Executive Summary Report

Reliability assessment of a MEMS-based isolation valve for propulsion systems

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NanoSpace is developing a one-time opening isolation valve, MEMS Isolation Valve (MIV), with the main function to ensure no leakage between two parts of a propulsion system until the propulsion system is activated. The target market is any satellite requiring isolation of any gaseous storage tank. Due to the simplicity of the device access to the device after system integration is not necessary. The MIV is operational in a wide pressure range.

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Executive Summary Report

Purpose & Application

The MIV is a one-time opening isolation valve with integrated filter. Its main function is to ensure no gaseous leakage between two parts of a propulsion system, until the propulsion system is activated.

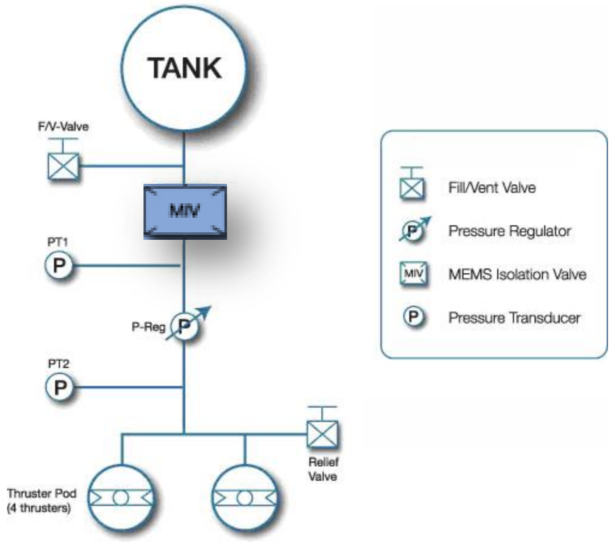
This solution could replace the heavier and large scale pyrotechnically actuated valves, in particular for applications where low mass flow is needed.

To reduce the weight → <75 g
To provide shock-free opening

Major Characteristics	
Flow rate	> 100 mg/s of Xe @ 190 bar
MEOP	1-190 BarA
Proof Pressure	465 BarA
Burst Pressure	950 BarA
Operating Temperatures	-20 to 50 °C
Voltage	28±4V
Current	<1 Amp
Power consumption	<20 W
Mass	<75 g
Technology Readiness	TRL-5
Design	All-welded Titanium design
Fluid Compatibility	Helium, Nitrogen, Xenon, Argon

Key features

- Low mass
- Robust
- Wide pressure range
- Shock-free opening
- Redundant actuation paths



Operation

The MIV is a simple, robust, and high pressure compatible micro isolation valve. The MIV is a normally-closed one-shot valve, sealed with a metallic seal providing a leak proof barrier. The valve is thus isolating the tank from the rest of the system until activation. The MIV could thus provide isolation during satellite integration (SmallGEO), or in flight functioning as a conventional isolation valve.

To open the valve an actuation voltage is applied. By preheating the valve electrically, the impact of the ambient temperature can be reduced significantly. The electro-thermal activation ensures a slow shock-free opening of the gas path. The MIV also includes a filter that that absorbs debris caused by the activation of the one shot valve. The filter structure also serves as a passive flow restrictor, reducing the shock wave downstream.

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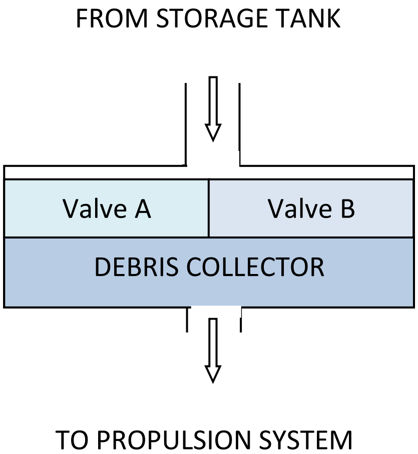
MEMS-based Isolation Valve

The functionality of the MIV can be divided into two separate functions in series; **seal valve** and **debris collecting region**. For redundancy there are two parallel and independently electrically connected seal valves, which imply two gas inlet holes, individually activated. The concept is novel and patented. The gas inlet hole is sealed with a metal alloy. Surrounding the inlet hole is a metallic heater element positioned. Each branch is actuated by energizing corresponding heater path pins on the electrical feedthrough by **applying a voltage across the individual resistive heater** of the MIV and melt the metal seal. The MIV is polar independent. The generated heat is localized around the metal seal. As the temperature increases the seal will melt. The gas pressure in the tank will force the melted metal into the chip, and the gas path is opened. The flow paths from the both valves are connected to the same debris collecting region. Schematically, the MIV is shown in the figure below.



System Design

The fully welded MEMS-based isolation valve module consists (as a minimum) of the following major components/subassemblies: a robust casing, electrical feedthrough, gas inlet and outlet, a MEMS valve chip (with two normally-closed valves,) and an integrated MEMS filter chip. Two variations of the filter were designed. One design targeted filtering all particles larger than 10µm, and the second design filtering all particles larger than 30µm. Although the separate parts or components, e.g. micro heaters, fulfil their individual requirements in terms of performance, life time, temperature etc., their mutual integration require specially developed manufacturing procedures and quality control steps. Also the interface between the micro- and the macro-world is a critical system level aspect. For example, the mechanical clamping of the brittle silicon chips needed special attention. Mechanical and electrical interfaces are major challenges that not only has to be solved, but also demonstrated in space several times before this of MEMS-product will be accepted by the space community. Environmental testing as vibration, shock, proof- and burst pressure as well as thermal vacuum are performed on fully welded components, whilst the performance testing is mainly on chips in clamped housings.

Fabrication and Testing

Fabrication

A set of valve chip and filter chip was manufactured using conventional MEMS fabrication techniques. The valve wafer was diced after heater element deposition, where after each sample is treated individually. To simplify handling each valve disk is individually numbered within the batch. The filter disks are not individually marked. In total 6 valve batches and 7 filter batches was started over the duration of the project.

In addition to the MEMS hardware chip housing was designed and manufactured. Two dismountable housings was manufactured for easier chip analysis post actuation. A total of 7 welded housings was manufacture over the duration of the project.

Figure 1 SEM picture a top view picture of a manufactured filter disk.

Validation testing

The objective with the chip validation activity is to **validate** that the MIV design conform to functional specification requirements. This is primarily done by testing. Earlier generations of the MIV indicated some flow variations depending on pressure applied during actuation. In the validation tests only the high pressure case is investigated.

However, there is a variation in actuation temperature. Therefore actuation at different temperatures is evaluated. The outcome from these tests is:

- **Post actuation flow rate vs. actuation temperature**
- **Actuation time vs. temperature**

To validate the chip it is important in the development to be able to visually inspect a sample after each test. Since a fully welded housing cannot easily be opened for MIV sample inspection the flow related chip tests are performed with the chips mounted in a clamped housing. This makes it possible to easily investigate the MIV chip after test.

MEMS-based Isolation Valve

Evaluation testing

The objective with the evaluation activity is to evaluate the **full capability** of the MIV, i.e. the functionality of the MIV outside the range defined by the requirements. This includes, for example, actuation at an extended **temperature range**, inlet **pressure range**, and **energy** required to open the valve. Also included are test to verify the **construction** reliability. In this work, the isolation capability of the valve is evaluated by **pressurizing the inlet** before actuation at various pressures, as well as for a period of time close to the real case of the time needed for filling the tank and launching. **Leak** and **valve degradation** are recorded. The other important property of the MIV is to evaluate any flow rate degradation compared to the pristine mass flow. This is evaluated by measuring the **flow post actuation.**

Experimental results

Engineering models has been built and tested. In addition several actuations were performed using clamped test housings, to verify performance on chip level.

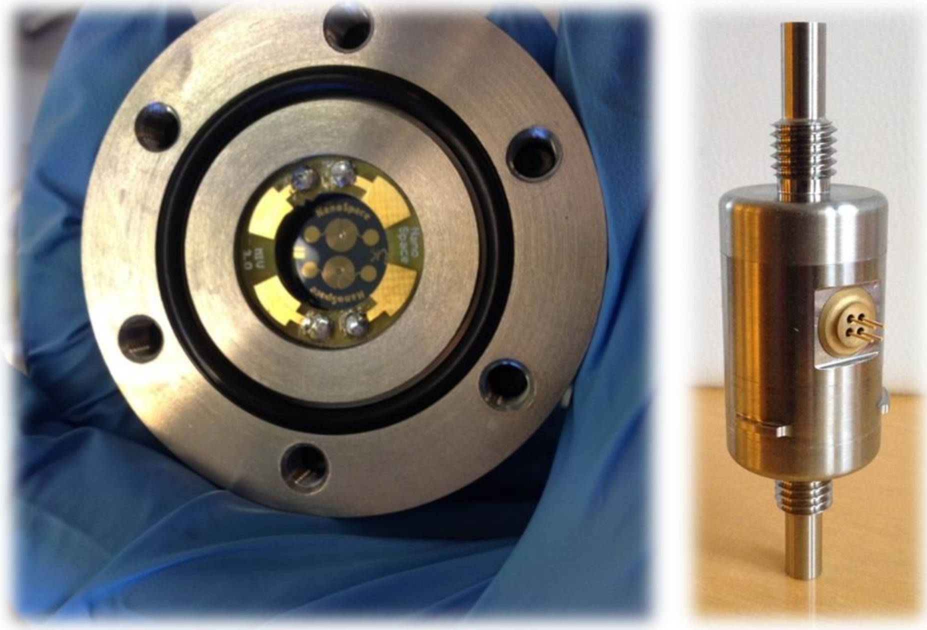


Figure 2. Chip mounted in test fixture (left) and fully welded housing (right).

This measurement gives the reference flow rate to which post actuation flow rate must be compared, since after actuation the inlets are partly blocked with seal remains, which restrict the flow. The measurements are only performed up to 7 barA feed pressure, due to technical limitations of the test equipment. Therefore a secondary task emerges; to evaluate the most restricting part of the MIV chip design. The main restriction has two apparent causes, either the inlet or the filter design. Valve chips from different batches as well as different filter designs were tested. Eleven pristine flow rates are visualized in Figure 3, showing the mass flow rate [mg/s, N_2, room temperature] as function of inlet pressure.

MEMS-based Isolation Valve

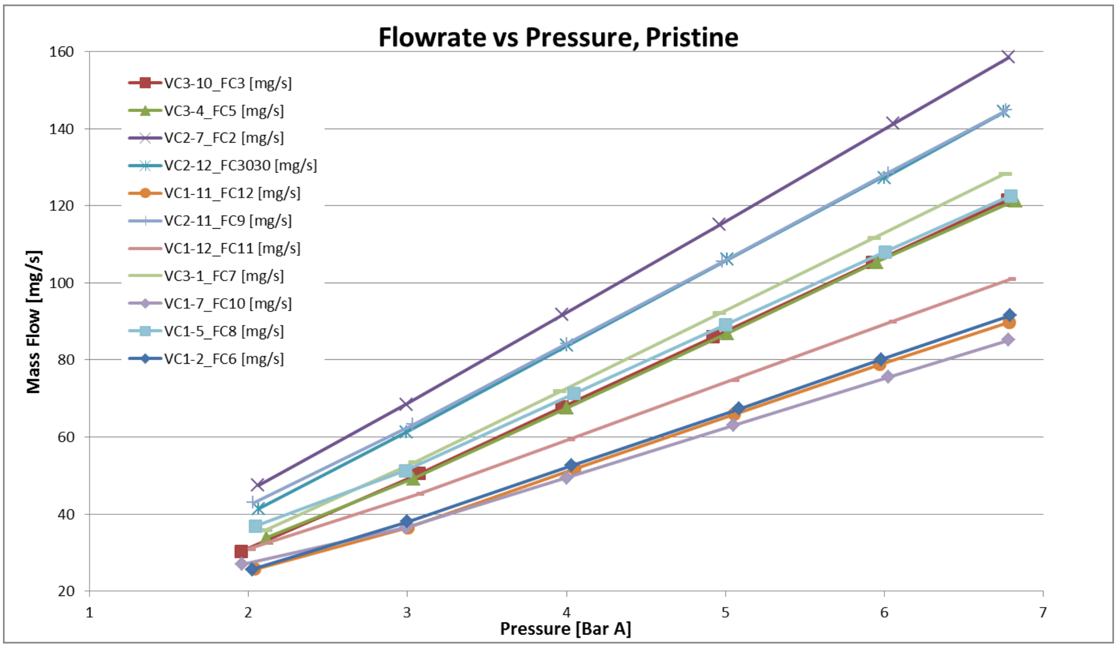


Figure 3. Results of pristine flow. Flow rate [G N2] as function of inlet pressure [BarA].

The variations between samples of the same batch are caused from etch variations over the surface, whilst the variation between batches are caused by varying under/over etch and other MEMS fabrication variations. The main restrictor to the flow rate is concluded to be the inlet holes. The flow rates at these low pressures clearly indicate that the design will meet flow rate requirements as pressure is increased.

During validation testing the actuation tests of the MIV are only partly successful. It is shown that the actuation proceeds as expected at room temperature or at elevated temperatures. Under those circumstances the MIV opens within 10 seconds, despite slightly too low applied power (too high heater resistance). During evaluation testing this is solved by preheating the valve electrically. Thus the impact of the ambient temperature and the applied pressure can be reduced drastically. It is also clearly seen that the flow rate after actuation without preheating is reduced compared to when preheating is applied. The remaining flow is roughly 1/5 of the pristine flow, rather than more than half as can be expected with preheating. The reason for the strongly varying flow rate between samples is the amount remaining solder in the opened inlet channel, which originates from the amount and quality of solder applied, as well as the heat transferred into melting the solder and to the debris collecting region. Figure 3 show the results from actuation at 1 Bar G, with 3 W preheat and 10 W actuation power, which gives an opening time of <1 second.

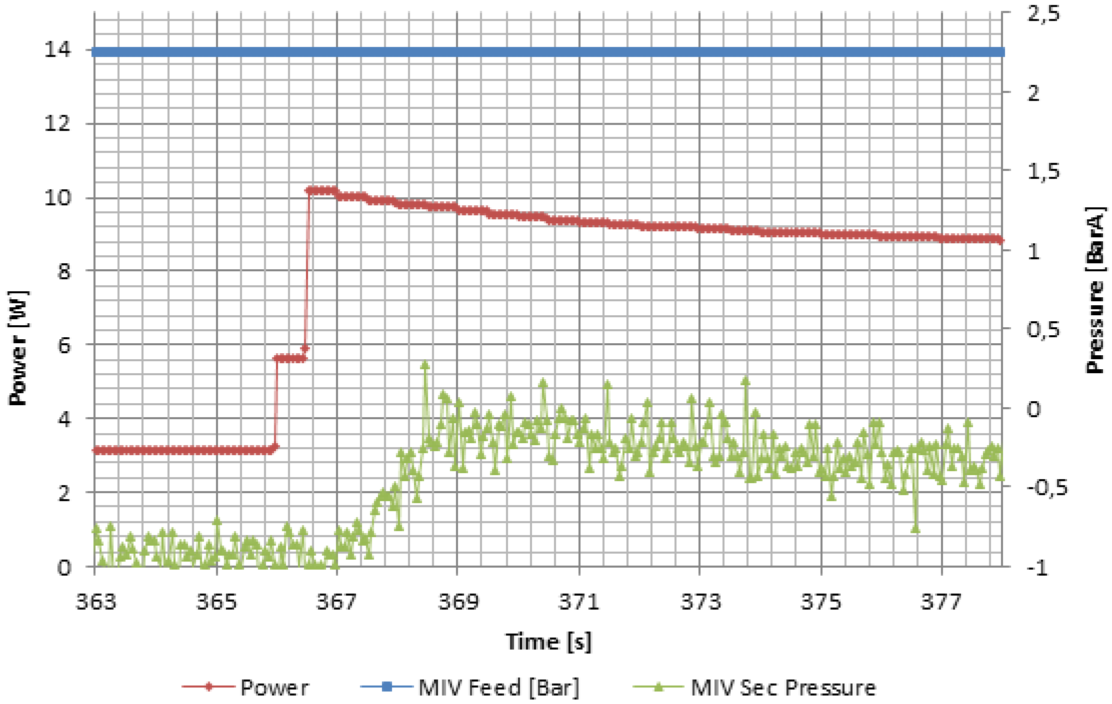


Figure 4. 1 BarG actuation

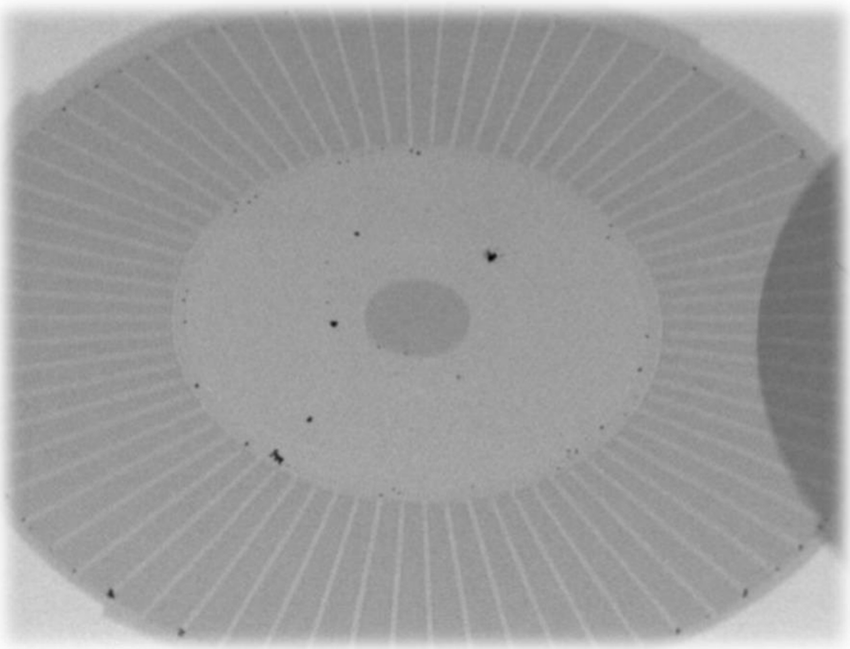


Figure 5. X-ray picture of the distributed solder after actuation (black regions)

As seen in Figure 5, both inlets are fully open. The solder is distributed in the filter as re-solidified spheres away in the vicinity of the inlets, but not beneath. The X-ray inspection clearly reveals the overcapacity of the filter.

MEMS-based Isolation Valve

Concludig remarks

NanoSpace is one of very few European companies devoted to development of MEMS products for space applications and has flown a number of new MEMS components in space, for the first time on the Prisma mission 2010. The presented MEMS isolation valve is an example of how size and mass can be decreased and still allows redundancy and fulfil the requirements of the device. The first Prisma cold gas micro-propulsion system was not designed with a pico- or nanosatellite application in mind and hence no optimization of power consumption or low pressures for the valves was made. These two challenges remained to be resolved before the developed module fully meets the requirements of a nano satellite mission, e.g. a CubeSat mission.

NanoSpace is developing a one-time opening isolation valve, MEMS Isolation Valve (MIV), with the main function to ensure no leakage between two parts of a gaseous system, e.g propulsion systems, until the system is activated. The target market is any satellite requiring isolation of any gaseous storage tank. Due to the simplicity (no pyro-techniques) of the device access to the device after system integration is not necessary. The MIV is operational in a wide pressure range. The level of opening of the valve is independent of the pressure in the range 1-190 BarG applied pressure.

The promising result of low pressure actuations achieved during the evaluation tests is one important stepping stone. In addition, the results on the energy needed to achieve a successful actuation are important for an updated design for low power applicationsInspection of the filter chips after actuation reveals immense overcapacity of the filters. Both the housing and the chip sustain high pressures. Due to the actuation procedure preheating step, the chip reaches an estimated temperature of > 100 °C before the actuation, which reduces the ambient temperature influence on the opening procedure. For low to medium pressure applications the present MEMS isolation valve has potential of being a competitive isolation valve, especially for electric propulsion systems. The small size and the simplicity of the MIV make it suitable for isolation in nano satellites and for separation, during assembly, in SmallGEO applications.

Bottom line:

NanoSpace MIV is a low mass MEMS Isolation Valve operating in a wide pressure range!

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