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# 고공모사 환경에서의 1 lbf급 단일액체추진제 로켓엔진 연소성능시험

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# Hot Firing Performances of 1 lbf-Liquid Monopropellant Rocket Engine under the Environment of High Altitude Simulated

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ABSTRACT

This paper summarizes a satellite program-specific performance requirements and test results for the verification of standard mono-propellant hydrazine thruster (MRE-1) producing 0.95 lbf (4.2 Newtons) nominal steady-state thrust at an inlet pressure of 350 psia (2.41 Mpa). Performance characteristics are shown in terms of thrust behavior at steady state and pulse mode firing. Hot firing test philosophy is briefly introduced, too.

초 록

추진제 주입 압력 350 psi 에서 0.95 lbf 의 정상상태 공칭추력을 내는 단일액체추진제 하이드라진 추력기의 검증을 위한 성능 요구조건과 시험결과를 요약한다. 성능특성은 정상상태 및 펄스 모우드 연소상태에서의 추력 거동으로 제시되고 지상연소시험과정이 간략히 소개된다.

## 1. INTRODUCTION

The NASA has selected the TRW MRE-1 thruster as the standard 1 lbf thruster in 1970's. The unit has been continuously reconfigured structurally and thermally for subsequent flight spacecraft applications as dual thruster module and flight-qualified

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extensively. The major application of monopropellant hydrazine propulsion systems today is attitude and velocity control of unmanned satellites. This is true not only because of the large number of satellite missions, but because hydrazine systems offer many advantages over the alternative approaches to performing the attitude control and stationkeeping functions.

KOMPSAT-2 satellite propulsion system incorporates the monopropellant propulsion system. Recently in 2003, hot firing test facility has been built up and verified by KARI and HANWHA Corp. Based upon this infra-structure, the KOMPSAT-2 thrusters were acceptance-tested. Performance verification features and test philosophy of the thruster are followed on.

## 2. THRUSTER PERFORMANCE REQUIREMENTS and TEST PHILOSOPHY

### 2.1 Performance Requirements

Thruster is operated by an electrical command signal that opens the propellant valve to permit the flow of hydrazine (N2H4) into the catalytic reactor. The decomposition products of hydrazine are discharged through the nozzle to obtain thrust. All performance criteria are based on an inlet pressure range of 50 to 350 psia during acceptance testing, or re-baseline testing of protofilght and delta-qual. test program.

The thruster, when supplied with the propellant and specific electrical and mechanical interfaces, shall provide the steady state and pulse mode performance. The performance criteria for steady state vacuum thrust and specific impulse are depicted in Fig. 1 and Fig. 2, respectively. It also has requirements for total impulse predictability, impulse-bit repeatability of 3σ, margins of 1.5 factor of safety, and constraints of no-constraints on the firing condition, etc.

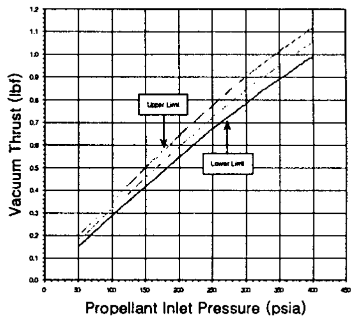


Fig. 1 B.O.L. Steady State Thrust

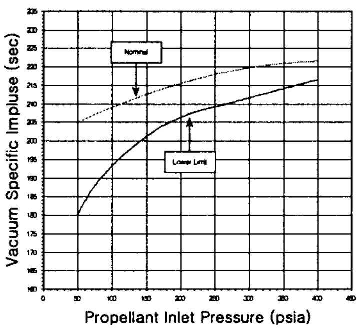


Fig. 2 Steady State Specific Impulse

### 2.2 Test Configuration of Thruster

Thruster consists of a thrust chamber assembly (TCA: thrust chamber, catalyst bed, feed tube, injector and thermal barrier tube) and a dual seat (one coil per seat) solenoid operated propellant valve (Ref. 1). The TCA is shown for reference in Fig. 3. The KOMPSAT-2 TCA nozzle has a 30 degree cant angle.

Fig. 3 TCA Configuration

The driver for the valve is configured as per Fig. 4. Test valve driver has the same electrical performance characteristics as the flight one not to cause any parasitic testing effect on the thruster performance.

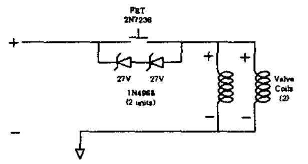

Fig. 4 Valve Driver Circuit

The thruster mechanical interface to the test stand (Thrust Measurement Rig) is shown in Fig. 5. The TMR has the on-line thrust calibration capability to enable structural and thermal compensation while hot-fire testing in vacuum environment.

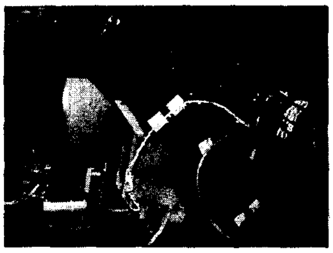

Fig. 5 Thrust Measurement Rig

The thruster is supplied with monopropellant grade hydrazine (N2H4) per MIL-PRF-26536E (Ref. 2). All fluids entering the thruster is filtered through a $10\mu$ abs., or better, filter.

### 2.3 Test Philosophy and Hot Firing Sequences

An acceptance test program is performed on each production unit (TCA) to ensure the thruster performance. The acceptance program is comprised of TCA weight measurement, gas flow impedance test, electrical test with slave valve assembled to TCA, pre-HFT inspection, alignment with test stand, acceptance hot fire test, post-HFT inspection, and re-weighing TCA, etc.

For all hot fire tests, the thrust chamber assembly tested is assembled to a slave (non-flight) valve. The slave valve is identical to the flight valve and complies with the valve's functional requirements (dribble volume, pressure drop, opening and closing response, pull-in, drop-out, and size).

All hot fire testing is conducted under the simulated altitude of 100,000 ft minimum (0.16 psia maximum). Each thrust chamber assembly is hot-fire tested as per the specific test matrix to verify compliance with the performance requirements (Ref. 3).

## 3. TEST RESULTS and DISCUSSION

Thruster performance parameters to be acquired through test, as a minimum requirement, are the propellant mass flow rate, steady state vacuum thrust, vacuum specific impulse, impulse-bit, temperatures for some critical locations, propellant supplying pressure, and vacuum pressure.

Configuration of the thruster installed on TMR and its glow phenomenon during hot firing are shown in Fig. 6. Temperature of the heated thrust chamber gets to over 900 ℃ while continuous burning and a heat conduction occurs through thermal barrier tube of thruster up to the upstream valve component, whereas the temperature of flow control valve should not exceed 121 ℃.

Thrust behavior at continuous burning and a single shot thrust of pulse mode firing are depicted in Fig. 7 and Fig. 8, respectively. The square waves which can be found prior to and after oscillatory thrust curve in Fig. 7 are pre- and post-thrust calibration references. Thrust shows typical of 1 lbf thruster at 400 propellant inlet pressure.

Referring to the 50 ms of firing pulse with a square wave, an ignition delay and tail-off behavior can be found in Fig. 8. There shows also a dynamic pressure variation caused by a sudden shut-off of flow control valve. This pressure propagation through upstream tubing system can result in a water hammering with exaggerated peak pressure in the absence of pressure mitigation components.

The raw thrust data is reduced into net thrust with vacuum correction and calibration, and to specific impulse with mass flow rate. Figure 9 presents a B.O.L thrust falls on the performance criteria bounds at each propellant pressure.

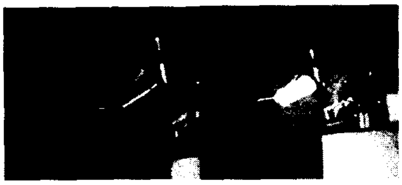

Fig. 6 Thruster Glowing prior to Ignition and during Steady State Firing

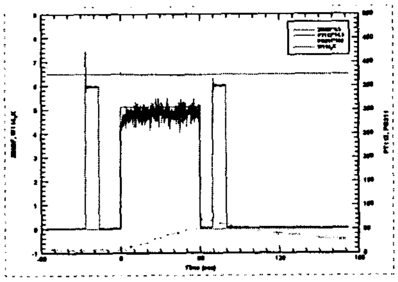

Fig. 7 Thrust Behavior at Steady State Firing with 400 psi Propellant Pressure

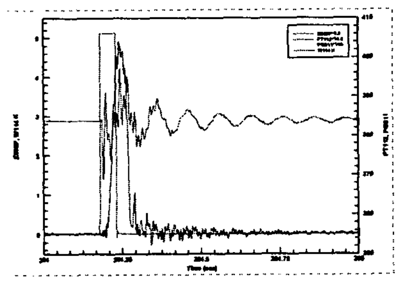

Fig. 8 Thrust Behavior at Pulse Mode Firing with 400 psi Propellant Pressure

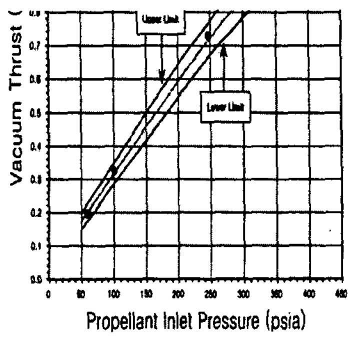


Fig. 9 BOL Steady State Thrust Performance

4. CONCLUSION

Performance requirements and acceptance test philosophy of 1 lbf liquid monopropellant thruster are presented. The firing result shows typical behavior of flight-proven thruster and meets the performance requirement within specified criteria bounds.

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