Research of Reactive Traction Induced by the Laser

M. A. Shulepov, E. I. Lipatov, A. N. Panchenko

Institute of High Current Electronics SB RAS, 2/3 Akademicheskii Ave., Tomsk, Russia, 8-3822-491443, E-mail: mixshlp@yandex.ru

Abstract – There are results of investigations of some metals and plastics used as "fuel" for the creation of laser-plasma of jet engine (LPJ), which hypothetically should be used for the correction of small-size satellites orbits. The main criteria of the material necessary to be used for obtaining of maximal jet thrust was determined.

1. Introduction

In connection with a problem of launching and correction of small-size satellite orbit very urgent problem today is the development and creation of engines with an action isn't based on an event of jet thrust creation due to chemical fuel burning. An idea of such engines development was expressed still by K.Tsyolkovsky and confirmed by R.Goddard in 1917. The actuating medium of such engines (usually cesium, rubidium, mercury, bismuth, argon, xenon) is ionized, and than formatted ions (in another words electrified gas) are accelerated in the strong electrostatic field up to speeds of dozens and hundreds kilometers per a second. That's why such engines are named ion engines. For ionization as rule, current discharge is used. Using of this mechanism has a number of disadvantages. It was proposed a spark occurs due to focusing of laser irradiation pulse to be used as an ionizer.

2. Obtaining of the pulse transmitted to the target by piezoelectric cell

At interaction of focused pulse laser irradiation to the material on its surface (at observance of conditions) the plasma torch taking away a material part with certain speed occurs. As a result the target gets a pulse of certain magnitude determined as well by target characteristics (density, mass, etc.) as by influencing irradiation parameters. Investigations of pulse transmission were carried out with using of CO_2 and XeCl – lasers. For determination of mechanical impulse dependence according to the methods with using of piezoelectric cell we used a set up schematically shown in Fig. 1.

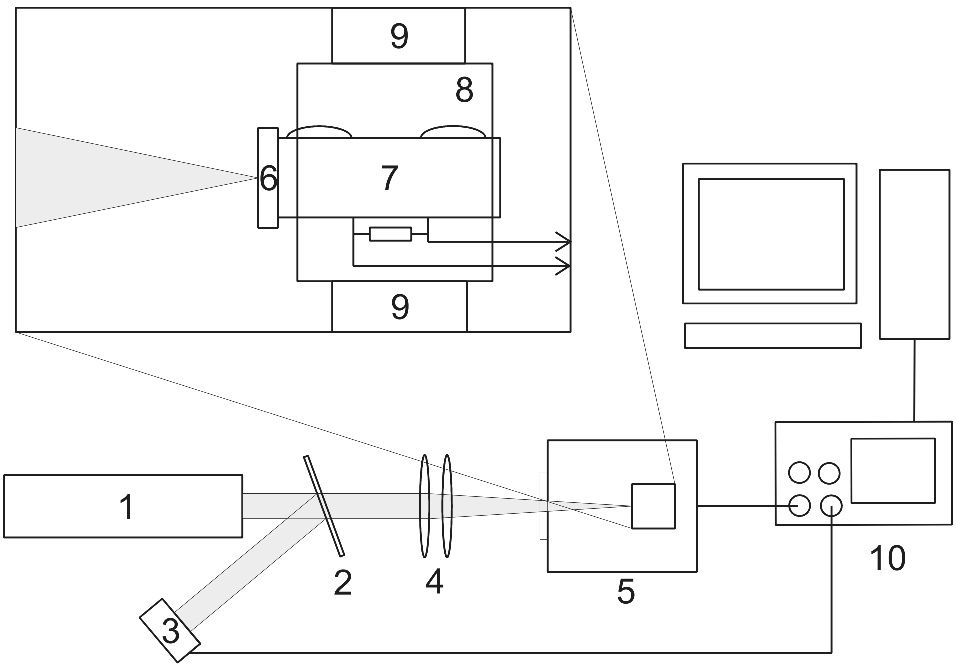

Fig. 1. The scheme of set up for the determination of mechanical impulse, generated at influence of laser with piezoelectric cell using . 1 – laser, 2 – datum plane, 3 – photodetector FP–1 (FEK–22), 4 – irradiation focusing system, 5 – vacuum chamber, 6 – sample, 7 – piezoelectric cell, 8 – damping holder, 9 – rigid holders, 10 – registration system (oscillograph + computer)

The sample was hardwired to piezoelectric cell flank and replaced in the vacuum chamber ($10^{-2} \div 10^{-3}$atm). CO_2 or XeCl – laser irradiation was focused on the sample surface in the spot of~$0{,}25 \div 1 mm^2$ area. Each impulse was controlled by photodetectors FP–1 (at IR radiation controlled by photodetectors FP–1 (at IR radiation impact) or FEK–22 (in case of ultraviolet radiation impact).

Energy in CO_2 laser pulse after optical scheme passage on the sample surface was Q= 200 ÷ 450 mJ; pulse duration on half-height $\tau_{1/2} \approx 80$ ns. Radiation pulses forms on 10,6 μm, using in concrete experiment for graphite (C), magnesium (Mg), indium (In) and plumbum (Pb) targets radiation are given in Fig. 2. For UV impact by irradiation we used XeCl eximer laser with the next parameters of pulse radiation.

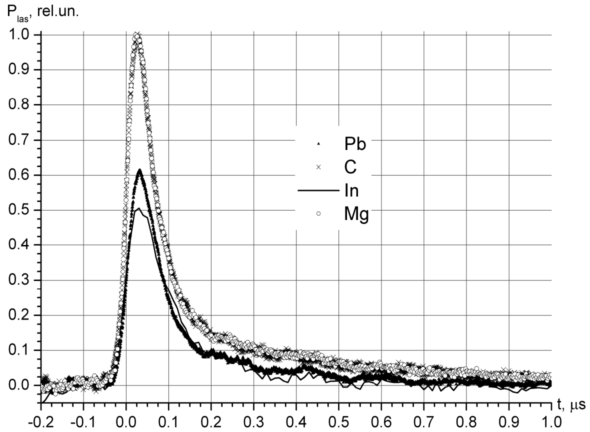

Fig. 2. Radiation pulses oscillogram of CO_2–laser used for different metals irradiation

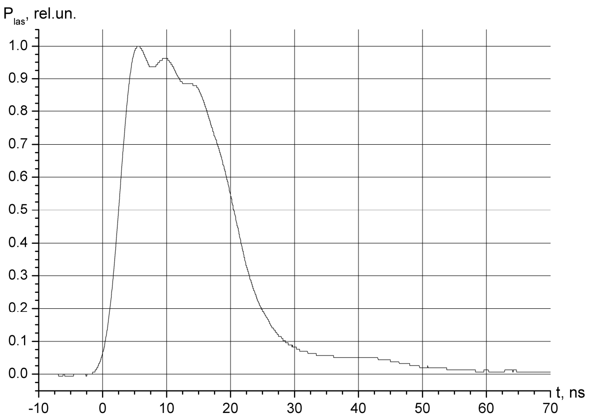

Fig. 3. Oscillogram of XeCl–laser radiation pulses

Energy on the sample surface Q=60÷100 mJ; radiation pulse duration on the half-height $\tau_{1/2} \approx 25$ns (in Fig. 3). during the experiments we determined the next parameters:

1) magnitudes of mechanical impulse by registration of piezoelectric cell charge changing;
2) impulse magnitudes by the simple ballistic pendulum;
3) mass ejection.

In experiments we used the material with densities given in Table I.

Table I. Densities of target material used in experiment

Material	Density, kg/dm^3
Polystyrene	1,06
Magnesium	1,74
Teflon	2,1
Graphite	2,25
Zirconium	6,44
Indium	7,28
Tantalum	16,6

Due to interaction of laser radiation with target a part of material was disposed from the sample surface, and due to recoil momentum of erosion torch the stress wave occurred and propagated in the sample. Due to sample rigid attachment on the piezoelectric cell surface an impulse was propagated to the piezoelectric cell practically without distortions. As it is known due to deformation wave (acoustic wave) a discharge is formed in piezoelectric cell

$$q = d \cdot F_x , \tag{1}$$

where d – piezoelectric modulus, F_x – magnitude of forced causing the deformation and as a consequence potential difference occurs and its changing was registered during the experiment. Due to there is an impulse

$$P = \int_t F dt , \tag{2}$$

Inserting (1) expression to the (2), we obtain the next expression for impulse calculation

$$P = \frac{1}{d} \int_t q dt \tag{3}$$

The magnitude of d piezoelectric modulus of our piezoelectric cell approximately is $200 \cdot 10^{-12}$ C/N.

We obtained the charge magnitude calculating an area under the first half-period of current oscillograms, measured from the piezoelectric cell. Because of namely the first half-period corresponds passing of deformation wave from the surface with a fixed sample to piezoelectric cell back part. Oscillograms of the first half-period of piezoelectric cell response for different metals are shown in Fig. 4, 5.

The maximal impulse (N·s) at impact of XeCl – laser impact was observed for polystyrene and tantalum targets, at IR radiation impact for indium and plumbum targets. For ease of interpretation obtained impulses values were equated to the radiation power in the pulse and it allows comparing the experiment results obtained at impact on that materials by another laser type radiation. Results of impact on the materials are given in Table II.

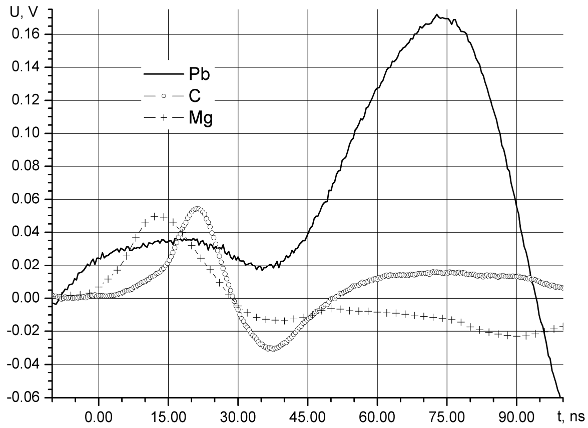

Fig. 4. oscillograms of Pb, C, Mg responses at laser pulse impact

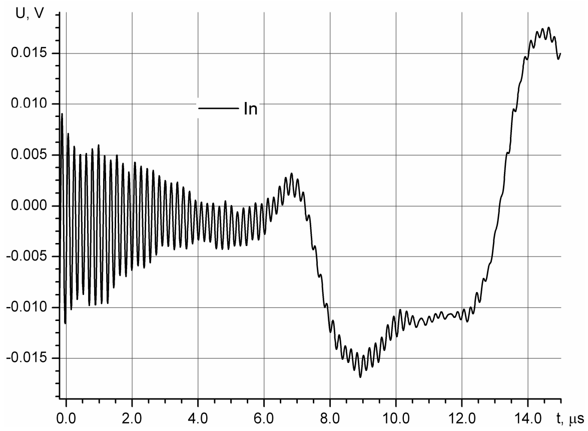

Fig. 5. oscillograms of In response at laser pulse impact

3. Mass ejection under the XeCl–laser radiation impact

Experiments on mass ejection measurements were carried out according to the next methods. The target was located in the quartz lens focus. We made 100 shots to each sample with the average energy per a series about 80 mJ, pulse duration $\tau_{1/2} \approx 25$ ns (in Fig. 3). Radiation was focused on the surface to the spot with sizes of 1,5 × 1,5 mm^2. Before the treatment and after it samples were weighed by VLR–200 analytical balance, and measurement error is ± 0,15 mg. Obtained results are given in Table III. Specific mass ejection at that didn't exceed $\Delta m/Q = 8 \times 10^{-8}$ g/mJ. Obtained magnitude of specific mass ejection well coincides with measurement data of mass ejection in break current magnitude in erosion torch. High bound of mass ejection estimated according to break current was $\Delta m/Q < 3 \times 10^{-7}$ g/mJ. For metals the magnitudes of mass ejected due to impact are not over than device measurements errors and they are in zero range. It means that at impact on these materials the mechanical impulse magnitude fist of all depends on expansion velocity of outbreak production, but not on their quantity (in Table II). That is also true that outbreak production of materials ease destructible by radiation (Polystyrene) have relatively small expansion velocity. But in this case a quantity of ejected material is significantly more (see Table III) and due to this one the mechanical impulse increases.

Table II. Values of specific impulse propagated to the targets of different materials

Material	Recoil momentum, N·s	P_{peak}, W	Specific impulse, N·s/W
Indium (CO_2)	12.675	2.5×10^{6}	5.069×10^{-6}
Plumbum (CO_2)	1.4054	2.75×10^{6}	5.11×10^{-7}
Magnesium (CO_2)	0.167	5.64×10^{6}	2.98×10^{-8}
Graphite (CO_2)	0.123	5.52×10^{6}	2.23×10^{-8}
Polystyrene (XeCl)	3.7328	2.4×10^{6}	1.55×10^{-6}
Magnesium (XeCl)	1.17805	2.56×10^{6}	4.60×10^{-7}
Teflon (XeCl)	0.46	2.2×10^{6}	2.09×10^{-7}
Graphite (XeCl)	0.4688	2.56×10^{6}	1.83×10^{-7}
Zirconium (XeCl)	1.2856	2.48×10^{6}	5.18×10^{-7}
Indium (XeCl)	1.155	2.8×10^{6}	4.12×10^{-7}
Plumbum (XeCl)	0.45344	2.4×10^{6}	1.89×10^{-7}
Tantalum (XeCl)	7.6072	2.32×10^{6}	3.28×10^{-7}

Table III. Data on mass ejection under UV – laser radiation impact

Material	Before influenc, g	After influenc, g	Mass differenc e, g
Magnesium	0.61575	0.6158	$-5\cdot10^{-5}$
Indium	1.22465	1.22455	$1\cdot10^{-4}$
Zirconium	0.6553	0.6555	$-2\cdot10^{-4}$
Graphite	3.3298	3.32915	$6.5\cdot10^{-4}$
Plumbum	2.7108	2.71045	$3.5\cdot10^{-4}$
Tantalum	0.537	0.53705	$-5\cdot10^{-5}$
Polystyrene	0.1648	0.16445	$3.5\cdot10^{-4}$
Teflon	0.42835	0.428	$3.5\cdot10^{-4}$

At CO_2–laser radiation impact on metals hypothetically there is the next mechanism. In spite of plumbum and indium are the metals and well reflect infrared emission, mechanical impulse magnitude for them as minimum for an order exceeds the same values for magnesium and graphite. Due to indium and plumbum are refractory materials (T_{melt}=156,6 ˚C and 327,5 ˚C accordingly), that within time of impact impulse existence a lot of metals vapors making a mechanical impulse at evaporation is formatted and possibly plasma formed under the pulse impact influences intensively. Magnesium possessing high melting temperature, small atomic weight and high reflectivity factor can not make a significant pulse. Graphite is easy destructible, reflectivity factor in range of 10,6 μm is about 60 %, relatively investigated materials it is friable and due to that in spite of outbreak production bundle the registered pulse is relatively small.

References

As it is known the value of impulse (jet thrust) depends on mass of rejecting substance and speed of its emission. Experiments showed that the least impulse value corresponds materials with the density of 1,7÷2,5 kg/dm^3.

If we increase the density of subject to the impact materials, i.e. increase impulse due to increase of rejected substance speed, we obtain substances, and it takes bundle energy for their destruction.

If to use materials with a density of 1 and less (significantly more substance quantity is ejected, but expansion velocity is less than in previous case), we have a problem of impulse transfer from target surface to the useful body, because the materials with such density have not special structure hardness.

Therefore for obtaining of the maximal impulse value we should use material with the next parameters.

- high hardness;
- ease destructible (low melting and evaporation temperature);
- High absorption factor;
- High atomic mass.

Probably in this case the best material will be a certain composite consisting of powder (substance with high atomic mass) and its grains are joined with each other by substance ease destructible under radiation impact. At that this composite material should have high hardness for impulse wave will not decay in process of passing through it.