May 19, 1970 W. B. McLEAN Re. 26,887

PROPORTIONAL NAVIGATION SYSTEM FOR A SPINNING BODY IN FREE SPACE

Original Filed June 8, 1959 5 Sheets-Sheet 1

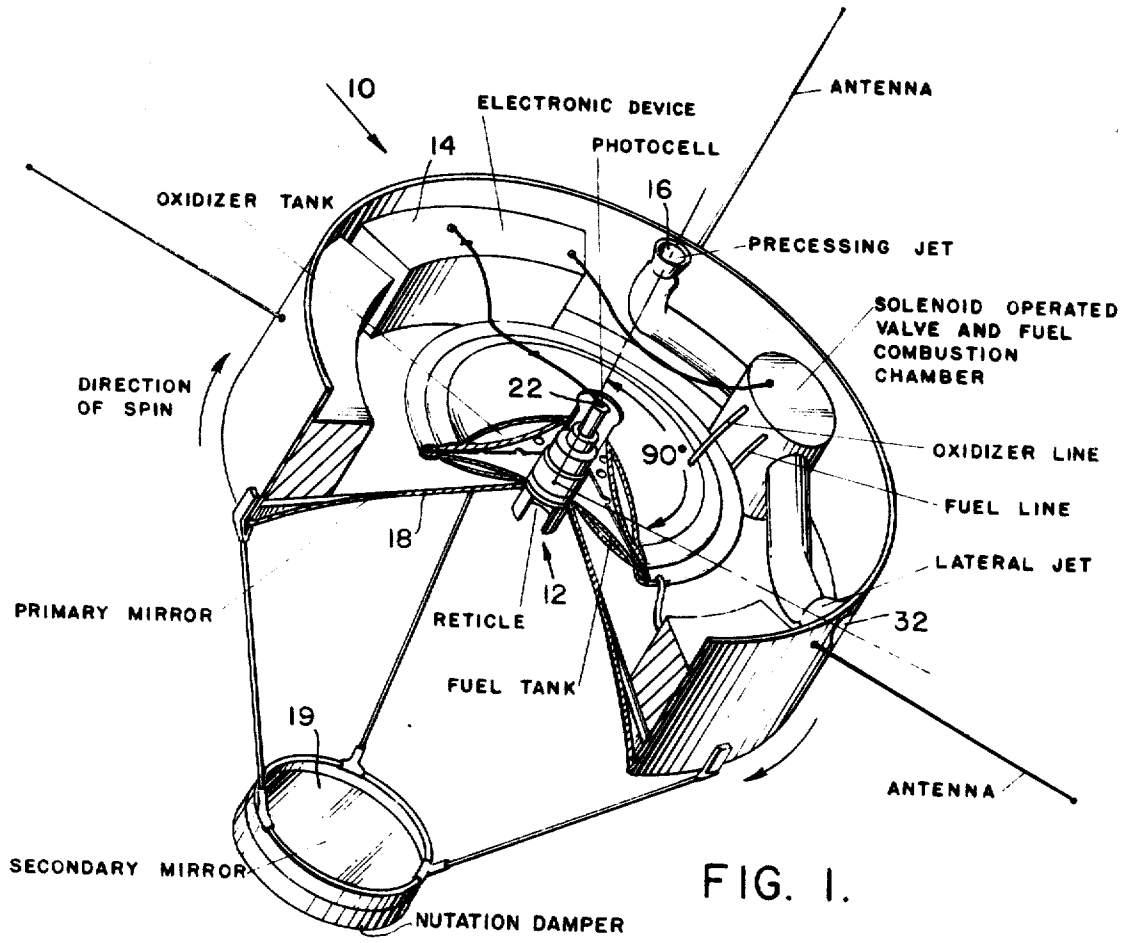



FIG. 1.

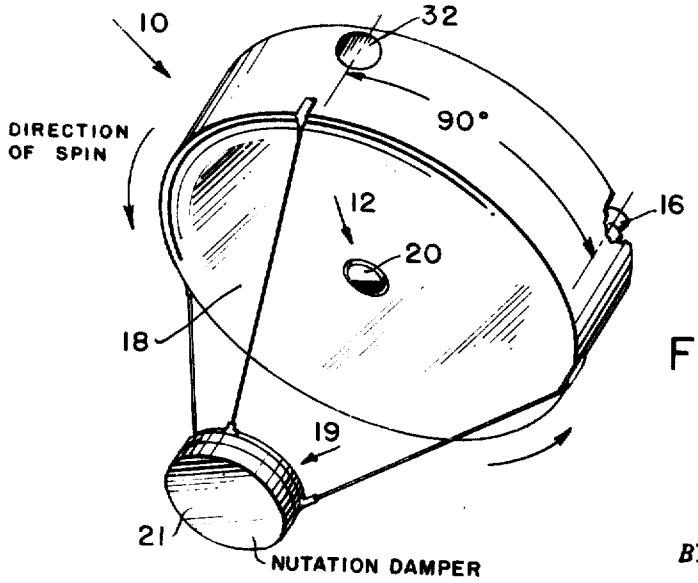



FIG. 2.

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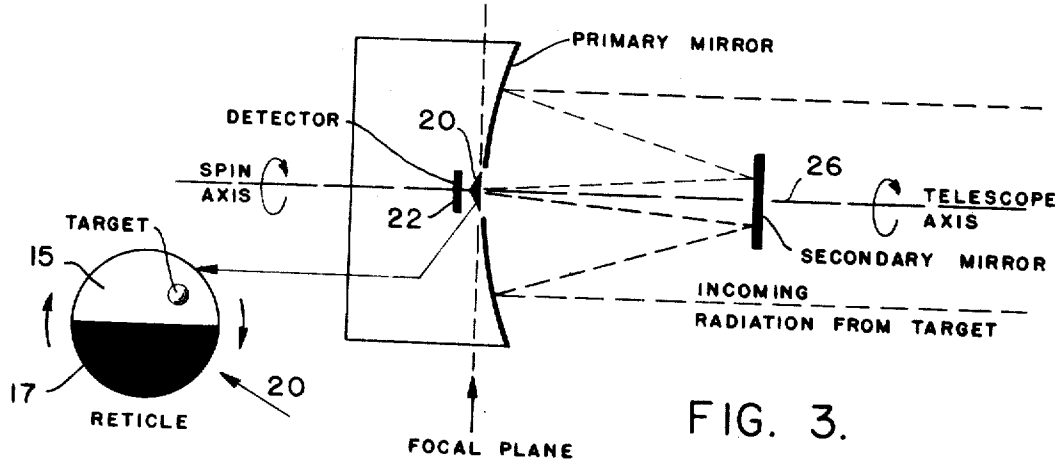



FIG. 3.

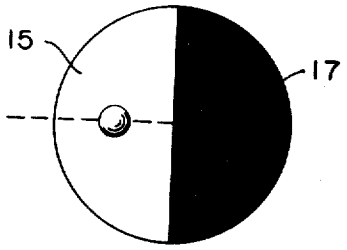



FIG. 4.

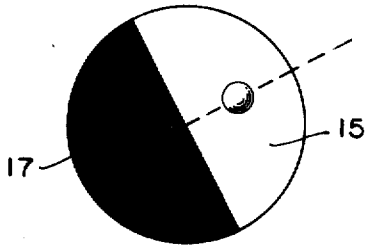



FIG. 5.

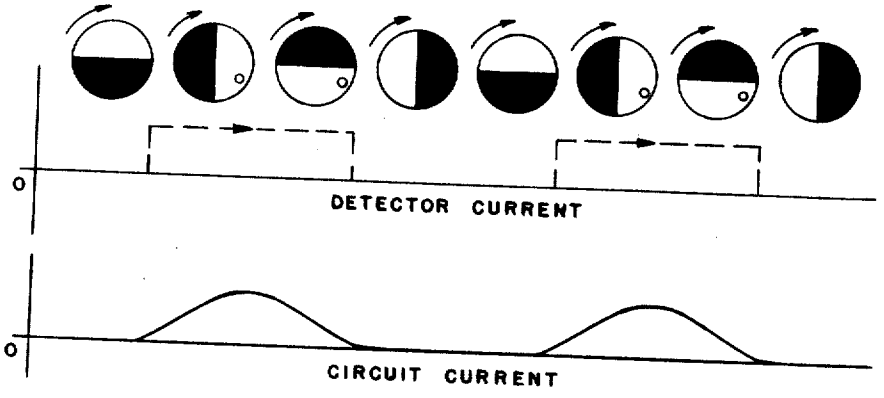



FIG. 6.

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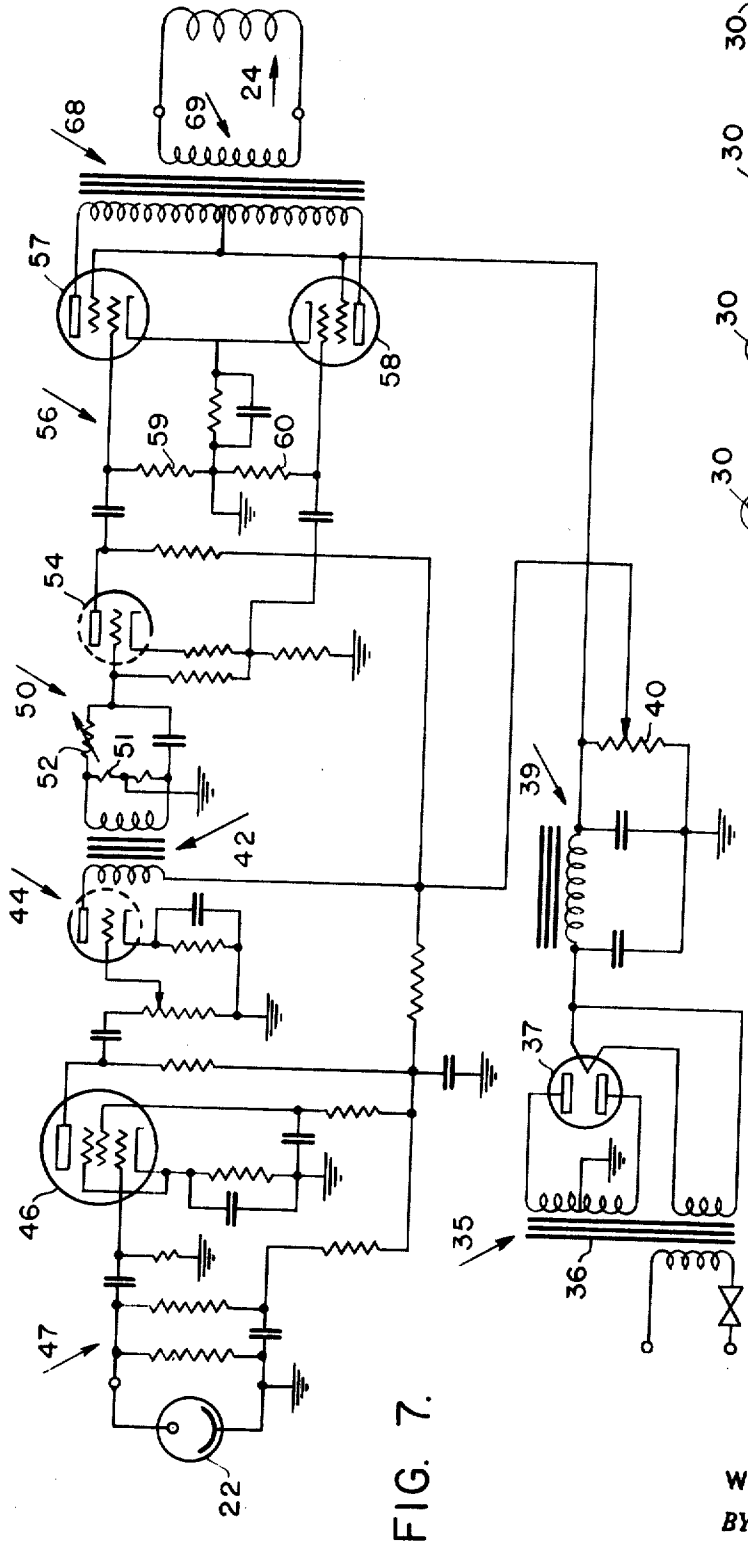



FIG. 7.

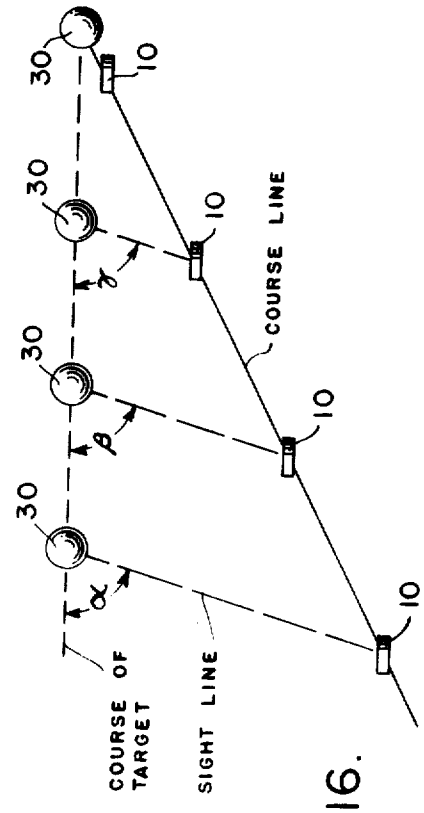



FIG. 16.

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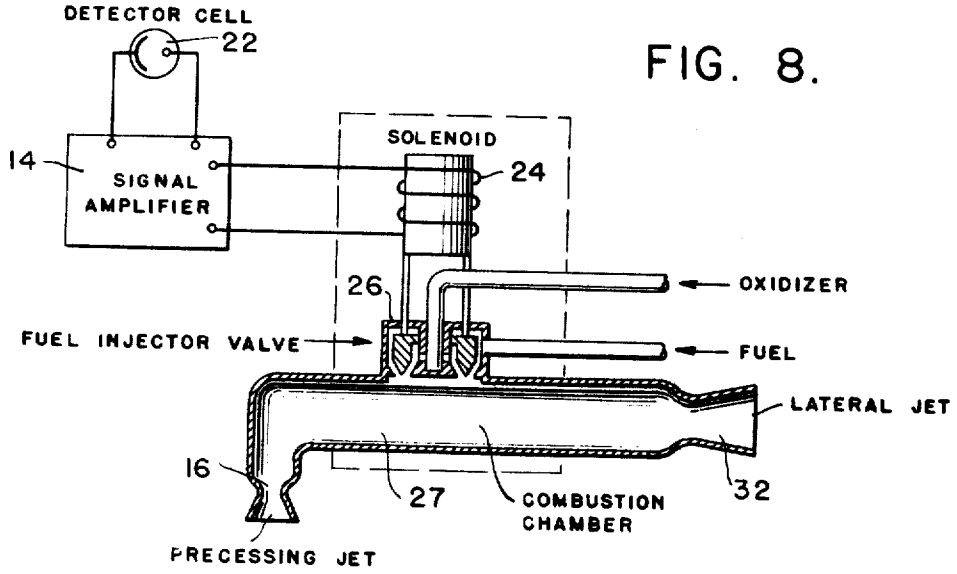



FIG. 8.

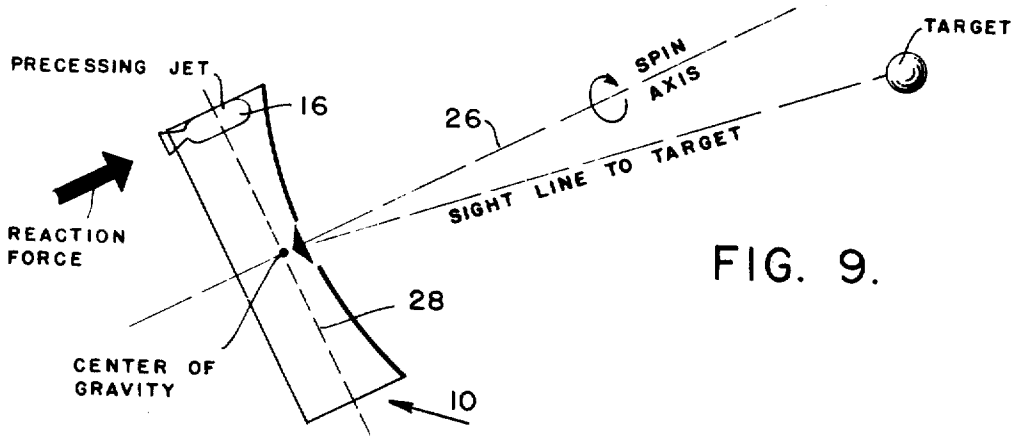



FIG. 9.

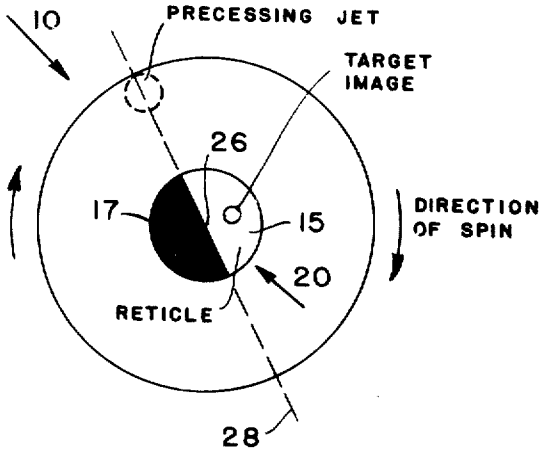



FIG. 10.

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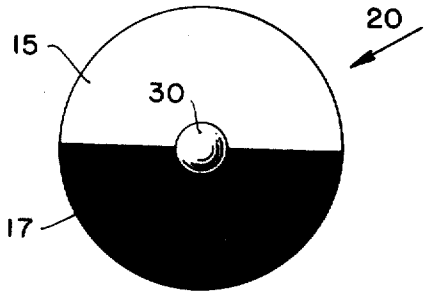



FIG. 11.

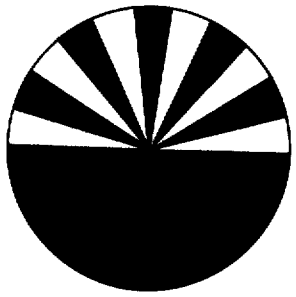


FIG. 12.

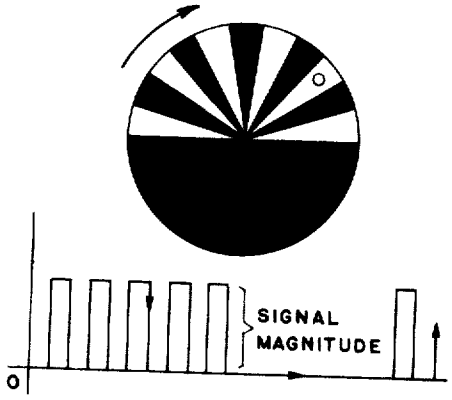



FIG. 13.

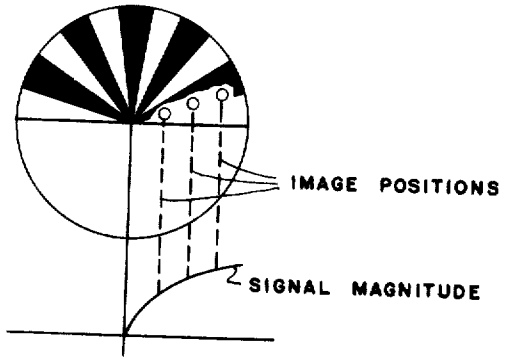
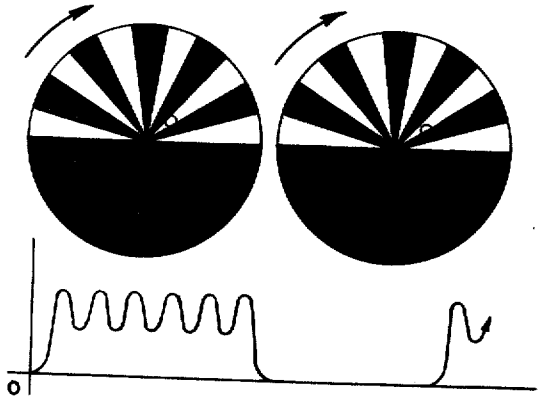



FIG. 15.

FIG. 14.




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26,887

# PROPORTIONAL NAVIGATION SYSTEM FOR A SPINNING BODY IN FREE SPACE

William B. McLean, China Lake, Calif., assignor to Walter G. Finch, Baltimore, Md.

Original No. 3,216,674, dated Nov. 9, 1965, Ser. No. 818,979, June 8, 1959. Application for reissue May 15, 1967, Ser. No. 646,745

Int. Cl. B64g 1/20

U.S. Cl. 244—3.16 48 Claims

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.**

*ABSTRACT OF THE DISCLOSURE*

*The direction of a radiation source is detected to provide signals to control jet motors, one of which is oriented to produce a precessing torque on a spinning vehicle; another of which is oriented to provide an acceleration lateral to the spin axis. The motors operate intermittently in synchronism with the spin of the vehicle. A nutation damper damps out nutational movement.*

The invention herein described may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

The present invention relates to space vehicles and more particularly to an *orientation and velocity control* [automatic and self-contained navigation] system for a space vehicle spinning about its central axis as it travels in space.

The present device utilizes the properties of a spinning body in free space for *orientation and velocity control* [proportional navigation] thereof. A body spinning in free space has [all the] properties of a gyroscope, and therefore, by imparting a spin to a space vehicle assembly it can be made to perform like a gyroscope while traveling in free space. To achieve stable spin about a fixed geometrical axis in the body a nutation damper is *employed* [required]. By including, in the space vehicle assembly, a [tracking] system for detecting electromagnetic radiation [with its optical] [axis coinciding with the spin axis of the vehicle] and a variable thrust jet motor on the outer periphery of the spinning vehicle, the vehicle can be made to precess so as to [always] point its spin axis *in a predetermined direction* [at a target body that is emitting electromagnetic] [radiation]. To provide [a collision course between] *velocity control of* the spinning vehicle [assembly and] [the target body] a second jet motor for producing lateral acceleration is provided whose thrust axis passes through the center of gravity of the spinning vehicle [and is 90° around the periphery of the] [vehicle from the precessing jet motor]. By controlling both jet motors with a single valve so that the pressure behind each jet is varied proportional to the *detected* [target] signal the vehicle can be made to travel a course which will result in a collision with *a* [the] target body. This device can be made to operate in any environment, including the earth's atmosphere, in which the motion of the vehicle or body is controlled primarily by the jet motors. To achieve this condition, aerodynamic forces must be reduced to a minimum.

It is an object of the invention therefore to provide [*a*] *an orientation and velocity control* [self-] [contained navigation] system for a vehicle traveling in space or in any environment where the relative motion of the vehicle is controlled primarily by the propulsion means contained therein.



It is another object of the invention to provide a new and useful vehicle for space travel having *an orientation and velocity control* [a self-contained guidance] system therein which will automatically follow a collision course with a target body emitting electromagnetic radiations.

Still another object of the invention is to provide a *vehicle* [device] which utilizes the properties of a spinning body in free space for *orientation and velocity control* [proportional navigation] thereof.

A further object of the invention is to provide a vehicle which when having a spin imparted thereto will perform like a gyroscope while traveling in free space, and which contains tracking and propulsion means for following a collision course with a chosen target body that is emitting electromagnetic radiation.

A still further object of the invention is to provide a proportional navigation system for a space vehicle where the propulsion system is controlled by a target signal from a seeker contained in the vehicle.

Other objects and many of the attendant advantages of this invention will become readily appreciated as the same becomes better understood by references to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is a perspective view of *an exemplary* [a preferred] embodiment of the invention showing the interior of the vehicle;

FIG. 2 is a perspective view of the vehicle of FIG. 1, showing the opposite side thereof;

FIG. 3 is a diagrammatic view showing how radiation from a target is focused onto the reticle and detector in the vehicle via the primary and secondary mirrors of the vehicle seeker;

FIG. 4 illustrates the relative position of reticle and target image at the time of maximum current;

FIG. 5 illustrates an angular position of the reticle relative to the target for maximum current;

FIG. 6 shows the relationship and form of detector current and circuit current with reticle and target position;

FIG. 7 is a circuit diagram of a seeker amplifier for amplifying signals generated by the photodetector cell;

FIG. 8 is a diagrammatic illustration of the circuitry and propulsion system for *an exemplary* [a preferred] embodiment of the present invention;

FIGS. 9 and 10 are diagrammatic views of the vehicle showing its direction of spin and illustrating how the reaction force from the precessing jet causes the vehicle to precess, as would a gyroscope, to align its spin axis with the line-of-sight to the target body;

FIG. 11 shows the position of a target image for constant radiation through the reticle;

FIG. 12 shows a reticle with alternating clear and opaque sectors on one half, and wholly opaque on the other half thereof;

FIG. 13 illustrates the position of a target for maximum current when using the reticle of FIG. 12;

FIG. 14 shows target positions for small current using the reticle of FIG. 12;

FIG. 15 illustrates the signal magnitude as affected by position of the target image on the reticle; and

FIG. 16 illustrates a vehicle traveling in space on a collision course with a target body.

A body or space vehicle spinning in free space has [all the] properties of a gyroscope, and if provided with a nutation damper, such as disclosed in U.S. Pat. 2,734,-384, issued Feb. 14, 1956, or in U.S. Pat. application Ser. No. 789,216, filed Jan. 26, 1959 and now U.S. Pat. No. 3,034,745, issued May 15, 1962, for Spin-Axis Stabilized Space Vehicle Structure, the spinning vehicle will maintain a fixed orientation in space unless acted upon by some external force or forces. Such external forces may

be provided by reaction forces produced by jet propulsion motors carried in the spinning space vehicle.

Referring now to the drawings, like numerals refer to like parts in each of the figures.

*An exemplary embodiment of the* [The] present invention [is for navigating] *comprises* a space vehicle **10** illustrated in FIGS. 1 and 2, which is presumed to be traveling in space and spinning about its central axis, acting like and having all the properties of a gyroscope. The spin of the vehicle is usually imparted thereto at the time it is launched into space, but jet means can be provided in the vehicle itself for imparting the spin, if desired. A seeker **12**, comprising a telescopic comparator mounted on the spin axis of the vehicle, detects electromagnetic (e.g., infrared) radiation from a target, such as the moon, a planet, or some other space vehicle, and generates a signal in accordance with the position or bearing of the target relative to the optical axis of the telescope which axis coincides with the spin axis of the vehicle. This signal is amplified and converted into an alternating current signal whose time of occurrence or phase is determined by the relation of the seeker to the target position. In direct response to the signals from the seeker a small jet motor **16** on the outer periphery of the spinning vehicle is caused to operate. By properly orienting this jet motor with respect to the seeker, as shown in FIGS. 1 and 2, the spinning vehicle **10**, since it acts like a gyroscope, will be precessed in space in such a manner as to have its spin axis and thus the optical axis of the telescope point directly at a target which is imaged on the seeker **12**. In this system the target signal generated by the seeker is not resolved into any coordinate system; the magnitude of the signal provides the magnitude of the correction signal. When accurate tracking is achieved the magnitude of the signal is proportional to the angular rate of the line joining the target and the seeker in space.

The optical system of the target seeker comprises a folded reflecting telescope, having primary and secondary optical mirrors **18** and **19**, whose optical axis coincides with the spin axis of the vehicle and spins with the vehicle about those coinciding axes. Mounted on the back of mirror **19** is a nutation damper **21** which may be of the type disclosed in the aforementioned Patent 2,734,384 or application Serial No. 789,215 and now abandoned. Although the nutation damper is shown for convenience as mounted on mirror **19**, it is understood, of course, that it could be supported elsewhere; as, for example, on the vehicle body on the other side thereof. A schematic diagram of the vehicle and seeker is shown in FIG. 3. The optical system, which includes an image chopper or reticle **20** mounted at the focal plane of the telescope for rotation therewith, forms radiation from the target into an image and chops it, producing a pulsed radiation signal. A photodetector cell **22**, such as a lead sulfide detector, is mounted directly behind the image chopper **20** and converts the pulsed radiation signal into an alternating current that can be processed by the vehicle's circuitry, hereinafter described.

The chopper action can be understood by considering a simple image chopper or reticle as shown in FIG. 4. Its surface is divided into two main sectors of 180°. When the telescope forms the image of the targe on the wholly clear portion **15** of the reticle, the radiation passes through the reticle and impinges on the detector. When the image falls on the opaque portions **17** of the reticle the radiation is interrupted, and the detector receives no energy.

The current from the detector is related to the rotational position of the reticle. Whenever the target image is wholly in the clear portion **15** of the reticle, the circuit current is at maximum. For instance, if the target is to the right of the telescope, the current will be at maximum when the clear part **15** of the reticle is on the left side of the axis, as in FIG. 4. The direction of the target relative to the telescope axis determines the time of occurrence or phase of the maximum current, as in FIG. 5



for instance. Because the electronic circuitry used rounds-off the pulses, the current from the seeker amplifier **14** appears as an undulating line, as shown in FIG. 6. The signal from the detector **22** is amplified by the circuit of FIG. 7, and, still containing both phase and amplitude information, is fed back to the solenoid coil **24** of a solenoid operated valve **26**, as shown in FIG. 8, which operates the precessing jet motor **16**. Thus the signal produces an alternating field in the solenoid **24** with just the frequency at which the vehicle **10** is spinning.

With the reticle **20** mounted on vehicle **10** the signal frequency is identical with the spin rate of the vehicle. Therefore, the current is automatically and exactly synchronized with the vehicle spin.

The alternating field, synchronized with the vehicle spin acts on the solenoid operated valve **26** and thus the precessing jet **16** and results in a torque on the spinning vehicle proportional to the current in the solenoid coil **24**. The spinning vehicle assembly **10**, acting like a gyroscope, precesses in response to this alternating field.

Consider the forces on the spinning vehicle. Viewing vehicle **10** of FIGS. 9 and 10 from beyond the target, the vehicle is seen as spinning in a clockwise direction with the target to the left of the spin axis **26** and the target image appearing to the right (FIG. 10). Radiation passing through the clear portion **15** will produce a current which energizes solenoid **24** and activates precessing jet **16**. The reaction force from the precessing jet **16**, shown as a heavy arrow in FIG. 9 exerts a torque on the vehicle which is felt as a precessing force 90° around in the direction of clockwise rotation and effects a turning of the vehicle so that the spin axis **26** points directly at the target and the target image is centered on the reticle **20**.

The spinning vehicle, acting like a gyroscope rotating about spin axis **26**, thus transforms the torque, produced by the precessing jet **16**, about an axis that goes through the center of gravity and normal to the paper into a precession or rotation of spin axis **26** about axis **28** which is perpendicular to and intersects the thrust axis of the precessing jet **16** and intersects the center of gravity of the vehicle **10**, as shown in FIGS. 9 and 10. That is, with gyro rotation about a first axis, a torque applied about a second axis will cause the gyro to precess about a third axis, all of the axes being normal to each other. As the current in the solenoid **24** passes through a maximum, operating the valve **26** and thus the precessing jet **16**, the torque produced by the thrust of the precessing jet precessing the vehicle and telescope, is maximum. It is only necessary, then, that the reticle **20** have the correct position with respect to the precessing jet **16** for this maximum current to occur at just the right time to produce a torque in the direction of the target.

Because the current is maximum when the target image is in the center of the clear segment **15** of reticle **20**, the torque on the vehicle and telescope is in the direction of the target; see FIG. 10. The vehicle acting like a gyroscope responds to this torque by precessing its spin vector (i.e., axis) toward the target. With the telescope axis along the spin vector, the telescope thus rotates toward the target. In this manner the gyro-like spinning vehicle assembly **10** keeps the telescope pointed at the target body.

If the seeker telescope is pointing directly at the target **30**, FIG. 11, a constant amount of radiation passes through the reticle **20** at all times; the detector generates no pulsating current; no current flows in the solenoid coil; and the vehicle experiences no precessing torque. The telescope remains pointed in this fixed direction in space, looking at the target, until a change in the bearing angle (line-of-sight to the target) causes the target image **30** to move away from the center of the reticle.

As described, the seeker **12** would receive a full tracking signal as soon as the image barely moved off the center of the reticle **20**. However, the preferred reticle has

alternating clear and opaque sectors, as shown in FIG. 12. This pattern gives the chopping frequency a more convenient value for electronic amplification and reduces background clutter from background radiation. In addition, it makes the tracking signal proportional to the bearing rate.

The target image formed on the reticle is not infinitely small. When this target image, in FIG. 13, moves well away from the center of the reticle, the widening pie-shaped sectors alternately completely block the radiation, then permit it all to pass. The pulsating current is then at maximum. FIG. 13 also shows target position for maximum current.

If the image nears the center of the reticle, the narrow ends of the pie-shaped sections only partially obscure and partially transmit the image radiation as shown in FIG. 14. The magnitude of the amplified current, as a function of target image position, appears as in FIG. 15. The vehicle will receive smaller precession torques when the image is only slightly off the telescope's center than when the target is well away from the telescope's axis, as shown by the different positions of the target image in FIG. 15.

While the vehicle travels precisely on a course to intercept the target or reach the target destination, by means of a lateral jet **32** hereinafter explained, the telescope will point directly at the target and no signal will result, because the image will be at the null point of the chopper **20**.

When the direction to the target changes because of changes in target or vehicle velocity, if any, the target image moves away from the reticle center and creates a tracking signal. The displacement of the image grows until the vehicle's precession rate just equals the sight-line rate of the target. Thus, the seeker telescope mounted on the vehicle reports any changes in the direction of the target that require alteration of the seeker optical axis (i.e., vehicle spin axis) to have it coincide with the line-of-sight from the vehicle to the target. Because the telescope's precession rate depends upon the magnitude of the thrust produced by the precessing jet (current in the solenoid of valve **26** controls the precessing jet), the pressure difference across the jet (which is proportional to the coil current) becomes a direct measure of the bearing rate to the target.

A space vehicle **10** traveling in space on a collision course with another body **30** moving in space is shown in FIG. 16. With the range between the space vehicle **10** and the other body **30** (e.g., a target planet) closing and the bearing angle remaining constant (i.e., $\alpha=\beta=\gamma$) the vehicle and other body will inevitably collide.

A vehicle of constant speed launched on a collision course with a target body in space moving at a constant speed should maintain a constant bearing to the target body to close the range to zero. The vehicle-to-target bearing must be constant at the end of flight for a collision, and a constant bearing throughout flight will ensue a collision. Since the principles of a collision course are well known in the art, a further discussion on this point is not considered necessary.

To provide a mechanism of establishing a collision course between the space vehicle **10** and a target **30** moving in space, the spinning vehicle must be provided with a lateral acceleration which is in the plane determined by the sequential positions of the sight line from vehicle to target and be of a magnitude proportional to the sight line rate. This can be accomplished by providing the vehicle **10** with a second jet (a lateral jet) **32** whose thrust axis is through the center of gravity of the spinning vehicle, and whose thrust axis is 90° from the thrust axis of the precessing jet as measured around the periphery of the spinning assembly, as shown in FIGS. 1 and 2.

If both the precessing jet **16** and the lateral jet **32** are controlled by a single valve **26**, FIG. 8, in such a way that the pressure behind each jet is varied proportional to the incoming target signal from detector **22**, then it can be shown that a direct proportionality exists between the sight line rate and the lateral acceleration of the vehicle in space. This is the necessary and sufficient condition for a proportional navigational course which will result in the collision of the vehicle and target bodies.

Referring again to FIG. 7, this figure shows a wiring diagram of an amplifier which amplifies the target signal generated by the photodetector cell **22** and feeds it to solenoid coil **24** which operates valve **26** and thus the jet motors **16** and **32**.

The amplifier circuit, shown by way of example, includes a conventional power supply **35** including a transformer **36** having primary and secondary windings and a fullwave rectifier as shown at **37**. Associated with the power supply **35** is a filtering network **39** of conventional form supplying a potentiometer **40**. Potentiometer **40** supplies power to a phase shift transformer **42**, the primary of which is in the plate circuit of an amplifier tube **44**. The photocell **22** is connected in the grid circuit of an amplifier tube **46** which is a five element tube having screen and suppressor grids as shown. The input circuit of tube **46** includes photocell **22** and filter circuits **47** to limit the range of frequencies to which the system will be sensitive.

The output of tube **46** is connected to the control grid of tube **44** which controls the primary of transformer **42**.

The secondary of transformer **42** connects to a conventional phase shifting circuit network as shown at **50** including a center tapped resistor **51** connected across the secondary and grounded, and a rheostat **52**. By adjustment of rheostat **52** the phase of the signal pulses being transmitted can be adjusted. The phase shifting circuit **50** is connected to a phase splitting tube **54**, the output of which connects to a push-pull power amplifier circuit **56**. Circuit network **56** includes push-pull connected tubes **57** and **58**. Numerals **59** and **60** indicate grid resistors.

The power amplifier network **56** is connected to the primary of output transformer **68** and the secondary **69** of this transformer is connected to the solenoid coil **24** which operates valve **26** for the precessing and lateral thrust jets **16** and **32**.

By adjusting the variable resistor **52**, the phase, or time of occurrence, of the signal pulses from photodetector cell **22** can be adjusted relative to the angular position of the precessing jet **16** about the spin axis **26** of the vehicle so that the direction of precessing is such as to achieve straight line precession of the vehicle in realigning its spin axis **26** with the line-of-sight from the seeker to the target as illustrated in FIGS. 9 and 10. Another method of adjusting the phase relative to the angular position of the precessing jet, as previously described, is by physically orienting the clear and opaque sectors of the reticle about the spin axis with respect to the precessing jet **16**.

Referring again to FIG. 8, this figure illustrates how signals generated by photodetector cell **22**, from radiation from a target impinging thereon, are amplified by signal amplifier **14** and caused to operate solenoid **24** which in turn actuates a single valve **26**. Valve **26** is a fuel injector type valve which feeds correct amounts of fuel and oxidizer, for example, into combustion chamber **27**. Both the precessing jet **16** and lateral jet **32** are fed at equal gas pressures from combustion chamber **27**. The passages from combustion chamber **27** to the jet nozzles are large in cross-sectional area with respect to the cross-sectional area of the jets in order that there will be no pressure drop between the combustion chamber and the jet nozzles.

Though the gas pressure at each of the nozzles are equal to each other at all times, the cross-sectional areas of the nozzles are of different sizes in order to establish the proportionality of the lateral acceleration and the sight line rate. Less thrust will usually the necessary to precess the vehicle than will be needed for moving the

vehicle on a collision course to eventually collide with a target.

Injector valve **26** is of the type for controlling the quantity of oxidizer and fuel entering the combustion chamber and of acting to shut off the propellant flow completely. With this type of valve the thrust of the jets **16** and **32** can be varied according to the amount of oxidizer and fuel allowed to enter the combustion chamber from the oxidizer and fuel tanks, shown in FIG. 1, in response to current passing through solenoid **24**. Injector valve **26** is similar to that disclosed in U.S. Patent 2,810,259 issued October 22, 1957.

It has been presumed that the vehicle is traveling at a forward velocity imparted to it when it was launched on its travel in space. Where additional forward velocity of the vehicle is desired, to that imparted thereto at the time of launch, the lateral jet may be canted back at an angle to give a forward thrust vector as well as the lateral thrust vector. It must be noted, however, that the thrust axis of this jet must pass through the center of gravity of the vehicle.

By properly directing a single jet with respect to the center of gravity of the body in order to generate a pulsating torque equivalent to that of the precessing jet, as previously described, the single jet can be used to achieve the precessing mechanism as well as lateral and forward thrust. The thrust axis from the single jet must pass close to but displaced from the center of gravity of the vehicle by the amount necessary to produce a torque about the center of gravity equal to that previously produced by the precessing jet.

Obviously, many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

**1.** In *combinaton,* a vehicle *having propulsion means therein* and capable of traveling in free space while rotating about its central spin axis and having all the properties of a gyroscope, *and* a proportional navigation system comprising seeker means mounted on the spin axis of the vehicle for detecting electromagnetic radiation from a target body and generating electrical signals in response to said radiation, *and* means responsive to the electrical signals generated by said seeker means for operating *said* propulsion means in said vehicle in a manner to precess the vehicle to point its spin axis directly at the target body and to move said vehicle along a collision course with said target body.

**2.** A device as in claim **1** wherein said seeker means includes a folded reflecting telescope whose optical axis coincides with the spin axis of the vehicle, a reticle mounted at the focal plane of said telescope for rotation therewith and for chopping radiation from the target formed into an image thereon into a pulsed radiation signal, and a photo-detector cell mounted behind said reticle to convert the pulsed radiation signal into an alternating current.

**3.** In a vehicle capable of traveling in free space while rotating about its central spin axis and having all the properties of a gyroscope, a proportional navigation system comprising seeker means mounted on the spin axis of the vehicle for detecting electromagnetic radiation from a target body and generating electrical signals in accordance with the bearing of the target relative to the spin axis of the vehicle in response to said radiation, means for converting said signals into an alternating current the time of occurrence of which is determined by the target position, means responsive to the electrical signals generated by said seeker means for operating propulsion in said vehicle in a manner to precess the vehicle to point its spin axis directly at the target body and to move said vehicle on a collision course with said target body.

**4.** A vehicle capable of traveling in free space while rotating about its central spin axis and having all the properties of a gyroscope, including a proportional navigation system comprising seeker means mounted on the spin axis of the vehicle for detecting electromagnetic radiation from a target body and generating electrical signals in response to said radiation which are in accordance with the bearing of the target relative to the spin axis of the vehicle, means for converting said signals into an alternating current the time of occurrence of which is determined by the target position, means responsive to these converted electrical signals for operating propulsion means in said vehicle including a small jet on the outer periphery of the spinning vehicle in a manner to precess the vehicle to point its spin axis directly at the target body and a second jet to move said vehicle along a collision course with said target body.

**5.** A device as in claim **4** wherein said second jet has its thrust axis passing through the center of gravity of the vehicle and said second jet is positioned 90° from the precessing jet as measured around the periphery of the spinning vehicle.

**6.** A vehicle capable of traveling in free space while rotating about its central spin axis and having all the properties of a gyroscope, including a proportional navigation system comprising seeker means mounted on the spin axis of the vehicle for detecting electromagnetic radiation from a target body and generating electrical signals in response to said radiation which are in accordance with the bearing of the target relative to the spins axis of the vehicle and the time of occurrence of which is determined by the position of the target body thereabout, means responsive to the electrical signals for operating means in said vehicle including a small jet on the outer periphery of the spinning vehicle in a manner to precess the vehicle to point its spin axis directly at the target body and a second jet to move said vehicle on a collision course with said target body.

**7.** A device as in claim **6** wherein said second jet has its thrust axis passing through the center of gravity of the vehicle and said second jet is positioned 90° about the periphery of the spinning vehicle as measured from the precessing jet.

**8.** A device as in claim **6** wherein the cross-sectional areas of the nozzles of said jets are of different sizes such as to establish the proportionality between the vehicle's acceleration along a collision course and the precession rate of pointing the vehicle's spin axis directly at the target body.

**9.** A device as in claim **6** wherein said small jet has a thrust axis which is parallel to the spin axis of the vehicle.

**10.** A device as in claim **9** wherein the torque produced by thrust from the precessing jet is transformed into a precession of the vehicle's spin axis in a direction perpendicular to both the spin axis and the axis intersecting the center of gravity of the vehicle perpendicular to the thrust axis of the precessing jet.

**11.** A device as in claim **6** wherein said means responsive to said electrical signals for operating the propulsion means comprises a solenoid operated valve for feeding fuel to a combustion chamber in amounts proportional to and in phase with said electrical signals.

**12.** A device as in claim **11** wherein said combustion chamber has passages connected therewith to said precessing jet and said second jet for supplying gases of combustion to said jets at equal pressures.

**13.** A device as in claim **11** wherein said solenoid operated valve is operable to vary the thrust from both said propulsion jets in proportion to said electrical signals.

**14.** A device as in claim **6** wherein nutation damper means is included therein for stabilization of the vehicle's spin axis.

**15.** *In combination, a* [A] gyroscopic spinning body *having an axis of spin* for *use in* detecting an energy emitting source, [said spinning body having an axis of spin,] means *on said body* responsive to energy emitted

from said source and providing an output signal representing the radial direction of said source with respect to said axis of spin, and precessing means *within said body* responsive to said output signal for causing said spin axis to approach alignment with said energy emitting source.

16. *In combination, a* [A] gyroscopic spinning body *having an axis of spin and adapted* for tracking an energy emitting source, [said spinning body having an axis of] [spin,] means *carried by said spinning body* responsive to energy emitted from said *energy emitting* source *for generating an output signal, and* [carried by said spinning body,] means *within said body* responsive to said *output signal* [first mentioned means] for applying a precessing force to said spinning body [and causing] *to cause* said spin axis to approach alignment with said energy emitting source.

17. The device of claim 16 wherein said force is an intermittent force applied at a frequency equal to the spin frequency of said spinning body.

18. *In combination, a* [A] spinning body *having an axis of spin and having all the properties of a gyroscope and adapted* for tracking an energy emitting source, [said spinning body acting as a gyro and having] [an axis of spin] means *carried by said spinning body* responsive to energy emitted from said *energy emitting* source [carried by said spinning body, said means] *for* providing an output signal having a frequency equal to the spin frequency of said spinning body, and precessing means within said body, responsive to *said* [the] output signal of said [first mentioned] *responsive* means for applying an intermittent force to said spinning body *to cause* [which intermittent force causes] said spin axis to approach alignment with said energy emitting source.

19. The combination as recited in [device of] claim 18 [having additional], *and additionally* means responsive to *said* [the] output signal [of said first mentioned] [means] for applying an additional intermittent force to said spinning body *to cause* [which additional intermittent force causes] motion of said spinning body transverse to said axis of spin.

*20. A vehicle capable of traveling in free space and adapted to be spin stabilized about a spin axis, said vehicle including:*

*means for generating a signal having a frequency proportional to the spin frequency of said vehicle;*

*means on said vehicle for applying torque to said vehicle; and*

*means responsive to said signal and coupled to said torque applying means for causing said vehicle to precess so as to reorient said spin axis in a predetermined direction.*

*21. In combination, a vehicle capable of traveling in free space and adapted to be spin stabilized about a spin axis,*

*means in said vehicle for generating a signal having a frequency proportional to the spin frequency of said vehicle;*

*means on said vehicle for applying a force to said vehicle having an acceleration component transverse to said axis of spin;*

*means responsive to said signal and coupled to said force applying means for causing said vehicle to precess and change its velocity;*

*and nutation damper means carried by said vehicle for damping nutational movement.*

*22. In a vehicle capable of traveling in free space while rotating about a spin axis, an orientation control system comprising:*

*means carried by said vehicle for generating a signal having a frequency proportional to the spin frequency of said vehicle;*

*jet means on said vehicle having a thrust axis displaced from the center of gravity of said vehicle; and*

*means responsive to said signal and coupled to said jet means for operating said jet means for applying a torque to said vehicle for causing said vehicle to precess so as to move said spin axis to point in a predetermined direction.*

*23. In a vehicle capable of traveling in free space and adapted to be spin stabilized about a spin axis, a velocity control system comprising:*

*means carried by said vehicle for generating a signal having a frequency proportional to the spin frequency of said vehicle;*

*jet means on said vehicle having a thrust component substantially through the center of gravity of said vehicle; and*

*means responsive to said signal and coupled to said jet means for operating said jet means to apply a force to said vehicle to cause said vehicle to precess, with said force having an acceleration component transverse to said axis.*

*24. In a vehicle capable of traveling in free space while rotating about a spin axis, orientation control apparatus comprising:*

*jet means on said vehicle having a thrust axis displaced from said spin axis and having a thrust component substantially paralleling said spin axis; and*

*means coupled to said jet means for operating said jet means for applying a torque to said vehicle for causing said vehicle to precess so as to move said spin axis to a predetermined orientation.*

*25. In a vehicle capable of traveling in free space and capable of being spin stabilized about a spin axis, velocity control apparatus comprising:*

*jet means on said vehicle having a thrust component acting substantially through the center of gravity of said vehicle; and*

*means coupled to said jet means for operating said jet means to apply a force to said vehicle to cause said vehicle to precess, with said force having an acceleration component transverse to said axis of spin.*

*26. In a vehicle capable of traveling in free space and adapted to be spin stabilized about a spin axis, an orientation control system comprising:*

*detector means carried by said vehicle and adapted to directionally detect an object in space and for generating a signal in response thereto; means carried by said vehicle for applying a torque to said vehicle; and*

*means responsive to said signal and coupled to said torque applying means for causing said vehicle to precess so as to orient said spin axis with respect to said object.*

*27. An orientation control system comprising:*

*a spin stabilized vehicle; means carried by said vehicle and responsive to energy emitted from an energy emitting source for generating a signal;*

*means carried by said vehicle; for applying a torque to said vehicle; and*

*means responsive to said signal and coupled to said torque applying means for causing said vehicle to precess so as to orient its spin axis with respect to said energy emitting source.*

*28. In a vehicle capable of traveling in free space while rotating about a spin axis, an orientation control system comprising:*

*means carried by said vehicle and responsive to energy emitted from an energy emitting source for generating a signal;*

*means carried by said vehicle for applying a torque to said vehicle; and*

*means responsive to said signal and coupled to said torque applying means for causing said vehicle to precess so as to orient said spin axis with respect to said energy emitting source.*

*29. In a vehicle capable of traveling in free space and adapted to be spin stabilized about a spin axis, a velocity control system comprising:*

means carried by said vehicle and responsive to energy emitted from an energy emitting source for generating a signal;

means responsive to said signal for applying a force to said vehicle to cause said vehicle to precess and accelerate said vehicle substantially transverse to said axis;

and nutation damper means carried by said vehicle for damping nutational movement.

30. In a vehicle capable of traveling in free space while rotating about a spin axis, an orientation and velocity control system comprising:

means carried by said vehicle and responsive to energy emitted from an energy emitting source for generating a signal; and

means responsive to said signal for applying a torque to said vehicle for precessing said vehicle to point its spin axis to a predetermined angle with respect to said source and for applying a force to said vehicle for causing acceleration of said vehicle substantially transverse to said axis.

31. In a vehicle capable of traveling in free space while rotating about a spin axis, an orientation control system comprising:

means carried by said vehicle and responsive to energy emitted from an energy emitting source for generating a signal;

means on said vehicle for applying torque to said vehicle; and

means responsive to said signal and coupled to said torque applying means for causing said vehicle to precess so as to reorient said spin axis in a predetermined direction with respect to said source.

32. In a vehicle capable of traveling in free space while rotating about a spin axis, an orientation control system comprising:

means carried by said vehicle and responsive to energy emitted from an energy emitting source for generating a signal;

jet means on said vehicle having a thrust axis displaced from said spin axis and having a thrust component substantially paralleling said spin axis; and

means responsive to said signal and coupled to said jet means for operating said jet means for applying a torque to said vehicle for causing said vehicle to precess so as to reorient said spin axis with respect to said energy emitting source.

33. In a vehicle capable of traveling in free space and adapted to be spin stabilized about a spin axis, a velocity control system comprising:

means carried by said vehicle and responsive to energy emitted from an energy emitting source for generating a signal;

jet means on said vehicle having a thrust component acting substantially through the center of gravity of said vehicle; and

means responsive to said signal and coupled to said jet means for operating said jet means for applying a force to said vehicle to cause said vehicle to precess and accelerate said vehicle substantially transverse to said axis of spin.

34. In a vehicle capable of traveling in free space while rotating about a spin axis, an orientation control system comprising:

detector means carried by the vehicle and responsive to electromagnetic radiation for generating an electrical signal indicative of the bearing of the source of said electromagnetic radiation relative to an axis of the vehicle;

means carried by said vehicle for applying an intermittent torque to said vehicle about an axis different from said spin axis; and

means responsive to said signal and coupled to said torque applying means for causing said vehicle to precess so as to reorient said spin axis with respect to said source.



35. In a vehicle capable of traveling in free space and adapted to be spin stabilized about a spin axis, a velocity control system comprising:

detector means carried by the vehicle and responsive to electromagnetic radiation for generating an electrical signal indicative of the bearing of the source of said electromagnetic radiation relative to an axis of the vehicle;

means responsive to said signal for applying an intermittent force to said vehicle to cause said vehicle to precess and accelerate said vehicle substantially transverse to said axis of spin; and

nutation damper means carried by said vehicle for damping nutational movement.

36. In combination, a spin stabilized vehicle,

means carried by said vehicle and responsive to energy emitted from an energy emitting source for generating a signal having a frequency which is a function of the spin rate of said vehicle when spinning; and

means responsive to said signal for applying an intermittent torque to said vehicle about an axis different from said spin axis to cause said vehicle to precess so as to move said spin axis to approach alignment to a predetermined orientation with respect to said source.

37. In combination, a spin stabilized vehicle,

means carried by said vehicle and responsive to energy emitted from an energy emitting source for generating a signal having a frequency equal to the spin rate of said vehicle when spinning; and

means responsive to said signal for applying an intermittent torque to said vehicle about an axis different from said spin axis to cause said vehicle to precess so as to move said spin axis to approach alignment to a predetermined orientation with respect to said source.

38. In combination, a vehicle capable of traveling in free space and adapted to be spin stabilized about a spin axis,

means carried by said vehicle and responsive to energy emitted from an energy emitting source for generating a signal having a frequency which is a function of the spin rate of said vehicle when spinning; and

means responsive to said signal for applying an intermittent force to said vehicle to cause said vehicle to precess and accelerate said vehicle transverse to said axis.

39. In combination, a vehicle capable of traveling in free space and adapted to be spin stabilized about a spin axis,

means carried by said vehicle and responsive to energy emitted from an energy emitting source for generating a signal having a frequency equal to the spin rate of said vehicle when spinning; and

means responsive to said signal for applying an intermittent force to said vehicle to cause said vehicle to precess and accelerdate said vehicle transverse to said axis.

40. A spin stabilized vehicle, said vehicle including:

means carried by said vehicle and responsive to energy emitted from an energy emitting source for generating a signal having a frequency equal to the spin rate of said vehicle when spinning; and

means responsive to said signal for applying an intermittent torque, to said vehicle about an axis different from said spin axis, at a rate which is equal to the frequency of said signal, with said intermittent torque causing said vehicle to precess so as to move said spin axis to approach alignment to a predetermined orientation with respect to said source.

41. In combination, a vehicle capable of traveling in free space and adapted to be spin stabilized about a spin axis,

means carried by said vehicle and responsive to energy emitted from an energy emitting source for generating a signal having a frequency equal to the spin rate of said vehicle when spinning; and

means responsive to said signal for applying an intermittent force to said vehicle at a rate which is equal to said frequency of said signal to cause said vehicle to precess and accelerate said vehicle transverse to said axis of spin.

42. A vehicle capable of traveling in free space and adapted to be spin stabilized about a spin axis, said vehicle including:

means for generating a signal having a frequency proportional to the spin frequency of said vehicle;

means on said vehicle for applying torque to said vehicle;

means responsive to said signal and coupled to said torque applying means to cause said vehicle to precess so as to reorient said spin axis in a predetermined direction; and

nutation damper means carried by said vehicle for damping nutational movement.

43. In combination,

a spin stabilized body, means carried by said body for generating a signal having a frequency proportional to the spin frequency of said body;

means disposed within said body for supplying fluid under pressure;

at least one controllable valve connected to said means for supplying fluid under pressure;

at least one jet-forming means connected to said valve;

and control means coupled to said valve for actuating said valve in pulses synchronized with the spin of said body.

44. In combination,

a spin stabilized body, means carried by said body for generating a signal having a frequency proportional to the spin frequency of said body;

fluid supply means associated with said body;

a controllable valve connected to said fluid supply means;

fluid expulsion means coupled with said valve and oriented to expel said fluid along a line displaced from a line passage through the center of gravity of said body;

and control means coupled to said valve for controlling said valve in pulses synchronized with the spin of said body.

45. In combination,

a spin stabilized body, means carried by said body for generating a signal having a frequency proportional to the spin frequency of said body;

fluid supply means associated with said body;

a controllable valve connected to said fluid supply means;

fluid expulsion means coupled with said valve and oriented to expel said fluid substantially along a line normal to said axis;

and control means coupled to said valve for controlling said valve in pulses synchronized with the spin of said body.

46. In combination,

a spin stabilized body, means carried by said body for generating a signal having a frequency proportional to spin frequency of said body;

and means associated with said body for expelling fluid more than once from a particular location thereon to exert a series of incremental forces on said body during several revolutions of said body about said axis, said means controlling the duration of each expulsion of fluid to be short compared to the time of one revolution of said body about said axis, said means controlling the time of occurrence of each expulsion of fluid to be at a predetermined part of the cycle of revolution of said body about said axis, whereby said series of incremental forces provide a net force on said body in a predetermined direction.

47. In combination,

a spin stabilized body, means carried by said body for generating a signal having a frequency proportional to spin frequency of said body;

fluid supply means associated with said body, a controllable valve connected to said fluid supply means;

fluid expulsion means coupled with said valve for expelling said fluid from said body in a fixed direction with respect to said body;

and control means coupled to said valve for actuating said valve more than once to apply a series of incremental forces to said body during several revolutions of said body about said axis, said control means controlling the duration of each actuation of said valve to be short compared to the time of one revolution of said body about said axis, said control means controlling the time of occurrence of each actuation of said valve to be at a predetermined part of the cycle of revolution of said body about said axis, whereby said series of incremental forces provide a net force on said body in a predetermined direction.

48. In combination,

a spin stabilized body;

means carried by said body for generating a signal having a frequency proportional to the spin frequency of said body;

and means responsive to said signal for applying a torque to said body to precess the spin axis of said body through a desired sequence of orientation.

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# UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Reissue No. 26,887 May 19, 1970

William B. McLean

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

Column 9, line 55, "in" should read -- on --. Column 10, line 55, "vehicle;" should read -- vehicle --. Column 12, line 59, "accelerdate" should read -- accelerate --. Column 13, line 44, "passage" should read -- passing --. Column 14, line 9, cancel "said", first occurrence.

Signed and sealed this 23rd day of February 1971

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

WILLIAM E. SCHUYLER, JR.
Commissioner of Patents