EFFICIENT DE-ORBITING OF MICRO- AND NANO SATELLITES USING THE IFM NANO THRUSTER

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ABSTRACT

In the last decade, the Indium FEEP technology has been developed to a mature product that provides a very high Δv capability within a compact and lightweight design. This paper summarizes simulation efforts investigating the suitability of this technology for deorbiting CubeSats as well as Small Satellites up to 300kg.

1 INTRODUCTION

Building on 30 years of successful flight heritage of Liquid Metal Ion Sources, the department of Aerospace Engineering at FOTEC has developed LMIS for Field Emission Electric Propulsion (FEEP) applications. The different technologies are shown in the picture below.

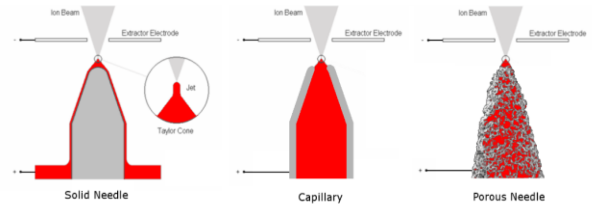

Figure 1 Three types of Indium FEEP emitter.

More than 100 emitters have been performance tested and the successful completion of a 13 000-hour endurance test shows no degradation in emitter performance. [1], [2]

Core element of this success is the porous tungsten crown emitter (on the right) which features a dynamic thrust range of 1 µN to 1 mN at 3000 s to 6000 s Isp. [3] Depending on the mission requirements a power processing unit based on COTS or high-rel components can be used.

The high flexibility of the ion emitters allows different fields of application. Two different thruster modules have been designed, manufactured, and have undergone extensive testing. The IFM 350 thruster was developed within preparatory studies of the ESA Next Generation Gravity Mission (NGGM). The module is made for high performance and long-term operation. [3]

The IFM Nano thruster uses the same porous tungsten crown emitter technology without the need for miniaturization due to the development of the PPU. The complete system, as shown in the picture below, fits into 1 dm² volume and weighs less than 1 kg. [4]

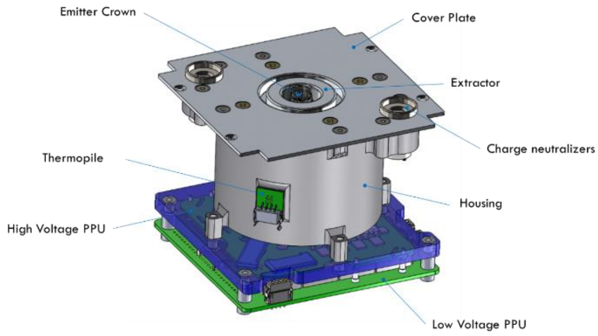

Figure 2 The IFM Nano Thruster Module, 10x10x6 cm.

2 DEORBITING SIMULATIONS

The problem from calculating the deorbit of a satellite is that it can be approximated by a two body problem with only a force in the flight direction acting on the satellite, with the radius r being the distance from the center of mass of the earth to the satellite. The change of r over time can be split into two terms by using the orbital energy E, where the first one can be directly evaluated, and the second term corresponds to the power that is applied to the point mass.

$$\dot{r}(t) = \frac{dr}{dt} = \frac{dr}{dE}\frac{dE}{dt}$$

The power introduced to the objects is simply the product of force and orbital velocity $\frac{dE}{dt} = F \cdot v$. If the force F is assumed to be a constant, the time derivative of r can be found to be

$$\dot{r}(t) = \frac{dr}{dE}(r) * F \cdot v(r)$$

In a central potential, the derivative the energy of an object of mass m with respect to the distance from the origin can be written as $\frac{dE}{dr}(r) = -\frac{m\mu_E}{2r^2}$, where μ_E is earths standard gravitational parameter. The circular velocity of the satellite is $\sqrt{\frac{\mu_E}{r}}$. The force F consists of the sum of atmospheric drag and propulsion force, which are both assumed to act only parallel to the flight direction. Hence the time derivative of r can be simplified to:

$$\dot{r}(t) = -\frac{2r^2}{m\mu_E} * (D + T)\sqrt{\frac{\mu}{r}}$$

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Which can be numerically integrated. As a solver, the scipy.odeint integrator was used, which is wrapping the LSODA routine of the FORTRAN77 library ODEPACK [5]. As a verification, the results for the time until re-entry depending on the initial altitude was compared to literature values, and the typical value of 600 - 700 km for 25 years re-entry time was retrieved, which is also found in the ISO 27852 standard.

Following the modelling approach in [6], the drag force of the low density atmosphere in LEO can be derived by using an empirical density model that relates the density at a certain altitude h to the solar flux (measured by the index f10.7) and the magnetic activity index Ap.

$$\rho(h) = 6 * 10^{10} \exp(-\frac{h-175}{H})$$

with H = T /m , T = 900 + 2.5 (F10.7 - 70) + 1.5*Ap and m = 27- 0.012 (h - 200). Within these calculations, the Solar Radio Flux F10.7 was kept fixed at 300 and the geomagnetic A index Ap at 40, which corresponds to a relatively high solar activity.

3 RESUTLS AND DISCUSSION

Satellites above 700km need a significant delta v capability in order to be transferred into an orbit that can cope with the 25 year requirement of satellite disposal, as can be seen in Figure 3. This is particularly relevant for satellites in a high LEO and MEO orbit.

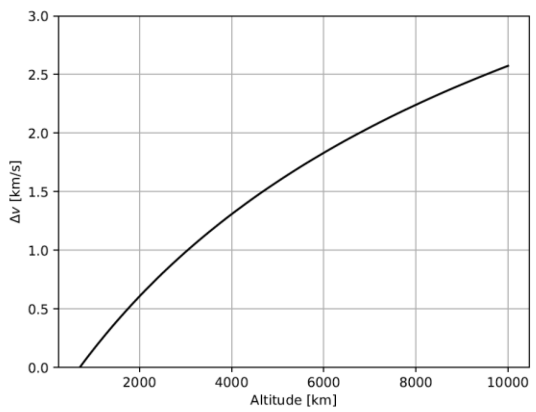

Figure 3 Δv requirement to lower the orbit to 700km.

3.1 De-Orbiting of CubeSats

The IFM Nano Thruster uses 0.6 U volume in a CubeSat and can easily be integrated in all common structures. It needs to be supplied with either 12V or 28V of power and a number of communication interfaces have been developed including UART and I2C. The use of solid Indium as a propellant and the very high specific impulse allow for a very compact and lightweight design. One single IFM Nano Thruster can provide 5000 Ns of total impulse with less than 1kg system mass. The drawback of this technology is the high power to thrust ratio. It is to be traded off for orbit raising manoeuvres, but does not present an issue for deorbiting.

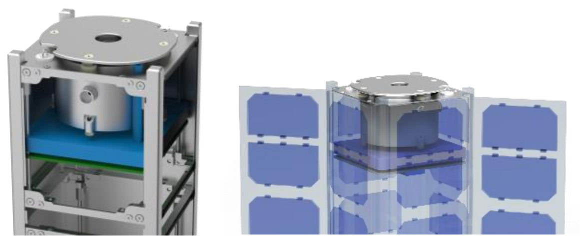

Figure 4 The IFM Nano Thruster in a CubeSat Structure

The following figures show that CubeSats can be deorbited from relatively high altitudes within 100 to 200 days.

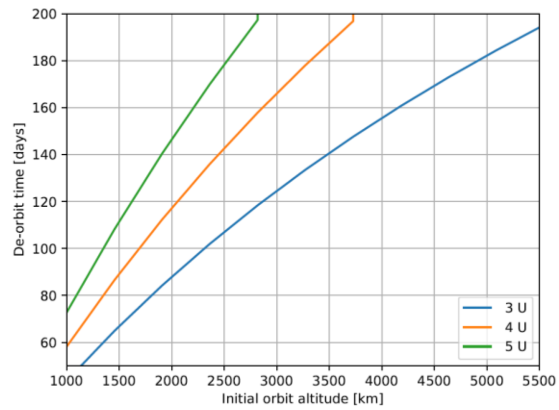

Figure 5 Deorbiting Time for different sizes of CubeSats.

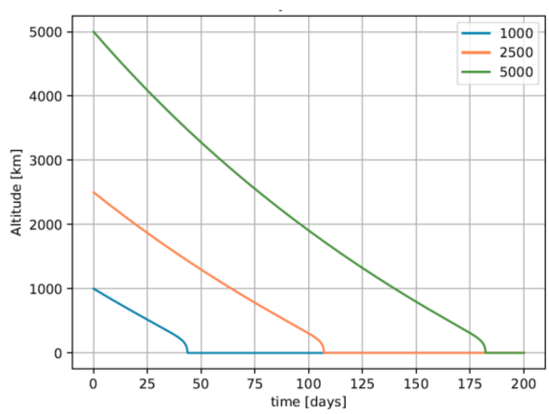

Figure 6 Re-entry of a 3U CubeSat with one IFM Nano Thruster Module.

3.2 De-Orbiting of Small Sats (50-200kg)

The modular approach of the IFM Nano Thruster allows for a clustering of the individual pre-qualified building blocks to provide custom solutions without added development times or costs. Figure 7 shows that up to 7 thruster modules that can be fitted into a 32 inch ESPA separation ring.

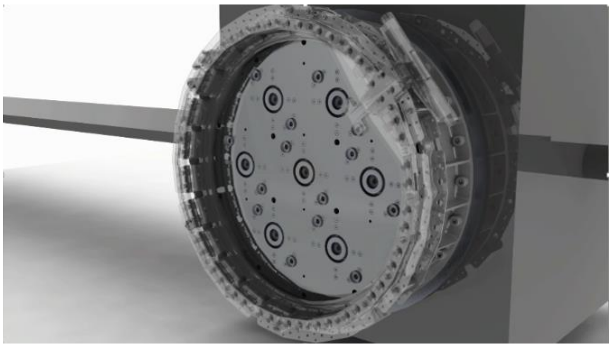

Figure 7 Cluster of 7 IFM Nano Thruster Modules inside a 32 inch ESPA ring

While the number of modules that are being implemented for an initial orbit manoeuvre is usually defined by the thrust requirement, deorbiting can be realized with a significantly smaller number of modules, as the transfer time is not as critical. Figure 8 shows how for different spacecraft's between 50 and 200 kg, the altitude from which deorbiting is required corresponds to the number of IFM Nano thruster modules that will need to be implemented. A 75 kg spacecraft can be deorbited from a 2000 km orbit to 700km with only two IFM Nano Thruster modules, that have a total mass of the complete propulsion system of below 2kg including thruster, PPU and propellant.

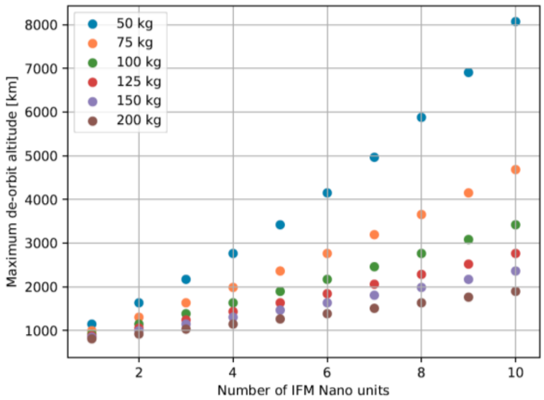

Figure 8 Maximum De-Orbiting Capability of a cluster of IFM Nano Thrsuter Modules on a 50-200kg spacecraft

Figure 9 shows the re-entry of a 50kg satellite using between 2 and 7 thruster modules.

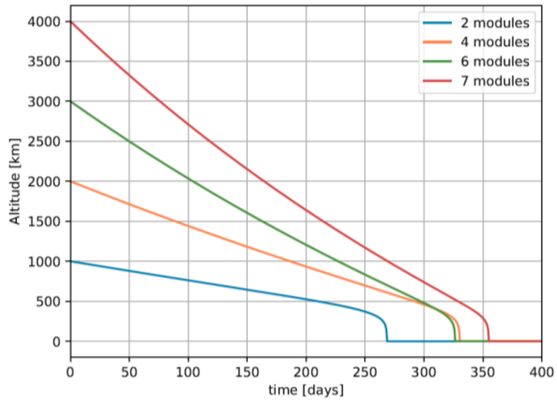

Figure 9 Reentry of a 50kg Satellite with a cluster of IFM Nano Thruster Modules.

4 CONCLUSIONS

The IFM Nano thruster seems to be an interesting option for deorbiting CubeSats and Small Satellites up to 200kg. Especially for MEO satellites between 2000 and 20000 km, the extremely high Total Impulse Density (Total Impulse per System Mass and System Volume) of the technology is highly beneficial, while its drawback, the high power to thrust ratio is not considered to be as severe for deorbiting as for beginning of life orbit changes. It is important to keep in mind however, that the thruster is not providing any attitude control capabilities and is therefore relying on a functional AOCS system to deorbit the spacecraft.

5 REFERENCES

[1] A. Reissner *et al.*, "Testing and Modelling of the mN-FEEP Start-Up Performance," presented at the Joint Conference of 30th International Symposium on Space Technology and Science 34th International Electric Propulsion Conference and 6th Nano-satellite Symposium, Hyogo-Kobe, Japan, 2015.

[2] A. Reissner, "Lifetime Testing of the mN-FEEP Thruster," 2016.

[3] A. Reissner, N. Buldrini, B. Seifert, and F. Plesescu, "Detailed Performance Characterization of the mN-FEEP Thruster," presented at the Space Propulsion 2014, Cologne, Germany, 2014.

[4] A. Reissner, "The IFM 350 Nano Thruster - Introducing very high Δv Capabilities for Nanosats and Cubesats," 2016.

[5] A. C. Hindmarsh, "ODEPACK, A Systematized Collection of ODE Solvers , R. S. Stepleman et al. (eds.), North-Holland, Amsterdam, (vol. 1 of), pp. 55-64.," *IMACS Trans. Sci. Comput.*, vol. 1, pp. 55–64, 1983.

[6] J. Kennwell, "Satellite Orbital Decay Calculations." IPS Radio and Space Service, 1999.