

# MICRO-PROPULSION AND POWER DEVELOPMENTS AT AIT

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**Abstract:** The increasing application of micro-satellites (from 10 kg up to 100 kg) as well as CubeSats for a rising number of various missions demands the development of miniaturized propulsion and power systems. Our department at the Austrian Institute of Technology is developing a number of micropropulsion technologies including both electric (FEED and  $\mu$ PPTs) and micro chemical thrusters (mono and bi-propellant) targeting high-performance at small scales. Also a micro turbine, a compact thermoacoustic Stirling engine as well as a novel hydrogen storage system based on microspheres is under development promising novel power conversion solutions at small scales.

**Keywords:** FEED, PPT, Chemical Propulsion, Micro Turbine, Stirling Engine

## INTRODUCTION

The Space Propulsion & Advanced Concepts department at the Austrian Institute of Technology has a long history in developing miniaturized Liquid-Metal-Ion-Sources (LMIS) for space applications dating back to the AUSTROMIR mission in 1991 [1]. A number of scientific instruments followed, including the application of the ion source for active spacecraft potential control of satellites (ASPOC) as well as for a secondary ion mass spectrometer. To date, more than 16,500 h were accumulated on various spacecraft.

Since the late 1990s, our department focused on space propulsion applications, using the space-proven LMIS designs for field-emission-electric-propulsion (FEED) thrusters enabling ultra-precise attitude and orbit control required for highly-demanding drag compensation. Over the last 5 years, our activities expanded in a number of other micropropulsion areas such as  $\mu$ PPT thrusters for CubeSats or chemical micropropulsion including the development of micro mono-propellant and bi-propellant thrusters using green propellants.

In recent years, the development of micro power converters (turbine and Stirling engine) as well as innovative gas storage solutions based on microspheres started to expand our activities towards novel micro power technologies. This paper will give an overview of our activities so far.

## MICROPROPULSION

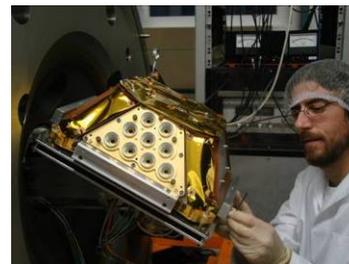
### Field-Emission-Electric-Propulsion

A Liquid-Metal-Ion-Source (LMIS) is the core element of a Field-Emission-Electric-Propulsion (FEED) thrusters. In order to provide an extremely accurate attitude and orbit control of satellites during

the entire duration of the mission, such thrusters need to provide a thrust level of several tens of  $\mu$ N up to 100  $\mu$ N for several years of continuous operation.

Our LMIS uses indium as propellant due to its high atomic mass, low ionization potential and good wetting properties. Moreover, it can be handled in atmosphere with no risk, which greatly simplifies testing and also relaxes complex sealing procedures prior to launch. Another significant advantage of indium propellant is the fact that the propellant is solid during launch due to its melting point at 156°C.

The ion source consists of a needle or capillary which is covered or filled with indium which is heated above the melting point (156.6 °C). Then a sufficiently high electric potential is applied between the emitter and an extractor electrode to emit ions and accelerate them. Typical emitter voltages range from 3.5–10 kV for currents of 1-150  $\mu$ A of a single LMIS. This corresponds to a thrust of 0.1-15  $\mu$ N. Depending on the total impulse that the thruster has to deliver, several different tank reservoirs were developed ranging from 0.22 g up to 30 g of indium capacity.



*Fig. 1: LISA PF In-FEED Thruster Installed at AIT.*

To achieve higher thrust it is necessary to either cluster individual LMIS or to use LMIS with multi-emission tips. Both approaches have been pursued.

The LMIS-clusters are presently at a higher TRL due to extensive development and testing especially during the GOCE and LISA PF programs.

AIT and Astrium are presently developing a FEEP thruster for ESA's LISA Pathfinder program [2]. This thruster shall provide a thrust level of 0.1 – 100  $\mu\text{N}$  with a cluster of 9 emitters (see Fig. 1). An extensive qualification program is currently underway to qualify the indium FEEP thruster technology. In an endurance test lasting over 3,650 hours a total impulse of 586 Ns was collected with a flight representative thrusters unit in combination with a flight-representative power supply provided by Galileo Avionica. The thruster has an exceptionally low rate of sparks and its noise was found to be well below the stringent noise requirements of LISA ( $<0.1 \mu\text{N}/\text{Sqrt}(\text{Hz})$ ). Based on the performance of the thruster during the 3,650 hours, the expected lifetime of the system was extrapolated to 39,000 hours generating a total impulse of 6,300 Ns at an average thrust of 50 $\mu\text{N}$ .

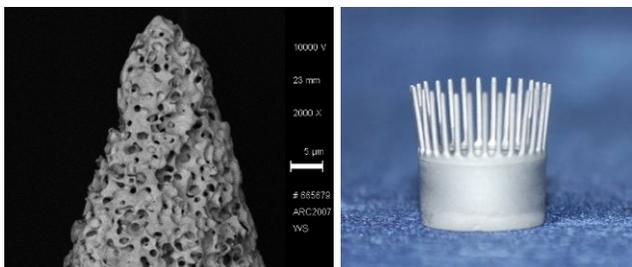


Fig. 2: Porous Tungsten FEEP Thruster, Porous Tip (Left) and Crown Multi-Tip Emitter (Right).

In order to further increase the number of emitters and to make the overall module more compact, a new type of high-current ion source was developed based on porous tungsten. There are two basic types of emitter geometries for LMIS: needle and capillary based emitters. The needle emitters have usually much larger electrical impedances compared to the capillary emitter which makes them suitable for clustering. However, capillary emitters are usually more stable and reliable – and they can be produced with very similar characteristics. We therefore decided to design a multi-tip emitter using porous tungsten needles in order to combine the advantage of high electrical impedance with excellent stability.

The emitter is manufactured using the Micro-Powder Injection Moulding technique ( $\mu\text{-PIM}$ ) from the AIT Powder Technology Center. A special feedstock is prepared using tungsten micro-powders and the needle structure is formed using dedicated moulding tools. After sintering, the porous emitter

structure can be etched similarly to the traditional solid tungsten needle emitters. Currently, 85% porosity and micron-sized pores can be achieved.

We designed a 28-tip crown emitter which can produce currents in the range of 3 mA (corresponding to 350  $\mu\text{N}$ ) as shown in Fig. 2. Our test data indicated an exceptional operational stability of the ion source and no measurable change in performance after more than 20 thermal cycles and exposure to oxygen. This behaviour is attributed to the excellent capillary properties of the porous needle itself.

### Micro-PPT Thrusters

CubeSats are usually passive satellites that do not have their own propulsion system for changing orbits (e.g. de-orbiting) or to do attitude and orbit control which limits their functionality.

We are presently developing a miniaturized Pulsed Plasma Thruster ( $\mu\text{PPT}$ ) with Teflon propellant, which aims at providing up to 4 thruster units and an integrated electronics package with a weight of  $<200 \text{ g}$  and a volume that can be integrated on CubeSats [2]. Our design benefits from recent activities that have identified a technique to achieve low circuit inductances, and therefore high peak currents and efficiency in a PPT circuitry. A prototype thruster with dimensions of only a few milli-meters under testing is shown in Fig. 3.



Fig. 3: Prototype  $\mu\text{PPT}$  Thruster During Testing.

### Green Propellant Chemical Micropropulsion

Green propellants such as hydrogen peroxide have recently gained much attention as they can significantly reduce costs and operational risks compared to traditional toxic and carcinogenic propellants such as hydrazine. This is especially important for small satellites which have smaller budgets available and some of them are even built and operated by university labs. AIT is leading the GRASP consortium [2] in the 7<sup>th</sup> EU framework program which is assessing, investigating and testing green propellant options in order to quantify the

benefits and to perform trade-offs with respect to classical propellants (<http://www.grasp-fp7.eu>).

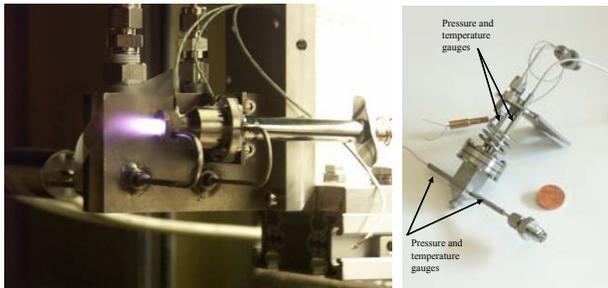


Fig. 4: Micro Bi- and MonoPropellant Thruster.

Our department is presently developing a micro bi-propellant engine using green propellants (87.5% concentration hydrogen peroxide and non-toxic propellants such as kerosene or ethanol) for the 1-3 N thrust range with a specific impulse of  $>320$  s [2]. This is of particular interest for smaller spacecraft that require short pulses. With the size of only a cubic-centimeter, a thermal power of about one kW can be generated which may also be of interest for the development of miniaturized high-density power cells as shown in Fig. 5.

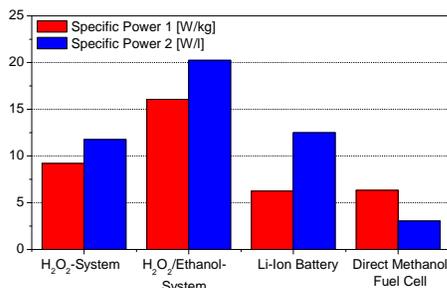


Fig. 5: Comparison of Energy Storage Solution.

The bipropellant thruster consists of three main components: the pressurized tank, a decomposition chamber (monolithic catalyst), and the thruster itself. While the fuel is fed directly into the combustion chamber, the hydrogen peroxide is lead over a catalyst bed in which it decomposes into steam and oxygen. A particular feature of our thrusters is that the propellants are fed into the chamber at such pressures that they react hypergolic which eliminates the need for an igniter.

Based on a similar philosophy as the bipropellant thruster the development of a monopropellant thruster was initiated with a thrust level of several hundred mN and a specific impulse of up to 180 s. Although a monopropellant thruster delivers less specific impulse than a bipropellant thruster it offers a lower system complexity.

## MICROPOWER-CONVERSION

### Micro-Turbine Energy Converter

One of the main drawbacks of transcritical CO<sub>2</sub> heat pumps is the lower COP (coefficient of performance) compared to conventional heat pump systems which originates from the non isothermal heat rejection in the gas cooler. This drawback can be compensated by utilizing the pressure difference between the high pressure and low pressure part of the heat pump for work recovery. This is feasible as the pressure difference is considerably larger in case of CO<sub>2</sub> heat pumps compared to conventional systems.

Such work recovery can be realized by substituting the expansion valve between the high and low pressure side by an expansion machine. Due to the low flow rate of the working fluid, the turbine type is based on the Pelton turbine with specific two phase flow turbine blades. In addition to the turbine part, miniature bearings and a small scale generator are important parts of the system. Thermodynamic simulations showed an absolute micro-turbine power yield between 60-150 W for a 2 kW heating system.

Our 3<sup>rd</sup> generation turbine demonstrated a continuous power output of 60 W at 45,000 rpm [3]. The system has a height of 200 mm and a diameter of 100 mm, whereas the turbine blade has a diameter of only 30 mm (see Fig. 6). The main component of the system, the turbine blade, and its performance has been evaluated by simulations. Investigating the influence of operational parameters such as the mass flow rate, system pressure and rotational speed, a significant improvement of the power output should be obtained targeting up to 100 W.

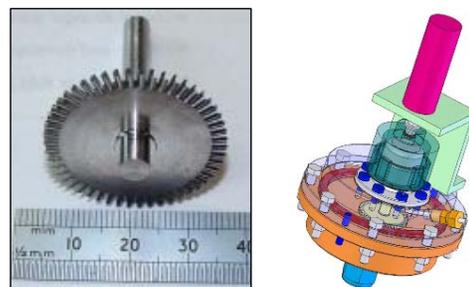


Fig. 6: Micro Turbine and Generator Schematic.

### Thermoacoustic Stirling Engine

Waste heat is a primary source of energy loss in many applications. Compact Stirling engines could be useful in areas such as heating, ventilation and air conditioning (HVAC), automotive and mobile sectors including auxiliary power supply, computer waste

heat- and power recovery devices as well as radio-isotope power generators for deep space probes.

A compact thermoacoustic Stirling engine with a theoretic power capability of 100 W and an efficiency of more than 10 % relative to Carnot's efficiency was developed at AIT [4]. Its length is 34 cm and it consists of only 7 parts. The thermoacoustic design replaces classical Pistons with sound waves making such kind of engine virtually maintenance free since there are no moving parts that can wear out, making it ideal for space or remote area environments.

The presented small-scale thermoacoustic prime mover has been shown to work with the working fluids helium, neon, nitrogen and argon and has demonstrated an acoustic power output of 20 W at a maximum efficiency of 8.6 % relative to Carnot. In order to achieve our compact dimensions and high power densities, the heat exchange stacks were manufactured out of a single piece using micro-EDM machining (see Fig. 7). Improvements in the surface roughness of the heat exchangers should increase our efficiency up to 15%. By adding longer resonators (traveling-wave design), such thermoacoustic Stirling engines can reach efficiencies of >35%.

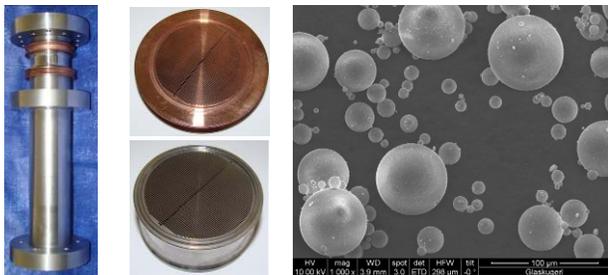


Fig. 7: Thermoacoustic Stirling Engine, EDM Parts and Hydrogen Storage in Microspheres.

### Hydrogen Storage in Microspheres

Hydrogen storage technologies are increasingly important for a number of future applications. We are presently developing an innovative hydrogen storage system that combines the advantages of both hollow glass microsphere and chemical compound hydrogen storage but cancels their respective drawbacks [4].

Water is used as a functional liquid to carry the hollow glass microspheres (5 – 200  $\mu\text{m}$  diameters, see Fig. 7) which are loaded with up to 700 bar of hydrogen gas. The sphere-wall is impermeable for hydrogen at ambient temperature; the heating of the spheres increases the diffusion of hydrogen through the wall. The next part consists of a chemical hydride e.g.  $\text{NaBH}_4$  which is injected together with the

microspheres into a reaction chamber. There the water reacts catalytically with the hydride producing hydrogen and heat. This heat is now used to release the hydrogen from the hollow microspheres providing a double hydrogen generation process without any external energy or heat during storage or gas release.

In order to concentrate the heat to the microspheres, the spheres are coated with a catalyst increasing the overall efficiency. An important aspect is that all end products in this process are recyclable. Analysis shows that such a system can reach hydrogen storage capacities of up to 10 wt% at ambient pressures and temperatures, which is considered a trigger in order to bring hydrogen solutions to automotive and other applications. Further applications for gas filled and coated microspheres were identified in the area of biogas upgrading, gas generation on satellites (helium filled microspheres), additives for cryogenic fuels, and radiation safety and will be analyzed in the future.

### CONCLUSION

A number of micro propulsion and power have been developed at AIT that can be used for space and for a number of spin-off applications.

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