DEVELOPMENT OF A NEW MEMS PROBE FOR THRUST MEASUREMENT IN ELECTRIC PROPULSION TESTING

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Thrust measurement

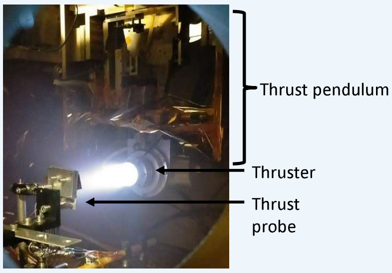


Fig. 1 The thrust probe is immersed in the plasma jet of the ONERA ECR thruster. An arm can move it with other diagnostic probes. A pendulum measures the ECR thrust

Thrust can be obtained by:

- ❑ Integration of the generalized momentum flux on the thruster surface (pendulum)
- ❑ Integration of the flux on a section of the thruster plasma beam (target, electrostatic probe)

Standard in the industry but:

- ❑ Design constrained by vacuum tank size
- ❑ Some test conditions prevent their use (cold-start tests)
- ❑ It cannot be used with some large and heavy thrusters

Question

Can we use ONERA's highly sensitive MEMS sensor for thrust measurements?

Challenges

Thermal effects
Electrostatic effects
Ion sputtering
Plasma sheat

Working Principle

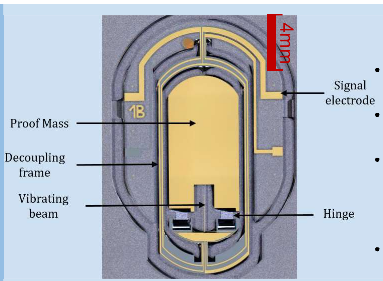
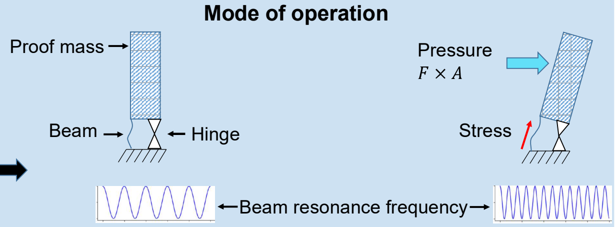


Fig. 2 Microscope photography of the quartz resonator.

Sensor design

- The pressure sensor is based on a quartz accelerometer from the ONERA.
- **Hinges** and a **beam** link the sensor frame to the **proof mass** (with a surface **A**).
- The beam is actuated at **resonance frequency** ν_0 through piezoelectric actuation using electrodes deposited on the beam surface.
- Metallic layer → reduce thermal and electrostatic effects

Mode of operation



$$\nu = \nu_0 + S_1 AF + S_2 (AF)^2 + \delta(T)$$

Fig. 3 Mode of operation of the pressure sensor

ν_0	S_1	S_2	$\delta(T)$	Noise
$50kHz$	0,3 Hz/µN.cm^{-2}	$-8{,}3 \times 10^{-7}$ Hz/(µN.cm^{-2})^2	0,45 Hz/°C	0,14 mHz/µN.cm^{-2} @10s

The plasma applies a pressure on a surface A' of the proof mass of 2 sensors mounted in **differential measurement configuration**. The **difference between both frequency drifts** gives:

$$\Delta f = 2 S_1 A' F$$

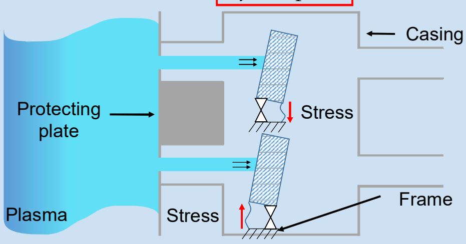


Fig. 4 Schematic of a side view of the probe representing two sensors in the differential measurement configuration

A shutter is used to protect or expose the sensors to the plasma. Tubes in the case evacuate the plasma and the gases.

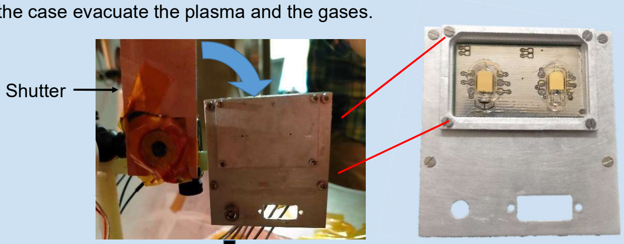


Fig. 5 Photography of the probe and the shutter

Manufacturing of the probe

Measurements

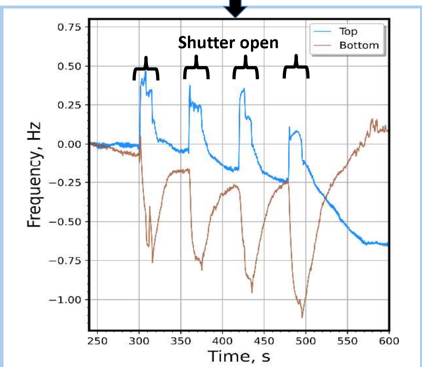


Fig. 6 Frequency change of the two sensors when the shutter is opened at minutes 5, 6, 7, and 8 for 15s each time.

Estimated frequency drift from plasma properties:

$$\Delta f_{estimated} = 3\ mHz$$

Measured frequency drift

$$\Delta f_{measured} = 0{,}48 \pm 0{,}04\ Hz$$

The thruster is running with the probe located in the thruster axis at 25cm. The signal from the top sensor goes up while the other one goes down as expected. The amplitude of these changes is **100 times higher than predicted** (5mHz).

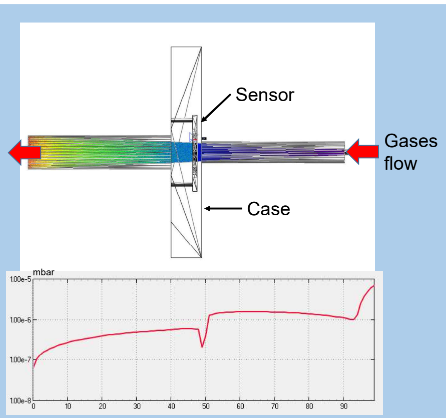


Fig. 7 Simulation of the probe on Molflow+ software. The plasma builds up in front of the whole proof mass creating, a pressure gradient.

With the low plasma pressure, ions behave in the **free molecular flow regime**. They bounce randomly between the proof mass and the case walls. The gases build up in the sensor's front face, **creating a pressure gradient across the proof mass**. A simulation on Molflow+ software validates this hypothesis.

Conclusion:

- ✓ A probe, using MEMS-based pressure sensors in a differential configuration, was developed
- ✓ The probe was used in the plume of an ECR thruster.
- ✓ Various biases were corrected (variation, probe charging) to obtain a repeatable signal.
- ✓ Repeatable unwanted perturbations still influence the pressure measurement, possibly the gas buildup in the probe cavity.

Perspective :

→ Try this design on a different plasma source
→ Design a new probe (sensor + casing) to improve the measurement
→ Understand the plasma flow when a probe is immersed in the plasma jet (simulation)