MEMS BASED MICROPROPULSION – FLIGHT OPPORTUNITY IN 2008

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ABSTRACT

Development of a MEMS-based (Micro Electro Mechanical System) micropropulsion system has been pursued at Uppsala University, Sweden since 1997. From 2005 and on, the continued development towards the first flight opportunity in 2008 will be done within the frame of NanoSpace – a newly established company with the mission to provide MEMS-based products for the space segment. The first flight opportunity for NanoSpace micropropulsion system system is the PRISMA programme.

PRISMA is an international (Sweden, Germany, France, Denmark) technology demonstration program, led by Swedish Space Corporation, with focus on rendezvous and formation flying. Moreover, a number of novel technologies (e.g. RF metrology sensor for Darwin, autonomous formation flying based on GPS and vision based sensors, ADN-based "green propulsion") will be demonstrated in space for the first time. PRISMA is a two satellite LEO mission with a launch scheduled to late 2008. One of the satellites will act as a "target" while the other one will be a "chaser" that performs rendezvous and formation flying maneuvers. The current "chaser" design has the MEMS-based cold gas micropropulsion system developed by NanoSpace onboard. The system includes two or more microthruster pods each including four thrusters with micro- to milli-Newton thrust capability. Besides demonstrating low noise, low thrust, a major objective of micropropulsion flight demonstration is to verify critical system level aspects such as the interfaces from the micro- to the macro-world. Mechanical and electrical interfaces are a major challenge that has to be solved and demonstrated before MEMS-based products will be accepted in a wider market. Notably, the micropropulsion system on PRISMA is regarded as a flight experiment and hence not mission critical. The planned flight experiment will unambiguously demonstrate the performance and verify a number of these critical items, in preparation for future space missions.

The flight opportunity in 2008 represents a unique opportunity to demonstrate the MEMS-based micropropulsion system, and thus take a significant step to enable greater satellite functionality, while significantly reducing cost and weight.

INTRODUCTION

Propulsion systems with the capability to deliver accurate micro- to milli-Newton thrust levels has been identified as mission critical for many advanced space systems such as Darwin, Gaia, LISA and Microscope, to mention a few, currently under development. Different technologies are being pursued, and one of the promising concepts is based on Micro Electro Mechanical System (MEMS) technology. This technology has been developed in Uppsala Sweden since 1997.

The MEMS based cold gas micropropulsion system discussed in this paper is designed with the aim to the meet the highest requirements on low thrust, i.e. micro- to milli-Newton levels with low noise and proportional control capability. The subject micropropulsion system is not only suited for precision control of advanced space systems but also as primary propulsion for miniatyrised satellites where low mass, volume and power consumption are driving criterions.

Regardless whether the main objective is to reduce size and cost or to enable precision formation flying, the concept of MEMS-based micropropulsion needs to be demonstrated in space before this new technology will be accepted on a broader base. In this perspetive, the PRISMA programme represents a unique opportunity to perform a first flight demonstration of a MEMS based micropropulsion.system.

SYSTEM DESIGN

The MEMS based micropropulsion system is in principle similar to a conventional cold gas system – though with the functional difference that the thrust can be modulated proportionally in the sub milli-Newton range instead of through on/off modulation.

A generic micropropulsion subsystem is shown schematically in Fig. 1., and does typically consist of the following major components/subassemblies:

- A high pressure-type propellant tanks,
- two or more thruster pod subassemblies,
- a pressure regulator,
- a system filter,
- two pressure transducers,
- a pressurant fill/vent valve, and
- a pressure relief valve

The propulsion system does also consist of tubing to connect all components, mounting structure, heaters and thermostats, electrical connectors and wiring required for conducting power to the components and heaters as well as telemetry to the spacecraft.

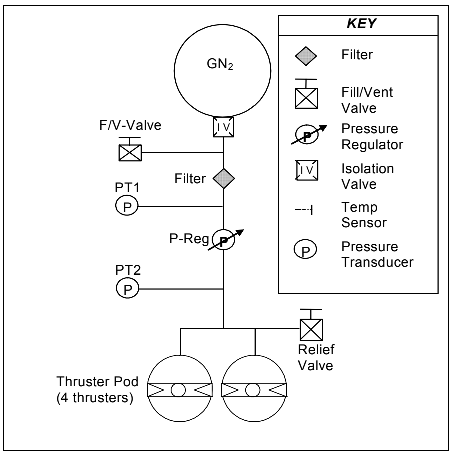

Fig. 1. Schematic system layout of a micropropulsion subsystem

MEMS-related Challenges

Although the separate components, e.g. micro-coils, fulfill their individual requirements in terms of, performance, life time, temperature etc the possibility to integrate them within the rest of the MEMS-based system is critical. Besides demonstrating low thrust, low noise capability, a major objective of a micropropulsion flight demonstration is to verify critical system level aspects such as the interfaces from the micro- to the macro-world. Mechanical and electrical interfaces are a major challenge that has to be solved and demonstrated before MEMS-based products will be accepted in a wider market.

THRUSTER POD

The thrusters pod which differs signicantly from a conventional cold gas thrusters does in this case contain four individual milli-Newton thrusters arranged in-plane and orthogonal to each other. The thrusters pod can even include electrical and mechanical filters, heaters, pressure- and temperature-sensors, control electronics and a CAN interface. This offers a significantly reduced size and mass compared to four conventional cold gas thrusters.

The thrusters pod is depicted in Fig. 2., which also gives the dimensions.

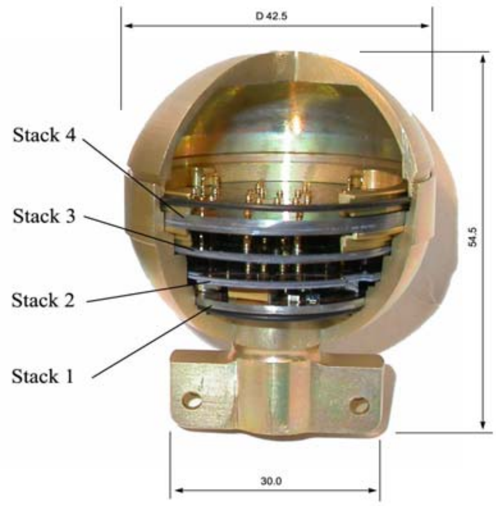

Fig. 2. Thruster pod containing MEMS-based micropropulsion wafer stacks.

A schematic view of the thrusters pod is given in Fig. 3.

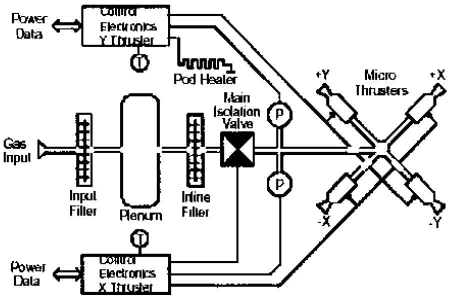

Fig. 3. Schematic view of a thruster pod with 4 millinewton MEMS thrusters

Design Requirements, Thruster Pod

The essential design requirements for a the thrusters pod is in summary the following:

- Propellant: N_2 (G)
- Maximum thrust: > 1 mN
- Minimum thrust: < 1 μN
- Specific Impulse:> 100 sec (heated N_2)
  > 50 sec (cold N_2)
- Thrust noise: < 0.1 $\mu N/Hz^{0.5}$
- Total Impulse: 10 kNs
- Design Life time: 8 years on orbit
- Power consumption: < 1W (per thruster)
- Mass 60 g

- Dimensions: 42.5 mm (dia), 54.5 mm (height)

Micro-Coil Heaters:

The major disadvantage of all cold gas propulsion systems namely the relatively low specific impulse, is overcome by internal heating of the gas. This is of significant importance when the system is miniaturised [1]. Micro-coil heaters, fabricated using laser chemical vapour deposition (LCVD), is a component which is possible to integrate in a thruster in silicon. The coil manufacturing process uses the high temperatures of a focused laser beam to dissociate molecules, resulting in the adsorbtion of free atoms onto the surface of a substrate. LCVD can be used to form 2- or 3-dimensional microstructures [2].

Micro-coils (Fig. 4.), made out of Diamond-like Carbon (DLC), have been manufactured and tested at elevated temperatures i.e. above 1200K.

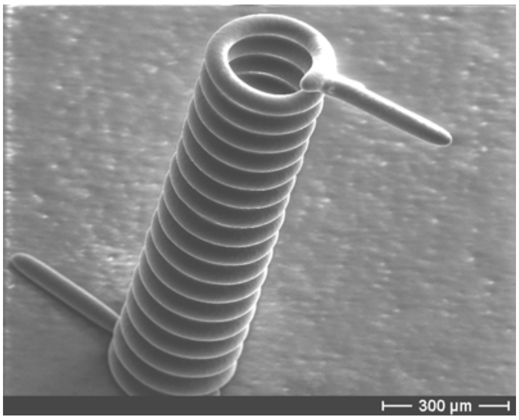

Fig. 4. SEM picture of a LCVD manufactured DLC coil.

Initial cycling and life- and cycle tests are presently ongoing.

PRISMA

PRISMA is a technology mission for demonstrating formation flying and rendezvous technologies, developed by Swedish Space Corporation [3]. The project is funded by the Swedish National Space Board, and supported by in-kind contributions from the German Aerospace Centre (DLR), Alcatel Alenia, Danish Technical University, ECAPS and NanoSpace.

The primary goals are to perform Guidance, Navigation and Control demonstrations and sensor technology experiments for a family of future missions where rendezvous and formation flying are a necessary prerequisite. The GNC demonstrations are: Autonomous Formation Flying, Homing and Rendezvous, Proximity Operations and Final Approach and Recede Operations.

The mission consists of two spacecraft, an advanced and highly manoeuvrable 140 kg satellite, and a simplified 40 kg spacecraft without manoeuvrability. Both shall be launched together on a Dnepr Launch vehicle as secondary payload into a sun-synchronous orbit at around 700 km altitude. The launch is scheduled for second half of 2008 and the mission lifetime is approximately 8 months.

Spacecraft Layout

The MAIN S/C layout is depicted in Fig. 5.

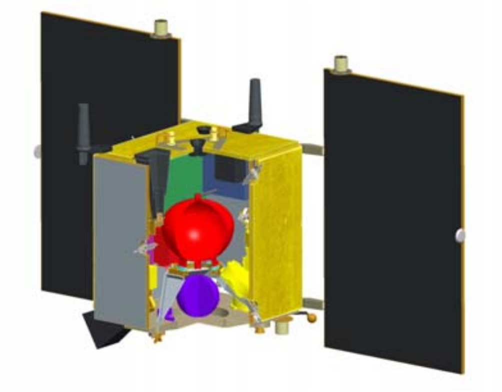

Fig. 5. An illustration of the MAIN S/C.

It is based on a box shape of approximately 700x700x1000 mm sides. The body has 2 deployable solar panels of in total 2 m^2.

The micropropulsion thruster pods are located on the bottom deck and are oriented such that the 4 thrusters on each of the 2 pods can be operated. The system is not primarily intended to give delta-V to the MAIN S/C, but the location does not rule out the possibility.

The TARGET S/C is a smaller box with one bodymounted solar panel of approximately 0.5 m^2.

Mission Design

The two spacecraft (shown in Fig. 6.) have fundamentally different roles in the mission. The TARGET has no orbit control capability but follows the trajectory in which it is injected. The MAIN has full translational capability, and will perform a series of manoeuvre experiments around the TARGET on both close and long range using the different sensors provided.

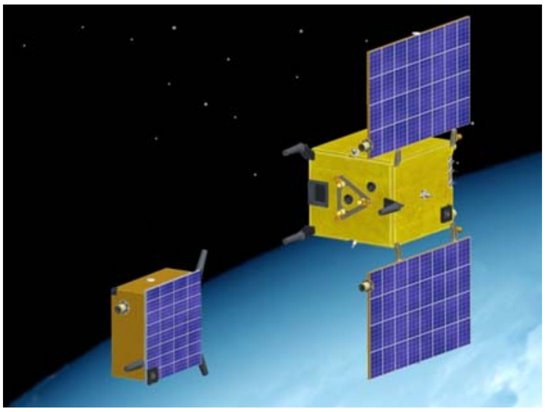

Fig. 6. A nominal flight configuration – the MAIN “looks at” the TARGET with its antennas and sensors

The backbone navigation sensor is based on GPS receivers on both satellites. The TARGET communicates its position to the MAIN via an intersatellite link, and the relative position and velocity can be calculated in real time with centimetre accuracy. The GPS system, giving even higher accuracy after on-ground post processing, will be used to verify different sensor systems performance, including the micropropulsion system.

After separation and start-up of the TARGET, the MAIN will start with an experiment series as given by the experiment schedule

Micropropulsion Flight Experiment

To flight-demonstrate the MEMS-based micropropulsion system on the PRISMA platform is planned. The inclusion of the micropropulsion system does not require any additional sensors or software functionality other than the micro-thrusters themselves and their command interface. The thrusters have to be mounted on a three-axis stabilised and reaction-wheel controlled spacecraft.

Four different methods to evaluate performance of the micropropulsion system:

- Reaction wheel response
- Attitude response
- RF metrology data in proximity operations
- Using GPS-data

The experiments will verify thrust levels in the range 10 micro-Newton to 1 milli-Newton.

One possible experiment is to demonstrate the effective impulse of the thrusters for different thrust levels by applying thrust commands to a spacecraft that is independently attitude-controlled by means of reaction wheels. In this way, the thruster impulse will constitute an external disturbance which is compensated for by the attitude control. As a result, there will be a change on the reaction wheel speed, or angular momentum. Distributing commands over e.g. a full orbit revolution will result in significant change in reaction wheel speed even for very low thrust levels (down to 50 micro-Newton).

Another possible in-flight experiment is to use the micropropulsion system for attitude control during a period of time when the satellites ordinary AOCS is switched off. It is even possible to halt the reaction wheels during this period in order to create an extremely silent environment in which low noise thrust can be verified.

A third possible experiment is to use the micropropulsion system during proximity operations where the satellite's relative position can be determined with millimetre precision using the RF metrology onboard.

A fourth possible experiment is to use data from the GPS system, which after on-ground post processing can determine the spacecraft position with centimetre accuracy.

CONCLUDING REMARKS

Whether the main objective is to reduce size and cost or to enable precision formation flying, it is absolutely necessary to demonstrate the concept of MEMS-based micropropulsion in space. Besides demonstrating low noise, low thrust, a major objective of a flight demonstration is to verify critical system level aspects such as the mechanical and electrical interfaces from the micro- to the macro-world. For these purposes, the PRISMA programme represents a unique opportunity to demonstrate this new technology and thus take a significant step to enable greater satellite functionality, while significantly reducing cost and weight.

ABOUT NANOSPACE

NanoSpace is a Swedish company with the goal to be a supplier of MEMS-based propulsion products to space industry [4]. The technology is a spin-off from the research and development work performed at the Ångström Laboratory at Uppsala University and initiated by Lars Stenmark. Besides the MEMS-based micropropulsion system, other MEMS based products –such as a Xenon Feed System for electric propulsion - is also under development by NanoSpace.

ACKNOWLEDGEMENT

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