Plume Characteristics of the Indium Needle Emitter (InFEEP) Thruster*†

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Characterization test campaigns involving ion beam analysis and overall performance evaluation are being performed in the dedicated FEEP test facility at the ESA Electric Propulsion Laboratory on the European Field Emission Thrusters developed under ESA funding. These are the ARCS Indium Liquid Metal Ion Source (LMIS, also referred as InFEEP) and the Alta FEEP. This paper presents part of the achieved results on the first series of tests carried out by ESA on two ARCS InFEEP modules.

Introduction

ESA funded Filed Emission Thrusters are the candidate propulsion system for new scientific missions that need drag-free attitude control and very precise pointing. In order to gain a better insight about its potential and limits in view of it's possible application on important ESA scientific missions, the ESTEC Electric Propulsion Section has set-up a dedicated test facility, including state of the art diagnostic tools. Several test campaigns have been undertaken and more are planned in the future.

A series of experimental characterization tests have been performed in this facility on Alta FEEPs [1] and a first test campaign has been carried out on two similar sources of the Austrian Research Centers Seibersdorf (ARCS) Indium LMIS, also commonly referred to as "InFEEP", deliverables of an ESA contract. Both the first and the second model, each tested for more than 7 – 8 hours, performed some intervals of relatively stable behavior, during which it has been possible to realize interesting plume scans with the laboratory advanced electrostatic probe diagnostic system. Overall performance tests have been also carried out, but further analysis on other sources is needed prior publication of the test results.

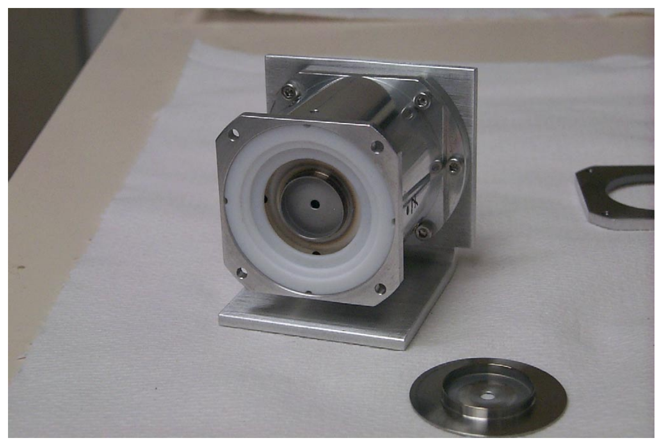

Figure 1 –InFEEP module nr.2 used in the tests at ESTEC

Diagnostic System

The thruster was set up in the ESTEC Electric Propulsion Laboratory Vacuum Facility No 1, and the emitter was directly interfaced with the laboratory power supplies and control software.

The diagnostics system [1] developed in cooperation with Centrospazio, represented in Figure 2, is based on two simple electrostatic probes that scan plume density distribution along the three axis and can also

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be used to instantaneously identify the position in space of the thrust vector. In these tests it has been used to locally measure the beam divergence angle and to acquire 2-D plume images. The two wire probes are mounted on a frame structure, perpendicular to each other, and are moved by two stepper motors via four chains. The structure supported on four ultra high vacuum bearings used as wheels, slides on two Teflon guides, allowing the probes to be positioned at a maximum distance of 50 cm from the thruster.

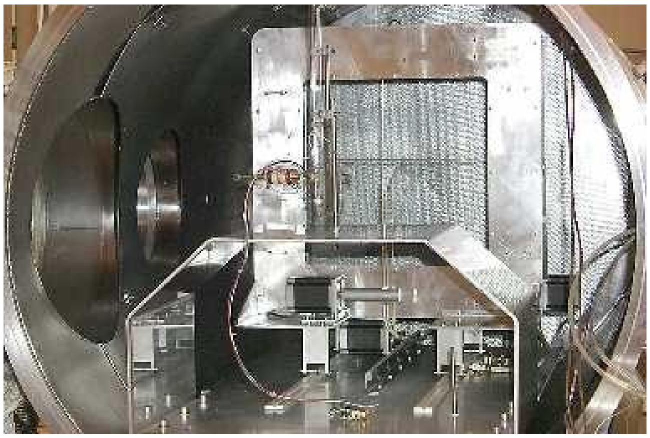

Figure 2 – Diagnostic system installed in the vacuum chamber

The structure is made of aluminum mainly because of its low sputtering yield, and the structure surfaces facing the plume can be coated by graphite to further reduce the sputtering yield when necessary. During these tests actually the beam exposed aluminum surfaces were coated with Graphoil® sheets. The two probes, orthogonal to each other, are two cylindrical tungsten rods long enough to contain the cross section of the ion beam, which is connected to ground in the course of an ammeter. By measuring the current flowing through the ammeter as a function of the position of the probe in the plume, the ion density distribution can be derived, being proportional to the current collected by the probe.

The current measured is mainly due to the ions that hit the probe at high speed, generating a direct ion current plus a small current caused by the electron secondary emission from the impinged probe. The current collected by the probe can be used to estimate the ion density distribution in the plume, which is responsible for the thrust generation. In the performed test the ion density in the plume was mapped while keeping the probe grounded.

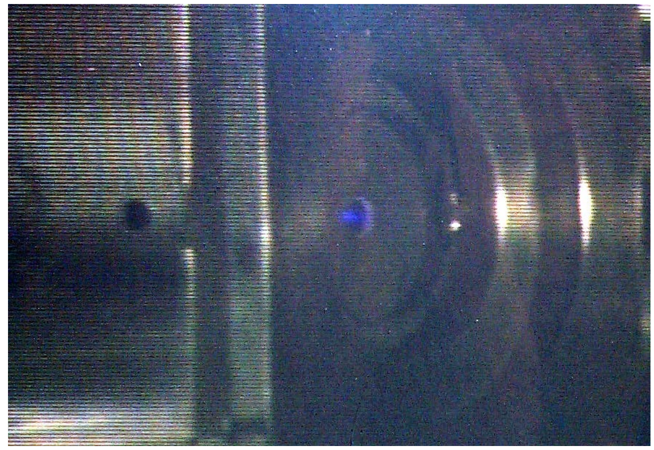

Figure 3 – InFEEP during operation at ESTEC

In this experiment the horizontal and vertical wire probes have been used to cross the plume separately (one at a time), thus yielding the 1-D envelope of the integral along the probe of a quantity proportional to the ion density. Repeating this scanning procedure at various distances from the thruster, 2-D maps of the plume have been obtained (top views and side views). An automatic acquisition system based on a LabVIEW custom designed program is used to collect the data matrix that was subsequently analyzed and graphically outfitted with a Matlab interface. An arbitrary scale proportional to the collected current was assigned to the third dimension in order to qualitative represent the plume characteristics.

Plume characteristics

In Figure 7 there is represented a top view scan of the InFEEP plume, taken while the thruster was firing at a calculated thrust of about 8μN and operating in voltage control mode (open loop). An enlargement of the plots describing the most important recorded parameters in the considered firing interval is reported in Figure 4. The scans were performed between t=1.8 h and t=1.9 h. The chamber pressure at the beginning of the test was $7.4 \cdot 10^{-9}$ mbar. The emitter was powered by a FuG HCN 1400-20000 power supply (voltage range: 0-20 kV; current range: 0-60 mA); the heater was connected to a Delta Elektronika E 030-3 power supply (voltage range: 0-30 V; current range: 0-3 A). The extractor was grounded to the vacuum chamber.

A three-step heating procedure was followed as specified by ARCS: three ten-minute increasing voltage intervals of 7V, 9V and 10.5V respectively were sequentially applied to the heater. In the considered interval the thruster was voltage regulated, and for thrust levels below 10μN its behavior was fairly linear, though affected by sporadic instantaneous discontinuities (sparks). The presence of instabilities appears from the three discontinuities in the color distribution of Figure 3 (every point plotted in the map is calculated as the average of over 100 probe measurements in 0.1s). Higher spark rates and higher instability for higher emission levels have prevented the execution of smooth plume scans at thrust levels above the 10μN range. Stable emission is necessary for a coherent plume image. If the beam current changes macroscopically during the timeframe of the acquisition process, the plasma density distribution measured is not reflecting the actual one. A thrust stabilizer (digital closed loop controller) is being developed for this purpose.

A transversal section of the plume scan, taken at about 140mm from the thruster, is represented in
Figure 5. For every similar section it is possible to give an estimation of the average local beam divergence angle, calculated trigonometrically from the central axis in order to exclude 2.5% of the total measured current (plot area). The central axis, passing from the emitter needle, is identified as the average position of the maximal current. It is interesting to notice (Figure 6) how the experimental divergence angles calculated in this way converge to about 30° at a close distance from the exit plane.

The effects on the plume of an additional grounded electrode, installed at 4mm from the needle tip after the extraction electrode, on the second InFEEP model tested, may be observed in Figure 8. In this case the scan was performed with the vertical probe, so that the final result is a "side view". The ion beam, seriously affected by the additional plate, appears tapered and more concentrated.

Obviously the shield has a deleterious impact on overall thruster performances, since it draws an important drain current, thus was removed for the planned following tests.

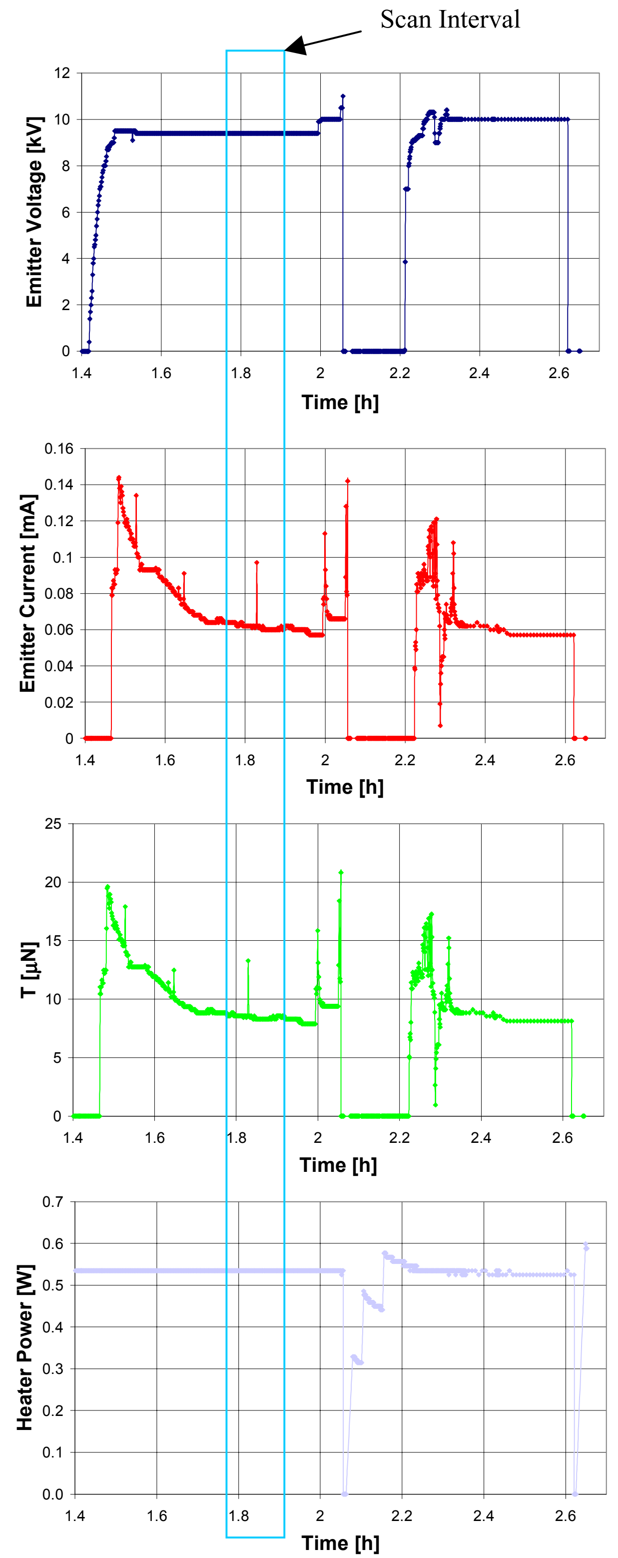

Figure 4 – Scan interval, main operative parameters

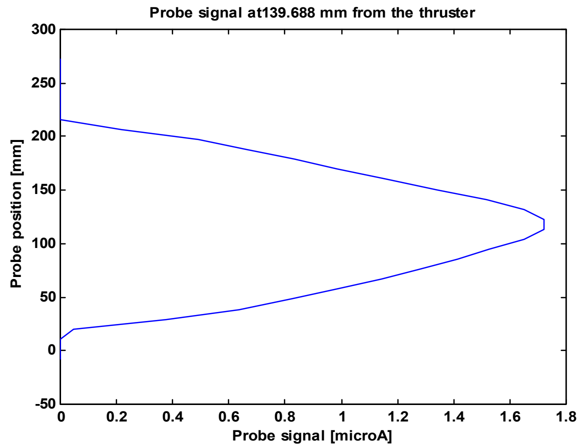

Figure 5 – Plume scan section

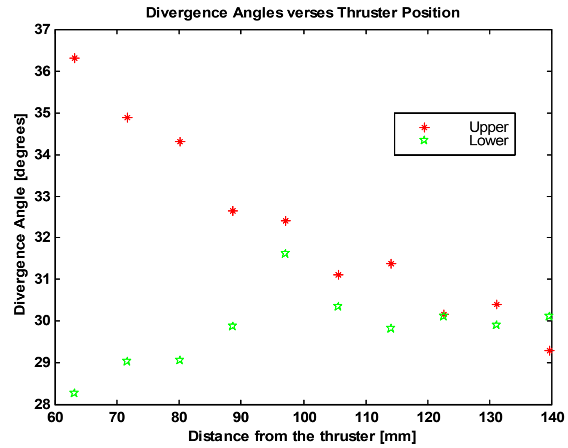

Figure 6 – Beam divergence angle calculation

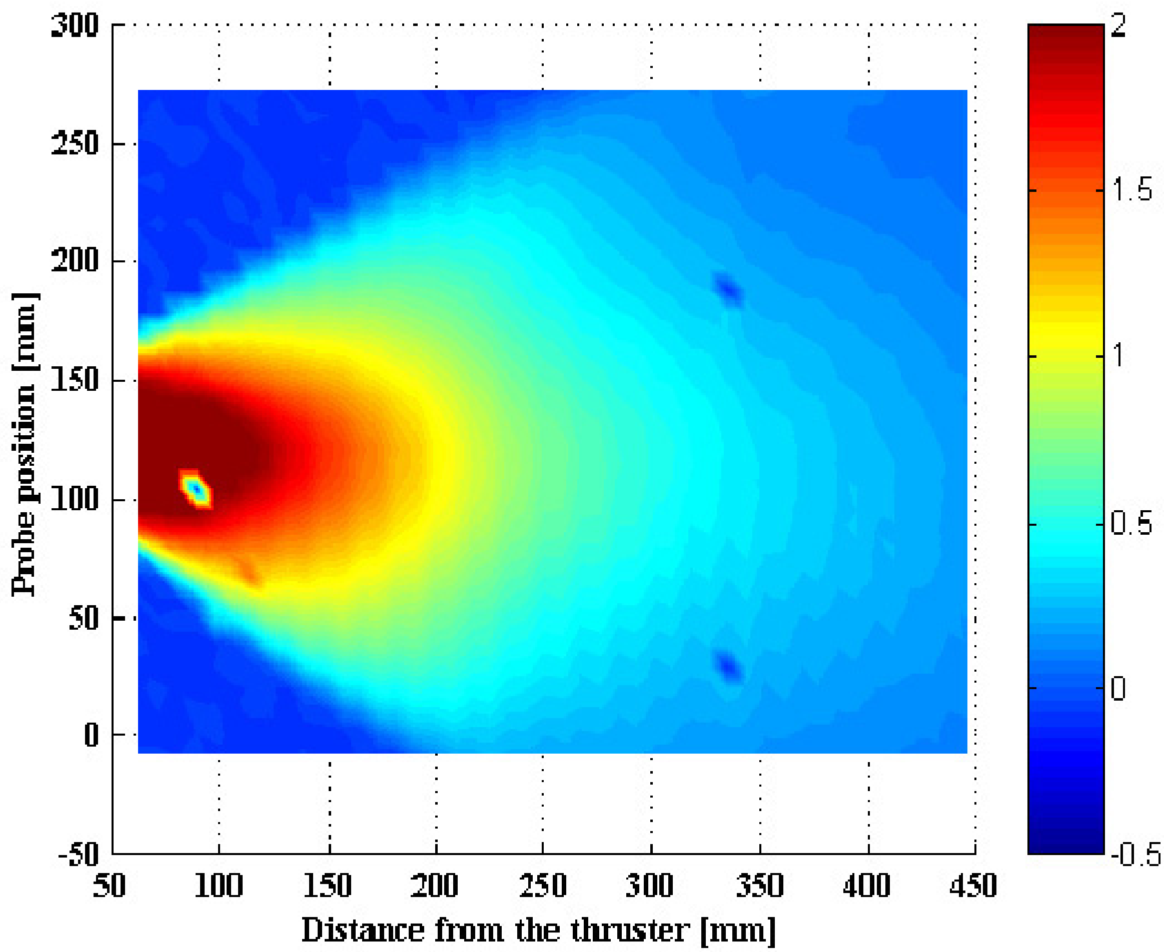

Figure 7 – InFEEP plume scan, top view.

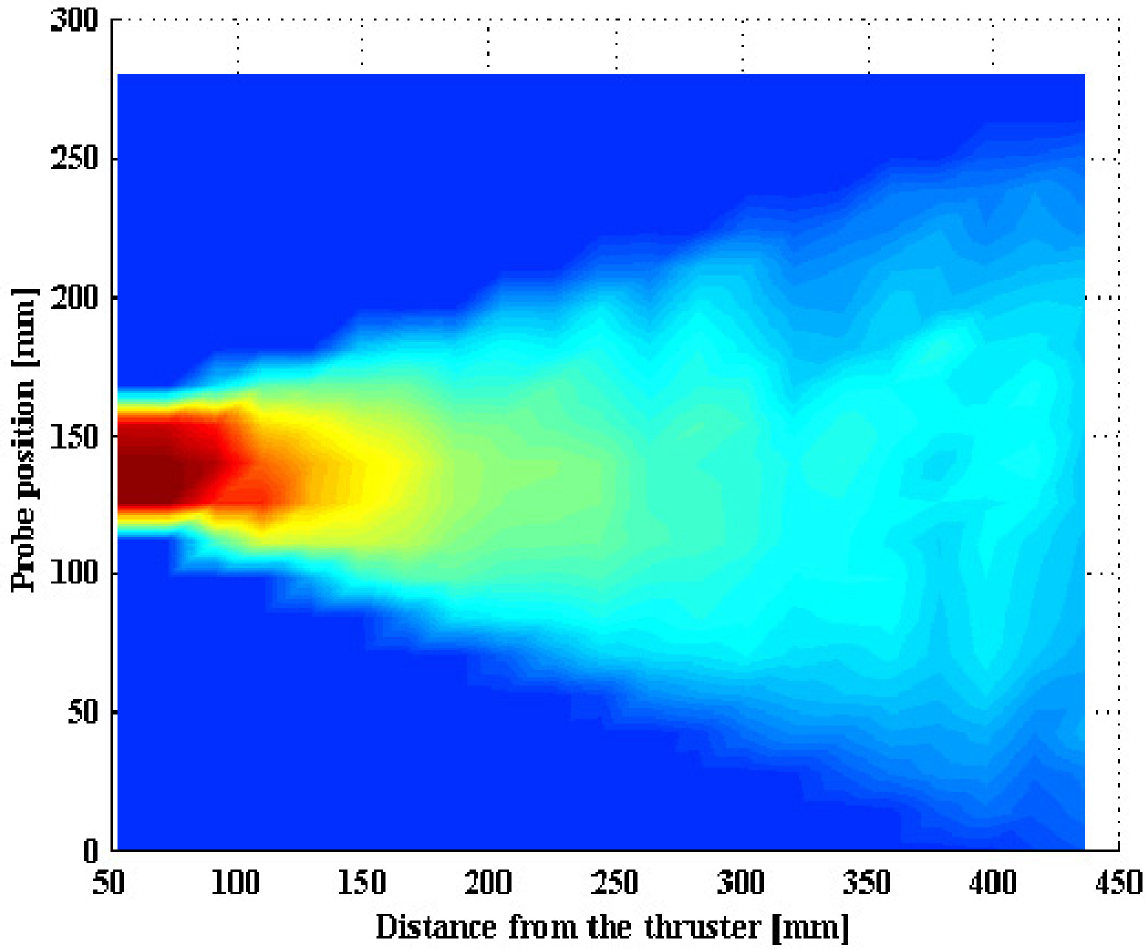

Figure 8 – Shielded InFEEP plume scan, side view

Conclusions

The diagnostic system for the acquisition of plume characteristics that equips vacuum facility no 1 in the ESA Electric Propulsion Laboratory, developed for FEEP thrusters, has been used to acquire plume characteristics of two ARCS In LMIS (InFEEP) thrusters developed under ESA funding and deliverables of an ESA contract.

InFEEP plumes have been for the first time experimentally acquired and imaged. The beam divergence at ~8 µN was found to be 30°, in agreement with previous ARCS tests.

Plume images on a second ARCS module mounting a ground screen after the extractor electrode (also grounded) showed clear interference on the beam course. The beam divergence in this second case resulted to be less than 15°, but expectantly a drain current on the ground shield electrode in the order of 75% of the emission current was recorded.

Further investigations, detailed performance and possibly endurance tests are envisaged on new ARCS sources in the near future to assess new developments in terms of efficiency, lifetime and stability.

Acknowledgments

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References

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