LOW POWER HALL THRUSTER FOR THE ESEO SATELLITE

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ESEO satellite will be launched in 2004 by SSETI (Students Space Exploration and Technology Initiative). It will be built by European students and will integrate a small Hall thruster. This paper will present the design and integration issues of this 10 W thruster on a 120 kg satellite. The purpose of the device is not to be used as means of propulsion but as payload. It is an experiment in order to study the possible use of electric propulsion for a future moon mission on a small spacecraft.

1. Introduction – the ESEO satellite

ESEO stands for European Students Earth Orbiter, and it is the name of satellite that is being designed and is going to be built by university students all around Europe.

The SSETI project started in 9th October 2001 with the cooperation of about 300 students in about 15 universities all over Europe and with the ESA (European Space Agency) coordination. The purpose of the project was to design and build a micro satellite from scratch.

How can we expect to accomplish this hard task? The idea is to divide a large set of complicated tasks in small amounts of less complicated ones. In our case, as we are a large group of students, this is achieved dividing the all satellite in smaller subsystems that, although correlated are somewhat independent from each other. For example, there is a team from Italy that has the responsibility to design and build the power system, there is another team in Germany responsible for the propulsion system and so on.

Of course, has it is expected, all the teams have to communicate with each other regularly so that all the parts of the satellite can, in fact, in the end, form a real satellite. This is done mainly in chat sessions over the internet and one or two times a year at ESTEC (European Space Research and Technology Center), in the Netherlands.

The ESEO satellite itself, is a micro satellite – a box measuring about 1 x 0.8 x 0.8 meters and weighting about 120 Kg. It is going to be launched by an Ariane 5 launcher some date in the first semester of 2004 along with a main passenger – a satellite of probably over 1000 Kg. It is a responsibility of the students to design and build satellite and to find sponsoring for it. It is ESA's responsibility to oversee all the process of the design and building and also to pay for the launch of the satellite.

About the mission itself, the satellite will be launched in GTO (Geostationary Transfer Orbit) in the first semester of 2004. It will stay on orbit for 28 days which is also the expected lifetime for the satellite. Each orbit which is calculated to last for about 10 hours is a very eccentric one: the apogee is at about 30 thousand kilometers and the perigee is at about 600 kilometers. This means that the satellite will pass several times by the Van Allen Belts which can be a problem if we use too many non-space qualified parts.

2. Status of the project

The process of building a satellite if usually formally divided into several phases. The first one is the pre – phase A study. It consists mainly of a feasibility study about all the possible choices that can be made for the satellite. The second phase (phase A), is the definition of all the structures that are present on the satellite. By the end of this phase, it should be clear what are the mission objectives and the system requirements of the satellite – no design details have to be available yet. Phase B is about designing all the subsystems – refined technical details and all technical solutions have to be available by the end of this phase. Phase C is about building and testing the subsystems, including the engineering, thermal, flight models and others as well as integration. Subsequent phases include the launch and operation of the satellite.

Currently, the ESEO project is in late phase B. Mission objectives as well as decisions about what to include or not on the satellite have already been made and the subsystems are all being designed and thoroughly defined. By the end of this phase, the configuration of the satellite has to be set and fixed.

3. Low power Hall Thruster as part of the payload

ESEO will have a payload of one or two cameras – one wide angle camera and one narrow angle camera, and a small hall thruster as payload. The main propulsion system will not be the hall thruster that we are building, but instead it will be a regular cold gas propulsion system. This decision was made mainly because the hall thruster that we are designing now is not a proved system – it should be, when built, the least power consuming hall thruster ever built.

The main idea is then to build up a thruster based on previous tested and proved-to-work systems but modify it in order to overcome the power, budget and space limitations imposed by the very nature of the project itself.

On all the design we had always to remember the main goals of the project. The main objective was, since the beginning, to take students that know very little or nothing about space industry and, with the help of ESA's experts, to make them enthusiastic about the project and to make them really build a satellite (although a small one!) that is really going to space. Alongside with this, the objective is to build a very good system – the satellite, based on technology and solutions not space qualified. As it is known, almost all components that are sent to space on commercial satellites are space qualified ones. A space qualified component is one that is proved to work on very rigorous conditions – at a very wide range of temperatures, being continuously bombarded by various types of radiation and in vacuum.

The reason for these commercial satellites to use this kind of components is very simple: usually these spacecrafts are machines that need several years of design, some years to build and some million euros of total cost. Also, these spacecrafts have to last for several years in a hostile environment and so all the critical components should be as good and reliable as possible.

Our mission is quite different. In fact, ESEO is to last only for 28 days (operating time), and so the cumulative effects of radiation, for example, are not a very big concern. Of course, we still have to qualify some of the critical components to space and use others that are already qualified but, for some subsystems as the entire payload, this is not critical. The main goal is to test things that were never used in space and to use commercial devices instead of space qualified ones in order to test them in space and to reduce costs which is something very critical in space industry nowadays.

The hall thruster, as part of the payload, is not a critical component of the spacecraft. It is an experiment and its main purpose is to see if it is possible to build and to run a small hall thruster with such a low amount of power (10 W) and to operate it as efficiently as possible.

For all the reasons pointed above, the thruster will not be built or designed with space qualified parts and, of course, it will not have any redundant parts (like two hollow cathodes or such).

4. Hall Thruster technical specifications

We now try to answer the question: how are we going to build such a system? Or by other words how are we going to build a hall thruster with a power budget of only 10 W and at the lowest cost possible?

The technical solutions we are trying to implement are now presented here. The hall thruster is divided into four parts. Namely the discharge chamber, the hollow cathode, the fuel feed system and the electronics control box. The high level system design is presented here in figure 1. A description of all the parts follows.

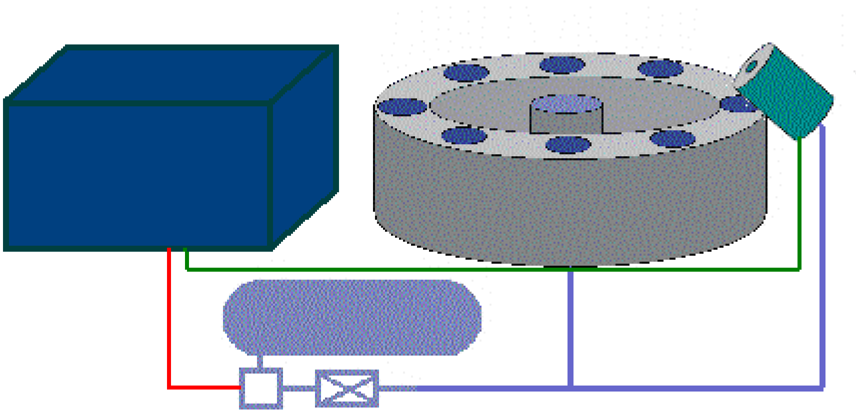

Fig. 1

4.1 Discharge chamber

The discharge chamber will be a regular one – it's design will be based on other proved systems.

Our inclination goes to building an anode layer discharge chamber as it is the cheapest one to build – it avoids the drawback of having to use some insulation like ceramic material, which surely has great costs.

About the dimensions and materials it will probably done in aluminum or a metallic alloy of some type that proves to be both resistant and not to expensive as well as light enough. The coils necessary to induce the required magnetic field – estimated to be of about 50 to 60 Gauss, are going to be built by us, as they will have to comply with some rather strict requirements.

The propellant feed system will be connected to the bottom of the discharge chamber through 5 orifices that will release gas into it.

The core of the coils will be made of iron to enhance the magnetic fields as possible.

4.2 System control (electronic)

The system control will consist of a printed circuit board (PCB), which is going to send signals to the feed system and the hollow cathode as well as the coils in the discharge chamber.

These signals are necessary to make the on / off control of the fuel valves, in the case of the fuel feed system. This system will not have a regulated output – meaning that it is either on or off.

The control signals to the hollow cathode will be, of course to power on the heater and to control the level of heating. This can be done by controlling the current that passes through the heater.

The system control will also have to control the current that passes through the coils to control the intensity of the magnetic field. This intensity will probably be fixed and so will the current. Again probably only on / off signals should be sent.

The system will function based on a small chip that is and acts like a digital computer. These can be programmed easily with a personal computer and that makes the design of the all electronics easy.

4.3 Hollow cathode and propellant feed system

A number of system level considerations shape the design philosophy of the hollow cathode and propellant feed, system which are not common to electric thrusters used on other platforms. Primary amongst these is the very role of the thruster itself: it is not a mission-critical component of the spacecraft's AOCS or propulsion subsystems; rather it is an experimental addition to an otherwise complete package. Associated to this are budgetary constraints: the volume, mass and finance that would be available to a critical component to allow redundancy are not allowed for in this case.

These factors lead to compromises in design which, in other applications on EP-reliant platforms, would not be acceptable. One example of this is the hollow cathode. It is conventional to have two cathodes present to allow redundancy but in this case, it is simply not practical to do so, nor is it considered to be a necessity for the mission. Redundancy has therefore not been implemented.

Another problem associated with designing a non-mission-critical component of a micro satellite is the budgetary restrictions imposed by the system-level specifications: power, mass, volume and financial budgets all place major constraints on the design. The power budget, for instance, is 10W for the whole thruster. Once up and running, the exothermic electron release process will keep the temperature in the hollow cathode at an acceptable level, but achieving this self-sustaining level is difficult. On the start-up transient, it is intended that the entire 10W available will be applied to the heating coils. The volume constraints limit the insulation that can be applied to the outside of the heating coils, but it is estimated that around 90% of the heat output from the heating coil can be applied to the cathode. If the propellant is allowed to flow through the cathode during this start-up phase, the forced convection heat transfer coefficient is too high to allow the temperature to build up to the required level, so the flow must be stopped during this phase.

The start-up transient is then a three-stage process: first, as much power as possible is passed to the heater to get the low work-function sleeve up to the required operating temperature; when this is attained, the flow is initiated; when the flow control valve has ceased drawing power, the temperature of the cathode is monitored and heat supplied as necessary while all remaining power is directly applied to the generation of thrust. The thruster will be used intermittently through the flight, so this transient procedure will be executed on a number of occasions, allowing data to be extracted and lessons to be drawn for future missions.

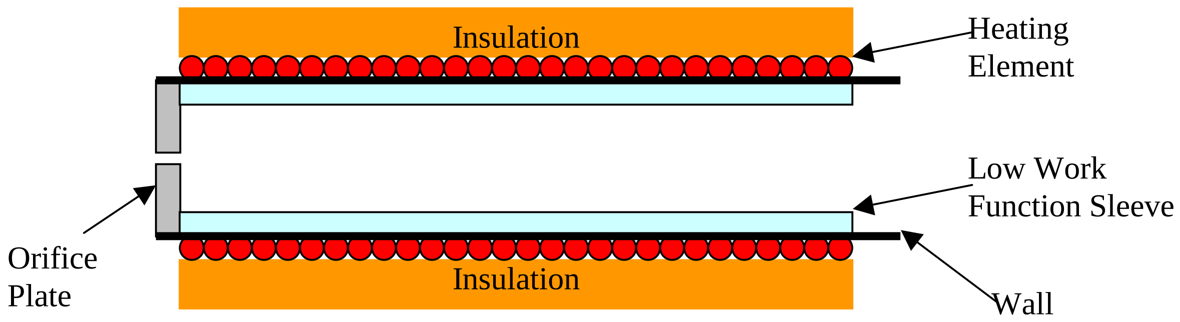

Fig. 2 – Hollow cathode design

The choice of propellant for the mission was a topic of much discussion. Three options presented themselves early in the design: xenon, argon and carbon dioxide. Xenon is the most conventional choice of propellant because it is chemically inert, meaning that corrosion of the cathode should be avoided, and has a high atomic mass meaning that if it is stored in gaseous form, its gas constant is low allowing a given mass to be stored in a smaller volume or at lower pressure than would be possible for other propellants.

One of the primary goals of SSETI, and of the ESEO satellite in particular, is public outreach and engagement. For this reason, it was thought that using a propellant that could be found on Mars would give the mission applicability to a topic of public, as well as scientific, interest. Hence, the possibilities of using carbon dioxide and argon were explored.

Carbon dioxide presented a number of advantages over argon, not least of which was cost. The one concern expressed over its use was that its reactivity at high temperatures could lead to corrosion and loss of performance of the cathode. The mission lifetime is so short (nominally 28 days) that this was felt to be acceptable, so CO_2 was chosen.

The propellant feed system is fairly conventional: similar systems have been used successfully in numerous electric propulsion systems, and it is extremely similar to many cold gas thruster systems. The main difference is the flow rate required: for ESEO, a flow rate of 0.02 grams per second has been specified. This introduces some peculiar design problems, most of which have now been overcome. The regulator will reduce the pressure from the storage condition down to well under 1 bar. From here, it will be passed through an orifice plate before reaching the discharge chamber and hollow cathode. The size of the orifice will be tuned, by analysis backed up by experiment, to allow the specified flow rate to pass.

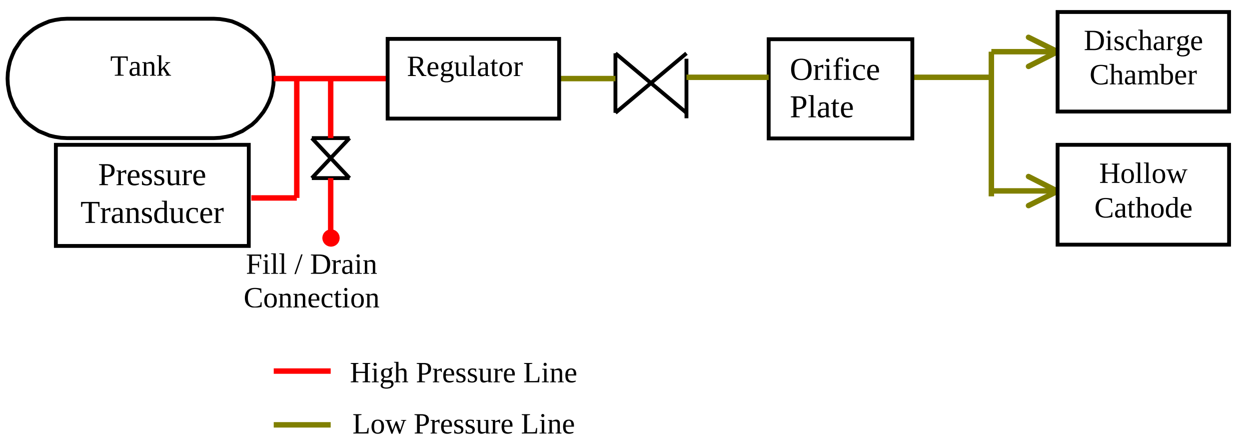

Fig. 3 – propellant feed system

5. Our goals

As it was said earlier on this work, the idea is not, for now, to achieve a very reliable thruster. The thruster itself is not a critical part of the spacecraft. It is, instead, an experiment.

As an experiment it is expected to run and produce results. The results that we expect to get are mainly the thrust levels achieved. This we can get by the AOCS (Attitude and Orbit Control System) computer. The thruster will be mounted on the spacecraft with a thrust angle such to produce a spin on the y axis. This spin, calculated to be small, should however be enough to be detected by the AOCS attitude sensors. From the amount of spin induced as well as the time that it takes to reach a certain angle of inclination from normal attitude, thrust levels and performance can be estimated.

The mission goals in what concerns the hall thruster are essentially to prove the system is feasible and to prove it works. The secondary mission goal will be to test the thruster and to extract results about its efficiency, reliability, power consumption and so on.

6. Conclusions

In conclusion we can say that this project has proven to be very important and that it has already taught many important things about technology development, team work and about space and space technology itself. For this it has already been worth everybody's effort to run this project.

For what concerns the hall thruster itself, the design is on course and it is not finished yet. This means that major decisions about the design have already been made, but that the details concerning technical drawing, necessary currents and voltages and so on are not done yet.

If proved to work, this hall thruster will open the market of hall thrusters to small spacecrafts and will surely bring some added value to both ESA and the ESEO project.