LISA Pathfinder FEEP Subsystem

Davide Nicolini
European Space Agency - ESTEC
Scientific Projects Department
LISA Pathfinder Project

[Presented by César García, LISA Pathfinder Project]

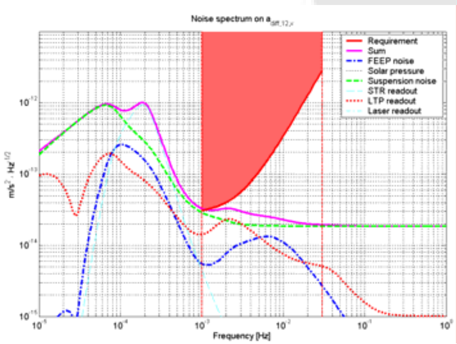
LISA Pathfinder FEEP Subsystem

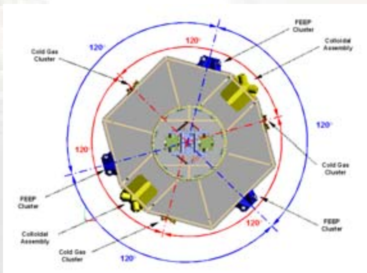
- The FEEP thruster development for LISA in recent years was carried forward in the frame of the Microscope project and related LISA technology activities and more recently in the frame of the the LISA Pathfinder project.
- Main development objectives are:
  - To design and manufacture proportional thruster systems (thruster + power control unit + neutralizer) in the range between 1 and 100 uN, with a thrust noise of 0.1 uN/sqrt(Hz), a bandwidth of 10 Hz and excellent controllability
  - To continuously guarantee such performances over the lifetime required (5 years for LISA)
  - To demonstrate, on ground, the performance (in particular thrust noise is difficult to measure)
- Under LISA Pathfinder contract
  - In Phase 1 (15 months): the FEEP technology development phase will be completed and brought to qualification level;
    - Development Model which is a QM for thrusters and neutraliser with non-flight components for the PCU
    - Environmental and performance tests
    - 2,000 hr of life-time test
    - Technology specific tests
  - In Phase 2: Flight hardware will be produced and verified
  - Phased 1 kicked off in June 06

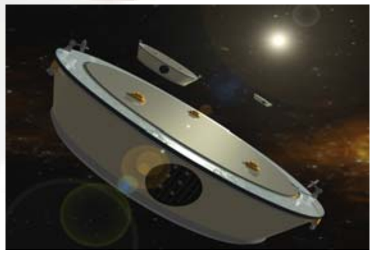
LISA Pathfinder FEEP Subsystem

- The applicable drag-free propulsion requirements for FEEP.

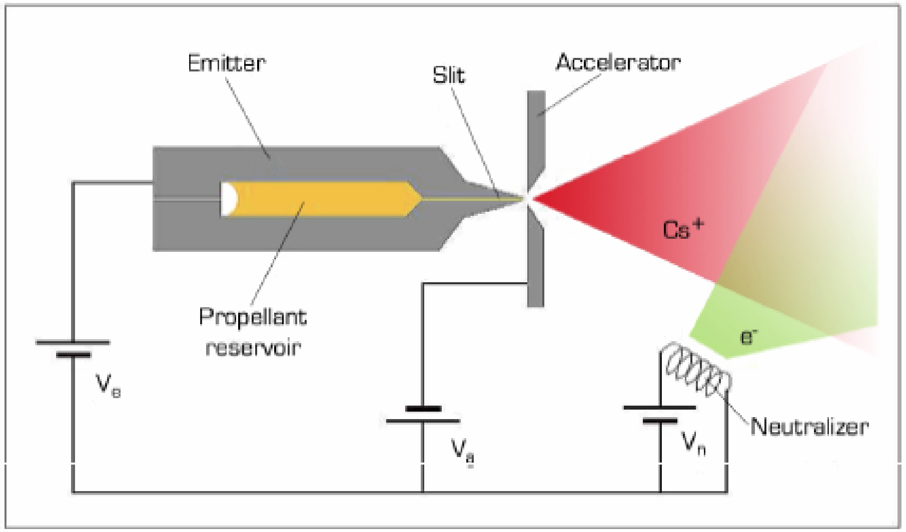
	LISA Pathfinder	*MICROSCOPE*	*LISA*
• Thrust:	1 – 100 N	1 – 150 N	1 – 100 N (TBC)
– resolution:	0.1 N	0.1 N	0.1 N
– noise (1 mHz – 1 Hz):	0.1 N/Hz$^{1/2}$	0.1 N/Hz$^{1/2}$	0.1 N/Hz$^{1/2}$
– linearity & bias:	2 N	2 μN ± 5%	2 μN
– repeatability:	0.5 N ± 0.5%	0.5 μN ± 0.5%	0.5 μN ± 0.5%
– direction stability:	0.5 deg	0.5 deg	0.5 deg
– response time:	100 ms (30 N step)	160 ms (10 N step)	100 ms (30 N step)
– actuation frequency:	10 Hz	4 Hz	10 Hz
• Total impulse:	2,500 Ns	3,100 Ns	5,000 Ns
– lifetime (@ average thrust):	~9,000 hrs (@ 75 N)	~9,000 hrs (@ 100 N)	~18,000 hrs (@ 75 N)





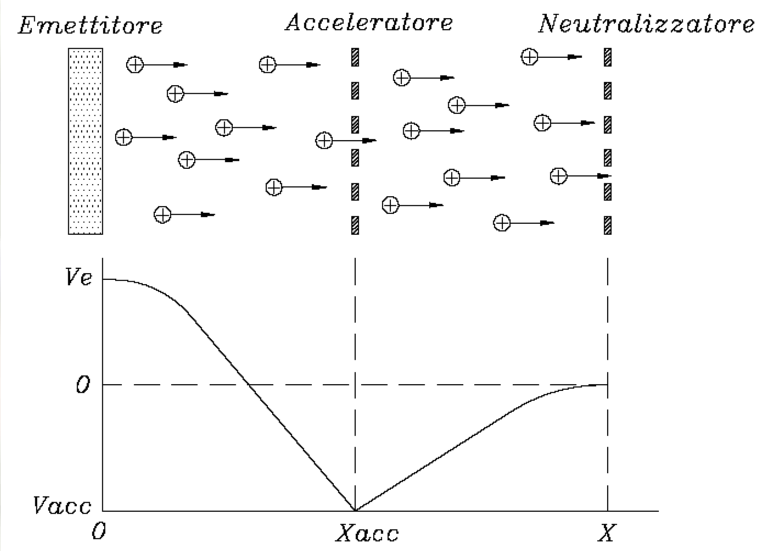


Field Emission Thruster concept



$$qV_e = \frac{1}{2}Mv_e^2 \Rightarrow v_e = \sqrt{\frac{2qV_e}{M}}$$

$$\dot{m}_i = \frac{MI_b}{q} \qquad I_b = I_e - I_a$$



FEEP is an electrostatic type thruster:

⇒ thrust is generated by ions accelerated at high exhaust velocities by electric fields;

⇒ electrons need to be emitted downstream in the same quantity for charge balancing.

Field Emission Thruster concept

The ion beam current is a function of the applied total voltage:

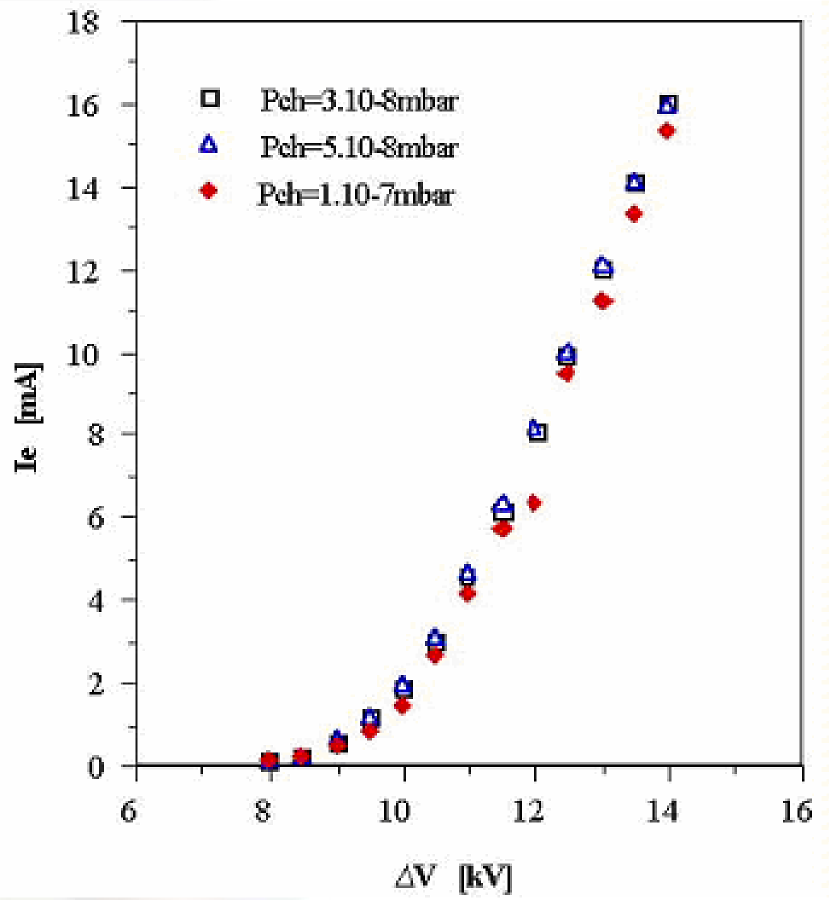
$$I_b = f(V_e, V_a)$$

$\Rightarrow$ Thrust is controlled only by one parameter (emitter voltage or beam current):

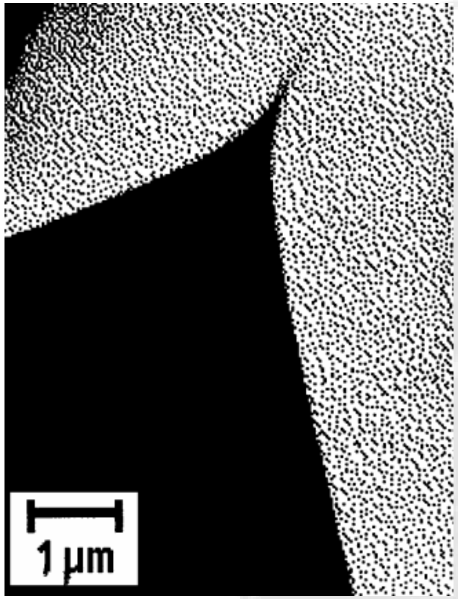
$$T = \eta_{div} I_b \sqrt{\frac{2MV_e}{q}} = kI_b\sqrt{V_e}$$

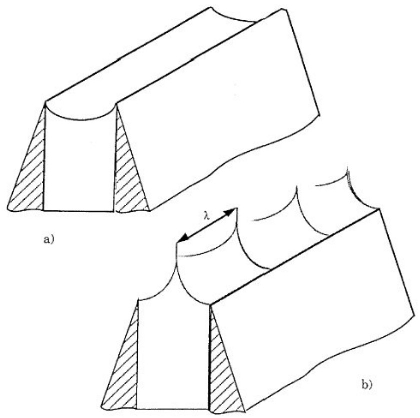
Power supply mass is a function of thrust, specific impulse and efficiency:

$$m_p = \alpha P = \frac{\alpha T v_e}{2\eta} = \frac{\alpha \dot{m} v_e^2}{2\eta}$$



Field Emission Thruster concept



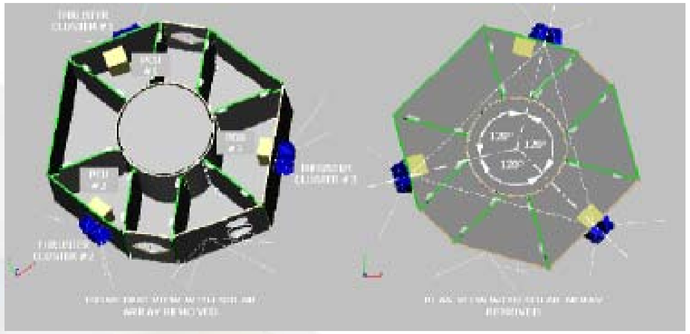


Ions are generated by field emission, i.e. direct ionization of a liquid metal by applying an intense electric field at its free surface.

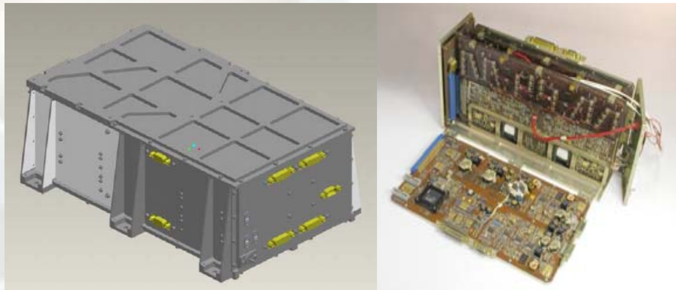
- A Taylor cone forms due to the intense field strength, from which the ion emission occurs
- A needle ion source emits ions from one Taylor cone formed on its tip
- A linear (slit) ion source emits ions from many Taylor cones which form naturally along the slit (up to 120/mm)
- Each Taylor cone nominally emits a current of 1 A, but can reach up to 10 A (corresponding approximately to 1 N of thrust), above which it gradually becomes unstable and starts to emit droplets

LISA Pathfinder FEEP Subsystem

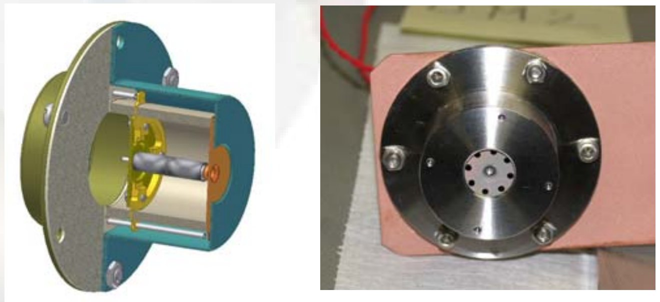
- The main constituents of the FEEP subsystem are:
  - Thruster Assembly (TA)
    - The FEEP thruster, the high energy ion source the produces the desired thrust, with its propellant tank
  - Neutralizer Assembly (NA)
    - The low energy electron source that balances the charge accumulated by the ion emission
  - Power Control Unit (PCU)
    - The electronic box that provides power and controls the thruster and the neutralizer
- There are 3 clusters of 4 TA on the spacecraft, each with its own PCU and NA.
- A single PCU drives 4 TA; a single NA neutralizes the charge of 4 TA.



Subsystem layout on the spacecraft



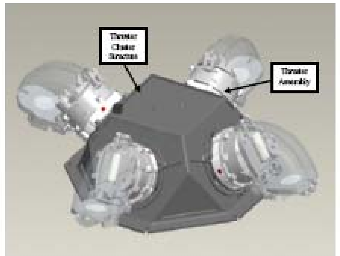
PCU



NA

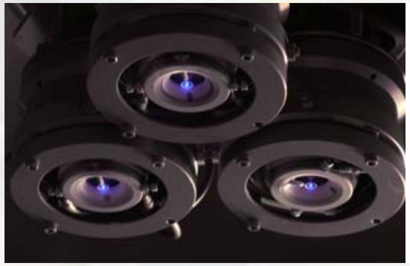
LISA Pathfinder FEEP Subsystem

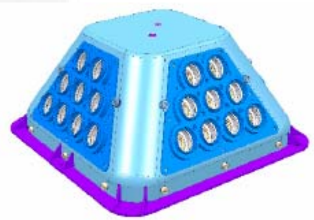
- Two FEEP thruster technologies are under development in Europe. Both technologies are to be qualified in the frame of the LISA Pathfinder FEEP phase 1 activities. One will be selected for phase 2 (flight) in mid 2007.
- Slit FEEP technology
  - Based on slit ion source
  - Uses the alkali metal Cesium
  - Thrust range from 0.1 to 150 N



Slit FCA design

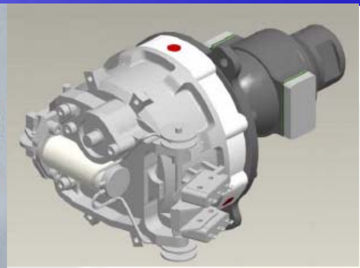
- Needle FEEP technology
  - Based on needle ion source
  - Uses the metal Indium
  - Thrust range from 0.1 to 10 N, requires clustering for extending the thrust range (9 needle thruster is being qualified for LISA Pathfinder)

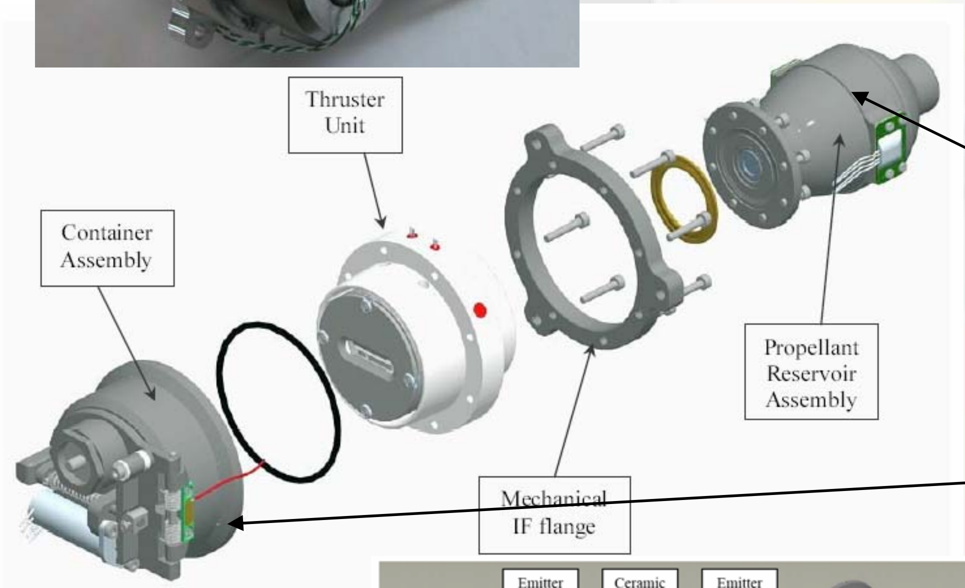


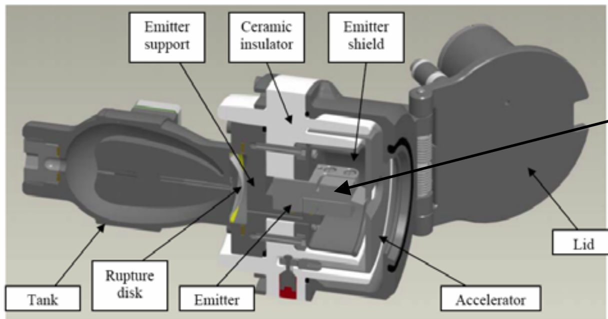


Needle FCA design

Slit FEEP technology







The core part of the TA is the Thruster Unit (the ion source). Attached to it the propellant tank to feed the thruster and the container to keep the thruster in protected environment.

- Tank: the Cesium propellant is sealed by a rupture disk to be opened in space by the propellant's thermal expansion, and then flows to the thruster by capillarity

- Container: the thruster is kept under clean argon sealed by a lid mechanism to be opened in space

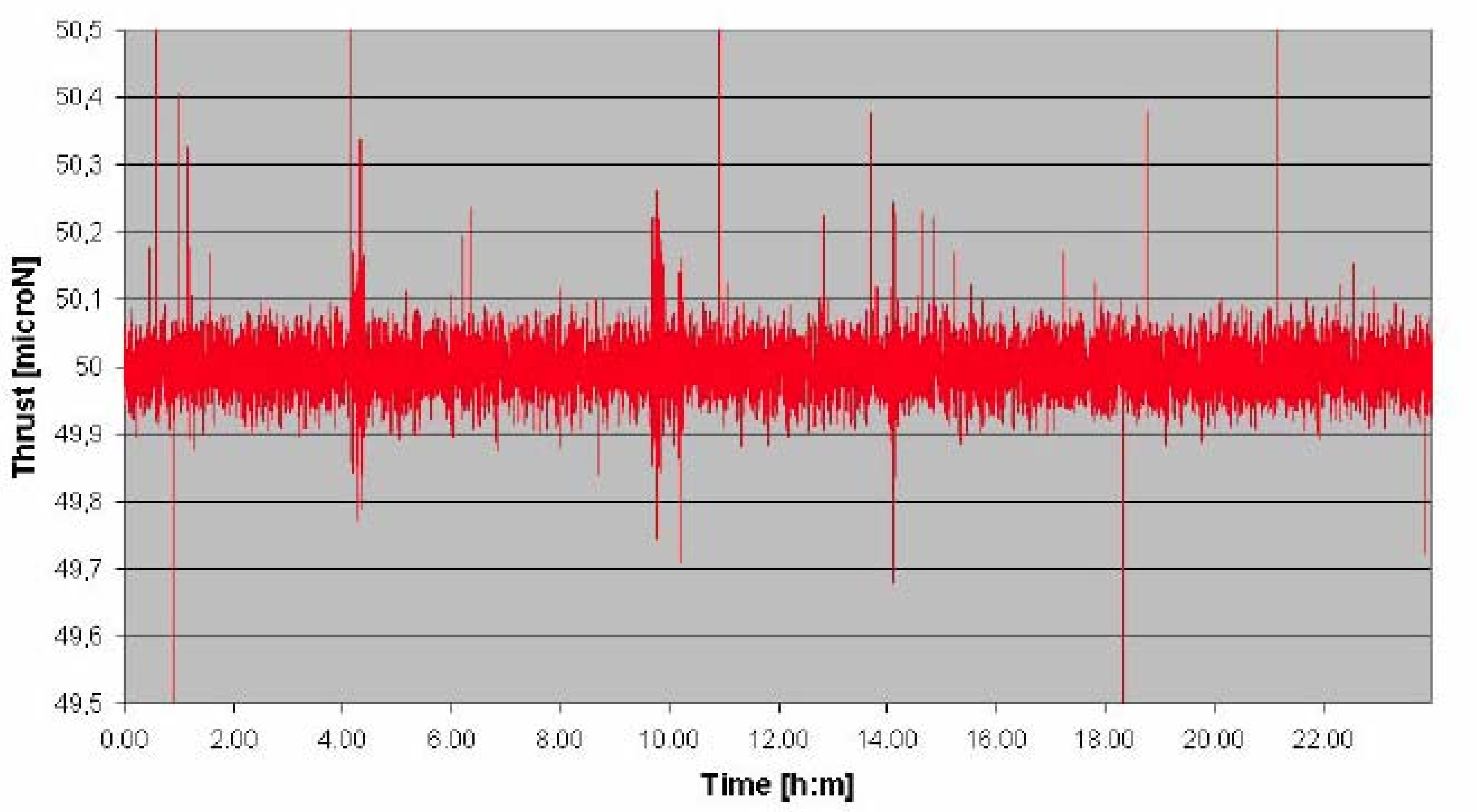
- Thruster Unit: the ceramics support and shield the high voltage electrodes (emitter and accelerator)

Slit FEEP technology

- The main goal of the LISA Pathfinder phase 1 is to solve all the remaining engineering issues, in particular at tank level and at thruster level. Then perform a full qualification campaign at subsystem level and a partial life test (2000 hours).
- At present the status is:
  - Performance has been characterized by indirect measurements, i.e. measuring the currents and voltages outputs of the PCU to the Thruster
  - The emitter was endurance tested, up to 500 Ns (1600 hours)
  - The complete thruster assembly (without tank sealing device) was tested demonstrating excellent performance
  - PCU BB (thruster high voltages supply only) and TA tested for dynamic response;
- Planned activities:
  - Thruster qualification and lifetime test
  - PCU test together with the TA
  - Direct thrust measurements to be performed with the Nanobalance

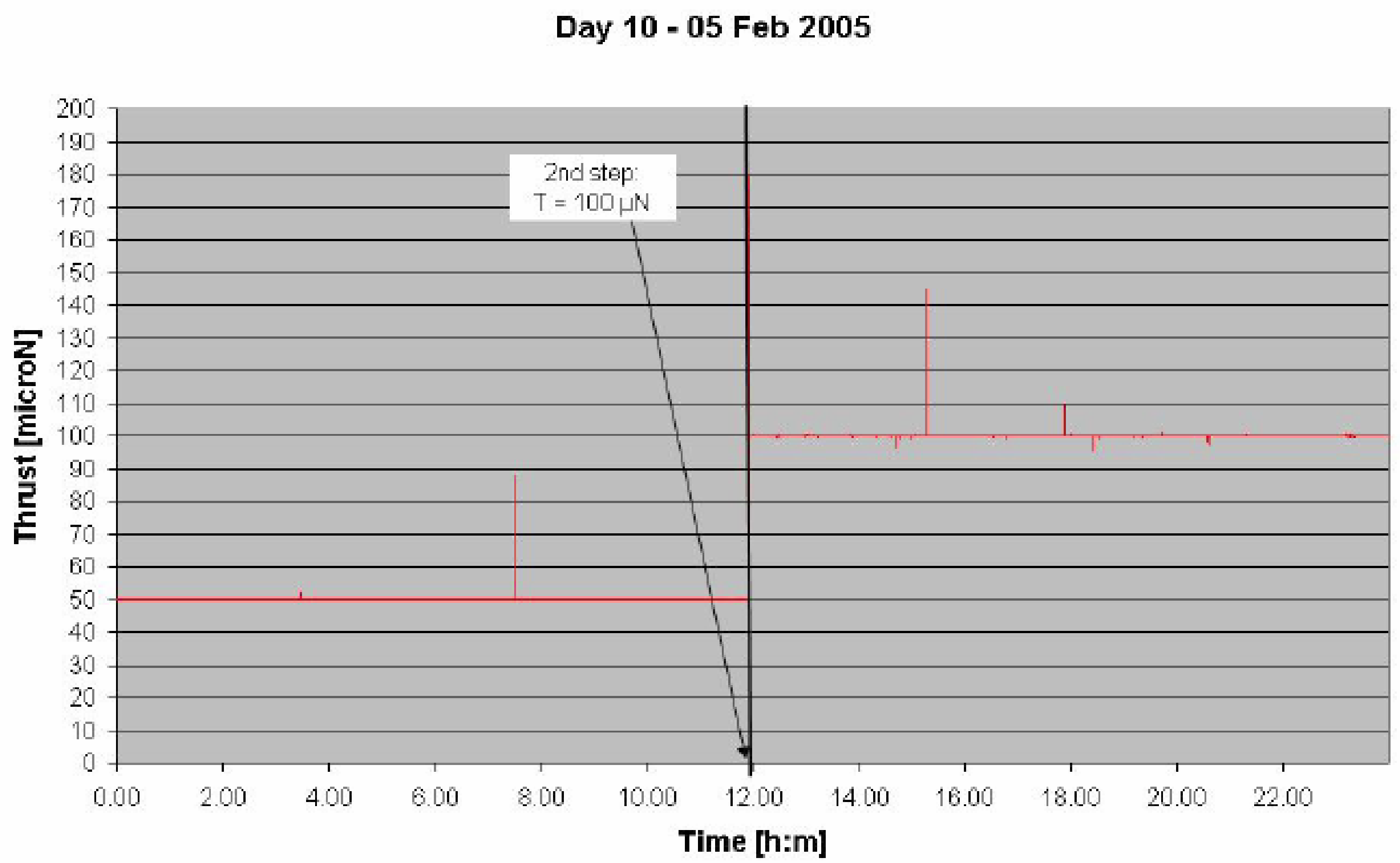
Slit FEEP technology

24-hour constant thrust phase (50 microN)



Slit FEEP technology

Transition from 50 to 100 microN profile



Slit FEEP technology

Response time in open loop (FEEP + BB PCU)

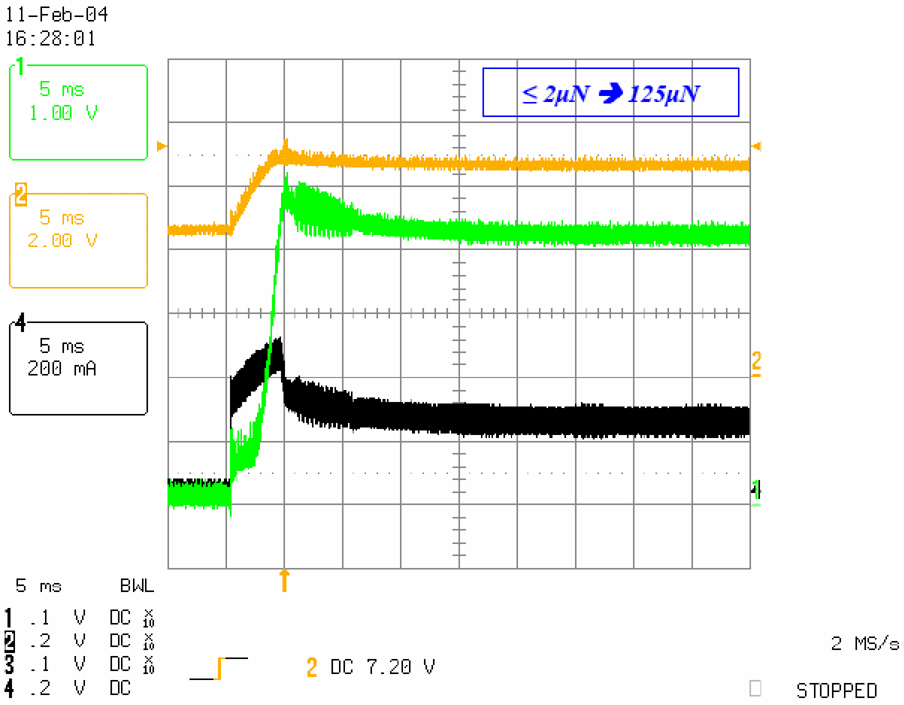


Fig. 5-1: Thrust variation from ~2µN to 125µN.

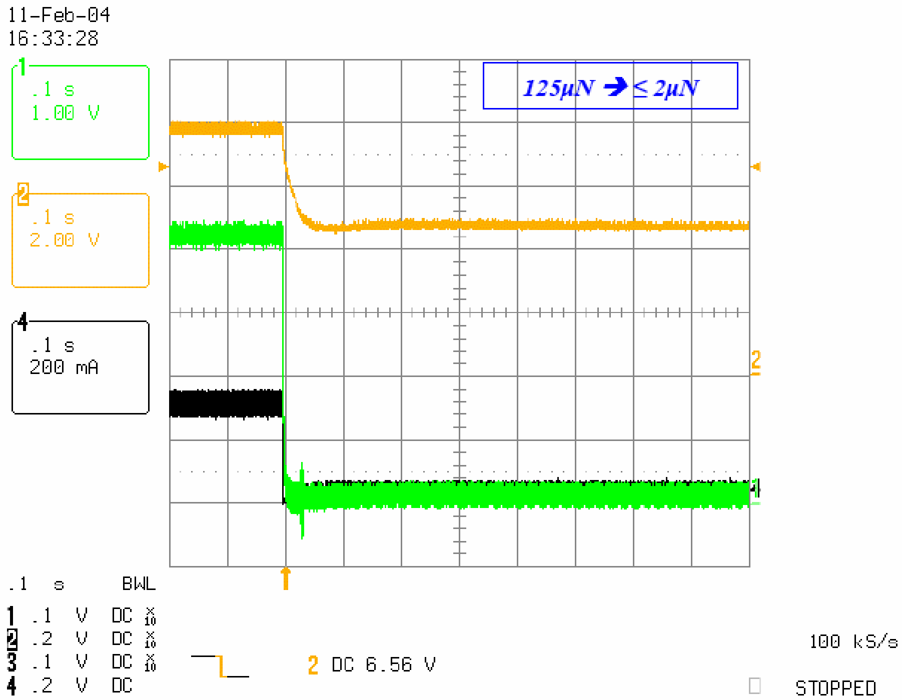
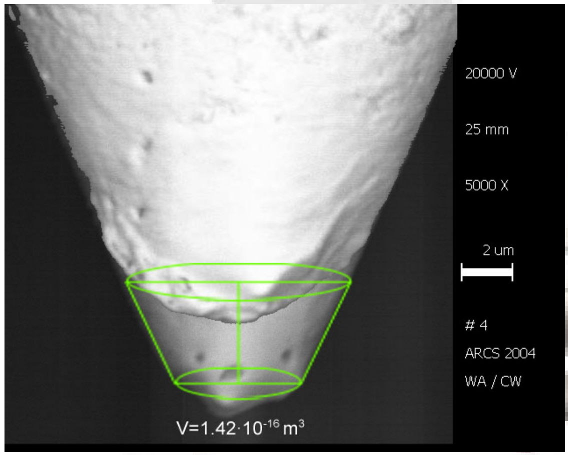
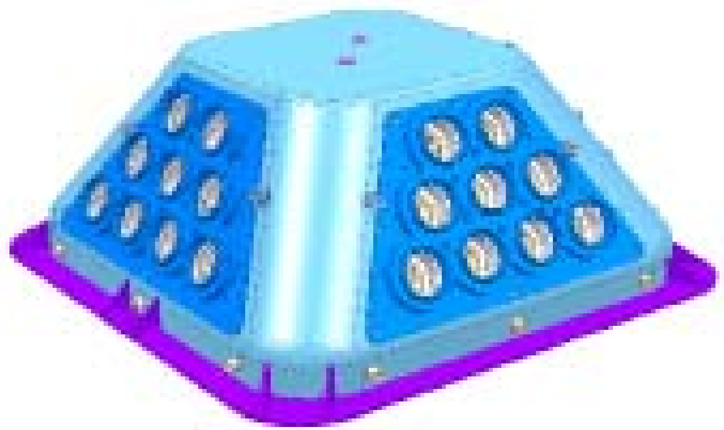


Fig. 5-2: Thrust variation from 125µN to ~2µN.

Needle FEEP technology

- The Indium technology is based on a needle concept for the emitter
- The high thrust requirement is obtained by clustering 9 needles per thruster driven by a single power supply.
- In order to achieve the proper current distribution on the needles, high impedance resistors are used.
- The pre-resistors dissipation during thruster operation are used to aide the propellant heaters.
- Each needle ion source has its own propellant tank capable of holding up to 15g of Indium.



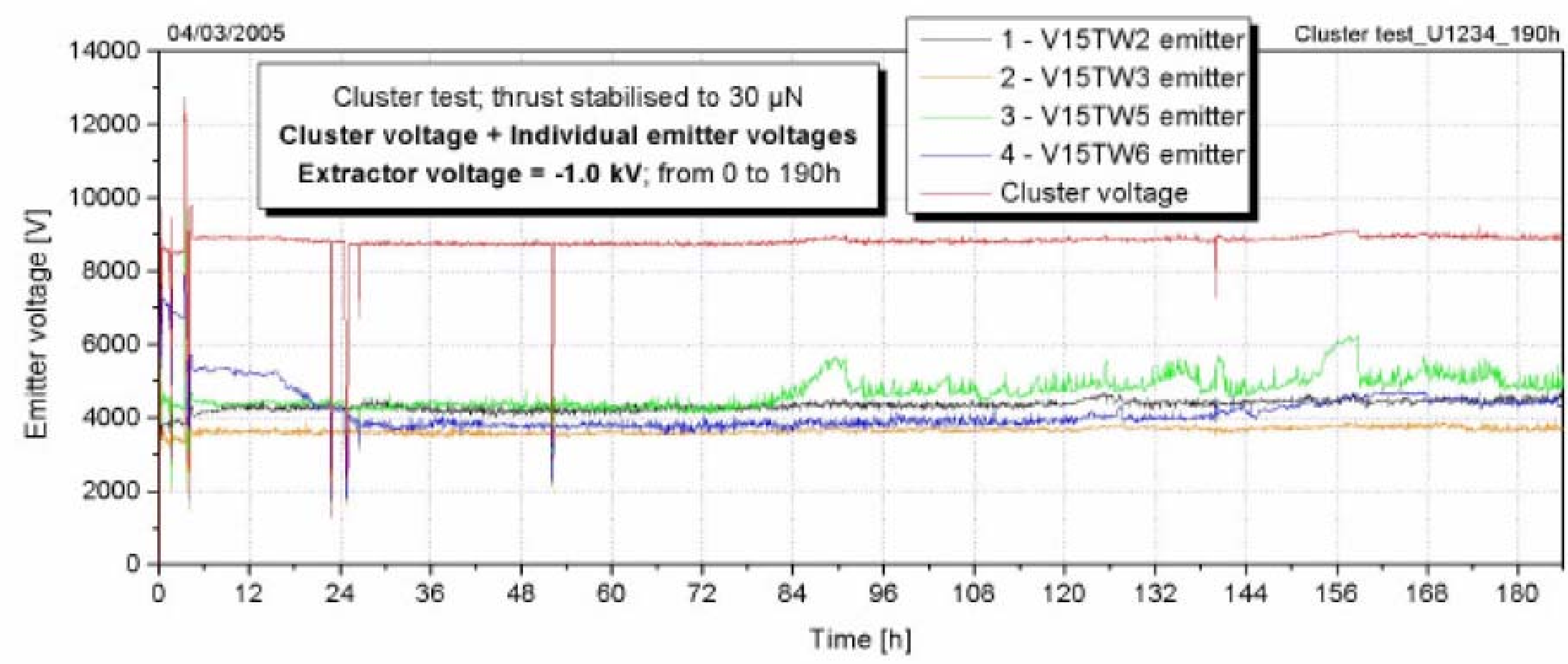


Needle FEEP technology

- As for the slit FEEP, the main goal of the LISA Pathfinder phase 1 is to solve all the remaining engineering issues, in particular at needle and tank level and at thruster level (clustering). Then perform a full qualification campaign at subsystem level and a partial life test (2000 hours).
- At present the status is:
  - All the performances have been characterized by indirect measurements, i.e. measuring the currents and voltages outputs of the PCU to the Thruster
  - A reduced set of emitters were endurance tested up to 5000 hours
  - A 4 needle thruster cluster BB has been performance and endurance tested
- Planned activities:
  - The complete thruster assembly design, build and performance testing
  - The PCU build and testing with the thruster
  - Thruster qualification and lifetime test
  - Direct thrust measurements to be performed with the Nanobalance

Needle FEEP technology

- During the performance test the 4 emitter thruster/cluster showed a very good performance and the difference between the pseudo-thrust and the actual thrust was minimal (0.73 uN, 2.3% of the thrust command. Req is 2 uN)



Conclusions

- The LISA Pathfinder FEEP subsystem is the design reference for the LISA system. The only relevant requirement difference between the two missions is lifetime (~ double in LISA)
- The current developments for the FEEP technology in Europe show that the thrust performance is achievable.
- TRL 4-5 already achieved
- LISA Pathfinder development will bring **both** European FEEP thruster systems to flight standard design and close to qualification
- One thruster type will be chosen for FM manufacturing and flight on LISA Pathfinder