The iodine Satellite (iSat) Propellant Feed System - Design and Demonstration

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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).

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] One of the systems under development to support such a technology is the propellant feed system, which must be capable of storing solid iodine propellant, applying heat to sublime the stored solid into the vapor phase, and then control the flow of low-pressure gaseous iodine to both the thruster and cathode. In a test conducted in 2016, a first-generation iodine propellant feed system was integrated with a cathode and Hall thruster.[4] While this test had to be terminated, the feed system in this first test was able to support both cathode and integrated cathode and thruster operation prior to the termination of the test.

In the present paper, we describe work performed since that initial integrated test. The effort uses lessons learned from the previous integrated test, retiring risk associated with the iodine propellant feed system, answering open design-space questions, and demonstrating iodine flow control in an integrated system. The work is undertaken at both the component level and then at the integrated subsystem level to systematically improve the feed system design, improving the hardware fidelity so the appearance and operation of he system are as flight-like as possible.

At the component level, the work focuses on the propellant tank, the feed system tubing, the valves used to control the flow to the cathode and thruster, and the heaters that maintain the temperature of the flowpaths and keep iodine from redepositing and clogging the system. Work on the propellant reservoir focuses on fabricating a tank that matches the geometry of the flight design, which allows for the identification of flight tank fabrication issues that may arise and permits thermal testing of a tank possessing the same size and thermal mass as the flight design, which can be used to anchor thermal modeling of the component. This is critical for finalizing the tank heater power requirements that feed into the heater design. All metallic materials in the feed system are hastelloy or Inconel, as these materials are resistant to chemical attack by the highly-reactive iodine vapor. The tubing in the iodine feed system must possess ports to permit a neutral gas purge of the system that clear impurities after iodine is loaded into the propellant tank. A procedure is discussed whereby these ports are crimped and sealed after the purge process is completed so as to not re-expose the iodine system to air. The valves are a critical component for control of the flow to the thruster and the cathode. Significant effort has gone into upgrading the materials of the valves to make them more resistant to chemical attack and into developing an understanding of the use of these valves during the startup and operation of the cathode and thruster. The heaters that line the entire feed system are designed to draw minimal power from the power processing unit (PPU) while still having the capacity to maintain all the feed system components at the temperatures required to discourage iodine deposition inside components downstream of the propellant tank exit. The heaters possess two separate resistive traces, giving the design redundancy should a failure occur in the primary heater circuit of one of the heater zones.

The task of operating a feed system in conjuction with a thruster and cathode is undertaken in a series of sub-steps. The system is first assembled and operated on xenon gas, using the valves for cathode startup and thruster control

based on measurement of the discharge current. After startup and control on xenon are demonstrated, the thruster will be transitioned to iodine operation, demonstrating thruster startup and feed system control while using a xenon-fed cathode. Finally, the last step is to integrate an iodine-compatible cathode with the system, demonstrate autonomous cathode start-up with open-loop control and thruster start-up with closed-loop control for multiple cycles.

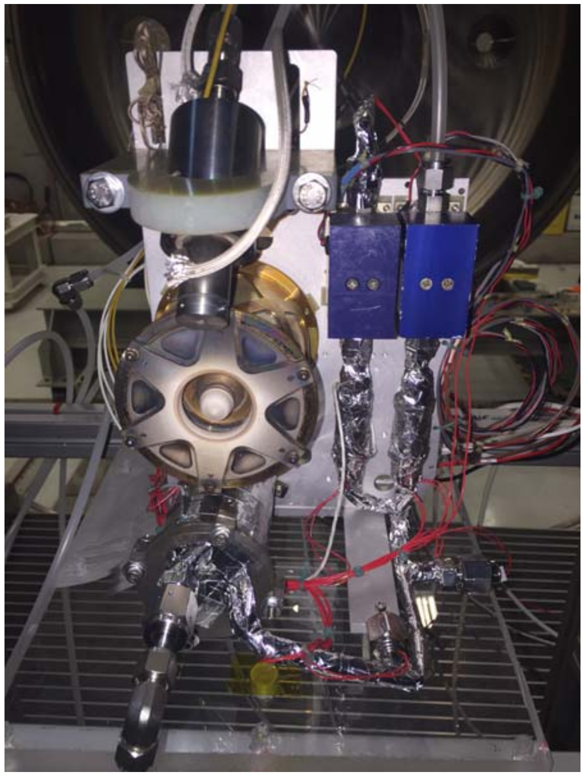

Figure 1. Assembled iSAT feed and propulsion system.

References

[1] *CubeSat Design Specifications*, rev. 13, The CubeSat Program, California Polytechnic State University, San Luis Obispo, CA (2014).

[2] J. Szabo, B. Pote, S. Paintal, M. Robin, A. Hillier, R.D. Branam, and R.E. Huffman, "Performance Evaluation of an Iodine-Vapor Hall Thruster," *J. Propuls. Power* Vol. 28, No. 4, pp. 848–857 (2012).

[3] J.W. Dankanich, K.A. Polzin, D. Calvert, and H. Kamhawi, "The iodine Satellite (iSAT) Hall Thruster Demonstration Mission Concept and Development," in *50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference*, Cleveland, OH (2014). AIAA Paper 2014-3910.

[4] K.A. Polzin, S.R. Peeples, A.O. Burt, A.K. Martin, A. Martinez, J.F. Seixal, and S. Mauro, "Development, Demonstration, and Analysis of an Integrated Iodine Hall Thruster Feed System," in *AIAA Propulsion and Energy Forum 2016*, Salt Lake City, UT (2016). AIAA Paper 2016-4730.

Figure 2. iSAT thruster operating on iodine propellant.