Laser Propulsion in Free Flight

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Abstract

Experiment of laser propulsion in free flight has never been conducted. At Institute of Fluid Science (IFS), Tohoku University, propulsive impulse generation by focusing on a rest projectile was demonstrated. Based on the ideas obtained from this experiment, experiment of laser propulsion of a projectile in flight by focusing CO_2 laser beam is being prepared for. The objective velocity increment in experiment is about 50 m/s.

Introduction

A laser propulsion technology has been researched as a future technology of launching and acceleration since 1956. Some experiments of laser propulsion, such as LITA (Laser-driven In-Tube Accelerator) [1] and Light Craft Technology [2] were conducted. These were experiment of launching a rest object.

Investigation of acceleration of an object flying at high speed using laser beam is necessary. Because phenomena in laser propulsion targeting on an object flying at high speed has not been studied yet. This technique can be applied to technology of elimination of space debris, acceleration of spacecraft, missile defense technique, etc...

In our experiment we investigate effect of variety of ambient pressure and velocity of projectile.

Theory

Laser propulsion offers an important parameter, the momentum coupling coefficient C_m [3]. This is defined as the ratio of target momentum $m\Delta v$ produced to incident laser pulse energy W during the ejection of laser-ablated material. It is also written as the ratio of thrust F to incident power P:

$$C_m = \frac{m v}{W} = \frac{F}{P} \qquad (1)$$

Hence, more thrust is obtained as C_m increases via relationship

$$F = PC_m \qquad (2)$$

Velocity increment is estimated in case C_m, W, and m are known.

Experimental

A large energy pulsed CO_2 TEA laser (General Physics Institute, Moscow, Russia) is used for the experiment at IFS. The maximum output pulse energy is 380J.

A cross section of laser beam is shown in Fig.1. This shape was recorded onto a thermal paper. An inner 8mm×8mm square indicates that this area does not have laser beam intensity.

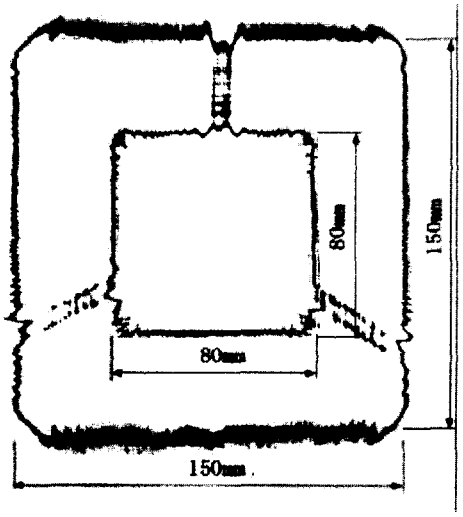

Fig1. Beam pattern of cross section (150mm×150mm)

Present Status

The measurement of maximum speed and momentum coupling œefficient targeting on a rest projectile with an ablator was conducted in case both without and with the in-tube confinement effect [4]. Polyacetal was used for both projectile and ablator.

Without the in-tube confinement effect, mass, speed, and momentum coupling coefficient of projectile are 1.35g, 32m/s, and 145N/MW, respectively. With the in-tube confinement effect, those of projectile are 1.45g, 63m/s, and 310N/MW, respectively. In this case, shock waves generated by laser reflect on the tube wall, which enhance an impulse.

Challenge for Laser Propulsion in Free Flight

A schematic diagram of the experimental setup is shown in Fig.2. Projectile is shot from the driving section by using double diaphragm technique. The volume of the driving section, the double diaphragm section, and the driven tube are pressurized to 5.0 MPa, 2.5 MPa, and 0 MPa, respectively. Driver gas is Helium.

Fig.3 shows schematic diagram of projectile for this experiment. The material is aluminum alloy 7075. The weight is 3.33g. Back of projectile, circular portion, spreads a little so that Helium gas does not flow forward of a projectile. Polyacetal is

to be used for ablator, which is put on a projectile as shown in Fig.3.

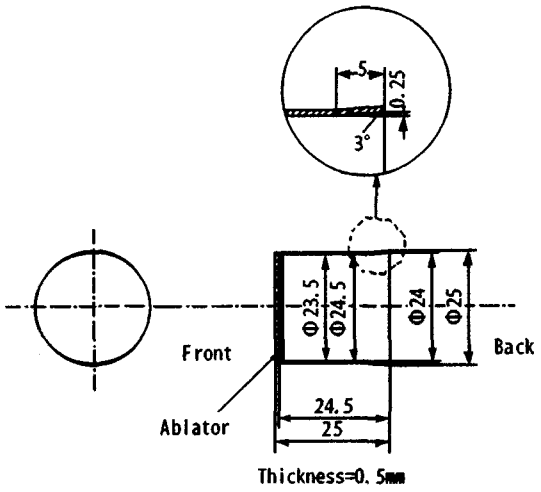

Fig.3 Schematic diagram of projectile (unit: mm)

A projectile flies into the vacuum chamber at high speed, at least over 500m/s. CO_2 TEA laser is triggered, when a projectile flies into the vacuum chamber. Laser beam reflects on 3 Al plane mirrors, is condensed through the ZnSe lens (F=1650mm), and goes through the ZnSe window. It reflects on the Cu plate, and then is focused on a projectile. Because the Cu plate has a square hall in the center of itself, projectile can go through it. Also, laser reflects on the Cu plate without risk of reflection on the inner wall of the vacuum chamber because of the shape of cross section of laser beam.

ZnSe lens and ZnSe window are necessary. It is impossible that Al concave mirror is used for condensing laser beam due to the restriction of arrangement of other devices. Equation (2) indicates laser beam energy should not be reduced for larger thrust when beam is focused onto a projectile. Hence, it is impossible that a glass window is used for the experiment. The transparency of ZnSe window is about 100%. Hence, ZnSe window can be used for the experiment.

Projectile goes into the projectile catcher with casters underneath after impulse is generated. The catcher absorbs impact without damaging the chamber.

Conclusion

After examining relation between pressure and velocity of Helium gas, we will conduct experiments with variable ambient pressure in the vacuum chamber. We expect unknown fluid dynamic phenomena is observed when impulse is generated by laser in the condition of atmospheric ambient pressure. And we are going to investigate into effects of variety of ambient pressure and velocity of projectile in laser propulsion in free flight.

References

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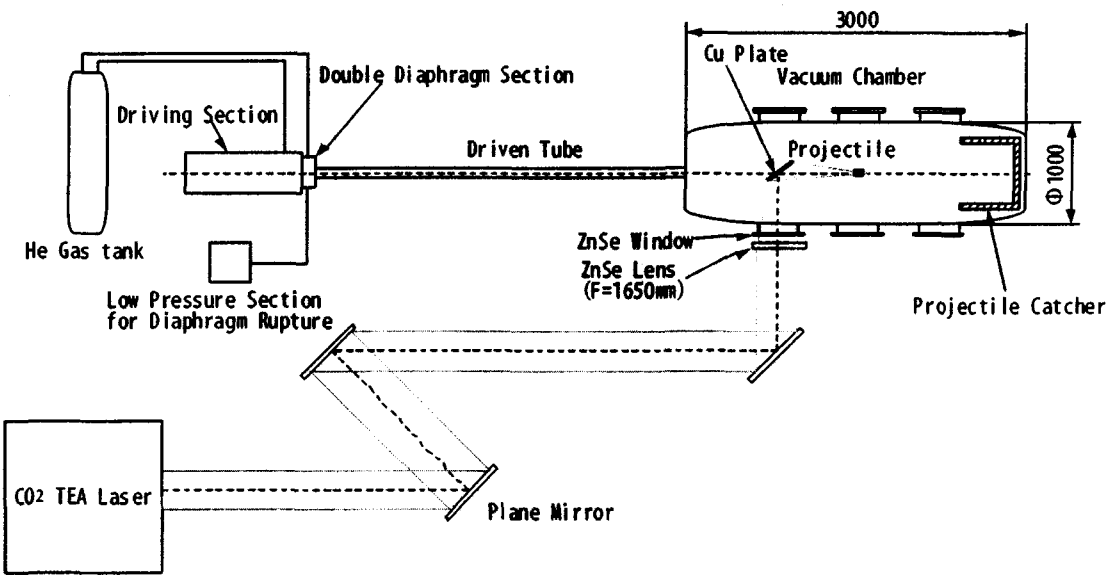

Fig.2 Schematic diagram of experimental setup (unit: mm)