Laser ablation propulsion

PhD workshop, 02/12/20

Pietro Battocchio
An intense \((GW/cm^2)\) and short \((ns)\) laser pulse irradiates the target material.

Some mass is removed from the irradiated area.

**Metals**
Ejection of vapor and liquid nanodroplets.

**Polymers**
Ejection of decomposition products: gas and chain fragments.
Ablation mechanisms

Two mass removal mechanisms are involved:

1. Fast vaporization or decomposition of the material

2. Phase explosion
   - As $T \sim T_c$ (critical temperature), extreme thermodynamic conditions
   - Homogeneous nucleation of vapour bubbles
   - Ejection of liquid nanodroplets
Laser ablation propulsion

**Small ejected** mass ($\mu g$) leaves the material at **very high exhaust velocity** (km/s)

**Momentum conservation**

$$m_{\text{target}} \Delta v_{\text{target}} = m_{\text{ejected}} v_{\text{exhaust}} \sim \mu N s$$

**Thrust generation on target material**

Laser ablation can be exploited as a **propulsion system**
Applications of laser ablation propulsion

Two main applications in the space field:

Deorbiting of space debris

1970
1980
2000
2018

GEO ~35000 km
~2000 km
LEO

Power storage (laser) far from fuel
(target material on board)

Solution to mass and power limitation

Propulsion for small satellites

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Experimental apparatus for impulse measurements

Pendulum oscillates before and after impulse

Variation in its angular velocity is measured

Oscillation angle $\sim 1^\circ$

Amplitude on scale $\sim 10$ cm

20 ns

$\lambda = 248$ nm

KrF excimer laser

vacuum chamber

window

mirror

lens

20 ns

$\lambda = 248$ nm

KrF excimer laser

control electronics

vacuum pump

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Experimental apparatus for impulse measurements

3D printer displacement system

Probe laser

High-Speed Camera

Upper optical window

250 mm lens

Incidence angle

Lateral Window

Excimer laser

GeeTech

Multigauge

V1

V2

V3

V4 refill

3D printed components

stepper motors for vertical displacement

vertical normal to target

horizontal

45°

laser beam

stepper motors for horizontal displacement

threaded rods

target

mirror for probe laser

fulcrum screws

stabilization screws

screw to correct c.o.m position
Impulse measurement: data analysis

High speed (1000 fps) video of reflected probe laser

Incoming beam

Reflected beam

Image analysis: scale calibration
Impulse measurement: data analysis

Incoming and reflected beam coincide

Image analysis: tracking the motion of reflected probe laser

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Impulse measurement: data analysis

Displacement of reflected spot $S(t)$

Oscillation angle $\theta(t)$

Impulse instant $t_{imp}$

Period of oscillation $T$

Mass of the pendulum ($m$), c.o.m. position ($d$), arm ($r$)

Angular velocity before and after impulse

$\omega(t) = \frac{d\theta(t)}{dt}$

Variation in angular velocity $\Delta\omega$ at $t_{imp}$

Generated impulse:

$J = \frac{I\Delta\omega}{r}$

Resolution: 50 nN s
Impulse measurements on poly (vinyl chloride) (PVC)

Materials can be designed to generate higher impulse

Addition of carbon nanoparticles in PVC as absorbers of laser radiation
Future works

Tune polymer properties to understand their role in impulse generation
  • Mix of PVC and PSS

Systematic study of propulsion performances of Aluminum
  • Impulse generated at different laser incidence angles: role of plasma shielding
  • Measure of ejected mass during impulse generation
Thank you!