

# Status of the Miniaturized Flow Control "μFCU"

*Presented at Joint Conference of 30th International Symposium on Space Technology and Science  
34th International Electric Propulsion Conference and 6th Nano-satellite Symposium,  
Hyogo-Kobe, Japan  
July 4 – 10, 2015*

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**Abstract:** Flow control units are key components of electric propulsion systems. AST Advanced Space Technologies GmbH developed a miniaturized flow control unit in a program funded by the European Commission between 2011 and 2013. This flow control unit called "μFCU" has been pre-qualified on unit level (TRL5+). The first μFCU has been developed for small thrusters. It delivers 1-8 sccm xenon at an inlet pressure of 2.2 bar. By variation of the internal flow channel geometry the μFCU can be optimized for a required flow range. Two subtypes, one for micropropulsion with a full scale flow of 1.0 sccm at 1 bar and one for larger thrusters with 100 sccm at 2.2 bar, are under development. It has been demonstrated that the range can also be adjusted by the inlet pressure. The first μFCU design has been used for tests ranging from 1.9 sccm at 0.8 bar to 45 sccm at 6.5 bar. In 2014 coupling tests with electric propulsion systems started to evaluate system integration aspects and to demonstrate the readiness of μFCU. First integration tests with a large radio frequency ion thruster RIT-22 of Airbus DS GmbH were very successful. Tests with a RIT-μX thruster for micropropulsion are in preparation within an ESA project.

## I. Introduction

AST Advanced Space Technologies GmbH (AST) and her partner network started the development of a miniaturized flow control unit (μFCU) in 2012. The development activities have been funded by the European Commission within the 7<sup>th</sup> Framework Program. The project ended 2013 with a pre-qualification<sup>1,2</sup>. During pre-qualification the μFCU device performed the relevant environmental test of a potential qualification program to demonstrate the design maturity. The underlying generic unit specification had been derived from different mission scenarios defined together with potential customers. The μFCU allows an adjustment of the full scale flow range by changing the inlet pressure. By this feature the same device can be used for different types of thrusters with different flow requirements without design changes. Since 2014 this has been used by AST to perform coupling tests with large ion thrusters as well as with thrusters for micropropulsion with the same μFCU (EQM3).

In addition to the inlet pressure adaption the flow of a μFCU can easily be adjusted by changing the flow resistors inside the unit. A design and manufacturing of a flow control for micropropulsion with a maximum full scale flow of about 1 sccm xenon has been started in 2014 within an ESA project in the scope of Euclid mission. In parallel a μFCU for high flows up to 100 sccm is manufactured in an in-house development to improve the knowledge on scaling effects and to provide a test unit to interested customers.

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## II. General Design

The  $\mu$ FCU is part of an electric propulsion system. It acts as a gas flow regulator for the propellant to the thruster. The  $\mu$ FCU is connected to the gas feeding system with regulated pressure. It has two outputs for regulated flows that can be individually controlled. One outlet is for high flows, the second for low flows. A typical application is to use one line for the thruster and the second for the neutralizer.

The baseplate structure of the  $\mu$ FCU called "flow path board" contains microchannels. From the top side active and passive components are placed. In one row three valves are welded into the board. Below the valves a row of three tube stubs provides a mechanical interface to the flow lines (Figure 1). Below the tube stubs round particle filter elements are implemented. On the bottom side of the  $\mu$ FCU the access holes to the valves are closed by end caps. Markings to identify the  $\mu$ FCU and information about the line configuration are engraved on the top side. Four mounting holes at the corners of the unit allow a mechanical fixture.

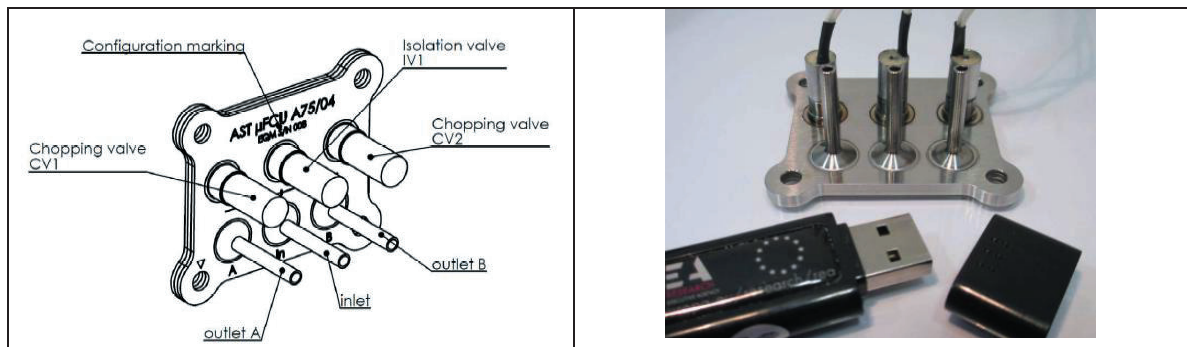


Figure 1. The miniaturized flow control unit " $\mu$ FCU".

| $\mu$ FCU EQM3             |                   |                                                 |                                                                   |
|----------------------------|-------------------|-------------------------------------------------|-------------------------------------------------------------------|
| <b>Mass</b>                | 63 g              | <b>Particle filter</b>                          | 5 $\mu$ m in inlet and outlet                                     |
| <b>Size</b>                | 46 mm x 54 mm     | <b>Operational life</b>                         | >50 000 hrs typ.                                                  |
| <b>Inlet pressure</b>      | 1.0 to 6.0 bar    | <b>Control Mode</b>                             | Open loop<br>Closed loop on thruster parameter e.g. anode current |
| <b>Full range flow</b>     | 10 sccm @ 2.3 bar | <b>Req. temperature stability for open loop</b> | +/- 5°C                                                           |
| <b>Op. temperature</b>     | -30°C to +80°C    | <b>Leakage</b>                                  | <10 <sup>-6</sup> scc/s GHe                                       |
| <b>Non-op. temperature</b> | -40°C to +100°C   | <b>Particle filter</b>                          | 5 $\mu$ m in inlet and outlet                                     |
| <b>Operational Voltage</b> | 24 V              | <b>Operational life</b>                         | >50 000 hrs typ.                                                  |
| <b>Average power</b>       | < 2.5W            |                                                 |                                                                   |

The flow schematic is shown in figure 2. A common inlet line is protected by a 5 $\mu$ m particle filter in front of an isolation valve that shuts-down the flow to the  $\mu$ FCU. Behind the isolation valve the flow splits into the individual control lines. Each line has a set of flow restrictors, a chopping valve, and a (nonlinear) fluidic low pass filter. All valves are driven with 24V in pull-in/hold operation. The chopping valves generate a pulsed gas flow. The average flow can be adjusted by the pulse width and the frequency of the pulses. The fluidic low pass filter smooths the pulses to a steady flow without ripple. The cut-off frequency can be adjusted to the optimum flow range. An example of the filter frequency response is given in figure 3 for nitrogen. With xenon the ripple is further reduced. The typical chopping frequency of a  $\mu$ FCU is between 1Hz and 3 Hz.

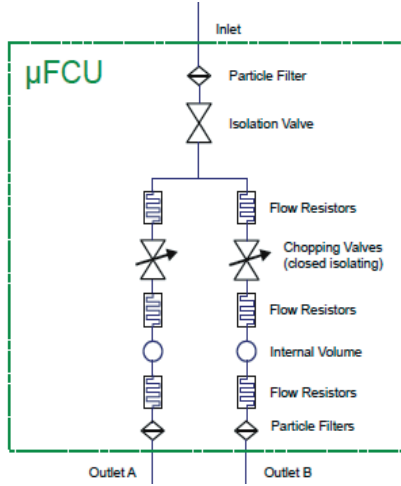


Figure 2. Flow schematics.

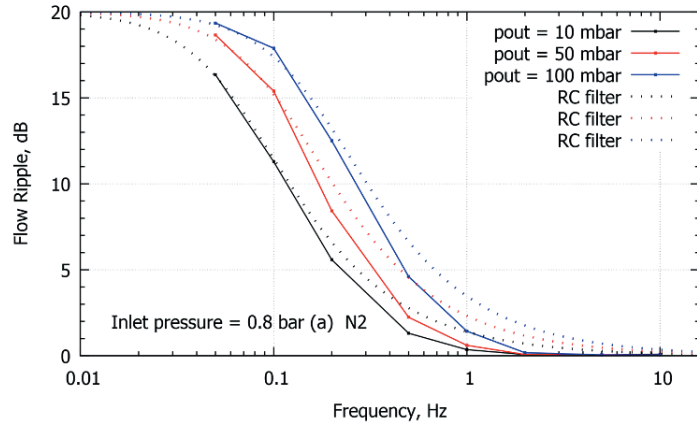


Figure 3. Bode diagram of the filter characteristic of EQM 3 (measured with Nitrogen) compared to RC filter characteristic.

In the scope of ESA's Euclid project a  $\mu$ FCU with filters at reduced cut-off frequencies has been developed for a chopping frequency of 0.33 Hz. Such small frequencies are required to enlarge the control range to very small flow rates below 0.2 sccm.

The  $\mu$ FCU is designed for pressures from 1 bar(abs) up to 6 bar(abs) but has been tested from 0.8 bar(abs) to 9 bar(abs). With the adjustment of the inlet pressure the flow range can be changed linearly. This has been used for several coupling tests with  $\mu$ FCU EQM3.

### III. Coupling Tests

#### A. Model "EQM 3"

EQM 3 is the "working horse" of our flow control unit development. The originally design was for xenon flows of about 8 to 10 sccm full scale. It has been tested for an extended flow range from 0.05 to above 60 sccm by adjusting the inlet pressure as shown in figure 4. It was also used for coupling tests with gridded ion thrusters.

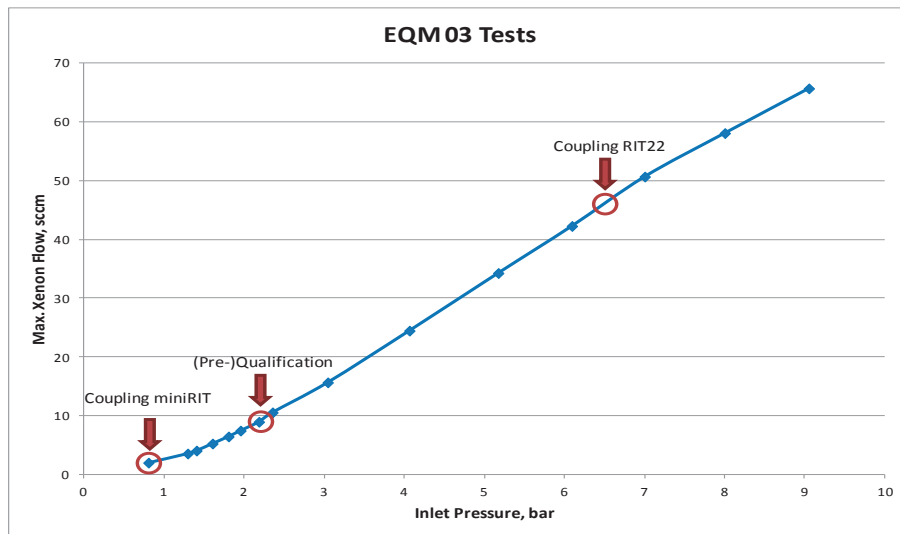
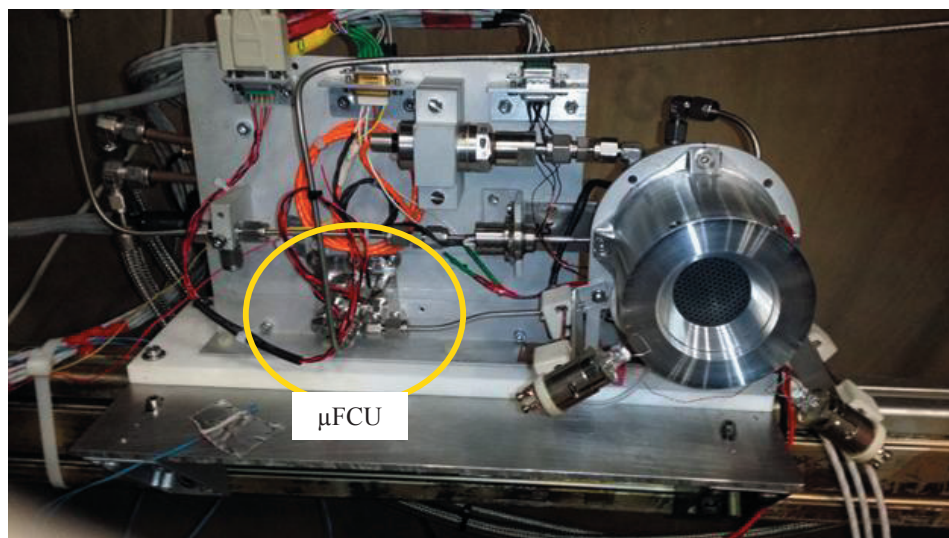


Figure 4. Full scale flow ranges of EQM3 adjusted by inlet pressure

The coupling tests with RIT ion thrusters have been performed within two test campaigns. The first test together with a RIT-22 took place at Giessen University in September 2014. The flow control was installed outside the vacuum chamber in parallel to the normally used commercial flow controller. It was controlled by AST's unit tester equipment. After parameterization of the thruster the gas supply was switched to the  $\mu$ FCU. Then the RIT-22 was operated at all relevant working points again to identify potential differences. It turned out that the  $\mu$ FCU fitted very well to the thruster. The thruster could be started and operated. The operation was nominal and no ripple or other effects have been detected. During the test the  $\mu$ FCU has been operated in open-loop as well as in a closed loop. In the latter a special control algorithm using a parameter derived from the RIT RFG power has been tested.

The second test campaign also performed at Giessen University investigated the compatibility with a RIT- $\mu$ X thruster. The flow range of the  $\mu$ FCU EQM 3 had been set to 1.7 sccm full range by reducing the inlet pressure to 0.8 bar. At such small flow rates the flow step response of a system is dominated by the length of the flow line between FCU and thruster. As consequence the  $\mu$ FCU was placed inside the vacuum chamber close to the thruster. The line length was about 20 cm. The set-up is shown in figure 5.



**Figure 5. RIT- $\mu$ X propulsion system inside the vacuum chamber.**

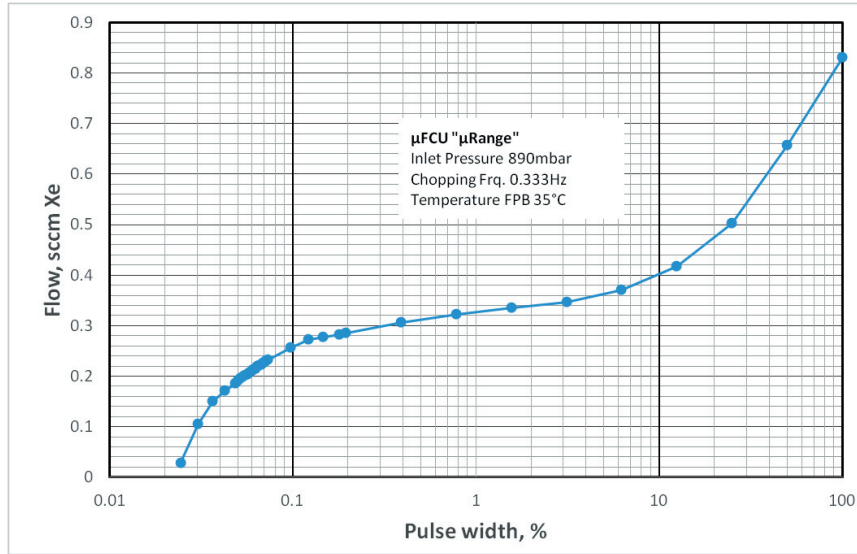
It has been demonstrated that it was able to drive the thruster for its full operational range but at the lowest limit of the throttle capability of the  $\mu$ FCU EQM 3 at about 0.4 sccm. A further reduction of the flow was possible by lowering the chopping frequency but this showed an increase in the flow ripple.

### **B. Model " $\mu$ Range"**

It is expected that the development of the RIT- $\mu$ X for micropropulsion, e.g. as candidate for ESA's Euclid mission, requires even lower flows down to 0.05 sccm. Therefore an optimized  $\mu$ FCU with different low pass filter layout is required. This new concept is internally referred to as " $\mu$ Range". It is developed in a contract with ESA to provide a  $\mu$ FCU capable to drive a thruster capable to fulfill the requirements of Euclid or NGGM.

The new  $\mu$ FCU has been design and manufactured and is currently (may 2015) performing thermal vacuum tests in the frame of the acceptance tests. After the acceptance tests the unit will be delivered to ESTEC and will be integrated into a RIT- $\mu$ X system for test.

The first results from factory tests show that the cut-off frequency of the fluidic filter has been significantly reduced. For operation at 0.3 Hz a flow ripple did not show up. The flow response to a changed pulse width at fixed frequency is shown in figure 6.



**Figure 6. Flow response to pulse width modulation at fixed frequency of 0.33 Hz.**

#### IV. Conclusion

AST's miniaturized flow control unit "μFCU" has grown mature in the past years. First coupling tests demonstrated that the unit can easily be integrated into existing propulsion systems without major changes. The full scale flow range can be adjusted by the inlet pressure. This reduces the number of individual designs to cover the different types of electric propulsion systems.

A μFCU dedicated for micropropulsion systems has been manufactured and will be tested at ESTEC.

#### Acknowledgments

The first development project "μFCU" was funded by the European Commission within the 7<sup>th</sup> framework program.

The development of a μFCU for micropropulsion thrusters is carried out in the scope of European Space Agency's Euclid mission.

We would like to thank our project and development partners especially Airbus DS for the possibility to perform the coupling tests with the RIT system.

#### References

- <sup>1</sup>Harmann, H.-P. et. al.: *μFCU - A Miniaturized Flow Control unit for Xenon*, IEPC-2013-227, 33rd International Electric Propulsion Conference, Washington D.C., USA., Oct. 2013
- <sup>2</sup>Rothaus, S.. et. al.: *μFCU - Results of a Prequalification Test Campaign*, IEPC-2013-228, 33rd International Electric Propulsion Conference, Washington D.C., USA., Oct. 2013