FIG. 4

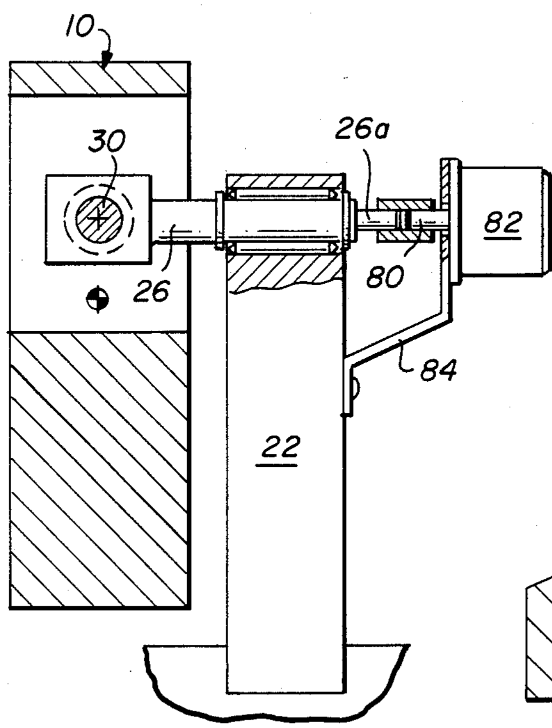

FIG. 5

REACTIVE ATTITUDE STABILIZATION SYSTEM

TECHNICAL FIELD

This invention relates to the stabilization of a platform mounted on a vehicle which subjects the platform to angular and linear accelerations. In a more specific aspect, a slide mounting is provided in such a manner as to react to stabilize the platform.

BACKGROUND ART

Satellite communication terminals aboard various vehicles including ocean going vessels and land based units require stabilization of instrument platforms. Such operations take place in environments where motion of pitch and/or roll are present.

There are many instances where antennas and various instrumentation are required to be stabilized against motion disturbances encountered on moving vehicles. These applications include, but are not limited to, satellite antennas, microwave antennas, radar antennas, navigation equipment, cameras and various optical and positioning devices. The vehicles aboard which these systems might be used include commercial and military land vehicles, ships, aircraft and missiles.

There are two general types of vertical stabilization systems in use:

1. Closed loop servo systems which use servo motors, servo amplifiers, angular transducers and vertical references (usually small vertical gyros) to sense angular displacements of the vehicle and make the necessary corrections for each axis.
2. Direct mechanical stabilization systems, which use two or four large flywheel assemblies acting as direct-acting gyros. The following patents relate to direct mechanical stabilization systems:

U.S. Pat. No. 3,893,123
U.S. Pat. No. 4,020,491
U.S. Pat. No. 4,193,308
U.S. Pat. No. 4,197,548.

DISCLOSURE OF THE INVENTION

A reactive attitude stabilization system to be carried by a vehicle is provided in which a first shaft is pivotally mounted on the vehicle in a normally horizontal position. A second shaft is supported in horizontal relation at its midpoint by the first shaft and is oriented perpendicular to the first shaft. Slideable nonrotating bearing means supports a platform on the second shaft for translation along the second shaft. Resilient means opposes translation of the platform in either direction along the second shaft and normally maintains the intersection of the axes of the first and second shafts vertically above the center of gravity of the platform whereby an acceleration induced shift of the second shaft axially and horizontally relative to the platform causes a torque due to gravity to counteract the acceleration dependent torque which acts on the center of gravity and which tends to displace the platform. In a multiaxis form, third and fourth horizontal shafts are supported, one from each end portion of the second shaft with the platform mounted on slideable nonrotating bearing means provided on the third and fourth shafts.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1** and **2** illustrate a single axis stabilization system;

FIG. **3** is a top view of a two axis stabilization system;

FIG. **4** is a sectional view taken along lines **4—4** of FIG. **3**;

FIG. **5** illustrates the platform control of an angular position transducer.

DETAILED DESCRIPTION

Referring now to FIG. **1**, a platform **10** which is to be stabilized comprises a rectangular frame open at the center. On the top portion of platform **10** is mounted a representative load, an antenna **12**. A counterweight **14** is shown forming part of the platform **10** and is located below the rectangular portion. The platform with its counterweight **14** is formed such that the center of gravity **18** of the platform and its load is located vertically below the pivotal axis **20**. Platform **10** is supported on a shaft **26** which extends from the upper end of an arm **22** which is secured at its base to a vehicle represented by the body **24**.

As best shown in FIG. **2**, shaft **26** is mounted in an anti-friction pivot bearing **28** which is mounted at the upper end of the arm **22**. Shaft **26** normally is horizontal and will be so described for the purpose of the following explanation.

A shaft **30** is coupled at its midpoint to and is integral with shaft **26**. Shaft **30** also is horizontal and is perpendicular to shaft **26**. Shaft **30** supports platform **10** by way of bearing **32** on one end and bearing **34** on the other end. The bearings **32** and **34** are mounted in suitable apertures in the vertical arms of the platform **10**. Shaft **30** extends horizontally both directions from its junction with shaft **26**.

Bearings **32** and **34** are of unique character. They are linear ball bearings which permit non-rotative sliding movement of the platform **10** along shaft **30** and relative to shaft **26**. The slide motion in either direction is indicated by arrow **36**. Thus, if there is acceleration of arm **22** mounted on vehicle **24** in the direction of arrow **38** a shift will result in the location of the center of gravity **18** to the right when shaft **26** moves to the left relative to the platform **10**.

Linear springs **40** and **42** surround shaft **30**. They oppose movement of shaft **26** in either of the directions indicated by arrow **36** depending upon accelerations of vehicle **24**. Due to inertia, the platform **10**, including antenna **12** with its load and weight **14**, opposes acceleration. As the center of gravity **18** is displaced from a position vertically below axis **20** of shaft **26**, a torque is produced by the vertical force due to gravity which tends to oppose the torque produced by the horizontal acceleration.

Thus, in its simplest form, the invention involves stabilization of platform **10** which is pivoted about horizontal axis **20** and which is suspended by low-friction linear sliding bearings **32** and **34** to permit it to shift horizontally in either direction, the movement being perpendicular to the pivot axis **20**. This horizontal motion is restrained by linear elastic members or springs **40** and **42**. The springs **40** and **42** maintain the spring-mass system in equilibrium position unless and until any external force is applied. The center of gravity of the stable platform when in the equilibrium condition is located slightly below the pivot axis **20**, which causes the platform always to assume normal or vertical position due to gravity.

Thus, by the present invention, the angular relationship between the platform **10** and the direction of gravity is automatically maintained. This is so when the horizontal acceleration forces in the direction of arrow **36** are encountered upon movement of the vehicle **24**. Such acceleration forces will be present due to turning maneuvers and or whipping action of the ships masts on which antennae may be mounted.

Stabilization is accomplished by permitting linear displacement of the entire platform and its load. The center of gravity of the suspended spring-mass system shifts horizontally. This in turn causes a torque due to gravity about the pivot axis which is opposite and can be made nearly equal to the torque caused by horizontal accelerations acting on the center of gravity.

It will be recognized that the system shown in FIGS. **1** and **2** is a single axis reactive stabilization system. It is self stabilizing and requires no external inputs.

Recapping, a first shaft **26** is pivotally mounted on vehicle **24** as to be normally horizontal. A second shaft **30** is supported in horizontal relation at its midpoint by the first shaft **26** and is oriented perpendicular to shaft **26**. Slide bearing means **32, 34** support the platform **10** on the second shaft **30** for translation along the second shaft. Resilient means **40, 42** oppose translation of the second shaft **30** in either direction relative to the platform and normally maintain the intersection of the axes of the first and second shafts vertically above the center of gravity of the platform **10** whereby an acceleration induced shift of said second shaft axially and horizontally relative to said platform causes a torque due to gravity to counteract the acceleration dependent torque which acts on the center of gravity and which tends to displace the platform. The bearing means **32, 34** inhibit rotation of the platform **10** relative to the second shaft **30**. Platform **10** has a central bay through which shaft **30** passes with resilient means **40, 42** surrounding shaft **30** and engaging platform **10** with opposed forces such that the intersection of the axes of shafts **26** and **30** lies normally vertically above the center of gravity of platform **10**. Shaft **30** is pivotally supported by shaft **26** for rotation on bearing **34** about the axis of shaft **30** and relative to shaft **26**.

It will also be recognized that in FIG. **1** the relative size of the antenna **12** relative to platform **10** and the bearing structures has been made out of proportion in order to illustrate the principle involved.

It will now be appreciated that unlike other methods, the present system does not require any high speed rotating components such as gyros, servo motors or direct acting flywheels. It does not require any electrical components at all and, consequently, does not need electrical power. Costs are reduced significantly, reliability is improved and use of the system is permitted where available electric power is limited.

Another significant advantage of this invention is that it compensates for vertical errors caused by horizontal accelerations such as those encountered during sustained turning maneuvers of a vehicle. Direct mechanical stabilization systems cannot tolerate such conditions without significant error. For example, a ship turning at a sustained rate of 3.0° per second with a forward speed of 25 knots will cause a vertical error of 3.9° in a direct mechanical stabilization system due to finite limitations of its inertial capacity. The system of the present invention does not exhibit such errors.

One key to the successful operation of the present invention is the use of linear ball bearings which are anti-friction bearings that permit slide movement of the shaft **30** through bearings **32** and **34**. The linear displacement is necessary. Suitable bearings may be of the type manufactured and sold by Thompson Industries, Inc. of Manhasset, N.Y. and identified as Super Ball Bushing Bearings.

Referring now to FIGS. **3** and **4**, a two-axis system is shown. The basic principle of the single axis system is here extended to a second horizontal axis which is perpendicular to the first axis. This provides a self-stabilizing two-axis platform capable of isolating instrumentation against both pitch and roll motions as encountered in various vehicles and vessels. This is accomplished to a high degree of accuracy without the use of complex servo systems, gyros or any other electrical components.

In FIGS. **3** and **4** the same reference characters as have been used where corresponding parts are found in FIGS. **1** and **2**.

Shaft **26** is mounted at the upper end of arm **22** which is mounted on the vehicle **24**. Shaft **26** is horizontal. Shaft **30** is connected to the end of shaft **26** with shaft **26** being mounted in anti-friction bearings **28**. Shaft **30** is slideably mounted on linear bearings **32** and **34**. In this embodiment, linear bearing **32** is mounted for rotation in bearings **32*a*** at one end of a cylinder **50** shown as having an arcuate cutaway side opening through which shaft **26** extends. Spring **40** is mounted near one end of shaft **30** between the end of linear bearing **32** and a stop ring **30*a***. Bearing **34** is mounted for rotation in bearing **32*b***. Spring **42** is mounted near the other end of shaft **30** between the end of the linear bearing **34** and a stop ring **30*b***.

A shaft **60** extends from the end of cylinder **50** and supports platform **10** by means of linear bearing **62**. Bearing **62** is mounted in an arm forming part of the stabilized platform **10**. In a similar manner, a second shaft **64** extends from the opposite end of cylinder **50**. The axis of shaft **26** is horizontal relative to the vehicle's normal attitude only but not stabilized relative to the horizon. The axes of shafts **30, 60** and **64** are stabilized relative to the horizon and thus are all horizontal shafts. Shaft **64** supports linear bearings **66**. Spring **68** is mounted between frame member **50** and one end of bearing **66**. Spring **70** is mounted between the other end of bearing **66** and stop ring **72**. Platform **10** is shaped with counterweight **14** so that the center of gravity **18** is vertically below the axis of shaft **30** where it intersects the axis of shaft **26**.

Upon acceleration in the direction of arrow **36**, the platform **10** will tend to remain fixed whereas the shafts **26** and **30** will move resulting in a displacement of the center of gravity from a location vertically below the axis of shaft **26**. In contrast, upon accelerations of the shaft **26** in the direction of arrow **74**, the stabilized platform will tend to remain fixed whereas shafts **26, 30, 60** and **64** will move relative to the platform, thus causing the center of gravity to be removed from a position directly under the intersection of the axes of shafts **26** and **30**, thereby creating a reactive torque.

Having described a single axis and a two-axis system, it is anticipated that the invention, in addition to use as a stabilizing system for instrumentation directly, also can be used as a vertical reference feedback device for servo systems. In such case, it would rotationally position one or more transducers, such as synchros, potentiometers, or digital transducers, which in turn would provide an error signal to a servo system to actively stabilize instrumentation using servo motors, gear trains, etc.

It is to be noted that linear bearings **32**, **34**, **62** and **66** that utilize balls have been discussed. Other types of low friction linear motion devices, linkage mechanisms, or gas bearings might also be used.

Recapping, a first shaft **26** is mounted on vehicle **22** for rotation about a normally horizontal axis. Shaft **30** is supported in horizontal relation at its midpoint by shaft **26** and is oriented perpendicular to shaft **26**. An intermediate frame **50**, shown as a cylinder, extends along and is mounted on shaft **30** for translation parallel to the axis of shaft **30** and for rotation about the axis of shaft **30**. Two normally horizontal shafts **60**, **64** extend from intermediate frame **50** parallel to shaft **26** and at points normally equidistant from shaft **26** and with the axes of all shafts **26**, **30**, **60**, **64** normally in the same plane. Slide bearings **62**, **66** support platform **10** on shafts **60**, **64**. Resilient means **40**, **42** on shaft **30** and means **68**, **70** on shaft **64** normally oppose translation of shaft **30** and shafts **60**, **64** relative to platform **10** in the direction of the axis of shaft **30** and in the direction of the axes of said two shafts **60**, **64** normally to maintain the center of gravity of platform **10** vertically below the intersection of the axes of shafts **26** and **30**.

Intermediate frame **50** comprises a cylinder having rotational bearings **32*a***, **32*b*** at the ends thereof. Shaft **30** has slide bearings journaled in rotational bearings **32*a***, **32*b*** which engage shaft **30** for rotation relative to the axis of cylinder **50**. Shafts **60**, **64** extend from the walls of cylinder **50** adjacent opposite ends thereof. Cylinder **50** is partially cut away intermediate its length in the region of coupling of shaft **30** to shaft **26**. Springs **40**, **42** on shaft **30** are mounted to bear against said slide bearings **32**, **34** to urge intermediate frame **50** in opposite directions away from shaft **26**.

Further, rearrangement and inversion of various parts may be possible. For instance, when a shaft is shown to be stationary relative to a housing which is the movable member, it is obvious that the housing could be made stationary with the shaft providing relative motion.

Further, it is possible to provide for a part of the platform (instead of the entire platform) to slide horizontally while being opposed by resilient means to accomplish the same objective. In such an embodiment, the magnitude of the linear motion required must be increased proportionally to the ratio of the total pivoted platform weight divided by the weight of the sliding portion.

Referring again to FIGS. **3** and **4**, it will be noted that shaft **30** as well as shaft **26** are parts of the pendulum supported by the arm **22**. However, they do not shift relative to arm **22**. Thus, it will be appreciated that shafts **26** and **30** are nonslideable parts of the pendulum and that other parts of the platform also may be mounted in a nonslideable manner. Thus only a part of the platform, instead of the entire platform, needs to be mounted for a slide movement horizontally in opposition to the resilient means. In such case, the magnitude of the linear motion required to generate an adequate reactive torque would have to be increased in proportion to the ratio of the total pivoted platform weight divided by the sliding portion weight.

In FIGS. **1**, **2** and **4** an antenna **12** has been shown as the load on platform **10**. The description has been directed towards utilization of the antenna **12**. It is to be understood that the stabilized platform may be utilized differently than shown in FIGS. **1**, **2** and **4**. More particularly, as shown in FIG. **5**, the stabilized platform **10** is mounted on horizontal shaft **30** which in turn is supported by the pivoted shaft **26**. Platform **10** does not support an antenna. Rather it is coupled through an extension **26*a*** of shaft **26** to the input shaft **80** of an angular position transducer. The transducer **82** is mounted by a bracket **84** of arm **22**. The angular position transducer **82** may be a potentiometer, a synchro, or an optical encoder, such as are well known and used widely for angular position detection.

It should be noted that the type of system described herein can also be supplemented with direct acting flywheels to further improve stability. Such a combination can achieve stabilization performance levels superior to even the more sophisticated servo type systems. This performance is feasible because the required inertial capacity for any given set of conditions would be reduced by two orders of magnitude as compared to a conventional direct mechanical stabilization system.

Having described the invention in connection with certain specific embodiments thereof, it is to be understood that further modifications may now suggest themselves to those skilled in the art and it is intended to cover such modifications as fall within the scope of the appended claims.

I claim:

1. A reactive attitude stabilization apparatus for use with a moving vehicle, comprising:

a platform to be stabilized having a center of gravity;

a first shaft pivotally mounted on the vehicle and defining a first axis which is normally horizontal;

a second shaft supported by said first shaft and defining a second normally horizontal axis which intersects said first axis at a point located vertically above said center of gravity of said platform in the absence of acceleration forces;

slide bearing means for mounting said platform on said second shaft, said slide bearing means enabling vehicle acceleration forces to induce a translation of said platform along said second axis, thus displacing said center of gravity to obtain a torque about said first axis due to gravitational force to counteract a torque about said first axis due to acceleration force, thereby stabilizing said platform; and

resilient means for opposing translation of said platform in either direction along said second axis to define an equilibrium position wherein said platform center of gravity is located vertically below said intersection of said first and second horizontal axes.

2. The reactive attitude stabilization apparatus of claim **1** wherein said slide bearing means inhibit rotation of said platform about said second shaft.

3. The reactive attitude stabilization apparatus of claim **1** wherein said second shaft is pivotally supported by said first shaft for rotation about said first axis.

4. A reactive attitude stabilization system to be carried by a moving vehicle, comprising:

a first shaft pivotally mounted on the vehicle and defining a first axis which is normally horizontal;

a second shaft supported by said first shaft and defining a second normally horizontal axis having a perpendicular intersection with said first axis;

a platform mounted on said second shaft and including nonrotatable slide bearing means for translation of said platform along said second axis, said platform having a center of gravity normally located vertically below said intersection of said first and second axes;

said nonrotatable slide bearing means enabling vehicle acceleration forces to induce a translation of said platform along said second axis, thus displacing said platform center of gravity from vertically below said intersection to obtain a torque about said first axis due to gravitational force so as to counteract rotation of said platform about said first axis due to vehicle acceleration force; and

resilient means for opposing axial translation of said platform in either direction along said second axis to define an equilibrium position wherein said platform center of gravity is located vertically below said intersection of said first and second horizontal axes.

5. A reactive multi-axis attitude stabilization system to be carried by a moving vehicle, comprising:

a first shaft pivotally mounted on the vehicle for rotation about a first axis which is normally horizontal;

a second shatf supported by said first shaft and defining a second normally horizontal axis having a perpendicular intersection with said first axis;

an intermediate frame rotatably and slideably mounted on and extending along said second shaft for rotation about and translation along said second axis;

third and fourth normally horizontal shafts defining third and furth axes, respectively, extending from said intermediate frame, parallel to and normally equidistant form said first shaft, said first, second, third and fourth axes all lying in the same plane;

a platform to be stabilized having a center of gravity normally located vertically below said intersection of said first and second axes;

slide bearing means for mounting said platform on said third and fourth shafts; and

resilient means on said second shaft and on at least one of said third and fourth shafts opposing translation of said intermediate frame along said second axis and of said platform along said third and fourth axes, respectively, to define an equilibrium position wherein said platform center of gravity is located vertically below said intersection of said first and second horizontal axes.

6. The reactive multi-axis attitude stabilization system of claim **5** wherein said intermediate frame comprises a cylinder having rotational bearings at the ends thereof, wherein said cylinder has slide bearings journaled in said rotational bearings engaging said second shaft for rotation of said cylinder about said second axis, wherein said third and fourth shafts extend from opposite ends of said cylinder, and wherein said cylinder is partially cut away intermediate its length in the region of coupling of said second shaft to said first shaft.

7. The reactive multi-axis attitude stabilization system of claim **5** wherein said resilient means on said second shaft are mounted to oppose translation of said intermediate frame in either direction along said second axis.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,609,083

DATED : Sep. 2, 1986

INVENTOR(S) : Stuhler

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

Col. 7, line 22,
"shatf" should be --shaft--.

Col 7, line 30
"furth" should be --fourth--.

Col. 8, line 1
"form" should be --from--.

Signed and Sealed this

Twenty-fourth Day of March, 1987

Attest:

DONALD J. QUIGG

Attesting Officer *Commissioner of Patents and Trademarks*