MODULAR THRUSTER AND FEEDING SYSTEM FOR MICRO-SATELLITE

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Abstract — The miniaturization of space applicable devices by means of micro system technology (MST) is pursued by many research groups. MST devices are often designed as stand alone and require individual packaging which makes them still quite large. Focusing on the integration of several MST components has the advantage of reducing size and mass much more. An integrated and miniaturized feeding and thruster system for micro satellites is presented which consists of a valve, a particle filter, a pressure sensor and a nozzle. The first prototype valve has been fabricated and tested.

Key Words: micro propulsion, thruster, satellite, packaging

I INTRODUCTION

The high cost of large satellites is a bottle neck for universities and research centers to incorporate new technologies that not yet have proven themselves and therefore risk the mission. The advent of the miniaturization of satellites enables low cost access to space and makes alternative technologies more attractive.

More advanced missions require the possibility to correct the attitude and/or altitude of a satellite by means of a propulsion system. Conventional, of the shelf propulsion system components, are too large and heavy to be used on micro satellites.

A couple of research groups are working on the miniaturization of micro propulsion systems by means of MST ([1],[2]). The approach which is mostly seen for building such complex systems is based on large wafer stack bonding. This approach is difficult and expensive and often consists of several functional parts that are fabricated in one and the same run. The drawback of this is that when one part of the system has become defective during fabrication the whole device is useless. Finally, the packaging of such a system is quite difficult and expensive.

In our vision on miniaturization, integration and packaging are of utmost importance. When MST is used the size of sub-systems can be reduced considerably. It is often the packaging that makes MST devices still quite large and time consuming.

We focus on the integration of several MST components in a modular way and choose a convenient package as the baseline. By selecting a convenient package first and adjusting the MST part to fit the package, overall size and mass are reduced and modularity is obtained [3]. All functions (e.g. pressure sensor and nozzle) are fabricated separately and a properly working device is selected first, before integration. When damaged during operation, some of these devices can even be replaced which is useful for terrestrial applications of this technology.

Our micro propulsion system is a simple blow down system of a rocket engine consisting of a thruster and feeding system and a propellant storage tank. Besides the use of micro system technology to reduce the size of the thruster and feeding system, a novel technology is developed by TNO which makes it possible to reduce the size of the propellant storage as well as the storage pressure drastically [4]. Cold gas generators (CGG) are used which contain a gas that is chemically stored inside a solid material. When ignited, nitrogen gas is released into a gas storage tank.
results in an impulse bit of 90µNs that can be achieved by a nozzle that generates a thrust in the order of 1mN in combination with a valve open time of 100ms.

A functional lay-out of the propulsion system is shown in Figure 1. It consists of two main parts, the propellant storage and the thruster and feeding system. The propellant storage consists of a plenum with 8 cold gas generators and is developed by TNO [4]. The thruster and feeding system, consisting of a valve, a particle filter, a pressure sensor and a nozzle, will be subject of the current study.

![Figure 1: Functional lay-out of the micro propulsion system](image)

The low storage pressure, typically between 1 and 4bar, that is possible with the cold gas generators, makes a pressure regulator redundant. Such a regulator is normally required when using high-pressure tanks. Moreover, the low pressure makes storage easier and makes the design of MST thruster and feeding system less critical.

To guarantee a precise impulse bit of 90µNs a normally closed on/off valve with an opening/closing time of <1ms is required. This valve has to be leak-tight for a safety pressure of 10bar. A total amount of 0.8gram nitrogen is carried by the cold gas generators. Less than 0.1gram/year loss of nitrogen due to leakage is allowed which means a valve leakage of $<1.6 \times 10^{-4}$sccm (standard cubic centimeters per minute). A particle filter is necessary to avoid particles getting stuck in the valve causing leakage. Additionally the storage pressure has to be measured to control the required impulse bit during operation. The pressure is also important for health monitoring (e.g. leakage) and to determine when a cold gas generator has to be ignited to refill the plenum.

II.2 THRUSTER AND FEEDING SYSTEM

Figure 2 shows a schematic of the thruster and feeding system. The glass tube is functioning as a hermetically sealed package, fluidic interconnect as well as a macro support for the fragile MST component. The MST part contains a valve seat and a nozzle. To connect the glass tube to the plenum, a precision machined metal part with a thread is attached to the glass tube.

![Figure 2: Schematic of thruster and feeding system](image)

The valve is normally closed by an embossed membrane which is stacked and fixed inside the glass tube using a spring. A piezo-disc is attached to the boss of the membrane. The size of the piezo-disc actuator determines the diameter of the glass tube which is 13mm inner- and 16mm outer diameter. When actuated, the piezo-disc pushes against the rigid edge of the membrane and by pulling the boss upwards the valve is opened, as shown in Figure 3. The piezo-disc has a free deflection of 19µm or a blocking force of 2.4N at zero deflection when 180V is applied and makes it possible to open or close the valve within 1ms.

A disadvantage is the high voltage that is required to actuate the piezo-disc which is not standard present in a micro-satellite and so additional electronics are necessary.
The fabrication of the silicon wafer containing the valve seat is done by two successive reactive ion etching steps. In the first step the outlet of the valve and break grooves are etched almost through a 525µm thick wafer leaving 40µm silicon standing. During the second step the valve seat is shaped and the valve outlet is opened by etching the last 40µm of silicon. The glass disc, supporting the valve is made by powder blasting. The silicon disc underneath is manufactured by simply etching through the wafer with reactive ion etching.

Several other functional sub-systems can be integrated inside the tube by a simple technique. Powder blasted glass discs have a tapered sidewall. When two glass discs are bonded together a V-shape is obtained, as can be seen in Figure 5. A Viton O-ring fits around the bonded glass discs. In the inside of the glass tube a small groove can be made by the lathe. When the glass stack is pushed in the tube the O-ring gets stuck in the groove. In this way the particle filter and pressure sensor can be integrated in the feeding system. In this way one can imagine all kinds of modular systems stacked inside a glass tube, i.e. complex filtration systems or chemical reactors.

The mass flow of air through the valve is measured at 1bar differential pressure. During this measurement no force is exerted by the spring on the valve sealing. Figure 6 shows the results of a valve actuated with a block pulse of 150V with duration of 20sec and a 50% duty cycle. When the valve is opened (+150V) the mass flow is out of the range of the flow-meter, above 230sccm. The measured flow when the piezo-disc is relaxed (0V) is below 1sccm.
IV.2 LEAKAGE MEASUREMENTS

To measure the leakage of the valve a specially designed holder is made wherein the valve is sealed except for the valve outlet. For this measurement the spring is exerting a considerable force on the valve sealing to see what the minimum leakage is that can be achieved. The valve chamber is pressurized to 1 bar differential pressure through the valve outlet. After filling, the pressure is monitored while the valve is leaking. The result is shown in Figure 7.

An exponential decay is observed in the pressure and can be described by:

\[ p = p_0 e^{-\frac{t}{\tau}} \text{ [bar]} \]

Where \( p_0 \) is the initial pressure, \( t \) is the time and \( \tau \) is the decay time estimated to be 8500 minutes as indicated by the dashed line in Figure 7. The volume of the valve chamber \( (V) \) is approximated by 7 ml. The leakage is then given by:

\[ \phi = \frac{V \cdot p_0}{\tau} \text{ [sccm]} \]

The calculated leakage is \( 8 \cdot 10^{-4} \text{sccm} \) which is 5 times worse than specified.

V DISCUSSION AND CONCLUSION

The design of a feeding and thruster system is shown and a prototype valve is fabricated and measured. A leak-tight valve is of the highest priority as it is most crucial for a successful flight experiment. The first generation valve is successfully actuated but shows too high leak-rates in the closed state. By applying an external force on the valve sealing it is possible to obtain a leakage in the order of the required leak-rate. However, it became impossible to open the valve since the piezo-actuator generates insufficient force to counteract the external force generated by the spring. The low leakage is quite a strong requirement and not easily satisfied with MST. In conventional valves these low leakages are obtained by using a soft layer which is pressed against a hard valve seat with a very high force [7]. Dirt particles are pressed in the soft layer so they will not cause leakage. Due to incompatibility with the fabrication process we are not able to use soft layers. When two hard surfaces are used one needs even more force to crush the dirt particles in order to prevent leakage which further complicates fabrication. In a future valve design the problem of leak-tightness has to be addressed.

ACKNOWLEDGEMENT

This work is funded by MicroNed Programme under MISAT cluster within the workpackage of Payload System.

REFERENCES