NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO
ATTN OF: GP

October 15, 1970

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General
Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned
U.S. Patents in STAR

In accordance with the procedures contained in the Code GP to Code USI memorandum on this subject, dated June 8, 1970, the attached NASA-owned U.S. patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No.	:	3,270,985
Corporate Source	:	Marshall Space Flight Center
Supplementary Corporate Source	:	
NASA Patent Case No.	:	XMF-01598

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Enclosure:
Copy of Patent

FACILITY FORM 602

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10 (PAGES)	(CODE)
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21

Sept. 6, 1966 R. SCHMIDT 3,270,985

REACTANCE CONTROL SYSTEM

Filed Dec. 26, 1963 2 Sheets-Sheet 1

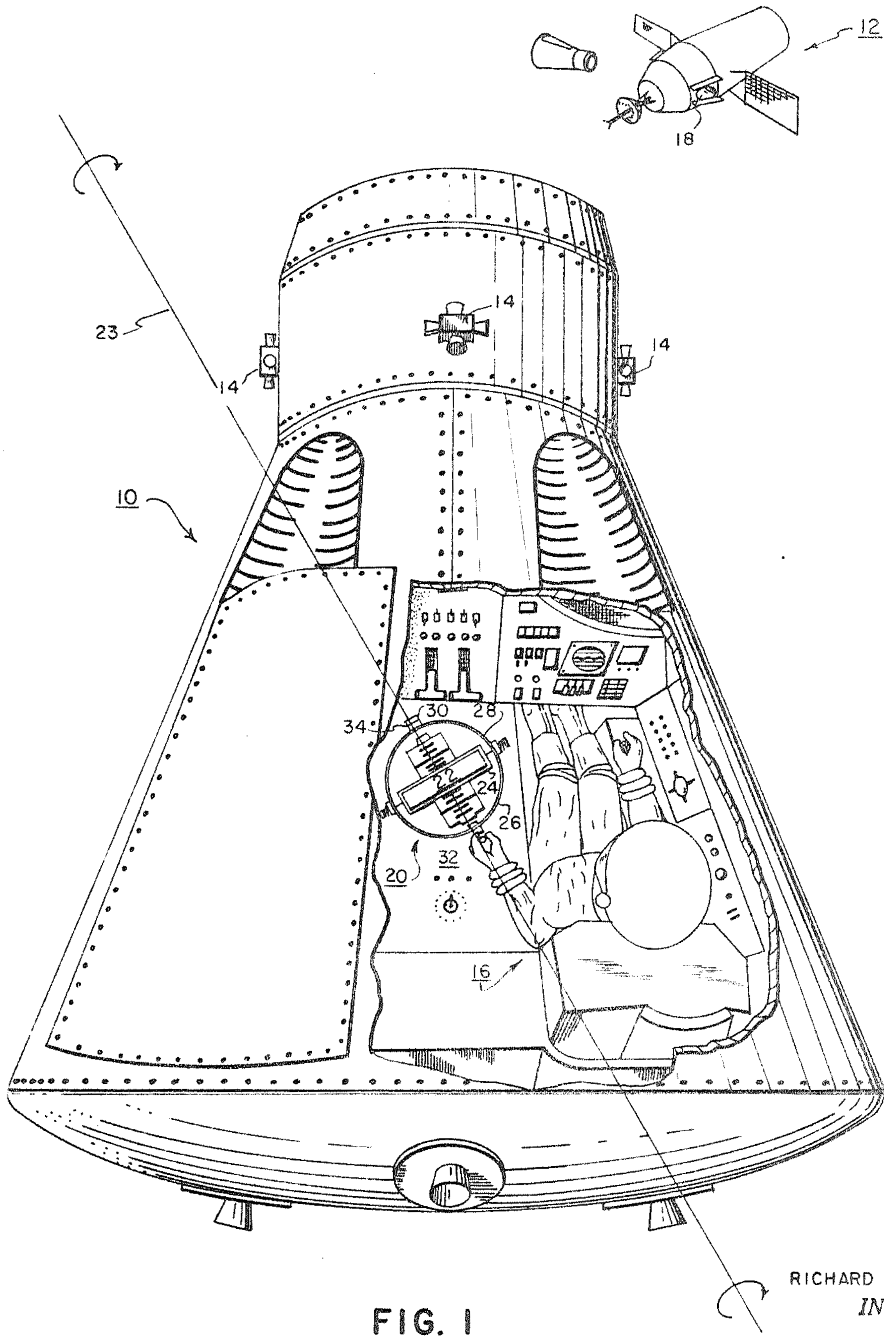

FIG. I

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N71-15583

Sept. 6, 1966 R. SCHMIDT 3,270,985

REACTANCE CONTROL SYSTEM

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2 Sheets-Sheet 2

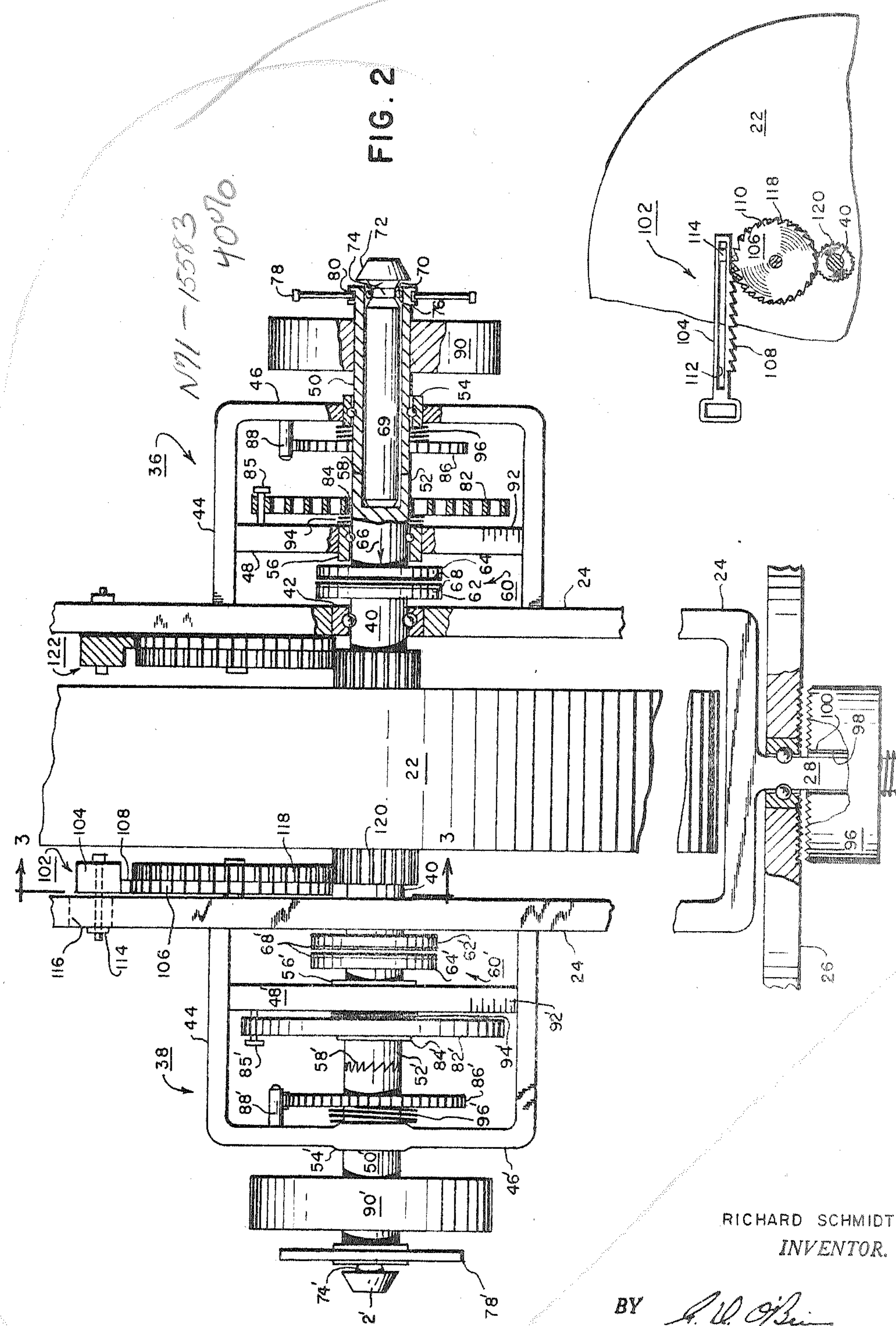

FIG. 2

N71-15583 40%

FIG. 3

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United States Patent Office

3,270,985

Patented Sept. 6, 1966

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3,270,985

REACTANCE CONTROL SYSTEM

Richard Schmidt, Madison, Ala., assignor to the United States of America as represented by the Administrator of the National Aeronautics and Space Administration

Filed Dec. 26, 1963, Ser. No. 333,770
19 Claims. (Cl. 244—1)

The invention described herein 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.

This invention relates generally to a reactance attitude control system for navigable bodies passing through a fluid or a non-fluid medium, and more particularly to the drive mechanism for operating such a system.

As is well known, conventional techniques for controlling the attitude of bodies such as aircraft, ships or the like passing through fluid mediums depend upon the torque reaction of the fluid medium with a movable control surface attached to and extending from the bodies into the mediums. However, in the event that the body to be controlled is moving through a substantial vacuum, such as exists in outer space, the body cannot be controlled by such forces because of the substantial absence of any fluid.

Various methods and systems have been proposed to provide attitude control for bodies such as, for example, space crafts which are traveling in a substantial vacuum, or for other reasons cannot use a movable reactance surface for control. One of the most promising systems for obtaining this control involves the use of an internal reactance force. One such system involves the use of a weighted material or reaction wheel that is displaced at a controllable rate and in a desired direction or directions within the craft in such a manner as to produce a variable torque rection against the craft thereby controlling its attitude independently of the absence or presence of a fluid medium outside of the craft. By suitably orienting the weighted material or reaction wheel within the craft, the torque can be produced about any desired craft axis and thus the movement of the craft can be varied as desired.

Although these prior known methods of controlling the attitude of a space craft have been proven feasible they have not found wide acceptance in the aerospace industry due to certain inherent disadvantages that each method possesses. Among the most noticeable disadvantages of these prior known reaction control systems is the large amount of power required to operate the systems, the heat produced within the space craft when such systems were started and stopped, the difficulty in solving the dynamical equations involved in their use, and the bearing longevity problem inherently found where a continuously rotating mass is involved. Furthermore, there has been some difficulty experienced in controlling the rate at which the space craft moves into the new attitude.

According to the present invention it has been found that these above enumerated disadvantages can be overcome by utilizing a reactance system in which the movable reaction producing mass is held motionless until movement of the craft being controlled is desired. To place the reactance system into operation, the reaction producing mass, which is preferably arranged to rotate about a movable axis, is first positioned so that the reaction forces generated when it is placed in motion will produce the desired movement in the craft. A stored source of energy is then coupled to and released into the reaction producing mass thereby setting it into motion thus causing the craft to rotate about the desired axes at a predetermined rate of movement. Once the craft has attained the desired attitude its rotational motion is arrested by stopping the movement of the reaction producing mass. This is done by coupling an energy storage system to the mass which serves to extract and store all the kinetic energy contained within the mass. The stored energy is thus available for later use in restarting the motion of the reactance mass when it is again desirable to alter the attitude of the craft.

Accordingly, the primary object of this invention is to provide a control system for a craft which is extremely reliable, inexpensive to produce and operate, light in weight, produces no heating problem when it is being used and can be easily placed into operation in a minimum length of time without the aid of elaborate computing devices.

Another object of this invention is to provide a reactance control system for a craft in which the reaction producing mass is arrested when the control system is not being utilized to control the attitude of the craft.

Yet another object of this invention is to provide a reactance control system for a space craft in which the movement of the reaction producing mass is arrested by an energy storage system which stores the kinetic energy contained therein for later use in restarting the motion of the mass.

These and further objects and advantages of this invention will become more apparent upon reference to the following description, claims and appended drawings wherein:

FIGURE 1 is a perspective view, particularly in section, of a space vehicle being maneuvered during the final phases of a docking operation by a reactance control system constructed in accordance with this invention;

FIGURE 2 is a view in elevation, together with a diametrical vertical cross-section with partial cutaway, of the control system shown in FIGURE 1; and

FIGURE 3 is a cross-sectional view in slightly reduced size taken along line **3—3** of FIGURE 2.

In order to better understand the construction and use of this novel reaction system it will be described in connection with an earth-orbiting space vehicle. It is to be understood, however, that various other uses may be found for this novel reaction system. For example, a control system constructed in accordance with this invention will give superior results when used in an aircraft, boat, submarine or other assorted earth bound craft. Other uses will be readily apparent to those skilled in the art.

With continued reference to the accompanying drawings wherein like reference numerals designate similar parts throughout the various views, and with initial attention directed to FIGURE 1, reference numeral **10** is used to generally designate an earth-orbiting space vehicle which is entering the final phase of a docking maneuver with an earth-orbiting space station **12**. The yaw, pitch and roll of the space vehicle **10** during this maneuver, as well as throughout most of its flight, is normally controlled by small attitude rockets **14** mounted on the exterior skin of the vehicle. When these rockets are operating properly the astronaut **16** is able to control the attitude of the space vehicle throughout its flight and to bring it into a proper mating with the air-lock **18** on the space station **12**. Although these rockets **14** are highly reliable, it has nevertheless been found desirable to incorporate a so-called "back-up" control system into the design of the space vehicle **10**. Since such a back-up system must be extremely reliable, relatively light, small and easily brought into operation, it was determined that a reactance control system which could be operated manually by the astronaut would be especially well suited for emergency use in outer space. Such a manually operated reactance control system for use in the space vehicle **10** is shown generally at **20**.

The manually operated reactance control system **20** consists of a reaction wheel **22** which is coupled to and is free to rotate within a gimbal ring **26** by suitable shafts **28**. A U shaped supporting housing **30** is rotatably mounted by suitable means (not shown) to the floor **32** of the space vehicle **10** and the gimbal ring **26** is rotatably suspended within this housing by suitable shafts **34**. The reaction wheel **22** is thus mounted in a gimbal network which permits three degrees of freedom, i.e., the rotational axes of the wheel **22** can be moved within the gimbals to any desired position. Once the reaction wheel **22** is properly positioned all the gimbals **26–30** are locked in place so that the reaction wheel **22** is no longer free to move for reasons that will be more fully explained hereinafter.

Since the present reactance control system **20** is to normally be used only in an emergency, such as would exist if the attitude rockets **14** of the space vehicle **10** ceased to function, it is necessary that the system be as independent as possible of all other systems within the vehicle. To realize the ultimate in simplicity and reliability, it is necessary that the complete control system be manually powered and operated by the astronaut. Accordingly, the control system **20** must be provided with a manually operated drive means which is capable of both spinning the reaction wheel **22** up to the proper operating speed in a minimum of time and of sustaining such rotation over a prolonged period when such operation is necessary or desirable. Furthermore, the starting and stopping of the reaction wheel should, ideally, produce no heating of the space craft since such heat would have to be dissipated by the cooling system of the craft. One method by which the normally stationary reaction wheel **22** can be instantly brought up to operating speed, maintained there, and later stopped without producing such a heating problem is shown in FIGURES 2 and 3.

As seen in FIGURE 2, the drive system for the reaction wheel **22** consists of two substantially identical units **36** and **38** operationally mounted on either side of the wheel. For purposes of clarity, unit **36** will be described in detail while corresponding parts of unit **38** will be given the same numeral followed by a prime factor. Those differences that do occur between the construction and operation of units **36** and **38** will be more fully explained hereinafter.

The reaction wheel **22** is mounted on a shaft **40** that rides upon bearings **42** which are force-fitted within the gimbal ring **24**. The drive unit **36**, which is used to bring the reaction wheel **22** up to operating speed in the case of an emergency, is housed within a modified "A" frame **44** that is attached to the gimbal ring **24** by any suitable method such as welding or brazing. The closed end brace **46** as well as the cross-brace **48** of the A-frame **44** have apertures formed therein for receiving shafts **50** and **52**, respectively, so that the center axes of these shafts are aligned with that of the shaft **40**. The shaft **50** is preferably carried by a bearing **54** that is force fitted into the aperture formed in the end **46** of the A-frame **44** while a second bearing **56** is force fitted within the aperture formed in the cross-brace **48** for carrying the end of shaft **52**. Both of the shafts **50** and **52** are free to not only rotate about their center axes but also to move axial thereto.

The adjacent ends of the shafts **50** and **52** are provided with serrated or stair-step teeth **58** which mate so that the shafts are locked for rotation in a clockwise direction (as viewed from the end of unit **36**) but are free to slip when either shaft is rotated in a counterclockwise direction. The adjacent ends of shafts **50′** and **52′** of unit **38** are also provided with serrated teeth **58′** but they are cut so as to lock the shafts in a counterclockwise direction while permitting substantially independent rotation in a clockwise direction. The reasons for permitting the shafts to move laterally and to provide serrated teeth on the ends thereof will become more apparent later.

A coupling unit **60** is positioned between the adjacent ends of the shafts **40** and **52** and is adapted to selectively couple the rotational motion of one shaft to the other. For purposes of illustration the coupling unit **60** is shown as a friction clutch consisting of two parallel clutch plates or disks **62** and **64**, the plate **62** being secured to the shaft **40** while plate **64** is secured to the shaft **52**. As will be apparent, when the drive shaft **52** is moved in the direction of the arrowhead **66** the clutch surfaces **68** on the plates **62** and **64** will engage thereby effectively coupling the two shafts **40** and **52** together.

Two independently operated clutch actuators are provided in the unit **36** for moving the shaft **52** in the direction of the arrowhead **66** and thus press clutch plate **64** into frictional engagement with plate **62**. The first actuator, which is used to place the reaction wheel **22** in motion, consists of a shaft or rod **69** located within and passing through an aperture **70** formed along the center axes of shaft **50**. The left hand end of the rod **69** as viewed in FIGURE 2 butts against and engages the shaft **52** while the other end of the rod is provided with a knob **72** or other suitable operating device. A turned down portion **74** is provided on the rod **69** for receiving a "C" ring **76** that is frictionally engaged against the inner surface of the aperture **70**. This turned down portion **74** and "C" ring **76** permits the rod **69** to move a limited distance along its center axes without becoming separated from the aperture **70**.

The second clutch actuator is used to stop the rotation of the reactance wheel and consists of a knob **78** that is mounted in a "U" shaped channel or groove **80** cut around the periphery of the hollow shaft **50**. This arrangement permits the shaft to be moved axially while it is rotating by simply pressing in on the knob **78**.

A manually operated drive system such as a coiled spring, elastic band or the like is provided in the unit **36** for instantly bringing the reaction wheel **22** up to operating speed when the knob **72** is pressed. This drive system for clarity is shown as a coiled spring **82** which has one end secured through a suitable clutch means **84**, such as an electric clutch, to the shaft **52** while the other end thereof is secured to the cross-brace **48** by a peg **85**. The clutch means **84** is adapted to permit the spring **82** to slip about the shaft **52** when the shaft is rotating in a clockwise direction and the spring **82** is not wound. A ratchet wheel **86** is mounted on the shaft **50** while a spring loaded pawl **88**, which rides upon the wheel **86**, is carried by the closed end **46** of the A-frame. The pawl **88** will permit the ratchet wheel **86** to rotate in a clockwise direction but will not permit slippage of the wheel in the counterclockwise direction. A knob **90** is also mounted on the shaft **50** and is employed for loading the coiled spring **82** prior to its use.

In order to tell the amount of energy stored in the coil spring **82**, and thereby calculate the speed with which the reaction wheel will be rotated once the energy is transferred from the spring to the wheel, an indicator can be used with the unit **36**. Such an indicator is shown as calibrated marks **92** formed on the cross-brace **48**. As the coil spring **82** is wound the outer turn thereof will move along the calibrated scale thereby giving an indication of the energy contained in the spring.

A pair of springs **94** and **96** are provided for biasing the serrated teeth **58** together and the clutch plates **62** and **64** out of engagement with one another. The spring **94** is positioned between the cross-brace **48** and coiled spring **82** thereby tending to drive the shaft **52** to the right while spring **96** presses against the ratchet wheel **86** and the A-frame end **46** thus driving the shaft **50** to the left. The force exerted by each spring **94** and **96** is substantially the same so that they effectively cancel out and the shafts **50** and **52** will, thereby, only move when an external force is applied through the knobs **72** and **78**.

As mentioned hereinabove, the unit **38** is provided with a spring drive that is substantially identical to that contained in unit **36** with the exception that the serrated teeth **58′** lock for rotation in a counterclockwise direction, the coil spring **82′** is coiled so as to spin the reaction wheel in a clockwise direction when released, and the ratchet wheel **86′** and pawl **88′** will permit slippage in a counterclockwise direction. Thus it is seen that units **36** and **38** are identical except that unit **36** is designed to spin the reaction wheel **22** in a counterclockwise direction (as viewed from the end of unit **36**) while unit **38** is designed to spin the wheel in a clockwise direction.

The operation of the manually operated reactance control system can be explained in substantially the following manner. After the astronaut **16** has determined in which direction or plane the space craft **10** is to be rotated in order to bring it into the proper attitude for rendezvousing with the orbiting space station **12**, the astronaut will manually move the reaction wheel **22** within its gimbaled support until the axis or rotation plane **23** of the wheel is parallel to the desired correction plane. Since the reaction wheel is at rest, a negligible amount of reaction will be produced by moving and locking the wheel in place. The gimbal rings **24** and **26** are then locked in place by any suitable locking device such as the spring loaded serrated knob **96** (FIGURE 2) shown mounted on the shaft **28** of the gimbal ring **24**. The knob is provided with a key-way **98** that engages the key **100** formed on the shaft **28** thereby preventing the shaft from rotating within the knob.

Once the gimbal rings **24** and **26** are securely locked in place the reaction wheel **22** is ready to be "spun-up" to operating speed by one of the spring drives. For purposes of illustration it is assumed that the space craft **10** is to be rotated in a clockwise direction about the rotational plane **23** of the reaction wheel **22**. This would require that the reaction wheel **22** be rotated in a counterclockwise direction with an angular velocity sufficient to produce the desired reaction force within a given period of time. The principal equation for determining the capabilities of a given reaction wheel to produce such a reaction force is,

$$\text{(I)} \qquad I_s w_s = I_r w_r$$

wherein I represents the polar moment of inertia, and ω the angular velocity with subscript s indicating the space craft and r the reaction wheel. By writing w in terms of the kinetic energy E, the following equation is obtained,

$$\text{(II)} \qquad w = \sqrt{\frac{2 \cdot E}{I}}$$

or

$$\text{(III)} \qquad E = \frac{1 \cdot w^2}{2}$$

From Equations I and II, the moment of inertia of the reaction wheel can be found as,

$$\text{(IV)} \qquad I_s w_s = I_r \sqrt{\frac{2E_r}{I_r}}$$

or

$$\text{(V)} \qquad I_r = \frac{(I_s w_s)^2}{2 \cdot E_r}$$

If the mechanical efficiency factor of the system is expressed as n, the input energy E, for one maneuver, is,

$$\text{(VI)} \qquad E^1 = (E_r + E_s)(1-n)$$

From Equation VI it is seen that the input energy is dependent primarily on the efficiency factor of the system and secondarily on the moment of inertia.

In the present instance, the effectiveness of the reaction

control system for controlling the attitude of the space craft **10** is illustrated as follows:

The reaction wheel **22** and the space craft **10** are assumed to have the following dimensions and characteristics:

Radius of the space craft (Rs) ----	1.5 meters.
Length of the space craft (Ls) -----	5 meters.
Equally distributed weights (Ws) ---	5000 kg.
Control angular velocity (ws) -----	2 (degrees/sec.) or 0.0349 (rad./sec.).
Radius of the center line of the reaction wheel ring (Rr) -----------	0.3 meter.
Efficiency of the reaction wheel system (n) ----------------------	0.97.
Input energy for one maneuver (E') --------------------------	15.0 m. kg.

The polar moment of inertia of the space capsule is given by,

$$I_s = \frac{3}{10}\frac{W_s}{g_o}Rs^2 = \frac{3}{10}\frac{5000}{9.81}1.5^2 = 344 \text{ meters kg. sec.}^2$$

The kinetic energy of the wheel is found using Equations III and VI,

$$E_r = \frac{E^1}{1-n} - E_s = \frac{E^1}{1-n} - (0.5 \cdot I_s \cdot w_s^2) = \frac{15}{1-0.97} - (0.5 \cdot 344 \cdot 0.349^2)$$

$$E_r = 500 \text{ meters kg.}$$

The angular impulse of the space capsule is,

$$I_s w_s = 344 \cdot 0.0349 = 12 \cdot \text{meters kg. sec.}$$

The moment of inertia of the reaction wheel is,

$$I_r = \frac{(I_s w_s)^2}{2 \cdot E_r} = \frac{12^2}{2 \cdot 500} = 0.144 \text{ meter kg. sec.}^2$$

Since the reaction wheel is in the shape of a ring its moment of inertia is,

$$I_r = \frac{W_r}{g_o}(R_r^2 + 3/4b^2)$$

where b is the radius of the ring section of the wheel, and g_o is the gravitational acceleration in meters/sec.^{2} at zero altitude. The expression $3/4b^2$ will be very small when compared to R_r^2 and can, therefore, be neglected. The weight W_r of the reaction wheel is,

$$W_r = \frac{I_r \cdot g_o}{R_r^2} = \frac{0.144 \times 9.81}{0.3^2} = 15.7 \text{ kg.}$$

The angular velocity of the wheel w_s is computed by Equation I as,

$$I_s w_s = I_r w_r$$

$$w_r = \frac{I_s w_s}{I_r} = \frac{344 \times 0.0349}{0.1444} = 83.37 \text{ (rad./sec.)}$$

or

$$w_r = \frac{83.37 \times 30}{\pi} = 796 \text{ (r.p.m.)}$$

To accelerate the reaction wheel up to this speed would require the astronaut to expend the same amount of energy as would be involved in lifting 15K grams to a height of one meter. An astronaut can easily provide this energy in a few seconds by simply rotating the knob **90** until the coil spring **82** is wound up to the desired mark on the scale **92**. If desired, the coil spring can be pre-wound just prior to the flight of the space craft **10** thereby preventing the body heat of the astronaut from raising thus placing an added load on his life support system. Furthermore, such a pre-wound spring would save any time that might otherwise be lost in winding the spring later in the flight. After each operation of the spring drive system the astronaut would only have to replace that energy expended due to bearing friction or the like which is very small.

Once the coil spring 82 has the correct amount of energy stored therein, the astronaut 10 can set the reaction wheel 22 in motion by pressing the knob 72 thereby pushing shaft 52 and the clutch plate 64 into engagement with the plate 62 and out of engagement with the serrated teeth 58. This results in the coil spring being freed from the ratchet wheel 86 and coupled to the reaction wheel 22 through the clutch 60. The coil spring 82 will then unwind thereby transferring its stored energy to the reaction wheel 22 by placing the wheel in motion. This rotation of the reaction wheel 22 will in turn produce a reaction force upon the space craft 10 thus causing the craft to rotate in the opposite direction from that in which the wheel is turning but about the same rotational axis

As soon as the reaction wheel 22 is brought up to full speed, the astronaut will release the knob 72 thereby permitting the spring 94 to once again return the shaft 52 to its original position with the serrated teeth 58 in contact with one another. The coil spring 82 is now unloaded and will remain in this condition until it is used for its decelerating function as will be more fully explained hereinafter.

To stop the rotation of the reaction wheel 22 when the space craft approaches the desired attitude the astronaut will actuate the deceleration system by pressing the knob 78′ so that the shafts 50′ and 52′ are moved toward the wheel thereby causing the clutch 60′ to engage. With the clutch 60′ engaged the kinetic energy contained in the rotating reaction wheel 22 will be transferred to the previously unloaded coil spring 82′ thus bringing the wheel to a stop. The stopping of the reaction wheel 22 in turn causes the rotation of the space craft 10 to stop and the control maneuver is completed. The ratchet wheel 86′ prevents the now loaded coil spring 82′ from unwinding until the knob 72′ is pressed.

As will be apparent, the only energy lost during the rotation of the space craft is that expended in overcoming friction which, in the present case, is very small. This lost energy can quickly be replaced by the astronaut simply by rotating the knob 90′ thereby winding the coil spring 82′ up until the desired amount of stored energy is attained as indicated by the scale 92′.

To again place the reaction control system in operation it is only necessary to unlock the gimbal rings 24 and 26, position the reaction wheel 22, lock the gimbal rings and press the knob 72′. The reaction wheel 22 will then be placed in motion by the coil spring 82′ and the space craft 10 will be moved into a new preselected attitude. To stop the maneuver the knob 78 is pressed and the energy of the reaction wheel stored in the coil spring 82.

In those instances where it is desirable for the reaction control system to operate over a prolonged period of time, such as where the space craft is to be slowly rotated for a number of times, the speed of the reaction wheel can be maintained at a preselected value by using a rack and pinion accelerating unit 102 consisting of a modified rack 104 and pinion 106 shown in FIGURES 2 and 3. The rack 104 consists of an arm having saw-tooth teeth 108 formed along its lower edge which are adapted to engage with similar teeth 110 formed on the pinion wheel 106. The rack 104 has an elongated slot 112 formed therein for receiving a pin or bolt 114 which permits the rack to move laterally across the pinion 106 thereby placing it in motion. The bolt 114 is preferably mounted in a slot 116 formed in the gimbal ring 24 for permitting the rack 104 to move vertically and out of engagement with the pinion wheel 106 when it is being readied for use in accelerating the reaction wheel 22.

A large geared wheel 118 is formed on the pinion wheel 106 for coupling the motion of the pinion wheel through a smaller geared wheel 120, which is mounted on the shaft 40, to the reaction wheel 22. Thus it is seen that when the rack 104 is pulled to the left in FIGURE 3 the reaction wheel 22 will be accelerated.

Since the reaction wheel can be spun in only one direction by a given rack and pinion arrangement (in a clockwise direction as seen in FIGURE 3, for example), and since it may be desirable to furnish energy to the wheel while it is rotating in the opposite direction, a second modified rack and pinion unit 122 is provided which is adapted to spin the wheel in the opposite direction. This second unit 122 can be omitted if desired since, by properly positioning the reaction wheel 22 prior to placing it in motion, any maneuver of the space craft 10 can be accomplished with the reaction wheel 22 designed for continuous rotation in only one direction.

From the foregoing it will be readily seen that the present reactance control system is extremely simple to use and, more importantly, is highly reliable. Furthermore, since the energy requirement for the reaction wheel is very small when compared to conventional systems, the astronaut can manually actuate as well as control the system. On space voyages which are to extend over a prolonged period of time the manually operated feature of the system will result in a considerable weight savings since no chemical fuels nor their storage, control or venting systems are required. The control equations for the reaction wheel system are also very simple thus eliminating the requirement that elaborate calculating systems be carried aboard the space craft. Since the reaction wheel is stationary except for those periods when a correction in the space ship's attitude is being made, and then the wheel is rotating at a very low speed, the longevity bearing problems will be reduced to a minimum.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiment is, therefore, to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than the foregoing description, and all changes which come within the meaning and range equivalency of the claims are, therefore, to be embraced therein.

What is claimed and desired to be secured by the United States Letters Patent is:

1. In combination with a craft adapted to move through a fluid or substantial vacuum, a reactance attitude control system for controlling the angular movement of said craft around a predetermined axis thereof, comprising:

(a) bearing means mounted on said craft,

(b) reactance producing means mounted on said bearing means and adapted to be placed in rotation about an axis parallel to said predetermined axis,

(c) a source of potential energy attached to and carried by said craft for placing said reactance producing means in rotation;

(d) coupling means for selectively connecting said source of potential energy to said reactance producing means thereby placing said reactance producing means in rotation,

said craft being moved about said predetermined axis by the reactance force produced by said reactance producing means;

(e) energy storage means mounted on said craft for receiving and storing the kinetic energy contained in said rotating reactance producing means; and

(f) means for connecting said rotating reactance producing means to said energy storage means so that the kinetic energy of said reactance producing means is removed therefrom and stored in said energy storage means and the movement of said craft is thereby stopped at a predetermined angular position.

2. In combination with a craft adapted to move through a fluid or substantial vacuum, a reactance attitude control system for controlling the angular movement of said craft around a predetermined axis thereof, comprising:

(a) supporting means mounted on said craft;

(b) movable reactance producing means mounted in spaced relation on said supporting means;

(c) a source of stored energy carried on said craft;

(d) coupling means for selectively coupling said source of stored energy to said movable reactance producing means thereby causing said energy to be transferred from said stored source to said reactance producing means for placing said reactance producing means in motion,

the reactance forces produced by said moving reactance producing means acting on said craft thereby causing said craft to move at a predetermined angular velocity about said axis;

(e) mechanically operated means attached to and adapted for supplying additional energy to said reactance producing means for maintaining the motion thereof at a predetermined value; and

(f) means selectively coupled to said reactance producing means for removing the kinetic energy contained in said moving reactance producing means thus stopping the movement of said reactance producing means and said craft at a preselected angular position on said axis,

said means being adapted to store said kinetic energy for later release into said reactance producing means thereby again placing said reactance producing means in motion.

3. The combination according to claim 2 wherein said supporting means is adapted to be moved thereby changing the axis about which said craft is rotated.

4. The combination according to claim 2 wherein said source of stored energy is an elastic member which is maintained in a deformed condition until released by said coupling means.

5. The combination according to claim 2 wherein said elastic member is a spring.

6. In combination with a craft adapted to move through a fluid or substantial vacuum, a reactance control system for controlling the angular movement of said craft around a predetermined axis thereof, comprising:

(a) movable support means mounted on said craft;

(b) rotatable shaft means mounted on said support means;

(c) reactance producing means attached to and adapted for rotating with said shaft means thereby producing an angular movement of said craft about said axis;

(d) a source of potential energy attached to and carried by said craft for placing said rotatable shaft means in motion;

(e) clutch means coupled between said rotatable shaft means and said source of potential energy,

said clutch means being adapted to selectively couple the energy of said source to said shaft means thereby placing said shaft means and said reactance producing means carried thereon in motion;

(f) manually operated loading means attached to said craft for transforming mechanical energy into potential energy and storing said potential energy in said source for later release through said clutch means;

(g) means for stopping the motion of said shaft means and said reactance producing means and thereby the rotation of said craft when said craft has reached a predetermined angular position.

7. In combination with a craft adapted to move through a fluid or substantial vacuum, a reactance control system for controlling the angular movement of said craft around a predetermined axis thereof, comprising:

(a) movable support means mounted on said craft;

(b) rotatable shaft means mounted on said support means;

(c) reactance producing means attached to and adapted for rotating with said shaft means thereby producing an angular movement of said craft about said axis;

(d) a source of potential energy attached to and carried by said craft for placing said rotatable shaft means in motion;

(e) first clutch means coupled between said rotatable shaft means and said source of potential energy,

said first clutch means being adapted to selectively couple the energy of said source to said shaft means thereby placing said shaft means and said reactance producing means carried thereon in motion;

(f) manually operated loading means attached to said shaft for transforming mechanical energy into potential energy and storing said potential energy in said source for later release through said clutch means;

(g) energy storage means attached to and adapted for receiving and storing the kinetic energy contained in said rotating reactance producing means; and

(h) second clutch means coupled between said rotatable shaft and said energy storage means,

said second clutch means being adapted to selectively couple said rotatable shaft to said energy storage means so that the kinetic energy of said reactance producing means is removed therefrom and stored in said energy storage means and the rotation of said craft is thereby stopped at a predetermined angular position.

8. The combination according to claim 7 wherein indicator means is operably connected to said source of potential energy for indicating the amount of energy stored therein.

9. The combination according to claim 7 wherein said movable support means is a gimbal assembly which permits said rotatable shaft means to be positioned in parallel with any predetermined axis of said craft.

10. The combination according to claim 9 wherein locking means are attached to said gimbal assembly for locking said assembly against movement in respect to said craft once said assembly is properly positioned along said predetermined axis.

11. The combination according to claim 7 wherein a rack and pinion assembly is operably attached to said rotatable shaft for imparting energy to and thereby maintain the rotational speed of said shaft at a predetermined level.

12. In combination with a craft adapted to move through a fluid or substantial vacuum, a reactance control system for controlling the angular movement of said craft around a predetermined axis thereof, comprising:

(a) a gimbal assembly consisting of at least an inner and outer ring having mutually perpendicular intersecting axes of rotation with said outer ring being rotatably secured to said craft;

(b) selectively operated locking means attached to said inner and outer rings for securing said rings against movement in respect to said craft;

(c) a first and second shaft mounted to rotate about a common axis on said inner ring with the axis of rotation thereof being mutually perpendicular to the axis of rotation and said inner ring;

(d) selectively operated clutch means mounted on the adjacent ends of said first and second shafts for rotatably securing said shafts together,

said clutch means being normally disengaged thereby permitting said shafts to rotate independently of one another;

(e) a reaction wheel attached to and adapted for rotation with said second shaft thereby producing an angular movement of said craft about said axis of rotation;

(f) an elastic member attached to said first shaft,

said elastic member being adapted for being deformed by rotating said shaft thereby storing potential mechanical energy therein;

(g) means attached to said first shaft for rotating said shaft thereby storing potential potential energy in said elastic member;

(h) catch means attached to said first shaft for locking said shaft against motion when potential mechanical energy is stored in said elastic member;

(i) and means for simultaneously releasing said catch means and engaging said clutch means so that the stored potential energy in said elastic member is transferred through said first and second shafts to said reactance wheel thereby placing said wheel in motion.

13. The combination according to claim **12** wherein said elastic member is a coiled spring.

14. The combination according to claim **13** wherein an indicator is operatively associated with said coil spring for indicating the potential mechanical energy contained in said spring thereby permitting the velocity with which said reaction wheel will be rotated when said energy is transferred thereto to be accurately determined.

15. The combination according to claim **14** wherein said catch means consists of a ratchet wheel fixedly mounted on said first shaft and held against rotation in the direction in which the potential mechanical energy is urging said shaft by a pawl,

said pawl permitting said shaft to freely rotate in the other direction.

16. The combination according to claim **15** wherein said means attached to said first shaft for rotating said shaft is a knob.

17. In combination with a craft adapted to move through a fluid or substantial vacuum, a reactance control system for controlling the angular movement of said craft around a predetermined axis thereof, comprising:

(a) a gimbal assembly consisting of at least an inner and outer ring having mutually perpendicular intersecting axes of rotation with said outer ring being rotatably secured to said craft;

(b) selectively operated locking means attached to said inner and outer rings for securing said rings against movement in respect to said craft;

(c) first, second, third, fourth and fifth shafts mounted to rotate about a common axis on said inner ring with the axis of rotation thereof being mutually perpendicular to the axis of rotation of said inner ring;

(d) first selectively operated clutch means mounted on the adjacent ends of said second and third shafts for rotatably securing said shafts together when said clutch means is operated,

said clutch means being normally disengaged thereby permitting said shafts to rotate freely of one another;

(e) second selectively operated clutch means mounted on the adjacent ends of said third and fourth shafts for rotatably securing said shafts together when said clutch means is operated,

said clutch means being normally disengaged thereby permitting said shafts to rotate freely of one another;

(f) a reaction wheel attached to and adapted for rotation with said third shaft thereby producing an angular movement of said craft about said axis of rotation;

(g) a first spring having one end thereof attached to said second shaft and the other end thereof attached to said inner ring,

said spring being adapted for being deformed by rotating said second shaft in a first direction thereby storing potential mechanical energy;

(h) a second spring having one end thereof attached to said fourth shaft and the other end thereof attached to said inner ring,

said spring being adapted for being deformed by rotating said fourth shaft in a second direction thereby storing potential mechanical energy;

(i) serrated teeth means formed on the adjacent ends of said first, second, fourth and fifth shafts,

(1) said serrated teeth on the adjacent ends of said first and second shafts being formed so as to lock said first and second shafts together when said first shaft is rotated in said first direction,

(2) said serrated teeth on the adjacent ends of said fourth and fifth shafts being formed so as to lock said fourth and fifth shafts together when said fifth shaft is being rotated in said second direction;

(j) first pawl means carried by said inner ring and urged into engagement with a first ratchet wheel fixedly mounted on said first shaft,

said ratchet wheel and pawl means being so designed as to prevent rotation of said first shaft in said second direction while permitting said shaft to freely rotate in said first direction for storing potential mechanical energy in said first spring;

(k) second pawl means carried by said inner ring and urged into engagement with a second ratchet wheel fixedly mounted on said fifth shaft,

said ratchet wheel and pawl means being so designed as to prevent rotation of said fifth shaft in said first direction while permitting said shaft to freely rotate in said second direction for storing potential mechanical energy in said second spring;

(l) first operating means extending through said first shaft and into engagement with the end of said second shaft,

said first operating means being adapted to slide said second shaft inwardly along its axis of rotation thereby operating said first clutch means while disengaging said serrated teeth between said first and second shafts thus permitting said first spring to transfer its potential mechanical energy to said reaction wheel to place said wheel in motion in said second direction;

(m) second operating means extending through said fifth shaft and into engagement with the end of said fourth shaft,

said second operating means being adapted to slide said fourth shaft inwardly along its axis of rotation thereby operating said second clutch means while disengaging said serrated teeth between said fourth and fifth shafts thus permitting said second spring to transfer its potential mechanical energy to said reaction wheel to place said wheel in motion in said second direction;

(n) first actuating means rotatably mounted on the outer end of said first shaft,

said first actuating means being adapted to slide said first and second shafts inwardly along their axis of rotation thereby operating said first clutch means thus permitting the kinetic energy of said rotating reaction wheel to be transferred to and stored as potential mechanical energy in said first spring for later use in restarting the rotation of said wheel; and

(o) second actuating means rotatably mounted on the outer end of said fifth shaft,

said second actuating means being adapted to slide said fourth and fifth shafts inwardly along their axis of rotation thereby operating said second clutch means thus permitting the kinetic energy of said rotating reaction wheel to be transferred to and stored as potential mechanical energy in said second spring for later use in restarting the rotation of said reaction wheel.

18. The combination according to claim **17** wherein at least one manually operated rack and pinion wheel assembly is operatively connected to said reaction wheel for transferring energy to said wheel thereby causing the velocity of said wheel to increase, said rack and pinion wheel assembly consisting of a pinion wheel gear train connected to said third shaft and a rack operatively associated with said pinion wheel gear train and carried by said inner ring.

19. The combination according to claim **18** wherein an indicator is operatively associated with each of said

first and second springs for indicating the amount of potential mechanical energy stored in each of said springs.

References Cited by the Examiner

UNITED STATES PATENTS

2,734,383	2/1956	Paine	74—1

3,116,035	12/1963	Cutler	244—1

FOREIGN PATENTS

211,412	11/1957	Australia.

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