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ANGULAR MOMENTUM EXCHANGE CONTROL DEVICE FOR SPACE VEHICLES

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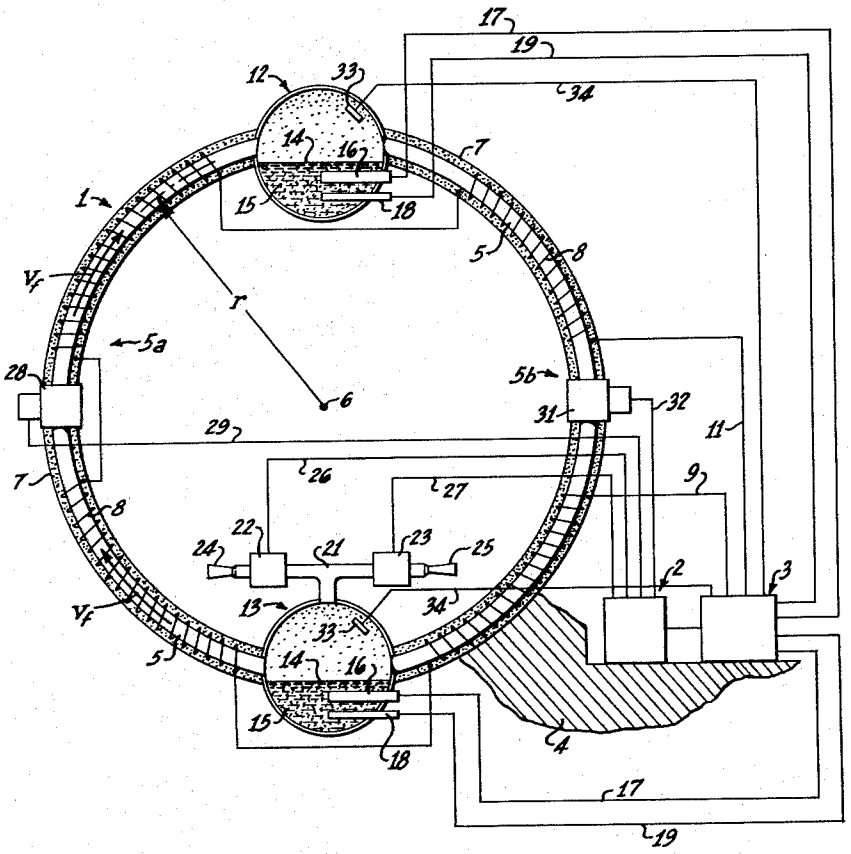

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ANGULAR MOMENTUM EXCHANGE CONTROL DEVICE FOR SPACE VEHICLES

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This invention relates to and in general has for its object the provision of an attitude-control device for space vehicles.

More specifically, one of the objects of this invention is the provision of a control device of the character described, including: an endless conduit divided into two conduit sections by a pair of vapor-generators; means for selectively activating said generators and means for selectively controlling the direction of travel of vapor through one or the other of said conduit sections.

Another object of this invention is the provision of a control device of the character above edscribed, including means for maintaining said conduit at a temperature above the condensation point of the vapor flowing through its two conduit sections.

Still another object of this invention is the provision of a control device of the character above described, including a pair of opposed nozzles arranged to be selectively placed in communication with one of said vapor-generators.

A further object of this invention is the provision of a control device of the character above described including an attitude-sensor operatively associated with and forming a part of the control device, the sensor being responsive to one of the attitudes of the space vehicle to be controlled, and the vapor-generators and various valves of the device being under the control of the sensor and its associated circuitry.

The invention possesses other advantageous features, some of which, with the foregoing, will be set forth at length in the following description where that form of the invention which has been selected for illustration in the drawings accompanying and forming a part of the present specification is outlined in full. This invention, as will be apparent, accomplishes the desired end results in a better and more facile way than is disclosed in the Haviland Patent 2,856,142, granted October 14, 1958. In said drawings, one form of the invention is shown, but it is to be understood that it is not limited to such form, since the invention as set forth in the claims may be embodied in other forms.

The single FIGURE of the drawings accompanying this application and forming a part hereof is a schematic representation of a control device embodying the objects of my invention.

As illustrated in this drawing, the control device includes a vapor loop assembly generally designated by the reference numeral **1**, an attitude-sensor and associated circuitry generally designated by the reference numeral **2**, and temperature-controller generally designated by the reference numeral **3**, all of which are arranged to be mounted on the frame or body of a space vehicle **4**.

Vapor Loop Assembly

The vapor loop assembly includes an endless conduit **5**, preferably of circular configuration and here shown for purposes of simplicity as including only one complete turn. However, for reasons which will presently become apparent, the conduit **5** may include several turns or convolutions. Preferably, the conduit **5** should be mounted coaxially with the attitude axis of **6** of the space vehicle about which it is desired to control the vehicle—either its yaw axis, roll axis, or pitch axis—and here it should

be noted that such axis does not necessarily contain the center of mass of the vehicle.

Surrounding the conduit **5** is a shell **7** of insulating material, and embedded therein is a resistance heater **8**, the leads **9** and **11** of which communicate with the temperature-controller **3**.

Intercepting the conduit **5** and dividing it into conduit sections **5***a* and **5***b* are a pair of opposed vapor-generators **12** and **13**. Each generator includes a body **14** of water or other liquid medium occluded in a sponge or wire mesh structure **15**, the purpose of the sponge being to retain the body of water within the generator at a point remote from its connections with the conduit sections **5***a* and **5***b*. Here it might be noted that space vehicles operate at conditions where gravity has little or no effect, and that consequently if no measures were taken to fix the water within the generator, relative movement between the body of water and the evaporator might result in the blockage of the generator inlet and/or outlet. Mounted in each vapor-generator is a heating element **16** communicating through a lead **17** with the temperature-controller **3**. Also mounted in each vapor-generator is a thermostat **18** communicating with the temperature-controller **3** through a lead **19**.

Communicating with the vapor-generator **13** through a T **21** are opposed electrically operated flow-modulating valves **22** and **23**, and connected respectively to these valves are opposed nozzles **24** and **25**. The valves **22** and **23** are respectively connected to the sensor **2** through leads **26** and **27** and can be selectively controlled by the sensor **2**.

Intercepting the conduit section **5***a* is an electrically operated flow-modulating valve **28** operatively connected with the sensor **2** through a lead **29**, and similarly intercepting the conduit section **5***b* is an electrically operated flow-modulating valve **31** operatively connected with the sensor **2** through a lead **32**.

Mounted in each vapor-generator is a pressure-sensor **33** operatively connected with the temperature-controller **3** through a line **34**.

Attitudes-Sensor and Temperature-Controller Assemblies

The attitude-sensor assembly **2** and temperature-controller assembly **3** per se need involve no invention, for known elements of this character can be used merely modified to effect the controls hereinafter set forth, and such modification is well within the purview of those skilled in the art. For this reason it has been deemed unnecessary to encumber this application with a detailed description of these elements.

Operation

Now consider the vapor-generator **13** to be at a higher temperature T_1 and saturated pressure P_1, and vapor-generator **12** at lower temperature and pressure values T_2 and P_2, and the conduit **5** temperature T_3 to be greater than T_1, all by action of the temperature-controller **3**. A pressure differential $P_1—P_2$ therefore exists across valve **28** and valve **31** when both valves are closed. As valve **28** is opened, vapor flows from generator **13** to generator **12** where the vapor is condensed and thus a clockwise (CW) fluid angular momentum is established. Depending upon the amount of opening of valve **28**, the flow velocity V_f will be greater or smaller and so will be the CW fluid angular momentum. Opening of valve **31** instead of valve **28** will cause a similar angular momentum in a counterclockwise direction. The flow velocity V_f adjusts itself so that the flow resistance of conduit and valve in question is equal to the available pressure differential $P_1—P_2$. Opening or closing of the valve in question, therefore, effects a change in flow velocity V_f.

Consider the conduit to be circular of radius r centered at the attitude-control axis 6 of interest. Angular momentum change of vapor in going from zero velocity to $\pm V_f$ is:

$$\Delta H_{vapor} = \pm m_f r v_f$$

where m_f is fluid mass in the conduit.

Consider the system composed of vehicle and vapor conduit. If no *external* forces are applied, system angular momentum remains constant

$$H_{system} = H_{vap} + H_{veh} = \text{constant}$$
$$\therefore H_{veh} = -H_{vap} = \mp m_f r v_f$$

The vehicle therefore acquires a counterclockwise (CCW) or clockwise (CW) angular momentum change of $\mp m_f r v_f$ and a CCW or CW rate change of:

$$\Delta W_v = \mp \frac{m_f r v_f}{I_v}$$

where Iv is vehicle inertia.

Also, since $m_f r v_f$ is equal to $\dot{m} r l$, where $\dot{m}$ is mass rate of flow and l is total conduit length, then for a desired angular momentum change ΔH, $\dot{m}$ can be made smaller by making r or l, or both, larger. This is generally desirable to minimize power input at one generator and heat-extraction rate at the other. As r is usually constrained by physical limitations of the vehicle, only l can be readily adjusted, and it is made large by using a plurality of conduit turns between generator 13 and generator 12 and between generator 12 and generator 13. Pressure differential and conduit cross-sectional area are chosen to match the desired flow and conduit parameters. When the liquid charge in generator 13 is exhausted (as evidenced by a drop of pressure P_1) the temperature-controller 3 transfers power to generator 12, thus reversing temperature levels in the two generators. For a clockwise vapor flow, valve 31 must now be opened, and for a counterclockwise flow, valve 28 must be opened. A signal from the temperature-controller 3 adjusts the polarity of the control signals to valve 28 and valve 31 to compensate for the changing roles of generator 12 and generator 13.

In applications where external disturbances on vehicle are alternatingly positive and negative, this invention allows attitude corrections to be made by the simple shuttling of vapor between generator 13 and generator 12 via the conduit 5, without loss to external space.

Where an external disturbance is sustained and unidirectional, the angular momentum capacity of the conduit 5 may be inadequate, but in this event the conduit momentum can be supplemented by permitting vapor to escape to atmosphere through one of the nozzles 24 and 25. The attitude-sensor here senses that an attitude deviation (and its direction) still persists and signals this to the attitude-sensor assembly 2, which in turn operates to selectively actuate one of the valves 22 and 23. The sequential operation of the four valves, 28, 31, 22 and 23, is somewhat as follows:

Consider the vehicle at rest in proper attitude so that output from sensor 2 is zero. Consider also that the vapor at that time is at rest. That is, valves 28 and 31 are closed. As a disturbance is applied to the vehicle, it starts to move so that an error signal appears at the sensor output. This causes valve 28 (or 31, depending upon which vapor generator is the heated one) to open to a degree necessary to compensate for the disturbance. If the disturbance is sustained, the valve must progressively open further. A point is reached where it is fully opened and the loop is in a condition called "saturated." As the disturbance continues, the vehicle will now move uncontrolled, building up a larger attitude error. However, the system is adjusted so

that when this error reaches a set value, valve 22 or 23 is caused to open, thus restoring the vehicle to proper attitude by reactive thrust. The temperature controller 3 indirectly influences the control of the modulating valves 28 and 31 in the loop in that it influences the polarity of signals from the sensor in response to the pressure levels in the two vapor generators. In this manner one or the other of the nozzles 24 and 25 is made to supplement the momentum generated in the conduit 5 a sufficient amount to correct the residual attitude deviation.

Through the control of the attitude-sensor 2 and its operatively associated temperature-controller 3 it becomes possible to selectively activate the vapor-generators 12 and 13, to selectively actuate and control the valves 28 and 31 and to selectively actuate and control the nozzle valves 22 and 23, all to the end that vapor may be made to flow through one or the other of the conduit sections 5*a* and 5*b* either in a clockwise direction or in a counterclockwise direction as desired, and to the end that if necessary the momentum resulting from the flow of vapor through either of the conduit sections 5*a* and 5*b* can be supplemented by the flow of vapor through one of the nozzles 24 and 25.

I claim:

1. An angular momentum exchange attitude-control device for space vehicles comprising: a first vapor-generator including a first liquid compartment and a first vapor plenum; a second vapor-generator spaced from said first vapor-generator and including a second liquid compartment and a second vapor plenum; means in each of said liquid compartments for holding liquid therein away from its associated vapor plenum; a first conduit interconnecting said first and second vapor plenums; a second conduit interconnecting said first and second vapor plenums; a first flow-modulating valve interposed in said first conduit; a second flow-modulating valve interposed in second conduit; each of said vapor-generators being provided with a heater for heating the liquid contents thereof; and means for heating each of said conduits.

2. A control device of the character set forth in claim 1 including means responsive to the attitude of said vehicle for controlling said first and second flow-modulating valves and for controlling said first and second vapor-generators.

3. A control device of the character set forth in claim 1 including an attitude-sensor operatively associated with said control device; means under the control of said sensor for selectively controlling said first and second valves for selectively activating said first and second vapor-generators.

4. A control device of the character set forth in claim 1 including means responsive to the pressures within said first and second vapor-generators for selectively activating said generators and said first and second flow-modulating valves.

5. A control device of the character set forth in claim 1 including first and second opposed nozzles communicating respectively through third and fourth valves with one of said vapor-generators.

6. A control device of the character set forth in claim 5 including an attitude-sensor operatively associated with said control device; means under the control of said sensor for selectively controlling first, second, third and fourth valves and for selectively activating said first and second vapor-generators.

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