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MICRO HALL EFFECT THRUSTER FOR NANOSATELLITE PROPULSION

A micro Hall effect thruster is proposed as electric propulsive system for CubeSats nanosatellites. A μ-PPI delivering a continuous axial thrust of 0.1mN with a power of a few W has been recently defined. It will be used on the nanosatellite Robusta-3 (3kg) from the University of Montpellier 2. The obtained thrust will allow to accelerate the deorbitation or to compensate the drag atmospheric effect in low orbits or to change the orbit of a CubeSat. The drag effect is analysed for Robusta-1 (1kg) from Space Track org. data and by numerical simulations. The μ-PPI thruster is under development.

Key words: *nanosatellite, propulsion, Hall effect thrusters, plasma propulsion.*

Introduction

The recent launch of seven Cubesats by a Vega European launcher in Feb. 2012 confirms the interest of many countries to nanosatellites following the specifications of CubeSats. Among these 7 CubeSats, there was Robusta-1 developed by the University of Montpellier-1 (France). The drag effect for the future ROBUSTA-3 (3 units) set in a circular orbit at 700km, will be very weak. It can be estimated at more 100 years that is non compatible with the French law (LOS) intending to limit the large quantity of debris in space (atmospheric reentry of all new objects within 25years after the end of their mission).

A micro-Hall Effect Thruster (named μ-PPI) from the laboratory GEMaC of the University of Versailles Saint-Quentin (France) is proposed for the deorbitation of ROBUSTA-3. This new HET thruster with permanent magnets is in the series of previous PPI thrusters developed by the laboratory GEMaC. The characteristics of this new μ-PPI have been studied in order to answer to new requirements for the deorbitation of the Robusta-3. The μ-PPI is described but not yet manufactured and tested in a vacuum chamber.

1. CubeSats nanosatellites

CubeSats specifications have been suggested in 1999 by the California Polytechnic State University (Cal Poly) and Stanford University (R.Twiggs). The purpose of these miniaturized satellites (1kg, 1dm3, 1W) is mainly to allow the launch of educational satellites for students with a low cost and to contribute to research in space. The Cubesats are extracted form the launcher by a Poly-PicoSatellite Orbital Deployer (P-POD) mechanism developed and built by Cal Poly. The first CubeSat was launched in 2003 from Plesetsk, Russia with six CubeSats (Danish AAU CubeSat and DTUSat, the Japanese CubeSat XI-IV and CUTE-1, the Canadian Can X-1, and the US triple-CubeSat Quakesat). Since 2003, many CubeSats have been sent in space with success (in 2005, 2007, 2010, 2011). Recently, seven CubeSats have been set in space on 13th of February 2012 by a VEGA launcher in the frame of a European programme (ESA) and also with the maiden flight of a VEGA. Different European countries are participating to this programme (Poland, Italy, Hungary, Spain, Romania and France with Robusta-1).

ROBUSTA-1 a 1U Cubesat was entirely designed and manufactured by University Montpellier 2 (UM2) students, both undergraduate and graduate [1,2]. This project derives from the CNES' call for proposal, EXPRESSO (EXpérimentations et PRojets Etudiants dans le domaine des SystèmeS Orbitaux et des ballons). The mission consisted in measuring, in flight, the shift of electrical parameters (voltages and currents), due to space radiations, on two types of electronic devices, the LM124 (quad operational amplifiers) and the LM139 (quad voltage comparators). Vega placed Robusta and 6 other Cubesats on an elliptical orbit. Atmospheric drag at perigee is strong enough to cause the re-entry of the satellites within 2,5 years. However, University Montpellier 2 and CNES are considering to launch new projects and in particular a 3U cubesat which raises the question of end of life deorbiting in the framework of the French Law on Space Operations (LOS).

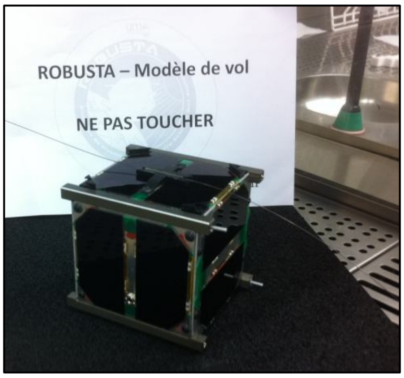

Fig. 1. Nanosatellite Robusta-1 (CubeSat)

The new French Robusta programme includes a nonosatellite Robusta-3 developed by the UM2 Centre de Technologie Spatiale SOLARIUM. Robusta 3 will be manufactured as a combination of three elementary elements (10cmx10cmx30cm, 3 kg) and launched on a LEO orbit at an altitude of 700km.

2. Micro thrust

The first orbits of the seven Cubesats after the launch from VEGA (13th Feb. 2012) are with an apogee around 1 461 km and a perigee around 328 km. The drag on the atmosphere conduct to a fall of the apogee as plotted on figure 2 from data of Space Track org. (USA) and an analysis from Sup'Sat association (Univ. Montpellier2). The lifetime of the CubSats is estimated to be 2.5 years

In high altitude the deorbitation of a CubeSat by atmospheric is too long as plotted on figure 3 with results from the DAS/NASA simulation and a Cowell-Runge-Kutta simple simulation (UPMC) [3] using the model of atmosphere from D.A.Vallado [4] with 28 exponential successive layers.

After a set of numerical simulations of the trajectories of Robusta-3, it appeared that an axial thrust of T =0.1mN associated to a drag on the lower layers of the atmosphere of Earth is convenient for a acceptable/raisonable deorbitation. This thrust is applied along the direction of the orbit of the nanosatellite. The thruster is fired when the nanosatellite is located on its orbit with an abscisse x greater than xchord as reported on the figure 4. The x axis has to be specified in space for a practical application mainly in relation with the Sun facing for energy collection. The thruster is set on the face of the third element to produce a constant thrust along the axis of Robusta-3.

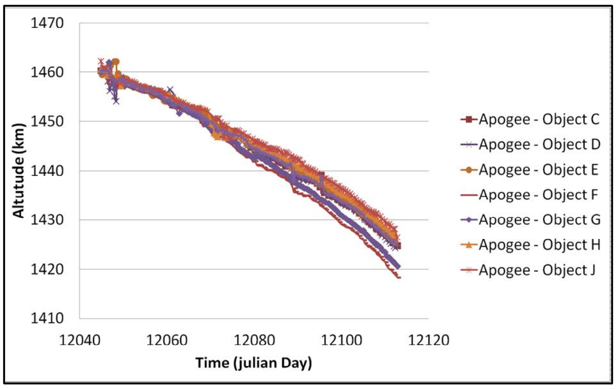

Fig. 2. Time evolution of the apogee altitudes of the Cubesats (Source – SpaceTrack and Sup'Sats association)

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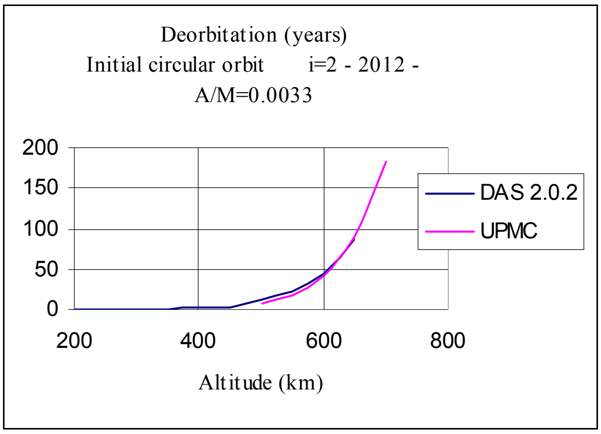


Fig. 3. Deorbitation after an initial circular orbit (i = 2°, cross section/mass = 0.003)

The figure 5 shows the number of days for a deorbitation with a thrust of 0.1mN, the number of days with a run of the thruster, for different values of xchord between 200 km and 600 km, the consumption of ergol (Xenon) by the electric micro thrusters.

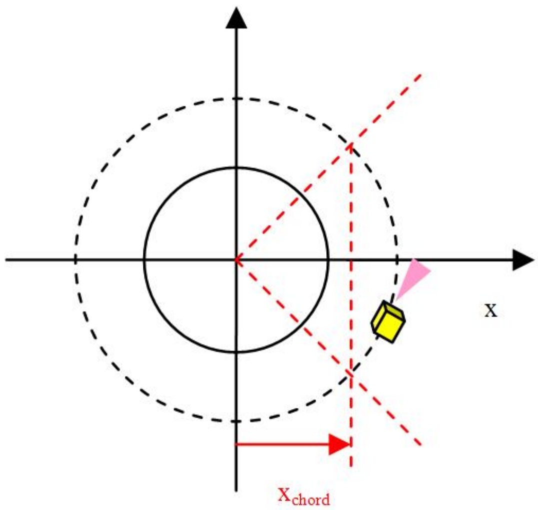


Fig. 4. Location where the thrusters is running ($x > x_{chord}$)

The deorbitation time is 427-1 048 days: when the x chord location increases, the flight duration is longer due to a long use of the natural atmospheric drag.

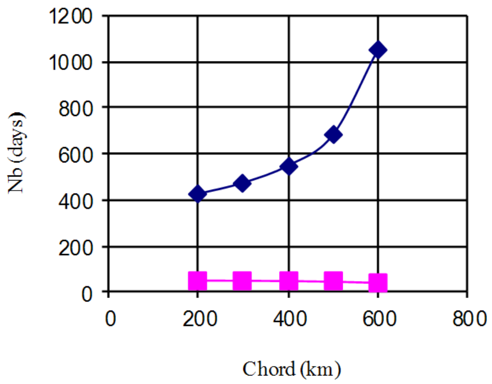
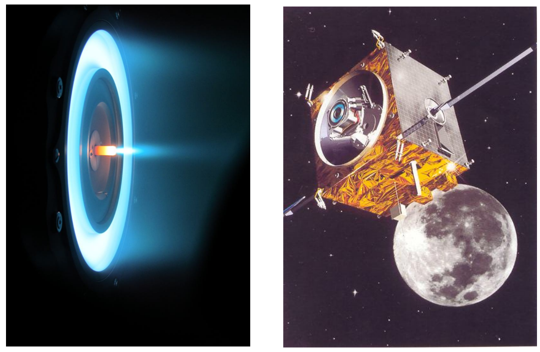


Fig. 5. Number of days for the deorbitation (in blue) and number of days of thrust (in red) for different values of x_{chord} (T=0,1mN)

3. Hall Effect Thrusters (HET)

Electric propulsion concept for spacecraft has been first suggested by Robert Goddard (1905). Stationary plasma thrusters (SPT) also named electron drift thrusters, Morozov type thrusters, Propulseurs par Plasma pour Satellites (PPS) are Hall Effect Thrusters (HET). The basic idea of a HET is the use of cathode-anode plasma discharge in a dielectric annular chamber. In this chamber the propellant is ionized by electron impact that it requires an external magnetic field to trap the electrons. However, only electrons are magnetized (electron Larmor radius lower than the dimension L of the chamber - ion Larmor radius >>L). A quasi axial electric field is generated by the fall of electron mobility in the region where the magnetic field is maximum. The propellant is injected through the bottom of the chamber and the produced ions are extracted by an electric field. In presence of the crossed ExB field, the electrons present an azimuthal drift velocity. This concept of HET allows a high specific impulse due to the velocity of the ions (15-20km/s) and a minimization of the propellant consumption for a asked mission in space. However, the mass flow rate is generally small and the level of thrust is not very large. The time required for the change of orbit is long. The performances of HET are well adapted to maintain the satellites in geostationary orbits and also in future for interplanetary journeys. The first HET in space was the Meteor meteorological satellite (two SPT-60, URSS, 1972). After this first use, a few hundred of SPT (from Fakel/ Russia) were used on Russian satellites or on European satellites. HET are developed in a wide range of size and electric power. In laboratories, the HET are from a few tens of W (58W: SPT-25/Fakel/Russia) to a few hundred of W (PPS300 from Snecma / France, Alta/Italy, PPI/France, IHET-300 from Rafael Space System, Israel, KM32, 150W-400W: Keldysh Research Inst./Russia and Astrium), to 20kW (BHT20k from Busek /USA, T-220 from Pratt&Whitney /USA, 25kW: SPT290 from Fakel/Russia, PPS20k/France) and 50kW (USA).



a b

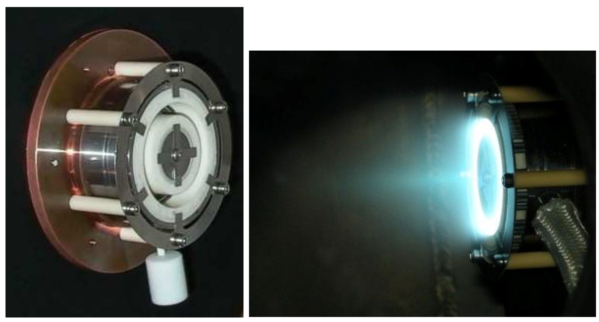
Fig. 6. Hall effect thrusters:
a – PPS20k-ML (20kW, 1N) Project HYPER FP7-Space; b – Smart-1 ESA mission with a PPS1350-G (Snecma - Safran Group)

SMART 1 was successfully sent to a Lunar orbit (Sept.2003-Nov.2004) thanks to a PPS1350G (T=88mN, Isp=1650s) from Snecma-Safran Group, France) with a propellant (Xenon) consumption of only 80kg.

4. μ–PPI Hall effect thruster

The above considerations led us to define a Hall effect thruster (HET) able to deliver a thrust of about 0.1 mN.

To our knowledge, such a thruster does not exist. In the past years, we designed and tested a new concept for HET built around permanent magnets: the PPI (Petit Propulseur Innovant) [5, 6].



a b

Fig. 7. PPI (200W): a – S_0;
b – test in NExET facility (ICARE - CNRS / Orléans)

Such a PPI delivers a 10 mN thrust under a 1 $mg.s^{-1}$ Xe flow and need a 200 W electrical power (figure 7) [5, 6]. More recently, owning to the fact that the efficiency of an HET depends on the channel surface/volume ratio, we decided to increase the channel width h, at constant mean diameter d and maximum magnetic field. Most of the published HET exhibit almost the same ratio, h/d ~0.16. Starting from a PPI with the conventional h/d = 0.16, we modified the thickness of the insulating ceramics, and so we obtained 3 different channel widths h_0, $2h_0$ and $3h_0$, i.e. as d remains the same, we got 3 different channel cross sections, S_0, $2S_0$ and $3S_0$. The 3 versions have been recently tested in the NExET facility at the laboratory ICARE (CNRS-Orléans-France). The main result is: the larger the channel the better the performances [7].

Our project is to deorbit a 3 module set (as for Robusta-3), the µ-PPI and its accessories occupying only a part (less than 50%) of one CubeSat. But the major constraint will be the available electrical power, say about 2 W. From the above simulations, a good compromise would be to build a 2W µ-PPI delivering about 0.1 mN thrust. These requirements are about 1 % of the characteristic of our standard PPI. One way to reach this could be to reduce the channel cross section by a factor of one hundred, while maintaining the same ion density and kinetic energy. Starting from one of our PPI, we will reduce d and h by a factor 10 [8,9]. This will lead to a µ-PPI smaller than 1 cm3, with a weight of a few grams. While quite small, this is mechanically feasible, as well the soft iron magnetic circuit, as the permanent magnets and the insulating ceramics. Numerical simulations (FEMM) show that the correct order of the magnetic field can be obtained by using SmCo permanent magnets. Several configurations will be tested to optimize the amplitude and profile of the magnetic field.

The discharge current of the µ–PPI of the thrust is deduced from the axial thrust (0.1mN) if one assumes a discharge voltage of 300V and estimated values for the divergence plume efficiency and for the part of voltage used to accelerate the Xenon ions. The Xe neutral flow rate is obtained from an estimation of the ionization efficiency. However, if a µ-PPI with a reduce channel section by 1/100 compared to a nominal PPI is mechanically feasible and if the asked level of magnetic field can be generated by permanent magnets, tests in vacuum chamber is strongly necessary. A micro-balance is under development. The thermal behaviour of the µ-PPI will be studied.

Conclusion

Using the experience in Hall effect thrusters and in small thrusters (PPI), a µ-PPI is proposed for the deorbitation of Robusta-3 3U CubeSat which is included in the future programme of the University Montpellier 2. This µ-PPI could be also used for other missions in space as rendezvous or drag compensation to increase the time of CubeSats in space.

Acknowledgment

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МИКРОХОЛЛОВСКИЙ ДВИГАТЕЛЬ ДЛЯ НАНОСПУТНИКОВ

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Микроускоритель Холловского типа предлагается использовать в качестве электрореактивной двигательной системы для наноспутников CubeSats. μ-PPI двигатель, обеспечивающий непрерывную тягу в 0,1 мН мощностью несколько Вт, был недавно спроектирован. Предполагается его использование на наноспутнике Робуста-3 (3 кг) из Университета Монпелье 2. Развиваемая двигателем тяга позволит ускорить вывод спутника с орбиты либо компенсировать сопротивление атмосферы на низких орбитах либо изменить орбиту CubeSat. Компенсационное действие было проанализировано для спутника Робуста-1 (1 кг) методом численного моделирования. μ-PPI двигатель находится на стадии разработки.

Ключевые слова: наноспутник, двигатели, Холловский двигатель, плазменные двигательные установки.

МІКРОХОЛЛОВСЬКИЙ ДВИГУН ДЛЯ НАНОСУПУТНИКІВ

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Мікроприскорювач Холловського типу пропонується використовувати як електрореактивну рухову систему для наносупутників CubeSats. μ-PPI двигун, забезпечуючий безперервну тягу в 0,1 мН потужністю кілька Вт був недавно спроектований. Передбачається його використання на наносупутнику Робуста-3 (3 кг) з Університету Монпельє 2. Розвиваєма двигуном тяга дозволить прискорити виведення супутника з орбіти або компенсувати опір атмосфери на низьких орбітах або змінити орбіту CubeSat. Компенсаційне дію було проаналізовано для супутника Робуста-1 (1 кг) методом чисельного моделювання. μ-PPI двигун знаходиться на стадії розробки.

Ключові слова: наносупутник, двигун, Холловський двигун, плазмові рухові установки.

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