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Technical Notes

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Comparative Study of Plastics as Propellants for Laser Ablation Plasma Thrusters

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Nomenclature

C_m = coupling coefficient
$F(t)$ = produced thrust
I_{SP} = specific impulse
$\overset{*}{Q}$ = energy of ablation per unit mass
v_E = exhaust velocity
v_T = target velocity

I. Introduction

A NEW analysis and comparison of laser ablation propulsion (LAP) parameters like specific impulse and coupling coefficient obtained while ablating different prospective plastic materials is presented in view of selecting the most suitable of them. The tests involved a medium–low energy pulsed laser along with a free-moving ballistic pendulum with a target pasted on it. In a novel application of 2-D position-sensitive detectors (PSDs) in LAP, the displacement measurements were taken by the noncontact optical triangulation with a laser. Their use gave the advantages of detecting any unwanted lateral movement of the pendulum. The study should have high utilization for the future LAP applications.

Laser ablation propulsion technique, introduced by Arthur Kantrowitz in 1972, depends upon the characteristics of laser source as well as those of the target material, as the momentum of the target is produced in reaction to the generated momentum of the ejecting particles [1–3]. Specific impulse values up to several thousand seconds are possible by properly choosing the propellant, that is, target material and the laser pulse characteristics. The momentum of the object may well also depend on the coupling coefficient of material–laser interaction. Earlier works include ablation with some of the materials included in this study, but here a list of three commonly available plastics is analyzed and compared [3–6]. Additionally, most researchers have employed mechanical force sensing for thrust measurement or charge-coupled device imager for displacement measurement [5], whereas others have used electromagnetic coils for sensing torque on the suspended target [3]. On the other hand, here a noncontact optical triangulation method is being employed using a precision PSD with 1 μm resolution and a stable He-Ne laser. This yields direct measurement and better accuracy along with lateral-shift error reduction, and thus useful output curves have been obtained.

II. Mathematical Model

Defining the coupling coefficient Cm as $m\Delta v/W$, the energy to ablate unit mass ($\overset{*}{Q}$) as $W/\Delta m$ [4,5,7] and applying the law of conservation of momentum on LAP apparatus, the following can be written:

$$\Delta v_T = C_m\left(\frac{w}{m_T}\right) \tag{1}$$

Specific impulse, commonly defined as the impulse (change in momentum) per unit mass of propellant, is commonly denoted by I_{SP} and can be approximated as $I_{SP} \sim m\Delta v/\Delta m$. It can be related to v_E by dimensional analysis as follows. Here the thrust produced by the laser energy is given by $F(t) =$ Thrust $F(t) = PC_m$ [4,5,7]

$$C_m\overset{*}{Q} \;=\; v_E = g\, I_{SP} \tag{2}$$

If the material is mounted over a pendulum as shown in Fig. 1, the angular displacement for low values of θ may be given as follows:

$$\theta \approx \tan\theta = \frac{X}{2D} \tag{3}$$

Here, X is the displacement of the reflected laser beam spot and D is the distance from the pendulum to the plane of measurement. The coupling coefficient derived from this measurement is given by Pakhomov and Gregory [4]

$$C_m = \frac{mgrT}{2\pi WL}\sqrt{2(1-\cos\theta)} \tag{4}$$

Here m is the pendulum's total mass, r is the pivot point to center of mass distance, T is the oscillation period, L is the pivot to target point length, θ is the angular displacement, and W is the energy per pulse of the laser.

III. Experimental Setup

The schematic diagram of the experiment is shown in Fig. 2. An Nd:YAG laser of 50 mJ/pulse energy at 1064 nm wavelength was used with a pulse duration of 8 ns, and it was operated in single shots mode. The focusing lens used is a biconvex lens that can focus the laser beam at its focal point to about 0.5 mm diameter of beam spot.

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