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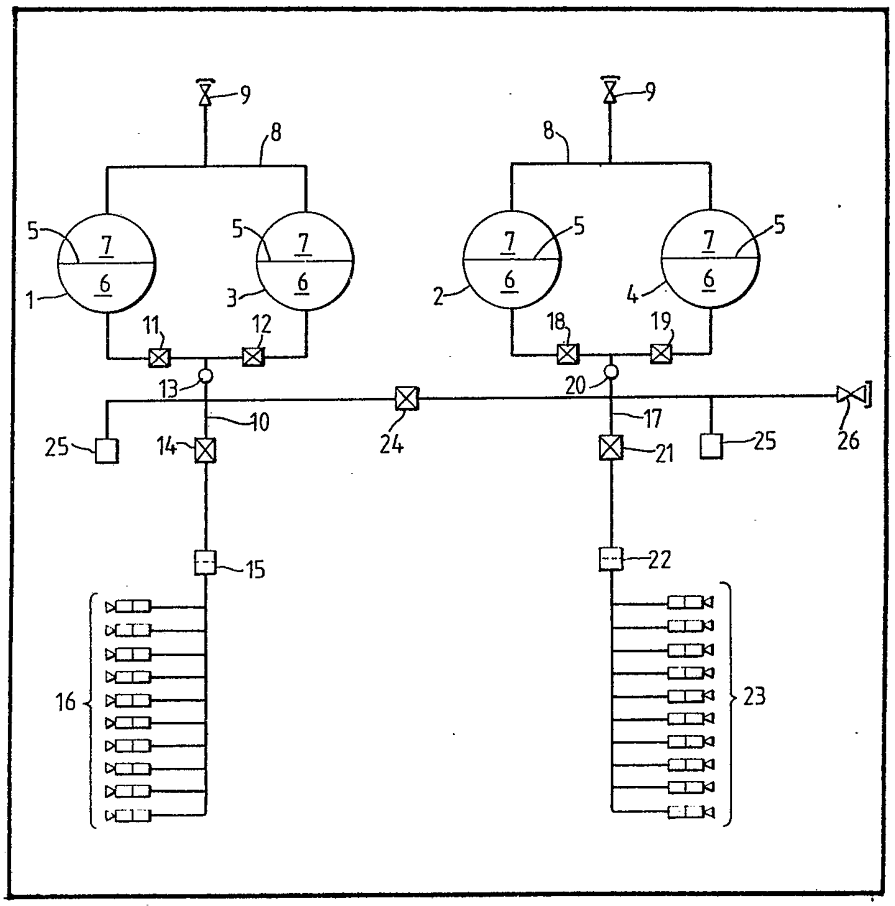
(54) **Propellant Feed System**

(57) Propellant is driven from a tank 1, 2, 3 or 4, for example to an attitude control thruster 16 or 23 of a spacecraft, by a liquid such as ammonia having a suitable vapour pressure at the expected operating temperature and acting on the propellant via a flexible diaphragm 5. Flow sensors 13, 20 and valves 11, 12 etc. control the way in which propellant is drawn from the tanks so as to maintain the balance of the spacecraft within predetermined limits.



The drawing originally filed was informal and the print here reproduced is taken from a later filed formal copy.

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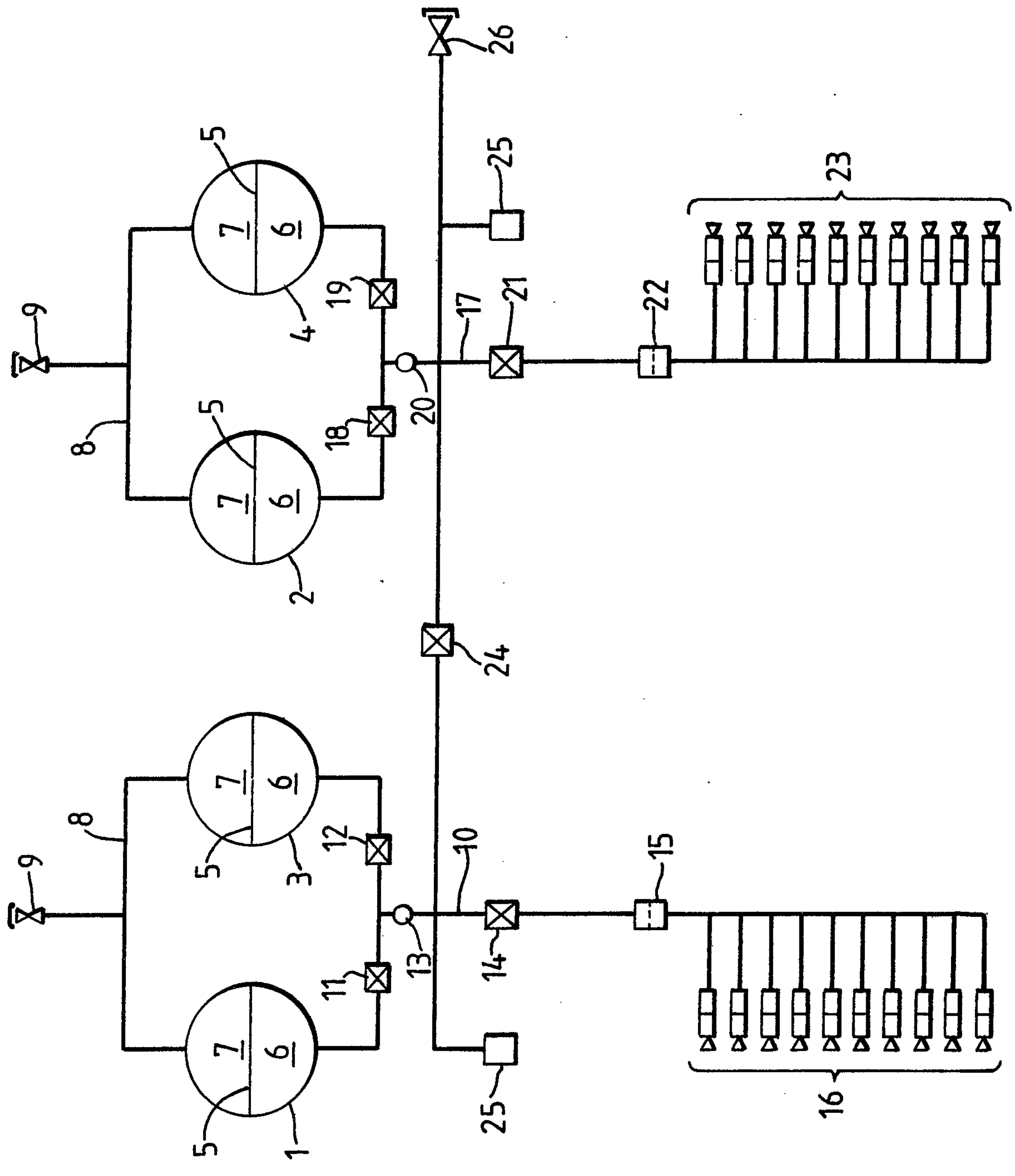

SPECIFICATION
Propellant Feed System

This invention relates to propellant feed systems, more particularly but not exclusively, to systems for supplying propellant to the attitude control thrusters of space satellites.

For space satellites, it is known to contain liquid thruster fuel, *e.g.* hydrazine, at one side of an elastomeric diaphragm within a closed chamber where it is maintained under pressure by a gas, for example, nitrogen, at the other side of the diaphragm. When a thruster is operated, the gas expands and provides the drive which feeds the fuel to the thruster.

As the gas expands and the fuel is expelled, the gas pressure falls and so there must be enough gas at a high enough pressure in the first place to ensure that, even when the chamber is nearly empty of fuel, the gas pressure remains sufficient. As a practical consequence of this, typically only about 75% of the chamber volume can be filled with fuel, the remainder being required for the drive gas. Even then the drive pressure falls substantially as the fuel is used, for example from about 22 Bar at the start down to perhaps 5 Bar when the chamber is nearly empty of fuel.

According to one aspect of the invention, there is provided a propellant supply system wherein, to cause the propellant to flow, there is applied to it the pressure exerted by a vapourisable liquid other than the propellant itself.

According to another aspect of the invention, there is provided a spacecraft comprising one or more propellant tanks, the or each of which has a movable member therein to divide the interior of the tank in two and a vapourisable liquid in the tank on one side of said member for exerting pressure on propellant at the other side of the member.

According to a third aspect of the invention, there is provided a spacecraft comprising first and second propellant tanks near respective different sides of the craft, valve means for enabling propellant to be drawn from the first or the second tank, flow measuring means for measuring the amount of propellant drawn from the tanks and means for controlling said valve means and for ensuring that when imbalance of the spacecraft, determined from the measurement of said flow measuring means, reaches a predetermined limit, propellant ceases to be drawn from one tank and starts to be drawn from the other.

For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawing, the single figure of which is a fuel feed system for the attitude control thrusters of a space satellite.

The satellite comprises four spherical fuel tanks 1, 2, 3 and 4 each divided in two by an elastomeric diaphragm 5 of the rolling type. The space 6 at one side of each diaphragm contains fuel, for example hydrazine, while the space 7 at the other side is partially filled with liquid ammonia.

The spaces 7 of the tanks 1 and 3, and the spaces 7 of the tanks 2 and 4, are interconnected by way of a respective conduit 8, each conduit being also connected to a respective valve 9 through which the ammonia is initially introduced into the tanks.

The spaces 6 of the tanks 1 and 3 are connected to a common conduit 10 by way of respective valves 11 and 12. The conduit 10 leads *via* a flowmeter 13, a latching valve 14 and a filter 15 to one set of attitude control thrusters 16. Similarly, the spaces 6 of the tanks 2 and 4 are connected to a second common conduit 17 by way of respective valves 18 and 19, the conduit 17 leading *via* flowmeter 20, latching valve 21 and filter 22 to a second set of thrusters 23.

The two conduits 10 and 17 are interconnected with one another *via* a latching valve 24 and a respective pressure transducer 25 is connected to each. Means are provided, for example the valve 26 connected to conduit 17, for enabling the spaces 6 to be filled with fuel.

The various valves are used to control the flow of the fuel to the thrusters as described later. When a thruster is to be operated, fuel is caused to flow to it by the vapour pressure of the liquid ammonia acting *via* the diaphragms 5 in the respective tanks. Sufficient liquid ammonia is loaded into each space 7 to ensure that, after all the fuel has been expelled from the corresponding tank, there is still a small amount of liquid left. The operating or drive pressure depends upon the ambient temperature. A typical operating temperature range may be from +9°C to+40°C, within which the vapour pressure of ammonia, and hence the drive pressure of the system, varies from 6.25 Bar to 15.9 Bar.

The system described above may allow an increase in the portion of the chamber which can initially be filled with fuel without necessarily modifying the construction of the chamber as used in the known system.

By way of example, the amount of ammonia loaded into each tank may be such as to take up 2% of the tank volume, and 83% of that volume may be usefully utilised for the fuel, the rest being taken up by ammonia vapour. With an operating temperature of around 20°C, the final pressure of the fuel at the thrusters might be around +8 Bar.

It will be realised that, normally, the rate at which fuel is expelled from each tank and hence the rate of change of volume of the ammonia containing spaces 7 will not be such as to cause significant cooling of the ammonia since heat is available to the ammonia from the walls of the tank and from the fuel in the spaces 6. These in turn are heated by solar energy. In a modification (not shown), the sun's rays may in fact be directed onto the tanks preferably by means which act to ensure that, directly or indirectly, all the tanks receive substantially the same amount of additional heat whether they be facing towards or away from the sun, while other equipment within the satellite is unaffected.

The tanks 1 and 3 on the one hand and the tanks 2 and 4 on the other, are positioned near opposite sides of the satellite so that, if one is at that side of the satellite which is facing the sun, the other is on the cold side of the satellite. The conduits 8 maintain respective uniform drive pressures in the tanks 1 and 3 and in the tanks 1 and 4 respectively and hence prevent the fuel being pumped between tanks 1 and 3 or between tanks 2 and 4 in dependence upon which of each pair of tanks faces the sun.

Instead of ammonia there may be used any other liquid which has a suitable range of vapour pressure at the operating temperature envisaged. For spacecraft, it is preferred that the liquid should have a range of vapour pressure which is within the range of about 5 to 20 Bars over a temperature range from about 4 to 40°C. By way of example, Freon (trade name) may be used.

When changes in attitude of the satellite are to take place, the latching valves are controlled as desired to feed fuel from the tanks 1 and 3 to one or both sets of thrusters and/or to feed fuel from tanks 2 and 4 to one or both sets of thrusters. The pressure transducers provide signals from which the ground operator or an automatic controller on board the craft can determine the best course. The thrusters themselves may comprise any suitable known type for example the types known as Augmented, Electrothermal, Hydrazine Thrusters or Catalytic thrusters.

For some applications the valves 11, 12, 18 and 19 and flowmeters 13 and 20 may not be necessary, the fuel being taken at roughly equal rates from tanks 1 and 3 and at equal rates from tanks 2 and 4.

However, for some other applications, it may not be sufficient to rely on the tanks emptying at equal rates as a result of the equal pressure therein because the rate of emptying may depend on factors other than pressure, e.g. small and perhaps unknown differences between the tanks themselves. Also, the satellite may be subject to such perturbations whilst in the weightless environment of space that the fuel is even transferred from one tank to another, thereby causing a mass imbalance from one side of the satellite to the other. It will be appreciated that this problem is also applicable to systems other than that described wherein a vapourisable liquid is used to provide the drive pressure, for example to the known system where pressurised gas is used, and hence the following description of a further development of the invention is also applicable to such other systems. The further development consists in measuring the flow of fuel from each tank and controlling it so as to ensure that the mass imbalance of the satellite does not exceed allowable limits. To this end the valves 11, 12, 18 and 19 and flowmeters 13 and 20 are provided.

During ground operations, the tanks 1 to 4 are filled to a known level and the satellite balanced. Then after launch and ejection of the satellite from the space vehicle, the valves 14 and 21 are opened automatically. The valves 11, 12, 18 and 19 may be opened and closed from the ground by way of the satellite's telecommunication system (not shown). For example, valves 11 and 18 might be opened first to allow fuel to become available to the thrusters from tanks 1 and 2. As the various thrusters are operated, the exact amount of fuel taken from tanks 1 and 2 is measured by the flowmeters which produce appropriate signals proportional to the volume flow rate. These signals are passed to a central processor (not shown) which continually adds up the flowrates and calculates the reduction in mass within tanks 1 and 2 by taking into account the propellant temperature, and hence density, as measured by suitable transducers (not shown). When the limits of mass imbalance which the satellite can tolerate are reached, the valves 11 and 18 are closed and the valves 12 and 19 opened instead so that fuel is now taken from tanks 3 and 4. At the same time, the central processor is zeroed and then begins to integrate the flow from tanks 3 and 4. When the mass taken from these reaches the aforementioned limit, a changeover to tanks 1 and 2 again occurs and so on. The command signals to zero the central processor and to open and close the valves can be transmitted from the ground through the satellite's communication system or automatically by suitable control circuits (not shown) provided on board the satellite.

It will be appreciated that the term "propellant" used herein applies not only to what in the spacecraft field is called "fuel" but also to say the oxidiser in a system where both an oxidiser and fuel are fed to the thrusters.

Claims

1. A propellant supply system wherein, to cause the propellant to flow, there is applied to it the pressure exerted by a vapourisable liquid other than the propellant itself.

2. A system according to claim 1, wherein said liquid is ammonia or Freon (trade name).

3. A spacecraft comprising one or more propellant tanks, the or each of which has a movable member therein to divide the interior of the tank in two and a vapourisable liquid in the tank on one side of said member for exerting pressure on propellant at the other side of the member.

4. A spacecraft according to claim 3, including means for directing solar heat to the or each tank.

5. A spacecraft comprising first and second propellant tanks near respective different sides of the craft, valve means for enabling propellant to be drawn from the first or the second tank, flow measuring means for measuring the amount of propellant drawn from the tanks and means for controlling said valve means and for ensuring that when imbalance of the spacecraft, determined from the measurement of said flow measuring

means, reaches a pre-determined limit, propellant ceases to be drawn from one tank and starts to be drawn from the other.

6. A spacecraft substantially as hereinbefore described with reference to the accompanying drawings.

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