Research Note

Thrust Measurement of a Cold Gas Thruster for KSLV-I under Vacuum Conditions*

Sangwoon JEON,1) Seul JUNG,2) Jihun KIM,3) and Joonyun KIM4)

1) Launcher Systems Development Team, Korea Aerospace Research Institute, Daejeon 305–806, South Korea
2) Department of Mechatronics Engineering, Chungnam National University, Daejeon 305–764, South Korea
3) Launcher Stage Engineering Team, Korea Aerospace Research Institute, Daejeon 305–806, South Korea
4) Launcher Electronics Team, Korea Aerospace Research Institute, Daejeon 305–806, South Korea

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1. Introduction

The Korea space launch vehicle-I (KSLV-I) is the first space launch vehicle in South Korea. KSLV-I is capable of launching a satellite weighing 100 kg into a low earth orbit. The first launch of KSLV-I occurred in 2009.1) Launch vehicles require a highly accurate attitude control system. The reaction control system (RCS) is one of the most common control systems on board launch vehicles for attitude and orbit control under vacuum conditions. The RCS utilizes 22 N-class cold-gas thrusters. The cold-gas thruster has been developed as one of the thrusters for use in space.2)

To perform a precise attitude maneuver and to analyze the flight test results of the RCS, accurate knowledge of the thrust level is essential.3) Since the RCS operates at high altitude, thrust measurements in a vacuum are very important. The thruster for KSLV-I has three nozzles: a middle nozzle for pitch or yaw control, which has an angle of 70 degrees, and nozzles at both ends for roll control, which have angles of 90 degrees.4) Thrust is measured at only two nozzles of the thruster, since the two end nozzles are symmetrical.

In this paper, the performance of the thruster for KSLV-I is analyzed with test results obtained under vacuum conditions.

2. Test Mode

Thrust measurement tests were conducted for continuous firing operations and for pulse firing operations as described in Table 1. There are two continuous firing modes and nine pulse firing modes. C1 mode is the main continuous firing mode. Two firing tests were performed for each test mode.

3. Test Results

3.1. Continuous mode test results

To show the general performance of the thruster nozzles and to compare different nozzles, the thrust data at ambient vacuum pressures less than 10.6 Pa are summarized in

![Fig. 1. Thrust under vacuum conditions.](image-url)
the exhaust gas. Therefore, a real nozzle will always have lower performance than an ideal nozzle. The thrust coefficient and Isp from the ideal nozzle calculations were approximately 1.6 and 70 s.

3.2. Pulse mode test results

Since we used a 100-Hz low-pass filter in the load cell indicator to reduce noise, there was some signal delay. Therefore, the load cell output cannot be used in the transient response analysis of the thrusters. The purpose of pulse mode tests is to see the response of the thruster to the chamber pressure, which shows the real thruster performance without a time delay. Results of the pulse mode tests are evaluated by chamber pressure integration and total impulse. The results of the integrated pressure and total impulse for nozzle 1 are shown in Fig. 2.

Integrated pressure and total impulse increase linearly with the total on time (total firing time) for all nozzles. Each thruster showed similar performance if the total on time was the same. P9 mode was 4.8% lower than the P5 and P7 modes. The difference between the P5 and P7 modes was less than 0.02%. The off time had no effect on the total impulse and integrated pressure. However, a long on time seemed to have a minor effect on the total impulse and integrated pressure.

Figure 3 shows the average pressure and average thrust for nozzle 1. Here, the average means the integrated value divided by the total on time. The average pressure and the average thrust decreased linearly with the total on time for all nozzles. However, the average pressure and average thrust of P9 mode was 2% lower than those of P8 mode. Although the total on time was the same, the average pressure and average thrust varied in relation to on pulse (on time). P9 mode was about 5% lower than the P5 and P7 modes. This implies that the average pressure and average thrust vary with on time.

The results of nozzle 1 show that shorter on time corresponds to a higher average pressure/thrust than longer on time. There is one main reason for this behavior. Short on time (large frequency) is especially critical, because the chamber pressure has an overshoot (peak value). As seen in Fig. 4, chamber pressure had a peak value 20% higher than the transient value of about 50–60 ms after each firing start. This effect is caused by the performance characteristics of the regulator we developed.

4. Conclusions

In this paper, thrust measurement tests for the thrusters of KSLV-I were conducted. The test results obtained in continuous mode show that the thrusters generate thrust of 23 to 26 N (±0.8 N), which satisfies the required specifications for KSLV-I. The test results obtained in the pulse mode show the overshoot phenomenon during a short on time and, in general, this overshoot causes disturbance to the system. This performance was applied in designing the autopilot program in the inertial navigation and guidance unit (INGU) of the second stage of KSLV-I. Three-axis attitude control of the second stage during the KSLV-I third flight test was successfully accomplished using the RCS and INGU applied with this analysis.

References

1) KARI: Research and Development of KSLV-I, MSIP, 2013.
2) Adler, S., Warshavsky, A., and Peretz, A.: Low-cost Cold-gas Reaction Control System for Slosat FLEVO Small Satellite, J. Spacecraft Rockets, 42, 2 (2005), pp. 345–351.
3) Stone, W. C.: Fast Variable-amplitude Cold Gas Thruster, J. Spacecraft Rockets, 32, 2 (1995), pp. 335–343.
4) Jeon, S.-W. and Jung, S.: Hardware in the Loop Simulation for the Reaction Control System using PWM-based Limit Cycle Analysis, IEEE Trans. Control Syst. Technol., 20, 2 (2012), pp. 538–545.