Pulse-mode Performance Characteristics of a Small Liquid-monopropellant Rocket Engine

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1. Design specification of thruster and test procedures

The design Specification of 70 N-class hydrazine (N_2H_4) thruster is summarized in Table 1. The thruster generates thrust through supersonic nozzle by chemical reaction of propellant throughout the catalyst in thrust chamber. This development model is designed to produce 67 N (15 lb_f) of nominal steady-state thrust at an inlet pressure of 2.41 MPa (350 psia). As depicted in Fig. 1, the thruster is composed of a solenoid-operated propellant valve and thrust chamber assembly (TCA) that is made of thermal barrier tube, propellant feed tube, injector, chambers, and converging-diverging nozzle. Test and evaluation model (TEM) is configured and fabricated so as to measure and sample the performance parameters such as pressure, temperature, and product composition at critical positions of the thruster. Nozzle expansion ratio (A_e/A_t) of flight model is set to 50 for the operation in outer space and/or at high altitude, whereas that of the TEM is modified to 10 in order to prevent the thrust loss owing to flow separation and shock occurring inside the nozzle at the atmospheric condition. Shape of the feed tube is determined to minimize heat soak-back which may cause the self-decomposition of hydrazine at pulse-mode operation. A monopropellant grade hydrazine per MIL-PRF-26536F is fed into double-stage catalyst chambers charged with granular iridium-coated alumina.

Table 1 Design specification of 70 N-class liquid-monopropellant hydrazine thruster

Parameter	Unit	Specification
F_v	N	67±5
I_{sp}	s	225±8
A_e/A_t	-	50
P_{cu}	MPa	1.55
P_{cd}	MPa	1.38
$\dot{m}_f$	g/s	29.2

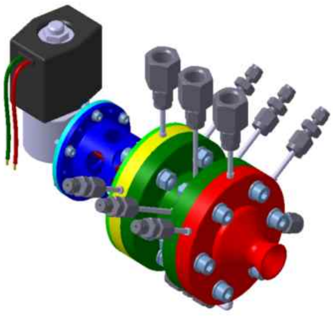

Fig. 1 Configuration of 70 N-class hydrazine thruster (TEM)

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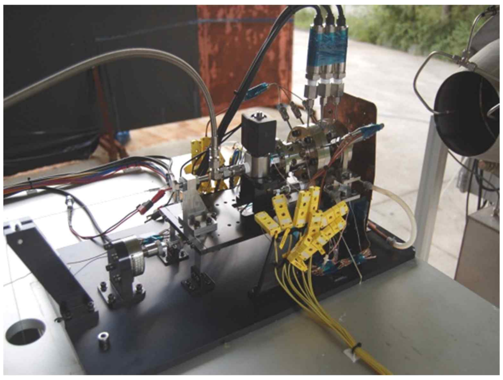


Fig. 2 Configuration of TMR and thruster (TEM)

Test measurement rig (TMR) applying single component system was constructed for the measurement of thrust in TEM. Test configuration of the hydrazine thruster installed on TMR is shown in Fig. 2. TMR has the on-line calibration capability which enables remotely a compensation for the variation of structural sensitivity caused by thermal effects and hysteresis during test firing. In the present study, pulse-mode firing results of the thruster are described at an inlet pressure of 2.41 MPa (350 psia), only. Thrusters are, at first, exposed to a burn-in process for the mechanical and chemical stabilization of catalyst bed, and then pulse firing is conducted according to the test procedures.

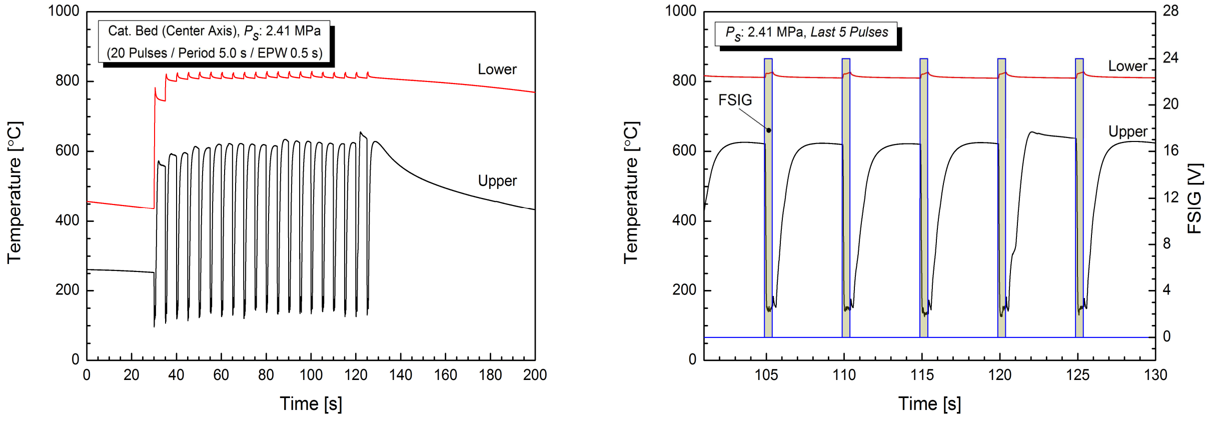
2. Test results and discussion

Variation of the temperature measured at radial center of upper and lower chamber is shown in Fig. 3. Liquid hydrazine discharged from injector decomposes across the catalyst bed producing ammonia (NH_3), nitrogen (N_2), and hydrogen (H_2) according to the following two-step reactions:

$$Exothermic:\ 3N_2H_4 \rightarrow 4NH_3 + N_2 - Q_1 \tag{1}$$

$$Endothermic:\ 4NH_3 \rightarrow 2N_2 + 6H_2 + Q_2 \tag{2}$$

While the reaction of Eq. (1) is exothermic, Eq. (2) is endothermic. Length to diameter ratio of reaction chamber and size/shape of catalyst particles are intimately associated with the flow residence time of decomposed gases as well as injected fuel liquid. Therefore, test and evaluation process according to the dimensional variation of catalytic reactor is indispensable for the design optimization of TCA. A number of test cases were drawn for the parametric test, among which test results for a standard model are to be presented in this work.



(a) Full range

(b) Last 5 pulses

Fig. 3 Thermal behavior at pulse-mode firing with 2.41 MPa of propellant supply pressure

Fig. 3(a) represents, internal temperature of reactor chambers rising up to about 625˚C and 825˚C after stabilization of catalyst bed. A repetitive temperature behavior is observable in Fig. 3(b).

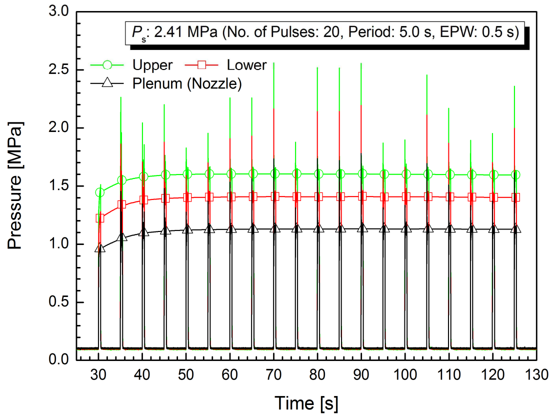


Fig. 4 Overall variation of chamber pressure and pulse-averaged pressures

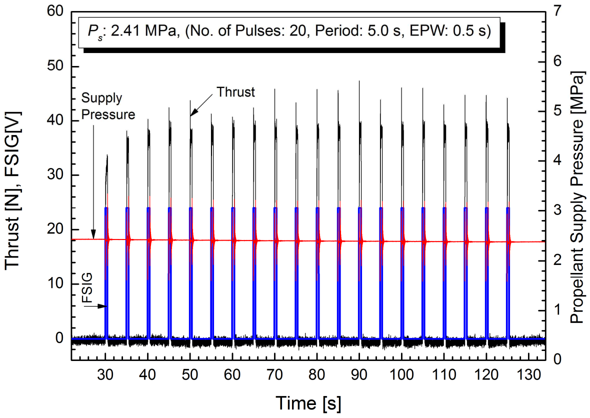


Fig. 5 Variational behavior of thrust and propellant supply pressure at pulse-mode firing with 2.41 MPa of propellant supply pressure

The static pressure variation in reaction chambers at pulse mode firing with 2.41 MPa (350 psia) of propellant supply pressure is shown in Fig. 4. Pressure drop occurs when the gas moves through inside of reaction chamber which is filled with catalyst. With the valve opening, pressure of the upper, lower, plenum chambers increase up to 1.60, 1.41, 1.13 MPa, respectively.

Figure 5 presents the thrust behavior and propellant supply pressure with pulse-mode firing signals (FSIG). A fuel pressure drop depending on flow line configuration, filters, orifices, and so forth occurs during the pulse repetition amounting about 0.05 MPa. The rising time to steady-state thrust is below 60 ms giving 38.1 N of average thrust.