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Design, development, and performance of an ammonia self-managed vaporization propulsion system for micro-nano satellites

Key words: Self-managed vaporization; Liquefied ammonia; Milli-Newton level propulsion; Micro-thrust; High-precision orbital control; Micro-nano satellite

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Motivation

1. All of the new applications of micro-nano satellites need a milli-Newton (mN) level propulsion system for all aspects of operations.

2. A high-efficiency propulsion system will provide orbital-maneuvering, high-precision attitude control, and station-keeping capabilities at a low cost; however, existing propulsion techniques cannot satisfy the requirements of micro-nano satellites.

3. Liquefied ammonia (NH_3) propellant has the highest theoretical specific impulse, but the problems of high vaporization latent heat and incomplete vaporization have not been solved.

Main idea

1. The ASVP system is presented and composed of an ammonia tank, a stop valve, a vaporizer, heaters, and thrusters. The structure is easy to build but effective in improving the performance.

2. Based on the physical chemistry theory and the ground tests, we propose the semi-empirical vaporization regularity formula, which indicates the liquefied ammonia vaporization features.

3. A PWM thrust control strategy for the ASVP system is proposed to achieve stable, uniform, and controllable thrust output.

Method

1. A multiplex parallel sieve type vaporizer and related vaporization control methods are put forward to achieve self-managed vaporization of liquefied propellant.
2. The propulsion operation procedure and its physical chemistry theories and mathematical models are thoroughly analyzed.
3. An optimal strategy of thrust control is proposed with consideration of thrust performance and energy efficiency.
4. The ground test of the propulsion system is conducted.

Major results

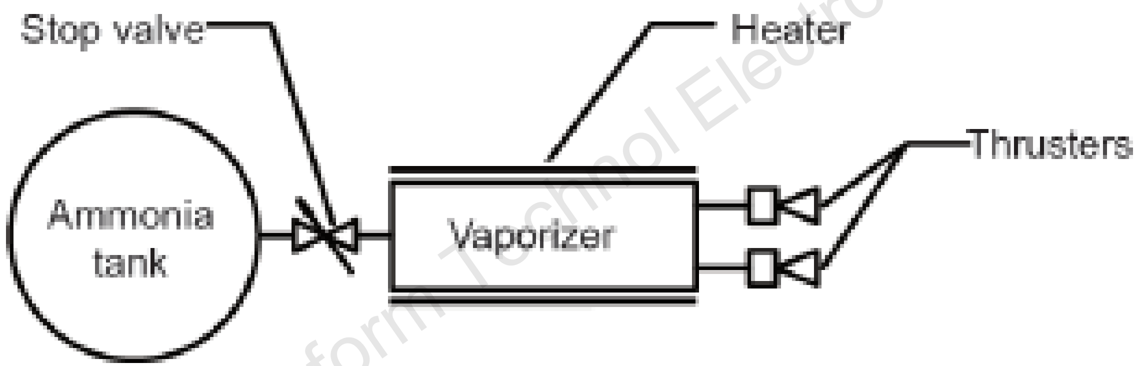


Fig. 1 General sketch of the ammonia self-managed vaporization propulsion (ASVP) prototype

Major results (Cont'd)

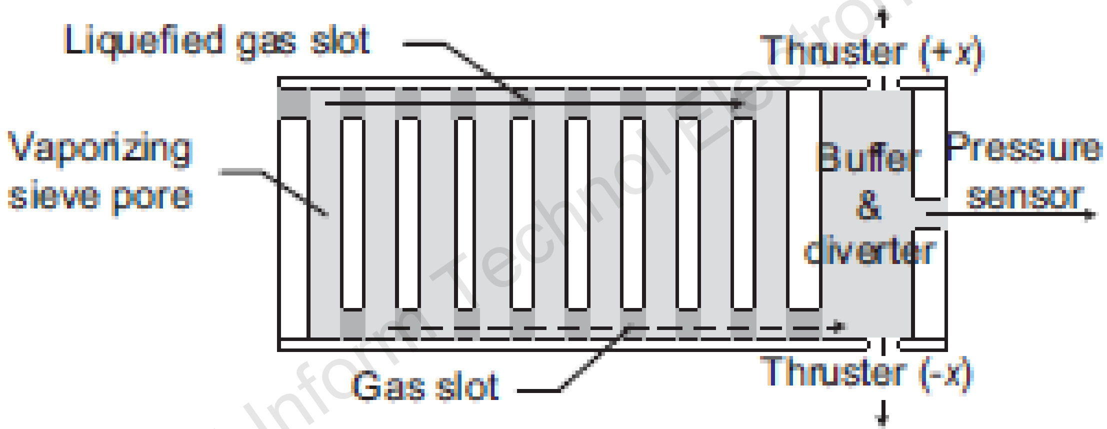
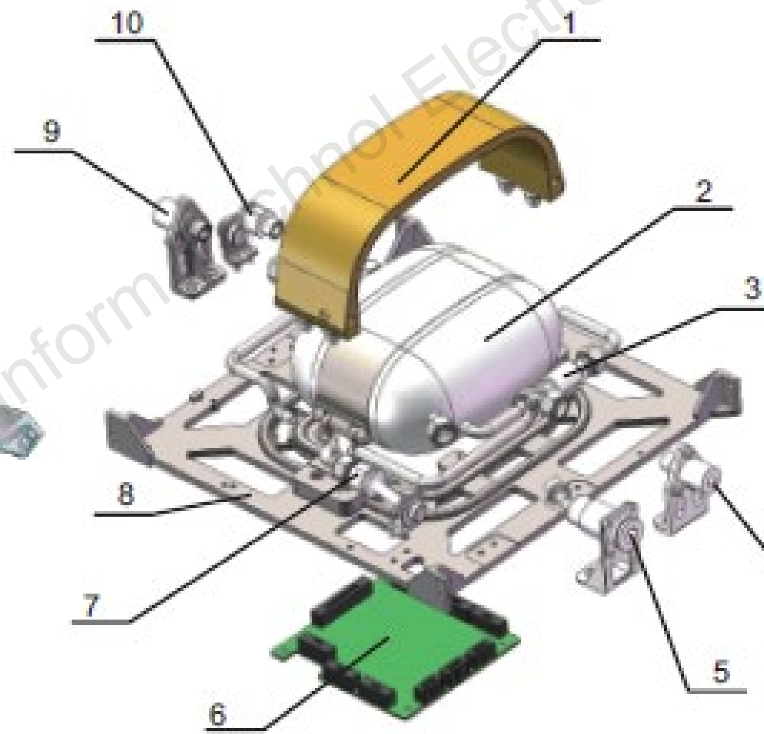


Fig. 2 Structure of the vaporizer

Major results (Cont'd)

Physical picture and exploded figure of ASVP



1. Vaporizer
2. Ammonia tank
3. Stop valve
4. Thruster (+*x* axis direction)
5. Propellant filler
6. Control circuit board
7. Vaporizer gas pressure sensor
8. Supporting frame
9. Thruster (-*x* axis direction)
10. Ammonia tank gas pressure sensor

Major results (Cont'd)

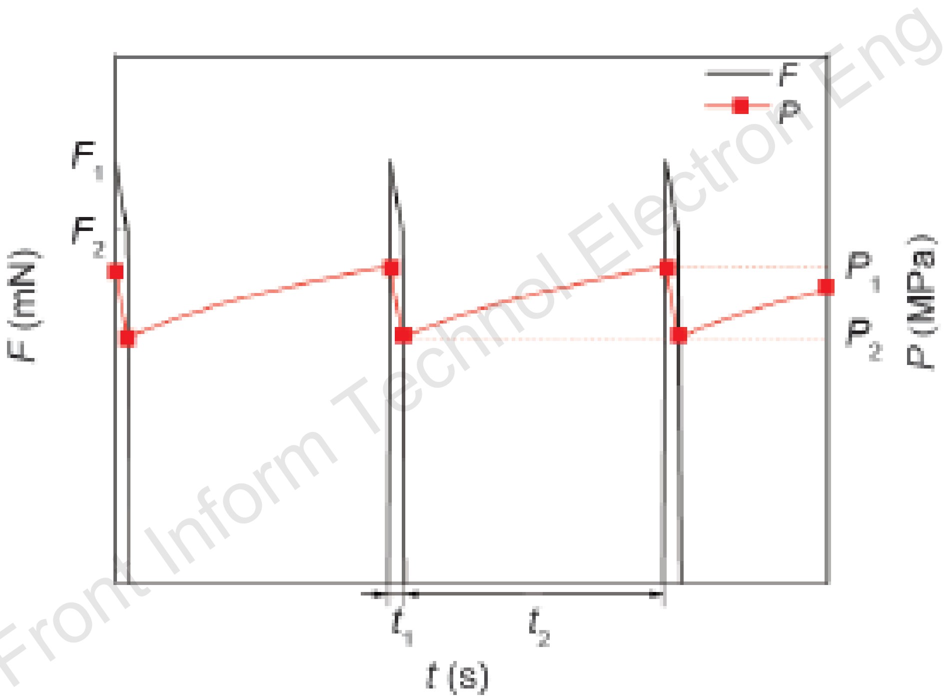


Fig. 10 Pulse width modulation (PWM) thrust control strategy for the ammonia self-managed vaporization propulsion (ASVP) system

Major results (Cont'd)

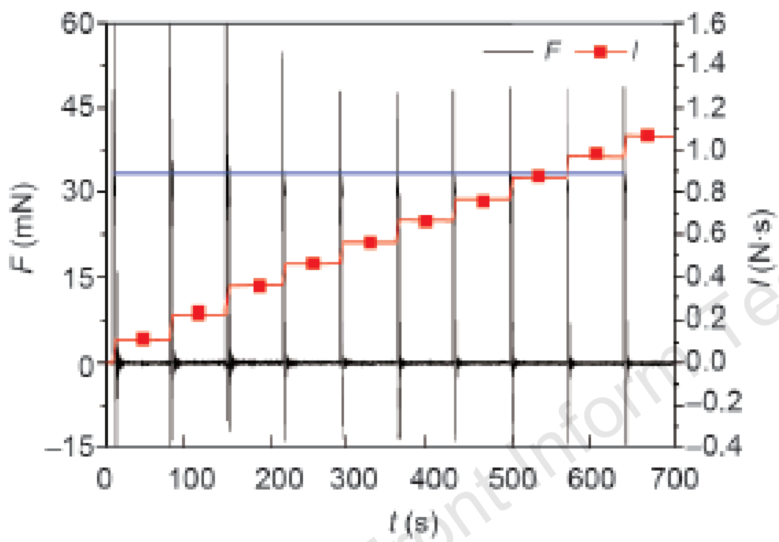


Fig. 13 Thrust testing results in the optimal strategy (10 thrust pulses). References to color refer to the online version of this figure

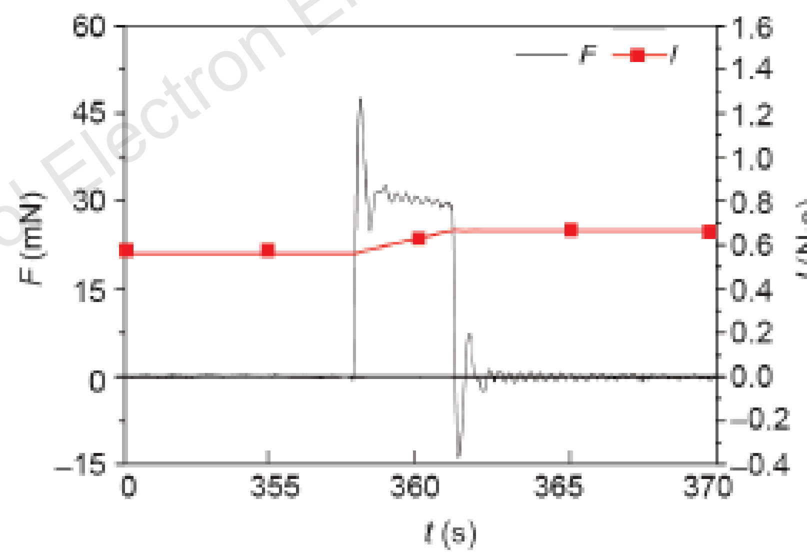


Fig. 14 Output thrust of a single thrust pulse

Major results (Cont'd)

Table 10 Comparison of the ammonia self-managed vaporization propulsion (ASVP) system and other liquefied ammonia mN-level propulsion systems

Propulsion system	Total mass (kg)	Propellant mass (kg)	Total power (W)	Operating mode	Thrust value (mN)	Specific impulse (s)
AMAST P3D	7 (without tanks)	50	800	Arcjet	100	450
YH-1	–	–	50–100	Blow down	120	103
BX-1	2.5	0.74	–	Flashing jet	860	34
ASVP	1.8	0.34	9	PWM	23–74	100–110

Conclusions

1. We have presented the ammonia self-managed vaporization propulsion (ASVP) system to provide a high-impulse density actuator for micro-nano satellites.

2. The PWM thrust control strategy has been adopted to control the vaporization process effectively, which makes the output thrust stable, uniform, and controllable.

3. Based on the existing design, an optimal strategy was presented to promote the complete vaporization of liquefied ammonia and the peak conversion efficiency of the power to thrust impulse.