Lunar environment simulation capabilities at CASPER

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Introduction

In close collaboration between the Center for Astrophysics, Space Physics and Engineering Research (CASPER) at Baylor University, Texas, and the Institute of Space Systems (IRS) at the University of Stuttgart, Germany, two plasma wind tunnel facilities of similar type have been established using the inductively heated plasma source IPG6, based on proven IRS designs. The facility at Baylor University (IPG6-B) will be subject of this poster. First experiments have been conducted with air, argon, oxygen and nitrogen as working gases and volumetric flow rates of several L/min at pressures of a few 100 Pa, although pressures below 1 Pa are achievable at lower flow rates. Currently a Pitot probe and a cavity calorimeter are used to characterize the plasma jet. In the near future additional diagnostics will be established and the use of other gases (i.e. hydrogen, helium), and the integration of a dust particle accelerator are planned. The intended fields of research are basic investigation into thermo-chemistry and plasma radiation, space plasma environments and high heat fluxes e.g. in fusion devices or during atmospheric entry of spacecraft.

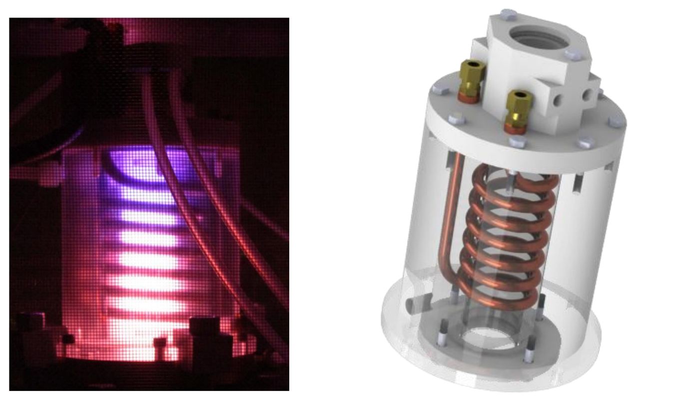

Figure 1. Plasma generator IPG6. Left: In operation with air plasma. Right: CAD-drawing.

Technical Information

The used plasma generator IPG6 is inductively driven . A coil is wrapped around the so-called discharge channel. This coil produces a strong alternating magnetic field which then induces strong azimuthal electric fields inside the discharge channel which heat the gas/plasma. The plasma is then exhausted into a vacuum chamber. As this method does not require any electrodes to heat the plasma no electrode erosion can take place which results in the production of a very pure plasma. Further the plasma source is very flexible concerning the working gas. Even chemically reactive gases can be used.

The coil in the plasma generator is driven by a RF power supply with 15 kW power and an operating frequency of 13.56 MHz. The plasma source is mounted on a cylindrical vacuum chamber of 1 m diameter and 2 m length which is pumped by a roots pump with 160 m³/h pumping speed. [1]

Recently the facility has been moved to the new Baylor Research and Innovation Collaborative. As part of this move a new vacuum chamber with more ports for better diagnostic access and a stronger vacuum system are planned and will be set up in summer 2013.

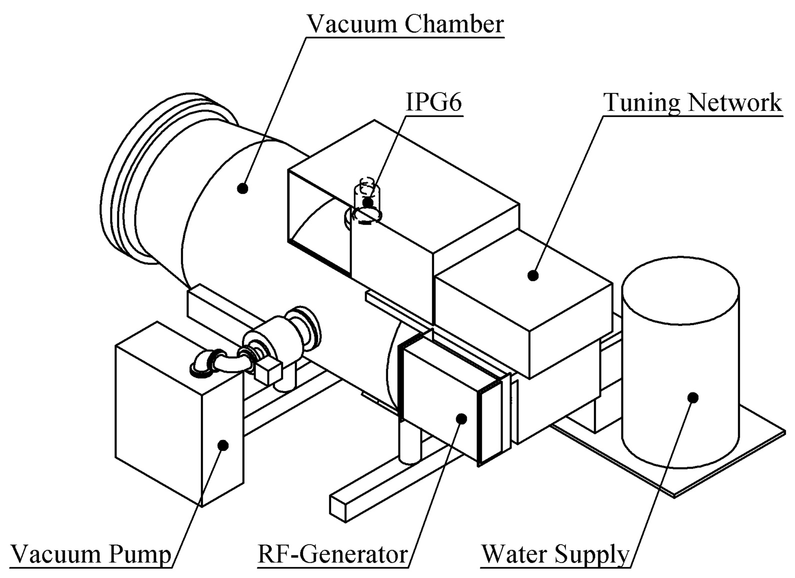

Figure 2. Current setup of the IPG6-B test facility.

Diagnostics

Currently there are three diagnostic systems available for the characterization of IPG6:

1. Cavity calorimeter to determine the total plasma jet power. [2] (Figure 3)
2. Pitot probe to measure the stagnation pressure and to allow rough heat flux estimations. [3] (Figure 4)
3. Oxygen sensors produced by the company ESCUBE. [4]

Besides these sensors several other facility parameters are recorded. These are the RF power coupled into the plasma source, the ambient pressure in the vacuum chamber and the heat losses in the plasma generator (Figure 5) . The latter played an important role in the optimization process of the plasma source.

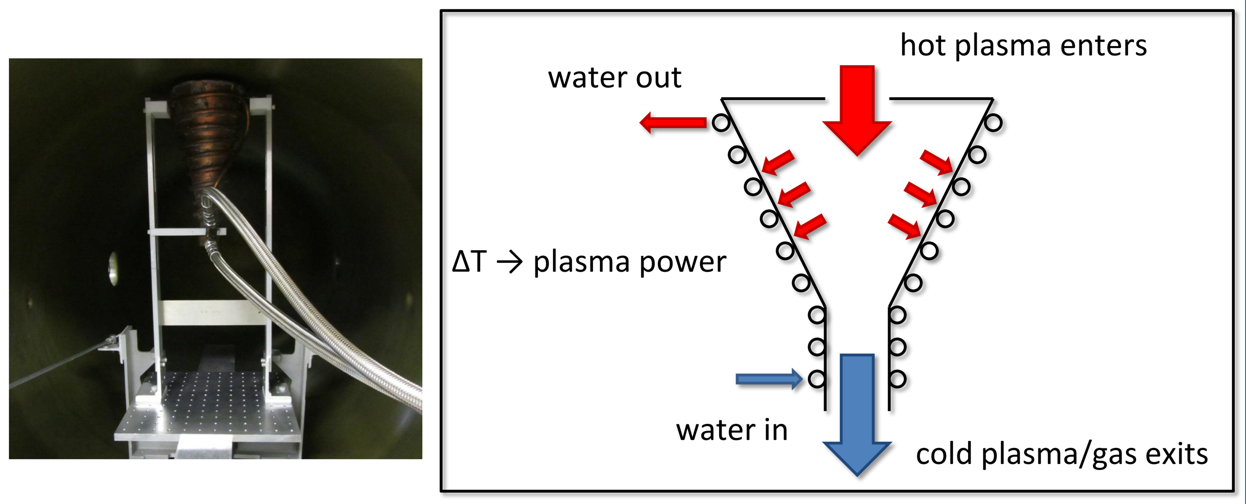

Figure 3. Cavity calorimeter. Left: Installed in vacuum chamber. Right: Working principle.

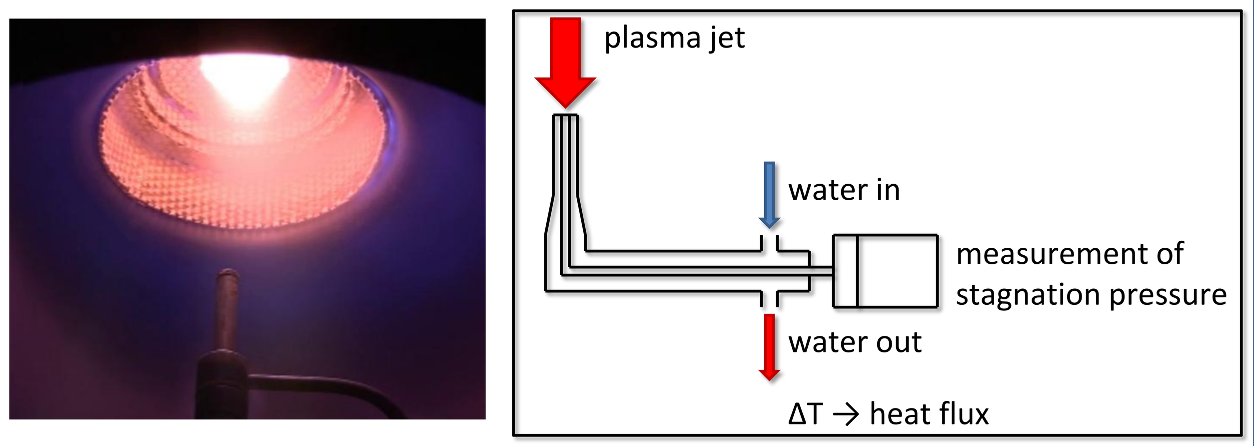

Figure 4. Pitot probe. Left: During operation of the facility. Right: Working principle.

<u>Future diagnostics</u>

In the near future a small scale heat flux probe will be built in order to measure heat flux profiles in the plasma jet. Further this probe will be usable as sample holder to expose material samples to the plasma jet.

Further measurements with a Langmuir probe are planned to obtain additional plasma parameters.

In medium term optical diagnostic methods like emission spectroscopy are considered .

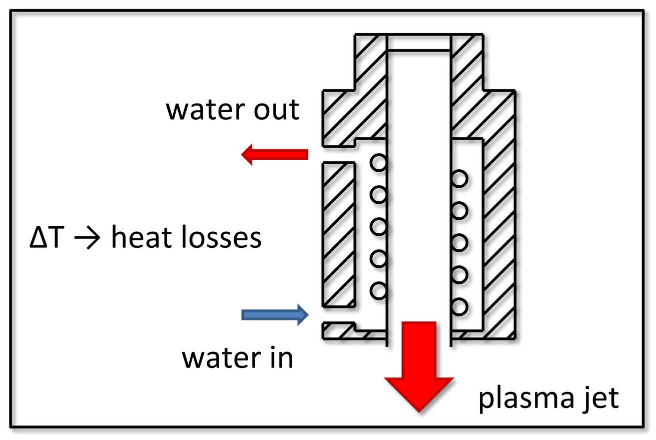

Figure 5. Schematic of the measurement of the heat losses in the plasma source.

Test results

During the last year the IPG6-B test facility was undergoing initial operation. The operating gases so far have been air, argon, nitrogen, and oxygen.

Most experiments are conducted with air at a gas flow rate of 9.2 liters/min and a static pressure of 400 Pa. Commonly used powers fall between 3 kW and 10 kW (Figure 6). Though the facility has been tested up to 13 kW. Calorimeter measurements show that the minimum efficiency of the IPG at 10 kW is 22%. Current heat fluxes have been roughly estimated to 2-3 MW/m² using the Pitot probe as heat flux probe.

Further the development of the stagnation pressure, while changing the plasma power, has been analyzed (Figure 7). It can be observed, that the dynamic part of the pressure clearly increases with increase of the power. However, due to the currently low pumping capacity the plasma velocity stays far subsonic at values of up to 0.35 Ma.

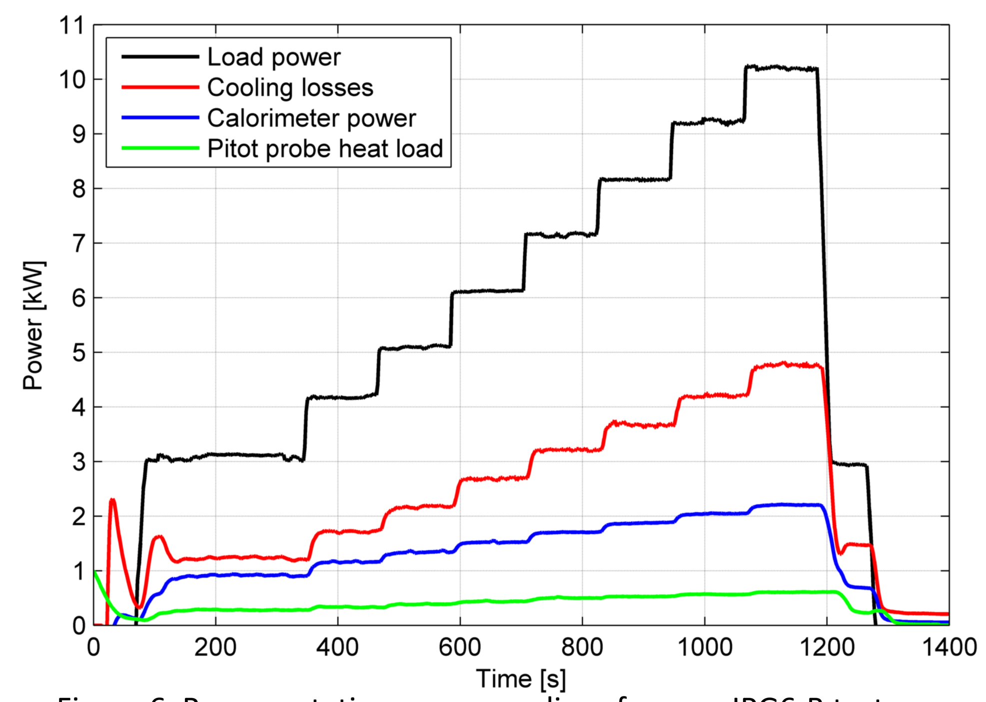

Figure 6. Representative power readings from an IPG6-B test run.

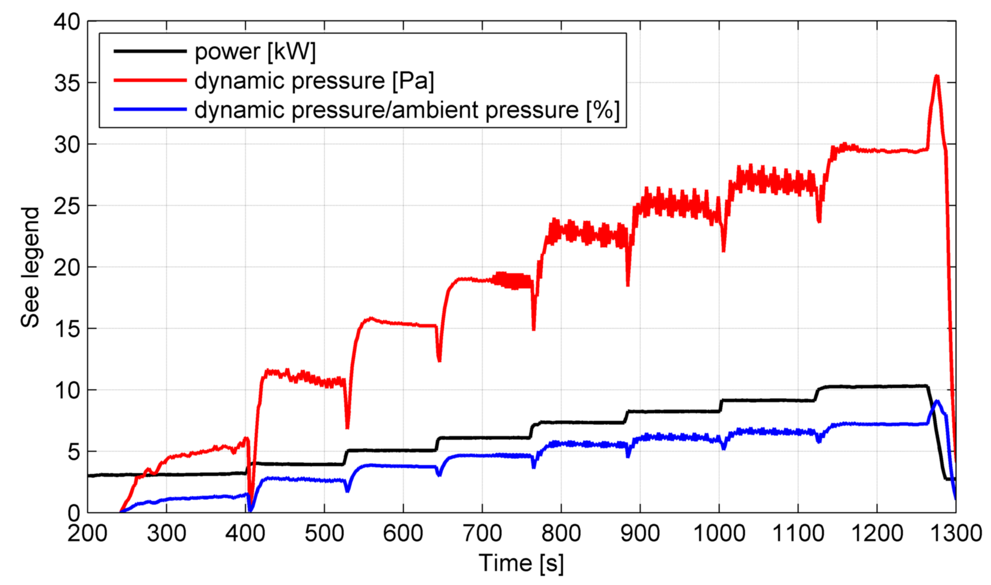

Figure 7. Representative pressure readings from an IPG6-B test run.

<u>Future tests</u>

In summer the IPG6-B test facility will be operational again being equipped with a new vacuum chamber and pumping system. Tests with the operating gas Helium are planned.

Further a magnetic nozzle will be tested in order to decrease heat losses in the plasma generator and to increase the flow velocity.

Guidance of the plasma with additional magnet coils along the plasma jet axis is being considered with a field strength of up to 0.1 T.

The qualification for hydrogen is a medium-term goal and will be addressed after the characterization for helium.

Research

<u>Potential Lunar Applications</u>

In order to create plasma conditions which are relevant for the lunar environment the test facility needs to be qualified for hydrogen plasma, which is a medium-term goal.

The interaction of hydrogen plasma with magnetic fields can be observed in order to understand the interaction of the solar wind with mini-magnetospheres on the Moon, which has been assessed in [5].

A side-arm could be used to create lower plasma concentrations. In this low density hydrogen plasma environment the charging behavior of lunar simulant dust could be observed.

Further a dust accelerator at CASPER can be used to accelerate lunar simulant dust to several hundred m/s [6, 7] in order to analyze for example resulting damages on spacecraft surfaces or the interaction of the dust with hydrogen plasma.

<u>Simulation of high heat fluxes</u>

The facility is capable of producing heat fluxes on the order of several MW/m². Thus, it can be used to create conditions similar to those during atmospheric entry of spacecraft. Varying the operating gas allows conditions relevant for entry into other planets atmospheres to be created. Using hydrogen as an operating gas as well heat fluxes as encountered in the divertor of tokamaks might be achievable. Further, using the mentioned dust accelerator will allow to simulate aspects of the combined dust and plasma conditions in divertors

<u>Basic investigations</u>

Research in the fields of plasma radiation and catalysis is planned. Both aspects are crucial for the understanding of the heat flux on thermal protection systems of spacecraft.

Conclusions

The IPG6-B test facility has been placed into operation and has undergone first characterization with air plasma during the past year. Tests show that high heat fluxes of several MW/m² can be achieved.

Recently the facility has been moved to the Baylor Research and Innovation Collaborative. As part of the move the facility will be equipped with a new vacuum chamber and pump system. For summer the characterization with helium plasma and the test of a magnetic nozzle are planned. Further a dust accelerator will be attached to the facility to observe the interaction between dust and plasma. In medium-term the qualification for hydrogen plasma is planned, which can make the facility a potential test bed for different aspects of the lunar environment.

References

[1] Dropmann M. et al. (2013) *IEEE Transactions on Plasma Science*. [2] Puckert D. et al. (2012) *AIAA Pegasus Conference*. [3]. Koch H. et al. (2012) WPDP XXIII. [4] Gomringer C. et al. (2012) WPDP XXIII. [5] Bamford R.A. et al. (2012), *PRL 109, 081101*. [6] Peters S. (2012) *Diploma Thesis, Institute of Space Systems, University of Stuttgart*. [7] Carmona-Reyes J. et al. (2004) *LPSC XXXV*, Abstract #1019.