Thermal Analysis for Design of Propulsion System Employed in LEO Earth Observation Satellite

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Abstract

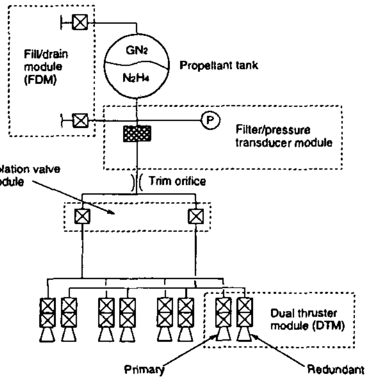
Thermal analysis is performed to protect the propulsion system of low-earth-orbit earth observation satellite from unwanted thermal disaster like propellant freezing. To implement thermal design adequately, heater powers for the propulsion system estimated through the thermal analysis are decided. Based on those values anticipated herein, the average power for propulsion system becomes 22.02 watts when the only one redundant catalyst bed heater is turned on. When for the preparation of thruster firing, 25.93 watts of the average power is required. All heaters selected for propulsion components operate to prevent propellant freezing meeting the thermal requirements for the propulsion system with the worst-case average voltage, i.e. 25 volts.

Keyword: *Propulsion System, LEO Earth Observation Satellite, Thermal Analysis, Thermal Design*

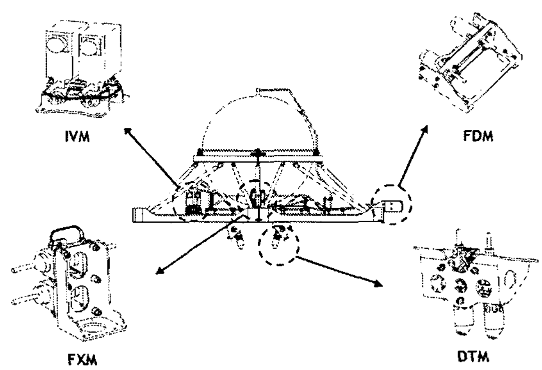
1. Introduction

The development of satellite is major indices of strong will for space exploration and of the level of space technology. The added value stemmed from space technology is so great that the importance of developing satellite cannot be emphasized too much. Since 1994, Korea Aerospace Research Institute (KARI) has developed a series of low-earth-orbit (LEO) earth observation satellites, that is to say, KOrea Multi-Purpose SATellite (KOMPSAT)[1].

KOMPSAT propulsion system employs 1.0 lbf (4.45 N) MRE-1 monopropellant hydrazine liquid rocket engine of NASA standard component. Propellant is supplied by pressure feeding system (PFS) with high operational reliability. Spherical titanium tank with 22 inches of diameter contains the hydrazine propellant of 160 lbm and the gaseous nitrogen pressurant of 350 psi. Propellant and pressurant in the tank are apart by internal diaphragm. The elastomeric polymer diaphragm of active expulsion type operates in a blowdown mode. It is possible to expel propellant effectively under reverse acceleration. At the operating pressure, 50~350 psi, the expulsion efficiency over 99% is achieved[2].



(a)



(b)

Fig. 1. Satellite propulsion system: (a) design schematic, (b) configuration

Major components rather than propellant tank and thruster, are latching valve, fill/drain valve, pressure transducer, and filter etc. Piping for propellant flow path, interface components, brackets, and the thermal control components such as heater, thermostat, and thermal sensor are included also. The system is modulized to facilitate manufacturing, assembly, and design change. It consists of dual thruster module (DTM), filter/pressure transducer module (FXM), latching isolation valve module (IVM), and fill/drain valve module (FDM) etc. For the single-fault tolerant of propulsion system, all on-orbit operation components including thrusters are designed to have the secondary circuit. The design schematic and configuration of KOMPSAT propulsion system are shown in Fig. 1.

2. Thermal Analysis

2.1 Thermal requirements and approach

For the propulsion system, the thermal management criteria are as follows[3]:

- Maintain all wetted components above 7 °C (45 °F).
- Maximum temperature at any point (except propellant valves & tank) not to exceed 49 °C (120 °F).
- Maximum allowable temperature resulting from thruster firing for propellant valves: 116 °C (240 °F).
- Maximum allowable temperature for propellant tank not to exceed 38 °C (100 °F).
- Keep catalyst bed temperature above 177 °C (350 °F).
- Heater sizing with maximum duty cycle of 70%.
- Single fault tolerance to propellant freezing & over-temperature.

To meet the above requirements, both a primary and a redundant heater circuit, each with two thermostats placed in series, will protect each hydrazine-wetted components, even if one heater circuit fails to operate. Heater power is turned off if any one of these thermostats is opened at its higher setpoint. Thus, even if one thermostat is failed closed, the second thermostat will turn off the heater. The primary thermostats installed for the KOMPSAT propulsion system will have a thermostat range of 11 °C (52 °F) to 18 °C (65 °F). The redundant thermostats installed for the KOMPSAT program are expected to have a thermostat range of 7 °C (45 °F) to 17 °C (63 °F). All such components shall be insulated with MLI.

For hot conditions, none of propulsion component heaters will be turned on, and the maximum propulsion component temperature will be less than the propulsion compartment temperature, i.e. the surrounding panel temperature. Since, generally, the compartment temperature goes up during the satellite lifetime due to an increase in the absorptivity of the outer spacecraft materials, any average power estimates predicted for propulsion components tend to decrease with spacecraft life. From this reason, the constant-worst-cold-case condition is considered hereafter. In addition, the thermal analysis on a module level is performed.

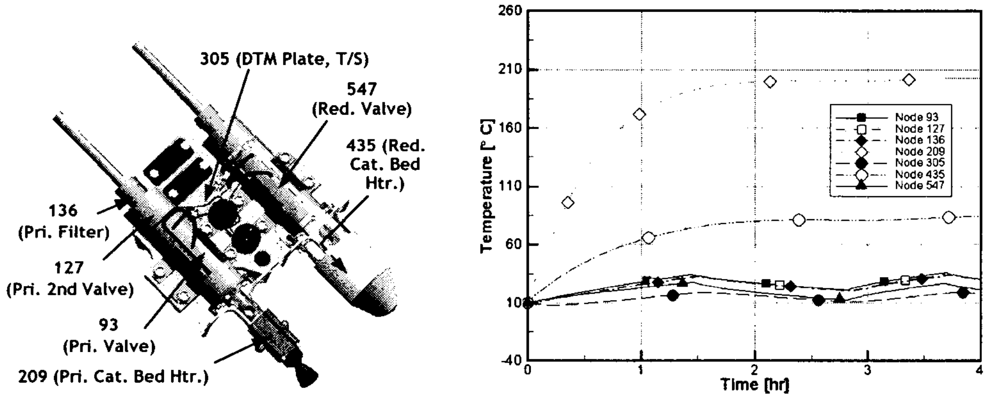
Referring to the electrical power system, the worst average voltage of battery cell accommodated for KOMPSAT is estimated as 1.31 volts. As the worst case, 21 of battery cells are considered. The worst-case harness voltage drop is estimated as 1.51 volts. Under this condition, the worst-case average voltage at the spacecraft component input terminal is calculated as 26 volts. This value of 26 volts is recommended to use as the spacecraft bus system level guideline for the spacecraft bus heater design. The lowest expected voltage for propulsion system is 25 volts to include conservatism in the heater sizing.

2.2 Method of analysis

Dedicated software, Thermal Analysis System (TAS)[4], is used to analyze thermal behaviors included herein. It is a general-purpose tool used to computer-simulate thermal problems. The program provides an integrated, graphical and interactive environment to the user. A single environment provides model generation, execution and post processing of the results. Models are generated using a set of elements. Full three-dimensional geometry can be created using two-dimensional plate and three-dimensional brick and tetrahedron elements. Resistance can be added using resistor elements. Properties can be temperature, temperature difference, time and time cycle dependent. Heat loads can be added on a nodal, surface or volumetric basis.

3. Analysis Results

As a representative illustration among thermal analysis results, a solid model of the DTM is shown in Fig. 2 (a) along with the node numbers. A valve patch heater resistance of 461 W has been selected. The three catalyst bed heaters on each thruster are connected in such manner that one-half the spacecraft bus voltage is applied to each of these heaters. When the 3 of primary catalyst bed heaters and 1 of redundant catalyst bed heater are turned on, the predicted transient temperature responses are shown in Fig. 2 (b). The catalyst bed heaters successfully raise the catalyst bed temperature to above 350 °F (177 °C) within one-a-half (1.5) hours under the conditions that bus voltage is 25 volts. It satisfies a temperature response requirement in the DTM specification.



(a) (b)

Fig. 2. Dual thruster module: (a) configuration and relevant nodes, (b) thermal response

4. Conclusion

The characteristics of thermal analysis for the design of satellite propulsion system are as follows:

- Simulation results for "constant-worst-cold-case" are exhibited.
- Active controlled heaters by means of thermostats are incorporated.
- Analysis on a module level is performed with TAS three-dimensional model.
- Thruster hot firing case is simulated.

Heater powers for the propulsion system estimated through the thermal analysis are contemplated. Based on these values anticipated herein, the average power for propulsion system becomes 22.02 watts when the only one redundant catalyst bed heater is turned on. When for the preparation of thruster firing, 25.93 watts of the average power is required. All heaters selected for propulsion components operate to prevent propellant freezing satisfying the thermal requirements for the propulsion system with the worst-case average voltage, i.e. 25 volts.

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