Lifetime Test of a Cold Gas Thruster

By Hans-Peter HARMANN and Heiko DARTSCH

AST Advanced Space Technologies GmbH, Stuhr, Germany

AST Advanced Space Technologies GmbH developed a 47 mN cold gas thruster for fine point missions. A precise pointing control requires an agile actuator with short reaction time and small impulse bits. The developed thruster allows short pulses of 20 µNs with pulse rates of up to 100 Hz. At high repetition rates the total number of actuations over lifetime becomes a demanding requirement. AST already showed up the potential of the used valve technology during the development of a miniaturized xenon flow control unit. In the presented test campaign the lifetime actuations of the cold gas thruster (engineering model, EM) have been demonstrated for more than one billion (10^9) actuations before the test was suspended for a long term storage test. It is intended to continue the test after the storage test. After the EM development the flight models (FM) have been produced. The formal qualification of the cold gas thrusters for the FORMOSAT 5 mission was performed by SpaceTech GmbH. This mission requires "only" 1.5 million actuations. After end of the qualification, it has been decided to continue with an extended campaign to cover the billion actuations by a formal verification process.

Key Words: Cold Gas Propulsion, Thruster, Formosat 5, Qualification, Lifetime test

1. Introduction

Formosat 5 is a small LEO earth observation satellite of 525 kg mass. Designed and developed by the Taiwanese Space Organization NSPO, it will provide a panchromatic imaging from a sun synchronous orbit at 720-km altitude. The five years mission is planned to be launch on a Falcon 9 rocket in 2016.

The satellite is controlled by four cold gas thrusters (CGT) with 47 mN thrust each at 1.5 bar(abs). These thrusters have been designed, developed and manufactured by AST Advanced Space Technologies GmbH (AST). A special feature of this type of thruster is the high number of lifetime actuations. This had been demonstrated on valve component level during the development of a xenon flow control unit. For the CGT development a dedicated lifetime test campaign has been conducted to investigate the lifetime capability and the stability of relevant thruster parameter. A second campaign in the frame of an extended thruster qualification program is ongoing.

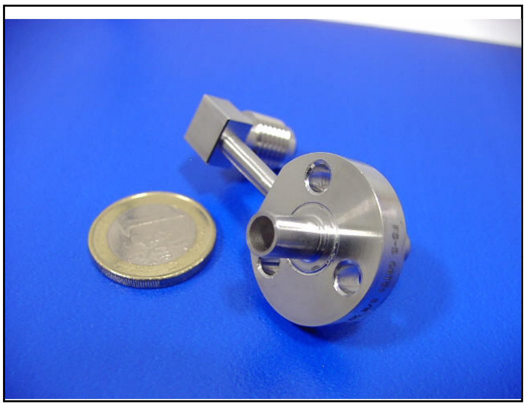

Fig. 1. AST's Nitrogen cold gas thruster

2. Cold gas thruster design

The CGT consists of the solenoid valve, a nozzle, a mechanical interface plate and the fluidic interface. The modular configuration allows the change of the nozzle diameter or the fluidic interface without modifications of the other parts

Table 1. CGT key figures

mass	43 gram
nom. thrust	47 mN @ 1.5 bar N_2
specific impulse	>69s
switch on time	<1ms
op. voltage range (pull-in)	22 to 36 V
resistance	140 Ohm
min. power (pull-in / hold)	3.5 W / 0.1 W (typ. 0.25 W)
temperature range	-25°C to +60°C

4 Development tests (accelerated lifetime test)

4.1. Test set-up

The accelerated lifetime test campaign has been conducted on an EM during thruster development. The tested EM was identical to the later FMs but taken from a first pre-series production batch (figure 3).

The purpose of the test was to improve our knowledge on mechanical lifetime limitations and wear effects.

For the test the CGT was connected to a pressurized Nitrogen gas supply and placed under ambient condition in the lab. A pressure sensor and a flow meter in the inlet line to the thruster monitored the propellant flow.

For an accelerated lifetime test the major stress and wear effect has to be applied in a representative way. For the CGT the switching transient of the valve introduces the major stress and wear on mechanics and seal elastomer. In a stable open or close position the remaining wear (gas dynamic wear on seal) can be neglected compared to the transient.

The AST CGT is able to open within less than a millisecond and close within 2 millisecond. The accelerated test operated the thruster at 100 Hz with 50% duty factor, so that the armature had three to four milliseconds to come to rest after a

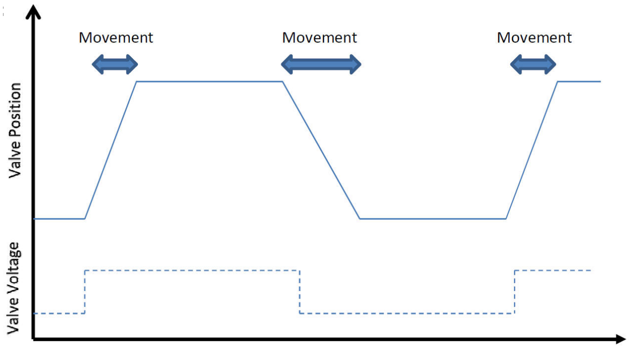

Fig. 2. Valve operation during accelerated lifetime test

With this operation scheme it is possible to perform more than eight million cycles a day. The total campaign operated the valve for one billion operations without applied gas flow and 100 million cycles with nominal gas flow. In total more than 30 kg Nitrogen has been consumed by the CGT.
Each working day of the half year test campaign the cycling was interrupted for measurement. For the measurement the gas flow was established at inlet pressure of 2.5 bar(abs). The capability to control the average flow by pulse width modulation has been investigated for different working points. A working point with duty factor of 0% was included to demonstrate the shut-off capability.

Fig. 3. Cold gas thrusters of pre-series production batch

4.2. Test results

During the first 250 million cycles a slight increase of the full flow by 3% has been determined. This is in correlation with former lifetime measurements on component level. The effect is related to a setting of the elastomer. For the following 500 million cycles the flow level stays pretty constant. After a total of 700 million actuations the flow a very slight tendency to decline. The same trend was detected for the throttled flow levels.

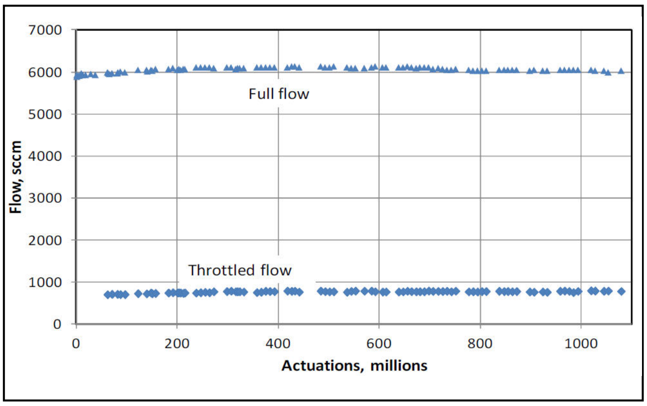

Fig. 4. Variation of the flow over lifetime

Over the full test time the variations in the mass flow for all working points remained within 3% of the starting conditions. The thruster was able to shut down below the sensitivity of the flow meter.
After the end of the test campaign the thruster was still functional. It has been removed from the set-up and put into a long storage test.

5. Qualification (QM)

5.1. Test set-up

The thruster qualification for Formosat 5 has been done in a combined acceptance and qualification test campaign. Six FM thrusters have been tested in parallel by SpaceTech GmbH Immenstaad (STI). One of the CGTs was applied to the extended qualification test levels. After all qualification tests (functional, pressure proof, vibration, thermal vacuum) the QM was sent to AST for lifetime testing.
The QM was placed in AST's vacuum test facility to provide representative operational conditions especially with respect to the gas flow dynamics.

Fig. 5. AST's vacuum facility

The inlet of the thruster was connected to a pressurized Nitrogen gas supply. The inlet pressure and gas flow was monitored by a pressure sensor and a Bronkhorst flow meter. The tests have been conducted with nominal inlet pressure of 1.5 bar (abs) to operate the thruster at the nominal working point.
During the qualification at STI the QM accumulated 340 thousand actuations. The total lifetime verification had to demonstrate 1.5 million cycles including a 50% margin.
The resulting 1.2 million cycles of the lifetime test had been split into 18 test blocks. At the beginning of the campaign each test block included 50K cycles, later after gaining confidence in the stable operation this has been increased to 100K cycles. The pulse frequency of the CGT was set to 15.4 Hz. Each day the thruster was shut down for about 16h simulating a non-operation phase.

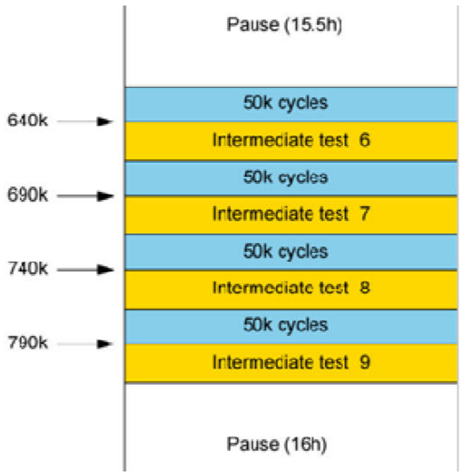

Fig. 6. Typical schedule of test blocks

Between each test block the

- coil resistance
- set-on time
- set-off time
- mass flow
- helium leakage rate at 1.5 bar GHe (integral)

have been measured to provide a monitoring of potential changes. The switch times and the electric parameters are sensitive probes for changes or failures in the internal mechanics of the valve or in its magnetic circuit. If the force of the spring, the magnetic force or dimensions between components change then the set-on/set-off voltages and with them the switch time will shift.

Before and after the test campaign

- HV insulation
- minimum open voltage,
- minimum hold voltage

have been checked.

5.2. Test results

a) Coil resistance

The coil resistance of 138 Ohm stayed constant over the full campaign.

b) Set-on time / set-off time

The set-on and set-off switch times have been measured for different voltage levels. Within the measurement accuracy the values did not change.
This is a clear indications that the internal conditions of the valve remained unchanged throughout the test.

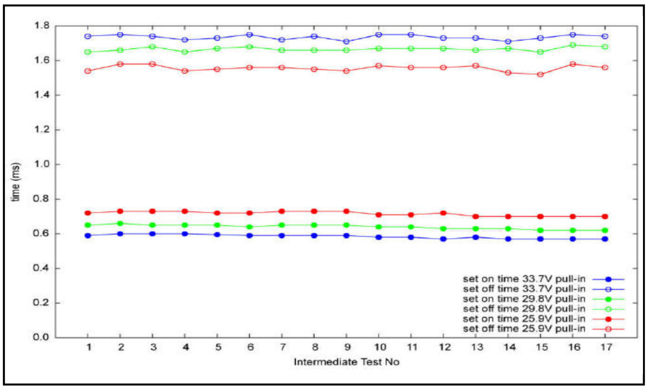

Fig. 7. Set-on time and set-off time stability

c) Mass flow

The measured mass flow at 1.5 bar(abs) and therefore the thrust level at nominal working point remained unchanged. The average value was 3320 sccm Nitrogen.

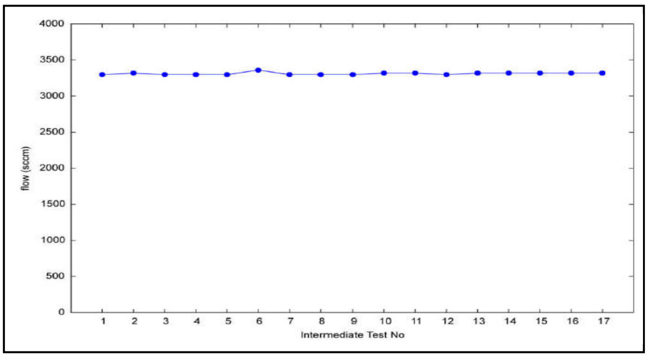

Fig. 8. Mass flow (thrust) stability

d) Helium leakage

The helium leakage test measured the integral leakage rate i.e. all leakages from seat leakage, welds, tubing and screw fittings inside the vacuum chamber. The rate has been determined at pressure of 1 bar(abs) and 1.5 bar(abs) GHe after elastomer saturation. Therefore the leakage includes also the Helium diffusion rate through FKM bulk material.
A slight trend to higher leakage rates can be determined over lifetime but far below the requirement of $2*10^{-5}$ mbar l/s. This is in correspondence with elastomer setting and run-in effects. An extended lifetime cycling campaign intended for 2016 will verify if the leakage stabilizes for higher lifecycles as expected or if the trend continues.

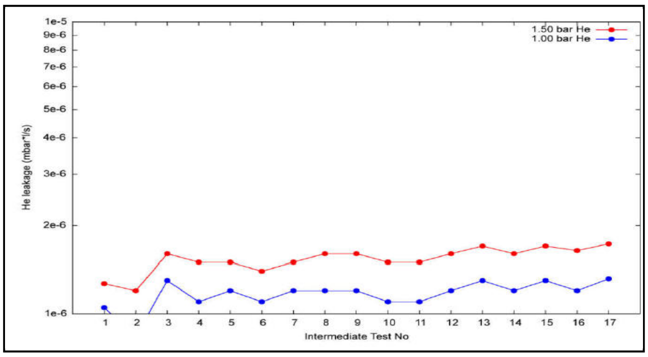

Fig. 9. Development of the leakage rate

e) HV insulation test

The high voltage insulation test at 500 V provided proof that the electric interface was still in good condition and without any non-conformances after the test.

f) Minimum open voltage / minimum hold voltage

The minimum open voltage and the minimum hold open voltage has been determined for nominal pressure before and after the cycling test. The values were 8V for the minimum open voltage and 2.2 V for the minimum hold voltage without changes.

5. Summary and conclusion

The AST CGT demonstrated an outstanding lifetime capability of more than one billion actuation cycles on an EM. In a formal space qualification program the thruster has been qualified for a 1.5 million cycles (incl. 50% margin) as it is state-of-the-art for today's mission scenarios.

6. Outlook

After the lifetime cycling test the QM has been put into a long term storage test. After one year of storage the thruster shall be remounted inside the vacuum chamber to continue the cycling in an extended lifetime campaign.

The huge number of lifetime cycles and the capability for short pulse times open the floor to pulse modulated cold gas propulsion. New mission scenarios with dynamic and precise attitude control become possible. A system concept exploiting these benefits is under investigation in cooperation with SpaceTech GmbH Immenstaad.

Acknowledgments

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