Hardware In The Loop Testing of an Iodine-fed Hall Thruster

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I. Abstract

CubeSats are relatively new spacecraft platforms that are typically deployed from a launch vehicle as a secondary payload,[1] providing low-cost access to space for a wide range of end-users. These satellites are comprised of building blocks having dimensions of 10x10x10 cm^3 and a mass of 1.33 kg (a 1-U size). While providing low-cost access to space, a major operational limitation is the lack of a propulsion system that can fit within a CubeSat and is capable of executing high Δv maneuvers. This makes it difficult to use CubeSats on missions requiring certain types of maneuvers (i.e. formation flying, spacecraft rendezvous).

Recently, work has been performed investigating the use of iodine as a propellant for Hall-effect thrusters (HETs) [2] that could subsequently be used to provide a high specific impulse path to CubeSat propulsion.[3,4] Iodine stores as a dense solid at very low pressures, making it acceptable as a propellant on a secondary payload. It has exceptionally high ρI_{sp} (density times specific impulse), making it an enabling technology for small satellite near-term applications and providing the potential for systems-level advantages over mid-term high power electric propulsion options. Iodine flow can also be thermally regulated, subliming at relatively low temperature (< 100 °C) to yield I_2 vapor at or below 50 torr. At low power, the measured performance of an iodine-fed HET is very similar to that of a state-of-the-art xenon-fed thruster. Just as importantly, the current-voltage discharge characteristics of low power iodine-fed and xenon-fed thrusters are remarkably similar, potentially reducing development and qualifications costs by making it possible to use an already-qualified xenon-HET PPU in an iodine-fed system. Finally, a cold surface can be installed in a vacuum test chamber on which expended iodine propellant can deposit. In addition, the temperature doesn't have to be extremely cold to maintain a low vapor pressure in the vacuum chamber (it is under 10^{-6} torr at -75 °C), making it possible to 'cryopump' the propellant with lower-cost recirculating refrigerant-based systems as opposed to using liquid nitrogen or low temperature gaseous helium cryopanels.

In the present paper, we describe testing performed using an iodine-fed 200 W Hall thruster mounted to a thrust stand and operated in conjunction with MSFCs Small Projects Rapid Integration and Test Environment (SPRITE) Portable Hardware In the Loop (PHIL) hardware.[5] This work is performed in support of the iodine satellite (iSAT) project, which aims to fly a 200-W iodine-fed thruster on a 12-U CubeSat. The SPRITE PHIL hardware allows a given vehicle to do a checkout of its avionics algorithm by allowing it to monitor and feed data to simulated sensors and effectors in a digital environment. These data are then used to determine the attitude of the vehicle and a separate computer is used to interpret the data set and visualize it using a 3D graphical interface. The PHIL hardware allows the testing of the vehicles bus by providing 'real' hardware interfaces (in the case of this test a real RS422 bus) and specific components can be modeled to show their interactions with the avionics algorithm (e.g. a thruster model). For the iSAT project the PHIL is used to visualize the operating cycle of the thruster and the subsequent effect this thrusting has on the attitude of the satellite over a given period of time.

The test is controlled using software running on an Andrews Space Cortex 160 flight computer. This computer is the current baseline for a full iSAT mission. While the test could be conducted with a lab computer and software, the team chose to exercise the propulsion system with a representative CubeSat-class computer. For purposes of this test, the "flight" software monitored the propulsion and PPU systems, controlled operation of the thruster, and provided thruster state data to the PHIL simulation. Commands to operate the thruster were initiated from an operator's workstation outside the vacuum chamber and passed through the Cortex 160 to exercise portions of the flight avionics.

Two custom-designed pieces of electronics hardware have been designed to operate the propellant feed system. One piece of hardware is an auxiliary board that controls a latch valve, proportional flow control valves (PFCVs) and

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valve heaters as well as measuring pressures, temperatures and PFCV feedback voltage. An onboard FPGA provides a serial link for issuing commands and manages all lower level input-output functions. The other piece of hardware is a power distribution board, which accepts a standard bus voltage input and converts this voltage into all the different current-voltage types required to operate the auxiliary board. These electronics boards are located in the vacuum chamber near the thruster, exposing this hardware to both the vacuum and plasma environments they would encounter during a mission, with these components communicating to the flight computer through an RS-422 interface.

The auxiliary board FPGA provides a 28V MOSFET switch circuit with a 20ms pulse to open or close the iodine propellant feed system latch valve. The FPGA provides a pulse width modulation (PWM) signal to a DC/DC boost converter to produce the 12-120V needed for control of the proportional flow control valve. There are eight MOSFET-switched heating circuits in the system. Heaters are 28V and located in the latch valve, PFCV, propellant tank and propellant feed lines. Both the latch valve and PFCV have thermistors built into them for temperature monitoring. There are also seven resistance temperature device (RTD) circuits on the auxiliary board that can be used to measure the propellant tank and feedline temperatures. The signals are conditioned and sent to an analog to digital converter (ADC), which is directly commanded and controlled by the FPGA.

References

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