New 2d Far Field Beam Scanning Device at DLR's Electric Propulsion Test Facility

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Abstract: DLR's electric propulsion test facility has a large vacuum chamber of 12m length. This size enables plasma plume measurements at a longer than usual distance, e.g. beyond 5m, compared to the usual distance of 0.5-1m. The beam shape at such long distances is of importance for spacecraft interaction and for a space debris removal technique that is based on momentum transfer by ion beams. In designing such a system we selected an x-y scanner working in a flat plane. Movements of the scanner, and data acquisition are controlled by a computer. The systems is intended for beam profiling of gridded ion thrusters in the first place, because these usually have a narrow beam with low divergence. On the other hand, as the system is not fixed to the vacuum chamber, measurements could also be taken closer to the thruster. This paper presents the new system for 2d beam scanning in the far field of electric propulsion thrusters.

I. Introduction

New requirements for space missions using electric propulsion can be observed, including high specific impulse, thrust, and active lifetime. Nowadays, electric thrusters have been applied in many space programs, among them GOCE, Dawn, Deep Space 1, SMART-1, Hayabusa, and Hayabusa 2. Electric thrusters are also used for north-south station keeping on commercial satellites, while orbit transfer maneuvers are investigated for commercial missions. Furthermore, new scientific missions will use electric propulsion, among them Bepi Colombo, the mission to planet Mercury.

A new issue nowadays is connected to the huge amount of space debris near Earth. NASA measurements show, '*that more than 21,000 orbital debris larger than 10 cm are known to exist. The estimated population of particles between 1 and 10 cm in diameter is approximately 500,000. The number of particles smaller than 1 cm exceeds 100 million*[1]'. Figure 1 shows the distribution of debris in LEO.

How can debris be removed? An EU-funded project, LEOSWEEP, is investigating a new concept. LEOSWEEP is program for removing debris objects from orbit, especially LEO. The idea is to have a satellite that, via an ion beam, transfers momentum to the debris object, and as a result changes the orbit of the object. This procedure is contactless and the acting satellite does not have to approach the object more than several tens of meters.

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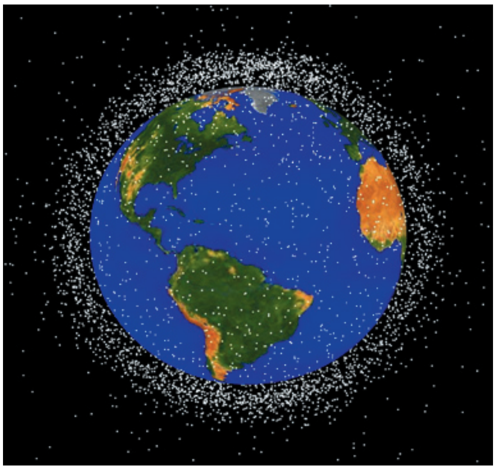

Figure 1. Debris objects at LEO (Picture by NASA[1]).

For such a mission the momentum transfer beam source must have a very low divergence. Figure 2 shows this concept[2] and it is obvious that, for high efficiency, the ion beam must impact on the debris object with high impulse and low beam divergence. As this is only a concept so far, these thruster parameters have to be studied in ground test facilities first and compliance with these prerequisites must be shown.

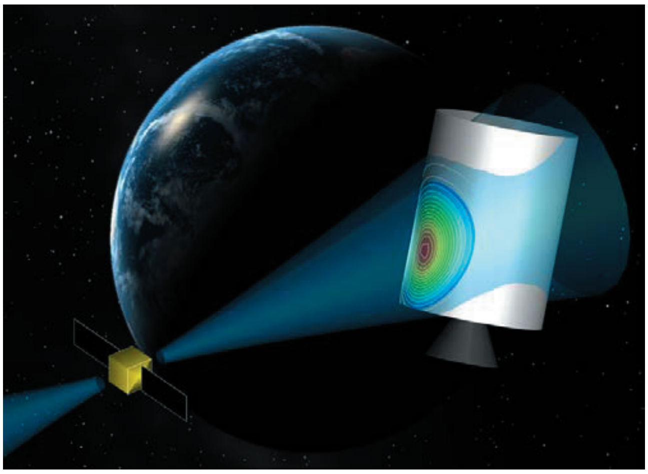

Figure 2. LEOSWEEP: The satellite transfers momentum to the debris object, here a rocket upper stage via electric propulsion thrusters (artist view[2]).

II. Measurement System and Vacuum Facility

A. DLR Vacuum Test Facility

The environment in space completely differs from the environment at ground, and with this one main difference between space and ground is the pressure, which is below 10^{-6} mbar even in LEO. Thus, a testing facility for electric thrusters has to provide a very low atmospheric pressure. Only a sophisticated vacuum system with high-speed pumping can give required pressure. Vacuum chambers obviously have an impact on the operation of a thruster, as residual atmosphere and sputtered particles of chamber walls can change the parameters of the thruster. As it’s impossible to provide manufacturing, assembling, and full testing of spacecraft in the space, it is necessary to improve the features of a vacuum tank, e.g. make it large, increase the speed of pumping, and provide means for investigation of the behavior of the ion beam inside the vacuum facility.

For the understanding of the interaction of the beam and the residual atmosphere it is necessary to have several measurement systems inside the facility. Moreover, when we are working on projects like LEOSWEEP, we are strongly interested in large vacuum chambers in order to provide full measurements of the plume at necessary long distance.

Figure 4. DLR's Electric Propulsion (EP) Test Facility.

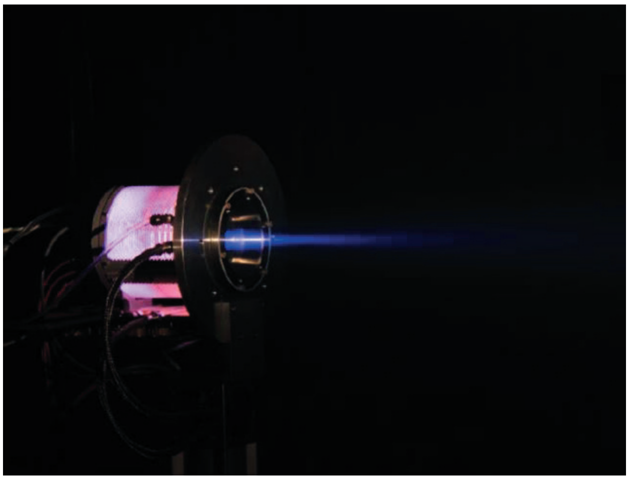

Figure 3. DLR's RIT thruster operating in the DLR vacuum chamber.

Figure 3 shows DLR's Electric Propulsion Test Facility. This large vacuum tank is 12 m long and 5 meter in diameter[3]. This is a new and modern vacuum chamber, which allows testing all types of electric thrusters like ion bombardment thrusters, radio frequency ion thrusters, and Hall effect thrusters.

For its own R&D purpose, DLR operates a RIT10 with 37 holes as a standard ion source. Figure 4 shows this thruster in operation inside DLR's test facility.

B. Linear scan device.

For the new envisaged investigations connected to beam divergence at longer distance a linear two-dimensional scanning device has been built and is installed in the facility. The new feature is the distance of the scanning system of approximately 7-10m from the thruster exit. This long distance is made possible by the size of the vacuum chamber, and is a good starting point for measurements of beam divergence.

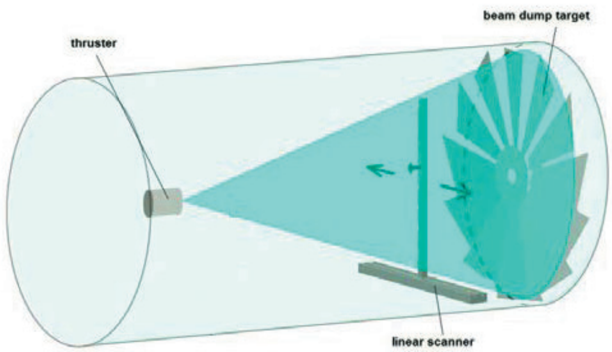

Figure 5. Measurement systems for near field and far field. A rotational scanner close to the thruster, and linear scanner at longer distance.

Figure 5 shows this concept. The new linear measurement system is composed of two linear rails, one of them is a 3 meters long rail with a platform. On top of this platform is fixed a shorter linear scanner with a length of 1.5 meters length. This second vertical rail was selected due to its on-site availability and re-use of components. An upgrade will be possible in the future. Figure 2 depicts a few more details about the new system. The components are described in the figure's legend. The motor controller and the data acquisition system (DAS) are connected to a personal computer.

Figure 7 shows measurement system outside of the vacuum chamber with an indication of the main components of the system. The legend is the same as in Figure 6. Thus, using this system it is possible to characterize the ion beam in two perpendicular directions in an automatic way.

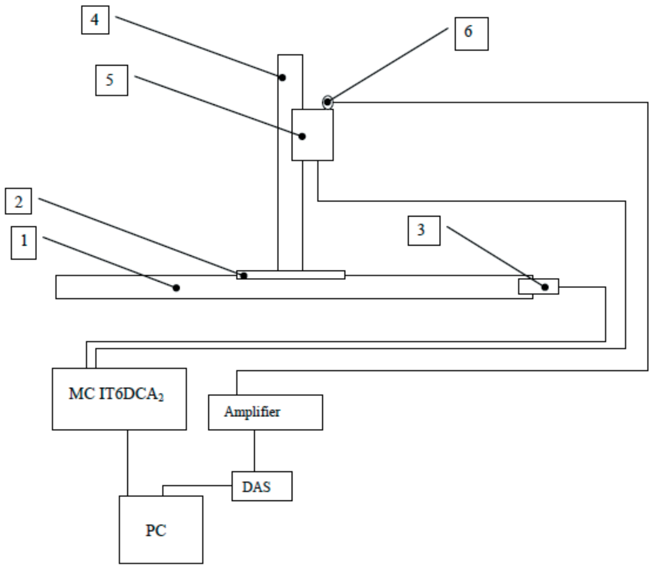

Figure 6. Details of the linear scanning system. 1-horizontal rail, 2-moving platform, 3-horizontal stepper motor drive, 4-linear vertical rail, 5-vertical platform with stepper motor, 6-probe(s).

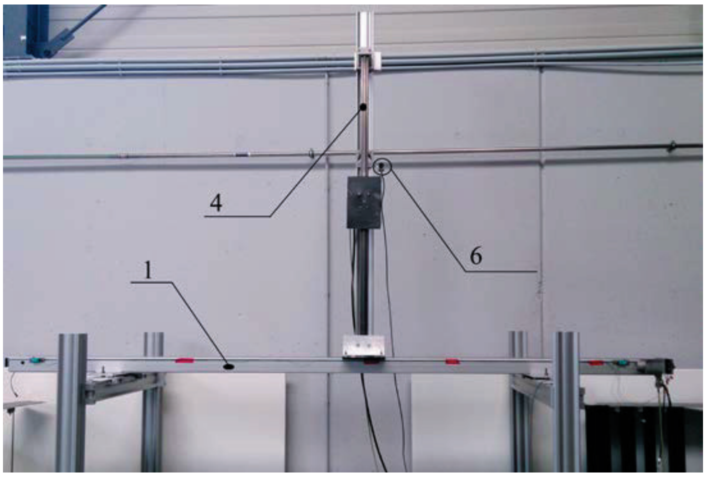

Figure 7. Details of the linear scanning system, system outside of the vacuum facility (components as above).

C. Measurement instruments

The moving system is flexible and can host different types of measurement sensors. Therefore, we are able to install different probes together or separately. At present, there is a Faraday cup (F-Cup) mounted at top of the small rail. Figure 8 shows the system in the vacuum chamber and a close-up of the sensor.

This F-Cup was designed and built by the University of Giessen, Germany. Its principle is displayed in Figure 9. A conductive housing at floating potential (3) separates beam plasma and plasma inside the probe. The aperture of the probe may be biased with a negative voltage, and it separates electron and ion components of the plasma. Only positively charged particles (ions) can reach the collector (2). This collector is connected to a current-to-voltage converter, an amplifier, and a data acquisition system (DAS, Figure 6). Using this probe, it is possible to measure ion current.

As mentioned above, there is a possibility to install together with the F-Cup another probe, for example a Langmuir probe. Using this probe we can measure parameters of plasma like concentration of charged particles, electron temperature and space potential[4].

Figure 10 shows a single Langmuir probe that shall be added to the F-cup. In this picture the tip (tungsten wire) and ceramic insulator can be seen. This probe was also designed and built by the University of Giessen. The construction of this probe is rather simple: there is a thin rod made of tungsten inside a ceramic tube. The theory of measurements with Langmuir probes precisely described in [5], as well as in [4], and will not be repeated here.

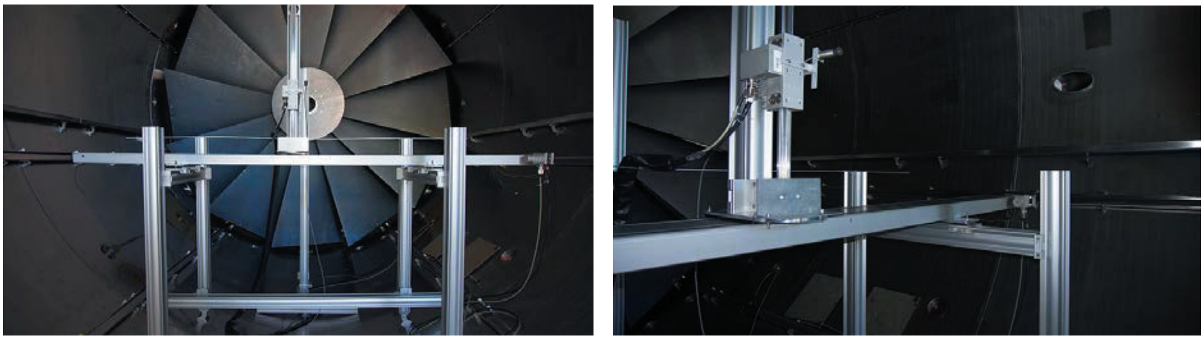

Figure 8. The system installed in DLR vacuum chamber. On the left is a close-up of the sensor.

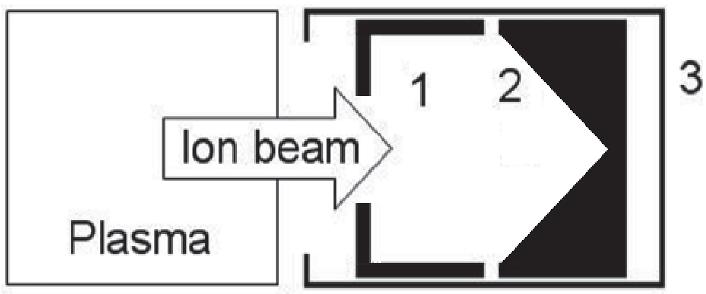

Figure 9. Schematic diagram of a Faraday cup.

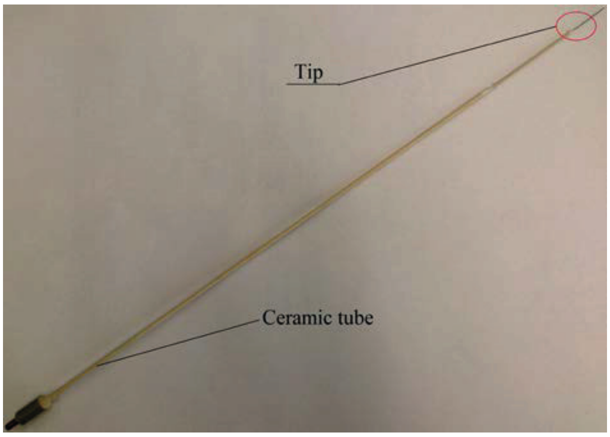

Figure 10. Single Langmuir probe.

III. Conclusion

In this paper the new 2d Far Field Beam Scanning Device at DLR's EP test facility was presented. Unfortunately the system could not start operation before July 2015, due to other commitments of the facility., but first results will be presented soon.

IV. Acknowledgements

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V. References

[1]http://orbitaldebris.jsc.nasa.gov, 1.7.2015
[2]https://leosweep.upm.es/en/ibs/ibs-concept-applications/31-the-ion-beam-shepherd-concept, 1.7.2015
[3]A. Neumann, and K. Hannemann, "Electric Propulsion Testing at DLR Goettingen: Facility and Diagnostics", Space Propulsion Conference 2014, Cologne, Germany, Paper Identification Number 2970582, 2014
[4]F.F.Chen, J.P.Chang, *Principles of Plasma Processing,* Plenum/Kluwer Publishers, 2002, Los Angeles, Part A7, Chapter XII.
[5]I. H. Hutchinson, *Principles of Plasma Diagnostics*, Cambridge University Press, 2nd edition, 2002