University of Michigan’s Upgraded Large Vacuum Test Facility

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History

LVTF is a six meter diameter by 9 meter length vacuum chamber constructed in 1961, Bendix Aerospace.

Plasmadynamics and Electric Propulsion Laboratory in 1992, University of Michigan under Gallimore

MPDs, arcjets, gridded ion thrusters, hall thrusters, hollow cathodes, plasma physics, industry & government test campaigns

LVTF (2009) shown at 31st IEPC
Motivation

1. Higher power thrusters
   flight thrusters range 5 kW – 12.5 kW
   research thrusters as high as 100 kW

2. Facility effects below 10 µTorr
Followed best practices reporting effective pumping speed*

- Mass flows in sccm (ref. room temp, 298 K)
- Internal stabil ion gauge in shown gauge envelope
- Mounted in the exit plane near thruster


\[
\text{Effective Pumping Speed} \quad \text{Pumping}_{\text{eff}} = \frac{\dot{m}}{P_{\text{measured}} - P_{\text{base}}}
\]
New Facility Configuration

Layout driven by constraints of the facility’s geometry

Added six additional TM1200i (35,000 l/s)
Installed six PEPL developed cryopumps (39,600 l/s)
Bottom line performance

Pre-upgrade specs
Seven Large Cryopumps
245,000 l/s (Xe) installed
~190,000 l/s (Xe) effective w/ thruster

Upgraded facility specs
Eighteen Large Cryopumps
653,000 l/s (Xe) installed
~500,000 l/s (Xe) effective w/ HET
600,000 l/s (Xe) effective cold flow
~600,000 l/s (Kr) effective w/ HET
LVTF performance
For 500,000 l/s effective pumping speed xenon

Recommended maximum pressure targets
HET performance testing < 30 µTorr
HET near field plume measurements < 13 µTorr

Small constellation hall thruster
1 kW, 3 mg/s, 400 V: 1 µTorr

NASA AEPS, high power operation#
12.5 kW, 23 mg/s, 600 V: 6.5 µTorr

X3, highest thrust point at NASA VF5*
99 kW, 236 mg/s, 400 V: 65 µTorr
NASA VF-5 pressure: 42 µTorr

# Source: R. Hofer et al., IEPC-2017-231
* Source: S. Hall et al., IEPC-2017-228
Supporting infrastructure

1. Significant Additional Capacity for LN2 for Thermovac Applications
2. Centralized process cooling water
3. Upgraded electrical circuits to support additional cryopumps
PEPL cryopump background

- Compact, high pumping speed cryopump for xenon and krypton.
- First demonstrated 1996 at JPL (C. Garner et al.)
- Shroudless operation is possible – LN 2 Free
- Thermal radiation dominates heat transfer
- Plate emissivity rapidly increases with ice

**Pumping Plate**
- < 55 K pumping plate for xenon
- < 43 K pumping plate for krypton
Design Targets for PEPL Cryopump

1. Liquid nitrogen free
2. Pump xenon and krypton
3. Performance > 35,000 l/s
4. Fit within 48ASA caps in LVTF
PEPL cryopump final design

Theoretical pumping speed condensing gas

\[ S_{th} = A \sqrt{\frac{T_i R}{2 \pi M}} \]

Theoretical pumping speed for Xe @ 298 K:
\[ S_{th} = 55,000 \times A \]

Modeling Details:
Emissivity = 1 (worst case), Copper TC = 400 w/m K (worst case)
Pump Surface Area = 0.72 M2
Radiative Load = 335W
Delta T Across Pump = 13 K

Final Design Thermal Model
- 90 cm x 85 cm x 0.95 cm (backplate)
- 46 cm x 46 x 0.95 cm (top plate)
- Copper plate mass = 75 kg
- MLI on rear – Zero radiative heat transfer to back of plate

Xe Pumping Speed for this plate:
39,600 l/s
1. Eff. pumping speed near theoretical (39,600 l/s)
2. 120 L condensed xenon gave ∆T of 2 K on plate
7 kW, 100 hour, 1000 l test

14.8 mg/s total flow – 4.3 µTorr Xe – Effective Pumping speed 484 kl/s
Questions

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Thermal Conductivity Cu Alloys

![Graph showing thermal conductivity vs. temperature for 99.99% and 99.9% copper alloys. The graph includes data points for Copper 101 and Copper 110. The image also shows a setup with 3X Silicon Diodes and Heaters.]