

Development of a Miniaturized Pressure Regulation System "mPRS"

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Abstract: An electronic pressure regulator provides a flow independent outlet pressure and an in-flight adjustable set point. These advantages compared to a mechanical regulator are paid with increased mass, size and very often a large pressure ripple. AST Advanced Space Technologies GmbH develops a new miniaturized electronic pressure regulator (mPRS) to overcome these drawbacks. The project is funded by the European Commission via its FP7 program. The new technology is based on AST's fluidic surface mounted devices technology (fSMD) that has already been used for a miniaturized xenon flow control unit. The new pressure regulator shall provide an in-flight adjustable outlet pressure between 1 and 25 bar at an inlet pressure of up to 350 bar. During the first year of development the major processes like high pressure proof electron beam welding have been developed and verified. The feasibility has been demonstrated for an elegant bread board model (EBB). The test was conducted with lab equipment but also in a full functional line including the mPRS, a flow control unit and an ion thruster (RIT-22 and μ N-RIT) .

I. Introduction

AST Advanced Space Technologies GmbH and her partner network have been funded by the European Commission to develop high pressure fluid components for space applications of European origin. The components shall be derived from existing technology bases. A special challenge in component development is the design of interfaces to other components and devices. Therefore the viability of the component design shall be demonstrated for a miniaturized electronic pressure regulator system "mPRS".

A. Target Missions

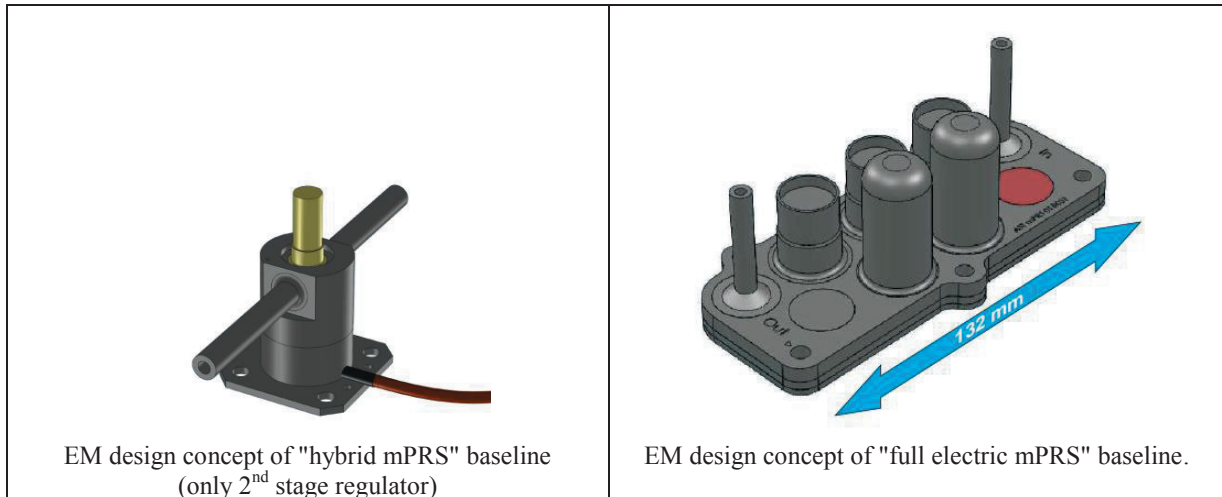
The target mission for the mPRS can be split into two categories. For chemical propulsion systems a high flow system with gas flows of up to 25000 sccm at an outlet pressure of 20 to 30 bar will be required. The media is Helium at a tank pressure of up to 350 bar.

The second scenario is a xenon fed electric propulsion system. This requires a tank pressure of 180 bar and an adjustable outlet pressure between 0.1 and 3 bar. The typical gas flow would be in the range from 1 sccm full scale for micropropulsion up to 200 sccm for high power thrusters. The upcoming full electric satellites furthermore ask for a much higher flow of 1000 sccm to 2000 sccm to supply Xenon cold gas thrusters from the same low pressure node.

B. General Design

The mPRS uses a two stage design. A first stage reduces the tank pressure to a roughly controlled intermediate pressure. The second stage performs a fine control to the adjustable output pressure level. The first stage task can either be fulfilled by state-of-the-art mechanical pressure regulator (hybrid baseline) or by an electronic reduction

stage similar to a bang/bang system (full electric baseline). Both baselines are evaluated within the project. The "hybrid mPRS" has already been set up as elegant bread board (EBB) model using a standard mechanical gas bottle pressure regulator as first stage. The second stage has been built with a low pressure valve that was available from a previous project. The full electric baseline has been designed and analyzed and will be built up as soon as the mPRS high pressure valves become available. It makes use of AST's fluid SMD technology that shall be adapted to high pressure applications.



C. Fluid SMD

The use of fluid SMD (fSMD) technology instead of discrete components connected by pipework can be compared to the transition from tube radios to modern electronics. In the early days of electronics components have been mounted on wooden baseplates. Interconnections had been made by thick wires soldered to the components. Later the printed circuit board has been invented. The PCB combines the baseplate function with the interconnection layer and allows a much higher component density at reduced cost. The next generation, the so-called surface mounted devices (SMD) technology, removed the wires from the components by integrating them into the package. The component is then directly onto solder pads on the PCB.

In fluid SMD the flow path board (FPB) occupies the role of the PCB. It is a multilayer stack of plates with integrated flow channels. The stack is welded by a hot pressing diffusion bonding process forming a solid and vacuum tight piece of metal with integrated channels. Like in the PCB the channels form a 3D-network. Components are directly placed and welded into holes on top of the FPB. The FPB and all of the components weld interfaces are made of stainless steel 316L. The basic diffusion bonding process for 316L has been developed during a former project developing a xenon flow control unit.

II. Project Overview

The project is divided into three phases. Each phase corresponds to one project year. The first year was dedicated to system engineering, design and development of assembly and manufacturing processes. The second year focuses on component development, viability demonstration of the baseline concepts and preparation of test facilities. The third and last year will be used to perform a pre-qualification for one of the two baselines. The decision will be taken end of 2015.

The major objectives of the project are

- Provide miniaturized high pressure valves of European origin
- Provide a high pressure flow path board of European origin
- Provide miniaturized high pressure sensors of European origin
- Provide an advanced miniaturized pressure reduction system of European origin
- Reduce the internal leakage of flow components to less than 10^{-6} scc/s GHe
- Proof the feasibility of subsystems made of fluidic surface mounted devices for high pressure applications
- Reach TRL5+ for the mPRS unit

D. Assembly Processes

Assembly processes and related quality assurance processes are key to the success of a high pressure system development. Right from the start of the project the development of the basic processes has been initiated. One is the diffusion bonding process of the flow path board (FPB), the second is the joining technology between components and FPB. Later is done by electron beam welding. For both processes a partner with special expertise contributes to the project.

Process parameters were highly optimized by a large number of tests in order to fabricate create vacuum tight and pressure proof joints. Both processes, the EB welding and the diffusion bonding, have been successfully used to assembly representative test samples for burst pressures exceeding 2000 bar. In micro section analysis of samples tested for high pressure no fractures or weaknesses in the crystallographic structure could be found (figure 1).

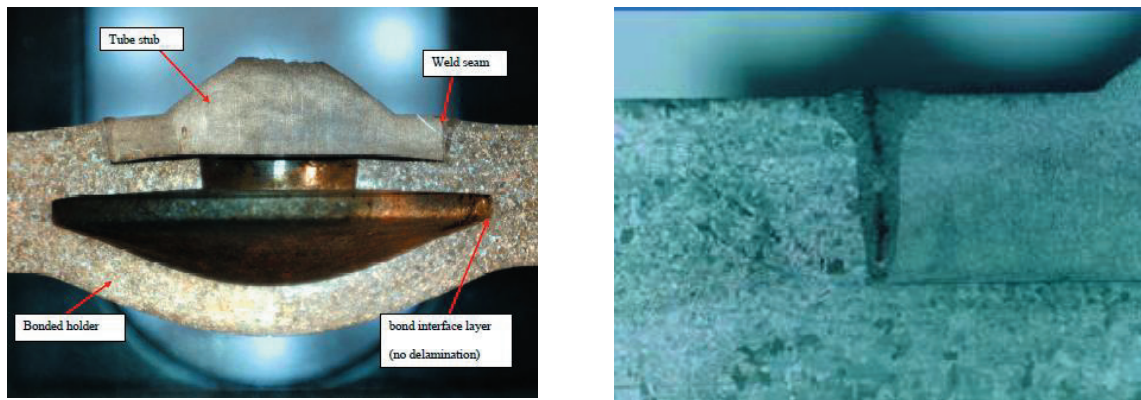


Figure 1. Test sample assembly of a bonded FPB and a tube stub welded with electron beam. This sample had been tested at 1200 bar. The pressure buckled the flat bottom structure without generation of cracks.

E. Component Status

The mPRS consists of several passive and active components:

- a. Flow path board (FPB)
- b. Particle filters
- c. Tube stubs
- d. Pressure sensors (low pressure and high pressure)
- e. Valves
- f. Electronics

a. Flow path board

The feasibility of the flow path board has been demonstrated. The bonding process and the related process parameter have been optimized. A large scale part has been manufactured to demonstrate that the required board size can be manufactured. The technology is on BB level. A design for the first EM has been finished and will be manufactured mid of 2015.

b. Flow path board

Particle filters with a grade of 5 μm have been developed and manufactured. They have been tested for filtration grade and gas flow capability. Further test for maximum filter capacity are pending.

c. Tube stubs

Tubes stubs and other simple machined parts have been manufactured. Tests for applying the related joining processes have been carried out successfully.

d. Pressure sensors

First pressure sensors (BB) have been manufactured and provided to build up the mPRS BB model. Two types of sensors are available. One for low pressure up to 50 bar and a second for pressures of up to 400 bar. Both have a stainless steel membrane to transmit the force to a sensing element that measures the absolute pressure. Such absolute sensor may have difficulties in long term drift if used with Helium. Therefore the viability of a diffusion barrier is subject to current development activity.

Mid of 2015 the EM sensors have been produced and currently undergo factory acceptance tests. They will be delivered to AST in the second half of the year for the EM mPRS assembly.

e. Valves

One key component of the full electric pressure regulator baseline is a high pressure valve. The valve shall be small, fast and only have low power consumption. The number of lifetime actuations shall exceed the 100 million which has already been demonstrated for the low pressure version of the same type (tested up to one billion cycles). By mid of 2015 the design phase had been finished and the parts production was ongoing. Until Q4/2015 the first high pressure valves are expected to be delivered to AST for building up the EM mPRS.

f. Electronics

Electronics at BB level were designed and manufactured in 2014. At the end of the year it has been successfully powered up and will be ready for system integration after factory acceptance tests mid 2015.

F. System Development (EBB)

In the first project year an elegant bread board model of the 2nd stage regulator has been manufactured to verify the viability of the overall operational concept. A simple gas bottle pressure regulator has been used as 1st stage regulator. The intermediate pressure was set to 8 bar, the maximum for the used low pressure valves. The adjustable outlet pressure ranges from 0.8 bar to 7.5 bar. The control algorithm was implemented in a unit tester built by AST. The special algorithm ensures a fast response without overshoots. Although the valve is a simple on/off solenoid type, the regulation is very precise, stable and shows merely no ripple (± 5 mbar, equivalent to less than 0.1% full scale).

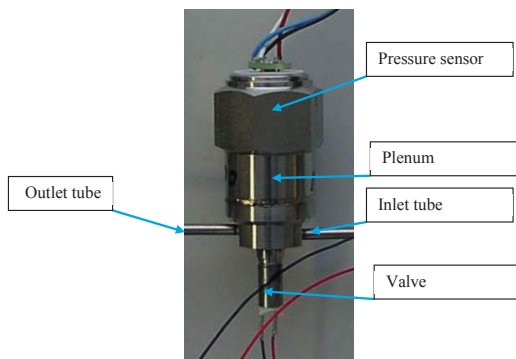


Figure 2. EBB model of 2nd stage regulator.

The performance of the EBB was investigated using commercial pressure sensors and mass flow meters. The flow has been adjusted either by a mechanical needle valve or using AST's xenon flow control unit. The EBB performed very well and extremely stable. It is meanwhile used as standard equipment within AST's lab for all precision measurement set-ups (e.g. tests on μ FCU for micropropulsion). Therefore data on the performance of the EBB within a relevant operational system environment are gained as side benefit.

Figure 3 shows the control stability in an application to supply a μ FCU. The media is xenon and the constant flow is 0.3 sccm. The pressure is set to 0.885 bar. The EBB shows a very stable operation with a ripple of ± 5 mbar. In the test the flow request had been increased to 60 sccm without a change in the ripple amplitude. Only the control valve opened more frequent.

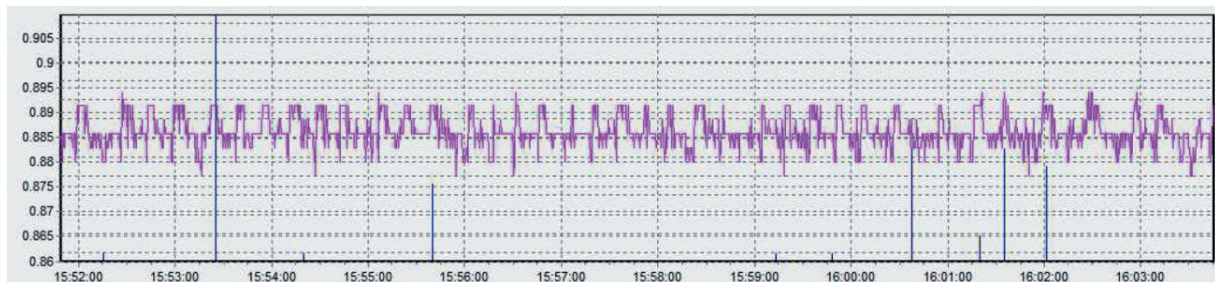


Figure 3. Pressure ripple at low flow of 0.3 sccm Xenon. (Pressure is given in bar.)

When the set point is changed, the pressure is adjusted very fast and without overshoot. Figure 4 and 5 show the step response for small steps and for large steps. The EBB has been tested with xenon and nitrogen gas. For nitrogen the step response is even faster than for xenon due to its lower gas viscosity.



Figure 4. Pressure step up from 2.0 bar to 2.8 bar in 200 mbar steps (xenon).

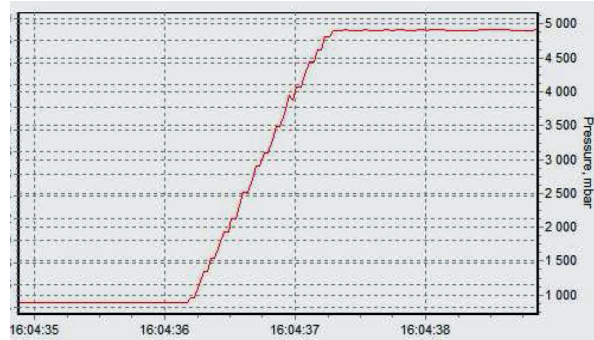


Figure 5. Large pressure step of 4 bar. Flow stepped up from 3 sccm to 20 sccm (xenon).

G. Coupling Tests with Ion Thrusters

The project took the opportunity to install the EBB mPRS 2nd stage regulator into the functional line of an electric propulsion system during ground tests. The purpose of the test was to demonstrate the operation of AST's flow control unit (EQM3) together with the ion thruster RIT-22 from Airbus DS¹⁾.

For this first coupling test the flow control system stayed outside the vacuum chamber. The setup is shown in figure 6. The EBB regulator is at the right side of the picture. With the regulator the inlet pressure of the μ FCU had been adjusted to the optimum value to cover the operational flow range of the RIT-22. During the campaign the electric propulsion system operated at xenon flows of up to 45 sccm.

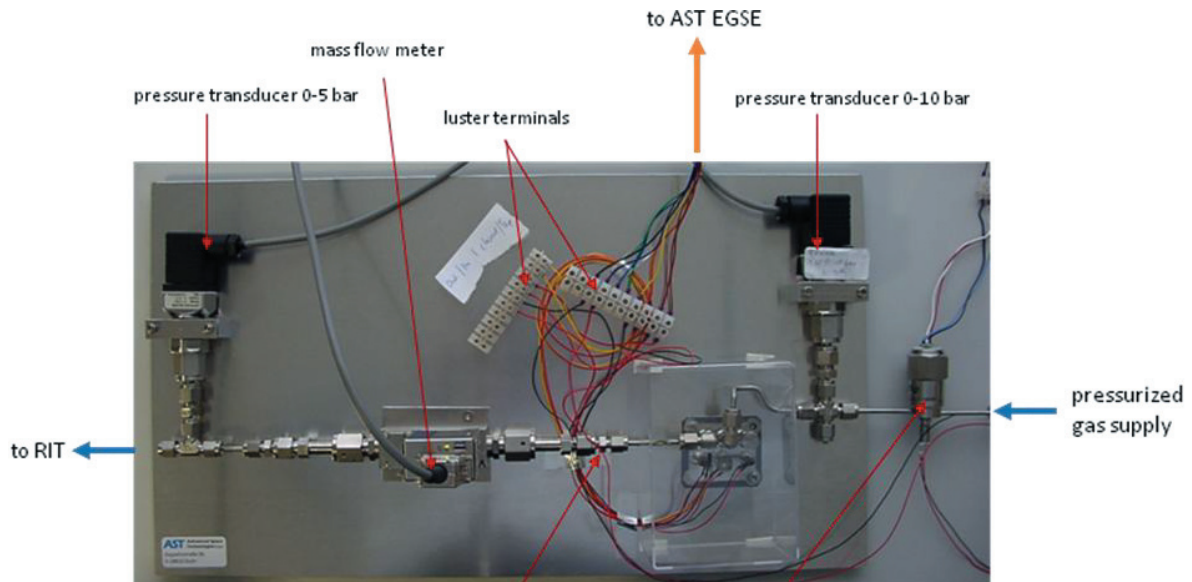


Figure 6. Test set-up for μ FCU / RIT-22 coupling test.

The same concept was used in a coupling test with a small RIT for micropropulsion applications. The μ FCU (EQM3) was now placed inside the vacuum chamber while the EBB regulator stayed outside. The μ FCU was

supplied with an inlet pressure between 0.8 and 1.5 bar to adjust to the optimum flow range of the thruster. The xenon flow during test ranged between 0.2 sccm and 1.5 sccm.

In both coupling tests the full functional flow line performed without flaw and fulfilled the operational requirements. Figure 7 gives an impression of the advantages of an electronic pressure regulator. The full scale flow capability of the μ FCU devices has been scaled by changing the inlet pressure by a factor of 30. If future system design make use of the mPRS together with the μ FCU this would enlarged the throttling capability to 1:150 and above.

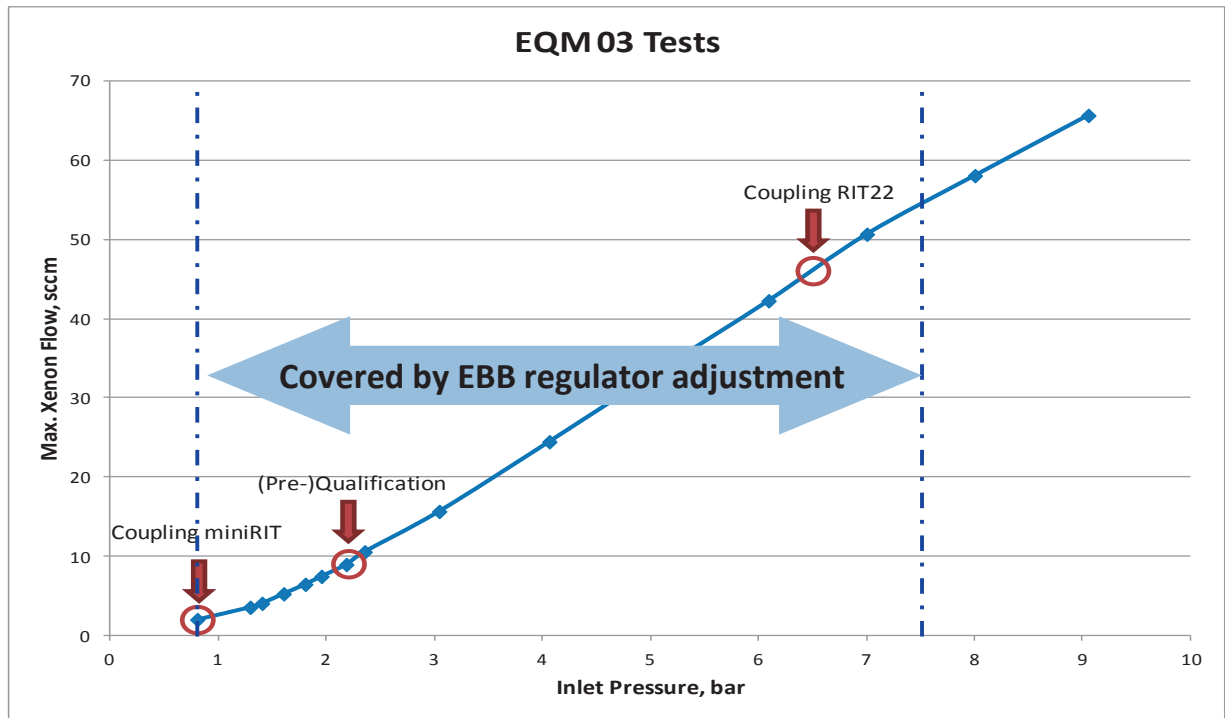


Figure 8. Scaling of μ FCU (EQM3) full scale flow by inlet pressure adjustment.

III. Outlook

At the end of 2015 all components shall have reached EM level. With those components available a full electric mPRS EM shall be manufactured and tested. In the last year of the project the mPRS will undergo all environmental tests required to demonstrate that the device is ready for a formal qualification program.

Acknowledgments

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References

¹Harmann, H.-P. et al., "Status of the Miniaturized Flow Control μ FCU", IEPC-2015-366, 34th International Electric Propulsion Conference, Kobe, Japan, July 2015